

# MAAP4 Applications Guidance

## Desktop Reference for Using MAAP4 Software, Revision 2



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# MAAP4 Applications Guidance

Desktop Reference for Using MAAP4 Software,  
Revision 2

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# PRODUCT DESCRIPTION

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The existing Modular Accident Analysis Program Version 4 (MAAP4) documentation consists of the MAAP4 User's Manual, the MAAP4 user's guides for input preparation, and transmittal documents that describe individual revisions. These components contain detailed information on the mechanics of running the code as well as detailed descriptions of the individual models, but they do not include specific applications guidance. This applications guidance document is intended to fill that gap by providing sufficient information to enable users to optimize their efforts and generate high-quality Level 1 probabilistic risk assessment (PRA) analyses.

## Results and Findings

MAAP4 is a computer code used by nuclear utilities and research organizations to predict the progression of light water reactor accidents. This applications guidance document provides the following:

- A description of the MAAP4 code
- Guidance for ensuring the quality of MAAP4 analyses
- Guidance on how to apply MAAP4 for Level 1 PRAs
- A compilation of summary information on the benchmarking of MAAP4 models
- An assessment of MAAP4's ability to adequately predict significant Level 1 PRA phenomena

## Challenges and Objectives

Two prior efforts that were related to the previous version of the code, MAAP3B, generated particularly useful information regarding the validation of the thermal-hydraulic models, code application guidance, and recommended sensitivity analyses. The first effort was a set of thermal-hydraulic qualification studies. The objectives of the studies were to evaluate the thermal-hydraulic modeling in MAAP3B and provide guidance on code use. The resultant reports contain detailed descriptions of relevant plant features, accident sequences, benchmarks, and input file components, as well as guidance on applications and limitations. The second effort was the creation of a set of recommended sensitivity analyses for an individual plant examination (IPE). The resultant document contains a review of key accident sequences and phenomena and recommended approaches for treating phenomenological uncertainties in IPEs. There is a consensus among current code users that similar thermal-hydraulic assessments, applications guidance, and recommendations for sensitivity analyses for MAAP4 would be advantageous. This report aims to satisfy these needs for Level 1 PRA risk-informed applications.

## **Applications, Value, and Use**

It is anticipated that this report will be used by analysts responsible for running the code, analysts responsible for incorporating MAAP4 results into PRA models, and others interested in MAAP4's capabilities (for example, utility personnel, regulators, reactor vendors, and researchers).

## **EPRI Perspective**

This guidance document provides sufficient information to enable users to optimize their efforts and generate high-quality Level 1 PRA MAAP4 analyses.

## **Approach**

The information in this report was primarily assembled from extensive experience using the MAAP4 code, from the MAAP4 User's Manual and user's guides, from the MAAP3B thermal-hydraulic qualification studies and sensitivity guidance described previously, from benchmark descriptions, and from the results of exploratory MAAP4 calculations performed to investigate specific topics for this effort.

## **Keywords**

Probabilistic risk assessment  
ASME PRA standard  
PRA scope and quality  
Success criteria  
Thermal-hydraulic analysis  
MAAP4



## ACRONYMS AND MAAP4 FILE TYPES

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|       |                                                         |
|-------|---------------------------------------------------------|
| ADV   | atmospheric dump valve                                  |
| AFW   | auxiliary feedwater                                     |
| AHF   | large loss-of-coolant accident in PWRs                  |
| AIChE | American Institute of Chemical Engineers                |
| ALWR  | advanced light water reactor                            |
| ANS   | American Nuclear Society                                |
| ANSI  | American National Standards Institute                   |
| AS    | accident sequence analysis (ASME PRA technical element) |
| ASCII | American Standard Code for Information Interchange      |
| ASME  | American Society of Mechanical Engineers                |
| ATR   | advanced thermal reactor                                |
| ATWS  | anticipated transient without scram                     |
| B&W   | Babcock & Wilcox                                        |
| BWR   | boiling water reactor                                   |
| CANDU | Canadian-designed pressurized heavy water reactor       |
| CDF   | core damage frequency                                   |
| CE    | Combustion Engineering                                  |
| CHP   | charging pump injection                                 |
| CRD   | control rod drive                                       |

---

|      |                                                                                       |
|------|---------------------------------------------------------------------------------------|
| CS   | PWR containment sprays                                                                |
| CST  | condensate storage tank                                                               |
| CSTF | Containment Systems Test Facility (Hanford Engineering Development Laboratory)        |
| CVCS | chemical and volume control system                                                    |
| DA   | data analysis (ASME PRA technical element)                                            |
| DCH  | direct containment heating                                                            |
| DOE  | U.S. Department of Energy                                                             |
| ECCS | emergency core cooling system                                                         |
| EDF  | Electricité de France                                                                 |
| EFW  | emergency feedwater                                                                   |
| EOP  | emergency operating procedure                                                         |
| EPR  | advanced pressurized water reactor by AREVA (originally European pressurized reactor) |
| EPRI | Electric Power Research Institute                                                     |
| ERIN | ERIN Engineering and Research, Inc.                                                   |
| ESF  | engineered safeguards                                                                 |
| F&B  | feed and bleed                                                                        |
| FAI  | Fauske & Associates, LLC                                                              |
| FLHT | Full-Length High Temperature experiments                                              |
| GCM  | generalized containment model                                                         |
| GE   | General Electric Company                                                              |
| GKA  | Gabor, Kenton & Associates, Inc.                                                      |
| HCTL | heat capacity temperature limit                                                       |
| HDR  | Heiss Dampf Reaktor                                                                   |

---

|         |                                                                          |
|---------|--------------------------------------------------------------------------|
| HEP     | human error probability                                                  |
| HFE     | human failure event                                                      |
| HLNC    | hot leg natural circulation                                              |
| HLCR    | hot leg creep rupture                                                    |
| HLR     | high level ASME PRA requirement                                          |
| HPCI    | high pressure coolant injection                                          |
| HPCS    | high pressure core spray                                                 |
| HPI     | high pressure injection                                                  |
| HPME    | high pressure melt ejection                                              |
| HPSW    | high pressure service water                                              |
| HR, HRA | human reliability analysis (ASME PRA technical element and general term) |
| IDCOR   | Industry Degraded Core Rulemaking Program                                |
| IE      | initiating events analysis (ASME PRA technical element)                  |
| IF      | internal flooding (ASME PRA technical element)                           |
| IIST    | INER Integral System Test facility                                       |
| INER    | Institute of Nuclear Energy Research                                     |
| IPE     | individual plant examination                                             |
| IRWST   | in-containment refueling water storage tank                              |
| ISLOCA  | interfacing system loss-of-coolant accident                              |
| ISO     | International Organization for Standardization                           |
| ISP     | international standard problem                                           |
| LE      | LERF analysis (ASME PRA technical element)                               |
| LERF    | large early release frequency                                            |
| LLOCA   | large loss-of-coolant accident                                           |

---

|                  |                                                       |
|------------------|-------------------------------------------------------|
| LOCA             | loss-of-coolant accident                              |
| LOFW             | loss of feedwater (BWR), loss of main feedwater (PWR) |
| LOOP             | loss of offsite power                                 |
| LP1              | low pressure injection train 1                        |
| LP2              | low pressure injection train 2                        |
| LPCI             | low pressure coolant injection                        |
| LPCS             | low pressure core spray                               |
| LPI              | low pressure injection                                |
| LWR              | light water reactor                                   |
| MAAP3B           | Modular Accident Analysis Program Version 3.0B        |
| MAAP4            | Modular Accident Analysis Program Version 4           |
| MB-2             | Model Boiler No. 2 (Westinghouse)                     |
| MCCI             | molten core concrete interactions                     |
| MCP              | main coolant pump                                     |
| MFW              | main feedwater                                        |
| MI, MII,<br>MIII | Mark I, II, or III BWR containment type               |
| MLOCA            | medium loss-of-coolant accident                       |
| MSIV             | main steam isolation valve                            |
| MSLB             | main steam line break                                 |
| MSSV             | main steam safety valve                               |
| MUG              | MAAP Users Group                                      |
| NEI              | Nuclear Energy Institute                              |
| NPSH             | net positive suction head                             |

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|      |                                               |
|------|-----------------------------------------------|
| NRC  | U.S. Nuclear Regulatory Commission            |
| NTU  | number of transfer units                      |
| OSU  | Oregon State University                       |
| OTSG | once-through steam generator                  |
| QU   | quantification (ASME PRA technical element)   |
| PC   | personal computer                             |
| PNL  | Pacific Northwest Laboratory                  |
| PORV | power-operated relief valve                   |
| PRA  | probabilistic risk assessment                 |
| PSA  | probabilistic safety assessment               |
| PWR  | pressurized water reactor                     |
| RCIC | reactor core isolation cooling                |
| RCP  | reactor coolant pump                          |
| RCS  | reactor coolant system                        |
| RG   | regulatory guide                              |
| RHR  | residual heat removal                         |
| RPV  | reactor pressure vessel                       |
| RWCU | reactor water cleanup                         |
| RWST | refueling water storage tank                  |
| S2HF | small loss-of-coolant accident in PWRs        |
| SBO  | station blackout                              |
| SC   | success criteria (ASME PRA technical element) |
| SCS  | shutdown cooling system                       |
| SG   | steam generator                               |

---

|         |                                                                               |
|---------|-------------------------------------------------------------------------------|
| SGTR    | steam generator tube rupture                                                  |
| SI      | safety injection                                                              |
| SLC     | standby liquid control                                                        |
| SLOCA   | small loss-of-coolant accident                                                |
| S/MLOCA | small or medium loss-of-coolant accident                                      |
| SNL     | Sandia National Laboratories                                                  |
| SPA     | upper compartment spray, train A                                              |
| SPB     | lower compartment spray, train B                                              |
| SPC     | containment (upper) compartment spray, train C                                |
| SR      | supporting ASME PRA requirement                                               |
| SRV     | safety relief valve, safety or relief valve                                   |
| SR5     | SCDAP/RELAP5 computer code (also referred to as S-RELAP5)                     |
| SSCs    | structures, systems, and components                                           |
| SY      | systems analysis (ASME PRA technical element)                                 |
| TMLB'   | loss-of-AC-power accident in PWRs, with or without RCP seal leaks (also TMLB) |
| THTF    | Thermal-Hydraulic Test Facility (Oak Ridge National Laboratory)               |
| TOAF    | top of active fuel                                                            |
| TSV     | turbine stop valve                                                            |
| UHI     | upper head injection                                                          |
| VVER    | Russian Federation pressurized water reactor                                  |
| WICE    | Westinghouse ice condenser                                                    |
| WLD     | Westinghouse large dry                                                        |
| XYPLOT2 | utility to plot MAAP4 output                                                  |

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| <b>File Suffix<sup>a</sup></b> | <b>MAAP4 File Type</b> |
|--------------------------------|------------------------|
|--------------------------------|------------------------|

|                 |                                                        |
|-----------------|--------------------------------------------------------|
| *.D##           | plot files (## represents the number of the plot file) |
| %.INC           | include file                                           |
| %.INI           | initialization file                                    |
| *.INP           | input file                                             |
| *.LOG           | log file                                               |
| %.PAR           | parameter file                                         |
| *.RES,<br>*.RDB | restart files                                          |
| %.RPT           | report file                                            |
| *.SUM           | summary file                                           |
| *.SYS           | system file                                            |
| *.TAB           | tabular output file                                    |
| %.TEP           | report template                                        |

<sup>a</sup>An asterisk (\*) represents the sequence name; a percent sign (%) represents an arbitrary input name.





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# 1

## OVERVIEW

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The Modular Accident Analysis Program Version 4 (MAAP4) is a computer code used by nuclear utilities and research organizations to predict the progression of light water reactor (LWR) accidents. This applications guidance document provides the following:

- A description of the MAAP4 code
- Guidance for ensuring the quality of MAAP4 analyses
- Guidance on how to apply MAAP4 for Level 1<sup>1</sup> probabilistic risk assessments (PRAs)
- A compilation of summary information on the benchmarking of MAAP4 models
- An assessment of MAAP4's ability to adequately predict significant Level 1 PRA phenomena

It is anticipated that this report will be used by analysts responsible for running the code, analysts responsible for incorporating MAAP4 results into PRA models, and others interested in MAAP4's capabilities (for example, utility personnel, regulators, reactor vendors, and researchers).

### 1.1 Creation of the Applications Guidance Document: Motivation and Method

The existing MAAP4 documentation consists of the MAAP4 User's Manual [1], the MAAP4 user's guides for input preparation, and transmittal documents that describe individual revisions. These components contain detailed information on the mechanics of running the code as well as detailed descriptions of the individual models, but they do not include specific applications guidance. This applications guidance document is intended to fill that gap by providing sufficient information to enable users to optimize their efforts and generate high-quality Level 1 PRA analyses. (The existing documentation is further described in Section 2.4 of this report.)

Two prior efforts that were related to the previous version of the code, MAAP3B, generated particularly useful information regarding the validation of the thermal-hydraulic models, code application guidance, and recommended sensitivity analyses. The first effort was the set of thermal-hydraulic qualification studies conducted by Gabor, Kenton & Associates (GKA) and S. Levy [2–5]. The objectives of the studies were to evaluate the thermal-hydraulic modeling in MAAP3B and provide guidance on code use. The resultant reports contain detailed descriptions

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<sup>1</sup> Level 1 PRA analysis relates to the progression of an accident from its initiating events to plant damage, for example, core damage. Level 2 analysis extends to the potential for release of fission products from the primary system and from the containment.

of relevant plant features, accident sequences, benchmarks, and input file components, as well as guidance on applications and limitations. The second effort was the creation of a set of recommended sensitivity analyses for an individual plant examination (IPE) by GKA [6]. The resultant document contains a review of key accident sequences and phenomena and recommended approaches for treating phenomenological uncertainties in IPEs. Use of the latter document was endorsed by the U.S. Nuclear Regulatory Commission (NRC) as part of the Brookhaven National Laboratory review of MAAP3B's applicability for IPEs. There is a consensus among current code users that similar thermal-hydraulic assessments, applications guidance, and recommendations for sensitivity analyses for MAAP4 would be advantageous. This report aims to satisfy these needs for Level 1 PRA risk-informed applications.

The MAAP4 code has been extensively benchmarked, and information about benchmarks is included in the MAAP4 User's Manual. However, only a portion of the benchmarks are discussed in the manual. Of those presented, not all are described in a format that readily allows for the systematic assessment of MAAP4's capabilities. As part of the preparation of this report, benchmarking information was gathered from a variety of sources and reviewed by a team of MAAP4 experts. Summaries of the benchmarks and results from the review were compiled so that they can be used for thermal-hydraulic assessments of significant Level 1 phenomena; that is, they can be used to understand MAAP4's capabilities, identify particular applications in which caution is advised, and provide a basis for determining areas and/or phenomena for which additional benchmarks would be beneficial. The benchmark compilation supported the identification of the ranges of code applicability, code limitations, and usage precautions. These identified items are included in this report.

The American Society of Mechanical Engineers (ASME) has issued a standard that contains requirements for PRAs that are used to support risk-informed decisions and prescribes a method for applying the requirements for specific applications [7]. In addition, the NRC has issued Regulatory Guide (RG) 1.200 [8]. It provides guidance on determining the technical adequacy of a PRA, and it endorses the ASME standard and method with limited exceptions and clarifications. This report contains suggestions on how the overall intent and the individual elements of both the standard and the regulatory guide that apply to MAAP4 can be met.

The need for a succinct description of MAAP4 was identified so that utilities, regulatory agencies, and research organizations would have a convenient tool for communicating pertinent information about MAAP4. The summary contained in this report concisely presents the phenomena modeled in the code, the structure of the code, and how the code has been applied.

The information in this report was primarily assembled from extensive experience using the MAAP4 code, from the MAAP4 User's Manual and user's guides, from the MAAP3B thermal-hydraulic qualification studies and sensitivity guidance described previously, from benchmark descriptions, and from the results of exploratory MAAP4 calculations performed to investigate specific topics for this effort. The report was authored by ERIN Engineering and Research, Inc. (ERIN), with contributions from Fauske & Associates, LLC (FAI), the Electric Power Research Institute (EPRI), and Erigo Technologies. It was reviewed by a peer review team that included Chan Paik, Robert Hammersley, and Robert Reeves of FAI, Ken Canavan and Frank Rahn of EPRI, and Marc Kenton of Erigo Technologies. The preparation of the report was funded by the MAAP Users Group (MUG) and EPRI.

## 1.2 Structure of the Applications Guidance Document

This MAAP4 applications guidance document is designed to be used as a reference when performing MAAP4 analyses and incorporating the results from the analyses into PRA models. The following is an outline of the contents of this report:

- Section 1:     Introductory information including the purpose, motivation, applicability, and scope of the report.
- Section 2:     Descriptive summary information about MAAP4, including general information about the code, the history of its development and use, a summary of the Level 1 PRA phenomena that are modeled, and a synopsis of the code's computational structure and design philosophy.
- Section 3:     Suggested practices for ensuring the quality of MAAP4 analyses. These address the development and testing of input files, code execution, documentation and review of sequences, control and traceability of results, training and certification of analysts, and communication with end users. Section 3 also contains a cross-reference of sections of this report with the intent and elements of the ASME standard and RG 1.200.
- Section 4:     An approach for conducting uncertainty and sensitivity analyses, including suggestions for investigating the effects of input parameters that control the phenomenological models in the code.
- Section 5:     Specific guidance on how to apply MAAP4 to Level 1 PRA analyses for boiling water reactors (BWRs). The guidance provides information on dominant plant features, controlling phenomena, and code logic that affect Level 1 sequences. It also addresses the determination of core damage, and it presents specific considerations for defining and analyzing sequences as a function of the type of initiating event.
- Section 6:     Specific guidance on how to apply MAAP4 to Level 1 PRA analyses for pressurized water reactors (PWRs). The guidance provides information on dominant plant features, controlling phenomena, and code logic that affect Level 1 sequences. It also addresses the determination of core damage, and it presents specific considerations for defining and analyzing sequences as a function of the type of initiating event.
- Section 7:     A compilation of summaries of MAAP benchmarks and a review of the results of the benchmarks with respect to the performance of the major thermal-hydraulic models and code capabilities.
- Section 8:     Guidance on the range of applicability of the code, its limitations, and usage precautions.
- Section 9:     References.

- Appendix A: MAAP4 units labels, units conversion factors, and guidance for handling units in input files; guidance for user-defined input calculations.
- Appendix B: MAAP4 modeling of BWR systems: input, output, and logic features.
- Appendix C: MAAP4 modeling of PWR systems: input, output, and logic features.
- Appendix D: Sample MAAP4 analyst certification guide.
- Appendix E: ASME PRA requirements applicable to MAAP4 analyses.
- Appendix F: Summaries of benchmarks that pertain to the MAAP4 modeling of Level 1 phenomena.



# 2

## INTRODUCTION TO MAAP4

---

The Modular Accident Analysis Program Version 4 (MAAP4) is a computer code that simulates the response of light water reactor (LWR) power plants during severe accidents. Given a set of initiating events and operator actions, MAAP4 predicts the plant's response as the accident progresses. The code is used to do the following:

- Predict the timing of key events (for example, core uncover, core damage, core relocation to the lower plenum, and vessel failure)
- Evaluate the influence of mitigative systems, including the impact of the timing of their operation
- Evaluate the effects of operator actions
- Predict the magnitude and timing of fission product releases
- Investigate uncertainties in severe accident phenomena

MAAP4 results are primarily used to determine Level 1 and 2 success criteria and accident timing for probabilistic risk assessments (PRAs). They are also used for equipment qualification analyses, fission product large early release frequency (LERF) determinations, integrated leak rate test evaluations, emergency planning and training, simulator verification, analyses to support plant modifications, generic plant issue assessments (for example, significance determinations), and other similar applications.

MAAP4 is an integral code. It treats the full spectrum of important phenomena that could occur during an accident, simultaneously modeling those that relate to the thermal hydraulics and to the fission products. It also simultaneously models the primary system and the containment and reactor/auxiliary building.

Parallel versions of MAAP4 support boiling water reactors (BWRs) and pressurized water reactors (PWRs), and there are also unique versions for CANDU, VVER, and ATR reactor designs. Although much of the information presented in this section and in other parts of this report is applicable to all versions of the MAAP4 code, the information primarily applies to the BWR and PWR versions. These two versions contain the same core model, containment and reactor/auxiliary building model, fission product model, and input and output schemes. They have distinct primary system models and engineered safeguards models. The code is applicable to both current and advanced LWR designs, with models that represent the passive features of the latter.

MAAP4 requires two input files. The first is the parameter file, which contains plant-specific information, output specifications, and user-controlled phenomenological parameters. The second is the sequence input file, which specifies the accident initiators, operator actions, and

sequence control times (that is, end time and print interval). After processing the information in the two files, the code predicts the sequence of events and corresponding plant conditions. It generates approximately 25 output files, including a synopsis of the sequence, a summary of events, tables of time-dependent results in a form suitable for plotting, and tabulated results that provide the details of the plant's status at selected times. The input and output files are described in more detail in Section 3 of this report.

## **2.1 MAAP Development History and the MAAP Users Group**

MAAP was originally developed for the Industry Degraded Core Rulemaking (IDCOR) program in the early 1980s by Fauske & Associates, LLC (FAI). At the completion of IDCOR, ownership of MAAP was transferred to the Electric Power Research Institute (EPRI), which was charged with maintaining and improving the code. Starting in the late 1980s, the MAAP3B version became widely used, first in the United States and then worldwide, to support success criteria determination, human action timing evaluations, and Level 2 analyses for individual plant examinations (IPEs). IPEs were used to identify plant vulnerabilities and to facilitate an increased understanding of severe accident phenomena. Therefore, the code has been applied to numerous containment designs and sequences for approximately 20 years.

The code was updated to the current version, MAAP4, in the mid-1990s. It extended MAAP's capabilities for accident management evaluations, primarily with refined core and lower plenum models. Other improvements include a generalized node and junction containment model and models that represent unique features of advanced LWRs. As part of the development process, MAAP4 was reviewed by a committee of independent experts to ensure that it is state-of-the-art and applicable for accident management evaluations. The development of MAAP4 was sponsored by several organizations, including EPRI and the U.S. Department of Energy (DOE). EPRI licenses MAAP4 to utilities, vendors, and research organizations, including universities.

The majority of MAAP4 users are members of the MAAP Users Group (MUG). The MUG provides direction and funding for code maintenance, enhancements, and benchmarking; facilitates information transfer through biannual meetings and the issuance of various communications on code problems and best practices; and supports industry and regulatory acceptance. As of April 2009, the MUG membership consists of approximately 50 organizations from 12 countries. FAI is the maintenance contractor for the code, and ERIN Engineering and Research, Inc. performs an independent review of maintenance activities.

The code has been developed and is maintained under FAI's quality assurance program, which is in compliance with U.S. 10CFR50 Appendix B and ISO 9001 quality assurance requirements.

## **2.2 Phenomena Modeled in MAAP4**

MAAP4 treats the spectrum of physical processes that could occur during an accident. Level 1 PRA phenomena include the following:

- Gas and water flow
- Natural circulation

- Steam evaporation and condensation
- Boiling
- Critical flow
- Conduction, convection, and radiation heat transfer
- Countercurrent flow

Level 2 PRA phenomena include the following:

- Cladding oxidation and hydrogen evolution
- Core material eutectic formation
- Core relocation
- Lower head–core debris dynamics
- Failure of vessel penetrations and/or the lower head
- Debris entrainment
- Debris-concrete interactions
- Ignition of combustible gases
- pH and iodine chemistry in containment
- Fission product release, transport, and deposition

The subsequent sections describe the MAAP4 models that relate to Level 1 PRA phenomena. Each section includes the names of the principal subroutines; detailed information about the models is contained in the corresponding subroutine descriptions in the MAAP4 User's Manual [1]. Also included are the sections of the parameter files that contain the input parameters specific to each group of models.

### **2.2.1 Primary System Thermal Hydraulics**

#### **2.2.1.1 BWR Primary System Thermal Hydraulics**

The BWR primary system model calculates the thermal-hydraulic conditions in the reactor pressure vessel. It tracks the mass and energy of water pools in the downcomer (including the water inside jet pumps and in the recirculation loops), in the core (including the water above the active core extending into the standpipes, separators, and upper plenum), in the control rod drive (CRD) tubes, and in the lower plenum. The remaining free volume constitutes a single gas space. The gas pressure is imposed on the water pools, and the individual water masses and energies are then used to determine the temperature of each pool. MAAP4 also tracks the two-phase mixture volume in each water region. The gas space is divided into eight nodes for heat transfer and gas flow calculations. The code tracks the gas temperature, mass fraction of hydrogen, and fission product masses in each of the gas nodes. Eleven primary system heat sinks are modeled, each as a two-dimensional slab.

The thermal-hydraulic model calculates water transport, gas transport, steaming and condensation, and heat transfer to the structures that interface with the containment. The code calculates the influx of feedwater and CRD flow as well as flow from emergency core cooling systems (HPCI, RCIC, core sprays, LPCI, and external water sources). The code also calculates water and gas flow from the primary system through the main steam line, safety and relief valves (SRVs), breaks, and other user-specified openings. In addition, the code models heat removal by isolation condenser, shutdown cooling, and reactor water cleanup systems. It also contains plant-specific models for injection and heat removal systems for Swedish plants.

Flows through openings in the BWR reactor pressure vessel are strongly coupled to the primary system pressure. In addition, internal water circulation flows might undergo rapid transients. The MAAP4 primary system calculations incorporate an anticipatory flow model that uses local time steps to capture the fluid dynamics. Coupled pressure and flow equations are evaluated and integrated analytically over the larger code time step to obtain realistic average flow rates. The use of local time steps allows the code to handle rapid transients and track the dynamics of the subcooled region and two-phase mixture volume in the core. It also allows more precise calculations of events, for example, the opening of SRVs based on pressure setpoints. The water and two-phase flow rates are dependent on calculated temperature, density, pressure, and hydrostatic head differences. A quasi-steady momentum balance (momentum equation) around the reactor coolant system loop is used to calculate natural circulation flow rates. Break flow rates are calculated either with the Bernoulli equation, which is a form of the momentum equation, or with a critical flow model.

*Principal subroutines:* BWRVSL, VSLFLO, FLOW, GENEVT, USEVT, PSHS, PSEQPT, ISOCON

*Parameter file sections:* Primary System, Engineered Safeguards, Control, Model, Initial Conditions, Isolation Condenser, O1/O2/O3/R1 (Swedish-specific sections)

### 2.2.1.2 PWR Primary System Thermal Hydraulics

The PWR primary system model calculates the thermal-hydraulic conditions in the reactor pressure vessel, the hot legs, the cold legs, and the primary side of the steam generators. (The pressurizer is treated in a separate model.) The primary system is divided into two loops: the broken loop and the unbroken loop. The user specifies how many actual loops are in each loop in the model and which loop contains the surge line to the pressurizer. (The terms *broken* and *unbroken* are misnomers: breaks can be modeled in either or both of the loops; the terms are carryovers from earlier, more restrictive versions of the code.)

There are 14 gas control volumes in the model: the core, upper plenum, broken and unbroken hot legs, broken and unbroken hot and cold leg tubes (hot and cold sides of the tubes) for U-tube steam generators, broken and unbroken *candy cane* piping for once-through steam generators (OTSGs), broken and unbroken tubes for OTSGs, broken and unbroken cross-over (intermediate) legs, broken and unbroken cold legs, downcomer, and reactor dome. There are six water pools: the core (includes the hot legs, the hot side of U-tubes, and the candy cane for OTSGs), broken and unbroken cold tubes (the cold side of U-tubes or the entire length of the tubes in OTSGs), broken and unbroken cross-over legs (includes the steam generator outlet plenum through to the outlet of the pumps), and downcomer (includes the horizontal portion of

the cold legs). In addition, there are 19 primary system structural heat sinks, which are modeled as two-dimensional slabs. Because the number of gas volumes is larger than the number of water pools, a pool can occupy several gas volumes.

The initial condition in the primary system is forced circulation of water through the reactor coolant loops by the main (reactor) coolant pumps. When steam first forms in the loops, the two phases are assumed to be homogeneously mixed. The water flow rates between the primary system pools are adjusted so that the individual void fractions match the system average void fraction, and energy is transferred between the pools so that the water and gas are all at a uniform temperature and pressure. During this phase (that is, forced circulation of homogeneous fluid) the heat transfer from the primary system to the steam generators is calculated using the Dittus-Boelter correlation for forced convection. The same treatment is used if the internal gas velocities are sufficiently high to cause water entrainment, such as occurs during the early phase of a large break loss-of-coolant accident (LOCA).

In an accident sequence, conditions will cause the pumps to be tripped off. After the pumps have stopped running, forced circulation is replaced by natural circulation. If the void fraction remains less than a user-specified criterion for phase separation, the same well-mixed treatment is used to model the natural circulation of the homogeneous two-phase fluid. The thermal-hydraulic model does not explicitly account for the conservation of momentum, which requires a substantially more complex model, so it does not calculate a natural circulation flow rate. This is required for a mechanistic calculation of the heat transfer from the primary system to the steam generators. Therefore, during this phase, the heat transfer is based on a user-supplied heat transfer coefficient.

When the void fraction exceeds the user-specified criterion for phase separation, the coolant becomes stagnant. The gas and water pools are no longer assumed to be intimately mixed and are treated separately in a gas-over-liquid configuration. For these conditions, the gas in each node can have a unique temperature, distinct from the pool temperature. When the water level is above the elevation of the reactor pressure vessel (RPV) inlet and outlet nozzles, it is assumed that there is enough water in the primary system to permit free communication among the core, cross-over leg, and downcomer pools, with a common collapsed water level. As the water level continues to drop, the pools are uncoupled and water spills from one pool to another. The heat transfer to the steam generators from the separated fluid system is calculated mechanistically, and it tends to be dominated by the condensation of primary system steam on the inside surface area of the tubes that are in direct contact with water on the secondary side.

The thermal-hydraulic model calculates water transport, gas transport, steaming, and heat transfer to the structures that interface with the secondary side and the containment. In addition to condensation onto the inside surfaces of the steam generator tubes, steam can condense on cold emergency core cooling system (ECCS) water injected into the primary system. When the accident progresses to core uncover, the level of detail in the calculations increases, and the modeling includes such phenomena as natural circulation of superheated gases in the vessel and in the hot leg (countercurrent flow).

At each time step, the code calculates the influx of water through makeup flow; accumulator flow; and high pressure, low pressure, and charging pump injection systems, as appropriate. It also calculates water and gas flow from the primary system through breaks, steam generator

tube ruptures (SGTRs), and other user-specified openings, as well as fluid transport between the primary system and the pressurizer through the surge line.

The code contains plant-specific injection system models for Spanish plants. It also contains models for the core makeup tanks and the passive residual heat removal system that are part of the AP600 and AP1000 advanced light water reactor (ALWR) designs.

*Principal subroutines:* PRISYS, FLOW, EVENTS, ENGSAF, GENESF, PSHS, PSEQPT

*Parameter file sections:* Primary System, Engineered Safeguards, Generalized Engineered Safeguards, Pump Characteristics, Control, Model, Initial Conditions, Quench Tank, Spain, AP600

### 2.2.1.3 PWR Pressurizer Thermal Hydraulics

The pressurizer is modeled as a single control volume, with one water pool and one gas node. The water and gas can be at different temperatures (which are also distinct from the primary system fluid temperatures). Calculations of the thermal-hydraulic conditions in the pressurizer account for evaporation, condensation, steam stripping due to steam and noncondensable gases sparging through the water pool, and water and gas exchange (co-current and countercurrent) with the primary system through the surge line and with the containment through relief valves and safety valves. Mass and energy contributions from pressurizer sprays and heaters as well as heat transfer to structures are also included.

*Principal subroutine:* PZR, FLOEXP

*Parameter file section:* Pressurizer

## 2.2.2 Core

The core model predicts the thermal-hydraulic behavior of the core, including the water and gas contained within the core boundary, and the response of core components during all phases of a sequence. The model is common to the BWR and PWR codes. The calculations are performed on a nodal basis. Users can specify up to 50 axial rows and 7 radial rings (channels); typically 13 to 33 axial rows (10 to 30 for the active core, 2 below the active core for the core support plate and the lower tie plate and lower gas plenum, and 1 above the active core for the upper tie plate and upper gas plenum) and 5 to 7 radial rings provide adequate resolution.

The code tracks the mass, energy, and temperature<sup>2</sup> of the following constituents in each node:

- Fuel (UO<sub>2</sub>)
- Cladding (Zr, ZrO<sub>2</sub>, stainless steel, steel oxide, and U-Zr-O)
- Fuel canister (Zr and ZrO<sub>2</sub>)
- Control blade (B<sub>4</sub>C, stainless steel, and steel oxide)

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<sup>2</sup> See Sections 5.2.2 (BWR) or 6.2.2 (PWR) for a discussion of the relative temperatures of the core constituents.

- Control rod or water rod (Ag-In-Cd or  $B_4C$ , stainless steel, steel oxide, Zr, and  $ZrO_2$ )
- Structural materials (Zr,  $ZrO_2$ , stainless steel, and steel oxide)

Input quantities include the initial masses of the different materials, the geometry of the constituents, and axial and radial peaking factors.

The initial core power is specified by the user. Decay power is determined from the ANSI/ANS decay heat correlation [9]. The user also has the option of specifying the decay power as a function of time in the PWR code. In addition, the BWR code can be run in an anticipated transient without scram (ATWS) mode, in which the power is calculated using either the Chexal-Layman correlation (power as a function of water level, pressure, and core inlet subcooling) [10] or a user-input power versus water level table. Shutdown using a standby liquid control (SLC) system is also modeled for ATWS sequences.

Consistent with the models in the rest of the primary system, a single temperature is calculated for the entire water pool contained in the core, but individual gas temperatures and steam and hydrogen fractions are calculated for each core node. Auxiliary calculations are used to estimate the elevation at which the coolant reaches saturation.

The dominant intra-nodal heat transfer processes among the fuel, cladding, fuel canisters, control blades, control or water rods, structural materials, and coolant are included in the core model. The code also calculates conduction and convection heat transfer between nodes (axially and radially), radial thermal radiation between neighboring nodes, and radiation to vessel internal structures.

Heat generated in the core is transferred to the water pool as sensible and latent heat. If there are BWR fuel cans, which limit radial flow in the core, distinct boiled-up water levels are determined for each water channel. Otherwise, cross-flow is calculated, and there is a single boiled-up level in the core region.

In addition to calculating water flow into the bottom of the core from the lower plenum and water and steam out of the top of the core, the code models water injection into the core region from BWR core sprays and LPCI injection systems and from PWR upper head injection systems.

MAAP4 contains a diverse and detailed set of models for calculating the oxidation of core constituents and their melting and subsequent transport. Because this report focuses on applications only up to core damage, these models are not described here. Detailed information about these models can be found in the MAAP4 User's Manual.

*Principal subroutines:* HEATUP, COVER, ROW, RATES1, CIRCUP, POWER, ATWS

*Parameter file sections:* BWR Heatup, PWR Core, Control, Model

### **2.2.3 PWR Steam Generators**

MAAP4 has separate models for U-tube and once-through steam generators. For either type of steam generator, the user selects a one-region or two-region model for the secondary side. In the two-region model for U-tube steam generators, Region 1 encompasses the tube bundle and riser section, and Region 2 encompasses the balance of the steam generator volume. The physical boundaries between Regions 1 and 2 are the tube bundle shroud and the risers. In the two-region model for OTSGs, Region 1 encompasses the tubes and Region 2 is the balance of the steam

generator fluid volume. The physical boundary between the regions is composed of the cylinder formed by the shroud and the steam baffle.

Either the one-region or the two-region model is adequate for most sequences, and historically the one-region model has been used for the majority of applications. However, the two-region model is useful when more refined secondary side thermal-hydraulic information is required. For example, the downcomer water level under high feed flow conditions (that is, prior to a reactor trip) is calculated more accurately using the two-region model. In addition, the two-region model will more accurately predict the water mass in the generators when auxiliary feedwater (AFW) is lost after having been operational, and it will calculate more realistic responses during a main steam line break (MSLB) sequence, including level swell and two-phase discharge through the break. When the steam generator dries out, the two-region model more accurately calculates natural convection heat transfer between the tubes and the shell, which is important primarily after the core is uncovered. Based on the improved capabilities, the two-region model is the recommended option.

The steam generator models calculate the heat transfer from the primary side water or condensing steam to the secondary side water and/or uncovered portion of the tubes. The calculations start with the masses and energies of the secondary side water and gas. The pressure, the temperature of each phase, the water levels, and the rates of change of the mass and energy terms are then determined. For the one-region model, the secondary side water is assumed to fill the downcomer and tube bundle to the same collapsed level. This assumption is applicable because MAAP4 is generally used for scenarios that involve quasi-steady behavior at decay power levels. Under these conditions, there is a negligible static head difference between the downcomer and the bundle. The two-region model calculates individual water levels in each region. It also has a tube bundle heat transfer model that tracks the subcooled length, a fully-imposed fluid momentum model, a two-phase swell model, and a structural heat sink model. Both the one-region and two-region models include equilibrium and non-equilibrium thermodynamics such that gas and water might or might not be in thermal equilibrium.

The models include the influx of feedwater through main and both motor- and turbine-driven AFW systems, and the influx of water and gas from the primary system through SGTRs. Water and gas are lost from the secondary side through main steam isolation valves (MSIVs), relief valves and safety valves, main steam line breaks, and feedwater line breaks. The calculations for the steam generators in the broken loop(s) and the unbroken loop(s) are the same except that SGTRs and feedwater line breaks are modeled only for the broken steam generators.

*Principal subroutines:* BSTGEN/USTGEN, BSG2R/USG2R, HXFRSG

*Parameter file sections:* Steam Generator, Initial Conditions, Control, Model

#### **2.2.4 Containment and Reactor/Auxiliary Building**

The same model is used for the containment and the reactor/auxiliary building. It is a generalized node and junction model and is common to the BWR and PWR codes. The user can specify a maximum of 30 compartment nodes in the BWR code and 40 in the PWR code, 200 distributed heat sinks, 200 lumped heat sinks, and 200 flow junctions. Five types of flow junctions can be defined:



- A normally open flow path
- A normally closed flow path designed to fail open on a pressure differential
- A flow path that simulates a vacuum breaker or a check valve
- A loop seal flow path
- A normally closed flow path designed to fail when core debris in the containment erodes the concrete more than a specified distance

Starting with the masses and energies of gas constituents and water in each compartment, the code calculates thermodynamic properties. It then computes gas and water flows between the compartments, heat transfer to internal and boundary heat sinks, condensation and evaporation, and other phenomena using semi-implicit methods to account for interdependencies in a stable fashion. An optional subnodal physics model can be employed to account for stratification due to non-homogeneous gas properties within a compartment and for buoyant plume dispersion between compartments. An unusual feature of the flow calculations is that they account not only for unidirectional natural circulation of gas and water, but also for countercurrent flow of gas and water through large junctions.

Containment engineered safeguards systems are modeled, including sprays, gas coolers, water heat exchangers, and hydrogen igniters and recombiners. Normally closed flow paths are used to represent containment vulnerabilities, which can then fail open based on user-defined criteria. Leakage in or out of the containment is modeled with normally open flow paths.

*Principal subroutines:* AUXREG, AUXFLO, AUX EVT, AUXESF

*Parameter file sections:* Auxiliary Building, Topology, Material, Distributed, Lumped, Pointers, Interfaces, Engineered Safeguards

### **2.2.5 Fission Products**

MAAP4 contains models that calculate the release of fission products from the core and relocated core material in-vessel, as well as from core debris ex-vessel. It also calculates the transport and deposition of fission products in the primary system and in the containment, and the release of fission products to the reactor/auxiliary building and the environment through containment leakage and failure paths. The code sorts the initial masses of a set of fission product elements into 13 groups and then tracks the mass of each group in each of four physical states (vapor, aerosol, deposited on surfaces, and contained in corium) in the various components of the primary system and containment. It also calculates the decay energy generated by each group in each location. The fission product models are applicable only to Level 2 PRA calculations, so they are not discussed further here. Detailed information about these models can be found in the MAAP4 User's Manual.

*Principal subroutines:* HEATFP, FP RELC, FPTRAN, POOLDF

*Parameter file sections:* Fission Product, Model

## **2.3 Computational Structure and Design Philosophy of MAAP4**

The MAAP4 code is written primarily in Fortran and can be run on a variety of computer platforms, most commonly PCs. The format of the input and output files is tailored to plant engineers. Users can control phenomena through flags and uncertainty parameters. The calculations are done in SI units; users have the option of specifying that the input and/or output quantities be in either SI or British units.

The code is modular, consisting of several hundred subroutines and functions that fall into four categories. The high-level routines include the main program, input and output routines, data storage and retrieval routines, and numerical integration routines. The system and region routines set the flags that define the status of the various systems and contain the differential equations for the conservation of the state variables, principally the masses and energies of the constituents in the individual volumes. The phenomenological routines contain the equations for determining the rates of change of the state variables within and between the individual volumes; these routines are the core of the code. The property and utility routines generate physical properties and perform mathematical operations. An overlying parallel structure exists between the thermal-hydraulic routines and the fission product routines in the code architecture.

The equations in MAAP4 are essentially lumped parameter, nonlinear, ordinary differential equations in time. The overall calculation scheme proceeds as follows. First, quantities such as pressure and temperature are calculated given the current values of the state variables (for example, masses and internal energies). Next, the rates of change of the state variables are determined by summing the contributions of each modeled phenomenon. Then, new values of the state variables are obtained by integrating their rates of change using a prospective time step. Finally, the fractional changes of key state variables are assessed; if any exceeds input criteria, the time step is reduced and the rates of change and integration calculations are repeated. The last step is performed because some rates of change (for example, those based on assumed quasi-steady behavior) depend explicitly on the time step.

The models in MAAP4 have been designed so that the code is fast running. This is a hallmark of MAAP. The primary means of achieving this objective are the use of quasi-steady modeling wherever appropriate, relatively coarse nodalization, and the largest possible time step consistent with the level of detail desired. Smaller values of the time step are used when key quantities are rapidly changing; larger values are used when conditions are relatively stable. The code also uses smaller time steps in some of the localized primary system thermal-hydraulic calculations, eliminating the need for the bulk of the calculations to be run with the smaller time steps. Other features that contribute to the code's speed are 1) the use of tabularized results and correlations from other computations rather than the incorporation of specific detailed models and 2) nonuniform levels of nodalization that reflect the magnitudes of the potential gradients. The result is that the code execution time is generally several orders of magnitude faster than problem time on a typical PC and considerably faster than most comparable codes.

In conjunction with the design features of the code that enable it to be fast running, the level of detail in the models is commensurate with the level of precision required for anticipated PRA applications. Furthermore, a central feature of the code's design philosophy is that the level of detail in the models tends to increase as conditions in the plant become more severe. To balance these characteristics, many of the key models incorporate input parameters that allow users to investigate the sensitivity of the results to variations in the calculations as a way of evaluating the

potential effect on the results if more complex, detailed models had been used. Examples of such parameters are the void fraction above which the phases separate in the PWR primary system (discussed previously) and a flag that indicates whether steam and water flows from the primary system to the containment are assumed to be intimately mixed. The bulk of the parameters that are used for uncertainty and sensitivity studies are contained in the *Model* and *Control* sections of the parameter file and are discussed further in Section 4 of this report.

The level of detail and precision in MAAP4 is quite acceptable for Level 2 PRA risk-informed applications. When the code is used for success criteria and other Level 1 PRA risk-informed applications, it is important that users are aware of the level of detail in the thermal-hydraulic modeling and the need to supplement best-estimate calculations with sensitivity studies, as appropriate.

The following example illustrates the modeling philosophy and how it affects the use of the code for Level 1 PRA analyses. As mentioned previously, the code does not mechanistically calculate single- or two-phase natural circulation of water in the reactor coolant system (RCS) of a PWR, and a strictly parametric model is employed. The code was written this way to avoid complexity and increase execution speed, and the method is generally justified because the temperature difference between the RCS and the steam generators is sufficiently small so that associated errors do not significantly affect the accident progression. However, the parametric treatment can lead to considerable variability in the two-phase conditions that determine the flow through a small break in the RCS, and sensitivity analyses are appropriate and recommended to bound these errors. If conditions in the RCS continue to degrade, the phases will eventually separate, and two-phase natural circulation ceases. Once the core uncovers, single-phase natural circulation of gas might begin—especially in high-pressure accidents—driven by temperature differences between the gas in the reactor vessel and in the steam generators. In contrast to the situation earlier in the accident, MAAP4 **does** contain an integral model for single-phase natural circulation of hot gases that has compared quite well to very detailed severe accident codes [11]. This feature of the code—that the modeling becomes more comprehensive as accident conditions worsen—explains why the use of MAAP4 for Level 1 PRA and other non-severe accident analyses requires that care be taken to compensate for simplifications in the modeling. Guidance on how to address and evaluate simplifications is included in the applications-specific sections of this report.

In addition to running the full code, MAAP4 can be run in a dynamic benchmarking mode in which only selected phenomenological models are exercised. This allows the actual MAAP4 routines to be used for testing and benchmarking comparisons without creating separate executables. The data and plant or experimental facility descriptions for some of the key benchmarks are included in the coding to facilitate user verification of the models.

## 2.4 MAAP4 Documentation

The MAAP4 code is documented in the MAAP4 User's Manual [1], the user's guides (that is, the six sample parameter files), and the MAAP4 transmittal documents [12, 13]. This applications guidance document is intended to be used in conjunction with the other documentation.

The User's Manual contains detailed information on how to prepare input files and execute the code as well as detailed descriptions of the models in the code, including descriptions of the individual subroutines and functions. It is currently distributed in hardcopy form and is undergoing a transition into electronic form. Components of the manual are updated in conjunction with updates to the code. The manual is divided into four volumes:

Volume I: User Guidance

- Code installation and operation
- Input and output files

Volume II: Code Structure and Theory

- Summary of models
- Subroutine and function descriptions

Volume III: Benchmarking

- Key benchmarks
- Plant benchmarks
- Integral experiment benchmarks
- Separate effects benchmarks

Volume IV: Optional Features

- MAAP4-GRAAPH graphical interface
- MAAP4-DOSE code for radiological calculations

The user's guides contain detailed descriptions and default values and ranges of the input parameters included in the parameter file. There are BWR guides for Mark I, Mark II, and Mark III containments and PWR guides for Westinghouse large dry (WLD) and ice condenser (WICE) plants with U-tube steam generators and for B&W plants with OTSGs. The guides are essentially sample parameter files and can be used as templates for plant-specific parameter files. They are distributed electronically.

A transmittal document accompanies each revision of the code. It contains information on code installation and execution, summaries of the changes made to the code since the previous revision, and discussions of the effect of the changes on the code results. It is distributed electronically. The version of the code that was used during the development of this applications guidance document is MAAP 4.0.6. The current version of the code is MAAP 4.0.7, and pertinent information from Rev. 4.0.7 has been included in this revision of the document.

The source code is an additional documentation resource. It is available electronically on an as-needed basis.

# 3

## ENSURE QUALITY OF MAAP4 ANALYSES

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This section offers guidance on ensuring the quality of MAAP4 analyses. To provide a context for the guidance, this section also contains brief descriptions and reference information on parameter files and sequence input files as well as a brief description of how to execute the code and interpret output files.

The guidance in this section addresses the following:

- Testing of a parameter file
- Planning and creating sequence input files
- Confirmation of successful code execution
- Control of files and documentation of runs
- Review of results
- Training and certification of code users

A summary of the requirements of the ASME standard for PRA applications [7] and the corresponding NRC regulatory positions on those requirements from RG 1.200 [8] that directly relate to MAAP4 analysis are included at the end of this section along with a cross-reference of the components of this guidance document with the intent and elements of the requirements.

The guidance in this section is intended to suggest “best practices” for using the code. Alternative approaches are acceptable if they meet the ASME standard or other controlling requirements. The guidance is consistent with Rev. 4.0.6 of the code, with some augmentation stemming from Rev. 4.0.7.

### 3.1 Introduction to Input and Output Files and Code Execution

MAAP4 requires two input files:

- A plant-specific parameter file
- A sequence-specific input file

The sequence-specific input file may contain nested subfiles. Additional input files are used for MAAP4-GRAAPH, which is an optional graphics display and user interface. (For a description of MAAP4-GRAAPH, see Volume IV of the MAAP4 User’s Manual [1].)

The code generates approximately 25 output files, including a synopsis of the sequence, a summary of events, tables of time-dependent results in a form suitable for plotting, and tabulated results that provide the details of the plant's status at selected times. The input and output files are described next, and the following general information applies to all of the files and to the code structure.

### **3.1.1 General Information**

#### **3.1.1.1 Variable Definitions and Access**

The definitions of the input parameters (variables) are contained in the reference parameter files that are provided with the code. These parameter files are also referred to as the *sample parameter files* and the *user's guides*. Definitions of calculated MAAP4 variables can be determined using the MAAP4 naming convention, which is described in Volume II, Section 2 of the User's Manual and in an abbreviated form at the top of the parameter files.<sup>3</sup> Additional references for calculated variable definitions are the lists of plottable variables on the MAAP4 web site, the plot file lists in the parameter files, the subroutine descriptions in Volume II of the User's Manual, and the source code listings (available upon request from EPRI). There is no master list of all of the MAAP4 variables with their definitions, but the lists on the web site contain a large portion of those that are of interest to users.

Only a subset of the MAAP4 variables can readily be assigned input values or be included in output files. These variables are in the MAAP4 *hash table*, which is contained in the body of the code. The hash table cross-references the names of the variables to their memory storage locations. The table includes the predominant variables of interest, but there is no list of all of the variables in the table in the code documentation. (It is possible to obtain access to variables that are not in the table by assigning them to dummy variables through changes to the source code and then recompiling the code, but this is not routinely done. The method for using dummy variables is discussed in Volume I, Section 3.2.19 of the User's Manual.)

#### **3.1.1.2 Units**

MAAP4 calculations are done in SI units. The input values, including the values of parameters in the parameter file, can be entered in either SI or British units. The code will convert the values of MAAP4 variables from British to SI according to the variable naming convention, which is used to determine the type of quantity being represented (for example, area, pressure, or time), and the value of the units flag. The flag is set by the user in the parameter and/or input file, and it can be toggled between British and SI units as needed.<sup>4</sup> The last value of the flag also determines the units of the output variables.

Including explicit unit labels for individual values or expressions on the lines in the parameter file or input file overrides the system of units set by the units flag. The units label applies only to the numerical value or mathematical expression on the line and does not toggle the overall

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<sup>3</sup> There are exceptions to the naming convention that are handled within the code.

<sup>4</sup> To set the flag, the lines \*SI and \*BR are used in the parameter file, and the lines SI, METRIC, BR, and BRITISH are used in the input file.

system of units. The label is applied only to the last term in an expression unless parentheses are used. It is recommended that explicit units labels be used in each assignment or expression for clarity. The allowed units labels are listed in Appendix A of this report and must be spelled exactly as shown in the list. For convenience, the factors used to convert from British to SI units are also included in the list in the appendix.

Examples of units labels in assignment statements and expressions are as follows:

PSETRV(1) = 1000 PSI

ALOCA = (3.14 \* (7/12) \*\*2) FT\*\*2

WHEN ZWRWST < 2.7 M

More information about units is included in the discussions of the parameter and input files that follow, in Appendix A, and in Volume I, Section 3 of the User's Manual.

### 3.1.1.3 Event Codes

MAAP4 uses flags to control the high-level logic during an accident simulation. These are referred to as *event codes* or simply *events*. They indicate such things as whether setpoints have been reached, if individual systems are operational, and if the primary system or containment has been breached. Each event code has an identifying number and is assigned a value of 0, meaning false, or 1, meaning true. There are three categories of events:

- **MAAP4 automatic (internal) events:** Event codes with numbers between 1 and 199 and between 1001 and 1450 have predefined meanings, and their status (true or false) is determined by conditions calculated by MAAP4. The initial status of each automatic event is set by the code based on calculated initial conditions. Generally, the initial status of an automatic event is false.
- **MAAP4 external events:** Event codes with numbers between 200 and 399 have predefined meaning, and their status is set by the user through input. These are the events that can be used to initiate the sequence and to take action in response to intervention conditions. The initial status of each MAAP4 external event is false.
- **User-defined events:** Event codes with numbers between 400 and 699 do not have predefined meanings; their meanings are defined by the user in the *Userevt* section of the parameter file or in the input file. These events allow the user to add logic to the code calculations. Their status is determined by MAAP4. The initial status of each user-defined event is false.

The definitions of the MAAP4 automatic and external events are different for the BWR and PWR versions of the code. Each of these events has a message string—a phrase that indicates its meaning when it is true. In most cases, another string indicates its meaning when it is false. The event message strings for events 1 through 399 are listed in the *Evtmes* section of the parameter file. The strings can be customized for a specific plant by modifying the parameter file. Users can also define message strings for user-defined events.

Along with the message strings, the *Evtmes* section of the parameter file contains detailed descriptions of the conditions that dictate the status of the internal events and the effect of changing the status of the external events. The event entries are in numerical order in the parameter file. The event codes and brief descriptions are also listed as a function of system in Appendices B and C for the BWR and PWR codes, respectively.

Examples of automatic and external events are as follows:

- The automatic BWR event that indicates that the feedwater pumps have tripped is event 19. As noted in the *Evtmes* section of the parameter files, this event is set to true if the feedwater pumps are turbine-driven (external event 294 is false) and one of the following is true:
  - The MSIVs have closed (automatic event 62 is true) or the turbine-bypass valves have been manually closed (external event 213 is set to true).
  - The reactor vessel water level is higher than the value of parameter ZHFW (internal event 182 is true).
  - The feedwater pumps are manually tripped (external event 209 is set to true).
- However, the pumps will not be tripped if they have been locked on by setting external event 208 to true.
- The event messages for event 19 are defined in the parameter files as FEEDWATER ON when the event is false and FEEDWATER PUMP TRIPPED when the event is true.

An example of a user-defined event to flag when the reactor coolant outlet temperature exceeds 600 K in a PWR simulation is as follows:

```
503 TWHPS > 600 K
503 TRUE  HIGH COOLANT TEMP
```

In this case, the event is assigned the number 503, and the message when the event is true is HIGH COOLANT TEMP.

### 3.1.2 Parameter Files

The parameter file provides a description of the plant for a MAAP4 accident simulation. It also contains phenomenological input, integration control input, output file specifications, event message strings, and, if applicable, user-defined events to augment code logic. Once created, the parameter file generally remains fixed and is used for all plant sequences. (The description of the plant can be augmented through sequence input files, as discussed next.)

A parameter file is usually constructed using one of the six sample parameter files that are distributed with the code as a template. The sample files—also referred to as the *user's guides*—contain detailed descriptions and default values and ranges of the input parameters. There are BWR sample files for plants with Mark I, Mark II, and Mark III containments and PWR sample files for Westinghouse large dry (WLD) and ice condenser (WICE) plants with U-tube steam generators and for B&W plants with OTSGs. The WLD sample file is also used for CE plants.

The parameter file is divided into the sections listed in Table 3-1. The section names begin with a single asterisk. The standard format of parameter assignments is as follows:

*parameter name      value    optional units label    // comment with allowed units labels*

For example, the line that assigns the value of the enthalpy of the BWR CST is

```
HCST            1.3514e5 J/KG            // Units: [J/KG, BTU/LB]
```



**Table 3-1**  
**Parameter File Sections**

| General Category                                      | Section Name                            | Types of Parameters in the Section                                                              |
|-------------------------------------------------------|-----------------------------------------|-------------------------------------------------------------------------------------------------|
| Control parameters                                    | Control                                 | Model selection and program control                                                             |
|                                                       | Model                                   | Input to key phenomenological models                                                            |
|                                                       | Concrete                                | Thermophysical properties of concrete                                                           |
|                                                       | Timing                                  | Timing control                                                                                  |
|                                                       | Integration                             | Integration control                                                                             |
|                                                       | Pltmap                                  | Variables to be written to data files for plotting                                              |
|                                                       | Prtlis                                  | Variable groups to be written to the tabular and/or log output files                            |
|                                                       | Pltdos                                  | Input to activate the generation of data files for the MAAP4-DOSE program (an EPRI dosage code) |
| Reactor core parameters                               | Heatup (BWR), Core (PWR)                | Reactor core configuration                                                                      |
|                                                       | Fission Product                         | Fission product initialization                                                                  |
| Primary system/safety system parameters               | Initial                                 | Initial conditions                                                                              |
|                                                       | Primary System                          | Reactor pressure vessel configuration                                                           |
|                                                       | Pressurizer (PWR)                       | Pressurizer configuration                                                                       |
|                                                       | Steam Generator (PWR)                   | Steam generator configuration                                                                   |
|                                                       | Engineered Safeguards                   | Engineered safeguards characteristics                                                           |
|                                                       | Generalized Engineered Safeguards (PWR) | Generalized engineered safeguards characteristics                                               |
|                                                       | Pump Characteristics (PWR)              | Generalized engineered safeguards pump characteristics                                          |
| Containment and reactor/auxiliary building parameters | Pointers                                | Compartment and junction identification indices                                                 |
|                                                       | Interface                               | Elevations for primary system–containment interfaces                                            |
|                                                       | Auxiliary                               | Containment and reactor/auxiliary building geometry and initial conditions                      |
|                                                       | Topology                                | Containment and reactor/auxiliary building flow paths                                           |
|                                                       | Debris                                  | Corium debris pools                                                                             |
|                                                       | Material                                | Heat sink thermal properties                                                                    |
|                                                       | Distributed                             | Distributed heat sinks such as walls and floors                                                 |
|                                                       | Lumped                                  | Lumped heat sinks such as metal structures                                                      |
|                                                       | Containment                             | Containment outer wall stress/strain option                                                     |

**Table 3-1 (continued)**  
**Parameter File Sections**

| General Category                   | Section Name              | Types of Parameters in the Section                                                      |
|------------------------------------|---------------------------|-----------------------------------------------------------------------------------------|
| Specific plant features parameters | Isolation Condenser (BWR) | Isolation condenser                                                                     |
|                                    | Quench (PWR)              | Quench tank                                                                             |
|                                    | Ice (PWR)                 | Ice condenser                                                                           |
|                                    | O1/O2/O3/R1 (BWR)         | Swedish-specific features                                                               |
|                                    | AP600 (PWR)               | AP600 and AP1000 core makeup tanks, passive heat removal system, and core reflood tanks |
|                                    | Spain (PWR)               | Spanish-specific injection systems                                                      |
| Event code parameters              | Evtmes                    | Event code messages                                                                     |
|                                    | Userevt                   | User-defined event codes                                                                |

The containment topology, event message, integration, plot and print file specifications, and user-defined events sections are exceptions: each has a unique format that is described in the sample files. The parameter values can be in integer, decimal, or scientific notation but can not be expressions or other variables (those capabilities are limited to the input file). In addition, commas are not allowed in the values, and periods should be used to mark the decimal point (for example, 1050.0 should be used instead of 1,050.0 or 1050,0). A parameter file is an ASCII text file and should not contain any hidden formatting characters such as tabs. Because there is no restriction on the length of a parameter file, it can contain numerous comments. The length of any line in a parameter file is limited to 78 characters; any characters beyond that are ignored by the code.

The parameter file is intended to be a best-estimate, as-built, as-operated representation of the plant. It includes both plant-specific parameters and those that are generic in nature, for example, those that control the phenomenological calculations. The definitions of the parameters are sufficient to determine which are plant-specific, and users obtain the values of these parameters from plant documentation such as drawings, safety analysis reports, system descriptions, and plant test data. Nominal values of the generic parameters are provided in the sample files, and users determine if they are appropriate for their analyses. The majority of the phenomenological parameters are in the *Control* and *Model* sections. The parameters in these two sections are discussed further in Section 4.

Additional information regarding the structure of a parameter file and the rules for formatting the entries is contained in Volume I, Section 4 of the User's Manual and at the top of the sample parameter files. Suggested guidance on the testing and control of a parameter file is included in Section 3.2 of this report.

### 3.1.3 Input Files

One main input file is used for each sequence. It contains such information as the title of the sequence, the name of the parameter file, sequence-specific changes to parameter values, start and end times, accident initiators, and intervention conditions and the actions to be taken when these conditions are met. Additional subfiles that contain portions of the input file can be nested within the main input file for convenience.

Input files are relatively short, usually fewer than 100 lines, and can be readily constructed without a template. The parameter file is used as a primary source of information for the input files for event code definitions, parameter names, parameter values, and so on.

Input files are composed of a series of statements and blocks. The most frequently used types are listed in Table 3-2. (Additional types are discussed in Volume I, Section 3 of the User's Manual.) The statements and blocks are identified by their keywords, and only those required for a sequence need to be included in a file.

There are two categories of variables in an input file:

- MAAP4 variables
- User-defined variables

MAAP4 variables are included in the code and are accessible through the hash table. User-defined variables are created in the input file through components such as function statements and can be used in subsequent portions of the input file. Values assigned to either type of variable can be numerical values in integer, decimal or scientific notation, mathematical expressions, or other variables. As with values in the parameter files, the values should not contain commas, and periods should be used to mark the decimal point (for example, 1050.0 should be used instead of 1,050.0 or 1050,0).

The order of information in the input files is flexible as long as it is logical. For example, changes to the parameter values should be included after—not before—the parameter file has been specified, and user-defined variables should be initialized before they are used. Unlimited comments and blank lines are allowed; in fact, it is recommended that they be used to enhance the legibility of the file and to document the intentions of the individual components. An input file is an ASCII text file and should not contain any hidden formatting characters such as tabs. The length of any line in an input file is limited to 78 characters; any characters beyond that are ignored by the code.

To include an event code in a component of the input file, either the variable `IEVNT(i)` with *i* set to the appropriate value or the corresponding message string can be used. The event message string must be typed exactly as it appears in the *Evtmes* section of the parameter file. It is recommended that a text editor be used to copy and paste the event message strings to ensure that they match those in the parameter file.

**Table 3-2**  
**Input File Components**

| Statement or Block                                          | Primary Function                                                                                                                                                |
|-------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| TITLE block                                                 | Contains the title of the sequence                                                                                                                              |
| PARAMETER FILE statement                                    | Specifies the name and location of the parameter file                                                                                                           |
| PARAMETER CHANGE blocks                                     | Contain sequence-specific changes to the values in the parameter file                                                                                           |
| SENSITIVITY statement                                       | Allows users to adjust the values of phenomenological parameters beyond their normal ranges (usually the first line in a file)                                  |
| START TIME and END TIME statements                          | Specify the sequence times (start time must be set to 0)                                                                                                        |
| PRINT INTERVAL statement                                    | Specifies the interval at which the tabular and restart output is written                                                                                       |
| INITIATORS block                                            | Defines the conditions that initiate the accident sequence, including event codes that disable systems (multiple blocks are allowed but are not routinely used) |
| OPERATOR INTERVENTION blocks (also called CONDITION blocks) | Define intervention conditions and subsequent operator actions, changes in system operational characteristics, and changes in plant conditions                  |
| ALIAS statements and blocks                                 | Define terms that can be used in place of MAAP4 variable names in the input file                                                                                |
| FUNCTION statements and blocks                              | Assign mathematical expressions to variables                                                                                                                    |
| PLOTFIL blocks                                              | Add to or modify the plot file specifications that are in the parameter file                                                                                    |
| LOOKUP VARIABLE and LOOKUP EVENT blocks                     | Set the values of dependent variables as functions of independent variables                                                                                     |
| INCLUDE statements                                          | Add subsets of the input file                                                                                                                                   |
| REPORT and REPORT TEMPLATE blocks                           | Define the format and frequency of customized report output                                                                                                     |
| SI, METRIC, BR, BRITISH statements                          | Set the value of the units flag                                                                                                                                 |

The following points regarding units should be kept in mind when constructing input files with British units and when evaluating the output. These are elaborated on in Appendix A with examples.

- When MAAP4 variables are used in expressions in the input file, the values used when the expressions are evaluated by the code are in SI units.
- The code treats numerical values in the condition statements in operator intervention blocks as if they are in SI units unless explicit British units labels are used.

- The code converts the numerical values in the intervention action statements from British to SI units if they are being assigned to MAAP4 variables (using the naming convention to determine the conversion factor). The code does not convert the values if they are being assigned to user-defined variables and no units labels are included.
- It is not possible to specify the type of units for user-defined variables. If explicit units labels are added to lines in which user-defined variables are assigned values or in intervention conditions that depend on user-defined variables, the code will convert the values from British to SI units. However, the code will not register that the user-defined variable has units, which is relevant if it is used in subsequent input file components or if it is written to an output file.
- The code does not check the appropriateness of a British units label. If the label is a valid label (that is, it is in the list in Appendix A), the code will use the corresponding conversion factor, even if it is not appropriate for the particular parameter.
- The code treats values that are assigned to MAAP4 variables in action blocks within user-defined event blocks in British parameter and input files as if they are in British units, even if explicit SI units labels are included with the values. This is the result of a code error that has been corrected in Rev. 4.0.7. Therefore, values should be in British units in action blocks when the default system of units is British.

Detailed information regarding the options, structure, and syntax rules for the input statements and blocks is contained in Volume I, Section 3 of the User's Manual. Suggested guidance on constructing and testing input files is included in Section 3.3 of this report.

### **3.1.4 Code Installation and Execution**

The computational portions of the MAAP4 code are written in ANSI-standard Fortran 90. Two executables are distributed with the code:

- A Windows executable that can run on a PC with the Windows XP or 2000 operating system (as of Rev. 4.0.7, only Windows XP is supported)
- A DOS executable that can run on a PC in an MS-DOS window

The source code and platform-specific extensions to the source code are also available to facilitate the creation of executables for VAX and ALPHA platforms running Open VMS and HP platforms running UNIX. The Windows executable run with the XP operating system is the only PC platform formally supported by EPRI.

The MAAP 4.0.6 and 4.0.7 transmittal documents [12, 13] include hardware and software requirements, code technical specifications, and detailed instructions for code installation and execution. Instructions are also contained in Volume I, Section 2 of the User's Manual. These operations for Rev. 4.0.6 are described briefly next; the operations for Rev. 4.0.7 are similar.

#### 3.1.4.1 Installation

The MAAP 4.0.6 code is distributed on one CD-ROM. The CD contains an automated installation utility that guides the user through the process. There are two modes of installation:

- **Basic installation:** This is for installation on a PC Windows platform. It includes Windows and DOS executables, sample input and output files, the transmittal document, portions of the MAAP4 User's Manual, and the XYPLOT2 post-processor for output files containing plottable results.
- **Advanced installation:** In addition to the above, this includes the source code for subsequent creation of an executable for either a non-PC platform or a PC on which the source code will be modified for plant-specific or model development purposes (outside the MAAP4 quality assurance program). Advanced installation requires a password from EPRI.

#### 3.1.4.2 PC Execution

The following information relates to running MAAP4 on a PC using the executables supplied with the code. Information for running it on other platforms and/or with user-created executables is contained in Volume I, Section 2 of the User's Manual.

There are two ways to execute MAAP4 on a PC:

- Use the Windows dialog box with the Windows executable
- Use batch files to run the DOS executable in an MS-DOS window

The primary advantage of the Windows dialog box method is that the user can monitor how far each sequence has progressed. The primary advantage of the MS-DOS batch file method is that subfolders for each sequence can be created automatically. These are small differences; either method is conducive to easy setup of multiple sequences.

The different executables yield minor differences in the results. The results from both are equally valid; however, the Windows version is the officially supported version. Furthermore, there are differences in the results that depend on whether the Windows executable is used on a PC with the Windows XP or 2000 operating system and whether MAAP4-GRAAPH is invoked (as of Rev. 4.0.7, only Windows XP is supported). Criteria for what are considered minor, acceptable differences in results are described in Section 3.1.4.3.

The DOS executable catches more numerical errors than the Windows executable. If the Windows executable is to be used for the bulk of the analyses, it is useful to test representative sequences and the parameter file by running them with the DOS executable as a precaution.

##### 3.1.4.2.1 Windows Dialog Box

The Windows dialog box is opened using the BWR4 or PWR4 application icon and then using the pull-down menu to select an input file. Multiple sequences can be run simultaneously by opening individual dialog boxes. The code will write the output to the folder that contains the

input file. If a run is stopped before it is completed by the closure of the window, the results generated to that point will be written to the output files. (Additional features are available for running interactively, using MAAP4-GRAAPH, and compressing the output and initiating multiple sequences with “INI” files. Instructions for using these features are available from the code maintenance contractor.)

#### 3.1.4.2.2 MS-DOS Window

To run the code in an MS-DOS window with the DOS executable, it is necessary to create batch files. Samples of simple batch files to run the PWR code with the ZION4.PAR parameter file and the input files SS1PA and SS1PB are shown next. They can be modified to run either the BWR or PWR code with user-created input files. The DOS commands in the first file make a subdirectory in which to run the sequence using the sequence name and start the execution, and those in the second file start the first file for each sequence. If a DOS run is stopped before it is completed by the closure of the window, the results generated to that point will be written to the output files. If errors are encountered during execution, the code will look for the file f7713.EER, which contains definitions of Fortran error codes and is useful for diagnosing the cause of the difficulties. Although it is not distributed with the code, it is available from the code maintenance contractor.

##### **Batch file RUNM4P.bat, which runs the code**

```
mkdir .\%1
cd .\%1
copy ..\%1.inp
copy ..\ZION4.PAR zion4.par
c:\maap406\pwr\dos\pwr4dos %1.inp > %1.ERR
cd ..
```

##### **Batch file RUNALL.bat, which specifies the sequences to be run and starts RUNM4P**

```
CALL runm4p SS1PA
CALL runm4p SS1PB
```

Three circumstances that will prevent the code from executing are often encountered by users when first using the code:

- The folder names contain blanks. Blanks are not allowed; multiple names can be connected with underscores as a workaround.
- The parameter file is open using Microsoft Word. It can not be open with this editor for the sequence to start.
- The name of the input file is too long. The individual file name is limited to 50 characters, and the full name—including the directory path—is limited to 70 characters.

### 3.1.4.3 Verification of Installation and Comparison of Results

The code distribution CD contains sample input and two sets of corresponding output files that were generated on PCs with the Windows XP operating system and the Windows 2000 operating system, respectively (as of Rev. 4.0.7, only Windows XP output is provided). Correct installation of the code can be verified by comparing sample problem results generated on the user's computer with those on the distribution CD.<sup>5</sup> The code is installed correctly if the user-generated results agree digit-for-digit with the corresponding results on the CD. It is sufficient to compare the figures-of-merit that are written to the end of the log file and the values in a single plot file. If the values in these two sets of files match, the results in the other files will match as well. It is suggested that a large LOCA (low-pressure) sample sequence and a station blackout (SBO) (high-pressure) sample sequence be used to verify installation: this will ensure that most of the subroutines are being used. The sample sequences are listed in the next section.

For an alternative type of computer and/or operating system, the code is installed correctly if the figures-of-merit at the end of the user-generated log file agree with those in the log file on the CD for a given sample sequence within the following tolerances:

- The timing of key events (for example, core uncover, core relocation, and vessel failure) agree within approximately 5%.
- The dominant masses of  $\text{UO}_2$ , CsI, and SrO agree within approximately 10%.
- The fraction of cladding reacted in-vessel agrees within approximately 5%. This should be calculated as an absolute difference because, as fractions, the values are already normalized. (That is, the percent agreement is the difference between two values of the fraction reacted, multiplied by 100. The difference should not be divided by one of the values to obtain a relative value.)

If there is any difficulty with the verification of the installation, the user should contact the code maintenance contractor for further information and instructions. If the results obtained on an alternative computer platform are outside the noted tolerances, the contractor can assist the user in evaluating the results to determine if the differences represent a problem with installation or if they are due to acceptable variations in the sequences.

It is recommended that the verification of the code installation be documented. Elements of the documentation should include the following:

- The version of the code and other identifying information such as the number of the distribution CD
- The name of the individual performing the installation test; the location and date of the test
- Identifying information about the computer, including the operating system
- Identifying information about the executable, including how it was created if it was not distributed with the code

---

<sup>5</sup> The plotting program, XYPLOT2, is automatically installed by the MAAP4 installation utility. Because it is a separate piece of software and does not contain information needed for the determination of PRA assumptions or results, it is not necessary to verify its installation or performance.



- Names of the input and parameter files
- Acceptance criteria (either digit-for-digit or tolerances noted previously, depending on the platform)
- Test results, for example, figures-of-merit from the generated output and the sample output
- Conclusions
- Review and acceptance information
- Other items required by an organization's quality assurance program

It is common for users to compare results from sets of sequences in which there are specific differences in the input (for example, sequences in which a parameter value has been adjusted to determine the sensitivity of the results to the parameter) or from sequences that were run on different operating systems. Differences in results are considered to be insignificant if the variations in the figures-of-merit in the log files fall within the tolerances listed previously. For Level 1 PRA sequences, additional results should be compared because the figures-of-merit in the log files are primarily related to post-core damage events and debris and fission product distributions. Suggested key quantities for Level 1 PRA sequence comparisons are primary system pressure, primary system water level and temperature, pressurizer water level and pressure, the hottest core node temperature, steam generator pressure, and containment pressure. Differences of less than 5% in these types of results are considered to be within the code's computational resolution. Differences greater than 5% are not necessarily significant; the trends of the sequences should be compared to determine the implications of the differences. The timing and impact of events such as the actuation of automatic pressure relief and injection systems should be examined as part of these comparative evaluations.

### **3.1.5 Output Files**

MAAP4 writes to the following output files as a sequence is executed. The file names are the name of the input file plus the noted extensions. Additional information regarding output files is included in Volume I, Section 5 of the User's Manual. The discussion of input file components in Volume I, Section 3 also contains useful information about the attributes and options for output files.

#### **3.1.5.1 Log File (\*.LOG)**

The log file summarizes the processing and results of a sequence. The contents of the log file that are frequently used by the code user are as follows:

- The name of the input file, the version of the code, and the name of the parameter file (along with the first 12 lines of the parameter file)
- A listing of the input file interspersed with comments indicating how the information was interpreted
- Information about the *Model* parameter values
- For the PWR code, the initialization of primary system and steam generator quantities

- The sequence initiators, the intervention conditions as they are met along with corresponding actions, and changes to the status of user-defined events as they occur along with corresponding actions
- Information about the state of the lower head and its penetrations when debris first relocates to the lower plenum
- Information indicating how the lower head failed, if applicable, and how close the vessel is to failing by various mechanisms
- The times at which select phenomena occur such as ex-vessel steam explosions and the opening of containment failure junctions
- Diagnostic messages (see Section 3.3.2.1) and warning messages
- At the end of the sequence:
  - A summary of peak temperatures and pressures in the primary system and containment
  - A summary of the count of diagnostic messages
  - The figures-of-merit: results that define the overall progression of the sequence such as the time of significant events, the distributions of the debris mass, and the distributions of fission products

### 3.1.5.2 Summary File (\*.SUM)

The summary file records the progression of an accident sequence as a list of events that occur and the times of their occurrence. The events include the MAAP4 and user-defined event codes, the opening and closing of safety and relief valves, and the opening and closing of junctions in the containment and the reactor/auxiliary building. Users can control which event codes may be written to the summary file and the frequency for those events that cycle repeatedly using options in the *Evtmes* and *Userevt* sections of the parameter file.

### 3.1.5.3 Plot Files (\*.D##)

Users can define up to 25 “plot” files, each containing up to 200 plottable variables (increased to 40 and 250, respectively, in Rev. 4.0.7). The plot files are defined either in the *Pltmap* section of the parameter file or in the input file. The variables that can be included are the MAAP4 variables that are in the hash table (discussed previously) and variables defined by the user in the input file. The default lists in the *Pltmap* section of the parameter files, the lists of plottable variables on the MAAP4 web site, and the lists of calculated variables in Appendices B and C are primary sources of output variable definitions. The values of each variable are written to the plot files at intervals determined by the code (that is, the plot time steps), and these intervals can be different for each plot file. Users can control the plot time steps and the format of the plot files using input parameters in the *Control* and *Timing* sections of the parameter file. It is necessary to run a separate program to generate plots using the data in the plot files. The XYPLOT2 program distributed with MAAP4 is an easy-to-use utility for generating simple plots.

#### 3.1.5.4 Tabular Output File (\*.TAB)

The tabular output file contains tables of calculated values that are recorded at relatively infrequent time intervals. The user can control the content of the file by modifying the values in the IPSET1 array in the *Control* section of the parameter file. Options include primary system and steam generator conditions, core maps, containment and auxiliary/reactor building conditions, fission product distributions, mass and energy balances, and the status of event codes. Values are written to the tabular output file at the frequency set in the input file and whenever event 320 is set to true.

#### 3.1.5.5 Miscellaneous Output Files

The following output files are also written by the code based on user input. For details on the functions and content of the restart and report files, see Volume I, Section 3 of the User's Manual. For details on the MAAP4-GRAAPH output files, see Volume III of the User's Manual.

- Restart files (\*.RES and \*.RDB): Contain snapshots of the sequence, which can then be used to start the sequence at an intermediate time. The files were useful for long-running sequences on older computers, but increased computer speed has made them essentially obsolete.
- Report file (%.RPT): Contains customized report output.
- System file (\*.SYS): Contains the name and version of the code, the name of the input file, the sequence and execution times, and any system difficulties.
- MAAP4-GRAAPH output files.

### 3.2 Testing of Parameter Files

After the parameter file has been created, it should be tested before it is used for plant sequences. There are several recommended steps in this process:

1. Do a preliminary “shakedown” with a steady-state (null transient) sequence.
2. Perform a visual review of the input lines (versus the comment lines).
3. Test the file with several standard sequences to validate its overall performance.
4. Test any user-defined events that are included in the parameter file.

Users should perform each of these steps to gain confidence in the values in the parameter file and therefore in the results of their accident sequences. Users should also review the miscellaneous information at the end of this subsection for additional guidance.

Note that the parameter file can be tested only when the file is essentially complete; that is, it is not possible to test individual components of the file such as the sections that relate to the primary system or to the containment.

### 3.2.1 Preliminary Testing with a Steady-State Sequence

Testing the parameter file with a steady-state sequence is performed to accomplish the following tasks. Suggestions for each task are presented next.

1. Check that the lines in the file can be read by the code (for example, screen for typographical errors or hidden formatting characters).
2. Conduct a preliminary assessment of the initialization phase of a calculation, and make adjustments to parameter values.
3. Check that the parameter values are self-consistent.

Simple steady-state input files that can be used as examples for testing a BWR and a PWR parameter file are shown. The user should replace the sample parameter file name with the plant-specific file name (and directory location, if appropriate) and for the BWR sequence use the appropriate number for the environment node. Note that it is not necessary to send the heat load that would ordinarily go to the containment to the environment for the PWR sequence as is done in the BWR sequence because the containment conditions are not affected as much by the heat load.

#### BWR Steady-State Input File

```
SENSITIVITY ON

TITLE
  PB STEADY STATE
END

PARAMETER FILE PEACH4.PAR 25

PARAMETER CHANGE
  TDMAX = 1.0 // reduce maximum time step for steady-state
  ICRBAL = 1.0 // write core energy balance information to the tabular output file

C Send the heat load from the primary system to the environment if containment
C coolers are not operational by default by setting JNPS for each primary system
C node to the "containment" node that is the environment.
  JNPS(1) = 6
  JNPS(2) = 6
  JNPS(3) = 6
  JNPS(4) = 6
  JNPS(5) = 6
  JNPS(6) = 6
  JNPS(7) = 6
  JNPS(8) = 6
END
```

```

C Create functions to check the initial primary system water inventory,
C with and without the mass in the recirc loop. These values should
C be compared with plant values, and adjustments made as necessary.
FUNCTION MWATTOT = (MWPS + MSTPS) * 2.205 // total inventory, in lbm
FUNCTION MWATLES = (MWPS + MSTPS - MWRR) * 2.205
C                                     // total less recirc, in lbm
PLOTFIL 87
    MWPS, MSTPS, MWATTOT, MWRR, MWATLES
END

C Plot the input core exit quality, NXCORE, the input core inlet mass flow,
C WPST(1), and the calculated core inlet mass flow, WCORI. Adjust NXCORE
C so that WCORI ~= WPST(1)
PLOTFIL 88
    NXCORE, WPST(1), WCORI
END

START TIME IS 0.
END TIME IS 1800.    // run for 1800 seconds = 1/2 hour
PRINT INTERVAL IS 500.

```

### PWR Steady-State Input File

```

SENSITIVITY ON

TITLE
    ZION STEADY-STATE
END

PARAMETER FILE ZION4.PAR 25

PARAMETER CHANGE
    ZWCTLB = -1. //CONTROL AT INITIAL B-LOOP S/G LEVEL
    ZWCTLU = -1. //CONTROL AT INITIAL U-LOOP S/G LEVEL
END

START TIME IS 0.
END TIME IS 1800.    // 1/2 hour
PRINT INTERVAL IS 500.

```

#### 3.2.1.1 Task A: Check That the Parameter File Can Be Read

Users should run the code with the steady-state sequence and the parameter file to determine if the file can be read completely and if the code executes the initialization phase. It is common at this stage for there to be a few minor errors in the parameter file that need to be identified and corrected. If the sequence does not progress past the initialization phase (that is, the sequence ends when the problem time is still equal to 0), users should look in the log file for error

messages, warning messages, or other information that describes how the code interpreted the input. If the code reads the parameter file completely but the sequence does not run to the end time, users should look in the tabular output file: it also provides useful information about how the code initialized values.

As noted previously, common mistakes that users make when they first start running the code on a PC are leaving the parameter file open in Word, using blanks in the names of the input file and folders, and using too long of an input file name.

If the code can not read the parameter file completely and it is not clear what problem the code is encountering in the file, it can be helpful to run the code with the LIST option, which causes the parameter file to be written to the log file (see Volume I, Section 3 of the User's Manual). Depending on the error, the file will stop being written at the line containing the error. Users should look for hidden characters (such as tabs) and for array indices that are inconsistent with other parameter values if the problem is not readily identified.

In addition, the DOS executable version of the code can be used to troubleshoot parameter file errors as long as the code is run in an open DOS window. The causes of the errors might be displayed in the window, depending on the particular types.

### **3.2.1.2 Task B: Assess the Initialization Phase**

After the steady-state sequence runs to completion, users should conduct a preliminary assessment of the results of the initialization phase by reviewing the output files as follows. In addition, the values of several parameters, which can be determined only when the creation of the parameter file has been completed, should be adjusted as necessary.

- The log file should be checked for any warning messages, and the parameter file should be modified accordingly.
- The results of the initialization phase should be checked to make sure that they are reasonable and represent the plant. Most of these results appear at the beginning of the tabular output file. It is recommended that users review all of the entries written to that file when the problem time is equal to 0 to see how the code interpreted the various portions of the parameter file and to become familiar with the type of information that is written to the file, for example, the list of open ("active") junctions. There is also a list of calculated initial values for the primary system and steam generators in the PWR log file.
- For BWR parameter files, the calculated initial water inventory in the primary system should be checked. The inventory is the sum of the masses of water and steam, variables MWPS and MSTPS, respectively. These masses are written to the tabular output file and can be plotted. The initial inventory should be within 10% of the plant value, which typically can be obtained from the plant's volumes and weights drawings. Attention should be paid to including the mass of water in the recirculation loop when determining the plant value because this mass is often a nontrivial fraction of the total water mass. (Alternatively, the calculated mass of water in the recirculation loop, variable MWRR, can be subtracted from MWPS for the comparison.) If the calculated total inventory is outside this range, adjustments should be made to the primary system areas and volumes, starting with parameter AUSH (the average flow area in the upper downcomer) and with the recirculation

loop geometry parameters, XDRR and XZRR. Functions to determine the water inventory with and without the mass in the recirculation loop are included in the sample input file presented previously. The \*.d87 plot file can be opened with a simple file editor to see the values. (See Section 3.2.5 for additional considerations about the recirculation loop parameters.)

- For PWR parameter files, the calculated initial height of the water on the secondary side of the steam generator, ZWUS or ZWBS, should be checked. This involves setting the target water levels, input parameters ZWCTLB and ZWCTLU, to -1. The calculation of the water level with the two-region steam generator model is more accurate than that with the one-region model because of its enhanced thermodynamic modeling. When the one-region model is used, users may choose to adjust the secondary side volume versus height array, input parameters VOFZSG and ZOFSG, by setting the volumes in the lower portion of the array to smaller values to increase the water level while maintaining the total volume. This adjustment can be important when the code results are used to determine the human reliability analysis (HRA) timing for scenarios that involve actions such as the triggering of feed and bleed procedures based on low steam generator level. Because the representation of the secondary side water level is not precise in either steam generator model, users should calibrate the values of steam generator level versus mass using plant values. Users are strongly encouraged to consult the additional information regarding steam generator water levels that is included in Section 6.6.3.
- For PWR parameter files that use the one-region steam generator model, the values of the steam generator input parameters might lead to a warning regarding the calculated steam generator void fraction. This warning (written to the log file) occurs when the value of the initial steam generator water level, ZWSG0, is less than the calculated water level, ZWBS. A reasonable value for ZWSG0 is the bottom of the separators. The uncertainty in the one-region model is greater than the impact of variations in the value of ZWSG0 between the middle of the risers and the middle of the separators.
- The calculated core support plate porosity should be checked. The core support plate is in the lowest axial row in the core nodalization. The mass of the plate is specified with parameters MSSNFB(1) and MZRNFB(1) for steel and Zircaloy, respectively. If the mass includes the total mass of the plate assembly—including peripheral and support structures versus just the mass of the horizontal portion of the plate that is under the fuel bundles—the code might calculate an unrealistically small porosity. This is evident if the values of the array IGTYP are greater than 1. A table of IGTYP values is included in the tabular output file. As of Rev. 4.0.6, the code will terminate with an error message if the IGTYP values for the support plate are greater than 3. The mass of the core support plate should be reduced until IGTYP equals 1 for the bottom row, and the excess mass should be included in a lower plenum heat sink in the *Primary System* section of the parameter file. Note that for BWRs the mass should be added to the CRD tube mass in the first lower plenum heat sink rather than as a separate heat sink because of a code error (this has been corrected for Rev. 4.0.7, and separate heat sinks can be used).
- For BWR parameter files, the value of the quality of the coolant exiting the core, parameter NXCORE, should be adjusted so that the calculated value of the inlet mass flow of coolant into the core, variable WCORI, approximately equals the input value, parameter WPST(1). The value of NXCORE that gives a good match between the two inlet values might differ from the nominal plant value for the quality; this is acceptable (accident sequence results

are not particularly sensitive to the value of NXCORE). If the sample steady-state input file presented previously is used, the \*.d88 plot file can be opened with a simple file editor to see the calculated value.

- Users should ensure that the code has correctly determined the height of the exit of each junction  $j$  relative to the floor of the downstream compartment, variable ZJUNC( $j,2$ ), because of the multiple ways in which compartments and junctions can potentially be configured. This is discussed in the *Topology* section of the parameter file. To facilitate the checking of the values, users can include small plot files in the steady-state sequence that contain the entrance and exit elevations relative to the upstream and downstream compartments, ZJUNC( $j,1$ ) and ZJUNC( $j,2$ ). For horizontal junctions (vertical flow, parameter IHRB( $j$ ) equal to 1), if the code does not calculate the intended value of ZJUNC( $j,2$ ), users can specify values that will be used instead of the calculated values. The assignment of these values can be added in the *Topology* section after the junction definitions (after the END statement).

### 3.2.1.3 Task C: Check That the Parameter Values Are Self-Consistent

Users should check that the values in the parameter file are self-consistent by reviewing the various output files from the steady-state sequence to see if the values lead to a null transient rather than to an accident transient. The suggested method for evaluating the content of the output files to confirm a null transient is outlined next. If the output indicates that parameter file values lead to an accident transient, the calculated initial conditions should be reviewed in conjunction with the values of system setpoints and trip logic in the parameter file to determine which parameter values should be adjusted.

- The figures-of-merit at the end of the log file should be checked. The only values that should be non-zero are the end time and the initial fission product masses. In addition, there should be no diagnostic or warning messages in the log file.
- The summary file should contain only entries that are appropriate for a steady-state sequence. Specifically, the BWR summary file should have only entries indicating that there are water pools in the appropriate containment compartments, that the code is writing to the restart file on a periodic basis, and possibly that the code has started to call the fission product subroutines. (This happens if the amount of condensed water in the containment gas space surpasses a threshold; the condensation occurs because of slight imbalances in the initial conditions and is not a concern.) Summary files for Mark III containments will also have an entry indicating that the junction from the upper pool has been closed. The PWR summary file should have only entries corresponding to appropriate initial conditions, including equilibrium thermodynamic conditions in U-tube steam generators when the one-region steam generator model is used, and entries indicating that the pressurizer heater is cycling on and off and that the code is writing to the restart file on a periodic basis. Summary files for ice condenser containments will also have entries indicating vacuum breaker operation. (Summary files for PWRs might indicate that there are water pools in the containment. This occurs if there is sufficient condensation of the water vapor associated with high relative humidity initial conditions.) For both BWRs and PWRs, user-defined events that appear in the summary file should be reviewed to determine if it is appropriate that they should have been set to true in a non-accident scenario. Any additional events in the summary file indicate that there are potential inconsistencies in the parameter values that should be investigated.



- After checking the summary file, users should look at the plottable output. This can be readily done using the XYPLOT2 utility program that is distributed with the code. Users should scan through the plots in each plot file, ignoring plot files \*.d71–\*.d77 because these relate to the separate MAAP4-DOSE program. For a steady-state sequence, the plots should be mostly horizontal lines. Some will begin with a step function, which is acceptable. There will also be some plots that are linearly increasing because they are cumulative values. Those that tend to be less constant (either not horizontal or not linear) are generally heat transfer terms, which take longer to stabilize. This is also true of some variables that relate to the water masses and countercurrent flows in the containment. If plots of other variables show what appears to be nonuniform behavior, users should determine if the magnitudes of the values are small, and they should compare the trends of the variables with those from the steady-state sample sequences provided with the code. Any plot output that suggests nonsteady behavior should be investigated.

### 3.2.2 Visual Review of Input Lines

The parameter file contains substantially more comment lines than lines actually processed by the code. A useful step in validating the parameter entries in a file is to strip out the comment lines and then visually inspect the remaining lines. Without the comment lines, it is easier to read the entries and detect errors (for example, typographical errors or mismatches in the units). A simple program that will strip out the comment lines can be either generated by the user or obtained from ERIN.

### 3.2.3 Testing with Standard Sequences

It is recommended that the parameter file be tested with three standard sequences to validate the file's overall performance: a station blackout, a small LOCA, and a large LOCA. The code distribution CD contains input and output for the sequences listed in Table 3-3. The input files for testing can be constructed using these sequences as a guide. They have varying degrees of complexity, which makes them useful examples.

**Table 3-3**  
**Standard Sample Sequences**

| Code | Parameter File Containment Type | Input File | Type of Sequence                                                               |
|------|---------------------------------|------------|--------------------------------------------------------------------------------|
| BWR  | Mark I                          | SBO1A1     | Loss of AC and DC power                                                        |
|      | Mark I                          | SLOCA1     | Small LOCA, no injection                                                       |
|      | Mark I                          | LLOCA1     | Large LOCA, no low-pressure injection                                          |
|      | Mark I                          | ISSLOCA1   | Interfacing system Large LOCA, no injection (output provided as of Rev. 4.0.7) |
|      | Mark II                         | SBO1A2     | Loss of AC and DC power, no injection                                          |
|      | Mark II                         | SLOCA2     | Small LOCA, no injection                                                       |
|      | Mark III                        | SBO1A3     | Loss of AC and DC power, no injection                                          |

**Table 3-3 (continued)**  
**Standard Sample Sequences**

| Code | Parameter File Containment Type | Input File | Type of Sequence                                                                                |
|------|---------------------------------|------------|-------------------------------------------------------------------------------------------------|
| PWR  | WLD                             | TMLB       | Loss of AC power, RCP seal LOCAs                                                                |
|      | WLD                             | S2HF       | Small LOCA, no recirculation of injection                                                       |
|      | WLD                             | AHF        | Large LOCA, no recirculation of injection                                                       |
|      | WLD                             | ISS2HF     | Interfacing system Large LOCA, no recirculation of injection (output provided as of Rev. 4.0.7) |
|      | B&W                             | TMI19F     | Small LOCA, no injection                                                                        |
|      | WICE                            | CRA1AI     | Large LOCA, no injection                                                                        |

The user should begin by running each sequence, solving any problems with the input and/or parameter file until the sequences run to completion. The results should be then compared with the corresponding results from the sample sequences. For the two BWR and two PWR sample parameter files for which there is not a full complement of sample output, the user can create corresponding sequences and run them with the sample parameter files. The comparison consists of looking at the trends of the sequences as indicated by the key events and the debris and fission product distributions in the figures-of-merit tables, system actuations as indicated by events in the summary files, and the primary system and containment conditions shown in the plottable results. The mass and energy balances and the diagnostic message counts should also be checked, and any warning messages in the log files should be evaluated. Major differences between the test and sample sequences should be investigated. The differences might be the result of plant features, for example, different battery depletion times for BWR turbine-driven injection systems. Other types of differences are indications of areas in which the parameter file values might warrant adjustment.

### **3.2.4 Testing User-Defined Events**

All plant-specific user-defined events that have been included in the *Userevt* section of the parameter file should be tested. PWR users should also check that the events for creep rupture in the *Userevt* section have been modified to match their plant geometry, for example, the break elevation assignments. Test sequences should be devised that force the events to happen; the test input files should contain logic or plot files that can be used to check the user-defined logic and the resultant actions. This is an important step and should not be skipped because it is easy to make mistakes when creating user-defined events. A systematic process is recommended to ensure that all potential errors and/or omissions have been addressed (that is, the testing should ultimately demonstrate that the units are correct, the logic works as intended, deadbands and repeat statements are included as needed, and so on).

### 3.2.5 Miscellaneous Considerations for Parameter Files

The following considerations and suggestions should be kept in mind when creating and testing plant-specific parameter files. They reflect practical considerations and issues that have affected users in the past. Users are also encouraged to review the updates to the sample parameter files in future revisions because they often address issues that are relevant to current revisions (for example, clarifications, revised default values, and corrections to existing parameter descriptions). Similarly, they should periodically review the questions, enhancements, trouble reports, and *MAAP FLAASHs* posted on the MAAP4 web site for additional information about input parameters.

- There are no crucial parameters whose values need to be determined with a high degree of numerical precision. That is, it is not necessary to determine values to more than a few significant figures.
- Users should refer to Section 4 of this report for guidance on those parameters that reflect phenomenological uncertainties and should therefore be adjusted for sensitivity analyses.
- Values included in the parameter file should be well documented. This includes adding reference information for each parameter or set of parameters and indicating how the values were obtained from the reference information (for example, if calculations were made to determine the parameter values or if values are based on extrapolations). A useful method is to add the reference citation in comment lines under each parameter's description.
- It is also highly recommended that copies of the references be compiled either electronically or in hardcopy form so that they can be readily retrieved.
- The parameter file should be reviewed by an independent individual. The review should be documented according to the organization's procedures. (See Section 3.5 for information on user and reviewer training and certification.)
- It is more efficient to construct the parameter file as an ASCII text file rather than creating a database of values and then assembling the file from the database. There is no advantage to building the file from a database that offsets the increased effort involved in creating a database using one of the sample parameter files as a template, modifying the values, creating a utility to convert the information in the database into a parameter file, and verifying that the utility works as intended. Depending on the user's capabilities, the exception might be to build those portions of the parameter file that are primarily composed of arrays, such as the containment and auxiliary/reactor building section, using a database.
- Wherever possible, flow versus pressure or head curves for injection systems should represent system curves—not pump curves—so that **delivered** flow is accurately represented. MAAP4 does not calculate friction losses in the lines and water recirculation back to the source. These losses should be taken into account when specifying the flow parameters. This is particularly important when the code is being used to determine system performance margins for success criteria and timing for HRA analyses.
- The number of pumps is an input parameter for the majority of the modeled injection systems. The code multiplies the flow calculated from the input flow curve by the specified number of pumps. The number should be adjusted so that it reflects losses associated with multiple pumps. For example, low pressure injection driven by two pumps might deliver

only 1.7 times as much flow as from one pump. In that case, the number of low pressure pumps should be set to 1.7. The number of pumps does not need to be an integer value. (See Appendices B and C for additional information about flow curves.)

- In conjunction with identifying setpoints for automatic relief valve operation for the parameter file, BWR users should determine if the plant's relief valves require a minimum pressure differential between the primary system and the containment to remain open if they are manually opened. In addition, users should determine if there is a maximum containment pressure above which manually opened relief valves can not stay open. Logic to address the resultant valve cycling should be added to input files if appropriate. The cycling can have a substantial effect on fission product retention in the containment. (This is discussed further in Section 5.3.8.)
- For BWR plants, if all of the primary system valves discharge into the same containment compartment (which would be the case if the plant has only safety valves or if both the relief and safety valves discharge to the suppression pool), the areas of the valves,  $ASRV(i)$ , should be positive so that all of the flow is directed to the compartment designated by the pointer parameter JNRV. They should not all be negative such that all of the flow is discharged only to compartment JNSV because of a feature of the code logic. (Note that the calculated variables WWRV, WGRV, WWSV, and WGSV are the water and gas flows to compartments JNRV and JNSV, respectively. They are not necessarily the individual relief and safety valve flows.)
- When determining the appropriate values for the BWR recirculation loop parameters, it should be noted that the code calculates the total water volume in the recirculation loop based on only one value of the inner diameter of the piping, XDRR, and the total length, XZRR. Because the recirculation loop is actually made up of segments of various size pipes, the input values should be self-consistent such that the calculated volume is correct. That is, XZRR should be the equivalent length based on the value of XDRR to yield the total volume in all of the actual recirculation loops. (Note that the code also uses XZRR and XDRR to calculate the heat transfer from the water [or steam] to the piping. This will most likely be over-estimated using the guidance for setting the values based on volume. However, this is compensated for by the fact that MAAP4 does not account for the heat transfer to the pumps.)
- The BWR parameter AJET is defined to be the most restrictive (minimum) total flow area between the downcomer and the lower plenum. In plants with jet pumps, the code uses the value of AJET to calculate 1) the gas flow area and 2) the water level in the jet pumps. The minimum flow area is appropriate for the first application, but the average area should be used for the second application. Adjusting the value of AJET to be the average area can have a nontrivial impact on the timing of Level 1 sequences, and users with plants that have jet pumps should evaluate the sensitivity of their results to the value of AJET. (As of Rev. 4.0.7, AJET is defined as the average total flow area for all jet pumps and is used only to calculate the water level. A new parameter, ALDLP, is used to specify the minimum flow area.)
- For BWR parameter files, the reference elevation for the primary system parameters that are defined to be absolute elevations should be the same reference elevation that is used to determine the compartment floor elevations in the containment, for example, sea level or plant zero.

- As noted in Section 3.2.1.2, PWR users are strongly encouraged to consult the additional information regarding steam generator water levels that is included in Section 6.6.3.
- Open junctions should be included in the *Topology* section of the parameter file to represent leakage from the containment. Leakage can have a significant impact on accident progression. (Through Rev. 4.0.6, only the Mark I sample parameter file had a leakage junction, so it was easy to neglect to include one. They have been added to the other sample parameter files for Rev. 4.0.7.) The equations in the GFLOW1 subroutine description in the MAAP4 User's Manual can be used to calculate an appropriate area for the leakage junction. In addition, for junctions that represent doors and plugged openings in the containment and the reactor/auxiliary building, consideration should be given to plant data or other information sources regarding the pressures required to open the junctions. These values are a function of whether the directions of the pressure forces would push the doors or plugs against jambs or away from them.
- Single junctions that represent parallel flow paths should be defined in the *Topology* section such that the area term is the cumulative area of the flow paths and the height and width are representative of one of the flow paths. (The area should not be for a single flow path, and the height and width should not be cumulative.)
- The code calculates flow through junctions based on their areas and lengths. For junctions that are only partially covered by water on the donor side and uncovered on the receiver side, the flow should be based on the perimeters of the junctions using weir flow calculations (this has been added in Rev. 4.0.8). To avoid incorrect flows in parallel horizontal junctions (vertical flow, parameter IHRB(j) equal to 1) that share a common donor compartment, the lengths of the junctions should be set to the same values.
- The entries in the volume versus height table for each containment compartment, parameters VRBLK versus XRBLK, should be such that the last volume segment (the one corresponding to the top of the compartment) is a nontrivial fraction of the total volume. If it is too small, there can be inconsistencies in the calculated water levels in the containment.
- Users should be aware of the following miscellaneous parameter file items that will be addressed in future sample parameter files:
  - BWR parameter DPVESL for plants with jet pumps is the pressure developed by the recirculation flow across the jet pumps. It can be approximated as the difference between the pressure at the core inlet and the pressure in the steam dome (the top of the vessel). It is not the pressure developed in the recirculation line by the recirculation pump.
  - PWR parameter VFCEPMX is defined as the void fraction limit to trip the reactor coolant pumps (RCPs). There is no actual RCP trip based on the void fraction; the parameter is included so that the code will not treat the RCPs as operating under degraded conditions. Users should add sequence-specific logic as either user-defined events in the parameter file or as interventions in the input files to trip the RCPs based on the plant's emergency operating procedures (EOPs).
  - The sample parameter files have lower head penetrations only in the lowest of the five lower head nodes. In reality, the penetrations are spaced such that they would be in nodes 1 and 2. Users should indicate that there are penetrations in node 2 in the parameter file—NPT1(2) for all plants and NPT2(2) for BWR CRDs—so that the code can calculate the potential for failure in either node. It is not uncommon for the code to predict that penetrations in the second node will fail before those in the first node.

### 3.3 Preparation of Input Files and Confirmation of Successful Execution

The guidance in this section addresses the construction and testing of input files and the review of code results. The recommendations are geared to the generation of high-quality MAAP4 analysis.

#### 3.3.1 Creation of High-Quality Input Files

Once the parameter file has been successfully tested, the input files for plant-specific transient sequences can be created. This involves three steps for each sequence:

1. Define the sequence.
2. Construct the input file.
3. Test the input file.

##### 3.3.1.1 Defining the Sequence

Users are strongly encouraged to document the sequence definition in words prior to constructing the input file. This definition should clearly indicate 1) the initiators, 2) intervention conditions and associated actions, 3) calculated values of interest, and 4) questions that are to be answered based on the results of the sequence. It is also useful to document the expected plant response and/or key events, for example, that a particular system is expected to be automatically initiated or that the core is expected to be uncovered. A checklist of plant systems indicating their availability is a useful component of the written definition.

There are several benefits to starting with a written definition, and the importance of this step is often overlooked:

- The definition clarifies the explicit intent of the sequence to the analyst who will construct the input file and assess the results. This is particularly useful if the end user who defines the need for the sequence is not the analyst who constructs and executes it. In this case, there is the potential for incomplete communication; the former might not be cognizant of MAAP4's default logic and how it treats certain plant features, and the latter might not appreciate the effects of inherent assumptions. For example, the requesting end user might assume that the MSIVs will remain open, while the default logic and setpoints cause them to close. The analyst and the end user should agree on the definition prior to the construction of the input file.
- The definition serves as a checklist for the analyst who is constructing and executing the sequence. This contributes to higher quality and efficiency because it helps prevent unnecessary iterations on input files and sequence execution.
- The definition provides information about the sequence for future reference. It should be incorporated into the documentation of the sequence.
- The definition facilitates the review of the sequence. Every sequence whose results feed into an application should be reviewed. It is difficult for the reviewer to adequately review a sequence if the intent of the sequence is not explicitly clear.

### 3.3.1.2 Constructing the Input File

When constructing the input file, the elements (components) of the file should correspond to the elements in the written definition. It is generally recommended that input files contain only elements that are relevant for the particular sequence. There is a tendency for input files to contain elements that are not relevant because the files are often built from previous input files. These unused components can mislead the analysts and reviewers, even if the elements are commented out.

It is suggested that users include intervention conditions to help document the progression of events. This will force messages to be written to the log file when conditions of interest occur, even if no actions are taken. If more than one condition can cause an intervention (that is, a condition statement contains multiple components), it is useful to repeat the conditions individually without any actions so that it is clear from the log file which condition was met.

It is also recommended that input files contain succinct but adequate comments so that the intent of each of the elements is clear, both at the time of the analysis effort and in the future if the sequence is revisited.

In addition to the plot files defined in the parameter file, it is useful to define sequence-specific plot files in the input file that contain key variables that relate to the main purposes of the sequence, including relevant event code variables (IEVNT(*i*)) and user-defined variables created for the sequence. Using relatively short lists of variables for each plot file results in an output file that is an easy-to-read table. This allows the user to quickly review the results simply by opening the plot files without having to use a utility program to plot the results.

The frequency at which values are written to the plot files is determined by an algorithm that balances the need for increased plot frequency when select quantities are changing rapidly with the need for files that are of manageable size. The algorithm is described in the AUTODT subroutine description in the MAAP4 User's Manual and in the *Control* section of the parameter file. Generally the resultant plot time steps are larger than the sequence time steps even at the times of key events. It is useful to capture the values of the plot variables at each sequence time step during the time periods just after key events. This can be accomplished by either manually adjusting the frequency (discussed in the next subsection) or setting event 323. The following intervention condition can be used to capture the values at each sequence time step whenever the corresponding timer is set in an intervention condition for a key event.

```

IF TIMER #4 > 0.0 S AND TIMER #4 < 20.0 S
  REPEAT
    SILENT
    IEVNT(323) IS
    TRUE
END

```

For input files in British units, users need to keep in mind the following:

- It is necessary to specify explicit units in intervention condition statements

- Because all calculations are done in SI units, functions need to include units conversion factors as appropriate
- User-defined variables are treated as being dimensionless

Users should refer to the units information in Section 3.1 and in Appendix A of this report.

If function statements are included in the input file, users should remember that the functions will be evaluated twice each time step. This will affect only recursive calculations such as  $A = A + B$  or  $C = C * D$ . (Note that this does not apply to expressions in other input file components such as operator intervention blocks.) Also, if the time step is used in a function, the variable TDOLD (the time step from the previous integration) and not TD should be used. Both of these points are important if user-defined functions are created to obtain integrated output such as total mass (versus mass flow). This is discussed further in Appendix A.

Because of a limitation in the input processing routines, components that contain mathematical expressions or logic expression and incorporate parentheses might not be successfully processed, and the code will stop before the initialization phase. For example, the code will not successfully interpret `WHEN XWJET < ((ZCRU - ZCRL)/3 + ZCRL)` or `WHEN XWJET < ((5.4 - 2.7)/3 + 2.7)`. It will successfully interpret `WHEN XWJET < ZCRU/3 + 2.7`. Adding spaces before and after the parentheses will generally resolve the difficulty. A similar problem occurs with units labels that are not followed by a space.

BWR users should not use the REPORT feature because of a code error associated with setting external events that are in the initiators block. The feature can be used if the initiating events are included in a condition block such as `WHEN TIMD > 0. S`. This error has been corrected for Rev. 4.0.8. It is discussed in MAAP FLAASH 67.

### 3.3.1.3 Testing the Input File

After the input file has been constructed, it should be tested by running the sequence for a short interval and making temporary adjustments to force intervention conditions and user-defined events to be met. This step is important for quality purposes because it is used to confirm that the input file elements are being interpreted as intended. This ensures that the code will correctly calculate that a condition has or has not been met.

Increasing the frequency at which values are written to the plot files during key portions of a sequence is a useful tool for testing input files. The plot frequency can be increased by adjusting the values of parameters TDFQMX and TDFQMN. Setting them to very small values (less than the minimum time step, TDMIN) will force the code to write to the plot files every time step. This helps the user identify maximum values and understand the exact progression of events. Because writing to the plot files at high frequency can lead to very large files, it is recommended that this be done only during periods of interest, after which the plot frequency parameters can be reset to their original values. The frequency can be changed through interventions in the input file.



The log file should be reviewed to evaluate how the intervention conditions and user-defined events were interpreted. It should also be reviewed to confirm that parameters and variables used in the input file were correctly identified as either MAAP4 or user-defined variables (indicated in the assignment statements), that units were correctly addressed in the input file and handled by the code, and that any warning messages have been found and addressed.<sup>6</sup> This helps identify typographical errors. Another useful method for verifying that the units are being handled correctly is to plot the values of functions, user-defined variables, and MAAP4 variables whose values are adjusted in the input file. The summary file should be reviewed to determine if the events that occurred were intended. The summary file also contains useful information about the default logic in the code.

When testing an input file, if the run does not get past the initialization phase, users should look in the log file for the word ERROR to identify the source of the problem. For sequences that require complex input files, it is suggested that users start with simple files, test them, and add elements in stages, testing each addition.

The following are common input file mistakes:

- Not including an END statement in an input file statement block
- Using the wrong reference point for determining an elevation (absolute versus relative elevation)
- Using a single equal sign (=) instead of two equal signs (==) in a condition statement
- Using a single slash (/) instead of two slashes (//) for a comment
- Putting an AND or OR at the end of a condition line instead of on the next line
- Using a tab in the input file or parameter file
- Including a variable in a plot file list that is not “plottable”
  - A MAAP4 variable that is not in the hash table
  - A user-defined variable that was not defined or is more than one word
- Misspelling a MAAP4 variable
- Using a comma within a numerical value (for example, 1,050.0 or 1050,0)
- Not using an equal sign when assigning parameter values (that is, using the parameter file format versus the input file format)

Users should be aware that intervening on the sequence time, variable TIM, can have a slight effect on the results because the code will adjust the time step to meet the desired value. The value of the variable TIMD is equal to that of the variable TIM, and users can intervene on TIMD without altering the time step (for example, WHEN TIMD > 2000 S).

---

<sup>6</sup> The log file contains a list of values of the *Model* parameters whose values are not equal to the default values set in the code. Due to minor differences in the precision of the conversions between British and SI units, when the input is in British units the list might flag a value as being different from the default when in fact they are the same.

Users should be cautious when using alias names for timers in the input file. The alias names can not be used for all operations, for example, resetting timers using the RESET command. All components of the input file using aliases should be tested to ensure that the components will work as intended.

The values of the time step control parameters TDMIN and TDMAX are always in seconds, but the value of time step control parameter TDCORE can be in seconds or hours. A common mistake is to assume that TDCORE will be treated as being in seconds, so it is recommended that explicit units labels be included when setting the value of this parameter in the input and parameter files when British units are used.

### **3.3.2 Confirmation of Successful Execution**

After the code has run to completion, the analyst should review the output to verify that the sequence ran successfully, that is, that the code interpreted the input file as intended, that the masses and energies balance, that there are relatively few diagnostic messages, and that the results are physically reasonable. It is recommended that the analyst always critically review the output and not assume that a “well-behaved” sequence—one with few diagnostics and non-fluctuating plot results—executed as intended.

When reviewing the results of a sequence, the user should keep in mind the order of code execution:

1. The parameter file and local parameter changes in the input file are read.
2. Conditions are initialized.
3. Initiators are processed.
4. In a loop:
  - a) Conditions are evaluated and subsequent actions are taken.
  - b) Properties are calculated based on the values of the state variables (masses and energies).
  - c) Rates-of-change of the state variables are calculated.
  - d) Values of the state variables are updated by integration.

Interventions and actions might lag by a time step because of the order of execution. That is, a condition met during one time step might not impact the progression of a sequence until the next time step.

It is also useful to keep in mind that thresholds in the calculations can have significant impacts on the progression of a sequence. This is important when comparing the results from several sequences. Examples of thresholds include system actuation and trip points, vessel failure criteria, and containment failure criteria. It is recommended that users analyze the sensitivity of their results to pertinent thresholds.

Specific recommendations for reviewing output files are as follows.

### **Log File:**

- Review the beginning of the file to see how the code interpreted the input file.
- Review the body of the file to see what intervention conditions and user-defined events were actually met and what actions were taken. Assess these results to see if the actions happened in the expected order.
- Review the figures-of-merit table at the end of the file. It contains the times that key events occurred, the debris distribution in the containment, and representative volatile (CsI) and nonvolatile (SrO) fission product distributions.
- For Level 2 PRA sequences, review the information written to the file when the debris first relocates to the lower plenum and when the vessel fails.
- Look at the summary of diagnostic messages at the top of the figures-of-merit table. See Section 3.3.2.1 for further information about diagnostic messages.
- Look for warning messages and determine if they indicate a problem with the sequence. (Note that there is no list of possible warning messages; questions or concerns about warning messages should be directed to the code maintenance contractor.)
- Look at how each variable in the input file was identified to make sure they are correctly treated as MAAP4 or user-defined variables. The log file contains the phrase “Assigned MAAP4 variable” or “Assigned User variable,” depending on whether the variable is in the hash table. The values in the assignment statements should be reviewed to see how any units labels were applied. Checking these assignment statements is very helpful for catching typographical errors in the input file.

### **Tabular Output File:**

- Review the relative errors in the primary system and containment mass and energy balances. Values of the relative errors greater than approximately 1% for mass and primary system energy indicate a potential error in the calculations. This is also true of relative errors greater than approximately 1% early in a sequence and 2–3% later in a sequence for containment energy; the relative error increases as more complex containment phenomena such as MCCI are predicted to occur.
- Review the core energy balance terms to confirm that the various sets of terms balance.
- Review the table of fission product mass balances. The differences between Balance 1 and Balance 2 for each fission product group should be less than 0.1%. In addition, the balances should equal the initial values except for the tellurium terms ( $\text{Te}_2$  is converted to  $\text{TeO}_2$ ).

### **Summary File:**

- Review the progression of the sequence as outlined in the file. Determine if it matches the intent of the sequence and if it is physically reasonable. Check for unexpected events such as an early scram or system trips, particularly at the beginning of the sequence. The descriptive information in the parameter file and the system information in Appendices B and C are useful references for the logic included in the code.

### Plot Files:

- Review the plots of variables from the plot files. The XYPLOT2 utility program that is distributed with the code or another post-processor can be used to generate the plots.

#### 3.3.2.1 Diagnostic Messages

Diagnostic messages are written to the log file if numerical difficulties are encountered during a sequence. These messages are part of the MAAP4 coding (in contrast to compiler diagnostics for severe errors). Diagnostic messages indicate such things as the failure of iterative solutions to converge and the failure of property routines to find consistent solutions. Often the diagnostics occur when there are significant events or when residual masses and energies are small. The messages are written to the log file as they are generated, up to a maximum number to prevent excessively long files. The total number of each one generated is written at the end of the log file. A description of each message is included in Volume I, Appendix 5B/P of the User's Manual.

The determination of whether the diagnostics indicate a nontrivial problem with the sequence is a matter of judgment. Generally, if the number of occurrences of an individual diagnostic message (for example, diagnostic message 55) is on the order of 10 and the occurrences are generated briefly during significant events, are due to small calculated quantities, or if the convergence criteria are almost met, the diagnostic can be considered insignificant. If the number of occurrences is on the order of 100 or more, the cause of the diagnostic should be investigated prior to accepting the results. To resolve such issues, the focus should be on the first diagnostics that were generated. There is no prescribed method for determining the cause of the difficulties. The usual approach is to start with an examination of the plot results at the time that the first diagnostics were generated to find an indication of the cause. The routines that generated the diagnostics indicate in which region of the code the issue lies: primary system, steam generator, or containment.

Potentially useful information for investigating the cause of diagnostics can also be found in the tabular output, in the relevant subroutine descriptions in Volume II of the User's Manual, and in Volume I, Appendix 5B/P of the User's Manual. In addition, rerunning the sequence with a smaller maximum time step (parameters TDCORE and/or TDMAX) can sometimes substantially reduce the number of diagnostics. If many of the diagnostics are generated in the containment subroutines (for example, AUXREG or AUXFLO), they can often be eliminated by turning off the subnodal physics model using *Control* parameter ISBNOD without compromising the results. (The subnodal physics model is primarily intended for containments that are highly nodalized in the vertical direction, which is uncommon in current commercial reactors.)

#### 3.3.2.2 Variable Time Step

As discussed in Section 2, one method employed in MAAP4 to make it a fast-running code is the use of a variable time step. Using smaller values for TDCORE and TDMAX can sometimes reduce nonphysical fluctuations in sequences. MAAP4 selects the time step by requiring that certain "critical quantities" not change by more than the fractions specified in the *Timing* section of the parameter file. Critical quantities include such variables as the mass of steam in the primary system and the mass of water in each primary system node. When a particular critical

quantity is determined to be limiting (in that it forces the time step to have the value TD rather than the maximum time step), the “time lost” is calculated as  $TD_{MAX} - TD$ . The cumulative time lost due to each critical quantity is periodically written to the log file along with the average time step. This information is useful for debugging abnormally long-running sequences. More information about time step selection and control is included in the *Timing* and *Integration* sections of the parameter file and in the INTGRT subroutine description in the User’s Manual.

### 3.4 Control of Files, Documentation of Sequences, and Review of Analyses

#### 3.4.1 Control of Input and Output Files

MAAP4 input and output files should be controlled so that they are identifiable, accessible, and protected. This facilitates the review process, makes the information available for inclusion in applications, and allows the results to be reproduced. The particular method for controlling the files should be consistent with an organization’s individual procedures.

The following are recommended components of the process for controlling MAAP4 files:

- Sequence input files should be uniquely named. Because the name of the input file is used for the output files, the output will also be uniquely named. The input files can be numbered, such as PB001.inp, or named with identifiers that indicate the type of sequence, such as PB\_L1\_SLOCA\_A2 for a Peach Bottom Level 1 PRA small LOCA with a 2-in. (5-cm) diameter break. The names should be cross-referenced with the information in the sequence documentation.
- Parameter files should be uniquely named so that there is no ambiguity as to which version of the file was used to generate the results. Including the code version and the date in the name of the file is one method. For example, PB406\_Jul-1-06.par identifies the Peach Bottom file that is consistent with Rev. 4.0.6 of the code and was last revised on July 1, 2006. The same recommendations apply to any “include” files—the subfiles that contain portions of the input file—that are used in multiple sequences.
- It is useful to have the revision history listed at the top of the parameter file. The history can include a summary of changes made for each revision, the code version to be used with the file (for example, Rev. 4.0.6), and the date of the revision. It is recommended that key information regarding the revision history be written in the first 12 lines of the parameter file because these lines are repeated in the log file along with the file name.
- It is a good practice to clearly document individual changes within the parameter file. A suggested method is as follows:
  1. Comment out the old value rather than replace it (for traceability).
  2. Include a comment line with the following elements:
    - a) Revision of the file to which the change corresponds
    - b) Reason for the change

- c) Name of the analyst who made the change (use the full last name, not just initials, unless the initials are cross-referenced to the name elsewhere in the file)
- d) Date of the change
- 3. Include a reference citation for the change, if appropriate.
- 4. Clearly indicate the beginning and the end of the change.

An example change to a parameter file is as follows:

```
** Rev. 1   M. Cursey 12/12/05 start - reduce the value based on recent
**          information regarding the number of plugged tubes
** NTSG      14723.          // Dimensionless
NTSG      14231.          // Dimensionless
**
** This parameter is the number of tubes in one steam generator.
**
** Orig TMI Ref: OTSG Oper Plant Manual, Section B-04, Rev. 9, Sec. 6.4.
** TMI Ref: Leo Shanley, ERIN, to Mark Cursey, ERIN, email, 12/12/05:
**          OTSG A will have 1692 tubes plugged, OTSG B will have 908 tubes
**          plugged. Average = 1300 = 8.4% 15531 - 1300 = 14231.
** Rev. 1 end
```

- Write-protect the parameter file to avoid inadvertent changes to the file when it is being read. It is frequently opened by analysts when preparing input files and reviewing results because it is a primary reference for input and event information, so it is vulnerable to being unintentionally modified unless it is write-protected. An alternative is to save an archive version and use copies for the analyses. The date and time stamp can be checked to ensure that the file being used was not modified.
- The parameter and input files should be stored with the output files. It is useful to store each set of input and output files in an individual folder, with the parameter file and any common include files stored in a higher level folder.
- It is a good practice to write-protect the final set of files from an analysis effort (input and output) so that they can not be inadvertently modified or deleted. It is recommended that backup copies be made and a set be placed in a long-term storage system so that they can be retrieved in the future. The protection, backup, and storage of files should be done in a manner consistent with the organization's procedures.

### **3.4.2 Documentation of Sequences**

The documentation of MAAP4 sequences should convey sufficient information so that an analyst could reproduce the results, and so that the intent and outcome of the sequences and how the results were extracted and used to draw conclusions are clear to analysts and end users. The documentation is also part of the basis for reviewing the analyses. The final documentation for an analysis effort should be prepared and stored in a manner consistent with the organization's procedures.

The following are recommended elements of the documentation of MAAP4 analyses:

- The text of the documentation should explain the overall purpose of the analysis. There should be identifying information about the individuals who performed, reviewed, and approved the analysis as well as the date(s) of the effort.
- The parameter files, the version of the code, the choice of executable, and the computer operating system should be clearly identified.
- The input files that were used should be clearly identified, and the written intent of the sequences should be included. It is also useful to include a copy of each input file.
- What **could have happened** in a sequence versus what **did happen** should be clear from the documentation. For example, it is important to distinguish between an injection system not being available versus being available but not being initiated because setpoints were not reached. Similarly, if a system could have initiated by more than one trigger, the trigger that actually caused the system to actuate should be recorded. The end time of the sequence should be recorded so that if something did not happen, such as core uncover, it is understood in the context of the time frame that was simulated.
- Tabulating the input and results can facilitate the understanding of the sequences, both for the analysts and the end users. The table should clearly indicate what information corresponds to the input and what corresponds to the results. Table 3-4 is an example of a summary table for a set of sequences that can be expanded and modified to match the needs of a particular plant. This example also demonstrates how a table can be useful for readily determining the effect of updating the parameter file and the code, and for evaluating the sensitivity of the results to variations in the input.
- Key assumptions made for the analyses should be documented, and justifications should be provided. The sources of information should be clearly referenced and retrievable.
- The summaries and conclusions in the documentation should address the effects of uncertainties and the sensitivities that were evaluated.

### **3.4.3 Review of Analyses**

MAAP4 analyses should be independently reviewed before the results are used in plant applications. The review should be performed by a qualified MAAP4 analyst. (The requirements for a qualified analyst are described in Section 3.5.) It is preferable that the reviewer be someone who was not involved with the analysis effort, although this is often not possible because there are relatively few individuals who have MAAP4 expertise within typical organizations. Efforts should be taken to maintain the independence of the reviewer as much as is practical.

The reviewer should use the analysis documentation and the set of input and output files as the basis for the review. If necessary, he/she should run sequences to check results and investigate issues that arise. The reviewer should determine if the analysis effort is thorough, accurate, clear, and sufficiently well documented. The guidelines and suggestions in this section (all of Section 3) can form a basis for this assessment. Of particular interest are 1) that the input files match the written intentions, 2) that the sequences executed successfully (that is, the numbers of diagnostics are reasonable and the masses and energies balance), 3) that the results were properly extracted, interpreted (particularly the physical reasonableness of the sequence progressions), and adequately communicated in the documentation, and 4) that appropriate sensitivity analyses were performed.

**Table 3-4**  
**Example Sequence Summary Table**

| Sequence | Initiators                       | Version and Date of Run    | Input      |                                                                                 |                |                    |          | Results                    |              |               |                                  |                          |                                                  |
|----------|----------------------------------|----------------------------|------------|---------------------------------------------------------------------------------|----------------|--------------------|----------|----------------------------|--------------|---------------|----------------------------------|--------------------------|--------------------------------------------------|
|          |                                  |                            | Break Size | Number of ED Valves Available, <sup>a</sup> Possible Reason for ED <sup>b</sup> | ESFs Available | Sensitivities      | End Time | Depressurization Initiated | CST Depleted | Core Uncovery | First Relocation to Lower Plenum | Maximum Drywell Pressure | Diagnostics (total, routine generating the most) |
| DR001    | MFW trip                         | 4.0.5, 5/1/05              | —          | 7, standard 4                                                                   | RCIC           | —                  | 10 hr    | 19 min, shroud water level | 2.5 hr       | No            | No                               | 41 psia                  | 2, FLOW                                          |
|          |                                  | 4.0.6, 6/1/06 <sup>c</sup> | —          | 7, standard 4                                                                   | RCIC           | —                  | 10 hr    | 18 min, shroud water level | 2.7 hr       | No            | No                               | 45 psia                  | None                                             |
| DR002    | Small recirc line LOCA           | 4.0.5, 5/1/05              | 2.0" dia   | None                                                                            | LPCI           | —                  | 15 hr    | —                          | —            | 1.3 hr        | 10.1 hr                          | 103 psia                 | 12, AUXREG                                       |
|          |                                  | 4.0.6, 6/1/06 <sup>c</sup> | 2.0" dia   | None                                                                            | LPCI           | —                  | 15 hr    | —                          | —            | 1.4 hr        | 10.9 hr                          | 105 psia                 | 5 PTCAL                                          |
| DR002a   | Same as DR002, adjust break size | 4.0.6, 6/1/06              | 1.5" dia   | None                                                                            | LPCI           | —                  | 15 hr    | —                          | —            | 1.9 hr        | 11.7 hr                          | 105 psia                 | None                                             |
|          |                                  | 4.0.6, 6/3/06              | 3.0" dia   | None                                                                            | LPCI           | —                  | 15 hr    | —                          | —            | 0.9 hr        | 9.2 hr                           | 105 psia                 | 7 AUXREG                                         |
| DR002b   | Same as DR002, sens. to FELOCA   | 4.0.6, 6/1/06              | 2.0" dia   | None                                                                            | LPCI           | FELOCA = 0.1 vs. 0 | 15 hr    | —                          | —            | 1.3 hr        | 10.1 hr                          | 101 psia                 | 5 PTCAL                                          |
|          |                                  | 4.0.6, 6/3/06              | 2.0" dia   | None                                                                            | LPCI           | FELOCA = 1.0 vs. 0 | 15 hr    | —                          | —            | 1.3 hr        | 10.2 hr                          | 110 psia                 | 10 FLOW                                          |

1 in. = 2.54 cm

1 psia = 6.89 kPa

<sup>a</sup> ED = emergency depressurization. The maximum number of valves is seven.

<sup>b</sup> There are four standard conditions for depressurization: low shroud water level, high pool temperature, high drywell gas temperature, and high drywell pressure.

<sup>c</sup> Rerun to determine the effect of the new code version on the sequence.



The reviewer should record the information that was reviewed, the method used to perform the review (for example, did the reviewer confirm that the results in the documentation were correctly obtained from the applicable output files), and his/her conclusions about the quality of the analysis. Concerns should be communicated to the analyst, and any dialogue with the analyst and subsequent iterations in the analysis should be documented. The method and storage of the review documentation should be consistent with the organization's procedures.

#### **3.4.4 Update of Parameter Files and Analyses**

A parameter file and plant analyses should be reviewed and updated, if appropriate, when the following occur:

- The code maintenance contractor issues a new revision to the code
- There are relevant new data from the plant
- There is relevant new information from the maintenance contractor or from information exchanges within the MUG (such as occurs at the MUG meetings)

Because it is not practical to update all of the analyses every time there is new information, users need to make judicious decisions about when to update the parameter file and how much of the analyses should be repeated. It is recommended that a subset of the analyses be repeated whenever there is a new code revision, which includes updating the parameter files. Good documentation of analyses will help guide users as to which sequences should be reevaluated as a function of the new information. (Section 4 of this report contains suggestions for selecting pertinent sequences for sensitivity analysis; the suggestions are also applicable in this context.)

**Because code changes can sometimes affect the processing of components of the input and parameter files—particularly when an element of the processing scheme has been corrected or improved—users should retest their input and parameter files when the code has been revised before repeating their analyses (with both steady-state and transient sequences).**

When sequences are reevaluated, it is important that any significant changes to the results are conveyed to end users. They in turn must decide if the applications in which the MAAP4 results have been used need to be revisited. To facilitate this, it is beneficial to maintain cross-references of where specific MAAP4 results have been incorporated. End users should be encouraged to provide sufficient references to individual MAAP4 sequences when results are used in PRA documents so that the results can be readily traced back to specific MAAP4 sequences, as appropriate.

### **3.5 Training and Certification of MAAP4 Analysts and Communication with End Users**

To ensure the quality of MAAP4 analyses, individuals who create input and parameter files, execute the code and extract results, and review the analyses should be trained so that they can correctly use the code and understand its capabilities and limitations. It is recommended that these users demonstrate this knowledge to become certified MAAP4 analysts under an organization's engineering certification program.

End users are individuals who incorporate MAAP4 results into plant applications. They might also be certified analysts, but often they do not have this expertise. In this case, it is not expected that they be proficient in the use of the code. However, it is important that end users are cognizant of the code's features so that they can successfully communicate with the analysts and understand the results and insights that the analysts provide.

The first part of this section addresses the training and certification of MAAP4 analysts. The second part addresses the communication between the analysts and the end users.

#### **3.5.1 Training and Certification of MAAP4 Analysts**

It is recommended that MAAP4 training be adequate to ensure that the analyst

- Understands the overall purpose and structure of MAAP4
- Can create input files that will lead to accurate sequence simulations
- Understands the process involved in creating a parameter file that represents a specific plant and can participate in the creation of a file
- Is able to update a parameter file to a new revision using sample parameter files
- Understands the content of a parameter file and how it relates to input file preparation
- Understands the basic phenomena that are modeled in the code and knows where to find detailed information about the models
- Can verify installation and execute the code
- Can determine if a sequence has executed without numerical difficulties
- Understands the output and can accurately extract results

- Is cognizant of the parameters that represent phenomenological uncertainty and knows when it is appropriate to perform sensitivity analyses
- Is cognizant of the effect of thresholds such as vessel and containment failure criteria on the results
- Understands the code's range of applicability, its limitations, and the ways to address these limitations
- Is cognizant of the MAAP4 documentation
- Is cognizant of the MUG, the MAAP4 web site, and code maintenance activities, including issue reports and bulletins (such as trouble reports and *MAAP FLAASHs*)

Training can be accomplished either through formal means, such as participating in a training course conducted by a code contractor or other expert party, or by informal exercising of the code, usually under the supervision of a more experienced user. The training should involve hands-on components such as the creation and testing of input files, and more theoretical components such as a review of the code's primary system modeling.

As part of a MAAP4 analyst certification process, the trainee should be able to demonstrate competency in the areas listed previously. It is recommended that this be done to the satisfaction of a MAAP4 mentor. Ideally, the mentor should be an individual who has significant experience using the code and a solid understanding of the types of phenomena that are modeled. A mentor can be an employee in the same organization as the trainee or someone from an outside organization, such as a contractor. It is up to each organization to determine who qualifies as a mentor. The identity and qualifications of the mentor should be entered into the organization's certification documentation system, as appropriate. (The "registering" of mentors and an analyst certification program might be coordinated by the MUG in the future.)

The mentor may use a written certification guide that includes a list of MAAP4 knowledge and performance requirements; a sample certification guide is included in Appendix D. The mentor should be cognizant of the appropriate responses to each certification requirement. (Because this report is not intended to be a training manual, it does not contain a corresponding set of responses.) As illustrated in the sample, the certification guide might also include identifying information for the trainee and the mentor as well as signature requirements indicating completion of the process. The sample guide can be customized to meet an organization's particular needs. In addition, the entire process can be customized to address the amount of MAAP4 expertise that is available within an organization and the options for interfacing with other knowledgeable individuals when outside expertise is used.

It is suggested that organizations control work assignments to ensure that results from MAAP4 that are used in applications were generated and reviewed by certified analysts. This also applies to the preparation of final (versus draft and/or scoping) parameter files and sequence input files. It is not necessary that a certified analyst be responsible for installing the code on the computers that are used as long as the installation is verified (discussed in Section 3.1).

### **3.5.2 Communication Between Analysts and End Users**

Two-way communication between MAAP4 analysts and end users is strongly encouraged to ensure that the analyses meet the intentions of the end users and that the end users understand the bases for the results. The information transfer can be both formal and informal.

Communications regarding individual sequences can be facilitated by written descriptions of the intentions of the sequences and assumptions about how they will progress. The end users and analysts should agree on these descriptions before the analysts execute the sequences (the final versions of the sequences if the process is iterative). Documentation of the results should include important events and what triggers them.

PRA analysis is intended to be best-estimate and reflect the as-built, as-operated plant. Therefore, when there are changes at the plant (for example, changes to operating conditions or system automatic setpoints), the information might need to be integrated into the MAAP4 analyses. Active communication will help identify the kind of information that is needed by the analysts, particularly the specific details that are required in the parameter file.

Two-way communication will also help to ensure that the logic assumptions in MAAP4 are invoked in a way that is consistent with the controls at the plant. For example, it is assumed in the PWR code that the main feedwater will be tripped if the reactor trips. This is not always the actual situation, and the analyst should override the code's logic to match the plant's feedwater control logic using statements in the input files, if appropriate. It is important that both the end users and the analysts understand the system logic that is built into the MAAP4 models so that adjustments can be made, if necessary. Without this understanding, the analysts could incorrectly assume that the code logic is applicable, and the end users could incorrectly assume that the plant logic is accounted for in the models. (As noted elsewhere in this report, the logic for the various system models and components in the code is discussed in the sample parameter files and in the User's Manual. Portions that are of particular interest to users are also addressed in the applications guidance in Sections 5 and 6 and in Appendices B and C of this report.)

As analysts learn about code applications, model issues, and related items of interest from the code maintenance contractor and other MAAP4 users through forums such as the MUG meetings and the MAAP4 web site, they should communicate pertinent information to the end users. This is particularly important for items that can affect key results. An example of this is the simulation of BWR SRV cycling at low pressure. Some SRVs require a minimum pressure differential to remain open if they have been manually opened. If this characteristic is not accounted for in the input files, the code will predict greater fission product retention in the pool than would actually occur. The significant effect of this relatively obscure plant feature was communicated to analysts at a MUG meeting and should be reviewed with end users.

Two-way communication about uncertainties in phenomena and in the plant response (for example, drywell liner failure) will generally lead to higher quality MAAP4 analyses. Phenomenological uncertainties and suggested sensitivity studies are discussed in Section 4 of this report. This information might provide beneficial insights to end users as well as to analysts. Similarly, it is important for the analysts to be cognizant of the uncertainties that the end users have identified as part of their overall application efforts. Of particular interest to both parties are those aspects that could affect the timing of key events, success criteria, and the magnitude of releases.

### **3.6 ASME PRA Requirements**

The ASME Standard for the Probabilistic Risk Assessment for Nuclear Power Plant Applications [7] sets forth requirements for PRAs used to support risk-informed decisions for current commercial light water reactor plants and prescribes a method for applying these requirements for specific applications. It establishes requirements for a Level 1 PRA analysis of internal events while at power and for a limited Level 2 PRA analysis sufficient to evaluate the large early release frequency (LERF) for internal events while at power. In addition, the NRC has issued Regulatory Guide 1.200 [8]. It provides guidance on determining the technical adequacy of a PRA and endorses the ASME standard and method with limited exceptions and clarifications.

The requirements in the ASME standard are organized into the following nine technical elements:

- Element 1: initiating events analysis (IE)
- Element 2: accident sequence analysis (AS)
- Element 3: success criteria (SC)
- Element 4: systems analysis (SY)
- Element 5: human reliability analysis (HR)
- Element 6: data analysis (DA)
- Element 7: internal flooding (IF)
- Element 8: quantification (QU)
- Element 9: LERF analysis (LE)

The standard lists objectives and a set of minimum high level requirements (HLRs) for each element. It also lists supporting requirements (SRs) to meet each HLR. Each SR might be subdivided into three capability categories; the higher the category, the more rigorous the requirement in terms of the scope, level of detail, plant specificity, and realism.

One purpose of this report is to provide guidance on the use of MAAP4 such that, if followed, the analyses that are used for PRA applications will meet the ASME requirements. To achieve this objective, each HLR was reviewed to determine if it is directly applicable to MAAP4 analysis. For each applicable HLR, the corresponding SRs were then reviewed for their applicability.

Applicable requirements were identified for five of the nine technical elements: those that relate to accident sequence analysis, success criteria, human reliability analysis, quantification, and LERF analysis. The resulting lists of high-level and supporting requirements that directly relate to MAAP4 analysis are presented in Appendix E. For those SRs that differ as a function of capability category, the entries are for Categories II and III. Included in the lists are the corresponding NRC staff positions for the identified requirements as they appear in RG 1.200. The version of the standard addressed in the regulatory guide precedes the version that was current at the time of the creation of this report, so the texts in Appendix E have been meshed where necessary.

The assembled lists of applicable requirements were then examined, and five common elements were identified. These are listed in Table 3-5. The sections of this report that directly relate to these requirements are included in the table. The selection of applicable requirements is somewhat subjective because the standard is structured according to the elements of a PRA and was not intended to correspond directly to the analysis tools. This does not affect the guidance in this report.

**Table 3-5**  
**ASME Requirements That Apply to MAAP4 Analysis and Guidance**

| Category                              | Requirements<br>(refer to<br>Appendix E)                                                                                | Essential Elements                                                                            | Related Sections of<br>This Report |
|---------------------------------------|-------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|------------------------------------|
| Adequacy of<br>code                   | AS-A9<br>SC-B1, SC-B4<br>HR-G4<br>LE-B2 , LE-C1                                                                         | Developed, validated, and verified in sufficient detail to analyze the phenomena of interest  | 2.1, 2.2, 7, 8                     |
|                                       |                                                                                                                         | Capable of modeling systems and sequences of interest                                         | 2.2, 7, 8                          |
|                                       |                                                                                                                         | Applicable for range of conditions                                                            | 2.2, 7, 8                          |
|                                       |                                                                                                                         | Quality assured                                                                               | 2.1, 3.1, 3.4                      |
|                                       |                                                                                                                         | Matched with appropriate experimental data                                                    | 7, 8                               |
|                                       |                                                                                                                         |                                                                                               |                                    |
| Performance<br>of analysis            | AS-A9<br>SC-B1, SC-B3, SC-B4,<br>SC-B5<br>HR-G4<br>LE-A1, LE-A2, LE-B2,<br>LE-C1, LE-C3, LE-C4,<br>LE-C10, LE-D5, LE-E2 | Realistic, plant-specific models                                                              | 3.1, 3.2, 3.3, 3.4                 |
|                                       |                                                                                                                         | Plant-specific scenarios                                                                      | 3.1, 3.2, 3.3                      |
|                                       |                                                                                                                         | Account for system responses and operator actions                                             | 3.2, 3.3                           |
|                                       |                                                                                                                         | Use a well-defined, self-consistent process                                                   | 3.2, 3.3, 3.4                      |
|                                       |                                                                                                                         | Use only within known limits of applicability                                                 | 5, 6, 7, 8                         |
|                                       |                                                                                                                         | Use a level of detail consistent with initiating events                                       | 5, 6                               |
|                                       |                                                                                                                         | Model plant characteristics and sequences that influence LERF                                 | 3.2, 5, 6                          |
|                                       |                                                                                                                         | Check reasonableness and acceptability of results                                             | 3.1, 3.2, 3.3                      |
| Uncertainties<br>and<br>sensitivities | QU-E1, QU-E2, QU-E4<br>LE-D5                                                                                            | Identify key sources of uncertainty and key assumptions                                       | 4, 5, 6, 7, 8                      |
|                                       |                                                                                                                         | Evaluate the effect of uncertainties on results                                               | 4, 5, 6, 7, 8                      |
|                                       |                                                                                                                         | Evaluate sensitivity of results to uncertainty, both individually and in logical combinations | 4, 5, 6, 7, 8                      |
| Documentation<br>of analysis          | AS-C1, AS-C2, AS-C3<br>SC-C1, SC-C2, SC-C3<br>HR-I1, HR-I2, HR-I3<br>QU-F4<br>LE-G1, LE-G2, LE-G4                       | Document in a manner that facilitates PRA applications, upgrades, and peer review             | 3.4                                |
|                                       |                                                                                                                         | Document processes, input, methods, and results                                               | 3.4                                |
|                                       |                                                                                                                         | Document key assumptions and key sources of uncertainty                                       | 3.4, 4                             |
|                                       |                                                                                                                         | Document references                                                                           | 3.4                                |
|                                       |                                                                                                                         |                                                                                               |                                    |
| Qualifications<br>of analysts         | AS-A9<br>SC-B1, SC-B4<br>HR-G4<br>LE-B2                                                                                 | Code used by qualified, trained users                                                         | 2.1, 3.5                           |
|                                       |                                                                                                                         | Understand code and its limitations                                                           | 3.5, 5, 6, 7, 8                    |

# 4

## UNCERTAINTY AND SENSITIVITY ANALYSIS

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An essential element of a PRA is the characterization of uncertainties. This includes the identification of key uncertainties and an assessment of their impact on the results. As defined in the ASME standard for PRAs [7]:

- A *key source of uncertainty* is one that is related to an issue for which there is no consensus approach or model and where the choice of approach or model is known to have an impact on either of the following:
  - The risk profile (for example, CDF and LERF)
  - A decision being made using the PRA
- A *key assumption* is one that satisfies either of the following:
  - It is made in response to a key source of uncertainty with the knowledge that a reasonable alternative assumption would produce different results
  - It leads to an approximation made for modeling convenience with the knowledge that a more detailed model would produce different results

The term *different results* refers to a change in the plant risk profile and the associated changes in insights derived from the change in risk profile.

According to Regulatory Guide 1.200 [8], the sensitivity of the results to model boundary conditions and other assumptions and approximations is to be evaluated using sensitivity analyses. The sensitivity analyses are to consider the variations individually and/or in logical combinations to account for interactions between the variables.

The primary method for performing sensitivity analyses to assess the impact of uncertainties on MAAP4 results is the systematic adjustment of the subset of input parameters that influence the physical and chemical process calculations. Many of these parameters are contained in the *Control* and *Model* sections of the parameter files. They allow users and model developers to select individual models and plant-specific options and to specify values of key variables and scale factors.

As part of the effort to assemble guidance on the use of MAAP4 for this report, the parameters in the *Control* and *Model* sections were reviewed and categorized as follows:

- Plant-specific, reflect plant configuration
- Plant-specific, reflect plant configuration; adjust for sequences and sensitivity analysis
- Reflect phenomenological uncertainty; adjust for sequences and sensitivity analysis

- User option
- For research or model testing; default value is recommended

The categorization of each parameter is based on its definition, the level of understanding of the associated phenomena, its effect on figures-of-merit such as core uncovering and vessel failure, and the intent behind the incorporation of the parameters (that is, was it added for testing and research purposes or does it reflect an actual phenomenological uncertainty).

The category and, if applicable, guidance on the types of sequences and recommended values for sensitivity analyses for each parameter are included in the listings of the *Control* and *Model* parameters provided by the code maintenance contractor on the MAAP4 web site (in MAAP FLAASH 64). The guidance also includes recommendations regarding which parameters should be varied simultaneously versus individually. The information was subsequently added to the sample parameter files in Rev. 4.0.7. The listings on the web site also contain definitions, descriptive information, and default values. They were extracted from the master file that is used by the maintenance contractor to create the individual sample parameter files. Therefore, the parameters are in the order in which they appear in the parameter files, and BWR and PWR entries are interspersed.

The parameters that fall into each usage category have been sorted into Tables 4-1 through 4-5 as a complement to the detailed information in the listings. The tables indicate the version of the code (BWR and/or PWR), the name of the parameter, the parameter file section (*Control* or *Model*), and a brief description of the parameter's function or definition. The entries within each table are in the order in which the parameters appear in the parameter files.

- Tables 4-1 and 4-2 contain parameters that are plant-specific and reflect the plant configuration.
- Table 4-3 contains those that reflect phenomenological uncertainty.
- Those in Tables 4-2 and 4-3 should be adjusted for sequences and sensitivity analysis; the types of sequences and the general types of calculations that the parameters impact are indicated in these tables.
- Table 4-4 contains those that select user options. It is indicated in the table whether it is recommended that the default value be used and if the selection has no effect on the results.
- Table 4-5 contains those that are for research or model testing and the default value is recommended.

In addition to those in the *Control* and *Model* sections, there are parameters in other sections of the parameter file that users may choose to adjust for uncertainty and sensitivity analyses or that have a particular effect on sequences. Some of these are listed in Table 4-6. This is not an exhaustive list, and users should review their parameter file and sequence input files to identify others that should be adjusted for their applications. Of particular interest are those that represent thresholds for key events, such as system actuation setpoints and junction failure pressures. Also of interest are those that relate to initial plant conditions, engineered safeguard (ESF) system performance, and sequence initiators such as break size and location. Users should consider the overall movement of mass and energy in a sequence to determine additional parameters that could have a significant impact.



**Table 4-1**  
**Control and Model Parameters: Plant-Specific, Reflect Plant Configuration**

| <b>Code</b>                                                     | <b>Parameter</b> | <b>Control or Model</b> | <b>Function or Definition</b>                                                                                      |
|-----------------------------------------------------------------|------------------|-------------------------|--------------------------------------------------------------------------------------------------------------------|
| BWR                                                             | IBWR             | <i>Control</i>          | Identifies plant type                                                                                              |
| BWR                                                             | IJET             | <i>Control</i>          | Identifies primary system recirculation configuration                                                              |
| BWR                                                             | IILPCI           | <i>Control</i>          | Identifies LPCI injection location                                                                                 |
| BWR                                                             | IMAKE            | <i>Control</i>          | Identifies isolation condenser water source                                                                        |
| PWR                                                             | IBW              | <i>Control</i>          | Identifies type of steam generator                                                                                 |
| PWR                                                             | ISPAIN           | <i>Control</i>          | Specifies option for Spanish plant-specific coding                                                                 |
| PWR                                                             | IDOMEHOT         | <i>Control</i>          | Specifies if the water in the vessel dome is closer to the hot-side or cold-side temperature (added in Rev. 4.0.7) |
| PWR                                                             | IRECIR           | <i>Control</i>          | Identifies hardwired ESF pump lineup in recirculation mode                                                         |
| BWR and PWR                                                     | ISSCL            | <i>Control</i>          | Identifies type of cladding                                                                                        |
| BWR and PWR                                                     | IBCCR            | <i>Control</i>          | Identifies type of control rod material                                                                            |
| BWR and PWR                                                     | IBCCR2           | <i>Control</i>          | Identifies second type of control rod material (added in Rev. 4.0.7)                                               |
| BWR and PWR                                                     | IH2PAR           | <i>Control</i>          | Identifies type of passive autocatalytic recombiner (added in Rev. 4.0.7)                                          |
| BWR                                                             | IINERT           | <i>Control</i>          | Specifies if the initial containment atmosphere is air or nitrogen                                                 |
| PWR                                                             | IHVYREF          | <i>Control</i>          | Specifies if plant has heavy reflector material (added in Rev. 4.0.7)                                              |
| PWR<br>(in BWR files use default)                               | IHOLCB           | <i>Control</i>          | Specifies if there are holes in the core baffle                                                                    |
| BWR and PWR                                                     | IEXVSL           | <i>Control</i>          | Flag to allow ex-vessel cooling                                                                                    |
| PWR<br>(plant-specific for B&Ws; Westinghouse PWRs use default) | FWHL             | <i>Model</i>            | HLNC flow rate correlation coefficient                                                                             |
| PWR                                                             | FOVER            | <i>Model</i>            | Fraction of upper head injection (UHI) that goes into the core bypass versus into the core                         |
| PWR                                                             | FWETBW           | <i>Model</i>            | Fraction of OTSG tubes covered by AFW spray                                                                        |
| BWR and PWR                                                     | FENTRC           | <i>Model</i>            | Specifies DCH model                                                                                                |
| BWR and PWR                                                     | FDENTR           | <i>Model</i>            | De-entrainment efficiency for losses on structures for DCH                                                         |

**Table 4-2**  
**Control and Model Parameters: Plant-Specific, Reflect Plant Configuration; Adjust for Sequences and Sensitivity Analysis**

| Code                           | Parameter                                                                                                                     | <i>Control or Model</i> | Function or Definition                                                              | Type of Sequence for Which to Adjust                                                                                                                     | Area of Potential Impact                                             |
|--------------------------------|-------------------------------------------------------------------------------------------------------------------------------|-------------------------|-------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------|
| PWR                            | IDISCH<br>(or the corresponding parameters NDxxx and RDxxx for injection system xxx if the generalized ESF model is selected) | <i>Control</i>          | Identifies hardwired ESF pump discharge alignment                                   | Level 1 and Level 2 cold leg LOCA sequences (see Section 6.6.1 of this report for information regarding discharge locations relative to break locations) | Primary system and containment conditions                            |
| PWR                            | JNUTUB, JNBUTUB                                                                                                               | <i>Control</i>          | Specifies steam generator tube nodes for rupture calculations                       | Level 2 if rupture of interest                                                                                                                           | SGTR                                                                 |
| BWR                            | FOVER                                                                                                                         | <i>Model</i>            | Fraction of core spray or LPCI injection to the core that goes into the core bypass | Level 2, primarily LOCA sequences                                                                                                                        | Primary system and containment conditions, H <sub>2</sub> generation |
| PWR<br>(also BWR in Table 4-5) | FFRICR                                                                                                                        | <i>Model</i>            | Friction coefficient for axial gas flow between core and upper plenum               | Level 2                                                                                                                                                  | Primary system conditions                                            |
| PWR                            | FERSGT                                                                                                                        | <i>Model</i>            | Ratio of steam generator hot tube thickness to original thickness                   | Level 2                                                                                                                                                  | Induced SGTR                                                         |

**Table 4-3**  
**Control and Model Parameters: Reflect Phenomenological Uncertainty; Adjust for Sequences and Sensitivity Analysis**

| Code                           | Parameter      | Control or Model | Function or Definition                                                                                                          | Type of Sequence for Which to Adjust                                                                                                            | Area of Potential Impact  |
|--------------------------------|----------------|------------------|---------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| BWR<br>(also PWR in Table 4-5) | IMIX           | Control          | Indicates if interchannel mixing of gas in the core is enabled                                                                  | Level 2                                                                                                                                         | Core conditions           |
| PWR                            | VFSEP          | Model            | Void fraction above which the primary system inventory is no longer a homogeneous two-phase mixture                             | Level 1 and Level 2                                                                                                                             | Primary system conditions |
| PWR                            | VFCIRC         | Model            | Void fraction below which the primary system inventory is a homogeneous two-phase mixture (deadband with VFSEP)                 | Level 1 and Level 2                                                                                                                             | Primary system conditions |
| BWR and PWR                    | EPSCUT, EPSCU2 | Model            | Porosity below which the flow area and hydraulic diameter of the core node and collapsed core node, respectively, are 0.0       | Level 2                                                                                                                                         | Core melt progression     |
| BWR and PWR                    | FGBYPA         | Model            | Flag to divert gas flows in the core to the bypass channel when the entire core (PWR) or channel (BWR when IMIX = 0) is blocked | Level 2                                                                                                                                         | Core melt progression     |
| PWR                            | FCDDC          | Model            | Maximum fraction of perfect condensation on the free surface of the water in the cold leg                                       | Level 1 and Level 2 when there is injection (including from accumulators) after natural circulation in the RCS has stopped, particularly SLOCAs | Primary system conditions |
| PWR                            | FHLCRE         | Model            | Specifies hot leg creep rupture calculation model                                                                               | Level 2                                                                                                                                         | HLCR and/or induced SGTR  |

**Table 4-3 (continued)**

**Control and Model Parameters: Reflect Phenomenological Uncertainty; Adjust for Sequences and Sensitivity Analysis**

| <b>Code</b> | <b>Parameter</b> | <b>Control or Model</b> | <b>Function or Definition</b>                                                            | <b>Type of Sequence for Which to Adjust</b> | <b>Area of Potential Impact</b>                  |
|-------------|------------------|-------------------------|------------------------------------------------------------------------------------------|---------------------------------------------|--------------------------------------------------|
| BWR and PWR | FAOX             | <i>Model</i>            | Multiplier for cladding surface area for oxidation                                       | Level 2                                     | H <sub>2</sub> generation                        |
| BWR and PWR | FPEEL            | <i>Model</i>            | Fraction of ZrO <sub>2</sub> layer peeled off during flooding                            | Level 2 when core is recovered              | H <sub>2</sub> generation                        |
| BWR and PWR | TCLMAX           | <i>Model</i>            | Temperature used in time-at-temperature correlation for cladding rupture                 | Level 2                                     | Core melt progression                            |
| BWR and PWR | FZORUP           | <i>Model</i>            | Minimum fraction of Zr oxidized to keep cladding intact                                  | Level 2                                     | Core melt progression                            |
| BWR and PWR | LMCOL0–LMCOL3    | <i>Model</i>            | Criteria for time-at-temperature correlations for core node collapse                     | Level 2                                     | Core melt progression, H <sub>2</sub> generation |
| BWR and PWR | XDJETO           | <i>Model</i>            | Initial diameter of a corium jet entering the water in the RPV lower plenum              | Level 2, adjust with ENT0                   | In-vessel steam generation                       |
| BWR and PWR | ENT0             | <i>Model</i>            | Entrainment coefficient for a corium jet entering the water in the RPV lower plenum      | Level 2, adjust with XDJETO                 | In-vessel steam generation                       |
| BWR and PWR | ENT0C            | <i>Model</i>            | Entrainment coefficient for a corium jet entering the water in containment               | Level 2                                     | Steam generation in containment                  |
| BWR and PWR | FOPTLH           | <i>Model</i>            | Specifies model for debris in the RPV lower plenum                                       | Level 2                                     | Vessel failure                                   |
| BWR and PWR | FCRDR            | <i>Model</i>            | Fraction of core mass below which the remaining core is dumped into the RPV lower plenum | Level 2                                     | In-vessel conditions                             |

Table 4-3 (continued)

**Control and Model Parameters: Reflect Phenomenological Uncertainty; Adjust for Sequences and Sensitivity Analysis**

| Code        | Parameter | Control or Model | Function or Definition                                                                                                            | Type of Sequence for Which to Adjust                | Area of Potential Impact                             |
|-------------|-----------|------------------|-----------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------|------------------------------------------------------|
| BWR and PWR | FHTGAP    | Model            | Heat transfer effectiveness in the crust/lower head wall gap                                                                      | Level 2                                             | Vessel failure                                       |
| BWR and PWR | FQUEN     | Model            | Multiplier to the flat plate critical heat flux for lower plenum debris quenching by water                                        | Level 2                                             | Vessel failure                                       |
| BWR and PWR | ECREPP    | Model            | Maximum lower head penetration weld strain at failure                                                                             | Level 2                                             | Vessel failure                                       |
| PWR         | FAOUT     | Model            | Fraction of steam generator tubes carrying "out" flow in HLNC model                                                               | Level 2 high pressure sequences                     | Induced SGTR                                         |
| BWR and PWR | FCHF      | Model            | Flat plate critical heat flux for ex-vessel debris                                                                                | Level 2                                             | Containment conditions following vessel failure      |
| BWR and PWR | FELOCA    | Model            | Fraction of water break flow entrained as suspended water in containment                                                          | Level 1 LOCA sequences                              | Containment conditions                               |
| BWR and PWR | FNOMIX    | Model            | Flag to select mixing of water and steam flows from the RCS to containment                                                        | Level 1 LLOCA sequences                             | Containment conditions                               |
| BWR and PWR | FCDBRK    | Model            | Discharge coefficient for flows through primary system breaks (including SGTRs), BWR generalized openings, and BWR vessel failure | Level 1 and Level 2 with corresponding RCS openings | Primary system and containment conditions            |
| BWR and PWR | HTFB      | Model            | Film boiling heat transfer from corium to overlying water pool                                                                    | Level 2                                             | Heat transfer in core and from debris in containment |

**Table 4-3 (continued)**

**Control and Model Parameters: Reflect Phenomenological Uncertainty; Adjust for Sequences and Sensitivity Analysis**

| <b>Code</b>                    | <b>Parameter</b>                                        | <b>Control or Model</b> | <b>Function or Definition</b>                                                                                    | <b>Type of Sequence for Which to Adjust</b> | <b>Area of Potential Impact</b>          |
|--------------------------------|---------------------------------------------------------|-------------------------|------------------------------------------------------------------------------------------------------------------|---------------------------------------------|------------------------------------------|
| BWR and PWR                    | HTCMCR, HTCMCS, and, as of Rev. 4.0.7, HTCMFLR, HTCMSID | <i>Model</i>            | Downward and sideward heat transfer coefficients for convection from debris to lower crust for MCCI calculations | Level 2                                     | Concrete erosion, containment conditions |
| PWR                            | HTSTAG                                                  | <i>Model</i>            | Natural circulation steam generator primary side heat transfer coefficient                                       | Level 1                                     | Heat transfer to the steam generators    |
| PWR (EG also BWR in Table 4-5) | EWLHL, EG                                               | <i>Model</i>            | Emissivity of hot leg walls and gas                                                                              | Level 2                                     | HLCR                                     |
| BWR and PWR                    | FBNDCH                                                  | <i>Model</i>            | H <sub>2</sub> jet burning factor during HPME/DCH                                                                | Level 2 with DCH                            | Containment conditions                   |
| BWR and PWR                    | FPDIF                                                   | <i>Model</i>            | Diffusivity of fission products migrating through molten material for DCH                                        | Level 2 with DCH                            | Containment conditions                   |
| BWR and PWR                    | TJBRN                                                   | <i>Model</i>            | Temperature of H <sub>2</sub> jet entering compartment and causing local burns                                   | Level 2                                     | Combustion                               |
| BWR and PWR                    | TAUTO                                                   | <i>Model</i>            | Auto-ignition temperature                                                                                        | Level 2                                     | Combustion                               |
| BWR and PWR                    | DXHIG                                                   | <i>Model</i>            | Offset H <sub>2</sub> and CO mole fraction for ignition                                                          | Level 2                                     | Combustion                               |
| BWR and PWR                    | FLPHI                                                   | <i>Model</i>            | Flame flux multiplier                                                                                            | Level 2                                     | Combustion                               |

**Table 4-4**  
**Control and Model Parameters: User Options**

| <b>Code</b>                             | <b>Parameter</b> | <b>Control<br/>or Model</b> | <b>Function or Definition</b>                                                                           | <b>Recommended<br/>That Default<br/>Value Be Used</b> | <b>Has No<br/>Impact on<br/>Results</b> |
|-----------------------------------------|------------------|-----------------------------|---------------------------------------------------------------------------------------------------------|-------------------------------------------------------|-----------------------------------------|
| BWR and<br>PWR                          | ISORT            | <i>Control</i>              | Specifies option for integrating<br>figures-of-merit output                                             | True                                                  | True                                    |
| BWR<br>(also<br>PWR in<br>Table<br>4-5) | IDBLVL           | <i>Control</i>              | Specifies option for calculating<br>lower plenum debris level                                           | —                                                     | —                                       |
| PWR                                     | IRVFMD           | <i>Control</i>              | Specifies criterion for vessel<br>lower head relocation to the<br>cavity (added in Rev. 4.0.7)          | True                                                  | —                                       |
| BWR and<br>PWR                          | INODRB           | <i>Control</i>              | Number of compartments in<br>containment and<br>auxiliary/reactor building                              | —                                                     | —                                       |
| BWR and<br>PWR                          | IPLT1            | <i>Control</i>              | Specifies plot file output format                                                                       | —                                                     | True                                    |
| PWR                                     | INECCS           | <i>Control</i>              | Use external ESF models                                                                                 | True                                                  | —                                       |
| PWR                                     | INFANC           | <i>Control</i>              | Use external fan cooler/chiller<br>model                                                                | True                                                  | —                                       |
| PWR                                     | INSGFW           | <i>Control</i>              | Use external feedwater model                                                                            | True                                                  | —                                       |
| PWR                                     | IPSGIN           | <i>Control</i>              | Define steam generator<br>boundary pressure                                                             | True                                                  | —                                       |
| BWR and<br>PWR                          | IBCHX            | <i>Control</i>              | Specifies dynamic benchmark<br>option                                                                   | True                                                  | —                                       |
| BWR and<br>PWR                          | ICNTLTIM         | <i>Control</i>              | Specifies option for adjusting<br>time step based on operator<br>interventions (added in Rev.<br>4.0.7) | True                                                  | —                                       |
| BWR and<br>PWR                          | IIODIN           | <i>Control</i>              | Indicates that iodine chemistry<br>model is enabled                                                     | True                                                  | —                                       |
| PWR                                     | IRADCA           | <i>Control</i>              | Specifies option for thermal<br>radiation heat transfer in the<br>cavity (added in Rev. 4.0.7)          | True                                                  | —                                       |
| BWR and<br>PWR                          | IUXOLD           | <i>Control</i>              | Specifies option for user-defined<br>event code evaluation                                              | True                                                  | —                                       |
| PWR                                     | IMER             | <i>Control</i>              | Identifies Fortran unit number for<br>mass and energy release output<br>(added in Rev. 4.0.7)           | True                                                  | True                                    |

**Table 4-4 (continued)**  
**Control and Model Parameters: User Options**

| <b>Code</b>    | <b>Parameter</b>                    | <b><i>Control<br/>or Model</i></b> | <b>Function or Definition</b>                                                                    | <b>Recommended<br/>That Default<br/>Value Be Used</b> | <b>Has No<br/>Impact on<br/>Results</b> |
|----------------|-------------------------------------|------------------------------------|--------------------------------------------------------------------------------------------------|-------------------------------------------------------|-----------------------------------------|
| BWR and<br>PWR | IRSTW,<br>ISUM,<br>IPOUT,<br>IMVUNT | <i>Control</i>                     | Identifies Fortran unit numbers for restart, summary, tabular, and movie output files            | True                                                  | True                                    |
| BWR and<br>PWR | IPRJN,<br>ILISTVL                   | <i>Control</i>                     | Specifies option for pruning junction and valve output in the summary file (added in Rev. 4.0.7) | True                                                  | True                                    |
| BWR and<br>PWR | IPRTMLST                            | <i>Control</i>                     | Specifies option for writing time lost information to log file (added in Rev. 4.0.7)             | True                                                  | True                                    |
| BWR and<br>PWR | IPSET( <i>i</i> )                   | <i>Control</i>                     | Identifies Fortran unit numbers for blocks of tabular output                                     | True                                                  | True                                    |
| BWR and<br>PWR | IDBGWF,<br>IDBGTD                   | <i>Control</i>                     | Identifies Fortran unit number and frequency for debug restart file                              | True                                                  | True                                    |
| BWR and<br>PWR | IEMBAL,<br>ICRBAL,<br>ILPBAL        | <i>Control</i>                     | Selects mass and energy balance output                                                           | True                                                  | True                                    |
| BWR and<br>PWR | IRSBAD                              | <i>Control</i>                     | Specifies option for writing information when rates are not physical                             | True                                                  | True                                    |
| BWR and<br>PWR | IPTSAV,<br>IPTSPK,<br>IPTSMX        | <i>Control</i>                     | Values used in plot frequency algorithm                                                          | True                                                  | True                                    |



**Table 4-5**  
**Control and Model Parameters: For Research or Model Testing; Default Value Is Recommended**

| Code                           | Parameter | Control or Model | Function or Definition                                                            |
|--------------------------------|-----------|------------------|-----------------------------------------------------------------------------------|
| PWR                            | IBWNC     | Control          | Specifies hot leg countercurrent flow calculation option for OTSGs                |
| PWR                            | IHTHLG    | Control          | Specifies option for heat transfer between hot leg countercurrent flows           |
| BWR and PWR                    | IRUNG     | Control          | Specifies integration model                                                       |
| BWR and PWR                    | JNTGRT    | Control          | Specifies time step option                                                        |
| BWR and PWR                    | ISIDRL    | Control          | Indicates if model for sideward relocation within core is enabled                 |
| BWR and PWR                    | INOSIF    | Control          | Indicates if model for sideward relocation from core is enabled                   |
| BWR and PWR                    | ICANDL    | Control          | Indicates if mechanistic melt candling model is enabled                           |
| BWR and PWR                    | IDISSV    | Control          | Indicates if fuel-cladding dissolution calculations are enabled                   |
| BWR and PWR                    | IDISSB    | Control          | Indicates if fuel can-control blade dissolution calculations are enabled          |
| BWR and PWR                    | IEUTEC    | Control          | Indicates if U–Zr–O eutectic model is enabled                                     |
| PWR<br>(also BWR in Table 4-3) | IMIX      | Control          | Indicates if interchannel mixing of gas in core is enabled                        |
| BWR and PWR                    | IMPOOL    | Control          | Indicates if in-core molten pool calculations are enabled                         |
| BWR and PWR                    | IOXIDE    | Control          | Specifies Zr oxidation model                                                      |
| BWR and PWR                    | IAOXP     | Control          | Indicates if enhanced Zr oxidation during reflooding is calculated                |
| BWR and PWR                    | IBALON    | Control          | Indicates if clad ballooning and thermal expansion model is enabled               |
| BWR and PWR                    | IUSETD    | Control          | Specifies option for calculation of material properties of debris in lower plenum |
| PWR<br>(also BWR in Table 4-4) | IDBLVL    | Control          | Specifies option for calculating lower plenum debris level                        |

**Table 4-5 (continued)****Control and Model Parameters: For Research or Model Testing; Default Value Is Recommended**

| <b>Code</b> | <b>Parameter</b> | <b>Control or Model</b> | <b>Function or Definition</b>                                                                                                                                                                                                                                                                                                                                                                                                                    |
|-------------|------------------|-------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| BWR and PWR | IENT0            | <i>Control</i>          | Specifies option for calculating jet entrainment coefficients                                                                                                                                                                                                                                                                                                                                                                                    |
| BWR and PWR | IQDPB            | <i>Control</i>          | Specifies model for heat transfer from debris bed particles to water in lower plenum                                                                                                                                                                                                                                                                                                                                                             |
| BWR and PWR | IHGRAD           | <i>Control</i>          | Indicates if radiation heat transfer from upper debris crust in lower plenum is calculated                                                                                                                                                                                                                                                                                                                                                       |
| BWR and PWR | IOXIDHT          | <i>Control</i>          | Specifies model for heat transfer from oxidic debris to crust in lower plenum (added in Rev. 4.0.7)                                                                                                                                                                                                                                                                                                                                              |
| BWR and PWR | IXPSE            | <i>Control</i>          | Specifies option for boundary condition for embedded crust in lower plenum debris                                                                                                                                                                                                                                                                                                                                                                |
| BWR and PWR | IGCHF            | <i>Control</i>          | Indicates if critical heat flux gap boiling model for in-vessel debris cooling is enabled                                                                                                                                                                                                                                                                                                                                                        |
| BWR and PWR | IOPTVF           | <i>Control</i>          | Specifies vessel failure mechanisms to be considered                                                                                                                                                                                                                                                                                                                                                                                             |
| BWR and PWR | IEXFMOD          | <i>Control</i>          | Specifies extensive vessel failure criterion (added in Rev. 4.0.7)                                                                                                                                                                                                                                                                                                                                                                               |
| BWR and PWR | IXPSL            | <i>Control</i>          | Indicates if lower crust drains with rest of debris after RPV failure                                                                                                                                                                                                                                                                                                                                                                            |
| BWR and PWR | IDPQNC           | <i>Control</i>          | Indicates if temperature of particles from debris jet in RPV or containment calculated mechanistically                                                                                                                                                                                                                                                                                                                                           |
| BWR and PWR | ISBNOD           | <i>Control</i>          | Indicates if containment subnodal physics model related to stratification is enabled<br><br>Note: Consider disabling the model if numerous non-convergence diagnostics are generated. The use of the model is particularly appropriate for highly nodalized, more vertically oriented containments. It will have a smaller impact for less nodalized containments. The subnodal physics model leads to a slight over-prediction of the pressure. |
| BWR and PWR | IHTGPL           | <i>Control</i>          | Indicates if mass and energy transfer between gases and pools in containment is calculated                                                                                                                                                                                                                                                                                                                                                       |
| PWR         | IPSPR, ICPR      | <i>Control</i>          | Specifies version of steam tables for primary system and containment calculations                                                                                                                                                                                                                                                                                                                                                                |
| BWR         | FCO              | <i>Model</i>            | Void concentration factor in drift flux model                                                                                                                                                                                                                                                                                                                                                                                                    |
| BWR and PWR | FACT             | <i>Model</i>            | Multiplier to reduce hydraulic diameter and flow area when intact fuel node collapses                                                                                                                                                                                                                                                                                                                                                            |

Table 4-5 (continued)

**Control and Model Parameters: For Research or Model Testing; Default Value Is Recommended**

| Code                           | Parameter       | Control or Model | Function or Definition                                                                                                      |
|--------------------------------|-----------------|------------------|-----------------------------------------------------------------------------------------------------------------------------|
| BWR<br>(also PWR in Table 4-2) | FFRICR          | Model            | Friction coefficient for axial gas flow between core and upper plenum                                                       |
| BWR and PWR                    | FFRICX          | Model            | Gas cross-flow friction coefficient in core for in-vessel natural circulation                                               |
| BWR and PWR                    | FNCBP           | Model            | Specifies in-vessel natural circulation flow path                                                                           |
| BWR and PWR                    | NSAMP           | Model            | Number of time steps for averaging gas parameters for core–upper plenum natural circulation                                 |
| PWR                            | FHTPRI          | Model            | Multiplier for primary side condensation heat transfer coefficient during reflux cooling                                    |
| PWR                            | FROUPZ          | Model            | Froude number for countercurrent draining of pressurizer                                                                    |
| BWR and PWR                    | TEU             | Model            | Core node eutectic melting temperature                                                                                      |
| BWR and PWR                    | TEUBS           | Model            | Control blade and fuel can melting temperature                                                                              |
| BWR and PWR                    | FZRKB           | Model            | Fraction of fuel cans that can be dissolved by control blades                                                               |
| BWR and PWR                    | FDISSO          | Model            | Multiplier for contact area between fuel and Zr cladding during dissolution                                                 |
| BWR and PWR                    | TDOOXI          | Model            | Specifies option for increasing cladding surface area                                                                       |
| BWR and PWR                    | FEMBRT          | Model            | Fraction of total Zr that has oxidized that is sufficient to cause core collapse on reflood                                 |
| BWR and PWR                    | FXEGAP          | Model            | Fraction of Xe inventory in pellet-cladding gap                                                                             |
| BWR and PWR                    | FVISC           | Model            | Material viscosity multiplier in candling calculations                                                                      |
| BWR and PWR                    | TCLRUP          | Model            | Temperature at which fuel cladding fails if it has not already failed by ballooning for fission product release             |
| BWR and PWR                    | TCRRUP, TCRRUP2 | Model            | Temperature at which non-fuel rod cladding fails for control rod material release and melt relocation (added in Rev. 4.0.7) |
| BWR and PWR                    | VFCRCO          | Model            | Porosity of collapsed core region                                                                                           |

**Table 4-5 (continued)****Control and Model Parameters: For Research or Model Testing; Default Value Is Recommended**

| <b>Code</b>    | <b>Parameter</b>  | <b>Control<br/>or Model</b> | <b>Function or Definition</b>                                                                      |
|----------------|-------------------|-----------------------------|----------------------------------------------------------------------------------------------------|
| BWR and<br>PWR | LMU2A,<br>LMU2B   | <i>Model</i>                | Terms used in time-at-temperature calculation for in-core molten pool crust failure                |
| BWR and<br>PWR | FGPOOL            | <i>Model</i>                | Geometric factor used to define shape of in-core molten pool                                       |
| BWR and<br>PWR | XXPSMN,<br>XXPSML | <i>Model</i>                | Minimum and maximum lower crust thicknesses of debris in lower plenum                              |
| BWR and<br>PWR | XXPSMU,<br>XXPSME | <i>Model</i>                | Maximum upper and embedded crust thicknesses of debris in lower plenum                             |
| BWR and<br>PWR | XLFALS            | <i>Model</i>                | Width of failure opening when in-core molten pool side crust has failed                            |
| BWR and<br>PWR | FMOVE             | <i>Model</i>                | Controls relocation of solid U–Zr–O embedded in liquid U–Zr–O                                      |
| BWR and<br>PWR | TSPFAL            | <i>Model</i>                | Temperature used in time-at-temperature correlations for core support plate failure                |
| BWR and<br>PWR | ASPFAL            | <i>Model</i>                | Cross-sectional area used to calculated drainage of corium when support plate fails                |
| BWR and<br>PWR | FSAITO            | <i>Model</i>                | Constant used in Saito correlation for debris jet fragmentation                                    |
| BWR and<br>PWR | FDDP              | <i>Model</i>                | Multiplier for diameter of particulated debris from jets entering water pools                      |
| BWR and<br>PWR | FOXBJ             | <i>Model</i>                | Multiplier for particulated oxidation reactor fraction                                             |
| BWR and<br>PWR | VFENT             | <i>Model</i>                | Void fraction of steam in debris jet entrainment interaction zone                                  |
| BWR and<br>PWR | EPSB              | <i>Model</i>                | Assumed porosity of particulated debris bed in RPV lower plenum                                    |
| BWR and<br>PWR | XROF0,<br>XROF1   | <i>Model</i>                | Initial radius of localized and extensive lower head failures when size is not defined by geometry |
| BWR and<br>PWR | FDAMLH            | <i>Model</i>                | Lower head damage fraction for extensive failure                                                   |
| BWR and<br>PWR | XGAPLH            | <i>Model</i>                | Initial size of gap between debris and lower head wall                                             |
| BWR and<br>PWR | ECREPF            | <i>Model</i>                | Strain failure for vessel ductile material                                                         |
| BWR and<br>PWR | XGAPPB            | <i>Model</i>                | Minimum allowable thermal gap between particle bed and surroundings                                |

Table 4-5 (continued)

**Control and Model Parameters: For Research or Model Testing; Default Value Is Recommended**

| Code        | Parameter      | Control or Model | Function or Definition                                                                               |
|-------------|----------------|------------------|------------------------------------------------------------------------------------------------------|
| BWR and PWR | XGAP0          | Model            | Initial size of gap between debris and surface of lower head penetrations                            |
| BWR and PWR | FEMISD, FEMISP | Model            | Emissivities of debris within lower head penetrations and of penetrations                            |
| BWR and PWR | FRCOEF         | Model            | Debris friction coefficient used to calculate convective heat transfer coefficient                   |
| BWR and PWR | TDSTX          | Model            | Time delay after debris contacts pedestal or cavity before steam explosion                           |
| PWR         | FBVSGT         | Model            | Bobbin voltage for faulted steam generator tube                                                      |
| BWR and PWR | FPRAT          | Model            | Specifies fission product release correlation options                                                |
| BWR and PWR | FPVMP, FPNVMP  | Model            | Indicate if volatile and nonvolatile fission products can be released from in-core molten pools      |
| BWR and PWR | FTEREL         | Model            | Indicates if in-vessel Te release is allowed                                                         |
| BWR and PWR | FTENUR         | Model            | Oxidized mass fraction limit to bind Te with unoxidized Zr                                           |
| BWR and PWR | FFPREL         | Model            | Multiplier for in-core fission product and inert aerosol release rates                               |
| BWR and PWR | FCSIVP, FCSHVP | Model            | Multipliers to vapor pressures of CsI and CsOH for vapor-aerosol equilibrium                         |
| BWR and PWR | FVPREV         | Model            | Multiplier to vapor pressures of CsI and CsOH for revaporization                                     |
| BWR and PWR | XRSEED         | Model            | Initial seed radius for hygroscopic aerosol growth                                                   |
| BWR and PWR | FAERDC         | Model            | Ratio of existing airborne aerosol mass to aerosol mass that would result in steady-state conditions |
| BWR and PWR | GSHAPE, CSHAPE | Model            | Shape factors to account for non-spherical aerosols in coagulation and settling calculations         |
| BWR and PWR | FE0            | Model            | Aerosol collision efficiency                                                                         |
| BWR and PWR | FEFFDR         | Model            | Containment spray aerosol capture efficiency                                                         |
| BWR and PWR | XRDB           | Model            | Radius of aerosol particles released from debris beds into water pools                               |

**Table 4-5 (continued)****Control and Model Parameters: For Research or Model Testing; Default Value Is Recommended**

| <b>Code</b>    | <b>Parameter</b>                                | <b>Control<br/>or Model</b> | <b>Function or Definition</b>                                                                                           |
|----------------|-------------------------------------------------|-----------------------------|-------------------------------------------------------------------------------------------------------------------------|
| BWR and<br>PWR | FDFDB,<br>FDFJJ                                 | <i>Model</i>                | Multipliers to decontamination factors for aerosol releases from debris beds and containment junctions into water pools |
| PWR            | FDFBS                                           | <i>Model</i>                | Multiplier to decontamination factor for aerosol releases from SGTRs into water pools                                   |
| BWR and<br>PWR | FCHFRCR,<br>FCRHY,<br>FFLOOD,<br>FDROP          | <i>Model</i>                | Kutateladze numbers for flat plate critical heat flux, core hydrodynamic limit, flooding, and dispersed droplet flow    |
| BWR and<br>PWR | FENTR                                           | <i>Model</i>                | Multiplier to critical velocity for debris and water entrainment out of pedestal or cavity                              |
| BWR and<br>PWR | FCHTUR                                          | <i>Model</i>                | Churn-turbulent critical velocity coefficient                                                                           |
| BWR and<br>PWR | FSPAR,<br>FVOL                                  | <i>Model</i>                | Sparged pool and volumetric steam generation void fraction coefficients                                                 |
| BWR and<br>PWR | FVOLRB                                          | <i>Model</i>                | Void concentration factor in the drift flux model                                                                       |
| PWR            | FCDVF                                           | <i>Model</i>                | Vessel failure discharge coefficient (when pressure differential is small, used for water flow)                         |
| BWR and<br>PWR | HTCONC,<br>HTCONR                               | <i>Model</i>                | Overall heat transfer coefficients between fuel and cladding for covered and uncovered core nodes                       |
| BWR and<br>PWR | CDCMLP                                          | <i>Model</i>                | Exponent for two-phase debris pool heat transfer coefficient correction factor                                          |
| BWR and<br>PWR | CDU and,<br>as of Rev.<br>4.0.7,<br>CDUCN       | <i>Model</i>                | Exponent used to calculate convective heat transfer coefficients for MCCI crusts                                        |
| BWR and<br>PWR | FGCRXS<br>and, as of<br>Rev. 4.0.7,<br>FGCRXSID | <i>Model</i>                | Fraction of off-gas from sideward MCCI that enters molten corium pool                                                   |
| BWR and<br>PWR | HTBLAD                                          | <i>Model</i>                | Correction for heat transfer from control blades to bypass flow                                                         |
| BWR and<br>PWR | FRACAN                                          | <i>Model</i>                | Minimum fraction of fuel can that must be dissolved before the can ruptures                                             |
| BWR and<br>PWR | SCALH                                           | <i>Model</i>                | Scale factor for heat transfer to passive heat sinks                                                                    |
| BWR and<br>PWR | FUPOOL,<br>FDPOOL,<br>FSPOOL                    | <i>Model</i>                | Multipliers for upward, downward, and sideward convective heat transfer between core crust and/or molten pool nodes     |

Table 4-5 (continued)

**Control and Model Parameters: For Research or Model Testing; Default Value Is Recommended**

| Code                           | Parameter                   | Control or Model | Function or Definition                                                            |
|--------------------------------|-----------------------------|------------------|-----------------------------------------------------------------------------------|
| BWR and PWR                    | FNUDRP                      | Model            | Nusselt number for heat conduction into spray droplets                            |
| BWR and PWR                    | FXOCD                       | Model            | Minimum water level for complete steam condensation of containment junction flows |
| BWR and PWR                    | EW, EWL, EEQ, ECM, EGAS     | Model            | Emissivities of water, walls, equipment, corium surfaces, and steam               |
| BWR<br>(also PWR in Table 4-3) | EG                          | Model            | Emissivity of gas                                                                 |
| BWR and PWR                    | FCMDCH                      | Model            | Fraction of entrained corium assumed to be finely fragmented for DCH              |
| BWR and PWR                    | TTENTR                      | Model            | Water entrainment time constant for HPME/DCH                                      |
| BWR and PWR                    | FKUTA                       | Model            | Kutateladze coefficient in entrainment criterion for HPME/DCH                     |
| BWR and PWR                    | FOXDC                       | Model            | Fraction of metal in entrained debris that would oxidize during HPME/DCH          |
| BWR and PWR                    | FNSIX                       | Model            | Term used for inception of entrainment in Kim's HPME/DCH dispersal model          |
| BWR and PWR                    | FWEBER                      | Model            | Weber number for calculation of debris particle diameter for DCH                  |
| BWR and PWR                    | FMPDIF( <i>i</i> )          | Model            | Multiplier to base diffusion coefficient for fission product group <i>i</i>       |
| BWR and PWR                    | FASI, FASR, FABA, FAKO, FAC | Model            | Activity coefficients for SiO <sub>2</sub> , SrO, BaO, K <sub>2</sub> O, and C    |
| BWR and PWR                    | XSTIA                       | Model            | Steam mole fraction required to inert gas mixture at incipient auto-ignition      |
| BWR and PWR                    | TOXMP, TMLMP                | Model            | Melting points of oxidic and metallic debris                                      |
| BWR and PWR                    | LHOX, LHML                  | Model            | Latent heats of oxidic and metallic debris                                        |
| BWR and PWR                    | UOXMP, UMLMP                | Model            | Specific energies of solid oxidic and metallic debris at their melting points     |

**Table 4-5 (continued)****Control and Model Parameters: For Research or Model Testing; Default Value Is Recommended**

| <b>Code</b> | <b>Parameter</b> | <b>Control or Model</b> | <b>Function or Definition</b>                                                  |
|-------------|------------------|-------------------------|--------------------------------------------------------------------------------|
| BWR and PWR | CPOX, CPML       | <i>Model</i>            | Specific heats of oxidic and metallic debris                                   |
| BWR and PWR | KOX, KML         | <i>Model</i>            | Thermal conductivities of oxidic and metallic debris                           |
| BWR and PWR | DOX, DML         | <i>Model</i>            | Densities of oxidic and metallic debris                                        |
| BWR and PWR | VSCOX, VSCML     | <i>Model</i>            | Viscosities of oxidic and metallic debris                                      |
| BWR and PWR | STOX, STML       | <i>Model</i>            | Surface tensions of oxidic and metallic debris                                 |
| BWR and PWR | TSOLSO, TLIQSO   | <i>Model</i>            | Steel oxide solidus and liquidus                                               |
| BWR and PWR | TSCS, TLCS       | <i>Model</i>            | Steel solidus and liquidus                                                     |
| BWR and PWR | TMMS, TMMS       | <i>Model</i>            | Solidus and liquidus of other metals                                           |
| BWR and PWR | TFE2ML           | <i>Model</i>            | Fe <sub>2</sub> -metal melting point                                           |
| BWR and PWR | FNE1, FNE2       | <i>Model</i>            | Fe mole fractions at the Fe-rich and Fe-lean eutectic points                   |
| BWR and PWR | TE1, TE2         | <i>Model</i>            | Fe-rich and metal-rich eutectic temperature                                    |
| BWR and PWR | FGCSSR           | <i>Model</i>            | Critical H <sub>2</sub> mole fraction for Fe-steam reaction                    |
| BWR and PWR | FFEOX            | <i>Model</i>            | Adjusts stoichiometry of iron oxide                                            |
| BWR and PWR | CKABA            | <i>Model</i>            | Dissociation constant of H <sub>3</sub> BO <sub>3</sub>                        |
| BWR and PWR | CHNO3            | <i>Model</i>            | G value for radiolytic generation of HNO <sub>3</sub>                          |
| BWR and PWR | FCSOPH           | <i>Model</i>            | Mass fraction of CsOH that is chemically active in aqueous phase in sumps      |
| BWR and PWR | PCUTOF           | <i>Model</i>            | Pressure above which an explosive event (steam explosion) can not be initiated |
| BWR and PWR | TEXINT, TDSTEX   | <i>Model</i>            | Time intervals for an explosive event and between explosive events             |
| BWR and PWR | XRSP             | <i>Model</i>            | Average radius of debris particulated during a steam explosion                 |



**Table 4-6**  
**Additional Parameters That May Be Adjusted For Uncertainty and Sensitivity Analyses or**  
**May Have Particular Effects (not an exhaustive list)**

| Code        | Parameter                                  | Section                           | Function or Definition                                              | Recommendation                                                                                                                 | Impact                                                                                            |
|-------------|--------------------------------------------|-----------------------------------|---------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|
| BWR and PWR | CPCNO, CPHSM( <i>i</i> ), KHSM( <i>i</i> ) | <i>Concrete and Material Type</i> | Specific heat and thermal conductivity of concrete                  | Might be difficult for users to determine plant-specific values; use values appropriate for type of concrete                   | Containment conditions; values can have significant impact, particularly the specific heat values |
| BWR and PWR | TDCORE, TDMAX                              | <i>Timing</i>                     | Maximum time step before and after vessel failure                   | Reduce if there are a substantial number of diagnostics or instabilities; use smaller value with BWR isolation condenser model | All calculation areas                                                                             |
| BWR and PWR | NAXNOD, NCHAN                              | <i>Core (PWR), Heatup (BWR)</i>   | Core nodalization (number of axial rows, number of radial channels) | Increase the number of active axial nodes to 30 to improve reproducibility (for all calculations)                              | All calculation areas                                                                             |
| BWR         | AJET                                       | <i>Primary System</i>             | Flow area between the downcomer and the lower plenum                | Adjust to investigate the impact of two uses in the code through Rev. 4.0.6 (see Section 3.2.5 of this report)                 | Primary system conditions                                                                         |
| BWR         | TDSLCL                                     | <i>Primary System</i>             | Time period for shutdown after the initiation of SLC                | Adjust to investigate impact of value for ATWS sequences                                                                       | Primary system conditions                                                                         |
| BWR         | XSPARG                                     | <i>Primary System</i>             | HPCI and RCIC spray droplet diameter                                | Adjust to investigate impact of value for ATWS sequences                                                                       | Primary system conditions                                                                         |

**Table 4-6 (continued)**  
**Additional Parameters That May Be Adjusted For Uncertainty and Sensitivity Analyses or May Have Particular Effects (not an exhaustive list)**

| Code        | Parameter              | Section                | Function or Definition                                                                                                                      | Recommendation                                                                                                                                  | Impact                                                                                                                |
|-------------|------------------------|------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|
| BWR and PWR | XLPT1, XLPT2           | <i>Primary System</i>  | Length of instrument and CRD tubes through which debris can penetrate before the tubes are considered to have failed by debris melt-through | Adjust to evaluate uncertainty of prompt versus delayed vessel failure; difficult to determine plant-specific values                            | Vessel failure time                                                                                                   |
| PWR         | TIRRAD                 | <i>Primary System</i>  | Total effective irradiation time for the core                                                                                               | Adjust to investigate sensitivity to decay power (only an insignificant impact was observed for BWR sequences during testing for this report)   | Decay power, primary system response (parameter that has the most impact on decay power besides the full power level) |
| PWR         | PDCR0                  | <i>Primary System</i>  | Pressure rise across RCPs at full power                                                                                                     | Adjust for B&W plants for sequences involving a long period of two-phase natural circulation                                                    | Primary system conditions                                                                                             |
| PWR         | VOFZSG vs. ZOFSG array | <i>Steam Generator</i> | Volume versus height table for the secondary side in the one-region model                                                                   | Adjust to determine the impact of the calculated steam generator water level when using the one-region model (see Section 6.6.3 of this report) | Steam generator conditions                                                                                            |
| PWR         | ASGDC, AFLWSG          | <i>Steam Generator</i> | Cross-sectional areas in the steam generators                                                                                               | Adjust to determine the effect on uncover of the steam generator tubes, which impacts heat transfer                                             | Primary system and steam generator conditions                                                                         |

**Table 4-6 (continued)**  
**Additional Parameters That May Be Adjusted For Uncertainty and Sensitivity Analyses or May Have Particular Effects (not an exhaustive list)**

| Code        | Parameter                                                                        | Section                                                                                  | Function or Definition                                                              | Recommendation                                                                                                                                                                                                          | Impact                                                    |
|-------------|----------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------|
| PWR         | CO, COR2, FRTDSG, FRACSG, FRACSS, F1FRAC, F2FRAC, TDMXSS, TSUBMN, TSUBMX, FRPDEL | <i>Steam Generator</i>                                                                   | Two-region steam generator model parameters                                         | Adjust for sensitivity analysis for research only                                                                                                                                                                       | Primary system and steam generator conditions             |
| BWR         | TDBATT                                                                           | <i>Engineered Safeguards</i>                                                             | Duration of battery power                                                           | Adjust for all loss-of-power sequences                                                                                                                                                                                  | Primary system and containment conditions                 |
| BWR and PWR | Various                                                                          | <i>Engineered Safeguards, Generalized Engineered Safeguards and Pump Characteristics</i> | Flow versus pressure curves for ESF injection systems                               | Adjust for injection sequences; of particular importance when only pump curves, not delivered flow curves, are available for input; important when using results to determine system performance margins and HRA timing | Primary system and containment conditions                 |
| BWR         | HCST, TWSW, TWRBCC, TWRB0(i)                                                     | <i>Engineered Safeguards and Auxiliary</i>                                               | Enthalpy and temperatures of the CST water, service water, and the suppression pool | Use conservative best-estimate values                                                                                                                                                                                   | Effectiveness of injection water and cooling capabilities |
| PWR         | TRWST, TWEXT, TCWxx                                                              | <i>Engineered Safeguards and Generalized Engineered Safeguards</i>                       | Temperatures of the RWST and service water                                          | Use conservative best-estimate values                                                                                                                                                                                   | Effectiveness of injection water and cooling capabilities |

**Table 4-6 (continued)**  
**Additional Parameters That May Be Adjusted For Uncertainty and Sensitivity Analyses or May Have Particular Effects (not an exhaustive list)**

| Code        | Parameter                                             | Section                      | Function or Definition                                                                | Recommendation                                                                                                                                                                                                             | Impact                                                                                   |
|-------------|-------------------------------------------------------|------------------------------|---------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| PWR         | NKPROCACUM,<br>NKPROCUHI,<br>FKLOSSACUM,<br>FKLOSSUHI | <i>Engineered Safeguards</i> | Polytropic constant and head loss coefficient for accumulator discharge               | Adjust for sequences with accumulator injection, affects rate of injection                                                                                                                                                 | Primary system conditions                                                                |
| BWR and PWR | FCONDP( <i>i</i> )                                    | <i>Auxiliary</i>             | Control flag for the calculation of steam condensation on water pool surfaces         | Adjust for sequences in which there is injection and no containment heat removal                                                                                                                                           | Containment conditions                                                                   |
| PWR         | FSTICE                                                | <i>Ice Condenser</i>         | Control flag for the calculation of the steam mass fraction exiting the ice condenser | Adjust for sequences based on superheat in the steam entering condenser                                                                                                                                                    | Containment conditions                                                                   |
| PWR         | MICE0–<br>AMNDOR                                      | <i>Ice Condenser</i>         | Ice condenser parameters                                                              | Evaluate sensitivity of sequence results to ice condenser input parameters; of particular importance is the time at which the ice melts and the properties of the gas and condensate exiting the ice condenser compartment | Containment conditions: overall energy balance and hydrogen concentration in containment |
| BWR and PWR | ACMPLB( <i>i</i> )                                    | <i>Debris</i>                | Floor surface area that might be covered by a corium debris pool                      | Adjust for sequences in which debris-concrete interactions are nontrivial                                                                                                                                                  | Containment conditions, fission product releases                                         |

It is not practical to perform sensitivity analyses on all sequences using all of the recommended variations in the parameter values because the matrix of cases would be unreasonably large. Users should make judicious choices in deciding which sequences to use for sensitivity studies and how many variations to evaluate. It is suggested that a subset of sequences be selected that meets the following criteria:

- Covers the range of initiators and RPV conditions (for example, high and low pressure)
- Constitutes bounding cases for the determination of significant results, such as:
  - System capacities for success (for example, the number of valves for adequate depressurization and the number of pumps or heat exchangers for adequate cooling)
  - The maximum times available for operator actions (for example, system initiation and system recovery)
  - Threshold accident initiators (for example, minimum and maximum break sizes)
- Provides input into subsequent calculations such as fission product source terms

Sensitivities can then be investigated with this subset of sequences. The number of variations in the values of the input parameters can be minimized by using bounding values and by focusing on the effects of the variations on the specific figures-of-merit that are important for the application. Information from previous evaluations and the applications guidance provided in Sections 5 and 6 of this report can also be used to narrow the number of sensitivity cases.

Although it is desirable to limit the number of cases so that the analysis effort is manageable, users are encouraged to take advantage of the ease and speed of MAAP4 to run sets of sequences with input variations to increase their understanding of accident phenomena. In addition, experience has shown that at times it can be more productive and efficient to run a number of MAAP4 cases to evaluate the impact of particular parameter values on the results rather than to rely on user predictions of the impact. The application, the experience of the user, and supporting information all have a role in determining the optimum number of cases for a particular analysis.

When assessing the effects of changes in the input on the results, users should keep in mind that differences on the order of a few percent are not significant. Differences of this small magnitude can be numerical in nature due to the very large number of calculations that are performed every time step and to actual differences in the modeled physical and chemical processes. MAAP4 was not designed to be a highly precise code given the amount of uncertainty inherent in the various processes that can affect the progression of an accident. Therefore, small differences are consistent with the expected code performance.

The guidance in this section is intended only for MAAP4 analyses. Assessing the sensitivity of MAAP4 results is one component of the uncertainty evaluations that are integral to PRAs (according to the ASME standard) and other applications.



# 5

## BWR APPLICATIONS GUIDANCE

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### 5.1 Introduction

This section offers specific guidance on how to apply MAAP4 to Level 1 PRA analyses for BWRs. It is intended to provide insights and practical information so that users can optimize their efforts and generate high-quality analyses. The guidance provides information on plant features, phenomena, and code logic that are important for Level 1 applications. However, it is not intended to be comprehensive; insights and perspectives gained from this section can be extended to other aspects of MAAP4 Level 1 analysis.

The content of this section is supplemented by Appendix B, which addresses the MAAP4 modeling of individual BWR systems. **It is strongly recommended that users review the detailed information in the appendix prior to performing analyses to ensure that they are familiar with the system logic and options in the BWR code.**

The information presented here is consistent with Rev. 4.0.6 of the code, with some augmentation stemming from Rev. 4.0.7.

#### 5.1.1 Style

In this section, input parameters and calculated variables are capitalized, and their definitions are listed in Table 5-1. The code uses event codes to control high-level logic during an accident simulation. The three types of events—automatic, external, and user-defined—are defined in Section 3.1.1.3, and the BWR-specific events are discussed in Appendix B. They are referred to here by their numbers, by their message strings, or by the variable IEVNT(*i*), where *i* is their particular number.

#### 5.1.2 Sequences Used to Support the Guidance

To investigate and demonstrate the progression of Level 1 sequences, a set of six plant-specific parameter files was used in addition to the Mark I, Mark II, and Mark III sample parameter files. The parameter files represent plants with various primary system and containment configurations and collectively contain a range of realistic values of the plant-specific input parameters. All of the test sequences were run with the Rev. 4.0.6 Windows executable that is distributed with the code on a computer with the Windows XP operating system.

**Table 5-1**  
**MAAP4 Input Parameters and Calculated Variables Used in Section 5**

| Name                | Type                 | Definition                                                                                                                              |
|---------------------|----------------------|-----------------------------------------------------------------------------------------------------------------------------------------|
| ALOCA               | Input                | Area of the primary system break (actual area, multiplied by FCDBRK in the code to obtain the effective area)                           |
| AMSL0               | Calculated           | Initial minimum effective flow area through the main steam line                                                                         |
| ASRV( <i>i</i> )    | Input                | Effective area of valve <i>i</i> (relief and/or safety valve, not multiplied by a discharge coefficient in the code)                    |
| FCDBRK              | Input                | Discharge coefficient used to calculate effective flow areas for LOCA breaks, vessel failure openings, and generalized openings         |
| FELOCA              | Input                | Fraction of water break flow entrained as suspended water in containment                                                                |
| FNOMIX              | Input                | Flag to select mixing of water and steam flows from RCS to containment                                                                  |
| FWRR vs. TIRR array | Input                | Recirculation pump coastdown flow fraction versus time since trip (represents the coastdown curve)                                      |
| IEVNT( <i>i</i> )   | Input and calculated | Boolean variable for logic event <i>i</i>                                                                                               |
| IJET                | Input                | Recirculation configuration                                                                                                             |
| IMANON( <i>i</i> )  | Input                | Flag to manually open valve <i>i</i>                                                                                                    |
| IOPEN( <i>i</i> )   | Calculated           | Boolean variable that indicates valve <i>i</i> status (0 means closed; 1 means open)                                                    |
| ISTUCK( <i>i</i> )  | Input                | Flag to stick open valve <i>i</i> , simulating a mechanical failure                                                                     |
| JNDW                | Input                | Pointer that identifies the drywell compartment                                                                                         |
| JNLOC               | Input                | Pointer that identifies the compartment that receives the LOCA break effluent                                                           |
| JNRV                | Input                | Pointer that identifies one of the two compartments that receive valve discharge (nominally from the relief and/or combined SRV valves) |
| JNSV                | Input                | Pointer that identifies the other of the two compartments that receive valve discharge (nominally from the safety valves)               |
| NAXNOD              | Input                | Number of axial nodes in the core nodalization                                                                                          |
| NCHAN               | Input                | Number of radial channels in the core nodalization                                                                                      |
| NCYCLE( <i>i</i> )  | Calculated           | Count of the number of times valve <i>i</i> cycles                                                                                      |
| PDRV( <i>i</i> )    | Input                | Deadband for reclosing valve <i>i</i> in relief mode                                                                                    |
| PDWSCM              | Input                | High drywell pressure setpoint for reactor scram                                                                                        |
| PLMSIV              | Input                | Low primary system pressure setpoint for MSIV closure                                                                                   |
| PPS                 | Calculated           | Primary system pressure                                                                                                                 |



**Table 5-1 (continued)**  
**MAAP4 Input Parameters and Calculated Variables Used in Section 5**

| Name                         | Type       | Definition                                                                                                                 |
|------------------------------|------------|----------------------------------------------------------------------------------------------------------------------------|
| PPS0                         | Input      | Initial primary system pressure                                                                                            |
| PRB( <i>i</i> )              | Calculated | Pressure in containment or reactor/auxiliary building compartment <i>i</i>                                                 |
| PSCRAM                       | Input      | High primary system pressure setpoint for reactor scram                                                                    |
| PSETRV( <i>i</i> )           | Input      | Relief valve opening pressure setpoint for valve <i>i</i>                                                                  |
| QCR0                         | Input      | Initial core power                                                                                                         |
| TCLN( <i>i</i> )             | Calculated | Temperature of the cladding in core node <i>i</i>                                                                          |
| TCRHOT                       | Calculated | Mass-averaged temperature of the hottest core node (averaged over the individual core material components within the node) |
| TDBATT                       | Input      | Duration of battery power following the loss of all AC power                                                               |
| TDCORE                       | Input      | Maximum time step prior to vessel failure if less than TDMAX                                                               |
| TDMAX                        | Input      | Maximum time step after vessel failure, and before vessel failure if less than TDCORE                                      |
| TDMIN                        | Input      | Minimum time step                                                                                                          |
| TDMSBPV                      | Input      | Time period over which the turbine bypass valves close                                                                     |
| TDMSIV                       | Input      | Time period over which MSIVs close                                                                                         |
| TDMSSV                       | Input      | Time period over which the turbine stop valves close                                                                       |
| TDPOWR                       | Input      | Time period over which the power ramps linearly from full power to decay power following the onset of reactor scram        |
| TDRPT                        | Input      | Recirculation pump trip delay time                                                                                         |
| TDSCRM                       | Input      | Time delay between the reactor scram signal and the onset of scram                                                         |
| TDSLC                        | Input      | Time period for the reactor to shut down after the initiation of SLC                                                       |
| TGCH( <i>j</i> )             | Calculated | Temperature of the gas exiting core channel <i>j</i>                                                                       |
| TGPS                         | Calculated | Temperature of the gas in the primary system                                                                               |
| TIFWCD vs.<br>WFWCD<br>array | Input      | Feedwater coastdown curve                                                                                                  |
| TIM                          | Calculated | Problem time                                                                                                               |
| TIMD                         | Calculated | Problem time (equal to TIM; see Section 3.3.1.3 of this report)                                                            |
| TIMER #                      | Input      | Elapsed time array                                                                                                         |
| TIRRAD                       | Input      | Total effective irradiation time for the core                                                                              |
| TU2N( <i>i</i> )             | Calculated | Temperature of the fuel in core node <i>i</i>                                                                              |

**Table 5-1 (continued)**  
**MAAP4 Input Parameters and Calculated Variables Used in Section 5**

| Name                          | Type             | Definition                                                                                                                                    |
|-------------------------------|------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| TWPS0                         | Input/Calculated | Initial average primary system water temperature; reset to the average water temperature in the core by the code                              |
| TWRB0( <i>i</i> )             | Input            | Initial temperature of the water in containment node <i>i</i>                                                                                 |
| VWPS                          | Calculated       | Specific volume of the primary system water                                                                                                   |
| WBPMAX                        | Input            | Maximum bypass flow                                                                                                                           |
| WGLOC                         | Calculated       | Mass flow rate of gas through a LOCA break in the primary system                                                                              |
| WGRV                          | Calculated       | Mass flow of gas through the SRVs to compartment JNRV                                                                                         |
| WGSV                          | Calculated       | Mass flow of gas through the SRVs to compartment JNSV                                                                                         |
| WSTHPI vs.<br>PTURHP<br>array | Input            | Steam extraction curve for the HPCI turbine as a function of the differential pressure                                                        |
| WWLOCA                        | Calculated       | Mass flow rate of water through a LOCA break in the primary system                                                                            |
| WWRV                          | Calculated       | Mass flow of water through the SRVs to compartment JNRV                                                                                       |
| WWSV                          | Calculated       | Mass flow of water through the SRVs to compartment JNSV                                                                                       |
| XSPARG                        | Input            | HPCI and RCIC spray droplet diameter                                                                                                          |
| XWJET                         | Calculated       | Collapsed water level in the jet pumps relative to the bottom of the vessel                                                                   |
| XWSH                          | Calculated       | Collapsed water level in the downcomer relative to the bottom of the vessel; it is the level outside the jet pumps for plants with jet pumps. |
| ZCRL                          | Input            | Elevation of the bottom of active fuel relative to the bottom of the vessel                                                                   |
| ZCRU                          | Input            | Elevation of the top of active fuel relative to the bottom of the vessel                                                                      |
| ZHFW                          | Input            | High downcomer water level setpoint for feedwater trip (absolute elevation)                                                                   |
| ZLHPCI                        | Input            | Low downcomer water level used to turn on HPCI injection (absolute elevation)                                                                 |
| ZLMSIV                        | Input            | Low downcomer water level setpoint for MSIV closure (absolute elevation)                                                                      |
| ZLOCA                         | Input            | Absolute elevation of the primary system break                                                                                                |
| ZNLOC                         | Input            | Height of the centerline of the primary system break above the floor of the receiving compartment                                             |
| ZSCRAM                        | Input            | Low downcomer water level setpoint for reactor scram (absolute elevation)                                                                     |
| ZWSHC                         | Calculated       | Collapsed water level in the downcomer (absolute elevation)                                                                                   |
| ZWSHCD                        | Input            | Target water level in the downcomer used for HPCI and RCIC level control in the throttled mode (absolute elevation)                           |
| ZWV                           | Calculated       | Boiled-up water level in the core relative to the bottom of the vessel                                                                        |

### 5.1.3 Presentation and Interpretation of Results

The sequence results in the tables in this section are provided for demonstration purposes only. They are not exhaustive and should not be used to represent specific plants. The values have been rounded; differences in the last significant figures between comparable results are not significant. For example, 11.4 minutes is reported as 11 minutes while 11.5 minutes is reported as 12 minutes.

The following points should be kept in mind when reviewing the results presented in this section and interpreting results generated by sequences used in applications. Guidance on how to interpret code results is also presented in Section 3.1.4.3.

- Differences in results of less than a few percent are generally considered to be within the code's computational resolution and within the required resolution for PRA applications.
- The significance of differences is essentially a function of the purpose of the particular analysis. Furthermore, the differences should be interpreted in light of the variations in the input, the inherent uncertainty in the phenomena, and so on.
- Thresholds in the calculations (for example, system actuation and trip points) can have significant effects on the progression of sequences.
- Interventions, actions, and results can lag by a time step because of the order of execution.

## 5.2 Determination of Core Damage

The predominant figure-of-merit for Level 1 PRA analyses is the onset of core damage. The code does not contain criteria for core damage; instead, users determine the criteria based on PRA reference information. Examples of criteria for BWR core damage included in the success criteria element of the ASME standard for PRAs [7] are a collapsed liquid level in the primary system that is less than one-third of the core height **or** a peak core temperature that is greater than 1644 K (2500°F). The examples in the ASME standard are consistent with the general guidelines for the determination of core damage provided in the EPRI probabilistic safety assessment (PSA) applications guide [14]. In that report, suggested criteria are a collapsed liquid less than one-third of the core height, a core peak nodal temperature greater than 1255 K (1800°F), a core maximum fuel temperature approaching 1478 K (2200°F), **or** a core exit thermocouple reading greater than 922 K (1200°F). The following subsections provide guidance on how to identify when criteria related to water level and core temperature are met.

The definition of *core damage* in the ASME standard is the “uncovery and heat-up of the reactor core to the point where prolonged clad oxidation and severe fuel damage involving a large fraction of the core is anticipated.” The definition in RG 1.200 is the same except that it elaborates on the large fraction of the core being “sufficient, if released from containment, to have the potential for causing offsite health effects.” Although the water level criterion of less than one-third core height is almost always met well before the temperature criteria, the physical processes of oxidation and fission product release are directly tied to the core temperature—not to the water level. Based on the results of investigations discussed in Section 5.2.2, the criterion

of the core peak nodal temperature exceeding 1255 K (1800°F) is sufficiently conservative with respect to significant oxidation and fission product release.

### 5.2.1 Water Level

When reviewing MAAP4 results to determine the predicted primary system water level relative to the top of the core, two calculated levels are of interest. The first is the collapsed water level of the downcomer water pool, XWSH. This level corresponds to the level interpreted from plant instrumentation and is usually the level used in the determination of core damage. The second is the boiled-up level of the core water pool, ZWV. When the boiled-up level falls below the top of active fuel (TOAF) (that is, when ZWV is less than ZCRU), event 30 is set to true. The time that this occurs is assigned to the entry “time of core uncover” in the figures-of-merit table at the end of the log file.

The following functions and intervention conditions can be added to input files to record the times when the collapsed water level in the downcomer first falls below TOAF and when it first falls below one-third of the core height. The times at which the intervention conditions are met will be written to the log file.

- To record when the level falls below TOAF:

```
WHEN XWSH < ZCRU  
END
```

- To record when the level falls below one-third of the core height for plants with jet pumps (IJET = 1):

```
FUNCTION ONETHIRD = (ZCRU - ZCRL) / 3 + ZCRL  
  
WHEN XWJET < ONETHIRD AND TIMD > 0.0    // jet pumps  
END
```

Note that including the condition on time, TIMD, addresses the fact that a meaningful value of XWJET is not calculated until the end of the first time step.

- To record when the level falls below one-third of the core height for plants with internal, external, or no recirculation pumps (IJET = 2, 3, or 0):

```
FUNCTION ONETHIRD = (ZCRU - ZCRL) / 3 + ZCRL  
  
WHEN XWSH < ONETHIRD                      // IJET = 2, 3 or 0  
END
```

In these interventions, the input parameters ZCRL and ZCRU are the elevations of the bottom and top of the active fuel relative to the bottom of the vessel, respectively. The calculated level XWSH is the collapsed level outside the jet pumps for plants with jet pumps, and the calculated level XWJET is the collapsed level in the jet pumps. Both of these levels are also referenced to the bottom of the vessel.

User-defined variables can be created to record the collapsed water level relative to TOAF by inserting the following functions into the input file:

```
FUNCTION XTAF_M = XWSH - ZCRU      // in meters
```

```
FUNCTION XTAF_IN = (XWSH - ZCRU) * 3.28 * 12    // in inches
```

XTAF\_M and XTAF\_IN can be included in the list of variables written to plottable output files (see Section 3 of this report).

### 5.2.2 Peak Core Temperature

The MAAP4 core model calculates the temperatures of the individual core components—fuel, cladding, cans, and so on—on a nodal basis. It also calculates the mass-averaged temperature of the core material in each node, the *node temperature* (variable TNOD(*i*), where *i* is the core node). The mesh of the radial and axial core nodalization is moderate; it is not designed to be refined enough to calculate the temperatures of individual fuel assemblies, including the hottest fuel assembly. On the other hand, with standard values for the number of axial and radial nodes, one node represents approximately 1% of the active fuel.

The code automatically determines the maximum mass-averaged node temperature as a function of time. The variable representing this hottest node temperature is TCRHOT. Investigations using the sample Mark I SBO sequence with both Rev. 4.0.6 and Rev. 4.0.7 and with various core meshes show that the value of TCRHOT is within a few degrees of the hottest fuel temperature and the hottest cladding temperature of any of the nodes (variables TU2N(*i*) and TCLN(*i*), respectively). Therefore, TCRHOT is representative of the individual component temperatures. The SBO investigations also show that the difference in the time for the hottest node temperature to reach 1255 K (1800°F) and 1644 K (2500°F) is between 8 and 9 minutes (out of approximately 8 hours) for a variety of core meshes (from 50 to 235 active fuel nodes).

The gas temperature at the exit of each channel *j*, variable TGCH(*j*), and the cladding temperature in the corresponding top node are representative of the core exit temperature in each radial ring. The SBO investigations show that the hottest core exit temperature, which is in the innermost ring, reaches the suggested damage criterion of 922 K (1200°F) approximately 11 to 13 minutes before TCRHOT reaches 1255 K (1800°F).

The oxidation of the cladding and the release of fission products from the fuel are also indicators of core damage. The investigations show that the hottest core node temperature and the hottest core exit temperature exceed 1644 K (2500°F) before either the fraction of the cladding that has oxidized or the fraction of the volatile fission products that is released from the fuel exceeds 2%. They also show that recovery of HPCI or RCIC just prior to the time that the hottest core node reaches 1644 K (2500°F) is adequate to prevent significant (>10%) cladding oxidation or volatile fission product release.

Figure 5-1 shows the hottest core node and the core exit temperatures, the time that one-quarter of the core exceeds 1478 K (2200°F), and the fractions of oxidized cladding and volatile fission product release for a representative SBO case.

### 4.0.6 BWR SBO, 13 Axial, 5 Radial, 6 hr Battery

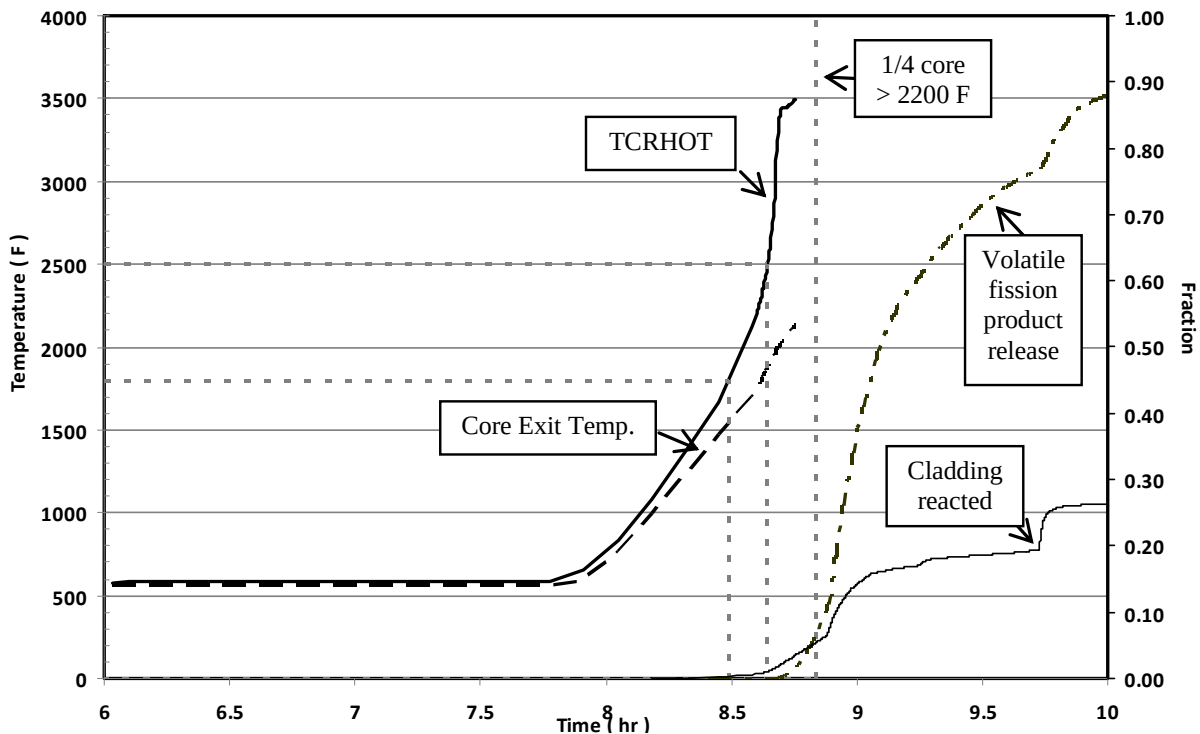


**Figure 5-1**  
**Core Damage Indicators for a Representative Mark I SBO**

The following intervention conditions can be added to input files to record the time at which one of the core damage temperature criteria is reached. The time will be written to the log file. Note that including the condition on time, TIMD, addresses the fact that a meaningful value of TCRHOT is not calculated until the end of the first time step.

```
WHEN TCRHOT > 1225 K AND TIMD > 10.0 S // in Kelvin
END
```

```
WHEN TCRHOT > 1800 F AND TIMD > 10.0 S // in Fahrenheit
END
```

MAAP4 does not calculate the initial temperature spike(s) associated with the sudden increase in pressure that accompanies MSIV closure, which in turn causes voids in the core to collapse, leading to a brief surge in power. In addition, sequences with injection at the time that the core temperature is increasing might lead to short-term temperature spikes above the core damage criterion. Therefore, users may choose to use a time-at-temperature criterion. This can be done by adding the following components to the input files:

```
PARAMETER CHANGE
  T_CRIT_REACHED = 0
  TIMWATCH = 0
END
```

```

WHEN TCRHOT > 1800 F AND TIMWATCH < 1.0
  SET TIMER #1
  TIMWATCH = 1
  REPEAT
  SILENT
END

```

```

WHEN TCRHOT < 1800 F AND TIMWATCH > 0.5
  RESET TIMER #1
  TIMWATCH = 0.2
  REPEAT
  SILENT
END

```

```

WHEN TIMER #1 > 100 S // 100 s is used as an example
  T_CRIT_REACHED = 1
  TIMWATCH = 2
END

```

### 5.3 Code Logic Features for Initiating Events and SRV Operation

Inherent in the MAAP4 code is logic that simulates the operational characteristics of primary system components. It is important for users to be aware of the default logic in the code and then to adjust input parameters and/or add input components (for example, user-defined events and interventions) so that the logic is essentially modified to represent the actual plant. The following subsections discuss portions of the code logic that are particularly important for Level 1 analysis. Additional information regarding the logic associated with the modeling of BWR systems is included in Appendix B.

#### 5.3.1 MSIV Closure

The MSIVs are modeled as one set of valves and will close when one of the following occurs:

- **Low primary system pressure:** The calculated pressure, PPS, falls below the value of input parameter PLMSIV.
- **Low downcomer water level:** The calculated collapsed water level in the downcomer, ZWSHC, falls below the value of input parameter ZLMSIV.
- **Forced closure:** External event 215, MSIVS LOCKED CLOSED, is set to true (as long as external event 214, MSIVS MAN OPEN, is false).

The MSIVs close over the time specified by input parameter TDMSIV, with a corresponding decrease in steam flow. (The area through the MSIVs decreases linearly; the decrease in the steam flow is a function of the area, the reduction in core power, and so on.)

In MAAP4, the initiation of MSIV closure leads directly to the initiation of scram. It also leads directly to the tripping of feedwater—unless external event 294 is set to true—to indicate that feedwater is motor-driven rather than turbine-driven and should not be tripped by MSIV closure.

In some plants, the MSIVs will not close on low primary system pressure after a certain period of time has passed following the generation of a scram signal (the scram having been initiated by a condition other than MSIV closure). This might be the result of the operator action of changing the reactor mode from “run” to “shutdown,” or it might be automatic. This is not included in the MAAP4 logic, and it can affect the progression of sequences, as discussed in Section 5.4.1. Users should determine when it is appropriate to prevent MSIV closure on low pressure and define their sequences accordingly. The following input file components can be used to establish this condition after a specified time has elapsed since the scram signal. The values should be appropriate for the particular plant.

```
C Logic to prevent MSIVs from closing on low primary system
C pressure 15 seconds after scram.
```

```
WHEN IEVNT(10) > 0.5    // scram signal has been generated
  SET TIMER #1          // use a unique timer number
END
```

```
WHEN TIMER #1 > 15 S
  PLMSIV = 0.0
END
```

### 5.3.2 Scram Signal

A reactor scram signal is generated when one of the following occurs:

- **High primary system pressure:** The calculated pressure, PPS, rises above the value of input parameter PSCRAM.
- **Low downcomer water level:** The calculated collapsed water level in the downcomer, ZWSHC, falls below the value of input parameter ZSCRAM.
- **Closure of the MSIVs:** See Section 5.3.1.
- **Closure of the turbine stop valves:** See Section 5.3.4.
- **High drywell pressure:** The calculated pressure, PRB(JNDW), rises above the value of input parameter PDWSCM.
- **Forced scram:** External event 255, REACTOR MAN SCRAMMED, is set to true.

A loss of offsite AC power essentially also causes a scram signal because the loss of power causes closure of the turbine stop valves. When one of the conditions to scram has been met, the core remains at full power for an additional time specified by input parameter TDSCRM, after which the power decreases to the decay power level over the period specified by input parameter TDPOWR. The exception is an ATWS scenario, in which the core remains at a higher power level. (See the following subsections for more information about the turbine stop valves, the



MAAP4 supply power logic, and the modeling of ATWS sequences; see Appendix B for more information about the time period to decrease to decay power levels.)

### 5.3.3 Loss of Feedwater

Feedwater is tripped off when one of the following occurs:

- **High downcomer water level:** The calculated collapsed water level in the downcomer, ZWSHC, rises above the value of input parameter ZHFW.
- **Closure of the MSIVs** (unless overridden with external event 294).
- **Closure of the turbine stop valves and the turbine bypass valves** (unless overridden with external event 294).
- **Forced trip:** External event 209, FEEDWATER MAN OFF, is set to true.

In MAAP4, the closure of the MSIVs or the turbine stop and bypass valves leads directly to the tripping of feedwater unless external event 294 is set to true to indicate that feedwater is motor-driven rather than turbine-driven.

The feedwater coasts down according to the curve specified by the TIFWCD versus WFWCD input array. For some plants, the duration of the coastdown is a function of the condition that causes the trip. A longer coastdown is more appropriate for a trip that results from closure of the MSIVs (a loss of backpressure) compared to a direct trip of the feedwater system (for example, due to loss of the condensate pumps). The duration can affect the progression of sequences, as shown in Section 5.4.1.

The code does not contain a model for the feedwater supply, so feedwater is not limited by any balance-of-plant conditions.

### 5.3.4 Turbine Stop Valve Closure

The turbine stop valves close when one of the following occurs:

- **Loss of offsite AC power:** External event 250, LOSS OF AC POWER, is set to true.
- **Forced closure:** External event 212, TURBINE STOP VALVES CLOSED, is set to true.

The turbine stop valves close over the time specified by input parameter TDMSSV, with a corresponding decrease in steam flow. (TDMSSV was added to the code in Rev. 4.0.6 but was not added to the sample parameter files until Rev. 4.0.7. The same is true of TDMSBPV, which is the time period for closure of the turbine bypass valves.)

Closure of the stop valves leads directly to the generation of a reactor scram signal. When the valves are closed, the flow out of the primary system is controlled by the area through the bypass valves. The maximum area is calculated based on the input parameter for the maximum bypass flow, WBP MAX.

### 5.3.5 Primary System Pressure Control

MAAP4 does not model the adjustments to the limiting flow area through the turbine stop valves or bypass valves to maintain the primary system pressure. Users should include input file components to reduce the minimum main steam line flow area to maintain pressure in sequences that are not initiated by MSIV closure. This can significantly affect the progression of sequences, as discussed in Section 5.4.1. It should be kept in mind that there is a substantial pressure drop between the primary system and the pressure control sensors (on the order of  $6.9 \times 10^5$  Pa [100 psi]), so the target pressure in the input file components should be the nominal pressure, not the lower pressure at the sensors.

The following are sample input file components that will control the pressure within 5 psi of the nominal value (in this case, 1050 psia) and will work if the steam flow is either through the turbine stop valves or through the bypass valves if the stop valves are closed. Users can incorporate these components into their input files, adjusting the values for their plant. The logic and values should be tested and adjusted using trial-and-error for each plant.

#### PARAMETER CHANGE

C Initialize user-defined variable for primary system pressure control

PCONTROL = 0

END

C Logic to simulate primary system pressure control prior to closure

C of the MSIVs (before IEVNT(62) = 1). PPS is the calculated primary

C system pressure, AMSL0 is the initial minimum flow area of the main

C steam line. The pressure is controlled between 1045 and 1055 psia. The

C modified values of AMSL0 are arbitrary, but less than the initial value.

IF IEVNT(62) < 0.5 AND PPS < 1045 PSI

AMSL0 = 0.05 FT\*\*2 // small area

PCONTROL = 1

REPEAT

END

WHEN PPS > 1055 PSI AND PCONTROL > 0.5

AMSL0 = 1.0 FT\*\*2 // larger area

PCONTROL = 0

REPEAT

END

### 5.3.6 Turbine Trip

MAAP4 does not model the tripping of the main turbines when the steam flow has been reduced following a scram. The main turbines would be tripped either by the operators or by the turbine-generator control system. Users should include input file components to close the turbine stop valves to stop steam flow to the turbines after a scram. The steam flow will then be diverted through the bypass valves.

The following are sample input file components that will close the turbine stop valves two minutes after the scram signal is generated. Users can incorporate these components into their input files, adjusting the time for closure for their plant. (The setting of the timer should be included only once and can be used for closing the stop valves and preventing MSIV closure on low pressure, as discussed above.)

```

WHEN IEVNT(10) > 0.5  // scram signal has been generated
  SET TIMER #1      // use a unique timer number
END

```

```

C Close turbine stop valves 2 minutes after scram to
C simulate feedback on low steam flow to the turbine, leading
C to isolation of the turbine by the turbine-generator control system.
WHEN TIMER #1 > 120 S
  IEVNT(212) = 1  // close turbine stop valves
END

```

### 5.3.7 Supply Power

The initial assumption in the BWR MAAP4 code is that AC power is available from an offsite source and an onsite diesel source. Each source can be made unavailable for a sequence using external events 250 and 251, LOSS OF AC POWER and LOSS OF DIESEL POWER, respectively. If neither source of AC power is available, DC power by batteries is assumed to be available for an amount of time prescribed by the input parameter TDBATT. The power requirements for each BWR system modeled by the code are presented in Table 5-2. If necessary, users can modify the logic to match the power requirements of the systems at their plants using input file components.

A loss-of-offsite-AC-power condition at a plant will lead to an electrical signal to close the MSIVs (versus a signal based on thermal-hydraulic conditions in the primary system). This is not modeled in MAAP4, so a loss-of-offsite-AC-power initiator should always be accompanied by an MSIV closure initiator. Even if the feedwater pumps are turbine-driven, offsite AC power is required for feedwater to be operational because the condensate pumps (which are upstream of the feedwater pumps) require offsite power. Therefore, external event 294, which prevents feedwater from being tripped by MSIV closure, should not be set to true in a loss-of-offsite-AC-power sequence.

The progression of a station blackout sequence, that is, one in which both offsite and onsite AC power are unavailable, can be highly dependent on the value of TDBATT. This is discussed further in Section 5.4.2.

**Table 5-2**  
**MAAP4 BWR Power Requirements**

| System                                                                           | Requires Offsite AC Power <sup>a</sup>                  | Requires Offsite or Onsite AC Power <sup>b</sup> | Requires Offsite AC, Onsite AC, or DC Power <sup>c</sup> | None <sup>d</sup> |
|----------------------------------------------------------------------------------|---------------------------------------------------------|--------------------------------------------------|----------------------------------------------------------|-------------------|
| Feedwater pumps operational                                                      |                                                         |                                                  |                                                          | X                 |
| CRD pumps operational                                                            | X or alternative power source available using event 277 |                                                  |                                                          |                   |
| Turbine stop valves stay open                                                    | X                                                       |                                                  |                                                          |                   |
| MSIVs stay open                                                                  |                                                         |                                                  |                                                          | X                 |
| Turbine bypass valves stay open                                                  |                                                         |                                                  |                                                          | X                 |
| Reactor protection system not activated (system in “run” versus “shutdown” mode) | X (indirectly through turbine stop valves)              |                                                  |                                                          |                   |
| Isolation condenser and makeup operational                                       |                                                         |                                                  |                                                          | X                 |
| Recirculation pumps operational                                                  | X                                                       |                                                  |                                                          |                   |
| Primary system valves can open in relief mode                                    |                                                         |                                                  | X                                                        |                   |
| Primary system valves can open in safety mode                                    |                                                         |                                                  |                                                          | X                 |
| HPCI operational                                                                 |                                                         |                                                  | X                                                        |                   |
| RCIC operational                                                                 |                                                         |                                                  | X                                                        |                   |
| HPCS operational                                                                 |                                                         |                                                  |                                                          | X                 |
| LPCS operational                                                                 |                                                         | X                                                |                                                          |                   |
| RHR (LPCI) operational                                                           |                                                         | X                                                |                                                          |                   |
| HPSW (alternate injection) operational                                           |                                                         |                                                  |                                                          | X                 |
| SCS operational                                                                  |                                                         | X                                                |                                                          |                   |
| RWCU operational                                                                 |                                                         |                                                  |                                                          | X                 |
| SLC operational                                                                  |                                                         |                                                  |                                                          | X                 |
| Drywell coolers and containment chillers operational                             |                                                         | X                                                |                                                          |                   |
| Containment purge operational                                                    |                                                         |                                                  |                                                          | X                 |
| Drywell purge operational                                                        |                                                         | X                                                |                                                          |                   |
| Containment air coolers operational                                              |                                                         |                                                  |                                                          | X                 |
| Igniters operational                                                             | X or alternative power source available using event 290 |                                                  |                                                          |                   |
| Auxiliary building CO <sub>2</sub> operational                                   |                                                         |                                                  |                                                          | X                 |

<sup>a</sup> Backup power is not credited.

<sup>c</sup> Diesel- or battery-backed.

<sup>b</sup> Diesel-backed.

<sup>d</sup> Either passive or assumed to have an independent power source.

### 5.3.8 SRV Operation

There are several plant-specific features of SRV operation that users should be aware of because of their potential to significantly affect sequences. They are not explicitly modeled in MAAP4, but they can be added using input file components or user-defined events in the parameter file. Users should determine whether they are applicable for their plants and, if so, add and test the input features.

#### 5.3.8.1 Cycling on Low Pressure Differential

Some SRVs have the characteristic that, if opened manually, they will close on a low pressure differential between the primary system and containment. This has only a minor effect on results prior to core damage, but it can have a significant impact on fission product releases for Level 2 sequences because the induced valve cycling substantially limits the availability of the flow path to vent the primary system to the suppression pool. (For example, sequences run with manual depressurization and cycling at low pressure yielded 45% CsI release to the environment compared to 3% without cycling [15].) Users should make an effort to determine if cycling at low pressures applies to their plant's SRVs because this characteristic is not emphasized in plant documentation and therefore can be inadvertently neglected.

If applicable for a particular plant, the following logic to close and reopen SRVs can be customized and added to an include file, which can then be used with each sequence. (Explicit code logic and input parameters were incorporated in Rev. 4.0.7 to address this issue.) In this example, if the first SRV is manually opened, it will close when the differential pressure between the primary system and the wetwell drops to 50 psid and reopen when the differential pressure increases to 100 psid. Similar sets of input can be written for other valves using separate 500-level events. Inherent in the logic is the assumption that manually opened valves are opened by setting the input flags IMANON(*i*) to 1 rather than changing the values of the set pressures, PSETRV(*i*). It is usually difficult to determine the pressure at which the valves will reopen; using a higher value is conservative with respect to fission product releases to the environment. To avoid long log files, the SILENT command can be used after each REPEAT, and it can be commented out to display the toggling of the valves in the log file for testing.

```
** +++++ CLOSE ON LOW PRESSURE DIFFERENTIAL +++++
**
** Manually opened SRVs will close when the differential pressure
** between the primary system and the wetwell drops to 50 psid. They
** will reopen at a higher but undetermined differential pressure -
** a value of 100 psid is assumed (conservative to use relatively
** high pressure differential to reopen with respect to fission
** product release to the environment).
**

INITIATORS
  PRESSDIF = 0
END
```

FUNCTION

    PRESSDIF = (PPS - PRB(4)) / 6895

END

C For SRV(1) -- repeat for other SRVs.

WHEN PRESSDIF < 50 and IMANON(1) IS TRUE

    IEVNT(551) IS TRUE

    IMANON(1) = 0

    REPEAT

END

WHEN PRESSDIF > 100 AND IEVNT(551) IS TRUE

    IEVNT(551) IS FALSE

    IMANON(1) = 1

    REPEAT

END

### 5.3.8.2 Closure on High Containment Pressure

Some SRVs have the characteristic that, if opened in relief mode or opened manually, they will close on high containment pressure. If applicable for a particular plant, the following logic can be customized and added to an include file, which can then be used with each sequence. (Explicit code logic and input parameters were incorporated in Rev. 4.0.7 to address this issue.)

\*\* +++++ CLOSE ON HIGH DRYWELL PRESSURE +++++

\*\*

\*\* Valves that were opened automatically in relief mode or opened

\*\* manually close on high drywell pressure -- 75 psig = 89.7 psia.

\*\* Use 14.7 as ambient pressure.

\*\* (Closure on high drywell pressure is not applicable for valves

\*\* opened in safety mode.)

\*\*

\*\* The following logic assumes that the setpoints and deadbands for valves

\*\* opened in safety mode are such that the valves will be closed prior to

\*\* reaching the highest relief setpoint pressure.

\*\*

\*\* A code limitation prevents the use of input parameter ILOCK(i)

\*\* to control the closing of the valves in relief mode on high drywell

\*\* pressure. The valve area is set to 0.0 as a way of closing the valve.

\*\* (The limitation was unsuccessfully removed in Rev. 4.0.7, and will be

\*\* removed in 4.0.8.)

C Save initial SRV area

WHEN TIM > 0.0

    ASRV\_SAV1 = ASRV(1)

    HIGHCONTPRES = 0.0

END

```

** Set the valve area to 0.0 to close the valve when the containment
** pressure is high, it is not already closed due to high containment
** pressure, and it is not open in safety mode. In this example the
** valve will stay open in safety mode until the pressure drops to
** 1093.7 psia.

```

```

WHEN PRB(2) > 89.7 PSI
AND HIGHCONTPRES < 0.5
AND PPS < 1093.7 PSI
  HIGHCONTPRES = 1.0
  ASRV(1) = 0.0
  REPEAT
END

```

```

** Reopen the valve when the containment pressure falls below 75 psig
** or when the valve should be open in safety mode.

```

```

WHEN PRB(2) < 89.7 PSI
AND HIGHCONTPRES > 0.5
OR PPS > PSETSV(1)
AND ASRV(1) == 0.0
  HIGHCONTPRES = 0.0
  ASRV(1) = ASRV_SAV1
  REPEAT
END

```

```

** Open the valve when it is forced open using ISTUCK.

```

```

WHEN ISTUCK(1) > 0.5
  ASRV(1) = ASRV_SAV1
  REPEAT
END

```

### 5.3.8.3 Reduction of Setpoints

In some plants, the setpoints of relief valves will be reduced after the valves have opened to decrease the potential for valve cycling. This is intended to improve valve operability and minimize containment fatigue. The following is an example of a user-defined event that can be added to parameter files to modify the opening setpoints, PSETRV(*i*), and the deadbands for closing the valves, PDRV(*i*). In this example, the setpoints are adjusted when two valves are opened simultaneously.

```

** +++++ ADJUST SRV SETPOINTS FOR LOW-LOW SET MODE +++++
**

```

```

** At the plant the setpoints are adjusted to keep the valves
** from cycling after two or more valves are opened in relief
** mode or manually. The setpoints only apply to the relief
** mode, so this event is set to true only when there is power
** (event 159 = 0).

```

```

603 IOPEN(1) > 0 AND IOPEN(2) > 0 AND EVENT 159 FALSE LOCKOUT

```

603 ACTION #3  
603 TRUE SRVS IN LOW-LOW SET MODE

```

ACTION #3
  PSETRV(1) = 1060.7 PSI // was 1076 psig, reopens at 1046 psig
                        // = 1060.7 psia
  PSETRV(2) = 1020.7 PSI // was 1076 psig, reopens at 1006 psig
  PDRV(1) = 120 PSI      // now closes at 926 psig
  PDRV(2) = 110 PSI      // now closes at 896 psig
END

```

#### 5.3.8.4 Prevention of Rapid Cycling

In some plants, the SRVs will not cycle rapidly in relief mode. The following logic can be added to prevent the valves from reopening in relief mode within a prescribed time.

```

**  ++++++ PREVENT CYCLING OF SRVs IN RELIEF MODE
**              IN LESS THAN 10 S ++++++
**
** Prevent the SRVs from reopening in relief mode within 10 seconds
** of closing. (Repeat for other SRVs)

```

```

C Define functions for SRV closing pressures (SI and BR units)
FUNCTION PRV1CL_PA = (PSETRV(1) - PDRV(1))
FUNCTION PRV1CL_PSI = (PSETRV(1) - PDRV(1)) / 6895

```

```
INITIATORS
  NRV1FLAG = 0
  PRV1CL_PA = 0
  PRV1CL_PSI = 0
C Time that the SRVs reclose in relief mode
  TIMRV1CL = 0
END
```

```

C Save initial SRV areas
WHEN TIM > 0.0
  ASRV_SAV1 = ASRV(1)
END

```

```

      WHEN PPS > PSETRV(1) AND NRV1FLAG < 1
        NRV1FLAG = 1
        REPEAT
      END

```

```

WHEN PPS < PRV1CL_PA AND NRV1FLAG == 1
  NRV1FLAG = 2
  TIMRV1CL = TIM + 10
  REPEAT

```



END

```

WHEN PPS > PSETRV(1)
AND NRV1FLAG == 2
AND TIM < TIMRV1CL
  ASRV(1) = 0.0
  NRV1FLAG = 3
  REPEAT
END

```

```

WHEN PPS > PSETRV(1)
AND NRV1FLAG == 2
AND TIM > TIMRV1CL
  NRV1FLAG = 1
  REPEAT
END

```

```

WHEN PPS > PSETRV(1)
AND NRV1FLAG == 3
AND TIM > TIMRV1CL
  ASRV(1) = ASRV_SAV1
  NRV1FLAG = 1
  REPEAT
END

```

## 5.4 General Considerations for Initiating Events

The user specifies the set of initiating events for each sequence. The initiating events modeled in MAAP4 include transients, loss of offsite and on-site power, loss-of-coolant accidents (LOCAs), and inadvertent opening of relief valves. The user can also specify that the reactor protection system fails, resulting in an anticipated transient without scram (ATWS) scenario.

### 5.4.1 Transients

Transients are a general class of sequences that are characterized by closure of the MSIVs and/or the turbine stop and bypass valves, loss of feedwater, and activation of the reactor protection system (that is, a scram). Conditions that lead to these events are discussed in Sections 5.3.1 through 5.3.8 and in Appendix B. The progression of transients can be significantly affected by the plant control logic. These logic features are also discussed in those sections, and users should ensure that their input files contain the necessary components to adequately model the logic at their plants. The following are of particular importance:

- **Primary system pressure control:** MAAP4 does not model the adjustments to the limiting flow area through the turbine stop valves or bypass valves to maintain the primary system pressure, so users should include logic to reduce the minimum main steam line flow area to maintain pressure in sequences that are not initiated by MSIV closure or turbine stop and bypass valve closure. (See Section 5.3.5.)

- **Prevention of MSIV closure on low pressure after scram:** In some plants, the MSIVs will not close on low pressure after a certain period of time has passed following the generation of a scram signal, so users should consider including the corresponding logic. (See Section 5.3.1.)
- **Turbine trip on low steam flow:** MAAP4 does not model the tripping of the main turbines when the steam flow has been reduced following a scram, so users should include logic to close the turbine stop valves after a scram. The steam flow will then be diverted through the bypass valves. (See Section 5.3.6.)

Of the three features, the primary system pressure control is the dominant one; if that logic is not added to the input files, the other two items are unlikely to have any influence because the MSIVs will close relatively early on low pressure.

A series of sequences was run with various combinations of the transient initiators, logic features, and input parameter values to characterize the predicted progression of transients and to investigate the relative importance of the input components. The sequences were run with both sample and plant-specific parameter files; similar results were obtained with the different files. Key figures-of-merit from several of these sequences are presented in Table 5-3. They were obtained with a plant-specific Mark I parameter file. In these sequences, all injection is assumed to be unavailable and there are no operator actions. The following conclusions are drawn from a review of the transient sequences, including those in the table:

- For sequences that include MSIV closure and loss of feedwater, the overall progression is the same. They all result in core damage, based on representative water level and core temperature criteria, and heat-up of the containment, represented by the temperature in the suppression pool.
- On the other hand, there are nontrivial differences in the time to core damage and the heat-up of the pool as a function of the initiator, logic features, and the duration of the feedwater coastdown. The importance of these differences depends on the required precision of the results, which is a function of the user's application. In these sequences (which have no injection), a feedwater trip is the most conservative with respect to the time to core damage, while an MSIV closure is essentially the most conservative with respect to heat-up of the suppression pool. (If injection is available, an MSIV closure sequence will likely be more conservative than a feedwater trip because an MSIV closure is more limiting with respect to the energy released from the primary system through the main steam line.)
- The logic features discussed previously can have a significant effect on the progression of a sequence, particularly the primary system pressure control logic. As can be seen from the scram and turbine stop valve closure sequences presented in Table 5-3, if the logic features are included the MSIVs do not close and the feedwater does not trip. Rather than progressing to core damage, the core remains covered with steam going out the turbine bypass and feedwater being returned. There is no balance-of-plant model in the code to track the availability of feedwater, so the code will predict that this situation continues indefinitely.

- The pressure control logic can influence the time to core damage and pool heat-up in sequences that result in MSIV closure, as seen in the loss of feedwater sequences presented in the table. The setpoints for MSIV closure due to low pressure and low level and the times used in the input file components for the logic features can affect the results because of their impact on the time of MSIV closure.
- As discussed in Section 5.3.3, the duration of the feedwater coastdown can be a function of the condition that causes the feedwater trip. A longer coastdown is more appropriate for a trip that results from closure of the MSIVs compared to a direct trip of the feedwater system. The feedwater coastdown time can have a minor impact on the figures-of-merit, with a shorter coastdown leading to earlier core damage.
- A transient initiated with closure of the turbine stop and bypass valves will progress in essentially the same way as an MSIV closure. Small differences are expected due to differences in the timing of the closure of the different valves.
- The time to transition from full power to decay power, input parameter TDPOWR, and the maximum turbine bypass flow, input parameter WBP MAX, can have a small effect on the figures-of-merit. A longer transition time leads to earlier core damage, and a larger bypass area leads to earlier core damage and more energy to the pool.
- Variations in the values of additional input parameters were seen to have a negligible effect on the figures-of-merit for the transient sequences. These include the MSIV closure time (TDMSIV), the scram delay time (TDSCRM), the recirculation pump trip delay time and coastdown curve (TDRPT and FWRR versus TIRR), the effective irradiation time (TIRRAD), the maximum time step (TDCORE), and the core nodalization (NAXNOD and NCHAN).

#### **5.4.2 Loss of AC Power and Injection Level Control**

The analysis of accident scenarios that involve the loss of AC power, either offsite or both offsite and onsite (that is, a station blackout), is essentially an extension of the analysis of transients. In MAAP4, the unavailability of AC power leads to a reactor scram (through closure of the turbine stop valves). In addition, many of the safety systems will be unavailable. Users should review the assumed supply power requirements for the various systems and make any necessary adjustments using input parameters or logic to ensure consistency between the models in the code and the plant's power requirements. The assumed power requirements are listed in Table 5-2.

The loss of offsite and onsite power are initiated by setting external events 250, LOSS OF AC POWER, and 251, LOSS OF DIESEL POWER, to true, respectively. Of interest in such sequences are the impacts of systems that are passive, have a dedicated, independent power source, or are powered by DC batteries. The availability of the last is governed by the duration of battery power, input parameter TDBATT.

**Table 5-3**  
**Transients: Influence of Initiators, Logic Features, and Feedwater Coastdown <sup>a</sup>**

| Initiator <sup>b</sup>                                     | MSIV Closure <sup>c</sup> |                       | Loss of Feedwater      |                        | Scram       |                        | TSV <sup>d</sup> Closure |
|------------------------------------------------------------|---------------------------|-----------------------|------------------------|------------------------|-------------|------------------------|--------------------------|
| Logic features and input variation                         |                           |                       |                        |                        |             |                        |                          |
| Pressure controlled prior to MSIV closure                  | n/a <sup>e</sup>          | n/a                   | Logic added            | Default <sup>f</sup>   | Logic added | Default                | Logic added              |
| Prevent MSIV closure on low pressure 15 s after scram      | n/a                       | n/a                   | Logic added            | Logic added            | Logic added | Logic added            | Logic added              |
| Close turbine stop valves 2 min after scram (turbine trip) | n/a                       | n/a                   | Logic added            | Logic added            | Logic added | Logic added            | n/a                      |
| Duration of feedwater coastdown <sup>g</sup>               | 25 s                      | 3 s                   | 3 s                    | 3 s                    | 25 s        | 25 s                   | 25 s                     |
| Short-term response                                        |                           |                       |                        |                        |             |                        |                          |
| MSIV closure signal                                        | 0 s                       | 0 s                   | 16 min (on low level)  | 22 s (on low pressure) | Does not    | 11 s (on low pressure) | Does not                 |
| Scram signal                                               | 0 s (on MSIV closure)     | 0 s (on MSIV closure) | 4 s (on high pressure) | 9 s (on low level)     | 0 s         | 0 s                    | 0 s (on TSV closure)     |
| Feedwater pump trip                                        | 0 s (on MSIV closure)     | 0 s (on MSIV closure) | 0 s                    | 0 s                    | Does not    | 11 s (on MSIV closure) | Does not                 |
| Sequence progression and core damage criteria              |                           |                       |                        |                        |             |                        |                          |
| Downcomer level < TAF <sup>h</sup>                         | 34 min                    | 23 min                | 19 min                 | 14 min                 | n/a         | 47 min                 | n/a                      |
| Core boiled-up level < TAF                                 | 42 min                    | 31 min                | 27 min                 | 22 min                 | n/a         | 55 min                 | n/a                      |
| Downcomer < 1/3 core height                                | 54 min                    | 40 min                | 35 min                 | 30 min                 | n/a         | 1.1 hr                 | n/a                      |
| Hottest core node temperature > 1255 K (1800°F)            | 1.1 hr                    | 50 min                | 45 min                 | 39 min                 | n/a         | 1.3 hr                 | n/a                      |
| Pool temperature at 2 hr (initial = 294 K [70°F])          | 316 K (109°F)             | 314 K (105°F)         | 304 K (88°F)           | 309 K (96°F)           | n/a         | 316 K (109°F)          | n/a                      |

<sup>a</sup> Sequences run with a Mark I parameter file, no injection.

<sup>b</sup> MSIV closure initiated with external event 215; loss of feedwater initiated with external event 209; scram initiated with external event 255; TSV closure initiated with external event 212.

<sup>c</sup> Essentially the same as turbine stop and bypass valve closure.

<sup>d</sup> TSV = turbine stop valve.

<sup>e</sup> n/a = not applicable.

<sup>f</sup> Default means logic not added (default logic in the code is used).

<sup>g</sup> Feedwater coastdown input parameters are TIFWCD versus WFWCD.

<sup>h</sup> TAF = top of active fuel.

As noted in Section 5.3.7, a loss-of-offsite-power condition at a plant will lead to an electrical signal to close the MSIVs (versus a signal based on primary system thermal-hydraulic conditions). This is not modeled in MAAP4, so a loss-of-offsite-AC-power initiator should always be accompanied by an MSIV closure initiator (external event 215). Furthermore, it is assumed that feedwater has an independent power source. In actuality, even if the feedwater pumps are turbine driven, offsite AC power is required for feedwater to be operational because the condensate pumps (which are upstream of the feedwater pumps) require offsite power. Therefore, external event 294, which prevents feedwater from being tripped by MSIV closure, should not be set to true in a loss-of-offsite-AC-power sequence.

The duration of battery power is a function of the loads on the DC power supply system, which are in part driven by the progression of the accident. Therefore, there is a coupling between the power available for the battery-backed systems and the impact of those systems. However, the code determines the availability of the batteries based only on the elapsed time since the loss of AC power and does not model the power drain as a function of the systems that are operating. Users should determine if it is necessary to adjust the value of input parameter TDBATT as a function of the systems that are operating for each loss-of-power sequence. In turn, MAAP4 analyses can be used to support the calculations of DC load shedding by generating information on the required performance of battery-backed systems for Level 1 success.

Because the turbine-driven injection systems, HPCI and RCIC, are potentially the largest drain on the batteries, the availability of battery power is related to the mode of level control for these systems. They can be operated in “bang-bang” mode, in which the flow cycles on and off based on the downcomer water level relative to low and high level setpoints, or in throttled mode, in which the flow is controlled to match a target level. The modeling of these two modes and their distinct effects on the amount of steam extracted to drive the turbines are discussed in Appendix B. The default in the code is the bang-bang mode, but it is likely that operators at the plants would control the systems in throttled mode based on their EOPs. External event 295, HPCI & RCIC FLOW CONTROL ON, is used to select the throttled option. When evaluating sequences in which the flow is controlled in bang-bang mode, users should keep in mind that the injection will cause a perturbation to the quasi-steady conditions in the primary system. The implications and response of the primary system to this situation are discussed in Section 5.6.1.

A series of loss-of-AC-power sequences was run with various combinations of the duration of battery power, the injection level control mode, and other related input parameter values to characterize the predicted progression of these types of sequences and to investigate the relative importance of the input parameters. They were run with both sample and plant-specific parameter files; similar results were obtained with the different files. Key figures-of-merit from several sets of these sequences are presented in Tables 5-4 through 5-6. They were obtained with a plant-specific Mark I parameter file. Only HPCI injection is assumed to be available, and it takes suction from the pool (versus from the CST). The nominal battery duration is 6 hours, and the nominal level control mode is based on cycling between low and high level setpoints that are 2.1 m (7.0 ft) apart. The sequences summarized in Table 5-4 show the influence of varying the battery depletion time. Those in Table 5-5 show the influence of the low level setpoint, which is reduced to different levels after the first HPCI cycle. This has the intention of reducing the number of cycles, thereby reducing the drain on the batteries. The sequences in Table 5-6 show the influence of the level control mode, the target level when the flow is throttled, and the steam

extraction rate. The following conclusions are drawn from a review of the loss-of-power sequences, including those presented in the tables:

- The duration of the batteries, as specified by parameter TDBATT, can have a significant effect on the progression of a sequence. This is particularly true if the injection is in bang-bang mode, in which case small differences in the duration can lead to relatively large differences in the results. This is demonstrated in Table 5-4, where a difference in TDBATT on the order of 0.1 hours leads to a difference in the time to core damage on the order of 1.5 hours. The reason for this strong, nonuniform dependence is that the duration of the batteries determines the number of injection cycles—all other things being equal—and it is the number of cycles that determines the amount of injected water. Because of the potentially large impact of TDBATT, users should ensure that the value of the parameter is appropriate for the individual sequences and should evaluate the sensitivity of their results to the value.
- The effect of the number of cycles is also demonstrated in Table 5-5, in which the low level setpoint for HPCI initiation, parameter ZLHPCI, is decreased to different levels after the first injection cycle. This simulates the operator adjusting the low level setpoint to extend the time between cycles as a way of extending the availability of the batteries. The low level setpoint influences the number of cycles and therefore the mass of water that is injected. The mass that is injected is not a monotonic function of the low level setpoint, whereas the time to core damage is a monotonic function of the injected mass. The low level setpoint also has a minor effect on the conditions in the containment.
- The time to core damage is less dependent on the amount of injected water in throttled mode compared to bang-bang mode, as demonstrated in Table 5-6. On the other hand, there is a direct relationship between the target water level and the time to core damage: the lower the level, the earlier the time.
- The overall progression of the sequences is essentially independent of the level control mode. Generally, the throttled mode results in a longer time to core damage and less stress on the containment (that is, the drywell pressure). However, the tradeoffs between the two modes is a function of plant-specific features such as the level setpoints and battery drain characteristics.
- The rate of extraction of the steam that drives the injection turbine has a small impact on the time to core damage and a somewhat more significant impact on the containment conditions. The rate for HPCI is determined by the WSTHPI versus PTURHP array.
- The initial temperature of the pool, TWRB0(*i*), and the HPCI spray droplet diameter, XSPARG, can have a small impact on the figures-of-merit. A hotter pool leads to earlier core damage and more energy to the drywell. A smaller droplet diameter also leads to earlier core damage.
- Variations in the values of additional input parameters were seen to have a negligible impact on the figures-of-merit for the transient sequences. These include the initial primary system pressure and water temperature (PPS0 and TWPS0).

**Table 5-4**  
**Loss of AC Power: Influence of Battery Depletion Time on Core Damage <sup>a</sup>**

| <b>Input variation</b>                          |            |                      |                             |            |        |
|-------------------------------------------------|------------|----------------------|-----------------------------|------------|--------|
| Battery depletion time <sup>b</sup>             | 5.0–5.1 hr | 5.2 hr               | 5.25 hr                     | 5.3–6.5 hr | 7.0 hr |
| <b>Sequence progression</b>                     |            |                      |                             |            |        |
| Number of HPCI cycles                           | 4          | 4 plus partial cycle | 4 plus larger partial cycle | 5          | 6      |
| <b>Core damage criteria</b>                     |            |                      |                             |            |        |
| Downcomer level < 1/3 core height               | 6.3 hr     | 6.4 hr               | 7.0 hr                      | 7.8 hr     | 9.3 hr |
| Hottest core node temperature > 1255 K (1800°F) | 6.6 hr     | 6.6 hr               | 7.3 hr                      | 8.1 hr     | 9.6 hr |

<sup>a</sup> Sequences run with a Mark I parameter file, loss of AC power and loss of feedwater, HPCI injection from the suppression pool, and bang-bang level control mode.

<sup>b</sup> Battery depletion time input parameter is TDBATT.

**Table 5-5**  
**Loss of AC Power: Influence of Low Level Injection Setpoint on Core Damage and Containment Conditions <sup>a</sup>**

| <b>Input variation</b>                                                                   |                        |                        |                        |                        |                        |
|------------------------------------------------------------------------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|
| Reduction in HPCI low downcomer level initiation setpoint after first cycle <sup>b</sup> | None                   | 0.6 m<br>(2 ft)        | 1.2 m<br>(4 ft)        | 1.8 m<br>(6 ft)        | 2.4 m<br>(8 ft)        |
| <b>Sequence progression</b>                                                              |                        |                        |                        |                        |                        |
| Number of HPCI cycles                                                                    | 5                      | 4                      | 4                      | 4                      | 3                      |
| Total HPCI injection                                                                     | 4.9e5 kg<br>(1.1e6 lb) | 4.4e5 kg<br>(9.7e5 lb) | 4.9e5 kg<br>(1.1e6 lb) | 5.3e5 kg<br>(1.2e6 lb) | 4.2e5 kg<br>(9.3e5 lb) |
| End of last HPCI injection cycle                                                         | 5.3 hr                 | 4.4 hr                 | 5.0 hr                 | 5.5 hr                 | 3.8 hr                 |
| Height of downcomer water above adjusted setpoint at 6 hr                                | 2 m<br>(7 ft)          | ~0 m<br>(~0 ft)        | 3 m<br>(10 ft)         | 4 m<br>(14 ft)         | 0.3 m<br>(1 ft)        |
| <b>Core damage criteria</b>                                                              |                        |                        |                        |                        |                        |
| Downcomer level < 1/3 core height                                                        | 7.8 hr                 | 7.1 hr                 | 7.8 hr                 | 8.4 hr                 | 6.8 hr                 |
| Hottest core node temperature > 1255 K (1800°F)                                          | 8.1 hr                 | 7.3 hr                 | 8.1 hr                 | 8.7 hr                 | 7.1 hr                 |
| <b>Containment conditions 1 hr after battery depletion</b>                               |                        |                        |                        |                        |                        |
| Drywell pressure                                                                         | 0.36 MPa<br>(52 psia)  | 0.37 MPa<br>(54 psia)  | 0.36 MPa<br>(52 psia)  | 0.36 MPa<br>(52 psia)  | 0.37 MPa<br>(54 psia)  |
| Pool temperature (initial = 294 K [70°F])                                                | 339 K<br>(151°F)       | 343 K<br>(157°F)       | 339 K<br>(151°F)       | 337 K<br>(147°F)       | 343 K<br>(157°F)       |

<sup>a</sup> Sequences run with a Mark I parameter file, loss of AC power and loss of feedwater, HPCI injection from the suppression pool, battery depletion time = 6 hours, and bang-bang level control mode.

<sup>b</sup> Low level setpoint input parameter is ZLHPCI.



**Table 5-6**  
**Loss of AC Power: Influence of Level Control Mode, Target Level, and Steam Extraction**  
**Rate on Core Damage and Containment Conditions <sup>a</sup>**

| <b>Input variations</b>                                            |                        |                        |                        |                        |                        |                        |
|--------------------------------------------------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|
| Level control mode <sup>b</sup>                                    | Bang-Bang              | Throttled              |                        |                        |                        |                        |
| Target level relative to high level in bang-bang mode <sup>c</sup> | —                      | -0.3 m<br>(-1.0 ft)    | -1.3 m<br>(-4.1 ft)    | -1.9 m<br>(-6.1 ft)    | -0.3 m<br>(-1.0 ft)    | -0.3 m<br>(-1.0 ft)    |
| Change in steam extraction rate <sup>d</sup>                       | —                      | —                      | —                      | —                      | 85%                    | 115%                   |
| <b>Sequence progression</b>                                        |                        |                        |                        |                        |                        |                        |
| Cumulative amount of HPCI water injected                           | 4.9e5 kg<br>(1.1e6 lb) | 5.3e5 kg<br>(1.2e6 lb) | 5.3e5 kg<br>(1.2e6 lb) | 5.3e5 kg<br>(1.2e6 lb) | 4.9e5 kg<br>(1.1e6 lb) | 5.3e5 kg<br>(1.2e6 lb) |
| Cumulative amount of steam to turbine                              | 3.6e4 kg<br>(7.9e4 lb) | 3.3e5 kg<br>(7.4e5 lb) | 3.4e5 kg<br>(7.5e5 lb) | 3.5e5 kg<br>(7.6e5 lb) | 3.0e5 kg<br>(6.7e5 lb) | 3.6e5 kg<br>(7.9e5 lb) |
| <b>Core damage criteria</b>                                        |                        |                        |                        |                        |                        |                        |
| Downcomer level < 1/3 core height                                  | 7.8 hr                 | 8.4 hr                 | 8.1 hr                 | 7.9 hr                 | 8.3 hr                 | 8.3 hr                 |
| Hottest core node temperature > 1255 K (1800°F)                    | 8.1 hr                 | 8.8 hr                 | 8.4 hr                 | 8.2 hr                 | 8.6 hr                 | 8.6 hr                 |
| <b>Containment conditions 1 hr after battery depletion</b>         |                        |                        |                        |                        |                        |                        |
| Drywell pressure                                                   | 0.36 MPa<br>(52 psia)  | 0.26 MPa<br>(38 psia)  | 0.26 MPa<br>(38 psia)  | 0.25 MPa<br>(36 psia)  | 0.31 MPa<br>(45 psia)  | 0.23 MPa<br>(34 psia)  |
| Pool temperature (initial = 294 K [70°F])                          | 339 K<br>(151°F)       | 343 K<br>(158°F)       | 344 K<br>(160°F)       | 346 K<br>(163°F)       | 341 K<br>(154°F)       | 346 K<br>(163°F)       |

<sup>a</sup> Sequences run with a Mark I parameter file, loss of AC power and loss of feedwater, HPCI injection from the suppression pool, and battery depletion time = 6 hours.

<sup>b</sup> Level control mode selected with external event 295.

<sup>c</sup> Target level input parameter for throttled mode is ZWSHCD.

<sup>d</sup> Steam extraction input parameters are WSTHPI versus PTURHP; changes are from nominal values.

### 5.4.3 Loss-of-Coolant Accident

LOCAs are initiated with a break in the primary system. The location and geometry of the break are defined by five input parameters:

- ALOCA, the area of the break
- ZLOCA, the absolute elevation of the break
- JNLOC, the pointer that identifies the compartment that receives the break effluent
- ZNLOC, the height of the centerline of the break above the floor of the receiving compartment
- FCDBRK, the discharge coefficient

In the flow calculations, an effective break area is used, which is the product of the values of ALOCA and FCDBRK. The primary system node that is used to determine the flow rate and the properties of the effluent is determined by the relative location of ZLOCA, as described in the sample parameter files.<sup>7</sup> The break is opened by setting external event 256, BREAK IN PRIMARY SYSTEM (LOCA), to true. The calculated water and gas mass flows through the break are variables WWLOCA and WGLOC, respectively. (The code uses stagnation conditions at the break location and the effective area to calculate the break flow; the model does not include the relatively minor effect of frictional pressure drops upstream of the break.)

The break area should be the chokepoint—that is, the minimum area—in the path from the primary system to the containment. For example, if the break is on the discharge side of a recirculation pump and the suction side has been isolated, the chokepoint will be at the jet pump nozzles if the composite area of the nozzles in the loop is smaller than the break in the recirculation line. In this case, the value of ALOCA should be set to the composite area and the value of FCDBRK should be relatively small to account for the high perimeter-to-area ratio.

Breaks are often classified as small, medium, and large. The distinction can be based strictly on the area of the break, or it can be based on how quickly the primary system depressurizes through the break, which determines which injection systems can be used. Using this functional approach, breaks can be categorized as follows:

- **Small break:** A small break is one that does not result in a pressure low enough to allow low pressure injection (for example, LPCI or LPCS) without some other means of depressurization, and the pressure remains high enough to sustain turbine-driven injection (that is, HPCI or RCIC). A low capacity injection system is sufficient to maintain the water inventory in the primary system. Generally, this is a break on the order of 3 cm (1 in.) in diameter.

---

<sup>7</sup> The break flow model includes a multiplier to calculate the effective radius of the break; it accounts for the orientation of the break and the acceleration of the fluid to the break. In the BWR, code the value of the multiplier is set to 2, which corresponds to a vertical break with full acceleration. Unlike the PWR code, there is no input parameter that allows the user to adjust the orientation and acceleration.

- **Medium break:** A medium break is one that does not result in a pressure low enough to allow low pressure injection without some other means of depressurization, and the pressure is initially high enough to support turbine-driven injection. However, the pressure decreases such that turbine-driven injection might not be sustainable, and a high-capacity system is necessary to maintain the water inventory. Generally, this is a break on the order of 8 cm (3 in.) in diameter.
- **Large break:** A large break is one that depressurizes rapidly enough to allow low pressure injection. A high-capacity system is necessary to maintain the water inventory. Generally, this is a break on the order of 13 cm (5 in.) in diameter.

The rate of depressurization is a strong function of the location of the break as well as its size because the location determines whether the initial effluent is water or steam. Breaks that are below the water level tend to result in a faster loss of inventory than those of the same size that are above the water level. This affects the functional classification of a particular size break as small, medium, or large. For example, the maximum diameter for a small break below the water level can be a factor of four smaller than the maximum diameter above the water level. The location of the break with respect to the water level should always be part of the initial description of a LOCA sequence.

There are situations in which the initial volumetric flow of water is used to communicate the size of a liquid break. For example, a small break representing leakage from a primary system component might be defined as a 50 gpm break. The values of ALOCA and FCDBRK that yield the specified volumetric flow can be determined through an iterative process using the calculated water mass flow, WWLOCA. It is convenient to calculate the corresponding volumetric flow using the specific volume of the primary system, VWPS. The following function block can be used to calculate the volumetric flow in gallons per minute:

```

FUNCTION
C Determine break flow in gpm
C WWLOCA = break flow in kg/s within code
C VWPS = specific volume of primary system water in m^3/kg within code
C   kg/s * m^3/kg * 35.31 ft^3/m^3 * 7.4895 gal/ft^3 * 60 s/min
  WWGPM = WWLOCA * VWPS * 35.31 * 7.4805 * 60
END

```

The volumetric flow will decrease as a result of depressurization of the primary system. In the event that a constant flow break is required, a lookup variable block can be used to adjust ALOCA as a function of the primary system pressure.

The area of a break can be changed during a sequence to represent such things as an increase in area due to erosion of the ruptured structure or the addition of a parallel break path.

Users should assess the sensitivity of the MAAP4 results to the effective area of the break by adjusting either the value of ALOCA or the value of FCDBRK. (Note that FCDBRK is also used as the discharge coefficient in the calculation of flow from the primary system to the containment through vessel failure openings and generalized openings.) The elevation should also be adjusted to assess the impact of water versus steam flow through the break. Two other *Model* parameters that can have an impact on LOCA sequences, specifically the containment

response, are FELOCA and FNOMIX. They are included in the list of parameters that potentially represent the greatest uncertainty in Table 4-3 and are discussed in Section 5.5.

Users should also be aware that the Rev. 4.0.6 and 4.0.7 versions of the code will under-predict break flow in SLOCAs when the break is covered by water, as would be the case when the injection rate is larger than the break flow. This can lead to the over-prediction of the times of key events such as CST depletion and the under-prediction of containment conditions such as pressure and temperature. This error has been corrected for Rev. 4.0.8 and is discussed in MAAP FLAASH 69. Users should incorporate the following workaround that was provided in the MAAP FLAASH for LOCA sequences that are run with Rev. 4.0.6 and Rev. 4.0.7:

```
WHEN TWSH < TSATPS-5.E0
  VMSH = (MWOSH + MWJET) * VWSH
  REPEAT
  SILENT
END
```

#### **5.4.4 Interfacing System LOCA**

An ISLOCA is a sequence with a primary system break outside containment. It can result in fission product release directly to the environment. Water lost through the break is not available for subsequent injection. An ISLOCA is initiated with the same input file components as a break into the containment except that JNLOC is assigned to the appropriate auxiliary/reactor building node. Users should remember to include input file components to disable systems that are immediately affected by such a break (for example, CRD if the break is in the CRD piping). MAAP4 can be used to determine the conditions in the vicinity of equipment and instrumentation in the auxiliary/reactor building, and the sequences can be constructed to disable those systems that would be inaccessible or adversely affected by the resultant flooding, high temperatures, high humidity, and/or high radiation levels.

#### **5.4.5 Inadvertent Opening of a Relief Valve**

A sequence that is initiated with an inadvertent opening of a relief valve is similar to a LOCA with respect to the primary system response, but because the relief valves discharge to the suppression pool, it has a different containment response. Users specify that a sequence is initiated with an inadvertent opening of a valve by including the line  $ISTUCK(i) = 1$  in the initiators block in the input file, where  $i$  is the number of the valve. Similarly, users can specify that a relief valve sticks open by including the line in a condition block. For example, the following block can be added to an input file to model a relief valve that has stuck open after 10 cycles:

```
WHEN NCYCLE(1) > 10
  ISTUCK(1) = 1
END
```

A relief valve can be opened with ISTUCK regardless of whether AC or DC power is available. The calculated water and gas flow through the relief valves are WWRV and WGRV or WWSV and WGSV, depending on the relief valve discharge location.

#### 5.4.6 Failure to Scram (ATWS)

The failure of the reactor protection system—that is, an ATWS condition—is coupled with other accident initiators such as an MSIV closure, a loss of offsite power, or a stuck-open relief valve. An ATWS sequence is specified by setting external event 257, ATWS RUN, to true.

Generally, an ATWS sequence has a higher degree of uncertainty associated with it than other sequences because of the coupled nature of the progression of the sequence and the core power level. Furthermore, the power level during an ATWS is a complex function of the primary system pressure, water level, and water temperature; it is calculated in the code in a relatively simple manner. Therefore, when using MAAP4 to analyze ATWS scenarios, users should pay particular attention to evaluating the influence of the logic features discussed in Section 5.3, and should investigate the impact of uncertainties in the input parameters that control the modeling of the MSIVs, feedwater, pressure relief, and safety injection. Because of the tight coupling between steam condensation on high pressure injection sprays and the ATWS power level, it is recommended that users evaluate the sensitivity of the sequences to the spray droplet diameter, XSPARG (for HPCI and RCIC) or XSPRCS (for HPCS).

When the SLC system is actuated, the code calculates the injected flow based on the input array of flow versus primary system pressure and uses the flow to determine the added water mass and energy. The core power is assumed to decrease in an approximately linear manner to the decay power over the time period specified by input parameter TDSLCL and is not calculated as a function of the SLC flow. In actuality, the time to get to the decay power level is a function of the amount of SLC water that is injected and is therefore a function of the accident scenario because of the scenario's impact on the primary system pressure. Users should determine an appropriate range of values for TDSLCL based on plant information and evaluate the sensitivity of their ATWS scenarios to this parameter.

### 5.5 Influence of *Model* Parameters for Level 1 Analysis

An essential element of PRA analysis is the characterization of uncertainties. As discussed in Section 4, this includes the assessment of the impact of adjustments to the input parameters that influence the physical and chemical process calculations, many of which are in the *Control* and *Model* sections of the parameter file. Recommendations for adjusting the parameters that potentially represent the greatest uncertainty are included in Table 4-3. Three of the parameters that fall under this category relate to BWR Level 1 LOCA sequences. A series of LOCA sequences was run with variations in the values of these parameters using the Mark I sample parameter file. The observed impacts are noted in Table 5-7. This information is intended to provide insight into the influence of these *Model* parameters and should not be considered definitive for all LOCA sequences.

**Table 5-7**  
**Observed Impact of *Model* Parameters for Level 1 Analyses**

| <i>Model</i><br>Parameter | Definition                                                                                                      | Type of<br>Level 1<br>Sequence                | Area of<br>Potential<br>Impact            | Observations                                                                                                                                                                                                                                                                                                                                                                             |
|---------------------------|-----------------------------------------------------------------------------------------------------------------|-----------------------------------------------|-------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| FELOCA                    | Fraction of water break flow entrained as suspended water in containment                                        | LOCAs                                         | Containment conditions                    | Minor to moderate impact on compartment conditions during the initial blowdown phase of the LOCA, primarily the gas temperature. The default value of FELOCA is 0, and the water from the break is added to the water pool in the receiving compartment. With higher values of FELOCA, the suspended water absorbs energy from the containment gas, resulting in lower gas temperatures. |
| FNOMIX                    | Flag to select mixing of water and steam flows from RCS to containment                                          | LLOCAs                                        | Containment conditions                    | Negligible impact on results for BWR LLOCAs with high and low pressure injection. (Significant impact observed for PWR LLOCA sensitivity study, which is discussed in Section 6.5.4 of this report.)                                                                                                                                                                                     |
| FCDBRK                    | Discharge coefficient for flows through primary system breaks, BWR generalized openings, and BWR vessel failure | LOCAs and sequences with generalized openings | Primary system and containment conditions | See the discussion of LOCAs in Section 5.4.3. The effective area of the break, which is the product of the actual break area and FCDBRK, is a significant input parameter for LOCA sequences.                                                                                                                                                                                            |

## 5.6 Miscellaneous Information for BWR Applications

### 5.6.1 Primary System Response to ECCS Injection

ECCS injection into the primary system is essentially a perturbation that disrupts the quasi-steady equilibrium between the water, steam, noncondensable gas, and solid structures. It takes a nontrivial amount of time for the system to regain equilibrium after injection has stopped. In addition, because the amount of water that is injected is a function of the height of the water in the downcomer but not a function of an anticipated primary system pressure, from a thermodynamic standpoint a high level injection trip setpoint is essentially an arbitrary value. When the injection stops, the downcomer water level generally continues to rise as a result of expansion. (This increase in level can be on the order of a foot or more.) The departure from equilibrium and its impact on water level, primary system pressure, and subsequently the distribution of decay energy between the primary system and the containment can be counterintuitive, particularly when the injection cycles between high and low level setpoints (potentially HPCI, RCIC, and HPCS).

When comparisons are made between sequences with injection, consideration should be given to the time at which the comparisons are made. This is because conditions both in the primary system and in containment are influenced by the degree to which the primary system is out of equilibrium as a result of injection. For example, pool temperatures can differ between two cases by a relatively large difference at one point in time but be close at another point that is only slightly earlier or later, depending on the relative injection histories.

### 5.6.2 Decay Power Calculation

MAAP4 uses the ANSI/ANS decay heat correlation [9] to calculate the core power after a scram. Several input parameters in the *Primary System* section of the parameter file are used in the correlation: the fuel enrichment, core exposure, total effective irradiation time, and fission terms (the capture and absorption rates and the fission power fractions). Plant-specific values for the fission terms are generally difficult to obtain and have an inherent uncertainty; testing has shown that the calculated decay power is relatively insensitive to variations in these parameters, so the values listed in the sample parameter files are adequate for plant-specific parameter files. It is recommended that users select self-consistent, end-of-cycle values from the options provided in the sample files.

There is a tendency to compute the value of the total effective irradiation time, TIRRAD, using the length of a single cycle. Instead, it should be calculated based on how long each part of the core has been exposed. For example, if approximately one-third of the core is replaced each cycle (a three-batch core), and a cycle is approximately 2 years with a 1-month outage for refueling, at the end of a cycle the average irradiation time is 46 months ( $1/3 \times [23 + 46 + 69 \text{ months}]$ ).

GE has determined that the decay heat correlation under-predicts the decay power by a few percent [16], with the percentage increasing over the time since shutdown (3% at  $10^4$  s [2.78 hr], 6% at  $10^6$  s [278 hr]). The under-prediction is within the uncertainty of the calculated power that arises from uncertainties in the values of the input parameters used in the correlation. However, the option to apply the correction factor to the calculation will be added in a future version of MAAP4. If users want to increase the decay heat for longer sequences to address the under-prediction, this can be readily accomplished by specifying increasingly larger values for the initial core power, QCR0, as a function of time. The decay power is calculated by determining a fractional power using the correlation and then multiplying the fraction by the input initial power, so the input initial power is used repeatedly in the calculations rather than just at the beginning of a sequence.

Users can set the value of the decay power by using a very large value for the time delay between the reactor scram signal and the onset of scram, TDSCRM, and then assigning the desired power value to QCR0. This essentially bypasses the decay power correlation and is useful for applications such as shutdown cooling analyses.

### 5.6.3 Isolation Condenser Sequences

For plants with isolation condensers, users should consider the effect of small leaks, as might occur in a recirculation pump seal, in transient and loss-of-power sequences. The resultant loss of primary system inventory can impact the success of sequences that rely on the isolation condenser for long-term heat removal. The leak can be modeled as a small break (see Section 5.4.3).

### 5.6.4 Heat Capacity Temperature Limit Curve

Input file components can be created to flag when the pool temperature reaches or exceeds the heat capacity temperature limit (HCTL) and simulate the operator actions to manually depressurize the primary system if the limit is exceeded. The following is an example of a lookup variable block that corresponds to the HCTL curve and operator actions to depressurize using three SRVs when the pool temperature exceeds the limit.

```
** <<<<<<<<< Heat Capacity Limit Curve Logic >>>>>>>>>
```

```
C Reference: EOP - RPV CONTROL
```

```
LOOKUP VARIABLE THCTL
```

```
PPS PSI    THCTL F
```

```
1114.7     115.
```

```
914.7      120.
```

```
714.7      130.
```

```
414.7      142.
```

```
214.7      155.
```

```
104.7      172.
```

```
103.7      200.
```

```
END
```

```
C Depressurize with 3 SRVs when the pool exceeds the HCTL curve
```

```
WHEN TWRB(4) > THCTL
```

```
IMANON(1) = 1
```

```
IMANON(2) = 1
```

```
IMANON(3) = 1
```

```
END
```



# 6

## PWR APPLICATIONS GUIDANCE

---

### 6.1 Introduction

This section offers specific guidance on how to apply MAAP4 to Level 1 PRA analyses for PWRs. It is intended to provide insights and practical information so that users can optimize their efforts and generate high-quality analyses. The guidance provides information on plant features, phenomena, and code logic that are important for Level 1 applications. However, it is not intended to be comprehensive; insights and perspectives gained from this section can be extended to other aspects of MAAP4 Level 1 analysis.

The content of this section is supplemented by Appendix C, which addresses the MAAP4 modeling of individual PWR systems. **It is strongly recommended that users review the detailed information in the appendix prior to performing analyses to ensure that they are familiar with the system logic and options in the PWR code.**

The information presented here is consistent with Rev. 4.0.6 of the code, with some augmentation stemming from Rev. 4.0.7.

#### 6.1.1 Style

In this section, input parameters and calculated variables are capitalized, and their definitions are listed in Table 6-1. The code uses event codes to control high-level logic during an accident simulation. The three types of events—automatic, external, and user-defined—are defined in Section 3.1.1.3, and the PWR-specific events are discussed in Appendix C. They are referred to here by their numbers, by their message strings, or by the variable IEVNT(*i*), where *i* is their particular number.

#### 6.1.2 Sequences Used to Support the Guidance

To investigate and demonstrate the progression of Level 1 sequences, a set of seven parameter files was used. The set included the three PWR sample parameter files, which represent WLD and WICE plants with U-tube steam generators and B&W plants with OTSGs, and four plant-specific parameter files. The test sequences were run with the Rev. 4.0.6 and Rev. 4.0.7 Windows executables that are distributed with the code on a computer with the Windows XP operating system.

**Table 6-1**  
**MAAP4 Input Parameters and Calculated Variables Used in Section 6**

| Name   | Type  | Definition                                                                                                                                      |
|--------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------|
| ABB    | Input | Broken loop break area (actual area, multiplied by FCDBRK in the code to obtain the effective area, total for all loops on the broken side)     |
| AFLWSG | Input | Cross-sectional area between the perimeter of the tube bundle and the tube bundle shroud (wrapper)                                              |
| AFWBB  | Input | Feedwater line break area (actual area, multiplied by FCDFWB in the code to obtain the effective area)                                          |
| AGOBHL | Input | HLCR area in the broken loop                                                                                                                    |
| AGOUHL | Input | HLCR area in the unbroken loop                                                                                                                  |
| AMSLB  | Input | Effective flow area for a MSLB (per steam generator); this area is added to the PORV and safety valve flow areas                                |
| APZBK  | Input | Pressurizer or surge line break area (added in Rev. 4.0.7, actual area, multiplied by FCDPZBK in the code to obtain the effective area)         |
| ASB    | Input | Primary side LOCA break area for a SGTR (actual area, multiplied by FCDBRK in the code to obtain the effective area)                            |
| ASBO   | Input | Primary side LOCA break area for a SGTR assigned to ASB (added in Rev. 4.0.7)                                                                   |
| ASGDC  | Input | Cross-sectional area of the lower portion of the steam generator downcomer                                                                      |
| AUB    | Input | Unbroken loop break area (actual area, multiplied by FCDBRK in the code to obtain the effective area, total for all loops on the unbroken side) |
| AUPDC  | Input | Cross-sectional area of the upper downcomer in U-tube steam generators for the two-region model                                                 |
| CBB    | Input | Multiplier to determine the effective radius of the broken loop break for calculating the void fraction of the break flow                       |
| CUB    | Input | Multiplier to calculate the effective radius of the unbroken loop break for calculating the void fraction of the break flow                     |
| FARVBX | Input | Scaling factors applied to the total computed flow area of the PORVs in the broken steam generator                                              |
| FARVUX | Input | Scaling factors applied to the total computed flow area of the PORVs in the unbroken steam generators                                           |
| FBB    | Input | Broken loop break location                                                                                                                      |
| FCDBRK | Input | Discharge coefficient for broken and unbroken loop breaks and a SGTR                                                                            |
| FCDDC  | Input | Maximum fraction of perfect condensation on the free surface of the water in the cold leg                                                       |
| FCDFWB | Input | Discharge coefficient for a feedwater line break                                                                                                |

**Table 6-1 (continued)**  
**MAAP4 Input Parameters and Calculated Variables Used in Section 6**

| Name                            | Type       | Definition                                                                                                                          |
|---------------------------------|------------|-------------------------------------------------------------------------------------------------------------------------------------|
| FCDPZBK                         | Input      | Discharge coefficient for pressurizer or surge line break (added in Rev. 4.0.7)                                                     |
| FCRPBH and FCRPBHL              | Calculated | Creep damage fraction in the upper and lower portions of the broken loop hot legs                                                   |
| FCRPUH and FCRPUHL              | Calculated | Creep damage fraction in the upper and lower portions of the unbroken loop hot legs                                                 |
| FELOCA                          | Input      | Fraction of water break flow entrained as suspended water in containment                                                            |
| FERSGT                          | Input      | Ratio of the steam generator tube thickness to its original thickness                                                               |
| FHXPx                           | Input      | Heat exchanger selection flag for generalized ESF pump set x                                                                        |
| FHXRH                           | Input      | RHR heat exchanger selection flag for the hardwired ESF model                                                                       |
| FHXSP                           | Input      | Containment spray heat exchanger selection flag for the hardwired ESF model                                                         |
| FMSLB                           | Input      | Break configuration flag for a MSLB                                                                                                 |
| FNOMIX                          | Input      | Flag to select mixing of water and steam flows from RCS to containment                                                              |
| FQHF vs. TIFQHF array and NFQHF | Input      | Fraction of full power as a function of time if the user-specified decay power option is selected                                   |
| FQINHF                          | Input      | Flag to select the option for the user-specified decay power calculation                                                            |
| FUB                             | Input      | Unbroken loop break location                                                                                                        |
| HALFLP                          | Input      | Flag to indicate that a sequence is simulating mid-loop (half-loop) operation                                                       |
| HTSTAG                          | Input      | Natural circulation steam generator primary side heat transfer coefficient                                                          |
| IDISCH                          | Input      | Flag to select the option for the discharge location of the primary system injection systems if the hardwired ESF model is selected |
| IDOMEHOT                        | Input      | Specifies if the water in the vessel dome is closer to the hot-side or cold-side temperature (added in Rev. 4.0.7)                  |
| IHLMAT                          | Input      | Hot leg material identifier                                                                                                         |
| IMANON( <i>i</i> )              | Input      | Flag to manually open valve <i>i</i>                                                                                                |
| IRECIR                          | Input      | Specifies the ESF pump lineup in the recirculation model for the hardwired ESF model                                                |
| ISG2R                           | Input      | Flag to select the steam generator model                                                                                            |
| JNASMP                          | Input      | Containment node containing the secondary (annular) containment sump                                                                |

**Table 6-1 (continued)**  
**MAAP4 Input Parameters and Calculated Variables Used in Section 6**

| Name             | Type       | Definition                                                                                                                                                                                                 |
|------------------|------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| JNBB             | Input      | Pointer identifying the compartment receiving the broken loop break effluent                                                                                                                               |
| JNCSP            | Input      | Containment node containing the containment sump                                                                                                                                                           |
| JNMSLB           | Input      | Pointer identifying the compartment receiving the MSLB effluent                                                                                                                                            |
| JNUB             | Input      | Pointer identifying the compartment receiving the unbroken loop break effluent                                                                                                                             |
| JNUCS            | Input      | Pointer identifying the compartment containing the RHR sprays and the upper compartment sprays                                                                                                             |
| MACUM            | Calculated | Total mass of water in the accumulators                                                                                                                                                                    |
| MHLTOT           | Input      | Mass of the hot leg                                                                                                                                                                                        |
| MWSG0            | Input      | Initial mass of water in each steam generator                                                                                                                                                              |
| NDxxx            | Input      | Flags to select the options for the discharge locations of the primary system injection systems in normal operation mode if the generalized ESF model is selected; xxx corresponds to the injection system |
| NHLBL            | Input      | Number of steam generators (actual loops) on the broken loop side                                                                                                                                          |
| NSB              | Input      | Break location identifier for a SGTR                                                                                                                                                                       |
| PBS              | Calculated | Pressure in the broken steam generator                                                                                                                                                                     |
| PPS              | Calculated | Primary system pressure                                                                                                                                                                                    |
| PPSH             | Input      | High primary system pressure setpoint for reactor trip                                                                                                                                                     |
| PPSL             | Input      | Low primary system pressure setpoint for reactor trip                                                                                                                                                      |
| PPZHT0           | Input      | Low primary system pressure to actuate pressurizer heaters                                                                                                                                                 |
| PPZSP0           | Input      | High primary system pressure to actuate pressurizer sprays                                                                                                                                                 |
| PRBHI            | Input      | High containment pressure setpoint for reactor trip (as of Rev. 4.0.7)                                                                                                                                     |
| PSGRV            | Input      | Opening pressure for all steam generator PORVs                                                                                                                                                             |
| PUS              | Calculated | Pressure in the unbroken steam generators                                                                                                                                                                  |
| QCR0             | Input      | Initial core power                                                                                                                                                                                         |
| QSGTOT           | Input      | Total heat transfer from the primary system fluid to the secondary side                                                                                                                                    |
| RDxxx            | Input      | Flags to select the options for the discharge locations of the primary system injection systems in recirculation mode if the generalized ESF model is selected; xxx corresponds to the injection system    |
| TCLN( <i>i</i> ) | Calculated | Temperature of the cladding in core node <i>i</i>                                                                                                                                                          |
| TCRHOT           | Calculated | Mass-averaged temperature of the hottest core node (averaged over the individual core material components within the node)                                                                                 |

**Table 6-1 (continued)**  
**MAAP4 Input Parameters and Calculated Variables Used in Section 6**

| Name                   | Type       | Definition                                                                                                                   |
|------------------------|------------|------------------------------------------------------------------------------------------------------------------------------|
| TDCORE                 | Input      | Maximum time step prior to vessel failure if less than TDMAX                                                                 |
| TDIFPS                 | Input      | High loop water temperature difference setpoint for reactor trip                                                             |
| TDMSIV                 | Input      | Time period over which the MSIVs close                                                                                       |
| TDPOWR                 | Input      | Time period over which the power ramps linearly from full power to decay power following the onset of reactor trip           |
| TDSCRM                 | Input      | Time delay between the reactor trip signal and the onset of the trip                                                         |
| TGCH( <i>j</i> )       | Calculated | Temperature of the gas exiting core channel <i>j</i>                                                                         |
| TGPS                   | Calculated | Temperature of the gas in the primary system                                                                                 |
| TIM                    | Calculated | Problem time                                                                                                                 |
| TIMD                   | Calculated | Problem time (equal to TIM; see Section 3.3.1.3 of this report)                                                              |
| TIRRAD                 | Input      | Total effective irradiation time for the core                                                                                |
| TU2N( <i>i</i> )       | Calculated | Temperature of the fuel in core node <i>i</i>                                                                                |
| TWCR                   | Calculated | Temperature of the water in the core                                                                                         |
| TWHPS                  | Calculated | Temperature of the water in the hot leg                                                                                      |
| TWLPS                  | Calculated | Temperature of the water in the cold leg                                                                                     |
| TWPS                   | Calculated | Average temperature of the water in the primary system                                                                       |
| VFCIRC                 | Input      | Void fraction below which the primary system inventory is a homogeneous two-phase mixture (deadband with VFSEP)              |
| VFCPMX                 | Input      | High primary system void setpoint for RCP trip                                                                               |
| VFPS                   | Calculated | Average primary system void fraction                                                                                         |
| VFSEP                  | Input      | Void fraction above which the primary system inventory is no longer a homogeneous two-phase mixture                          |
| VOFZSG vs. ZOFSG array | Input      | Volume as a function of height in the secondary side of the steam generators                                                 |
| WGBB                   | Calculated | Gas flow through a broken loop break                                                                                         |
| WGBST                  | Calculated | Total gas flow through the broken steam generator relief valves, safety valves, and the main steam line (includes MSLB flow) |
| WGFWBB                 | Calculated | Gas flow through a feedwater line break                                                                                      |

**Table 6-1 (continued)**  
**MAAP4 Input Parameters and Calculated Variables Used in Section 6**

| Name   | Type       | Definition                                                                                                                                                                         |
|--------|------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| WGPZBK | Calculated | Gas flow through a break in the pressurizer or surge line (added in Rev. 4.0.7)                                                                                                    |
| WGRV   | Calculated | Total gas flow through the pressurizer relief and safety valves                                                                                                                    |
| WGSB   | Calculated | Gas flow through a SGTR                                                                                                                                                            |
| WGUB   | Calculated | Gas flow through an unbroken loop break                                                                                                                                            |
| WGUST  | Calculated | Total gas flow through the unbroken steam generator relief valves, safety valves, and the main steam line (includes MSLB flow)                                                     |
| WSTBSB | Calculated | Steam flow through a MSLB if the break is only in the broken loop (FMSLB = 1)                                                                                                      |
| WSTUSB | Calculated | Steam flow through a MSLB if the break is in all loops (FMSLB = 2), such as in the piping common to all of the steam generators                                                    |
| WWBB   | Calculated | Water flow through a broken loop break                                                                                                                                             |
| WWBL   | Calculated | Flow rate of water through the broken loop                                                                                                                                         |
| WWBSB  | Calculated | Water flow through a MSLB if the break is only in the broken loop (FMSLB = 1)                                                                                                      |
| WWBST  | Calculated | Total water flow through the broken steam generator relief valves, safety valves, and the main steam line (includes MSLB flow)                                                     |
| WWFWBB | Calculated | Water flow through a feedwater line break                                                                                                                                          |
| WWFWBS | Calculated | Total feedwater (main or emergency) to the broken steam generators                                                                                                                 |
| WWFWUS | Calculated | Total feedwater (main or emergency) to the unbroken steam generators                                                                                                               |
| WWPZBK | Calculated | Water flow through a break in the pressurizer or surge line (added in Rev. 4.0.7)                                                                                                  |
| WWRV   | Calculated | Total water flow through the pressurizer relief valves and safety valves                                                                                                           |
| WWSB   | Calculated | Water flow through a SGTR                                                                                                                                                          |
| WWUB   | Calculated | Water flow through an unbroken loop break                                                                                                                                          |
| WWUL   | Calculated | Water flow through the unbroken loop                                                                                                                                               |
| WWUSB  | Calculated | Water flow through a MSLB if the break is in all loops (FMSLB = 2)                                                                                                                 |
| WWUST  | Calculated | Total water flow through the unbroken steam generator relief valves, safety valves, and the main steam line (includes MSLB flow) (available for input and output as of Rev. 4.0.7) |
| ZBB    | Input      | Broken loop break elevation above the bottom of the lower head                                                                                                                     |
| ZCRL   | Input      | Elevation of the bottom of active fuel relative to the bottom of the vessel                                                                                                        |
| ZCRU   | Input      | Elevation of the top of active fuel relative to the bottom of the vessel                                                                                                           |

**Table 6-1 (continued)**  
**MAAP4 Input Parameters and Calculated Variables Used in Section 6**

| Name   | Type       | Definition                                                                                                                                |
|--------|------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| ZNBB   | Input      | Height of a broken loop break above the floor of compartment JNBB                                                                         |
| ZNUB   | Input      | Height of an unbroken loop break above the floor of compartment JNUB                                                                      |
| ZPZHT  | Input      | Pressurizer heater low level trip (off) point referenced to the bottom of the pressurizer                                                 |
| ZPZSP  | Input      | Elevation of the pressurizer spray header above the bottom of the pressurizer                                                             |
| ZRISER | Input      | Elevation of the bottom of the risers (standpipes) in U-tube steam generators for the two-region model                                    |
| ZSB    | Input      | Break elevation of a SGTR above the top of the tubesheet                                                                                  |
| ZUB    | Input      | Unbroken loop break elevation above the bottom of the lower head                                                                          |
| ZUPDC  | Input      | Elevation corresponding the separation of the lower downcomer and the upper downcomer in U-tube steam generators for the two-region model |
| ZWBS   | Calculated | Collapsed water level in the broken steam generator downcomer                                                                             |
| ZWCPS  | Calculated | Collapsed water level in the primary system relative to the bottom of the vessel                                                          |
| ZWCTLB | Input      | Target collapsed water level in the broken steam generator downcomer for feedwater control                                                |
| ZWCTLU | Input      | Target collapsed water level in the unbroken steam generator downcomer for feedwater control                                              |
| ZWPZ   | Calculated | Pressurizer water level relative to the bottom of the pressurizer                                                                         |
| ZWPZ0  | Input      | Initial pressurizer water level relative to the bottom of the pressurizer                                                                 |
| ZWPZH  | Input      | High pressurizer water level setpoint for reactor trip relative to the bottom of the pressurizer                                          |
| ZWPZL  | Input      | Low pressurizer water level setpoint for reactor trip relative to the bottom of the pressurizer                                           |
| ZWRWST | Calculated | Water level in the RWST relative to the bottom of the tank                                                                                |
| ZWSG0  | Input      | Initial water level in the steam generator                                                                                                |
| ZWSGL  | Input      | Low steam generator water level setpoint for reactor trip relative to the steam generator tubesheet                                       |
| ZWUS   | Calculated | Collapsed water level in the unbroken steam generator downcomer                                                                           |
| ZWV    | Calculated | Boiled-up water level in the core relative to the bottom of the vessel                                                                    |

### 6.1.3 Presentation and Interpretation of Results

The sequence results in the tables in this section are provided for demonstration purposes only. They are not exhaustive and should not be used to represent specific plants. The values have been rounded; differences in the last significant figures between comparable results are not significant. For example, 11.4 minutes is reported as 11 minutes while 11.5 minutes is reported as 12 minutes.

The following points should be kept in mind when reviewing the results presented in this section and interpreting results generated by sequences used in applications. Guidance on how to interpret code results is also presented in Section 3.1.4.3.

- Differences in results of less than a few percent are generally considered to be within the code's computational resolution and within the required resolution for PRA applications.
- The significance of differences is essentially a function of the purpose of the particular analysis. Furthermore, the differences should be interpreted in light of the variations in the input, the inherent uncertainty in the phenomena, and so on.
- Thresholds in the calculations (for example, system actuation and trip points) can have significant effects on the progression of sequences.
- Interventions, actions, and results can lag by a time step because of the order of execution.

## 6.2 Determination of Core Damage

The predominant figure-of-merit for Level 1 PRA analyses is the onset of core damage. The code does not contain criteria for core damage; instead, users determine the criteria based on PRA reference information. Examples of criteria for PWR core damage included in the success criteria element of the ASME standard for PRAs [7] are 1) a collapsed liquid level below the top of active fuel for a prolonged period, 2) a core peak node temperature that is greater than 1478 K (2200°F) using a code with detailed core modeling, 3) a core peak temperature that is greater than 1255 K (1800°F) using a code with simplified core modeling (for example, a single-node lumped parameter), **or** 4) a core exit temperature greater than 922 K (1200°F) for 30 minutes using a code with simplified core modeling. The examples in the ASME standard are consistent with the general guidelines for the determination of core damage provided in the EPRI probabilistic safety assessment (PSA) applications guide [14]. In that report, suggested criteria are 1) a collapsed liquid below the top of active fuel, 2) a core peak nodal temperature greater than 1255 K (1800°F), 3) a core maximum fuel temperature approaching 1478 K (2200°F), **or** 4) a core exit thermocouple reading greater than 922 K (1200°F). The following subsections provide guidance on how to identify when criteria related to water level and core temperature are met.

The definition of *core damage* in the ASME standard is the “uncovery and heat-up of the reactor core to the point where prolonged clad oxidation and severe fuel damage involving a large fraction of the core is anticipated.” The definition in RG 1.200 is the same except that it elaborates on the large fraction of the core being “sufficient, if released from containment, to have the potential for causing offsite health effects.” Although the water level criterion of less



than the top of active fuel (TOAF) is almost always met well before the temperature criteria, the physical processes of oxidation and fission product release are directly tied to the core temperature—not to the water level. Based on the results of investigations discussed in Section 6.2.2, the criterion of the core peak nodal temperature exceeding 1255 K (1800°F) is sufficiently conservative with respect to significant oxidation and fission product release.

### 6.2.1 Water Level

When reviewing MAAP4 results to determine the predicted primary system water level relative to the top of the core, two calculated levels are of interest. The first is the collapsed water level of the primary system, ZWCPS. This level corresponds to the level interpreted from plant instrumentation and is usually the level used in the determination of core damage. The second is the boiled-up level of the core water pool, ZWV. When the boiled-up level falls below TOAF, event 49 is set to true. The time that this occurs is assigned to the entry “time of core uncover” in the figures-of-merit table at the end of the log file.

The following intervention condition can be added to input files to record the time when the collapsed water level first falls below TOAF. The time when the intervention condition is met will be written to the log file. The input parameter ZCRU is the elevation of the top of the active fuel relative to the bottom of the vessel.

```
WHEN ZWCPS < ZCRU
END
```

User-defined variables can be created to record the collapsed water level relative to TOAF by including the following functions in the input file:

```
FUNCTION XTAF_M = ZWCPS – ZCRU      // in meters

FUNCTION XTAF_IN = (ZWCPS – ZCRU) * 3.28 * 12    // in inches
```

XTAF\_M and XTAF\_IN can be included in the list of variables written to plottable output files (see Section 3 of this report).

### 6.2.2 Peak Core Temperature

The MAAP4 core model calculates the temperatures of the individual core components—fuel, cladding, control rods, and so on—on a nodal basis. It also calculates the mass-averaged temperature of the core material in each node, the *node temperature* (variable TNOD(*i*), where *i* is the core node). The mesh of the radial and axial core nodalization is moderate; it is not designed to be refined enough to calculate the temperatures of individual fuel assemblies, including the hottest fuel assembly. On the other hand, with standard values for the number of axial and radial nodes, one node represents approximately 1% of the active fuel.

The code automatically determines the maximum mass-averaged node temperature as a function of time. The variable representing this hottest node temperature is TCRHOT. Investigations using the sample WLD TMLB sequence with both Rev. 4.0.6 and Rev. 4.0.7 and with various core meshes show that the value of TCRHOT is within a few degrees of the hottest fuel

temperature and the hottest cladding temperature of any of the nodes (variables TU2N(i) and TCLN(i), respectively). Therefore, TCRHOT is representative of the individual component temperatures. The TMLB investigations also show that the difference in the time for the hottest node temperature to reach 1255 K (1800°F) and 1644 K (2500°F) is between 5 and 22 minutes (out of approximately 3 hours); the shorter time difference is associated with a smaller core mesh (approximately 50 active nodes), and the longer time difference is associated with a larger core mesh (several hundred active fuel nodes). The temperature predictions are more sensitive to the axial nodalization than the radial nodalization.

The gas temperature at the exit of each channel  $j$ , variable TGCH( $j$ ), and the cladding temperature in the corresponding top node are representative of the core exit temperature in each radial ring. The TMLB investigations show that the hottest core exit temperature, which is in the second to third ring, reaches the suggested damage criterion of 922 K (1200°F) approximately 15 to 22 minutes before TCRHOT reaches 1255 K (1800°F).

The oxidation of the cladding and the release of fission products from the fuel are also indicators of core damage. The investigations show that the hottest core node temperature and the hottest core exit temperature exceed 1644 K (2500°F) before either the fraction of the cladding that has oxidized or the fraction of the volatile fission products that is released from the fuel exceeds 5%.

Figure 6-1 shows the hottest core node and the core exit temperatures, the time that one-quarter of the core exceeds 1478 K (2200°F), and the fractions of oxidized cladding and volatile fission product release for a representative TMLB case.

#### 4.0.6 PWR TMLB, 13 Axial, 7 Radial

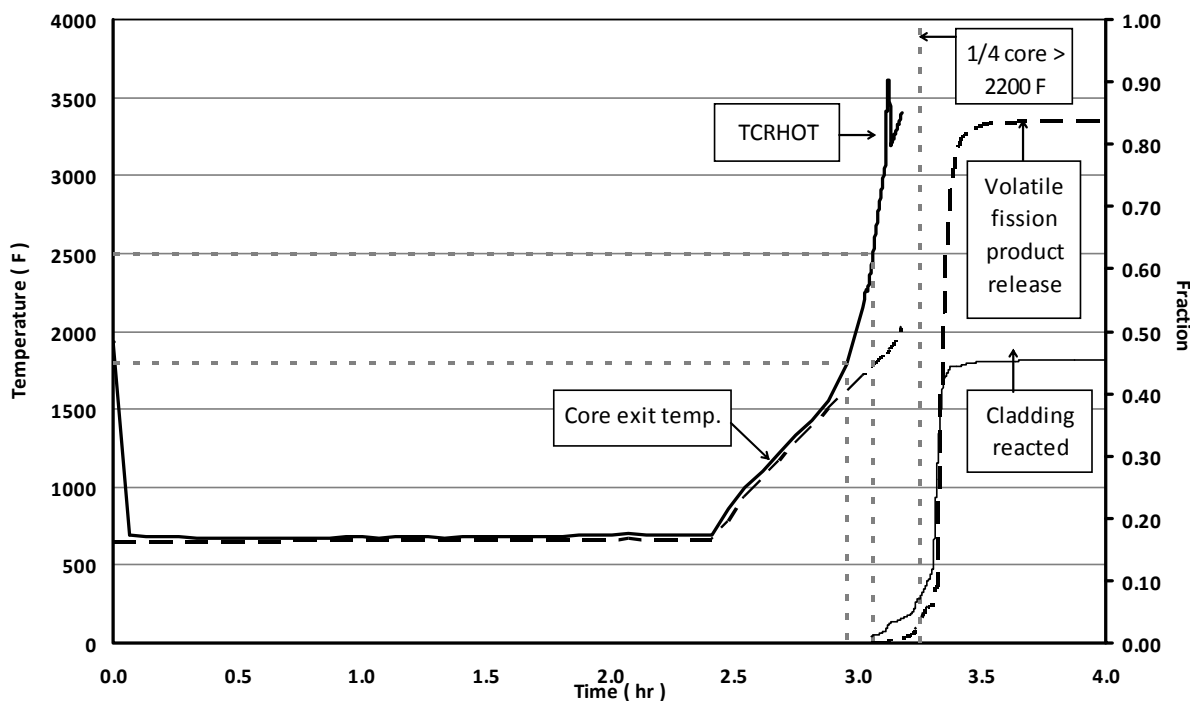


**Figure 6-1**  
**Core Damage Indicators for a Representative WLD TMLB**

The following intervention conditions can be added to input files to record the time at which one of the core damage temperature criteria is reached. The time will be written to the log file. Note that including the condition on time, TIMD, addresses the fact that a meaningful value of TCRHOT is not calculated until the end of the first time step.

```
WHEN TCRHOT > 1225 K AND TIMD > 10.0 S // in Kelvin
END
```

```
WHEN TCRHOT > 1800 F AND TIMD > 10.0 S // in Fahrenheit
END
```

Sequences with injection at the time that the core temperature is increasing might lead to short-term temperature spikes above the core damage criterion. Therefore, users may choose to use a time-at-temperature criterion. This can be done by adding the following components to the input files:

```
PARAMETER CHANGE
  T_CRIT_REACHED = 0
  TIMWATCH = 0
END
```

```
WHEN TCRHOT > 1800 F AND TIMWATCH < 1.0
  SET TIMER #1
  TIMWATCH = 1
  REPEAT
  SILENT
END
```

```
WHEN TCRHOT < 1800 F AND TIMWATCH > 0.5
  RESET TIMER #1
  TIMWATCH = 0.2
  REPEAT
  SILENT
END
```

```
WHEN TIMER #1 > 100 S // 100 s is used as an example
  T_CRIT_REACHED = 1
  TIMWATCH = 2
END
```

### 6.3 Code Logic Features for Initiating Events

Inherent in the MAAP4 code is logic that simulates the operational characteristics of primary system components. It is important for users to be aware of the default logic in the code and then adjust input parameters and/or add input components (for example, user-defined events and interventions) so that the logic is essentially modified to represent the actual plant. The following subsections discuss portions of the code logic that are particularly important for Level 1 analysis. Additional information regarding the logic associated with the modeling of PWR systems is included in Appendix C.

### 6.3.1 Reactor Trip Signal

A reactor trip (scram) signal is generated when one of the following occurs:

- **High primary system pressure:** The calculated pressure, PPS, rises above the value of input parameter PPSH.
- **Low primary system pressure:** The calculated pressure, PPS, falls below the value of input parameter PPSL.
- **High loop water temperature difference:** The temperature difference between the water in the hot and cold legs, TWHPS - TWLPS, exceeds the value of input parameter TDIFPS.
- **Low pressurizer water level:** The calculated collapsed water level in the pressurizer, ZWPZ, falls below the value of input parameter ZWPZL.
- **High pressurizer water level:** The calculated collapsed water level in the pressurizer, ZWPZ, rises above the value of input parameter ZWPZH.
- **AC power is lost:** External event 205, LOSS OF AC POWER, is set to true.
- **Reactor coolant pumps (RCPs) tripped off:** Internal event 4, MAIN COOLANT PUMPS OFF, has been set to true.
- **Charging pumps (CHPs) are on:** Internal event 11, CHARGING PUMPS ON, has been set to true and external event 257, DONT SCRAM WHEN CHARGING PUMP ON, is set to false.
- **Forced reactor trip:** External event 227, MANUAL SCRAM, is set to true.
- **Low steam generator water level:** The water level in either the broken or the unbroken loop steam generator, ZWBS or ZWUS, falls below the value of input parameter ZWSGL.
- **High containment pressure:** The containment pressure rises above the value of input parameter PRBHI (as of Rev. 4.0.7). The calculated containment pressure that is compared to the setpoint is either the pressure in the compartment containing the upper or RHR sprays (pointer JNUCS) or the third compartment if the spray pointer JNUCS is not set.

When one of the conditions to trip has been met, the core remains at full power for an additional time specified by input parameter TDSCRM, after which the power decreases to the decay power level over the period specified by input parameter TDPOWR.

### 6.3.2 Loss of Feedwater

Main feedwater (MFW) is tripped off when one of the following occurs:

- **Reactor trip:** Internal event 13, REACTOR SCRAM, has been set to true, unless overridden with external event 245, KEEP MAIN FEED ON AT SCRAM. This simulates the tripping of MFW by low primary system water temperature, which is not directly modeled in the code.
- **AC power is lost:** External event 205, LOSS OF AC POWER, is set to true.
- **Forced off:** External event 228, MAIN FW SHUT OFF, is set to true.

The code does not contain a model for the main feedwater supply, so feedwater is not limited by balance-of-plant conditions. The modeling of the time delay between the reactor trip and the tripping of MFW and the modeling of the coastdown of MFW are discussed in Appendix C. These can affect the amount of cold water pumped into the steam generators, which can have a significant impact on sequences.

### 6.3.3 MSIV Closure

The MSIVs on all steam generators will close when one of the following occurs:

- **Reactor trip:** Internal event 13, REACTOR SCRAM, has been set to true.
- **Forced closure:** External event 235, S/G MSIV: FORCED CLOSED, is set to true.

The MSIVs close over the time specified by input parameter TDMSIV, with a corresponding decrease in steam flow. (The area through the MSIVs decreases linearly; the decrease in the steam flow is a function of the area, the reduction in core power, and so on.)

### 6.3.4 RCP Trip

The RCPs are tripped off when one of the following occurs:

- **AC power is lost:** External event 205, LOSS OF AC POWER, is set to true.
- **High primary system void fraction:** The calculated average primary system void, VFPS, exceeds the value of input parameter VFPMX, which causes external event 215 to be set to true. This simulates a high vibration condition that can threaten the integrity of the pumps. There is no actual RCP trip based on the void fraction; the trip logic is included in the code to prevent the pumps from continuing to run at high void fraction, simulating the operators shutting off the pumps according to the plant's EOPs.
- **Forced off:** External event 215, MCP SWITCH OFF OR HI-VIBR TRIP, is set to true.

The code calculates the coastdown of the RCPs with a user-defined curve for flow as a function of time if they are tripped off by loss of AC power or if they are manually forced off. They will not coast down if they are tripped off by the high void fraction criterion; in this case, the pumped flow will be set to 0.0 immediately.

Users should include additional sequence-specific logic to trip the RCPs in order to simulate operator actions in the EOPs. Without this logic, code results might be impacted by inappropriately-extended RCP operation because the RCPs can add a significant amount of heat to the primary system while operating. One key operator action is the tripping of the pumps on low steam generator water level. The following is an example input file component that can be used to model this action. (Refer to Section 6.6.3 for more information on using steam generator water levels for operator actions.)

C 10% Narrow Range - Trip RCPs  
WHEN ZWUS < 29.3 FT OR ZWBS < 29.3 FT  
MCP SWITCH OFF OR HI-VIBR TRIP // event 215  
END

### **6.3.5 Primary System Pressure and Level Control Logic**

Pressurizer heaters and sprays maintain the primary system operating pressure. In the code, both systems are operating initially in an automatic mode provided that AC power is available and will function according to the logic described next.

Pressurizer sprays will operate if all of the following conditions are met:

- The flow rate of water in the unbroken loops (in the broken loop for a one-loop configuration), WWUL or WWBL, is non-zero. This requires the RCPs to be operating or coasting down.
- The collapsed water level in the pressurizer, ZWPZ, is below the elevation of the spray headers, input parameter ZPZSP.
- The pressurizer is saturated—not subcooled (internal event 38 is false).
- Either the operator has manually switched on the pressurizer sprays or the spray switch is in automatic mode and the pressure in the primary system is above the value of input parameter PPZSP0.

Pressurizer heaters will operate if all of the following conditions are met:

- The pressure in the primary system is below the value of input parameter PPZHT0.
- Collapsed water level in the pressurizer is above the value of input parameter ZPZHT.

Manually forcing off the sprays or heaters will override any of this logic for operation.

In addition, normal makeup and letdown are modeled and can be used as described in Appendix C.

### **6.3.6 Supply Power Logic**

The initial assumption in the MAAP4 code is that AC and DC power supplies are available. The majority of the systems modeled in the PWR code require AC power to operate. Only the pressurizer PORVs are able to operate using DC power. Systems having no power requirements to operate are the accumulators, turbine-driven AFW, the MSIVs, the pressurizer and steam generator safety valves, and containment air coolers.

The PWR code does not distinguish between offsite and onsite (emergency diesel generator) AC power. It is essentially assumed that all systems that need AC power are backed by emergency generators. Sequences in which only offsite AC is lost can be constructed by disabling just those systems that would not be powered with the emergency diesel generators, such as the RCPs.

A loss-of-AC-power condition at a plant will lead to tripping of MFW and the RCPs, which will result in a reactor trip. The normal response to this set of events would be to initiate AFW to maintain secondary side heat removal.

The power requirements for individual systems are presented in the system descriptions in Appendix C and listed in Table C-1.

## 6.4 General Considerations for Initiating Events

The user specifies the set of initiating events for each sequence. The initiating events modeled in MAAP4 include transients, loss of AC power, loss-of-coolant accidents (LOCAs), steam generator tube ruptures (SGTRs), main steam line breaks (MSLBs) and feedwater line breaks. The user can also specify contributing factors such as the failure of safety systems.

### 6.4.1 Transients

Transients are a general class of sequences that are characterized by a reactor trip (scram), a turbine trip, loss of main feedwater (LOFW), and loss of AC power. (Turbine trips are represented in MAAP4 by reactor trips.) Conditions that lead to these events are discussed in Sections 6.3.1 through 6.3.6 and in Appendix C. The progression of transients can be significantly affected by the plant control logic. These logic features are also discussed in those sections, and users should ensure that their input files contain the necessary components to adequately model the logic at their plants.

Among the most common transients are LOFW and the loss of AC power. LOFW events will result in initiation of motor-driven auxiliary feedwater (AFW). Low steam generator level will cause the reactor to trip. If AFW is unavailable, the event will rapidly progress to steam generator dryout and the demand on the operators to depressurize the primary system and start ECCS injection—referred to as *feed and bleed*—to prevent core damage. (Feed and bleed is discussed further in Section 6.6.4.)

The loss of AC power typically will involve cases with turbine-driven AFW available for a period of time defined by the plant's DC power capacity. In addition, an RCP seal LOCA is often assumed to occur at a defined time after the loss of AC power because of the loss of the capability to cool the seals.

During a transient, the following plant control features are of particular importance:

- **Steam generator inventory control:** MAAP4 assumes that the signal to initiate AFW is received upon loss of MFW. For a LOFW initiator, a low steam generator level will result in a reactor trip and closure of the MSIVs. Because MAAP4 does not model plant components downstream of the MSIVs, closure of the MSIVs simulates closure of the turbine stop valves and terminates any flow through the main steam line.

- **Steam generator pressure control:** MAAP4 includes models for both steam generator relief valves and spring-actuated safety valves. The relief valves can be used to *cool down* the secondary side, and thereby depressurize the primary side. Examples of input file components that simulate operator actions to cool down the secondary side are presented in Section 6.6.8.
- **Primary system pressure/inventory control:** If secondary side cooling becomes unavailable, the reactor coolant will heat up and begin to boil, resulting in steam and/or water discharge through the pressurizer PORVs. These valves discharge into the pressurizer relief (quench) tank and can be manually opened and closed by the operators. With a loss of secondary side heat removal, the EOPs will instruct the operators to begin feed and bleed actions using the available primary system injection and pressurizer PORVs.

PRA analysis requires the determination of success criteria and accident timing for a variety of transient scenarios. For sequences that involve successful operation of AFW, MAAP4 analyses can be used to determine the following:

- Number of AFW pumps required to maintain secondary side heat removal
- Number of steam generators receiving AFW flow
- Amount of AFW flow required
- Timing of CST depletion by AFW

After AFW is lost, the analysis is can be used to determine the times of steam generator dryout and core uncover.

A series of sequences was run with the three transient initiators and variations in the time of the RCP trip and the availability of AFW to characterize the predicted progression of transients and the impact of these two systems. All injection was assumed to be unavailable and there were no operator actions. The sequences were run with the sample four-loop WLD parameter file. Key figures-of-merit from these sequences are presented in Table 6-2. The following conclusions are drawn from the results:

- The sequences initiated with LOFW are the most conservative with respect to the core uncover time.
- The availability of AFW is a key factor in the progression of the sequences.
- The time of the RCP trip has an appreciable impact on the time of core uncover because of the energy added to the RCS by the pumps.



**Table 6-2**  
**Transients: Influence of Initiators, RCP Trip, and AFW<sup>a</sup>**

| Initiator                              | Reactor Trip <sup>b</sup> |                                 |                          |                                 |                                | LOFW <sup>e</sup>    |             |                                 | Loss of AC Power <sup>f</sup> |
|----------------------------------------|---------------------------|---------------------------------|--------------------------|---------------------------------|--------------------------------|----------------------|-------------|---------------------------------|-------------------------------|
|                                        |                           | RCP Trip at 10 min <sup>c</sup> | Loss of AFW <sup>d</sup> | Loss of AFW, RCP Trip at 10 min | Loss of AFW, RCP Trip at 0 min |                      | Loss of AFW | Loss of AFW, RCP Trip at 10 min |                               |
| Reactor trip                           | 0                         | 0                               | 0                        | 0                               | 0                              | 1.8 min <sup>g</sup> | 1.2 min     | 1.2 min                         | 0                             |
| CST depleted by AFW <sup>h</sup>       | 18.3 hr                   | 32.6 hr                         | No AFW                   | No AFW                          | No AFW                         | 16.9 hr              | No AFW      | No AFW                          | No AFW                        |
| RCPs tripped <sup>i</sup>              | 22.1 hr                   | 10 min                          | 1.6 hr                   | 10 min                          | 0                              | 21.0 hr              | 25 min      | 10 min                          | 0                             |
| Quench tank disk ruptured <sup>j</sup> | 21.6 hr                   | 39.2 hr                         | 1.2 hr                   | 1.6 hr                          | 1.6 hr                         | 3.2 hr               | 11 min      | 12 min                          | 1.7 hr                        |
| SG dryout <sup>k</sup>                 | 21.2 hr                   | 38.9 hr                         | 1.1 hr                   | 1.88 hr <sup>l</sup>            | 1.94 hr                        | 19.9 hr              | 10 min      | 10 min                          | 1.9 hr                        |
| Core uncovered                         | 22.6 hr                   | 41.1 hr                         | 1.8 hr                   | 2.3 hr                          | 2.4 hr                         | 21.5 hr              | 33 min      | 37 min                          | 2.4 hr                        |

<sup>a</sup> Sequences run with the Rev. 4.0.6 WLD sample parameter file. MFW tripped at time zero in all sequences. MSIV closure at time of reactor trip.

<sup>b</sup> Reactor trip initiated with external event 227. Main feedwater trip is coincident with reactor trip.

<sup>c</sup> RCP trip initiated with external event 215.

<sup>d</sup> Motor-driven AFW trip initiated with external event 224.

<sup>e</sup> LOFW initiated with external event 228.

<sup>f</sup> Loss of AC power initiated with external event 205.

<sup>g</sup> Reactor trip in LOFW cases caused by high primary system pressure.

<sup>h</sup> Internal event for CST depletion is 191.

<sup>i</sup> RCP trip on high void fraction or manually at either 0 or 10 minutes, as indicated; the 10-minute value is an estimate for the EOP step on low SG level. Internal event for RCP trip is 4.

<sup>j</sup> Quench tank disk rupture pressure is 6.89e5 Pa (100 psid). Internal event for quench tank disk rupture is 92.

<sup>k</sup> Internal events for steam generator dryout are 151 for the broken loop and 161 for the unbroken loop.

<sup>l</sup> Steam generator dryout occurs earlier in sequence with 10 minutes of RCP operation compared to RCP trip at time zero because of the heat addition from the pumps.

### 6.4.2 Loss of AC Power

The analysis of accident scenarios that involve the loss of AC power, either offsite or both offsite and onsite—that is, a *station blackout* (SBO)—is essentially an extension of the analysis of other transients. The logic in the PWR code does not distinguish between offsite and onsite (diesel-generated) AC power, and it is assumed that all systems that require AC power are diesel-backed. For this reason, if a user wishes to run a sequence in which only offsite AC is lost, it is necessary to manually disable those systems that are not diesel-backed instead of setting external event 205, LOSS OF AC POWER, to true, which will disable all AC-powered systems.

In MAAP4, the unavailability of AC power leads to a trip of the RCPs, which in turn results in a reactor trip. In addition, many of the plant's safety systems will be unavailable. Users should review the assumed supply power requirements for the various systems and make necessary adjustments using input parameters or logic components to ensure consistency between the models in the code and the plant's power requirements. The power requirements in the code are listed in Table C-1 in this report.

Of interest in the analysis of SBOs is the impact of systems that are passive, have a dedicated, independent power source, or are powered by DC batteries. These sequences should contain input file components that simulate changes in availability resulting from operator actions or the loss of the power sources. For example, turbine-driven AFW should be disabled when the batteries that control this system would have been drained. The following input file components simulate the loss of battery power after 4 hours, assuming that turbine-driven AFW is initiated at the beginning of the sequence coincident with the loss of MFW and motor-driven AFW:

```
WHEN TIMD > 4 HR
  UNBKN LOOP TURBINE DRIVEN AFW: NOT MAN ON
  BKN LOOP TURBINE DRIVEN AFW: NOT MAN ON
END
```

SBO scenarios typically involve RCP seal leakage because the cooling to the seals is not available. Typically, leakage rates are specified and break areas are determined by trial-and-error to match these rates. The standard practice is to define the leakage rates at normal operating conditions. See Section 6.4.3 for more information about including input file components to simulate seal leakage.

Table 6-3 shows the predicted progression of several SBO sequences with turbine-driven AFW available for a specified period of time. In addition to the loss-of-AC-power initiator, it is assumed that there is an RCP seal LOCA occurring 13 minutes into the event, with a leakage rate of  $1.32\text{e-}3 \text{ m}^3/\text{s}$  (21 gpm) per pump or  $5.30\text{e-}3 \text{ m}^3/\text{s}$  (84 gpm) total for the four-loop plant. The following observations are made from the results:

- Steam generator dryout occurs approximately 4 hours after loss of AFW
- Pressurizer safety valves begin to lift approximately 20 minutes after dryout
- Core uncover occurs approximately 30 minutes after the initial lifting of the pressurizer safety valves
- The onset of core damage occurs approximately 1 hour after core uncover

**Table 6-3**  
**Influence of AFW Operation Time in an SBO**

| Time of loss of AFW                                           | 4 hr   | 5 hr    | 6 hr    | 10 hr   |
|---------------------------------------------------------------|--------|---------|---------|---------|
| Steam generator dryout                                        | 8.1 hr | 9.2 hr  | 10.3 hr | 14.7 hr |
| Pressurizer PORVs open                                        | 8.4 hr | 9.6 hr  | 10.7 hr | 15.1 hr |
| Core uncovered                                                | 8.9 hr | 10.1 hr | 11.2 hr | 15.6 hr |
| Hottest core node temperature > 1255 K (1800°F) (core damage) | 9.8 hr | 11.0 hr | 12.2 hr | 16.8 hr |

### 6.4.3 Loss-of-Coolant Accident

LOCAs are initiated by opening a break in the primary system. Breaks are allowed in both the broken and unbroken loops. The location and geometry of the break are defined by a set of six input parameters for each loop; these parameters are listed in Table 6-4. (Breaks—ruptures—in steam generator tubes are discussed in Section 6.4.4. In addition, the capability to model breaks in the pressurizer was incorporated into Rev. 4.0.7.) The table also contains a cross-reference of the water pool associated with each break location. **It is important that users are aware that it is the downcomer water pool that is associated with breaks in the cold leg gas node, and injection into that pool is assumed to go into the vessel before it spills out of the break.** To model injection into the cold leg on the opposite side of a cold leg break such that the water will spill out of the break rather than fill up the downcomer, the injection should be directed to the intermediate leg water pool. The fraction of the injected water that goes out of the break before it is heated in the vessel can influence the progression of a sequence. It is recommended that users investigate the sensitivity of their results to the injection location for cold leg break sequences. See Section 6.6.1 and the PRISYS subroutine description in Volume II of the MAAP4 User's Manual for additional information regarding the correspondence of primary system gas nodes and water pools.

The break(s) is (are) opened by setting external event 209, PS BREAK(S) FAILED, to true. The calculated water and gas flows through the broken loop break are variables WWBB and WGBB, respectively, and the calculated water and gas flows through the unbroken loop break are variables WWUB and WGUB, respectively.

The area parameters ABB and AUB are the total break areas for the broken and unbroken loops, respectively. For plants with more than two loops, the broken and/or unbroken loops in the code represent two or more actual loops depending on the value of input parameter NHLBL, which is the number of actual loops (steam generators) on the broken side. If there is more than one break in a loop, the value of ABB or AUB should be the total for all of the breaks. For example, for sequences in which all of the RCP seals are assumed to leak and there is one loop on the broken side, the value of ABB should be set to the leakage area for one pump, and the value of AUB should be set to the leakage area for the remaining pumps. For a four-loop Westinghouse plant with seal LOCAs, the value of AUB would be three times the value of ABB.

**Table 6-4**  
**Primary System Break Input Parameters**

| Loop     | Primary System Location <sup>a</sup> |                                                                                |                           | Break Area <sup>b</sup> | Receiving Compartment Pointer | Break Elevations   |                   | Geometry Multiplier <sup>c</sup> |
|----------|--------------------------------------|--------------------------------------------------------------------------------|---------------------------|-------------------------|-------------------------------|--------------------|-------------------|----------------------------------|
|          | Break Location                       | Gas Volume (Node)                                                              | Water Pool                |                         |                               | Relative to Vessel | Relative to Floor |                                  |
| Broken   | FBB = 3                              | Broken hot leg                                                                 | Core                      | ABB                     | JNBB                          | ZBB                | ZNBB              | CBB                              |
|          | FBB = 4<br>(B&Ws only)               | Broken hot leg "tube"<br>( <i>candy cane</i> )                                 | Core                      |                         |                               |                    |                   |                                  |
|          | FBB = 6                              | Broken intermediate (cross-over) leg<br>(between cold side of SG and RCP)      | Broken intermediate leg   |                         |                               |                    |                   |                                  |
|          | FBB = 7                              | Broken cold leg (horizontal portion<br>between vessel and RCP outlet)          | Downcomer                 |                         |                               |                    |                   |                                  |
|          | FBB = 8                              | Downcomer (includes the lower<br>head)                                         | Downcomer                 |                         |                               |                    |                   |                                  |
| Unbroken | FUB = 9                              | Unbroken hot leg                                                               | Core                      | AUB                     | JNUB                          | ZUB                | ZNUB              | CUB                              |
|          | FUB = 10<br>(B&Ws only)              | Unbroken hot leg "tube"<br>( <i>candy cane</i> )                               | Core                      |                         |                               |                    |                   |                                  |
|          | FUB = 12                             | Unbroken intermediate (cross-over)<br>leg (between cold side of SG and<br>RCP) | Unbroken intermediate leg |                         |                               |                    |                   |                                  |
|          | FUB = 13                             | Unbroken cold leg (horizontal portion<br>between vessel and RCP outlet)        | Downcomer                 |                         |                               |                    |                   |                                  |

<sup>a</sup> Value is the gas node number.

<sup>b</sup> Actual area, multiplied by discharge coefficient parameter FCDBRK to obtain the effective area.

<sup>c</sup> Multiplier to determine the effective radius of the break for calculating the void fraction of the break flow; accounts for the orientation of the break and the acceleration of fluid to the break. A value of 2.0 corresponds to a vertical break, and a value of 0.1 corresponds to a horizontal break.

In the flow calculations, an effective break area is used, which is the product of the values of ABB or AUB and input parameter FCDBRK. (The code uses stagnation conditions at the break location and the effective area to calculate the break flow; the model does not include the relatively minor effect of frictional pressure drops upstream of the break.) The break area should be the chokepoint—that is, the minimum area—in the path from the primary system to the containment. For example, if the break is in an injection line and there is a flow restrictor between the break and the injection discharge location, the area at the restriction should be used if it is smaller than the break itself.

#### 6.4.3.1 Break Sizes

Breaks are often classified as small, medium, and large. The distinction can be based strictly on the area of the break or it can be based on how quickly the primary system depressurizes through the break, which determines which injection systems can be used. Based on this functional approach, breaks can be categorized as follows:

- **Small break:** A small break is one that does not result in a pressure low enough to allow low pressure injection without some other means of depressurization. High pressure injection (HPI) and charging pumps (CHP) are typically adequate to maintain core cooling depending on the size of the break and the injection rate at the elevated primary system pressure. Typical break sizes for *small* are up to  $2.0\text{e-}3 \text{ m}^2$  ( $0.022 \text{ ft}^2$ ) or approximately 5 cm (2 in.) in diameter.
- **Medium break:** A medium break is one that initially relies on high pressure injection for core cooling. Long-term cooling is provided by the RHR system. These sequences might result in automatic initiation of containment sprays—quickly depleting the RWST—upon a high containment pressure signal. Typical break sizes for *medium* are from  $3.0\text{e-}3 \text{ m}^2$  to  $2.0\text{e-}2 \text{ m}^2$  ( $0.034 \text{ ft}^2$  to  $0.20 \text{ ft}^2$ ) or approximately 6 cm (2.5 in.) to 15 cm (6 in.) in diameter.
- **Large break:** A large break is one that depressurizes rapidly enough to allow low pressure injection. A high capacity system is necessary to maintain the water inventory. Primary system accumulators are typically required to provide the initial core makeup. Typical break sizes for *large* are from  $2.0\text{e-}2 \text{ m}^2$  to  $0.28 \text{ m}^2$  ( $0.20 \text{ ft}^2$  to  $3.1 \text{ ft}^2$ ) or approximately 15 cm to 60 cm (6 in. to 24 in.) in diameter.

There are situations in which the initial volumetric flow of water is used to communicate the size of a liquid break. For example, a small break representing leakage from an RCP seal may be defined as a 21 gpm break. The values of ABB and/or AUB and FCDBRK that yield the specified volumetric flow can be determined through an iterative process using the calculated water mass flow, WWBB and/or WWUB, and the specific volume of the cold leg or hot leg water. The following are example input file components that can be used to determine the break areas for desired volumetric break flow rates. The first portion specifies the break locations and initializes the flow areas. The second portion is a lookup table that determines the specific volume of the water based on the cold leg temperature in units of cubic feet per pound. A similar table can be constructed for the hot leg water specific volume by using TWHPS instead of TWLPS. The third portion converts the calculated mass flows into volumetric flows. The volumetric flows can be written to a plot file, and the areas can be adjusted through short trial-and-error runs to obtain the desired initial flows. This example is representative of RCP leakage

in a four-loop plant with one pump in the broken loop and three pumps in the unbroken loop; the area of the unbroken loop break is three times that of the broken loop break.

PARAMETER CHANGE

C LOCA in the broken loop: location and area

C FBB = 7 for cold leg, = 3 for hot leg

FBB = 7

ABB = 1.2E-04 FT\*\*2

C LOCA in the unbroken loop: location and area

C FUB = 13 for cold leg, = 9 for hot leg

FUB = 13

AUB = 3.6E-04 FT\*\*2

END

C Lookup table to determine specific volume of water in the cold leg

C based on temperature; ft\*\*3/lbm

LOOKUP VARIABLE VCLCALC

| TWLPS F | VCLCALC   |
|---------|-----------|
| 530     | 2.0794E-2 |
| 540     | 2.1057E-2 |
| 550     | 2.1338E-2 |
| 560     | 2.1641E-2 |
| 570     | 2.1968E-2 |
| 580     | 2.2324E-2 |
| 590     | 2.2716E-2 |
| 600     | 2.3150E-2 |
| 610     | 2.3638E-2 |
| 620     | 2.4194E-2 |

END

C Functions to determine break flow in GPM

C VCLCALC = specific volume of water from table

C WWBB, WWUB = break flow in KG/S within code

C KG/S \* 2.204 LB/KG \* VCLCALC FT\*\*3/LB \* 7.4805 GAL/FT^3 \* 60 S/MIN

FUNCTION

WWBGPM = WWBB \* 2.204 \* VCLCALC \* 7.4805 \* 60

WWUGPM = WWUB \* 2.204 \* VCLCALC \* 7.4805 \* 60

WWTGPM = WWBGPM + WWUGPM

END

Because the volumetric flow through a break will decrease due to depressurization of the primary system as a result of the break, there is not a constant relationship between the break area and the flow during a sequence. In the event that a constant flow break is required, a lookup table—that is, a lookup variable block—can be used to adjust ABB and/or AUB as a function of the primary system pressure. For seal LOCAs, the standard practice is to define the leakage rates at normal operating conditions, and the corresponding break area is the one that yields the desired leakage rate at time zero. A comparison of flows as a function of pressure and temperature through a failed seal calculated with a constant area model and with a detailed model shows that a constant area model such as that used in MAAP4 is adequate for seal LOCAs [17].

The area of a break can be changed during a sequence to represent such things as an increase in area resulting from the erosion of the ruptured structure or the addition of a parallel break path.

Users should assess the sensitivity of the MAAP4 results to the effective area of the break(s), either by adjusting the values of ABB and/or AUB or the value of FCDBRK. (Note that in the PWR code, FCDBRK is also used as the discharge coefficient for SGTRs.) The break location and elevation should also be adjusted to assess the impact of the water and steam properties of the break flow. Three other *Model* parameters that can have an impact on LOCA sequences are FCDDC, FELOCA, and FNOMIX. They are included in the list of parameters that potentially represent the greatest uncertainty (see Table 4-3 in this report) and are discussed in Section 6.5.

#### 6.4.3.2 Location of RCP Seal LOCAs

A potentially important item to note for RCP seal LOCAs is that the elevation of the break in the primary system should correspond to the elevation where fluid—water or steam—can enter the annular area of the pump shaft leading to the seals (the thermal barrier for the seals). This elevation is an important factor in the calculation of water versus steam flow through seal LOCAs, but it can be difficult to determine the elevation from standard plant drawings. The barrier leading to the seal can be on the order of 1 m (3 ft) above or below the centerline of the cold leg piping. Users should determine plant-specific elevations based on detailed pump configuration information for seal LOCA sequences. In addition, it is recommended that the break elevation be limited to the top of the horizontal portion of the cold leg because if the cold leg is filled with water, only water will flow out of the break.

#### 6.4.3.3 Example Sensitivity to LOCA Location and Size

To investigate the plant response to LOCAs, a series of cases was executed with the WLD sample parameter file and the following key parameter variations:

- FBB: break location
- ABB: break area in the broken loop

For this analysis, it was assumed that AFW is available but all ECCS injection systems except accumulators have failed. The results are summarized in Table 6-5. The core uncover time is a strong function of the break size and is less sensitive to break location.

**Table 6-5**  
**LOCA: Influence of Break Location and Size**

| Break Size and Location   | 0.015 ft <sup>2</sup> Cold Leg | 0.015 ft <sup>2</sup> Intermediate Leg | 0.015 ft <sup>2</sup> Hot Leg | 0.0015 ft <sup>2</sup> Cold Leg | 0.15 ft <sup>2</sup> Cold Leg |
|---------------------------|--------------------------------|----------------------------------------|-------------------------------|---------------------------------|-------------------------------|
| Location parameter FBB    | 7                              | 6                                      | 3                             | 7                               | 7                             |
| Water pool                | Downcomer                      | Intermediate leg                       | Core                          | Downcomer                       | Downcomer                     |
|                           |                                |                                        |                               |                                 |                               |
| Reactor trip <sup>a</sup> | 2.7 min                        | 2.7 min                                | 4.6 min                       | 46 min                          | 16 s                          |
| RCPs tripped <sup>b</sup> | 47 min                         | 47 min                                 | 49 min                        | 7.9 hr                          | 4.6 min                       |
| Accumulators              | Does not inject                | Does not inject                        | Does not inject               | Does not inject                 | Depleted at 45 min            |
| Core uncovered            | 2.05 hr                        | 2.04 hr                                | 1.72 hr                       | 20.8 hr                         | 1.48 hr                       |

<sup>a</sup> Reactor trip occurs because of low primary system pressure and results in loss of MFW, MSIV closure, and initiation of AFW.

<sup>b</sup> RCP trip occurs because of a high void fraction in the primary system.

#### 6.4.3.4 Break in the Pressurizer or Surge Line

The capability to model breaks in the pressurizer or surge line was added in Rev. 4.0.7. The required input parameters are provided in the sample parameter files. The break is opened by setting the break area, parameter APZBK, to a positive value. The effective break area is the product of APZBK and the discharge coefficient parameter FCDPZBK. The calculated water and gas flows through the pressurizer or surge line break are variables WWPZBK and WGPZBK, respectively.

#### 6.4.4 Steam Generator Tube Rupture

SGTRs are particularly important for Level 2 PRA investigations because they can result in fission product release directly to the environment. The primary system response to a SGTR scenario is similar to that for other SLOCA scenarios; however, users should be aware of several subtleties that affect the secondary side. Although depressurization (cooldown) using relief valves on the unfaulted steam generators can reduce the primary system pressure and thereby decrease the break flow through the ruptured tube, operation of the relief valves on the faulted steam generator can provide the direct release pathway. In addition, there is the potential for the faulted steam generator to be *overfilled* by primary system water entering through the rupture, which could lead to a stuck-open relief valve. This places particular emphasis on the need for the operators to depressurize the RCS to reduce the break flow.

A SGTR can be part of the definition of a sequence, such as an initiating event, or it can be an induced failure resulting from material creep of an overheated tube. The following parameters are used to define the location and geometry of a tube rupture in either case:



- NSB, the break location key:  
= 4: hot tube side of the tube bundle (option only for U-tube steam generators)  
= 5: cold tube side of the tube bundle
- ASB, the actual (versus effective) break area
- ZSB, the break elevation relative to the top of the tubesheet
- FCDBRK, the discharge coefficient

Setting external event 209, PS BREAK(S) FAILED, to true opens the rupture. (This is the same event that is used to open breaks in other nodes of the broken and unbroken loops.) The event can be set by the user, or it can be set by the code following the calculation of failure by creep, which is indicated by the setting of internal event 63, BROKEN SG TUBE RUPTURE, to true. The sample parameter files contain example user-defined events that open the rupture when event 63 is set to true; these can be incorporated into plant-specific parameter files using appropriate values for the break parameters. The calculated water and gas flows through the rupture are variables WWSB and WGSB, respectively. (As with LOCA breaks, the code uses stagnation conditions in the tube and the effective area to calculate the SGTR flow; the model does not include the relatively minor effect of frictional pressure drops upstream of the rupture.)

Note that for plants with more than one steam generator on the broken side—that is, parameter NHLBL is set to a value greater than 1—each steam generator will have the same break. The total break area will be NHLBL times ASB. (This is in contrast to breaks specified by parameters ABB and AUB, which are not multiplied by the number of steam generators or loops.)

See Sections 6.6.8 and 6.6.9 for additional information regarding steam generator cooldown and thermally-induced SGTRs.

#### **6.4.5 Interfacing System LOCA**

An ISLOCA is a sequence with a primary system break outside containment. It can result in fission product release directly to the environment. Furthermore, water lost through the break is not available for subsequent injection. An ISLOCA is initiated with the same input file components as a break into the containment except that pointer JNBB or JNUB is assigned to the appropriate auxiliary/reactor building node. Users should remember to include input file components to disable systems that are immediately affected by such a break (for example, inventory makeup using CHP if the break is associated with the volume control system). MAAP4 can be used to determine the conditions in the vicinity of equipment and instrumentation in the auxiliary/reactor building, and the sequences can be constructed to disable those systems that would be inaccessible or adversely affected by the resultant flooding, high temperatures, high humidity, and/or high radiation levels.

#### **6.4.6 Main Steam Line Break**

Typically, MSLBs are not important contributors to predicted core damage frequencies. The location and geometry of the break are defined by the following input parameters:

- AMSLB, the effective (versus actual) flow area for a MSLB per steam generator; this area is added to the steam generator PORV and safety valve areas
- FMSLB, break configuration flag for a main steam line break
  - = 0: no break
  - = 1: break in the broken loop
  - = 2: break in piping common to the broken and unbroken loops
- JNMSLB, the pointer that identifies the compartment that receives the effluent from the MSLB

The break is opened and the location determined by the input parameter FMSLB. The MSLB water and steam flows are WWBSB, WSTBSB, WWUSB, and WSTUSB for the broken and unbroken loops, respectively. The calculated water and gas flows through the MSLB are also included in the appropriate variables for the total water and gas flows from the steam generators, WWBST, WWUST, WGBST, and WGUST. (WWUST is available for input and output as of Rev. 4.0.7.)

Note that for plants with more than one steam generator on the broken side—that is, parameter NHLBL is set to a value greater than 1—each steam generator will have the same break. The total break area will be NHLBL times AMSLB. (This is in contrast to breaks specified by parameters ABB and AUB, which are not multiplied by the number of steam generators or loops.)

#### **6.4.7 Feedwater Line Break**

A feedwater line break can be simulated using the one-region steam generator model in Rev. 4.0.6; the capability has been added to the two-region model in Rev. 4.0.7. A feedwater line break is initiated by setting the value of the break area, parameter AFWBB, to a non-zero value. The effective break area is the product of AFWBB and the discharge coefficient parameter FCDFWB. The break area should be the chokepoint—that is, the minimum area—in the water path. The calculated water and gas flows through the break are WWFWBB and WGFWBB, respectively.

#### **6.4.8 Stuck-Open Pressurizer PORV**

An accident can be initiated by the inadvertent opening and sticking of a pressurizer PORV, but this has a significantly lower probability than other accident initiators. The control of PORVs, including the modeling of their failure by sticking open or sticking closed, is discussed in Appendix C of this report.

#### **6.4.9 Failure to Trip (ATWS)**

The failure of the reactor protection system to trip the reactor—that is, an ATWS condition—can be represented in the PWR code by specifying the power as a function of time instead of using the default decay heat correlation. This is accomplished by setting the input parameter FQINHF to 1 and supplying appropriate values for the power versus time array, parameters NFQHF,

FQHF, and TIFQHF. Unlike the BWR code, the PWR code does not contain a correlation for ATWS power, and neither code contains a neutronics model. Generally, an ATWS sequence has a higher degree of uncertainty associated with it than other sequences because of the coupled nature of the progression of the sequence and the core power. The core power is a complex function of the primary system pressure, water level, and water temperature.

## 6.5 Influence of *Model* Parameters for Level 1 Analysis

An essential element of PRA analysis is the characterization of uncertainties. As discussed in Section 4, this includes the assessment of the impact of adjustments to the input parameters that influence the physical and chemical process calculations, many of which are in the *Control* and *Model* sections of the parameter files. Recommendations for adjusting the parameters that potentially represent the greatest uncertainty are included in Table 4-3. Seven of the parameters that fall under this category relate to PWR Level 1 sequences. A series of sequences was run with variations in the values of these parameters using the WLD sample parameter file. The observed impacts are summarized in Table 6-6. This information is intended to provide insight into the influence of these parameters and should not be considered definitive for all sequences. The subsections that follow provide additional details that support the observations listed in Table 6-6.

**Table 6-6**  
**Observed Impact of *Model* Parameters for Level 1 Analyses**

| <i>Model</i> Parameter | Definition                                                                                                                   | Type of Level 1 Sequence                                                    | Area of Potential Impact                  | Observations                                                                                                                                                                                                                                                                                                                      |
|------------------------|------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------|-------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VFSEP                  | Void fraction above which the primary system inventory is no longer a homogeneous two-phase, circulating mixture             | All sequences                                                               | Primary system conditions                 | <b>Significant impact</b> on the sequence progression for S/MLOCAs due to direct (switch to stagnant, separated conditions) and indirect (effect on containment pressure leads to variation of spray activation) threshold effects. See Section 6.5.1 for further information.                                                    |
| VFCIRC                 | Void fraction below which the primary system inventory is a homogeneous two-phase, circulating mixture (deadband with VFSEP) | All sequences                                                               | Primary system conditions                 | <b>Negligible impact</b> but value to be adjusted so it is less than VFSEP.                                                                                                                                                                                                                                                       |
| FCDDC                  | Maximum fraction of perfect condensation on the free surface of the water in the cold leg                                    | Sequences with injection after circulation has stopped, particularly SLOCAs | Primary system conditions                 | <b>Minor impact</b> on the primary system water temperature. See Section 6.5.2 for further information.                                                                                                                                                                                                                           |
| FELOCA                 | Fraction of water break flow entrained as suspended water in containment                                                     | LOCAs                                                                       | Containment conditions                    | <b>Minor impact</b> on compartment conditions during the initial blowdown phase of the LOCA, primarily on the gas temperature. With higher values of FELOCA, the suspended water absorbs energy from the containment gas, resulting in lower gas temperatures and pressures. See Section 6.5.3 for further information.           |
| FNOMIX                 | Flag to select mixing of water and steam flows from RCS to containment                                                       | LLOCAs                                                                      | Containment conditions                    | <b>Moderate impact</b> on compartment conditions. Separated streams lead to significantly higher containment gas pressures and moderately higher gas temperatures, while mixed streams lead to moderately higher containment water pool temperatures, including the water in the sump. See Section 6.5.4 for further information. |
| FCDBRK                 | Discharge coefficient for flows through primary system breaks, including SGTRs                                               | LOCAs and SGTRs                                                             | Primary system and containment conditions | See the discussion of LOCAs in Section 6.4.3. The effective area of the break, which is the product of the actual break area and FCDBRK, is a significant input parameter for LOCA sequences.                                                                                                                                     |
| HTSTAG                 | Natural circulation steam generator primary side heat transfer coefficient                                                   | All sequences                                                               | Heat transfer to the steam generators     | <b>Significant impact</b> on sequence progression for MLOCAs due to indirect threshold effects (insignificant effect on containment pressure leads to variation of spray activation). See Section 6.5.5 for further information.                                                                                                  |

### 6.5.1 Sensitivity to Parameters VFSEP and VFCIRC

The value of VFSEP, the void fraction above which the primary system coolant inventory is no longer a homogeneous two-phase, circulating mixture, can significantly impact the progression of small and medium LOCAs. When the system void fraction, variable VFPS, exceeds VFSEP, it is assumed that the two-phase fluid can no longer be carried over the highest point in the reactor coolant system, and the phases then separate into a relatively stagnant, gas-over-water configuration. The thermal-hydraulic behavior of the primary system is highly dependent on whether the coolant is in a homogeneous, circulating state or in a separated, stagnant state. Therefore, the timing of the switch in the assumed state of the fluid can strongly influence the subsequent calculations. The modeling of the thermal-hydraulic progression of the RCS during an accident is outlined in Table 6-7.

The default value of VFSEP, 0.5, is consistent with experiments (as noted in the sample parameter files), but there is inherent uncertainty in the value. There is also uncertainty associated with the use of an abrupt change in the state of the fluid versus a more continuous change. (Calculating the change mechanistically would require substantially more complex modeling, including equations to account for the conservation of momentum so that the natural circulation flow rate and void fraction distribution could be determined.) Users are strongly encouraged to evaluate the sensitivity of their S/MLOCA results to the value of VFSEP.

If the primary system cooled below the steam generators (that is, the pressure in the primary system is less than the saturation pressure in the generators), it is less likely that the RCS would continue to be in a homogeneous, circulating state. Therefore, it is suggested that users trigger phase separation when the heat transfer to the steam generators, variable QSGTOT, reverses—becomes negative—with the following input file component:

```
C Trigger phase separation when the RCS is cooled below the SGs
WHEN QSGTOT < 0.0
  VFSEP = 0.1
  VFCIRC = 0.05 // adjust so it remains < VFSEP
END
```

A large series of LOCA cases was run to investigate and demonstrate the effects of the value of VFSEP, including the relative influence of this parameter compared to other variations in the sequence definition. The base sequence is the S2HF sample problem run with the WLD sample parameter file. This sequence is initiated with a break in the intermediate leg, and it does not include logic to transfer ESF suction to the containment sumps (recirculation mode). The variations in the sequences are as follows:

- Break diameter: variations from 3.8 to 19.6 cm (1.5 to 7.7 in.) (input parameter ABB)
- VFSEP: values from 0.2–0.8; default = 0.5, recommended range = 0.3–0.7
- VFCIRC, the void fraction below which the coolant switches back to a homogeneous, two-phase, circulating mixture; its value must be less than the value of VFSEP, and other thermal-hydraulic criteria must be met for the switch
- Reduce VFSEP to 0.1 to force the switch to separated, stagnant conditions when the heat transfer from the primary system to the steam generators becomes negative

- Number of ESF pumps: 90–118% of the sample values to simulate uncertainties in the delivered flow curves (input parameters NHPI, NCHP, and NLPI)
- HTSTAG, the steam generator primary side heat transfer coefficient used when the RCS is in natural circulation mode: values from 425 to 2500 W/m<sup>2</sup>-C
- Accumulator discharge: 100% and 75% of the sample accumulator line length (input parameter XLACUM); isothermal and isentropic expansion of the gas in the accumulators (input parameter NKPROCACUM)
- Reactor trip and RCP trip: either both trip at 60 s or trip as a result of meeting setpoints
- Code version: Rev. 4.0.7 (base cases) and Rev. 4.0.6

**Table 6-7**  
**RCS Thermal-Hydraulic Progression During an Accident**

| Phase                                                                                       | Circulation Condition                                               | Coolant State                                       | Flow Between Water Pools and Void Fractions                                                                                                                                           | Heat Transfer to SGs                                                                                                              |
|---------------------------------------------------------------------------------------------|---------------------------------------------------------------------|-----------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|
| Initial                                                                                     | Forced circulation by RCPs                                          | Homogeneous, all liquid                             | Flow adjusted so all pools have same void fraction                                                                                                                                    | Calculated using forced convection correlation                                                                                    |
| Steam formation                                                                             | Forced circulation by RCPs or by high gas velocities early in LLOCA | Homogeneous, 2-phase fluid                          | Flow adjusted so all pools have same void fraction                                                                                                                                    | Calculated using forced convection correlation                                                                                    |
| After RCP coastdown                                                                         | Natural circulation                                                 | Homogeneous, 2-phase fluid                          | Flow adjusted so all pools have same void fraction                                                                                                                                    | Based on input heat transfer coefficient, parameter HTSTAG <sup>a</sup>                                                           |
| <b>VFPS &gt; VFSEP<sup>b</sup></b>                                                          |                                                                     |                                                     |                                                                                                                                                                                       |                                                                                                                                   |
| Phases separated and water pools are coupled (water level above inlet/outlet nozzles)       | Stagnant <sup>c</sup>                                               | Phases separated into gas-over-liquid configuration | Flow between pools to maintain balanced water heads on hot and cold sides; one void fraction for the core and downcomer (includes lower plenum) nodes; other nodes are gas over water | Calculated mechanistically; tends to be dominated by condensation on primary side of tubes where there is water on secondary side |
| Phases are separated and water pools are uncoupled (water level below inlet/outlet nozzles) | Stagnant                                                            | Phases separated into gas-over-liquid configuration | No flow between pools; individual void fractions                                                                                                                                      | Calculated mechanistically                                                                                                        |

<sup>a</sup> Natural circulation flow rate not calculated, which is required for a mechanistic calculation of the heat transfer.

<sup>b</sup> Internal events 155 and 164 are set to true. (Note that the messages for internal events 15 and 17 in the sample parameter files are incorrect—they do not indicate the switch from homogeneous to separated phases. This will be corrected in a future revision of the code.)

<sup>c</sup> After the phases separate there can be reflux cooling—counter-current natural circulation flow of condensation from the tubes to the cold leg water and steam generated in the code—but this is not a global circulation path.

The key results of the investigation are summarized in Table 6-8. More detailed results for the 5 cm (2 in.) SLOCA and the 8 cm (3 in.) MLOCA are presented in Tables 6-9 and 6-10, respectively. Results for variations in HTSTAG are also discussed in Section 6.5.5. In the SLOCA sequences, there is threshold in the progression for a value of VFSEP between 0.5 and 0.6. Smaller values of VFSEP lead to a relatively early switch to separated, stagnant conditions (on the first rise in void fraction), which directly influences the RCS pressure. The pressure remains high, limiting the timing and rate of accumulator discharge and limiting the amount of ESF injection. The system ends up in a long-term, quasi-steady balance between the break discharge and the injection, with slow depletion of the RWST inventory and, subsequently, comparatively late core uncover and relocation to the lower plenum. For larger values of VFSEP, the void fraction rises and then falls without reaching VFSEP. Without the switch in conditions, the RCS pressure falls enough to allow the rapid discharge of the accumulators and higher rates of ESF injection. There is a positive feedback effect of lower pressure with increased injection. The depletion of the RWST is relatively quick, leading to significantly earlier core uncover and relocation. The shaded columns in Table 6-9 correspond to these cases. The threshold effect of VFSEP on the SLOCA core uncover and relocations times is shown in Figure 6-2. This figure also illustrates the effect of reducing VFSEP when the heat transfer is reversed; this recommended logic eliminates the threshold. The impact of values of VFSEP on either side of the threshold on the void fraction, the RCS pressure, the mass of water in the accumulators, and the mass of water in the RWST are shown in Figures 6-3 through 6-6. The plotted variables are VFPS, PPS, MACUM, and MRWST, respectively. (Note that the value of VFPS after the switch to separated phases is not used in the calculations.)

There is also a threshold effect in the progression of the MLOCA sequences, but at a higher value of VFSEP—between 0.6 and 0.7—and as result of a different condition (not a direct result of the RCS pressure). The higher values of VFSEP lead to slightly later times for the switch to stagnation conditions. The small difference in the RCS behavior leads to a slight increase in the mass and energy discharged through the break, which leads to a slight increase in the containment pressure. The containment pressure is near the high pressure setpoint for automatic activation of the upper compartment sprays. The sprays are activated in the higher VFSEP cases and not activated in the lower VFSEP cases. Therefore, the value of VFSEP leads to an *indirect* threshold. When the sprays are activated, the RWST inventory is depleted relatively early, resulting in significantly earlier core uncover and relocation than in the cases in which the spray setpoint is not reached. The shaded columns in Table 6-10 correspond to the cases with containment sprays.

**Table 6-8**  
**Relative Influence of Variations on LOCA Sequence Progression**<sup>a, b</sup>

| Break Diameter         | VFSEP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Reduce VFSEP on Negative Heat Transfer                                                                                       | Number of ESF Pumps                                                                                                                                                                     | HTSTAG                     | Rev. 4.0.6 Compared to Rev. 4.0.7                                                                                                                                              |
|------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 5.1 cm (2.0 in.) SLOCA | <p><b>Large impact:</b> Threshold between VFSEP values of 0.5 and 0.6; higher values lead to much later switch to stagnation, earlier accumulator discharge, and increased ESF injection. Earlier depletion of accumulators and RWST leads to earlier core uncover and relocation. See Table 6-9 and Figures 6-2 through 6-6.</p> <p>Similar impact for smaller breaks. Value of VFSEP for threshold decreases with decreasing break size; for example, threshold is between 0.3 and 0.4 for break diameter of 4.8 cm (1.875 in.).</p> | <p><b>Large impact:</b> Logic useful in eliminating threshold on VFSEP.</p>                                                  | <p><b>Large impact:</b> As significant as the impact of VFSEP. More injection can lead to later switch to stagnation and earlier core uncover and relocation.</p>                       | <p><b>Minor impact</b></p> | <p>Same dependence on VFSEP, but not as much impact in Rev. 4.0.6 because core relocation for the earlier stagnation cases is earlier in this revision than in Rev. 4.0.7.</p> |
| 7.6 cm (3.0 in.) MLOCA | <p><b>Large impact:</b> Threshold between VFSEP values of 0.6 and 0.7; higher values lead to slightly later switch to stagnation. This leads to activation of containment sprays, which are not activated with the earlier switch to stagnation. The containment sprays result in earlier depletion of the RWST (and the accumulators) and earlier core uncover and relocation. See Table 6-10 and Figure 6-2.</p>                                                                                                                     | <p><b>Minimal impact:</b> Timing of switch to stagnant conditions does not prevent activation of the containment sprays.</p> | <p><b>Moderate impact:</b> Does not affect threshold on spray actuation, but increased injection affects time of depletion of RWST, which then affects core uncover and relocation.</p> | <p><b>Minor impact</b></p> | <p>Threshold occurs at a slightly higher value of VFSEP in Rev. 4.0.6; higher value out of recommended range.</p>                                                              |



Table 6-8 (continued)

Relative Influence of Variations on LOCA Sequence Progression<sup>a, b</sup>

| Break Diameter          | VFSEP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Reduce VFSEP on Negative Heat Transfer                                                                                    | Number of ESF Pumps | HTSTAG                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Rev. 4.0.6 Compared to Rev. 4.0.7 |
|-------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------|---------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|
| 10.2 cm (4.0 in.) MLOCA | <b>Large impact:</b> Sequence is very sensitive to whether the high containment pressure setpoint for containment sprays is reached. The pressure just exceeds or falls short of the setpoint depending on slight variations in the initial progression. These variations are not monotonic with VFSEP and are more sensitive to the value of HTSTAG. Activation of the containment sprays results in earlier depletion of the RWST (and the accumulators) and earlier core uncover and relocation. | <b>No impact:</b> Switch to stagnant conditions is before or just after the time when the heat transfer becomes negative. | —                   | <b>Large impact:</b> Sequence is very sensitive to whether the high containment pressure setpoint for containment sprays is reached. The pressure just exceeds or falls short of the setpoint depending on slight variations in the initial progression. These variations are not monotonic with HTSTAG. Activation of the containment sprays results in earlier depletion of the RWST (and the accumulators) and earlier core uncover and relocation. See Table 6-11 and Figures 6-12 through 6-14. | —                                 |
| 15.2 cm (6.0 in.) LLOCA | <b>Minimal impact:</b> Switch to stagnant conditions occurs within a few hundred seconds for all values of VFSEP.                                                                                                                                                                                                                                                                                                                                                                                   | —                                                                                                                         | —                   | —                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | —                                 |

<sup>a</sup> Sequence results are not sensitive to variations in the timing of the reactor trip and RCP trip, the accumulator line length, and whether the accumulator expansion is isothermal or isentropic.

<sup>b</sup> The value of VFCIRC did not influence the sequences because the other thermal-hydraulic criteria required to switch back to a homogeneous two-phase, circulating mixture were not met.

**Table 6-9**  
**Influence of Parameter VFSEP on SLOCA Sequence Progression<sup>a</sup>**

| VFSEP                                                 | 0.3     | 0.4     | 0.5 <sup>b</sup> |                | 0.6     |                                                    | 0.7     |                                       |
|-------------------------------------------------------|---------|---------|------------------|----------------|---------|----------------------------------------------------|---------|---------------------------------------|
| Additional Variations to Parameter Values             | —       | —       | —                | 105% Injection | —       | VFSEP = 0.1 on Negative Heat Transfer <sup>c</sup> | —       | VFSEP = 0.1 on Negative Heat Transfer |
| Switch to separated, stagnant conditions <sup>d</sup> | 0.6 hr  | 0.9 hr  | 1.3 hr           | 8.3 hr         | 8.8 hr  | 1.6 hr                                             | 9.1 hr  | 1.6 hr                                |
| RWST depleted <sup>e</sup>                            | 9.6 hr  | 9.6 hr  | 9.7 hr           | 6.8 hr         | 7.2 hr  | 9.6 hr                                             | 7.2 hr  | 9.6 hr                                |
| Accumulators depleted <sup>f</sup>                    | 16.3 hr | 16.4 hr | 16.6 hr          | 5.8 hr         | 2.6 hr  | 16.5 hr                                            | 2.6 hr  | 16.5 hr                               |
| Core uncovered                                        | 10.8 hr | 10.8 hr | 11.8 hr          | 10.3 hr        | 10.3 hr | 11.7 hr                                            | 9.7 hr  | 11.7 hr                               |
| First relocation of core to lower plenum              | 18.1 hr | 18.9 hr | 18.3 hr          | 12.4 hr        | 12.4 hr | 18.2 hr                                            | 11.8 hr | 18.2 hr                               |

<sup>a</sup> Sequences run with the Rev. 4.0.7 WLD sample parameter file. Based on the S2HF sample input file, initiated with a 5 cm (2 in.) break in the intermediate leg.

<sup>b</sup> Default value.

<sup>c</sup> When the heat transfer to the steam generators becomes negative, variable QSGTOT, set VFSEP to 0.1 to cause phase separation and the switch to stagnant conditions.

<sup>d</sup> Void fraction, variable VFPS, exceeds VFSEP. Sets internal events 155 and 164.

<sup>e</sup> Internal event for RWST depletion is 187.

<sup>f</sup> Internal event for accumulator depletion is 188.

**Table 6-10**  
**Influence of Parameter VFSEP on MLOCA Sequence Progression<sup>a</sup>**

| VFSEP                                                 |                                                               | 0.3         | 0.4         | 0.5 <sup>b</sup> | 0.6         | 0.7          |                                                    |                |
|-------------------------------------------------------|---------------------------------------------------------------|-------------|-------------|------------------|-------------|--------------|----------------------------------------------------|----------------|
| Additional Variations to Sequence                     |                                                               | —           | —           | —                | —           | —            | VFSEP = 0.1 on Negative Heat Transfer <sup>c</sup> | Without Sprays |
| Switch to separated, stagnant conditions <sup>d</sup> |                                                               | 0.2 hr      | 0.3 hr      | 0.3 hr           | 0.4 hr      | 0.5 hr       | 0.7 hr                                             | 0.5 hr         |
| Sprays                                                | Time when sprays came on or setpoint not reached <sup>e</sup> | Not reached | Not reached | Not reached      | Not reached | On at 0.9 hr | On at 0.9 hr                                       | No sprays      |
|                                                       | Peak containment pressure if no sprays                        | 2.288e5 Pa  | 2.315e5 Pa  | 2.341e5 Pa       | 2.400e5 Pa  | 2.457e5 Pa   | 2.457e5 Pa                                         | 2.457e5 Pa     |
| RWST depleted <sup>f</sup>                            |                                                               | 7.6 hr      | 7.6 hr      | 7.6 hr           | 7.6 hr      | 2.4 hr       | 2.4 hr                                             | 7.6 hr         |
| Accumulators depleted <sup>g</sup>                    |                                                               | 11.1 hr     | 11.0 hr     | 11.0 hr          | 11.1 hr     | 5.3 hr       | 5.3 hr                                             | 10.9 hr        |
| Core uncovered                                        |                                                               | 10.3 hr     | 10.1 hr     | 10.1 hr          | 10.3 hr     | 3.3 hr       | 3.3 hr                                             | 9.9 hr         |
| First relocation of core to lower plenum              |                                                               | 12.6 hr     | 13.1 hr     | 12.8 hr          | 13.0 hr     | 6.8 hr       | 6.8 hr                                             | 13.0 hr        |

<sup>a</sup> Sequences run with the Rev. 4.0.7 WLD sample parameter file. Based on the S2HF sample input file, initiated with an 8 cm (3 in.) break in the intermediate leg.

<sup>b</sup> Default value.

<sup>c</sup> When the heat transfer to the steam generators becomes negative, variable QSGTOT, set VFSEP to 0.1 to cause phase separation and the switch to stagnant conditions.

<sup>d</sup> Void fraction, variable VFPS, exceeds VFSEP. Sets internal events 155 and 164.

<sup>e</sup> Upper compartment sprays initiated if the pressure in that compartment exceeds 2.45e5 Pa, parameter PSP0. Upper compartment spray flow variable is WSPTA.

<sup>f</sup> Internal event for RWST depletion is 187.

<sup>g</sup> Internal event for accumulator depletion is 188.

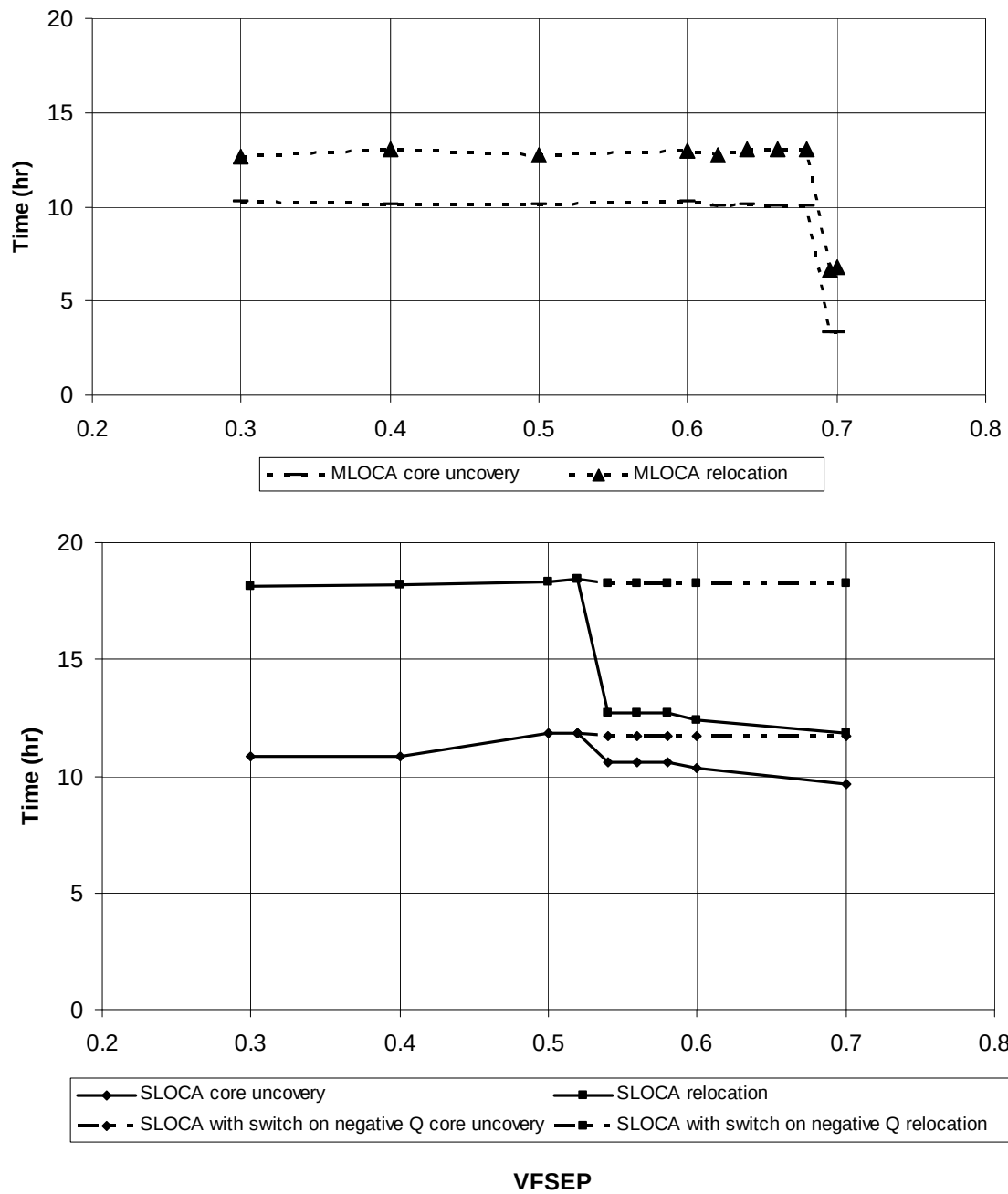


**Figure 6-2**  
**SLOCA and MLOCA Core Uncover and First Relocation as a Function of VFSEP**

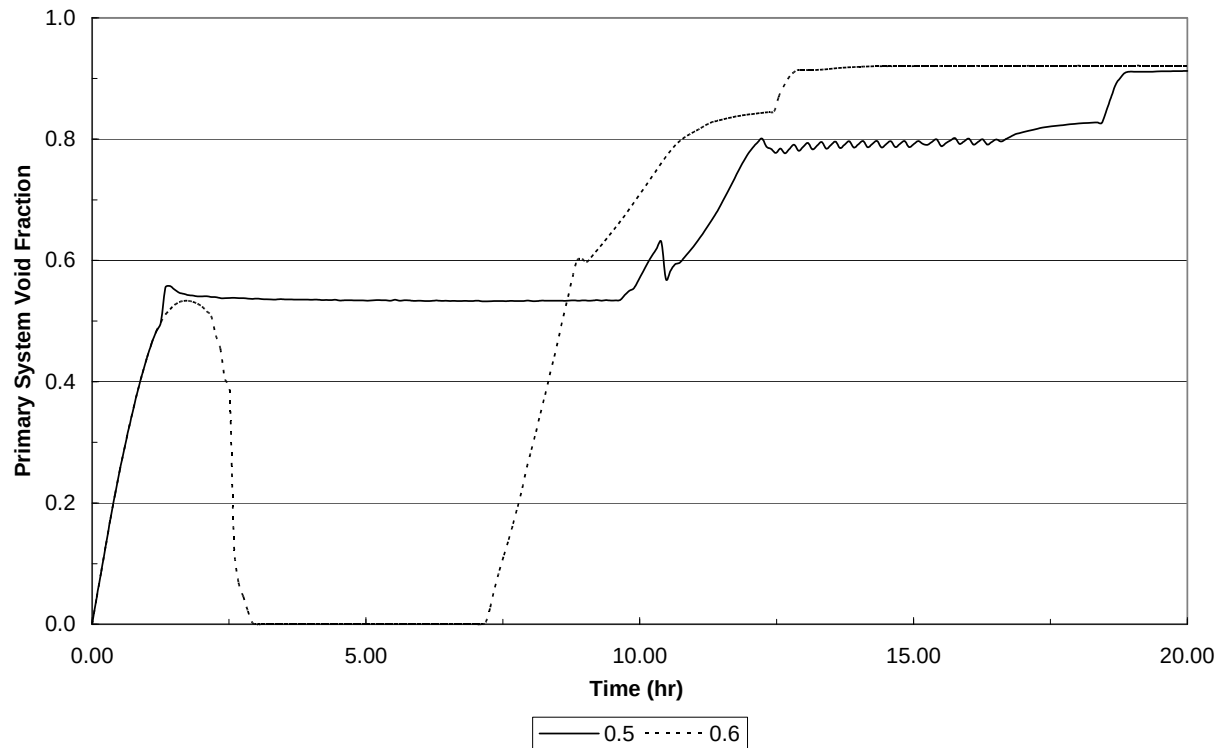


**Figure 6-3**  
SLOCA Primary System Void Fraction as a Function of VFSEP

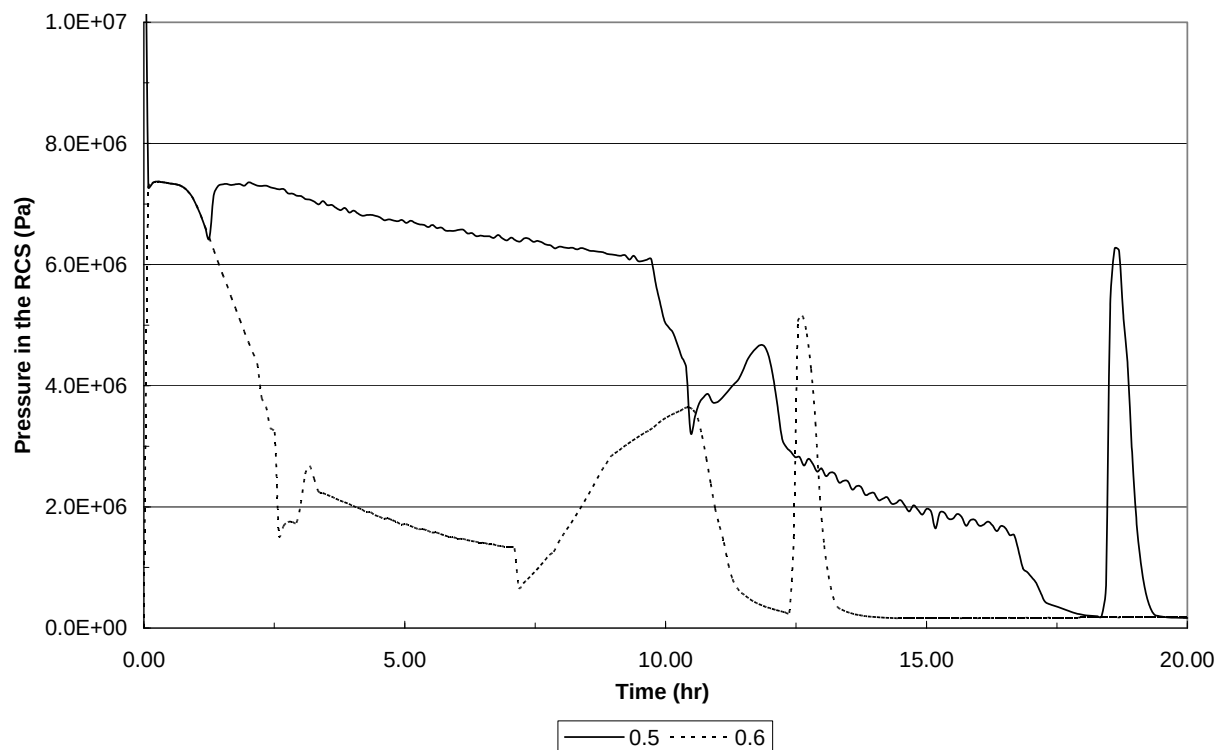


**Figure 6-4**  
SLOCA Pressure in the RCS as a Function of VFSEP

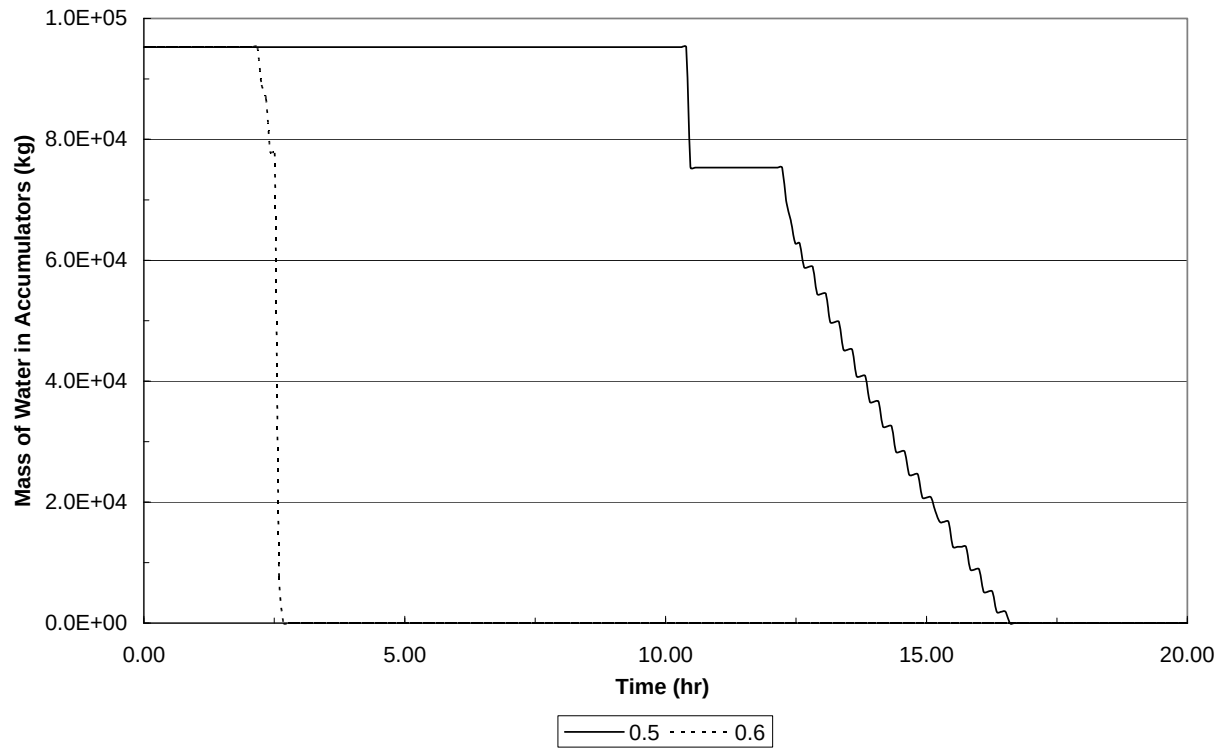


**Figure 6-5**  
SLOCA Mass of Water in the Accumulators as a Function of VFSEP

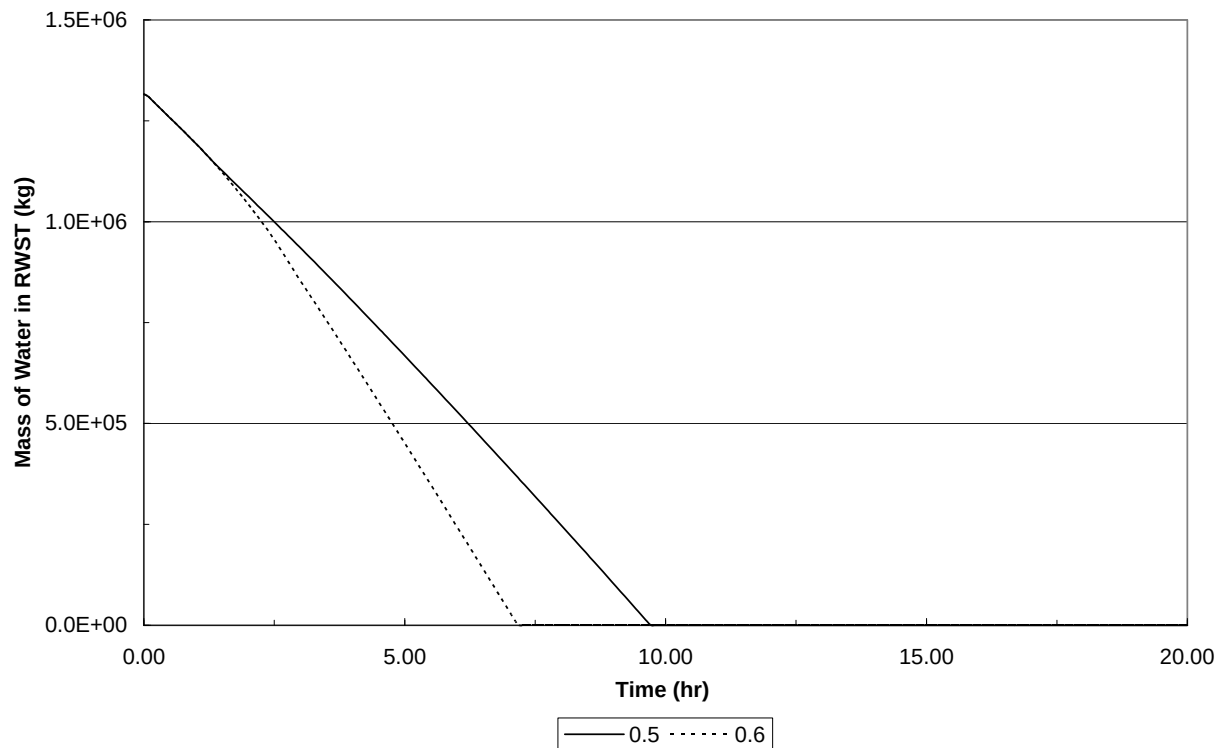


**Figure 6-6**  
SLOCA Mass of Water in the RWST as a Function of VFSEP

### 6.5.2 Sensitivity to Parameter FCDDC for an SLOCA

Two sets of SLOCA cases were executed to demonstrate the sensitivity to parameter FCDDC, the maximum fraction of perfect steam condensation on the free surface of the water in the horizontal portion of the cold leg. The cases included injection into the intermediate leg, and breaks in the intermediate leg and in the cold leg (downcomer water node), respectively. Depending on the injection flow rate, this parameter can affect the depressurization rate of the primary system. The default value of FCDDC is 1, which corresponds to the amount of condensation being the minimum of that computed by a simple Reynolds analogy and that which would saturate the film of water flowing through the horizontal portion of the cold leg. It is recommended that the sensitivity to smaller values of FCDDC be investigated when hydrogen is being generated because hydrogen reduces the potential for condensation. The two base SLOCA cases were run with FCDDC set to 1, and the sensitivity cases were run with a value of 0, which prevented the modeling of condensation. The impact of FCDDC on the downcomer water pool temperature for the cases with the break in the intermediate leg is shown in Figure 6-7. Allowing condensation led to a somewhat higher water temperature and a slightly earlier time to core uncover. The impact of FCDDC on the primary system pressure was relatively small. Similar results were observed for the cases with the break in the cold leg.

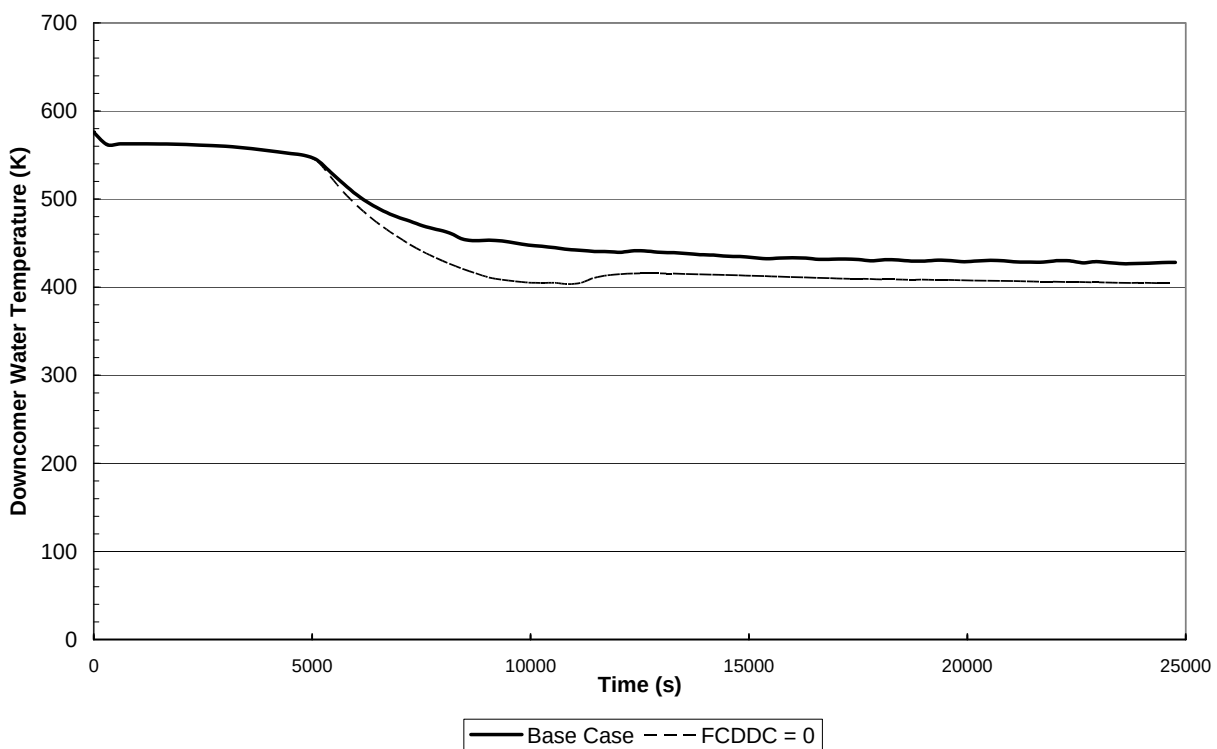


**Figure 6-7**  
**SLOCA Downcomer Water Temperature as a Function of FCDDC**

### 6.5.3 Sensitivity to Parameter FELOCA for an LLOCA

Three LLOCA cases with the break in the intermediate leg were executed to demonstrate the sensitivity to parameter FELOCA, the fraction of the water break flow that is entrained as suspended water into the containment atmosphere. In the base case, FELOCA is set to 0, so there is no entrainment of the break flow water—the water is directly added to the water pool in the receiving compartment. In the sensitivity cases, FELOCA is set to 0.5 and 1.0 so that 50% and 100% of the break flow water is entrained, respectively. The impact of these three values of FELOCA on the lower compartment temperature is shown in Figure 6-8. Entraining a fraction of the water leads to lower gas temperatures during the initial blowdown and when the injection water is depleted (approximately 2800 s). Entrainment also results in a slight decrease in the peak containment pressure at the beginning of the blowdown; the suspended water absorbs energy from the containment gas, resulting in lower gas temperatures and pressures.

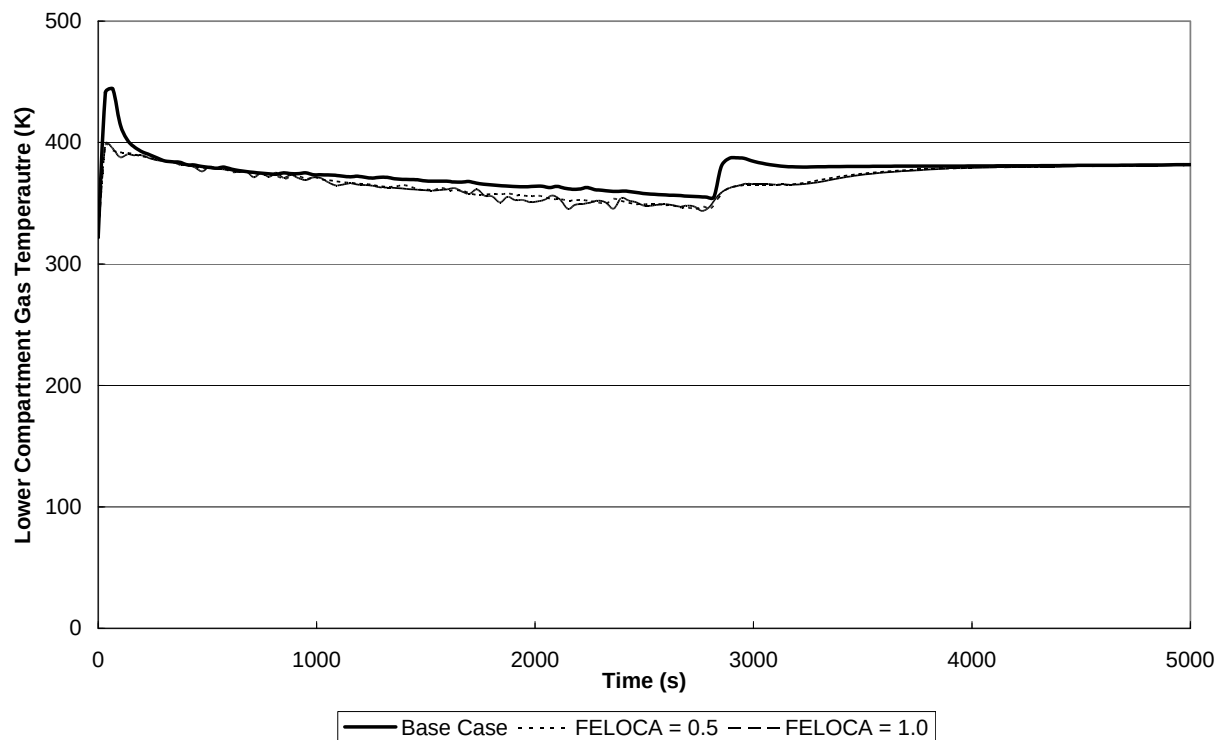


**Figure 6-8**  
LLOCA Lower Compartment Gas Temperature as a Function of FELOCA

### 6.5.4 Sensitivity to Parameter FNOMIX for an LLOCA

Two LLOCA cases with the break in the intermediate leg were executed to demonstrate the sensitivity to parameter FNOMIX, the flag that selects the option to mix the water and steam in the effluent from the RCS to the containment. The default selection is to calculate mixing—designated by a value of FNOMIX of 0—such that the water in the effluent stream can flash to steam based on the fluid enthalpy and the pressure in the containment. It is recommended that users investigate the sensitivity of LLOCA sequences to the assumption that the water and steam



are not mixed, selected by setting FNOMIX to 1. This is particularly appropriate for double-ended pipe breaks in which water would be discharged from one end of the pipe and steam would be discharged from the other end. Separated streams lead to higher containment gas pressures and temperatures, while mixed streams lead to higher containment water pool temperatures, including the water in the sump which could be used for injection. The influence of the value of FNOMIX on the containment atmosphere and the receiving compartment water pool is shown in Figures 6-9 through 6-11. The impact on the containment pressure is particularly strong.

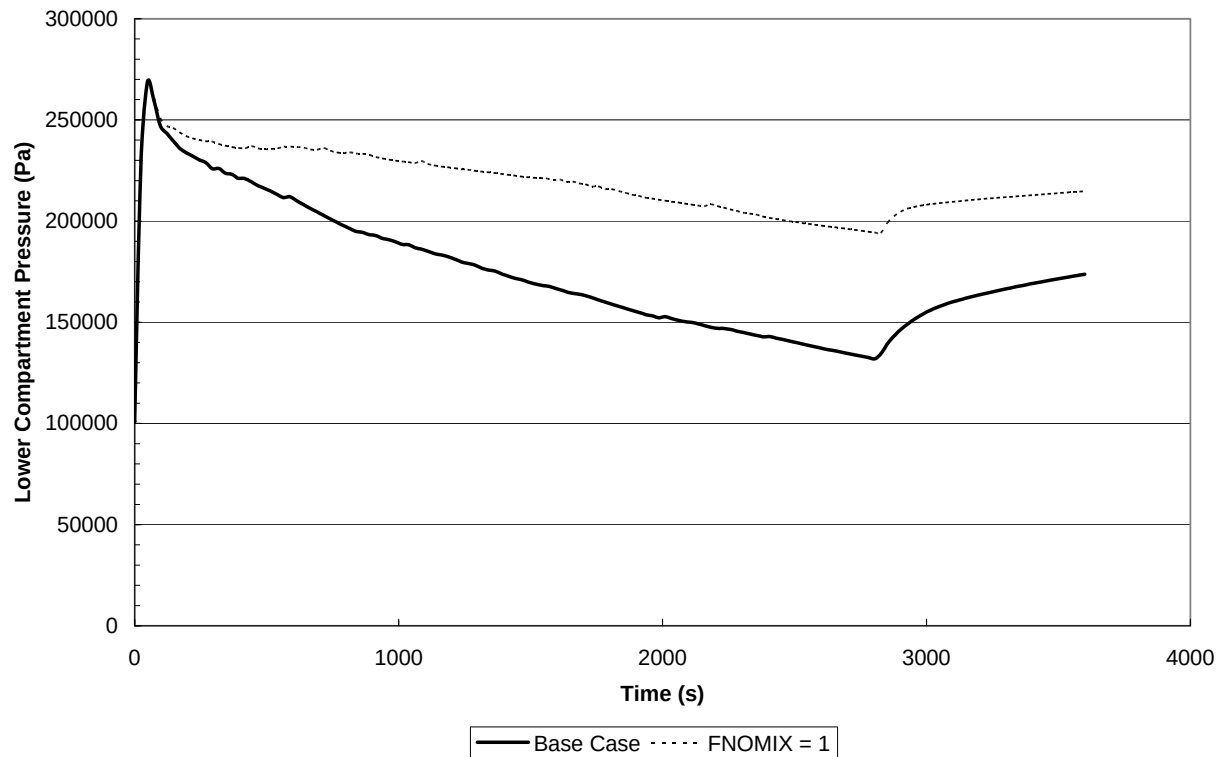


**Figure 6-9**  
**LLOCA Lower Compartment Gas Pressure as a Function of FNOMIX**

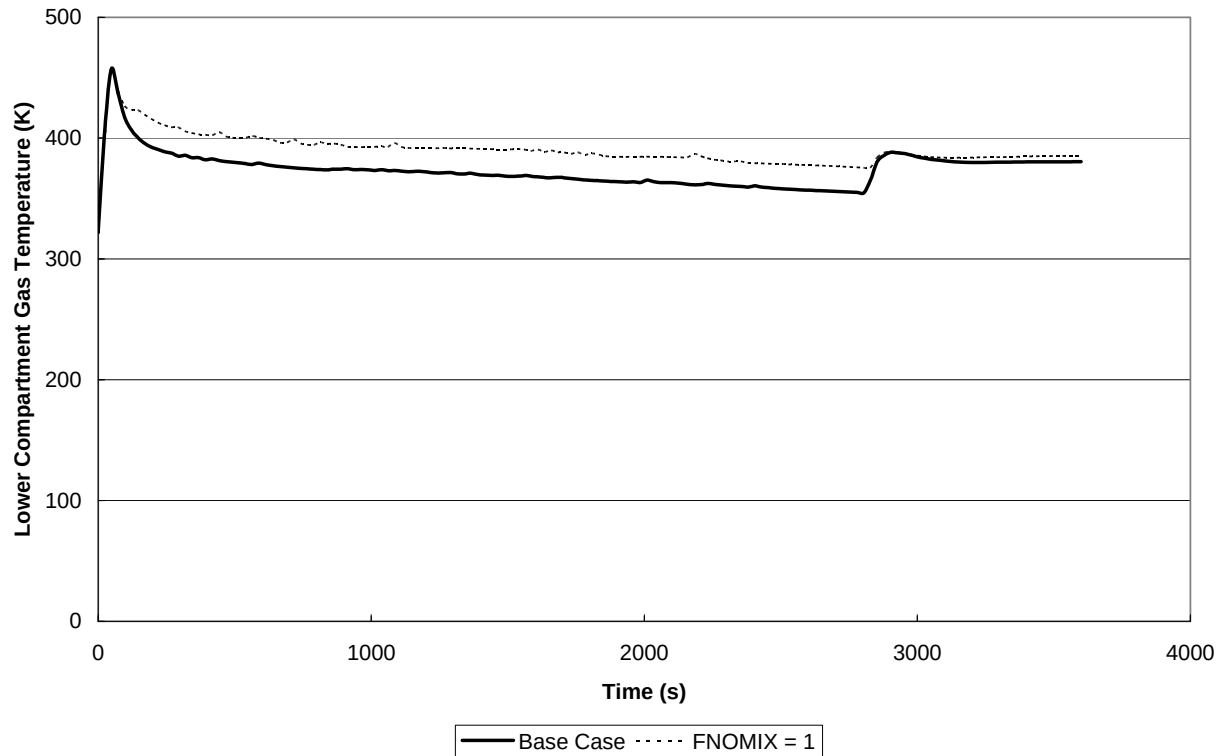


**Figure 6-10**  
**LLOCA Lower Compartment Gas Temperature as a Function of FNOMIX**

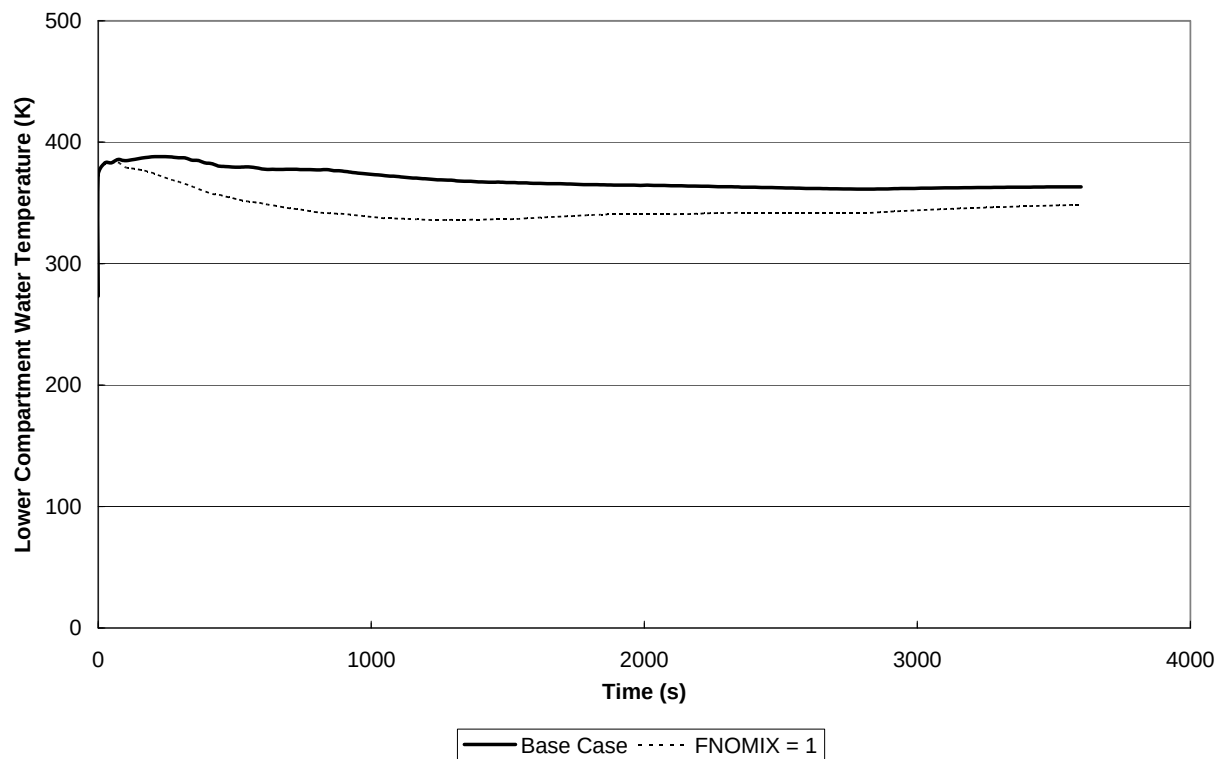


**Figure 6-11**  
**LLOCA Lower Compartment Water Temperature as a Function of FNOMIX**

### 6.5.5 Sensitivity to Parameter HTSTAG for an MLOCA

The effect of the value of parameter HTSTAG, the steam generator primary side heat transfer coefficient used when the RCS is in natural circulation mode, was investigated along with parameter VFSEP. As discussed in Section 6.5.1, a large series of LOCA cases was run using the S2HF sample problem with the WLD sample parameter file. Many variations in the definition of the sequence were made, including the value of HTSTAG, and the results are summarized in Table 6-8. HTSTAG has a large impact on the 10 cm (4 in.) diameter MLOCA cases. Detailed results for a subset of these cases are presented in Table 6-11. The information in the table illustrates that this set is very sensitive to whether the high containment pressure setpoint for activating containment sprays is reached (similar to the 8 cm [3 in.] MLOCA series discussed in Section 6.5.2), which is indirectly related to the heat transfer to the steam generators. The pressure just exceeds or falls short of the setpoint depending on slight variations in the initial progression of the sequence. If the sprays are activated, the RWST inventory is depleted relatively early, resulting in significantly earlier core uncover and relocation than in the cases in which the spray setpoint is not reached. The shaded columns in Table 6-11 correspond to the cases with containment sprays. The impact of values of HTSTAG that trigger and do not trigger containment sprays on the heat transfer to the steam generators, the containment pressure, and the mass of water in the RCS are shown in Figures 6-12 through 6-14. The plotted variables are QSGTOT, PRB(3), and MWPS, respectively.

Unlike the 8 cm MLOCA series, the impact of the variations in the adjusted parameter—in this case, HTSTAG—are not monotonic. Furthermore, very small variations in other input parameter values—for example, the cross-sectional area of the lower portion of the downcomer, ASGDC, and the cross-sectional area between the perimeter of the tube bundle and the tube bundle shroud, AFLWSG— influence whether the containment spray setpoint is reached, as shown in Table 6-11. This is indicative of acceptable numerical differences in sequences calculations leading to either reaching or just missing pertinent plant thresholds. From a PRA perspective, reaching the containment spray setpoint pressure should be treated as an uncertainty for this set of sequences.

## 6.6 Miscellaneous Information for PWR Applications

### 6.6.1 Primary System Gas and Water Pool Nodalization

As discussed in Section 2.2.1.2, the PWR primary system is divided into 14 gas volumes (nodes) and 6 water pools. Because the number of gas volumes is larger than the number of water pools, a pool can occupy several gas volumes. It is important for users to understand the relationship between the gas nodes and the water pools when specifying primary system breaks and injection locations. They are encouraged to consult the information in the PRISYS subroutine description in Volume II of the User's Manual. Figures 1 and 2 in the description present the gas nodalization for plants with U-tube and once-through steam generators, respectively. Figure 3 and Table 3 in the description show the water pools and their correspondence to the gas nodes for plants with U-tube steam generators; similar information for OTSGs can be inferred from the figures and the table.

**Table 6-11**  
**Influence of Parameter HTSTAG on MLOCA Sequence Progression<sup>a</sup>**

| HTSTAG                                                |                                                                     | 425, 700<br>(W/m <sup>2</sup> -C) | 850 (W/m <sup>2</sup> -C) <sup>b</sup> | 1000, 1150<br>(W/m <sup>2</sup> -C) | 1300, 1450,<br>1600 (W/m <sup>2</sup> -C) | 850 (W/m <sup>2</sup> -C)                    |                                                        |                           |
|-------------------------------------------------------|---------------------------------------------------------------------|-----------------------------------|----------------------------------------|-------------------------------------|-------------------------------------------|----------------------------------------------|--------------------------------------------------------|---------------------------|
| Additional Variations to<br>Parameter Values          |                                                                     | —                                 | —                                      | —                                   | —                                         | Maximum<br>Time Step<br>= 1.0 s <sup>c</sup> | Steam Generator Areas<br>(Two Cases Each) <sup>d</sup> |                           |
|                                                       |                                                                     |                                   |                                        |                                     |                                           |                                              | 99%                                                    | 101%                      |
| Switch to separated, stagnant conditions <sup>e</sup> |                                                                     | 573 s, 579 s                      | 579 s                                  | 583 s, 584 s                        | 583 s, 583 s,<br>583 s                    | 577 s                                        | 580 s, 581 s                                           | 580 s, 580 s              |
| Sprays                                                | Time when sprays<br>came on or setpoint<br>not reached <sup>f</sup> | On at 0.9 hr,<br>0.9 hr           | Not reached                            | On at 0.8 hr,<br>0.9 hr             | Not reached                               | On at 0.8<br>hr                              | On at 0.8 hr,<br>0.8 hr                                | Not reached               |
|                                                       | Peak containment<br>pressure if no<br>sprays                        | 2.464e5 Pa,<br>2.463e5 Pa         | 2.459e5 Pa                             | 2.462e5 Pa,<br>2.461e5 Pa           | 2.450e5 Pa,<br>2.459e5 Pa,<br>2.454e5 Pa  | 2.491e5 Pa                                   | 2.465e5 Pa,<br>2.465e5 Pa                              | 2.459e5 Pa,<br>2.456e5 Pa |
| RWST depleted <sup>g</sup>                            |                                                                     | 2.3 hr, 2.3 hr                    | 6.8 hr                                 | 2.4 hr, 2.4 hr                      | 6.8 hr, 6.8 hr,<br>6.8 hr                 | 2.3 hr                                       | 2.4, 2.3 hr                                            | 6.8 hr, 6.8 hr            |
| Accumulators depleted <sup>h</sup>                    |                                                                     | 3.2 hr, 3.1hr                     | 7.2 hr                                 | 3.1 hr, 3.1 hr                      | 7.2 hr, 7.2 hr,<br>7.2 hr                 | 3.2 hr                                       | 3.1, 3.0 hr                                            | 7.2 hr, 7.2 hr            |
| Core uncovered                                        |                                                                     | 4.2 hr, 4.3 hr                    | 8.6 hr                                 | 4.2 hr, 4.2 hr                      | 8.6 hr, 8.6 hr,<br>8.6 hr                 | 4.3 hr                                       | 4.2 hr, 4.2 hr                                         | 8.6 hr, 8.6 hr            |
| First relocation of core to lower<br>plenum           |                                                                     | 6.0 hr, 6.0 hr                    | 10.7 hr                                | 6.0 hr, 6.0 hr                      | 10.7 hr, 10.7 hr,<br>10.7 hr              | 6.1 hr                                       | 6.0 hr, 6.0 hr                                         | 10.7 hr, 10.7 hr          |

<sup>a</sup> Sequences run with the Rev. 4.0.7 WLD sample parameter file. Based on the S2HF sample input file, initiated with an 10 cm (4 in.) break in the intermediate leg.

<sup>b</sup> Default value.

<sup>c</sup> Parameter TDCORE; default value = 5.0 s.

<sup>d</sup> Cross-sectional area of the lower portion of the downcomer and cross-sectional area between the perimeter of the tube bundle and the tube bundle shroud; parameters ASGDC and AFLWSG, respectively.

<sup>e</sup> Void fraction, variable VFPS, exceeds VFSEP. Sets internal events 155 and 164.

<sup>f</sup> Upper compartment sprays initiated if the pressure in that compartment exceeds 2.46e5 Pa, parameter PSP0. (The value in the sample parameter file is 2.45e6 Pa. It was increased slightly to demonstrate threshold effect.) Upper compartment spray flow variable is WSPTA.

<sup>g</sup> Internal event for RWST depletion is 187.

<sup>h</sup> Internal event for accumulator depletion is 188.

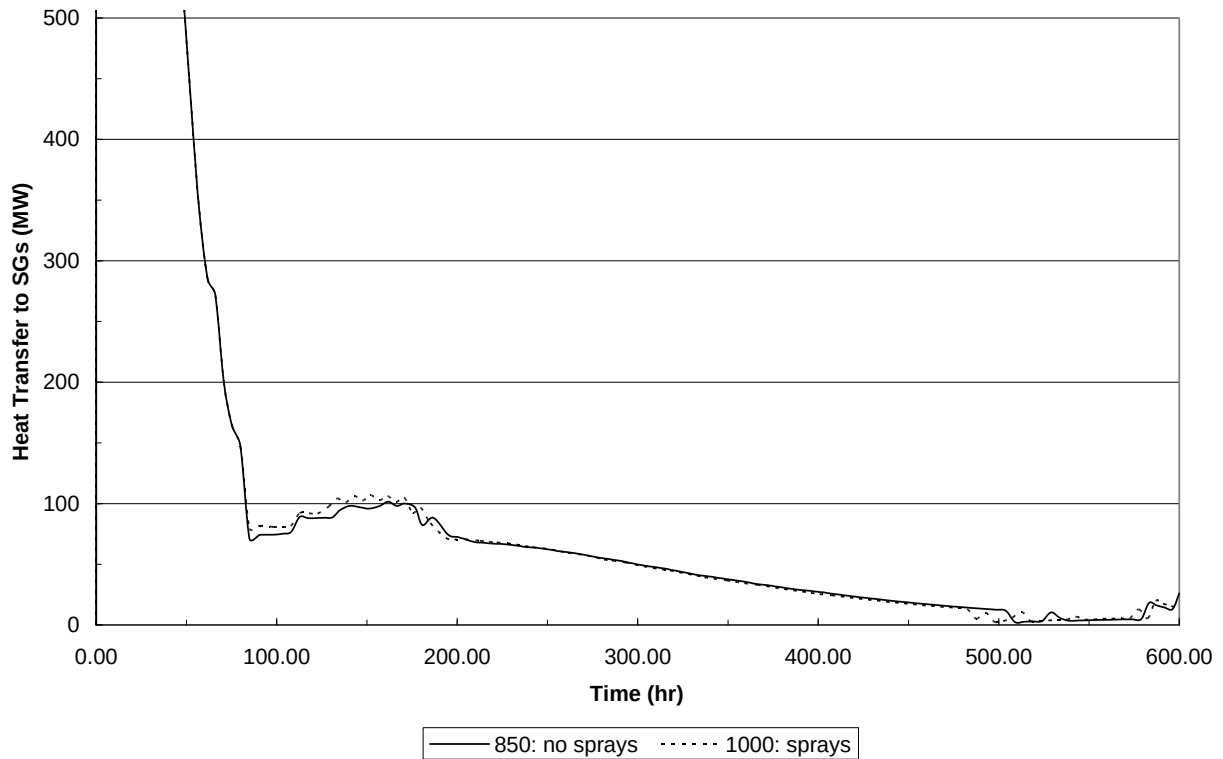


**Figure 6-12**  
**MLOCA Heat Transfer to the Steam Generators as a Function of HTSTAG**

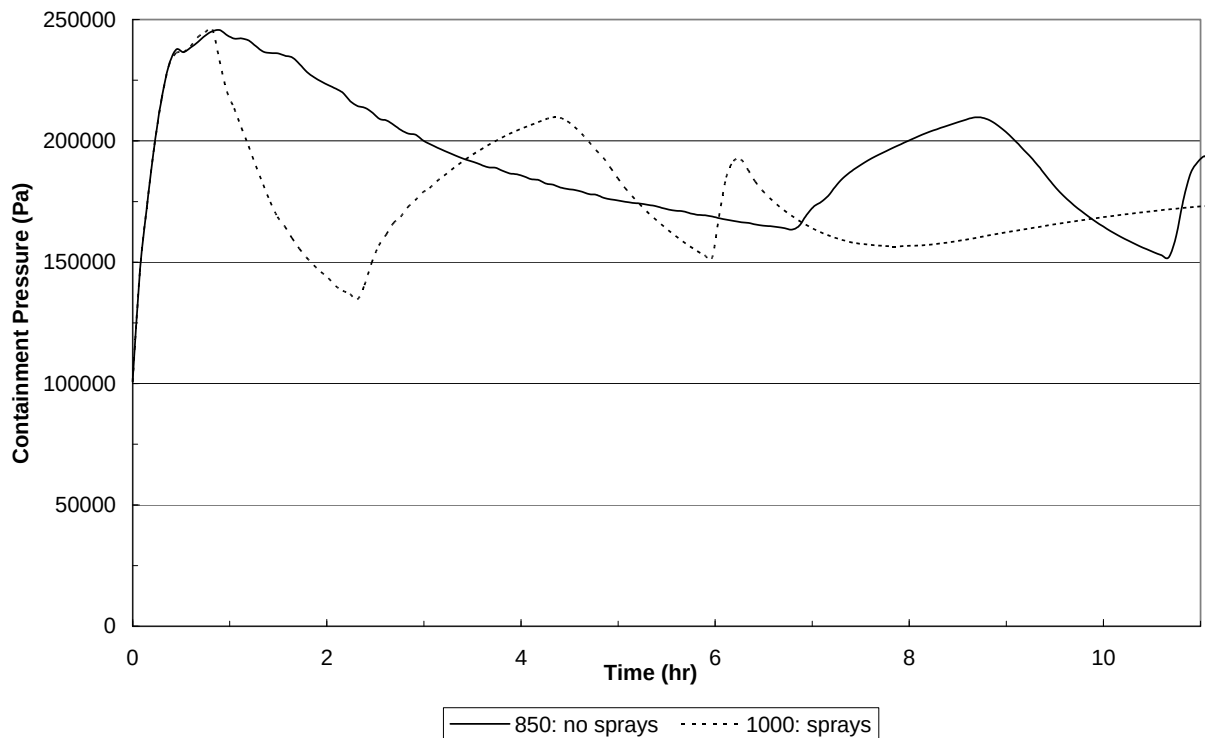


**Figure 6-13**  
**MLOCA Containment Pressure as a Function of HTSTAG**

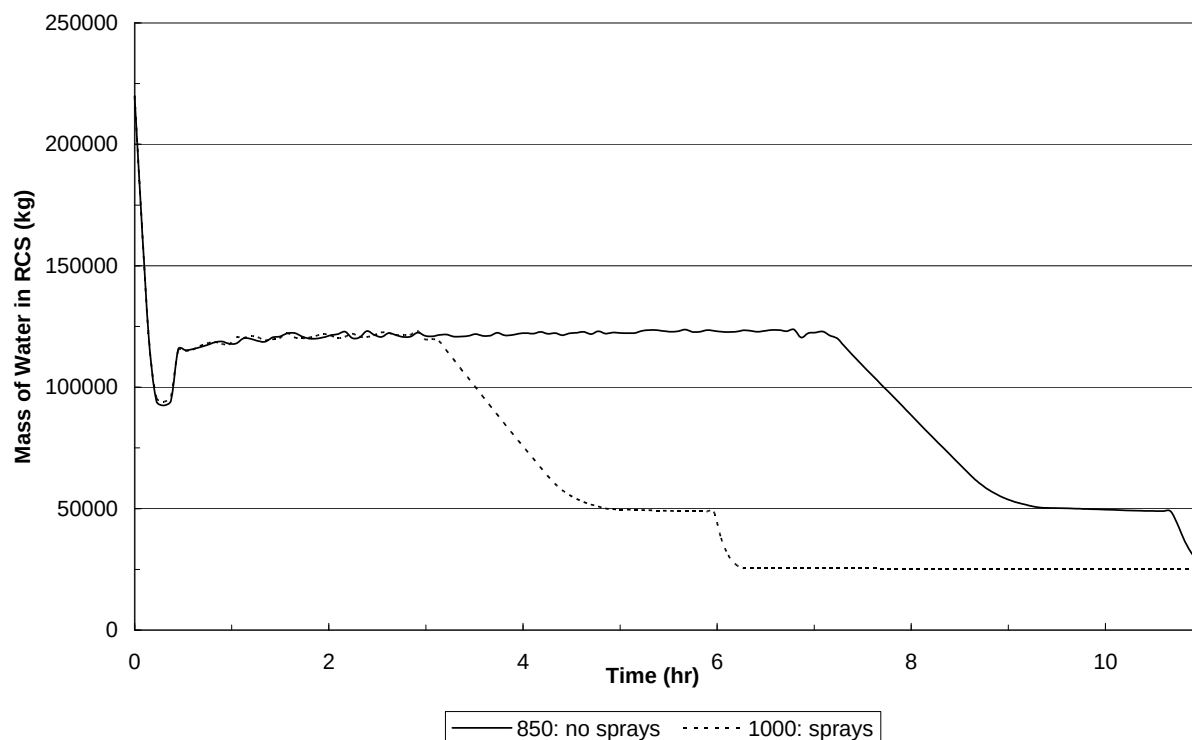


**Figure 6-14**  
**Mass of Water in the RCS as a Function of HTSTAG**

Section 6.4.3 of this report provides guidance on specifying primary system breaks, including Table 6-4, which provides a cross-reference for the gas volume and water pool associated with each break location. The discharge locations for injection into the primary system are specified by input parameters IDISCH if the hardwired ESF model is selected or NDxxx and RDxxx if the generalized ESF model is selected, where xxx is the injection system. In the code documentation, *discharge to the intermediate leg water pool* is referred to as *discharge to the cold leg*. This is potentially confusing because this discharge location does not include the water in the horizontal portion of the cold leg. The water in the horizontal portion of the cold leg is part of the downcomer water pool. Water that is injected into the downcomer water pool is assumed to fill up the downcomer before it fills up the horizontal portion of the cold leg. **This has particular implications for sequences with breaks in the cold leg gas node (FBB set to 7 or FUB set to 13) because water injected into the horizontal portion of the cold leg is assumed to go into the vessel first rather than directly out of the break.** The fraction of the injected water that goes out of the break before it is heated in the vessel can influence the progression of a sequence. It is recommended that users investigate the sensitivity of their results to the injection location for cold leg break sequences.

### 6.6.2 Primary System Dome Water Temperature: T-Hot and T-Cold Plants

Primary system designs vary as to whether the temperature of the water in the reactor vessel dome is closer to the temperature of the water in the cold leg—*T-cold* plants—or the hot leg—*T-hot* plants. Through Rev. 4.0.6, the code always models the water in the vessel dome as cold. With the T-cold assumption, the code might under-predict the decrease in the water volume in the primary system as the plant depressurizes for T-hot plants, resulting in a smaller predicted

pressure drop. (This limitation is discussed further in Table 8-2 and in the Oconee plant trip benchmark in Appendix F of this report.) A new model option was added in Rev. 4.0.7 to model T-hot plants, and the type of plant is specified with input parameter IDOMEHOT. Users with T-hot plants might want to consider using Rev. 4.0.7 to more accurately represent the primary system.

### **6.6.3 Steam Generator Water Level**

The collapsed water level on the secondary side of the steam generators is an important plant parameter, particularly for automatic plant response and manual operator actions during an accident. MAAP4 calculates the level as a function of the mass—using its equivalent volume—and the geometry of the secondary side. When the one-region steam generator model is selected, the collapsed level is determined using the volume versus height array, input parameters VOFZSG and ZOFSG. This level applies to both the downcomer water and the water surrounding the tubes. When the two-region model is selected, the code calculates individual collapsed levels in the tube bundle (Region 1) and in the downcomer region (Region 2). Each region is divided into three subsections, and each subsection has a constant cross-sectional area that is calculated from the corresponding input parameters.

In the steam generator, water flows from the downcomer to the tube bundle region and returns to the downcomer in a natural circulation path. This circulation flow is a result of the difference between the hydrostatic heads in the downcomer and the tube bundle region. The collapsed level in the downcomer region will be higher than in the tube bundle region because of the voids that result from steam generation in the tube bundle region and flow resistance. Therefore, the use of a single collapsed level in the one-region model leads to an under-prediction of the level in the downcomer region, and it is this level that is measured by plant instrumentation. Under high steaming and flow conditions, such as when the core is at full power and MFW is operating, the difference between the calculated and actual levels will be the most pronounced. Under accident conditions when the core is at a decay power level and the water inventory in the steam generators is being maintained by AFW, the static head difference will be minimal and the collapsed levels in the downcomer and tube bundle will be essentially the same. In this accident mode, the level predicted by the one-region model will be reasonably accurate. Users should reduce the target downcomer water level control system setpoints, parameters ZWCTLB and ZWCTLU, below their actual values to avoid adding too much feedwater at the beginning of an accident sequence when using the one-region model.

The two-region steam generator model accounts for the effect of the flow resistance as well as other related thermal-hydraulic phenomena, so it more accurately calculates the collapsed levels in the downcomer and tube bundle regions. However, the model is based on the assumption of uniform cross-sectional areas within the subsections in each of the regions. This assumption readily applies to OTSGs and U-tube steam generators in which there is a relatively sharp demarcation in the cross-sectional area at the transition from the lower downcomer to the upper downcomer. For these U-tube designs, the value of input parameter ZUPDC, the elevation that separates the lower downcomer from the upper downcomer, is close to the value of input parameter ZRISER, the elevation of the bottom of the risers (standpipes). (Note that ZUPDC might be above or below ZRISER.) For U-tube designs that have a more gradual expansion between the relatively narrow lower downcomer subsection and the open upper downcomer

subsection, the determination of a value for ZUPDC might be somewhat ambiguous. Furthermore, there can be a mismatch between the calculated and actual levels when the water level is between ZUPDC and ZRISER. This point is important for users because a subset of level setpoints that trigger plant responses or operator actions can be within this elevation range—generally, it corresponds to the span of the narrow-range level instrumentation.

It is recommended that users calibrate the calculated water levels as a function of the water volume using plant data. When evaluating the initialization of the water level during the testing of a parameter file, the mismatch in level with water volume should be taken into account. For the one-region model, adjustments to the volume versus height array can be made to match the initial target water level, but this can result in inappropriate changes if the calculated levels do not match water volumes under accident conditions. For the two-region model, adjustments can be made to the value of ZUPDC or AUPDC, the cross-sectional area in the upper downcomer, so the calculated initial downcomer water level is consistent with the plant value for a given initial steam generator water volume. In addition, users should calibrate the level setpoint parameter that is used to trip the reactor, ZWSGL.

In a global sense, the most important input parameter for initializing the conditions in the steam generators is MWSG0, the initial mass of water on the secondary side per generator. This parameter controls the amount of heat removed by the secondary side and, correspondingly, the time of steam generator dryout, which is a key event for accident sequences. Two other input parameters that significantly impact conditions in the steam generators are ASGDC, the cross-sectional area of the lower portion of the downcomer, and AFLWSG, the cross-sectional area between the perimeter of the tube bundle and the tube bundle shroud (wrapper). These parameters affect the time when the tubes are uncovered, which impacts the heat transfer from the primary system.

The values of the target downcomer water level setpoints can have a significant impact on the water mass in the generators. This is important for sequences in which AFW is available for a limited time. The mass of water remaining in the generators when AFW is no longer injecting can substantially influence the subsequent progression of a sequence and the time of key events.

The importance of the steam generator level, the potential for mismatches between the calculated and actual levels, and the impact of the steaming and flow rates on interpreting the mismatches during the testing of parameter files has led to an effort by the code maintenance contractor to develop more detailed guidance on the determination and calibration of steam generator geometry and setpoint parameter values. It is anticipated that the guidance will be provided to the MUG and posted on the MAAP4 website in the latter half of 2010. Additional information regarding the steam generator modeling is contained in the BSTGEN/USTGEN and BSG2R/USG2R subroutine descriptions for the one-region and two-region models, respectively, in Volume II of the User's Manual and in the sample parameter files.

#### **6.6.4 Feed and Bleed Analysis**

A potential response to the loss of secondary side cooling is to open a pressurizer PORV to depressurize the primary system and then start ECCS injection. This combined action is referred to as *feed and bleed*. Variables that are evaluated for feed and bleed sequence analysis include 1)



the number of opened PORVs, 2) the number and type of injection pumps or trains, and 3) the time delay before the action is initiated following the onset of the accident. MAAP4 can be a useful tool to calculate the optimal time for performing this action for a defined number of pumps (or trains) and PORVs.

MAAP4 feed and bleed analysis results presented at the PSA 2005 conference [18] include the information in Table 6-12. Predictions of core uncover and core damage for a transient accident scenario are correlated to the time when the RCPs were tripped, the time when injection was initiated, the number and type of injection pumps, and the number of PORVs that were opened. This approach for correlating plant-specific predictions can be very useful for documenting the basis for feed and bleed success criteria and accident progression timing.

An example of an operator action to initiate feed and bleed is provided next. This particular action starts all of the charging pumps and opens a single PORV after 1 hour. Setting the charging pump event to auto-initiation is required if they had been previously locked off.

```
WHEN TIMD > 3600. S
C Reset event 232 if the charging pumps were locked off:
  CHARGING PUMPS SWITCH: AUTO
C Set event 231 to true to start the charging pumps
  CHARGING PUMP SWITCH: MAN ON
C Manually open PORV number 1
  IMANON(1) = 1
END
```

**Table 6-12**  
**MAAP4 Feed and Bleed Results for a Transient <sup>a</sup>**

| Case ID in Reference | RCP Trip <sup>b</sup> |      | Auto SI <sup>c</sup> |    | Pumps <sup>d</sup> |   |     |   | Pressurizer PORVs <sup>e</sup> |   |   | Core Uncovered | Core Damage <sup>f</sup> |
|----------------------|-----------------------|------|----------------------|----|--------------------|---|-----|---|--------------------------------|---|---|----------------|--------------------------|
|                      |                       |      |                      |    | Charging           |   | HPI |   |                                |   |   |                |                          |
|                      | 10%                   | Void | Yes                  | No | 1                  | 2 | 1   | 2 | 0                              | 1 | 2 |                |                          |
| 21                   | ✓                     |      | ✓                    |    | ✓                  |   |     |   | ✓                              |   |   | Yes            | No                       |
| 22                   | ✓                     |      | ✓                    |    |                    | ✓ |     |   | ✓                              |   |   | Yes            | No                       |
| 23                   | ✓                     |      | ✓                    |    |                    |   | ✓   |   |                                | ✓ |   | Yes            | Yes                      |
| 24                   | ✓                     |      | ✓                    |    |                    |   |     | ✓ |                                | ✓ |   | Yes            | Yes                      |
| 25                   | ✓                     |      | ✓                    |    |                    |   | ✓   |   |                                |   | ✓ | Yes            | Yes                      |
| 26                   | ✓                     |      | ✓                    |    |                    |   |     | ✓ |                                |   | ✓ | Yes            | Yes <sup>g</sup>         |
| 27                   |                       | ✓    | ✓                    |    | ✓                  |   |     |   | ✓                              |   |   | Yes            | No                       |
| 28                   |                       | ✓    | ✓                    |    |                    | ✓ |     |   | ✓                              |   |   | Yes            | No                       |
| 29                   |                       | ✓    | ✓                    |    |                    |   | ✓   |   |                                | ✓ |   | Yes            | Yes                      |
| 30                   |                       | ✓    | ✓                    |    |                    |   |     | ✓ |                                | ✓ |   | Yes            | Yes                      |
| 31                   |                       | ✓    | ✓                    |    |                    |   | ✓   |   |                                |   | ✓ | Yes            | Yes                      |
| 32                   |                       | ✓    | ✓                    |    |                    |   |     | ✓ |                                |   | ✓ | Yes            | Yes                      |
| 33                   | ✓                     |      |                      | ✓  | ✓                  |   |     |   | ✓                              |   |   | Yes            | No                       |
| 34                   | ✓                     |      |                      | ✓  |                    | ✓ |     |   | ✓                              |   |   | No             | No                       |
| 35                   | ✓                     |      |                      | ✓  |                    |   | ✓   |   |                                | ✓ |   | Yes            | No                       |
| 36                   | ✓                     |      |                      | ✓  |                    |   |     | ✓ |                                | ✓ |   | Yes            | No                       |
| 37                   | ✓                     |      |                      | ✓  |                    |   | ✓   |   |                                |   | ✓ | No             | No                       |
| 38                   | ✓                     |      |                      | ✓  |                    |   |     | ✓ |                                |   | ✓ | No             | No                       |
| 39                   |                       | ✓    |                      | ✓  | ✓                  |   |     |   | ✓                              |   |   | Yes            | No                       |
| 40                   |                       | ✓    |                      | ✓  |                    | ✓ |     |   | ✓                              |   |   | Yes            | No                       |
| 41                   |                       | ✓    |                      | ✓  |                    |   | ✓   |   |                                | ✓ |   | Yes            | Yes                      |
| 42                   |                       | ✓    |                      | ✓  |                    |   |     | ✓ |                                | ✓ |   | Yes            | Yes                      |
| 43                   |                       | ✓    |                      | ✓  |                    |   | ✓   |   |                                |   | ✓ | No             | No                       |
| 44                   |                       | ✓    |                      | ✓  |                    |   |     | ✓ |                                |   | ✓ | No             | No                       |

<sup>a</sup> Reactor trip at time zero. The analysis was performed with Rev. 4.0.4 using a plant-specific WLD parameter file.

<sup>b</sup> RCPs tripped either at a low steam generator level of 10% narrow range (early in the sequence) or when the average void fraction exceeded 50% (the MAAP4 default value of input parameter VFCEMX, late in the sequence).

<sup>c</sup> Started injection either on an SI signal indicating that the containment pressure exceeded 3.4 psig or by simulating an operator action when the level in a steam generator level fell below 27% wide range. The low steam generator level condition was met earlier than the pressure condition.

<sup>d</sup> Charging pumps are the plant's high head pumps; HPI pumps are the plant's intermediate (SI) head pumps.

<sup>e</sup> PORVs manually opened when injection started.

<sup>f</sup> Core damage defined as the maximum core temperature exceeds 1800°F.

<sup>g</sup> This case results in core damage because of relatively late initiation of feed and bleed.

### 6.6.5 ECCS Injection and Containment Sprays in Recirculation Mode

When the bulk of the RWST inventory is depleted, operators are required to switch the suction for ECCS injection and containment sprays to a containment sump. This is an important operator action in a PRA. The following is an example input file component for modeling the switch based on low RWST level:

```
C Recirculation on LO-LO level (47% level, 24.9 ft from the bottom of the tank)
WHEN ZWRWST < 24.9 FT
  RECIRC SWITCH: MAN ON
END
```

External event 220, RECIRC SWITCH: MAN ON, switches **all** ECCS and containment spray systems into recirculation mode. For some PWRs, the ECCS injection pumps are switched into recirculation mode at a higher RWST level than that used for switching the containment spray pumps. This can be modeled in MAAP4 by using the generalized ESF model and changing the applicable recirculation suction pointers using multiple interventions in the input file. The generalized ESF model also allows the specification of different sumps for different systems. The containment nodes containing the sumps are identified by pointers JNCSMP (for both the hardwired and generalized ESF models) and JNASMP (for the generalized ESF model).

### 6.6.6 Failure of Injection and Containment Spray Cooling

Typically, a portion of a plant's low pressure injection and containment spray systems have heat exchangers to remove decay heat when the systems are operating in recirculation mode—that is, when they are taking suction from a containment sump. The presence and types of heat exchangers are identified by input parameters IRECIR, FHXRH, and FHXSP when the hardwired ESF model is selected and input parameter FHXP<sub>*x*</sub> for pump set *x* when the generalized ESF model is selected. Additional input parameters define the properties of the individual heat exchangers. The generalized ESF model allows users to specify individual heat exchangers for any ESF system in any operating mode.

PRA analysis often includes the investigation of the plant's response to an accident when an injection or spray system's heat removal function fails. Heat exchangers can be disabled in MAAP4 sequences by setting the values of FHXRH, FHXSP, or FHXP<sub>*x*</sub> to 0.0. They can also be disabled by setting external event 203, HX COOLING WTR OFF, to true, but this will disable all heat exchanger capability, including in other containment cooling systems such as fan coolers.

### 6.6.7 Decay Power Calculation

In the PWR code, the core power after a reactor trip—the decay power—is calculated either with the ANSI/ANS decay heat correlation [9] or with an input array of power versus time since reactor trip terms. Several input parameters in the *Primary System* section of the parameter file are used in the ANSI/ANS correlation: the fuel enrichment, core exposure, total effective irradiation time, and fission terms (the capture and absorption rates and the fission power fractions). Plant-specific values for the fission terms are generally difficult to obtain and have an inherent uncertainty; testing has shown that the calculated decay power is relatively insensitive

to variations in these parameters, so the values listed in the sample parameter files are adequate for plant-specific parameter files. It is recommended that users select self-consistent, end-of-cycle values from the options provided in the sample files.

There is a tendency to compute the value of the total effective irradiation time, TIRRAD, using the length of a single cycle. Instead, it should be calculated based on how long each part of the core has been exposed. For example, if approximately one-third of the core is replaced each cycle (a three-batch core), and a cycle is approximately 2 years with a 1-month outage for refueling, at the end of a cycle the average irradiation time is 46 months ( $1/3 \times [23 + 46 + 69 \text{ months}]$ ).

GE has determined that the decay heat correlation under-predicts the decay power by a few percent [16], with the percentage increasing over the time since shutdown (3% at  $10^4$  s [2.78 hr], 6% at  $10^6$  s [278 hr]). The under-prediction is within the uncertainty of the calculated power that arises from uncertainties in the values of the input parameters used in the correlation. However, the option to apply the correction factor to the calculation will be added in a future version of MAAP4. If users want to increase the decay heat for longer sequences to address the under-prediction, this can be readily accomplished by specifying increasingly larger values for the initial core power, QCR0, as a function of time. The decay power is calculated by determining a fractional power using the correlation and then multiplying the fraction by the input initial power, so the input initial power is used repeatedly in the calculations rather than just at the beginning of a sequence.

Users can set the value of the decay power by using a very large value for the time delay between the reactor trip signal and the onset of the trip, TDSCRM, and then assigning the desired power value to QCR0. This essentially bypasses the decay power correlation and is useful for applications such as shutdown cooling analyses.

### 6.6.8 Steam Generator Depressurization for RCS Cooldown

The modeling of operator actions to *cool down*—that is, depressurize—the RCS by depressurizing the steam generators is frequently required when analyzing sequences for a PRA. Typically, the rate of cooldown is prescribed in the EOPs and is indicated in degrees per hour. One method for modeling the cooldown is to control the steam generator relief valve setpoint as a function of time by means of a user-defined lookup table. The setpoint values in the table are precalculated to obtain the desired cooldown rate. The following is an example of such a table. As shown in the example, the start of the cooldown can be established by maintaining the normal relief valve pressure until the action is assumed to start—in this case, at 1.0 hr.

#### LOOKUP VARIABLE PSGRV

| TIM HR | PSGRV PSI |
|--------|-----------|
| 0.00   | 900       |
| 1.00   | 900       |
| 1.15   | 810       |
| 1.25   | 570       |
| 1.74   | 420       |
| 2.25   | 200       |
| 2.75   | 100       |

```

3.25      65
3.75      14
END

```

An alternative method that does not involve the precalculation of the relief valve setpoint pressures is to repeatedly set the setpoint pressure to the saturation pressure for a steadily decreasing primary side target temperature. The following are example input file components for this method, with a cooldown rate of 50°F/hr and changes to the target temperature 20 times per hour. Note that the resultant primary system water temperature in the core, TWCR, remains slightly above the target temperature.

```

PARAMETER CHANGE // initialize user-defined variables for plotting
  TARGET_T_K = 1000 // arbitrary value
  TARGET_T_F = 1000
END

PLOTFIL 84
  TARGET_T_K, TARGET_T_F, TWCR, PSGRV, PBS
END

WHEN TIM > 1.5 HR // sequence-specific condition to start the cooldown
  FARVBX = 0.3 // reduce area of S/G PORVs to simulate operator control
  FARVUX = 0.3
  SET TIMER #40
C 50 DEGREES F/HR COOLDOWN RATE
  COOLRATE = 50/1.8 // the 1.8 factor adjusts for F to Kelvin
C It might be necessary to increase the COOLRATE in the slightly for particular
C sequences, such as those in which there are temperature spikes due to
C temporary core uncover.
  TARGET_T_K = TWCR - COOLRATE/20 // using 1/20 of an
                                // hour as the time increment in the next block so need
                                // 1/20 of the temperature change during that time
  TARGET_T_F = TARGET_T_K * 1.8 - 459.6 // convert to F for output
  PSGRV = PSAT(TARGET_T_K)
END

WHEN TIMER #40 >= 0.05 HR AND TIMD < 2.5 HR // 1/20 of an hour
                                // increment and sequence-specific end time of cooldown
  TARGET_T_K = TWCR - COOLRATE/20
C Or use TARGET_T_K = TARGET_T_K - COOLRATE/20; might improve
C precision
  TARGET_T_F = TARGET_T_K * 1.8 - 459.6
  PSGRV = PSAT(TARGET_T_K)
  RESET TIMER #40
  REPEAT
END

```

### **6.6.9 Uncertainty in Creep Rupture of the Hot Leg and Steam Generator Tubes**

MAAP4 mechanistically calculates hot leg creep rupture (HLCR) using the mass of the hot leg, input parameter MHLTOT, and the hot leg material type, input parameter IHLMAT. There are significant uncertainties associated with the conditions leading to HLCR, so users should treat rupture as an uncertainty rather than relying on the code predictions.

The sample parameter files contain user-defined events that open the ruptures when HLCR is predicted, and these can be adapted for plant-specific parameter files. The input parameters AGOBHL and AGOUHL are used to set the rupture area. These parameters can be set to 0.0 to disable the opening of the hot leg; however, this will not disable internal events 33 and 34, UNBROKEN HOT LEG RUPTURE, and BROKEN HOT LEG RUPTURE, from being set to true when the code determines that failure due to creep would occur.

Similarly, the code mechanistically calculates the creep rupture of steam generator tubes and there are uncertainties with the conditions leading to tube rupture. As with HLCR, users should treat SGTR as an uncertainty rather than relying on the code predictions.

The variable ASB is used to set the area of the break when the rupture is predicted. Unlike the hot leg entries, setting the input failure area to 0.0 will not override the opening of the rupture. The workaround for code versions through Rev. 4.0.6 is to set parameter FERSGT, the ratio of the current tube thickness to its original thickness, to a high value to prevent the code from calculating that a tube would rupture. In Rev. 4.0.7 a new parameter, ASBO, was added to allow users to override the opening.

### **6.6.10 Mid-Loop (Half-Loop) Operation**

MAAP4 can be used to predict the progression of accidents that could occur when the plant is in *mid-loop* operating mode. This mode is established after the reactor has undergone a normal shutdown and the primary system water level has been decreased to approximately the mid-plane of the hot leg. Decay heat is removed by the RHR system with suction from the hot leg and discharge to the cold leg. The vessel might be open—for example, by the head having been removed for core refueling. When the plant is in mid-loop mode, the loss of RHR can lead to a severe accident.

In MAAP4, mid-loop operation is generally referred to as *half-loop* operation. Users indicate that a sequence is simulating a plant in mid-loop mode by setting the flag HALFLP to 1 in the parameter file or in the input file using a local parameter change (it should not be set as an initiator). The code will initialize the conditions in the primary system and the steam generators using the mid-loop-specific input values in the *Initial Conditions*, *Primary System*, and *Steam Generator* sections of the parameter file. This includes the determination of whether there is air in the primary system, as would be the case if the head had been removed. Specific information regarding the MAAP4 modeling of mid-loop operation can be found in the sample parameter files and in the PRISYS, BSTGEN/USTGEN, and XPREP subroutine descriptions in the User's Manual.

### **6.6.11 Subcooling Margin**

The subcooling margin in the RCS is an important property for PWR operation. The following input file component can be used to calculate the subcooling margin. In this case, the calculation is based on the core water pool temperature. Other options are the average water temperature, TWPS, or the temperature of the water in the hot leg, TWHPS.

FUNCTION

    SUBCM = TSAT(PPS) – TWCR

    SUBCMF = SUBCM \* 1.8 // convert from delta-K to delta-F

END





# 7

## MAAP BENCHMARKS

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The MAAP4 code has been extensively benchmarked, and information about the benchmarks has been presented and published in a variety of forums. To facilitate an assessment of the abilities of the code to model Level 1 phenomena based on the results of the benchmarks, the documentation of relevant benchmarks was collected and reviewed by a team of MAAP4 experts.<sup>8</sup> The benchmarks were gathered from the MAAP4 User's Manual, technical journals, conference proceedings, MUG meeting presentations, and technical reports. More than 30 benchmarks were collected; they fall into the following categories:

- Comparisons to plant events (PE entries)
- Comparisons to integral codes (IC entries)
- Comparisons to integral experiments (IE entries)
- Comparisons to separate effects experiments (SE entries)

### 7.1 Method for the Review of the MAAP Benchmarks

The team of experts—each member having extensive experience with the development and application of MAAP3B and MAAP4 as well as extensive knowledge of severe accident phenomena and plant response—reviewed the individual benchmarks in two stages. The first stage consisted of a preliminary review of the documentation of each benchmark to determine if 1) it contains adequate information on the method and results so that conclusions could be drawn and 2) the code was used in an appropriate manner (for example, not in a regime determined to be outside the range of applicability according to the limitations posted on the MAAP4 web site). The major code models—primary system thermal hydraulics, steam generator thermal hydraulics, core heat-up, and containment thermal response—evaluated by each benchmark were identified. Similarly, significant code capabilities validated by each benchmark were identified. These include critical flow through valves and breaks, ECCS injection, condenser heat transfer, voiding in the core, and hot leg natural circulation (HLNC).

The second stage consisted of an in-depth review of each of the benchmarks that met the preliminary criteria to determine the agreement between the MAAP4 results and the corresponding data and comparative analyses. The team studied the documented information and discussed the strength of the benchmark, the specific results, the conclusions drawn by the authors, and so on. To provide a framework for the collective assessment of the code's capabilities, the review was structured to 1) rate the degree of agreement between the sets

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<sup>8</sup> The team consisted of Jeff Gabor and Barbara Schlenger-Faber of ERIN, Chan Paik and Robert Reeves of FAI, and Marc Kenton of Erigo Technologies.

of comparative results and 2) capture pertinent information on code performance, limitations, and options for modeling particular phenomena.

The degree of agreement for the major code models is based on the following representative quantities. They were selected because of their importance to the success criteria and human reliability components of PRA analysis:

- BWR primary system thermal hydraulics: primary system pressure and water level in the vessel
- PWR primary system thermal hydraulics: primary system pressure, water level in the pressurizer, and water level in the vessel
- Steam generator thermal hydraulics: secondary side pressure and water level in the steam generators
- Core heat-up (generic to BWR and PWR): maximum core temperature
- Containment thermal response (generic to BWR and PWR): containment pressure

The team jointly rated the agreement for each of the major models as well as the overall degree of agreement as *very good*, *good*, *fair*, *qualitative*, or *inconclusive*. No *poor* agreements were identified. By necessity, the rating process was qualitative rather than quantitative. Consideration was given to whether the uncertainties associated with the documented sequence definitions and boundary conditions tended to be greater than those associated with the modeling approaches and phenomenological uncertainties.

The team also assessed the validation of the specific code capabilities as *validated by explicit results* or *qualitative or indirect validation*. No *inconclusive* or *negative* validations were identified.

Details about each of the benchmarks are assembled in Appendix F and include the following:

- Identifying information: authoring organizations, plant types (BWR, PWR, containment type, and so on), PRA levels, sequence types, time frames of the analyses, and MAAP code versions
- Agreement for major code models: elaboration and observations
- Validation of significant code capabilities: elaboration and observations
- Exemplified limitations and precautions
- Issues for further code development and user support
- Notes and recommendations for the users
- Conclusions drawn by the authors of the benchmark
- Documentation: reference citations

The entries in Appendix F have a consistent format; only the applicable or available details are included for each individual benchmark.

## 7.2 Benchmark Review Results

Tables 7-1 and 7-2 list the benchmarks that met the preliminary criteria of the first stage of the review process and contain the summary results from the team's in-depth review. The first table contains the degree of agreement for the major code models and the overall code. The second table contains the extent of the validation of the significant code capabilities.

Compilations of the degree of agreement for the major code models and the validation of the code capabilities are presented in Tables 7-3 and 7-4, respectively. Compilations of the benchmarks as a function of sequence type are presented in Tables 7-5 and 7-6 for BWRs and PWRs, respectively. Because not all of the benchmarks are of the same technical caliber and because some contain multiple independent sequences while others contain variations of a base sequence, the compilations should be viewed as general versus rigorous.

## 7.3 Conclusions from the Benchmark Review

Three sets of conclusions were drawn from the review of the benchmarks. First, the compilations in Tables 7-3 through 7-6 were examined to identify particular areas in which additional benchmarks would be beneficial for filling in gaps in the overall matrix of major code models, code capabilities, and sequences that are supported by benchmarks. Recommendations for additional benchmarks based on this examination of the number and level of agreement of the existing benchmarks are as follows:

- Major code models: steam generator thermal hydraulics for OTSGs
- Significant code capabilities: drywell/fan cooler heat and mass transfer
- BWR sequences:
  - SLOCAs and MLOCAs
  - Stuck-open SRVs with discharge to the suppression pool
  - ATWS conditions
- PWR sequences:
  - LLOCAs
  - SGTRs (These are in part supported by the SLOCA benchmark sequences, but additional benchmarks that focus on the secondary side response would be of value because of the complex coupling of the primary and secondary sides and the importance of SGTRs in Level 1 analysis.)
  - Mid-loop operation

Second, specific details of the benchmarks assembled in Appendix F that affect code applications were collected. These details include limitations, precautions, notes and recommendations for users, and issues for further code development and user support. They are listed in Section 8 along with additional items known to the team and the code maintenance contractor.

**Table 7-1**  
**Collected Benchmarks and Agreement for the Major Code Models Related to Level 1 Phenomena**

| Benchmark Type<br>(entry in Appendix F) | Identifier, Sequences, and Plant Type           | Agreement for Major Code Models                    |                                                              |                   |                                                  |                                 |                                         | Principal Sources of Documentation for the Benchmark |
|-----------------------------------------|-------------------------------------------------|----------------------------------------------------|--------------------------------------------------------------|-------------------|--------------------------------------------------|---------------------------------|-----------------------------------------|------------------------------------------------------|
|                                         |                                                 | Overall Code                                       | Primary System Thermal Hydraulics (pressure and water level) |                   | SG Thermal Hydraulics (pressure and water level) | Core Heat-Up (core temperature) | Containment Thermal Response (pressure) |                                                      |
|                                         |                                                 |                                                    | BWR                                                          | PWR               |                                                  |                                 |                                         |                                                      |
| Plant event (PE1)                       | TMI-2 LOFW; B&W                                 | Very good given uncertainty in boundary conditions | —                                                            | Good              | Fair (OTSG, one-region model)                    | Indirect support                | Qualitative                             | MAAP4 User's Manual and conference proceedings       |
| Plant event (PE2)                       | Davis-Besse LOFW; B&W                           | Fair                                               | —                                                            | Fair to good      | —                                                | —                               | —                                       | MAAP4 User's Manual                                  |
| Plant event (PE3)                       | Oyster Creek LOFW; BWR with isolation condenser | Very good given uncertainty in boundary conditions | Good                                                         | —                 | —                                                | —                               | —                                       | MAAP4 User's Manual                                  |
| Plant event (PE4)                       | Prairie Island SGTR; WLD                        | Good                                               | —                                                            | Good              | —                                                | —                               | —                                       | MAAP4 User's Manual                                  |
| Plant event (PE5)                       | Maanshan SBO; WLD                               | Good                                               | —                                                            | Good to very good | —                                                | —                               | —                                       | Presentation to the NRC                              |

Table 7-1 (continued)

## Collected Benchmarks and Agreement for the Major Code Models Related to Level 1 Phenomena

| Benchmark Type<br>(entry in Appendix F) | Identifier, Sequences, and Plant Type                                             | Agreement for Major Code Models                                       |                                                              |                                                                   |                                                  |                                 |                                         | Principal Sources of Documentation for the Benchmark |
|-----------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------|--------------------------------------------------------------|-------------------------------------------------------------------|--------------------------------------------------|---------------------------------|-----------------------------------------|------------------------------------------------------|
|                                         |                                                                                   | Overall Code                                                          | Primary System Thermal Hydraulics (pressure and water level) |                                                                   | SG Thermal Hydraulics (pressure and water level) | Core Heat-Up (core temperature) | Containment Thermal Response (pressure) |                                                      |
|                                         |                                                                                   |                                                                       | BWR                                                          | PWR                                                               |                                                  |                                 |                                         |                                                      |
| Plant event (PE6)                       | Oconee plant trip; B&W                                                            | Good                                                                  | —                                                            | Very good with code change to model plants with hot water in dome | —                                                | —                               | —                                       | Presentation to the MUG                              |
| Plant event (PE7)                       | LOOP and plant trip in 1992 MAAP3B Qualification Studies; Westing-house four-loop | Generally but not specifically applicable; good agreement with MAAP3B | —                                                            | —                                                                 | —                                                | —                               | —                                       | EPRI technical report                                |
| Integral code—compared to CENTS (IC1)   | SBO and LOFW with F&B; CE                                                         | Good                                                                  | —                                                            | Good                                                              | Fair to very good (U-tube, two-region model)     | —                               | —                                       | Conference proceedings                               |

**Table 7-1 (continued)**  
**Collected Benchmarks and Agreement for the Major Code Models Related to Level 1 Phenomena**

| Benchmark Type<br>(entry in Appendix F)               | Identifier, Sequences, and Plant Type | Agreement for Major Code Models |                                                              |                                |                                                  |                                 |                                         | Principal Sources of Documentation for the Benchmark |
|-------------------------------------------------------|---------------------------------------|---------------------------------|--------------------------------------------------------------|--------------------------------|--------------------------------------------------|---------------------------------|-----------------------------------------|------------------------------------------------------|
|                                                       |                                       | Overall Code                    | Primary System Thermal Hydraulics (pressure and water level) |                                | SG Thermal Hydraulics (pressure and water level) | Core Heat-Up (core temperature) | Containment Thermal Response (pressure) |                                                      |
|                                                       |                                       |                                 | BWR                                                          | PWR                            |                                                  |                                 |                                         |                                                      |
| Integral code—compared to SR5 (IC2)                   | LOFW and S/MLOCAs; U.S. EPR           | Good                            | —                                                            | Good to very good <sup>a</sup> | Fair to good (U-tube, one-region model)          | Fair to very good               | —                                       | Conference proceedings                               |
| Integral code—compared to TRACG02 (IC3)               | LOOPs with LLOCAs; BWR                | Good                            | Good                                                         | —                              | —                                                | Fair                            | —                                       | GE technical report                                  |
| Integral code—compared to RELAP5 (IC4)                | SBO with F&B for Palisades; CE        | Good                            | —                                                            | Fair to good                   | Good (U-tube, one-region model) <sup>b</sup>     | —                               | —                                       | Erigo letter report and presentations to the MUG     |
| Integral code—compared to SR5 and MELCOR (IC5 1 of 2) | LLOCA for Kuonsheng; BWR              | Good                            | Fair to good                                                 | —                              | —                                                | Good                            | —                                       | Journal paper and doctoral dissertation              |

Table 7-1 (continued)

## Collected Benchmarks and Agreement for the Major Code Models Related to Level 1 Phenomena

| Benchmark Type<br>(entry in Appendix F)               | Identifier, Sequences, and Plant Type  | Agreement for Major Code Models |                                                              |                   |                                                   |                                 |                                         | Principal Sources of Documentation for the Benchmark |
|-------------------------------------------------------|----------------------------------------|---------------------------------|--------------------------------------------------------------|-------------------|---------------------------------------------------|---------------------------------|-----------------------------------------|------------------------------------------------------|
|                                                       |                                        | Overall Code                    | Primary System Thermal Hydraulics (pressure and water level) |                   | SG Thermal Hydraulics (pressure and water level)  | Core Heat-Up (core temperature) | Containment Thermal Response (pressure) |                                                      |
|                                                       |                                        |                                 | BWR                                                          | PWR               |                                                   |                                 |                                         |                                                      |
| Integral code—compared to SR5 and MELCOR (IC5 2 of 2) | SBO for Maanshan; WLD                  | Good                            | —                                                            | Fair to good      | Good (U-tube, region model not specified)         | Good                            | —                                       | Journal paper and doctoral dissertation              |
| Integral code—compared to CENTS (IC6)                 | MLOCA for Palo Verde; WLD              | Inconclusive                    | —                                                            | Inconclusive      | Inconclusive (U-tube, region model not specified) | —                               | —                                       | Presentation to the MUG                              |
| Integral code—compared to CATHARE (IC7)               | S/M LOCAs; EDF/ Framatome PWR 900      | Good                            | —                                                            | Good to very good | Very good (U-tube, one-region model)              | —                               | —                                       | EDF technical report                                 |
| Integral code—compared to SR5 and MELCOR (IC8)        | TMLB' (SBO with no RCP seal leak); WLD | Good                            | —                                                            | Fair to good      | Good (U-tube, one-region model)                   | Indirect support                | —                                       | Journal paper                                        |

**Table 7-1 (continued)**  
**Collected Benchmarks and Agreement for the Major Code Models Related to Level 1 Phenomena**

| Benchmark Type<br>(entry in Appendix F) | Identifier, Sequences, and Plant Type                                 | Agreement for Major Code Models                                       |                                                              |              |                                                  |                                 |                                         | Principal Sources of Documentation for the Benchmark |
|-----------------------------------------|-----------------------------------------------------------------------|-----------------------------------------------------------------------|--------------------------------------------------------------|--------------|--------------------------------------------------|---------------------------------|-----------------------------------------|------------------------------------------------------|
|                                         |                                                                       | Overall Code                                                          | Primary System Thermal Hydraulics (pressure and water level) |              | SG Thermal Hydraulics (pressure and water level) | Core Heat-Up (core temperature) | Containment Thermal Response (pressure) |                                                      |
|                                         |                                                                       |                                                                       | BWR                                                          | PWR          |                                                  |                                 |                                         |                                                      |
| Integral code—compared to RELAP5 (IC9)  | LOOP with F&B for Millstone; CE                                       | Good                                                                  | —                                                            | Fair to good | Good (U-tube, one-region model)                  | Good                            | —                                       | Presentation to the MUG                              |
| Integral code—compared to MELCOR (IC10) | TMLB, LLOCAs and SLOCA; WLD<br><br>SBO, transients, and LLOCA; BWR    | Good                                                                  | Not available                                                | Good         | —                                                | —                               | —                                       | Conference proceedings                               |
| Integral code—compared to SAFE (IC11)   | Transients, SLOCA, and MSLB in 1992 MAAP3B Qualification Studies; BWR | Generally but not specifically applicable; good agreement with MAAP3B | —                                                            | —            | —                                                | —                               | —                                       | EPRI technical report                                |



Table 7-1 (continued)

## Collected Benchmarks and Agreement for the Major Code Models Related to Level 1 Phenomena

| Benchmark Type<br>(entry in Appendix F)           | Identifier, Sequences, and Plant Type                                                                               | Agreement for Major Code Models                                       |                                                              |           |                                                  |                                 |                                         | Principal Sources of Documentation for the Benchmark |
|---------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------|--------------------------------------------------------------|-----------|--------------------------------------------------|---------------------------------|-----------------------------------------|------------------------------------------------------|
|                                                   |                                                                                                                     | Overall Code                                                          | Primary System Thermal Hydraulics (pressure and water level) |           | SG Thermal Hydraulics (pressure and water level) | Core Heat-Up (core temperature) | Containment Thermal Response (pressure) |                                                      |
|                                                   |                                                                                                                     |                                                                       | BWR                                                          | PWR       |                                                  |                                 |                                         |                                                      |
| Integral code—compared to RELAP and RETRAN (IC12) | Transients, failed-open PORV, SGTRs, SLOCAs, and MSLB in 1992 MAAP3B Qualification Studies; Westing-house four-loop | Generally but not specifically applicable; good agreement with MAAP3B | —                                                            | —         | —                                                | —                               | —                                       | EPRI technical report                                |
| Integral experiments (IE1)                        | BETHSY LOFWs with F&B and SLOCA; EDF/ Framatome PWR 900                                                             | Very good                                                             | —                                                            | Very good | Very good (U-tube, one- and two-region models)   | —                               | —                                       | Presentation to the MUG                              |
| Integral experiments (IE2)                        | IIST SBO; WLD                                                                                                       | Very good                                                             | —                                                            | Very good | Very good (U-tube, one-region model)             | Very good                       | —                                       | Conference proceedings                               |

**Table 7-1 (continued)**  
**Collected Benchmarks and Agreement for the Major Code Models Related to Level 1 Phenomena**

| Benchmark Type<br>(entry in Appendix F)          | Identifier, Sequences, and Plant Type      | Agreement for Major Code Models |                                                              |           |                                                  |                                 |                                         | Principal Sources of Documentation for the Benchmark |
|--------------------------------------------------|--------------------------------------------|---------------------------------|--------------------------------------------------------------|-----------|--------------------------------------------------|---------------------------------|-----------------------------------------|------------------------------------------------------|
|                                                  |                                            | Overall Code                    | Primary System Thermal Hydraulics (pressure and water level) |           | SG Thermal Hydraulics (pressure and water level) | Core Heat-Up (core temperature) | Containment Thermal Response (pressure) |                                                      |
|                                                  |                                            |                                 | BWR                                                          | PWR       |                                                  |                                 |                                         |                                                      |
| Integral experiments (IE3)                       | MB-2 LOFWs, MSLBs, and MSLB with SGTR; WLD | Very good                       | —                                                            | —         | Very good (U-tube, two-region model)             | —                               | —                                       | Conference proceedings                               |
| Integral experiment (IE4)                        | OSU SLOCAs and failed-open PORVs; AP600    | Very good                       | —                                                            | Very good | Very good (U-tube, two-region model)             | —                               | —                                       | Conference proceedings                               |
| Integral experiment (IE5)                        | Waltz Mill containment; generic            | —                               | —                                                            | —         | —                                                | —                               | Fair                                    | MAAP4 User's Manual                                  |
| Integral experiment (IE7; see Table 7-2 for IE6) | CSTF containment; generic                  | —                               | —                                                            | —         | —                                                | —                               | Very good                               | MAAP4 User's Manual                                  |
| Integral experiment (IE8)                        | HDR containment; generic                   | —                               | —                                                            | —         | —                                                | —                               | Very good                               | Journal paper and conference proceedings             |
| Integral experiment (IE9)                        | ISP-35 containment; generic                | —                               | —                                                            | —         | —                                                | —                               | Very good                               | Conference proceedings                               |

Table 7-1 (continued)

## Collected Benchmarks and Agreement for the Major Code Models Related to Level 1 Phenomena

| Benchmark Type<br>(entry in Appendix F) | Identifier, Sequences, and Plant Type                                            | Agreement for Major Code Models                                       |                                                              |     |                                                  |                                 |                                         | Principal Sources of Documentation for the Benchmark |
|-----------------------------------------|----------------------------------------------------------------------------------|-----------------------------------------------------------------------|--------------------------------------------------------------|-----|--------------------------------------------------|---------------------------------|-----------------------------------------|------------------------------------------------------|
|                                         |                                                                                  | Overall Code                                                          | Primary System Thermal Hydraulics (pressure and water level) |     | SG Thermal Hydraulics (pressure and water level) | Core Heat-Up (core temperature) | Containment Thermal Response (pressure) |                                                      |
|                                         |                                                                                  |                                                                       | BWR                                                          | PWR |                                                  |                                 |                                         |                                                      |
| integral experiment (IE10)              | Semiscale: SLOCAs, LOOPs, and SGTRs in 1992 MAAP3B Qualification Studies for PWR | Generally but not specifically applicable; good agreement with MAAP3B | —                                                            | —   | —                                                | —                               | —                                       | EPRI technical report                                |
| Integral experiment (IE11)              | FIST: LOFWs and MLOCA in 1992 MAAP3B Qualification Studies for BWR               | Generally but not specifically applicable; good agreement with MAAP3B | —                                                            | —   | —                                                | —                               | —                                       | EPRI technical report                                |
| Integral experiment (IE12)              | MIST: SLOCAs in 1992 MAAP3B Qualification Studies for B&W                        | Generally but not specifically applicable; good agreement with MAAP3B | —                                                            | —   | —                                                | —                               | —                                       | EPRI technical report                                |

<sup>a</sup> One exception to the agreement is suspected to be the result of input differences.

<sup>b</sup> The exception to the agreement is a minor limitation in MAAP4 related to condensation in the steam generators.

**Table 7-2**  
**Collected Benchmarks and Validation of Significant Code Capabilities Related to Level 1 Phenomena**

| Benchmark Type<br>(entry in Appendix F) | Identifier and Plant Type                       | Capabilities                                                    |                                 |                                   |                 |      | Principal Sources of Documentation for the Benchmark |
|-----------------------------------------|-------------------------------------------------|-----------------------------------------------------------------|---------------------------------|-----------------------------------|-----------------|------|------------------------------------------------------|
|                                         |                                                 | Critical Flow Model                                             | ECCS Injection                  | Condenser Heat Transfer           | Voiding in Core | HLNC |                                                      |
| Plant event (PE3)                       | Oyster Creek LOFW; BWR with isolation condenser | —                                                               | —                               | BWR isolation condenser validated | —               | —    | MAAP4 User's Manual                                  |
| Plant event (PE4)                       | Prairie Island SGTR; WLD                        | —                                                               | PWR hardwired model validated   | —                                 | —               | —    | MAAP4 User's Manual                                  |
| Integral code—compared to CENTS (IC1)   | SBO and LOFW with F&B; CE                       | Qualitative support (PORV flow)                                 | PWR generalized model validated | —                                 | —               | —    | Conference proceedings                               |
| Integral code—compared to SR5 (IC2)     | LOFW and S/MLOCAs; U.S. EPR                     | Qualitative support (safety valve flow); validated (break flow) | —                               | —                                 | —               | —    | Conference proceedings                               |
| Integral code—compared to TRACG02 (IC3) | LOOPs with LLOCAs; BWR                          | Validated (break flow)                                          | BWR model validated             | —                                 | —               | —    | GE technical report                                  |

Table 7-2 (continued)

## Collected Benchmarks and Validation of Significant Code Capabilities Related to Level 1 Phenomena

| Benchmark Type<br>(entry in Appendix F)        | Identifier and Plant Type              | Capabilities                    |                                 |                         |                 |      | Principal Sources of Documentation for the Benchmark |
|------------------------------------------------|----------------------------------------|---------------------------------|---------------------------------|-------------------------|-----------------|------|------------------------------------------------------|
|                                                |                                        | Critical Flow Model             | ECCS Injection                  | Condenser Heat Transfer | Voiding in Core | HLNC |                                                      |
| Integral code—compared to RELAP5 (IC4)         | SBO with F&B for Palisades; CE         | Qualitative support (PORV flow) | PWR generalized model validated | —                       | —               | —    | Erigo letter report and presentations to the MUG     |
| Integral code—compared to CENTS (IC6)          | MLOCA for Palo Verde; WLD              | Validated (break flow)          | —                               | —                       | —               | —    | Presentation to the MUG                              |
| Integral code—compared to CATHARE (IC7)        | S/M LOCAs; EDF/ Framatome PWR 900      | Validated (break flow)          | —                               | —                       | —               | —    | EDF technical report                                 |
| Integral code—compared to SR5 and MELCOR (IC8) | TMLB' (SBO with no RCP seal leak); WLD | Qualitative support (PORV flow) | —                               | —                       | —               | —    | Journal paper                                        |

**Table 7-2 (continued)**  
**Collected Benchmarks and Validation of Significant Code Capabilities Related to Level 1 Phenomena**

| Benchmark Type<br>(entry in Appendix F) | Identifier and Plant Type                               | Capabilities                    |                                     |                         |                     |      | Principal Sources of Documentation for the Benchmark |
|-----------------------------------------|---------------------------------------------------------|---------------------------------|-------------------------------------|-------------------------|---------------------|------|------------------------------------------------------|
|                                         |                                                         | Critical Flow Model             | ECCS Injection                      | Condenser Heat Transfer | Voiding in Core     | HLNC |                                                      |
| Integral code—compared to RELAP5 (IC9)  | LOOP with F&B for Millstone; CE                         | Validated (PORV flow)           | PWR validated (model not specified) | —                       | —                   | —    | Presentation to the MUG                              |
| Integral experiment (IE1)               | BETHSY LOFWs with F&B and SLOCA; EDF/ Framatome PWR 900 | Validated (break and PORV flow) | PWR generalized model validated     | —                       | Qualitative support | —    | Presentation to the MUG                              |
| Integral experiment (IE3)               | MB-2 LOFWs, MSLBs, and MSLB with SGTR; WLD              | Validated (break flow)          | —                                   | —                       | —                   | —    | Conference proceedings                               |
| Integral experiment (IE4)               | OSU SLOCAs and failed-open PORVs; AP600                 | Validated (break and PORV flow) | PWR validated (passive systems)     | —                       | —                   | —    | Conference proceedings                               |

Table 7-2 (continued)

## Collected Benchmarks and Validation of Significant Code Capabilities Related to Level 1 Phenomena

| Benchmark Type<br>(entry in Appendix F) | Identifier and Plant Type                  | Capabilities                                  |                |                             |                                        |                               | Principal Sources of Documentation for the Benchmark |
|-----------------------------------------|--------------------------------------------|-----------------------------------------------|----------------|-----------------------------|----------------------------------------|-------------------------------|------------------------------------------------------|
|                                         |                                            | Critical Flow Model                           | ECCS Injection | Condenser Heat Transfer     | Voiding in Core                        | HLNC                          |                                                      |
| Integral experiment (IE5)               | Waltz Mill containment; generic            | —                                             | —              | PWR ice condenser validated | —                                      | —                             | MAAP4 User's Manual                                  |
| Integral experiment (IE6)               | PNL ice containment; WICE                  | —                                             | —              | PWR ice condenser validated | —                                      | —                             | MAAP4 User's Manual                                  |
| Separate effects experiment (SE1)       | THTF; generic                              | —                                             | —              | —                           | Validation of void fraction subroutine | —                             | MAAP4 User's Manual                                  |
| Separate effects experiments (SE2)      | Westing-house 1/7 <sup>th</sup> scale; PWR | —                                             | —              | —                           | —                                      | Validation of HLNC subroutine | MAAP4 User's Manual and EPRI technical report        |
| Separate effects experiment (SE3)       | Marviken and FAI blowdown; PWR             | Validated (PORV flow, also pressurizer model) | —              | —                           | —                                      | —                             | MAAP4 User's Manual                                  |

**Table 7-3**  
**Compilation of the Agreement for the Major Code Models Related to Level 1 Phenomena<sup>a</sup>**

| Major Code Model                       | Number of Benchmarks Reviewed by Experts | Agreement <sup>b</sup> |                   |                            |              |        |                         |              |
|----------------------------------------|------------------------------------------|------------------------|-------------------|----------------------------|--------------|--------|-------------------------|--------------|
|                                        |                                          | Very Good              | Good to Very Good | Good and Fair to Very Good | Fair to Good | Fair   | Qualitative or Indirect | Inconclusive |
| Overall code for BWR analysis          | 4                                        | 1                      | —                 | 3                          | —            | —      | —                       | —            |
| BWR primary system thermal hydraulics  | 3                                        | —                      | —                 | 2                          | 1            | —      | —                       | —            |
| Overall code for PWR analysis          | 18                                       | 5                      | —                 | 11                         | —            | 1      | —                       | 1            |
| PWR primary system thermal hydraulics  | 17                                       | 4                      | 3                 | 4                          | 5            | —      | —                       | 1            |
| PWR steam generator thermal hydraulics | 13                                       | 5 U-tube               | —                 | 5 U-tube                   | 1 U-tube     | 1 OTSG | —                       | 1 U-tube     |
| Core heat-up (generic to BWR and PWR)  | 8                                        | 1                      | —                 | 4                          | —            | 1      | 2                       | —            |
| Containment (generic to BWR and PWR)   | 5                                        | 3                      | —                 | —                          | —            | 1      | 1                       | —            |

<sup>a</sup> Does not include the MAAP3B benchmarks that are generally but not specifically applicable (good agreement obtained with MAAP3B).

<sup>b</sup> No poor agreement with the benchmarks was identified for any of the major code models.

Third, all of the assembled benchmark information was reviewed to determine in an overall sense either that MAAP4 is an appropriate tool for Level 1 analysis or that there are significant issues that adversely affect the adequacy of the code for such applications. It was concluded that the benchmarks support the use of MAAP4 for Level 1 analysis as long as users are aware of and follow the guidance in the other sections of this report, particularly Sections 3–6 and 8, and the corresponding appendices.



**Table 7-4**  
**Compilation of the Validation of Significant Code Capabilities Related to Level 1**  
**Phenomena**

| Code Capability                           |                                | Number of Benchmarks Reviewed by Experts |                                    |
|-------------------------------------------|--------------------------------|------------------------------------------|------------------------------------|
|                                           |                                | Explicit Validation                      | Qualitative or Indirect Validation |
| Critical flow model                       | PORV and SRV flow applications | 4 (including pressurizer model)          | 4                                  |
|                                           | Break flow applications        | 7                                        | —                                  |
| ECCS injection                            | BWR model                      | 1                                        | —                                  |
|                                           | PWR models                     | 6                                        | —                                  |
| Condenser heat transfer                   | BWR isolation condenser        | 1                                        | —                                  |
|                                           | PWR ice condenser              | 2                                        | —                                  |
| Voiding in the core                       |                                | 1                                        | 1                                  |
| HLNC                                      |                                | 1                                        | —                                  |
| Drywell/fan cooler heat and mass transfer |                                | 0                                        | —                                  |

**Table 7-5**  
**BWR Sequences Supported by Benchmarks**

| Sequence Initiating Event                                                                                                                                                     | Type of Benchmark (entry in Appendix F)              | Number and Types of Sequences | Overall Agreement                                                | Sequence Time Frame |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------|-------------------------------|------------------------------------------------------------------|---------------------|
| <b>BWR transients</b><br>(including SBOs, LOFW, and turbine trips)<br><br><b>Total with MAAP4:</b><br><b>3 + 4 minor support</b><br><br><b>Total with MAAP3B:</b><br><b>6</b> | Plant event: Oyster Creek (PE3)                      | 1 LOFW                        | Very good                                                        | 30 min              |
|                                                                                                                                                                               | Integral code comparison to TRACG02 (IC3)            | 2 LOOPs with LLOCAs           | Good                                                             | 8 min               |
|                                                                                                                                                                               | Integral code comparison to SAFE (IC11)—MAAP3B       | 4 LOFW                        | Good agreement with MAAP3B                                       | 15 min–2 hr         |
|                                                                                                                                                                               | Integral experiment comparison to FIST (IE11)—MAAP3B | 2 LOFW                        | Good agreement with MAAP3B                                       | 15–50 min           |
|                                                                                                                                                                               | Integral code comparison to MELCOR (IC10)            | 1 SBO and 3 transients        | Good: only a minor supporting benchmark for Level 1 applications | 40 hr               |
| <b>BWR LLOCAs</b><br>(excluding MSLBs)<br><br><b>Total with MAAP4:</b><br><b>3 + 1 minor support</b>                                                                          | Integral code comparison to TRACG02 (IC3)            | 2 LOOPs with LLOCA            | Good                                                             | 8 min               |
|                                                                                                                                                                               | Integral code comparison to SR5 and MELCOR (IC5)     | 1 LLOCA                       | Good                                                             | 4 hr                |
|                                                                                                                                                                               | Integral code comparison to MELCOR (IC10)            | 1 LLOCA                       | Good: only a minor supporting benchmark for Level 1 applications | 40 hr               |
| <b>BWR MLOCAs and SLOCAs</b><br><br><b>None with MAAP4</b><br><br><b>Total with MAAP3B:</b><br><b>2</b>                                                                       | Integral code comparison to SAFE (IC11)—MAAP3B       | 1 SLOCA                       | Good agreement with MAAP3B                                       | 1 hr                |
|                                                                                                                                                                               | Integral experiment comparison to FIST (IE11)—MAAP3B | 1 MLOCA                       | Good agreement with MAAP3B                                       | 8 min               |
| <b>BWR MSLBs</b><br><br><b>None with MAAP4</b><br><br><b>Total with MAAP3B:</b><br><b>1</b><br><br>Can be considered a subset of LLOCAs                                       | Integral code comparison to SAFE (IC11)—MAAP3B       | 1 MSLB                        | Good agreement with MAAP3B                                       | 7 min               |

**Table 7-5 (continued)**  
**BWR Sequences Supported by Benchmarks**

| <b>Sequence Initiating Event</b>                                          | <b>Type of Benchmark (entry in Appendix F)</b>                                                                                                                                                                                                                            | <b>Number and Types of Sequences</b> | <b>Overall Agreement</b> | <b>Sequence Time Frame</b> |
|---------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------|--------------------------|----------------------------|
| <b>BWR interfacing system LOCAs</b><br>(discharge outside of containment) | No supporting benchmarks, but essentially covered by LLOCA and S/MLOCA benchmarks.                                                                                                                                                                                        |                                      |                          |                            |
| <b>BWR stuck-open SRVs</b>                                                | No supporting benchmarks with stuck-open SRVs as an initiator, but similar to SLOCAs if discharge is to the gas space (versus to the suppression pool). Sequences are also supported by benchmarks in which stuck-open or manually opened SRVs are subsequent conditions. |                                      |                          |                            |
| <b>BWR feedwater line breaks</b>                                          | No supporting benchmarks, but essentially covered by S/MLOCA benchmarks.                                                                                                                                                                                                  |                                      |                          |                            |
| <b>BWR ATWS</b>                                                           | No supporting benchmarks.                                                                                                                                                                                                                                                 |                                      |                          |                            |

**Table 7-6**  
**PWR Sequences Supported by Benchmarks**

| Sequence Initiating Event                                                                                                                                                      | Type of Benchmark (entry in Appendix F)          | Number and Types of Sequences        | Plant Type    | Steam Generator Type and Model     | Overall Agreement          | Sequence Time Frame |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------|--------------------------------------|---------------|------------------------------------|----------------------------|---------------------|
| <b>PWR transients</b><br>(including SBOs, LOFW, and turbine trips)<br><br><b>Total with MAAP4:</b><br><b>19 + 1 minor support</b><br><br><b>Total with MAAP3B:</b><br><b>6</b> | Plant event: TMI-2 (PE1)                         | 1 LOFW with stuck-open PORV          | B&W           | OTSG, one-region model             | Very good                  | 5 hr                |
|                                                                                                                                                                                | Plant event: Davis-Besse (PE2)                   | 1 LOFW                               | B&W           | —                                  | Fair                       | 30 min              |
|                                                                                                                                                                                | Plant event: Maanshan (PE5)                      | 1 SBO                                | WLD           | —                                  | Good                       | 3 hr                |
|                                                                                                                                                                                | Plant event: Oconee (PE6)                        | 1 plant trip                         | B&W           | —                                  | Good                       | 15 min              |
|                                                                                                                                                                                | Plant event: four-loop (PE7)—MAAP3B              | 1 LOOP and 1 plant trip              | Westing-house | —                                  | Good agreement with MAAP3B | 3–5 min             |
|                                                                                                                                                                                | Integral code comparison to CENTS (IC1)          | 1 SBO and 1 LOFW with feed and bleed | CE            | U-tube, two-region model           | Good                       | 3 hr                |
|                                                                                                                                                                                | Integral code comparison to SR5 (IC2)            | 3 LOFWs                              | U.S. EPR      | U-tube, one-region model           | Good                       | 2 hr                |
|                                                                                                                                                                                | Integral code comparison to RELAP5 (IC4)         | 2 SBOs with feed and bleed           | CE            | U-tube, one-region model           | Good                       | 5–10 hr             |
|                                                                                                                                                                                | Integral code comparison to SR5 and MELCOR (IC5) | 1 SBO                                | WLD           | U-tube, region model not specified | Good                       | 5 hr                |
|                                                                                                                                                                                | Integral code comparison to SR5 and MELCOR (IC8) | 1 TMLB' (SBO, no RCP seal leak)      | WLD           | U-tube, one-region model           | Good                       | 5 hr                |
|                                                                                                                                                                                | Integral code comparison to RELAP5 (IC9)         | 1 LOOP with feed and bleed           | CE            | U-tube, one-region model           | Good                       | 3 hr                |

**Table 7-6 (continued)**  
**PWR Sequences Supported by Benchmarks**

| Sequence Initiating Event                                                           | Type of Benchmark (entry in Appendix F)                    | Number and Types of Sequences     | Plant Type            | Steam Generator Type and Model | Overall Agreement                                                              | Sequence Time Frame |
|-------------------------------------------------------------------------------------|------------------------------------------------------------|-----------------------------------|-----------------------|--------------------------------|--------------------------------------------------------------------------------|---------------------|
|                                                                                     | Integral code comparison to MELCOR (IC10)                  | 1 TMLB (SBO with RCP seal leak)   | WLD                   | —                              | Good: only a minor supporting benchmark for Level 1 applications               | 40 hr               |
|                                                                                     | Integral code comparison to RELAP and RETRAN (IC12)—MAAP3B | 2 transients                      | Westing-house         | —                              | Good agreement with MAAP3B plus code changes that were incorporated into MAAP4 | 5 min–1.4 hr        |
|                                                                                     | Integral experiment comparison to BETHSY (IE1)             | 2 LOFWs with feed and bleed       | 900 MWe EDF/Framatome | U-tube, one-region model       | Very good                                                                      | 1–2 hr              |
|                                                                                     | Integral experiment to IIST (IE2)                          | 1 SBO                             | WLD                   | U-tube, one-region model       | Very good                                                                      | 3 hr                |
|                                                                                     | Integral experiment comparison to MB-2 (IE3)               | 2 LOFWs                           | WLD                   | U-tube, two-region model       | Very good                                                                      | 2–12 min            |
|                                                                                     | Integral experiment comparison to Semiscale (IE10)—MAAP3B  | 2 LOOPs                           | Generic PWR           | —                              | Good agreement with MAAP3B                                                     | 3–5 hr              |
| <b>PWR LLOCAs</b> (excluding MSLBs)<br><br><b>Total with MAAP4: 2 minor support</b> | Integral code comparison to MELCOR (IC10)                  | 2 LLOCAs: location not identified | WLD                   | —                              | Good: only a minor supporting benchmark for Level 1 applications               | 40 hr               |

**Table 7-6 (continued)**  
**PWR Sequences Supported by Benchmarks**

| Sequence Initiating Event                                                                                            | Type of Benchmark (entry in Appendix F)                    | Number and Types of Sequences                                                                                                                    | Plant Type            | Steam Generator Type and Model     | Overall Agreement                                                              | Sequence Time Frame |
|----------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|------------------------------------|--------------------------------------------------------------------------------|---------------------|
| <b>PWR MLOCAs and SLOCAs</b><br><br><i>Total with MAAP4: 12 + 1 minor support</i><br><br><i>Total with MAAP3B: 8</i> | Integral code comparison to SR5 (IC2)                      | 1 SLOCA: location not identified<br><br>1 MLOCA: location not identified                                                                         | U.S. EPR              | U-tube, one-region model           | Good                                                                           | 2 hr                |
|                                                                                                                      | Integral code comparison to CENTS (IC6)                    | 1 MLOCA: break in the intermediate leg                                                                                                           | WLD                   | U-tube, region model not specified | Inconclusive                                                                   | 5 hr                |
|                                                                                                                      | Integral code comparison to CATHARE (IC7)                  | 1 SLOCA: break in the hot leg<br><br>1 MLOCA: break in the hot leg<br><br>3 SLOCAs: breaks in the cold leg<br><br>1 MLOCA: break in the cold leg | 900 MWe EDF/Framatome | U-tube, one-region model           | Good                                                                           | 2–12 hr             |
|                                                                                                                      | Integral code comparison to MELCOR (IC10)                  | 1 SLOCA: location not identified                                                                                                                 | WLD                   | —                                  | Good: only a minor supporting benchmark for Level 1 applications               | 40 hr               |
|                                                                                                                      | Integral code comparison to RELAP and RETRAN (IC12)—MAAP3B | 2 SLOCAs: breaks in the cold leg                                                                                                                 | Westing-house         | —                                  | Good agreement with MAAP3B plus code changes that were incorporated into MAAP4 | 30 min–1 hr         |

**Table 7-6 (continued)**  
**PWR Sequences Supported by Benchmarks**

| Sequence Initiating Event                                                                | Type of Benchmark (entry in Appendix F)                                            | Number and Types of Sequences         | Plant Type             | Steam Generator Type and Model | Overall Agreement                                                              | Sequence Time Frame |
|------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|---------------------------------------|------------------------|--------------------------------|--------------------------------------------------------------------------------|---------------------|
|                                                                                          | Integral experiment comparison to BETHSY (IE1)                                     | 1 SLOCA: break in the cold leg        | 900 MWe EDF/ Framatome | U-tube, two-region model       | Very good                                                                      | 2 hr                |
|                                                                                          | Integral experiment comparison to OSU (IE4)                                        | 2 SLOCAs: breaks in an injection line | AP600                  | U-tube, two-region model       | Very good                                                                      | Not provided        |
|                                                                                          | Integral experiment comparison to Semiscale (IE10)—MAAP3B                          | 4 SLOCAs: breaks in the cold leg      | Generic PWR            | —                              | Good agreement with MAAP3B                                                     | 13–50 min           |
|                                                                                          | Integral experiment comparison to MIST (IE12)—MAAP3B                               | 2 SLOCAs: breaks in the cold leg      | B&W                    | —                              | Good agreement with MAAP3B                                                     | 1–12 hr             |
| <b>PWR interfacing system LOCAs</b><br>(discharge outside of containment)                | No supporting benchmarks, but essentially covered by LLOCA and S/MLOCA benchmarks. |                                       |                        |                                |                                                                                |                     |
| <b>PWR stuck-open PORVs</b><br><i>Total with MAAP4: 2</i><br><i>Total with MAAP3B: 1</i> | Integral code comparison to RELAP and RETRAN (IC12)—MAAP3B                         | 1 failed-open PORV                    | Westing-house          | —                              | Good agreement with MAAP3B plus code changes that were incorporated into MAAP4 | 8 min               |
|                                                                                          | Integral experiment comparison to OSU (IE4)                                        | 2 failed-open PORVs                   | AP600                  | U-tube, two-region model       | Very good                                                                      | Not provided        |

**Table 7-6 (continued)**  
**PWR Sequences Supported by Benchmarks**

| Sequence Initiating Event                                                     | Type of Benchmark (entry in Appendix F)                                                    | Number and Types of Sequences | Plant Type    | Steam Generator Type and Model | Overall Agreement                                                              | Sequence Time Frame        |
|-------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|-------------------------------|---------------|--------------------------------|--------------------------------------------------------------------------------|----------------------------|
| <b>PWR SGTR</b><br><i>Total with MAAP4: 1</i><br><i>Total with MAAP3B: 5</i>  | Plant event: Prairie Island (PE4)                                                          | 1 SGTR                        | WLD           | —                              | Good                                                                           | 8 min                      |
|                                                                               | Integral code comparison to RELAP and RETRAN (IC12)—MAAP3B                                 | 2 SGTRs                       | Westing-house | —                              | Good agreement with MAAP3B plus code changes that were incorporated into MAAP4 | 50 min                     |
|                                                                               | Integral experiment comparison to Semiscale (IE10)—MAAP3B                                  | 3 SGTRs                       | Generic PWR   | —                              | Good agreement with MAAP3B                                                     | 5–40 min                   |
| <b>PWR MSLBs</b><br><i>Total with MAAP4: 3</i><br><i>Total with MAAP3B: 1</i> | Integral code comparison to RELAP and RETRAN (IC12)—MAAP3B                                 | 1 MSLB                        | Westing-house | —                              | Good agreement with MAAP3B plus code changes that were incorporated into MAAP4 | 5 min                      |
|                                                                               | Integral experiment comparison to MB-2 (IE3)                                               | 2 MSLBs<br>1 MSLB with SGTR   | WLD           | U-tube, two-region model       | Very good                                                                      | 2–3 min<br>17 min for SGTR |
| <b>PWR feedwater line breaks</b>                                              | No supporting benchmarks, but similar to LOCAs and, to a lesser extent, MSLBs.             |                               |               |                                |                                                                                |                            |
| <b>PWR mid-loop operation</b>                                                 | No supporting benchmarks.                                                                  |                               |               |                                |                                                                                |                            |
| <b>PWR ATWS</b>                                                               | No supporting benchmarks, but typically a very low contributor to core damage frequencies. |                               |               |                                |                                                                                |                            |



# 8

## RANGE OF APPLICABILITY, LIMITATIONS, PRECAUTIONS, AND ISSUES FOR FUTURE CONSIDERATION

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As discussed in Section 3, one criterion for producing high-quality MAAP4 analyses is an understanding of the code's range of applicability and its limitations. Of particular importance is the applicability of MAAP4 for generating results that can be used to determine success criteria and HRA timing. Users should also be cognizant of precautions and other pertinent recommendations. Tables 8-1 and 8-2 contain overall recommendations regarding the applicability of the BWR and PWR codes for Level 1 analysis, respectively. The recommendations are listed as a function of sequence type and plant feature.

The tables indicate whether the code can be run in *standard mode*, that is, using the existing models and addressing uncertainties using the guidance in Section 4 of this report, or whether the standard mode should be *augmented* by one or more of the following:

- Perform additional sensitivity analyses.
- Run a set of sequences to bracket the scenario(s) of interest.
- Add logic to the input and parameter files to compensate for limitations in the code. (This approach is particularly suitable for limitations related to balance-of-plant features that are outside the scope of the code.)
- *Baseline* the analyses using the results from more detailed analysis tools, for example, design basis codes.

The tables also indicate if the code is applicable for determining success criteria and HRA timing for short time frames (from the first three minutes after the initiating event to about ten minutes) and long time frames (from about ten minutes to tens of hours).

Specific limitations, precautions, notes, recommendations, and issues for further code development and user support are also listed in Tables 8-1 and 8-2. These items were extracted from the review of benchmarks (discussed in Section 7 and Appendix F of this report), contributed by the expert benchmark review team based on their knowledge of code models and their experience with code applications, and obtained from the MAAP4 web site.

The information in Tables 8-1 and 8-2 should be used in conjunction with the other information in this report, particularly the information in Sections 4, 5, and 6 and Appendices B and C. Inherently, the lists of limitations and precautions in the tables is not exhaustive. Users should also consult the code web site to keep up-to-date with code developments and additional issues.

**Table 8-1**  
**MAAP4 BWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis**

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|-------------------------------------------|-----------------------------------|---------------------------------|---------------------------------------------------|-----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| All BWR sequences                         | —                                 | —                               | —                                                 | —         | <p><b>Limitation of scope, 0–10 seconds:</b> MAAP4 is not the appropriate tool for predicting the very short-term response of a plant to an accident initiator. [from expert team recommendations]</p> <p><b>Limitation of scope, 10 seconds–3 minutes:</b> <i>MAAP4 should not be used to predict the <b>quantitative</b> response of the plant in the first three minutes of any BWR accident sequence.</i> This includes the details of the primary system conditions, mass and energy releases to the containment, and heat-up of the core (for example, peak cladding temperatures) because the code does not contain the logic features of the feedwater controller and pressure regulator systems and does not have a detailed neutronics model. Input components can be added to simulate the logic for the control systems, but this is outside the expected scope of code applications. MAAP4 can be used to obtain limited quantitative results in this early time frame if the analysis is augmented with more detailed analysis methods. From a Level 1 PRA perspective, the detailed plant response in the first several minutes of an accident is not important unless it has a significant impact on RCS inventory, which is rarely the case. This limitation on using the code for this early time frame does not affect the use of the code for severe accidents beyond the time frame, provided that the RCS inventory is appropriate. [from expert team recommendations]</p> |

Table 8-1 (continued)

MAAP4 BWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|-------------------------------------------|-----------------------------------|---------------------------------|---------------------------------------------------|-----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| All BWR sequences, continued              |                                   |                                 |                                                   |           | <p><b>Note:</b> In the BWR code, the extent of steam voiding in the core and the resulting water displacement into the downcomer might not be fully represented during the early portion of a sequence (the first several minutes). The predicted water level response might also be delayed because the model for water circulation between the downcomer, core, and core bypass is somewhat simplified, with one node for the combined downcomer, jet pump (if applicable), and recirculation pump water and one node for the combined core, core bypass, core shroud head, riser, and separator water. [from benchmark PE3]</p> <p><b>Recommendation:</b> Users should be aware of the default logic in the code that applies to the modeling of plant systems. Of particular interest are code logic features related to initiating events and SRV operation. These are discussed in Section 5.3 of this report. Users should adjust input values and/or add input components so that the logic represents their plant. [from expert team recommendations]</p> |
| BWR transients                            | Yes                               | —                               | Yes                                               | Yes       | —                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |

Table 8-1 (continued)

MAAP4 BWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|-------------------------------------------|-----------------------------------|---------------------------------|---------------------------------------------------|-----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| BWR LLOCAs, including MSLBs               | No                                | Yes, due to limitation          | No                                                | Yes       | <p><b>Limitation:</b> MAAP4 should not be used to determine the plant response in any LLOCA sequence <b>during the period before the initial recovery of the core</b> by injection (reflooding). This limitation on the pre-recovery phase of an LLOCA is due to the fact that several potentially influential thermal-hydraulic phenomena are not included in the primary system model, such as reverse flow through the core, departure from nucleate boiling, and condensation on safety injection flow. In LLOCAs that would in actuality have flow reversal, such as a large break in the external recirculation piping, MAAP4 will initially under-predict the amount of mass and energy discharged through the break. After recovery with adequate injection to prevent core damage, as determined by alternative analysis methods, MAAP4 can be used for the remainder of an LLOCA. The effects of the early under-prediction of the mass and energy release and the lack of detail in the thermal-hydraulic modeling do not have a significant impact on the code results beyond the initial recovery. In particular, the under-prediction of mass through the break is somewhat self-correcting because the break flow is a function of the primary system inventory. The period before recovery is most likely less than three minutes, so this limitation meshes with the overall scope limitation listed at the top of this table. [from expert team recommendations]</p> |

Table 8-1 (continued)

MAAP4 BWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|-------------------------------------------|-----------------------------------|---------------------------------|---------------------------------------------------|-----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| BWR LLOCAs, continued                     |                                   |                                 |                                                   |           | <p><b>Precaution:</b> If the break is in a recirculation line, users should consider whether part of the injected flow would go directly out of the break. This can be modeled by reducing the number of RHR pumps or reducing the flow in the head-flow curve, and then modeling the part that would go immediately out of the break into the drywell using drywell sprays with zero fall height. It can also be addressed through the choice of the LPCI injection location using parameter IILPCI. [from expert team recommendations]</p> <p><b>Precaution:</b> The break area should be the chokepoint—that is, the minimum area—in the path from the primary system to the containment. [from expert team recommendations]</p> <p><b>Recommendation for users:</b> The sensitivity of LLOCA sequence results to a spectrum of effective break sizes and locations should be evaluated. [from expert team recommendations]</p> <p><b>Recommendation for users:</b> The sensitivity of LLOCA sequence results to <i>Model</i> parameters FELOCA and FNOMIX should be evaluated. [from expert team recommendations]</p> |

Table 8-1 (continued)

MAAP4 BWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis

| Sequence Type or Particular Plant Feature                    | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|--------------------------------------------------------------|-----------------------------------|---------------------------------|---------------------------------------------------|-----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                              | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| BWR<br>MLOCAs,<br>SLOCAs,<br>and<br>feedwater<br>line breaks | Yes                               | —                               | Yes                                               | Yes       | <p><b>Limitation:</b> The Rev. 4.0.6 and 4.0.7 versions of the code will under-predict break flow in SLOCAs when the break is covered by water, as would be the case when the injection rate is larger than the break flow, because of a code error. This can lead to the over-prediction of the times of key events such as CST depletion and the under-prediction of containment conditions such as pressure and temperature. This error has been corrected for Rev. 4.0.8. It is discussed in MAAP FLAASH 69. Users should incorporate the workaround provided in the MAAP FLAASH for the LOCA sequences that are run with Rev. 4.0.6 and Rev. 4.0.7. [from documentation on the code web site]</p> <p><b>Precaution:</b> The break area should be the chokepoint—that is, the minimum area—in the path from the primary system to the containment. [from expert team recommendations]</p> <p><b>Recommendation for users:</b> The sensitivity of S/MLOCA sequence results to a spectrum of effective break sizes and locations should be evaluated. [from expert team recommendations]</p> <p><b>Recommendation for users:</b> The sensitivity of S/MLOCA sequence results to <i>Model</i> parameter FELOCA should be evaluated. [from expert team recommendations]</p> |

**Table 8-1 (continued)**  
**MAAP4 BWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis**

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                          |
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|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| BWR interfacing system LOCAs              | Yes                               | —                               | Yes                                               | Yes       | <p><b>Precaution:</b> Because the run of pipe between the primary system and the discharge location outside of the containment will be substantial, the specified area of the break and the discharge coefficient should include the equivalent length of the pipe. [from expert team recommendations]</p> <p>The entries in this table for LLOCAs and for S/MLOCAs also apply to interfacing system LOCAs, depending on the size.</p>                                                                                                              |
| BWR stuck-open SRVs                       | Yes                               | —                               | Yes                                               | Yes       | —                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| BWR ATWS                                  | Yes                               | —                               | Yes                                               | Yes       | <p><b>Precaution:</b> The code does not have a reactivity feedback model, so it does not model the significant pressure spike that is expected to occur within the first several seconds of an ATWS. For this reason, it can not be used to determine the number of valves that is needed to respond to a transient following the closure of the MSIVs under ATWS conditions. In a PRA, an assessment of the required number of valves is dependent on the probability that not all of the valves will open. [from expert team recommendations]</p> |

**Table 8-1 (continued)**

**MAAP4 BWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis**

| Sequence Type or Particular Plant Feature                               | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
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|                                                                         | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| BWR plants with injection driven solely by gravity (including the ABWR) | —                                 | —                               | —                                                 | —         | <p><b>Issue for code development and user support:</b> A code change was made to the subroutine that calculates the heat transfer within the covered nodes of the core (subroutine COVER) for AP600 benchmark sequences. The change allows oscillations in the two-phase level swell associated with steaming due to injection followed by subcooling, which then allows more injection. In the standard version of the code, these oscillations are suppressed to avoid numerical difficulties. The model deficiency affects only those plants with injection that is driven solely by a gravity head (versus a differential gas pressure) such as the ABWR, and it was appropriate to model the oscillations in the benchmark sequences. The code change improved the detailed primary system water level agreement late in the transients after the primary system depressurized. Incorporating the change into the standard version of the code, primarily to improve calculations for sequences in which there is repeated core uncover with intermittent injection, is under consideration. [from benchmark IE4]</p> <p><b>Note:</b> The BWR code does not contain an explicit model for gravity-driven injection. The existing parameters for a pumped injection system can be used with input file components to augment the logic. Alternatively, a gravity-driven system can be modeled with a containment node and a generalized opening to the primary system with an appropriate discharge coefficient. [from expert team recommendations]</p> |



Table 8-1 (continued)

MAAP4 BWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
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|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Sequences with HPCI or RCIC injection     | —                                 | —                               | —                                                 | —         | <p><b>Limitation:</b> The HPCI and RCIC turbine exhaust steam enthalpy is not calculated prior to adding the exhaust to the receiving compartment, designated with pointer JNTUR, because of a code error. In Rev. 4.0.6 and earlier, the value of the enthalpy used for the steam is the enthalpy of another effluent stream from the primary system calculated during the previous time step, so the impact of the error is minor. In Rev. 4.0.7, the value used for the enthalpy is essentially 0.0 (because of a change in a compiler setting). This leads to a significant over-prediction of pressure and temperature in compartment JNTUR, causing the premature shutoff of the injection systems and the over-prediction of the pressure and temperature in the primary system. This error has been corrected for Rev. 4.0.8. It is discussed in MAAP FLAASH 70. Users should incorporate the workaround provided in the MAAP FLAASH for applicable sequences run with Rev. 4.0.7. [from documentation on the code web site]</p> <p><b>Note:</b> The code does not calculate the impact of a condenser on the HPCI or RCIC turbine exhaust prior to its discharge to the suppression pool. A condenser can be simulated with the generalized isolation condenser model. [from expert team recommendations]</p> |

**Table 8-1 (continued)**  
**MAAP4 BWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis**

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
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|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| BWR miscellaneous                         | —                                 | —                               | —                                                 | —         | <p><b>Limitation:</b> An error in the BWR code affects the initiation of systems that have time-dependent logic, that is, systems that use time delays or have recorded initiation times. This error has an impact when both the REPORT feature is used in the input file and the systems are initiated with external events in the INITIATORS block. The error causes the events not to be activated as initiators. This error has been corrected for Rev. 4.0.8. It is discussed in MAAP FLAASH 67. Users should incorporate the workaround provided in the MAAP FLAASH when using the REPORT feature.</p> <p><b>Limitation:</b> The ILOCK flag is intended to prevent the automatic opening of a BWR SRV in relief mode. Because of a logic error in the code, this feature does not operate as intended (it has been corrected for Rev. 4.0.8). Users can work around this issue either by setting the area of the valve, ASRV(<i>i</i>), to 0.0 or setting the relief mode opening pressure, PSETRV(<i>i</i>), to a large value.</p> <p><b>Limitation:</b> The code treats values assigned to MAAP4 variables in action blocks within user-defined event blocks in British parameter and input files as if they are in British units, even if explicit SI units labels are included with the values. This is the result of a code error that has been corrected in Rev. 4.0.7. Therefore, values should be in British units in action blocks when the default system of units is British.</p> <p><b>Limitation:</b> Input file components that incorporate parentheses or units labels might not be successfully processed, preventing the calculations from starting. Adding spaces before and after the parentheses and labels will generally resolve the difficulty. (Examples of this limitation are presented in Section 3.3.1.2 of this report.)</p> <p><b>Limitation:</b> Only one lower plenum heat sink should be included in the <i>Primary System</i> section of the parameter file because of a code error. This has been corrected in Rev. 4.0.7.</p> |

Table 8-1 (continued)

MAAP4 BWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
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|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| BWR miscellaneous, continued              |                                   |                                 |                                                   |           | <p><b>Note:</b> The code does not model systems downstream of the MSIVs or upstream of the feedwater heater outlet. The feedwater enthalpy is an input parameter. For sequences in which the transient properties of the feedwater are important, users should include logic to adjust the enthalpy using input file components. This is relevant for sequences in which the feedwater pumps can continue to operate but steam to the feedwater heaters is not available and a refined heat balance is desired (for example, for suppression pool calculations).</p> <p><b>Limitation:</b> The code can model a solid containment volume (that is, a water-filled volume) provided that it is connected by an open junction to a non-solid volume—not just to another solid volume. Additional junctions can be added for solid volumes to work around this limitation.</p> <p><b>Note:</b> The containment model does not account for the entrainment of water from the surface of water pools or from heat sinks (condensation films) resulting from the blowdown from the primary system or from the sparging of gases through the suppression pool. This is conservative because the entrained water would reduce the superheat in the containment atmosphere, which would lead to a lower pressure and temperature.</p> <p><b>Limitation:</b> Vertical stratification of the suppression pool water is not modeled. This can affect the condensation of effluent from the SRVs and from the drywell vents, which then affects containment pressure. Stratification can also impact the temperature of ECCS injection when suction is from the pool, although this is expected to be minimal because of the mixing that would occur.</p> |

**Table 8-1 (continued)**

**MAAP4 BWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis**

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
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|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| BWR miscellaneous, continued              |                                   |                                 |                                                   |           | <p><b>Note:</b> Division of the suppression pool by vertical walls such as in a Mark II plant can be accounted for by using more than one containment node to model the pool. This is particularly important if debris would fall only into one portion of a divided pool in Level 2 sequences.</p> <p><b>Note:</b> The values of parameters for injection systems should reflect delivered flow for the systems and should not be based solely on pump performance.</p> <p>[miscellaneous entries from expert team recommendations or from documentation on the code web site]</p> |
| Benchmark sequences                       | —                                 | —                               | —                                                 | —         | <p><b>Recommendation for users:</b> Comparisons of MAAP4 results with other codes or plant data should include a comparative assessment of the time of the plant trip and the water inventory at that time. This is important for establishing consistent initial conditions. [from expert team recommendations]</p>                                                                                                                                                                                                                                                                |

**Table 8-2**  
**MAAP4 PWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis**

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
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|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| All PWR sequences                         | —                                 | —                               | —                                                 | —         | <p><b>Limitation of scope, 0–10 seconds:</b> MAAP4 is not the appropriate tool for predicting the very short-term response of a plant to an accident initiator. [from expert team recommendations]</p> <p><b>Limitation of scope, 10 seconds–3 minutes:</b> <i>MAAP4 should not be used to predict the <b>quantitative</b> response of the plant in the first three minutes of any PWR accident sequence.</i> This includes the details of the primary system conditions, mass and energy releases to the containment, and heat-up of the core (for example, peak cladding temperatures) because the initial water temperatures are coarsely nodalized (see the following note regarding temperatures), the code does not have a detailed neutronics model, and it does not model the complexities of the short-term secondary side response (for example, turbine bypass flow). MAAP4 can be used to obtain limited quantitative results in this early time frame if the analysis is augmented with more detailed analysis methods. From a Level 1 PRA perspective, the detailed plant response in the first several minutes of an accident is not important unless it has a significant impact on RCS inventory, which is rarely the case. This limitation on using the code for this early time frame does not affect the use of the code for severe accidents beyond the time frame, provided that the RCS inventory is appropriate. [from expert team recommendations]</p> |

**Table 8-2 (continued)**  
**MAAP4 PWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis**

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
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|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| All PWR sequences, continued              |                                   |                                 |                                                   |           | <p><b>Note:</b> The code uses a single mass-averaged water temperature, variable TWPS, when the water is circulating. In addition, hot-side and cold-side temperatures, variables TWHPS and TWLPS, are calculated when the RCPs are running using a simple quasi-steady-state energy balance across the core (they are the quasi-steady core inlet and outlet water temperatures). TWHPS is used to calculate heat transfer to the steam generators, and both variables are used to calculate break flows, depending on the break location. The two temperatures converge to TWPS when the reactor has been tripped. Individual water node temperatures are calculated after the loops switch from circulating to stagnant conditions (that is, when the phases have separated and global natural circulation stops). [from expert team recommendations]</p> <p><b>Limitation:</b> During an accident, coolant will flow in a global natural circulation mode after the RCPs have stopped but before the phases separate and the coolant becomes stagnant. The code does not calculate the void fraction distribution in the RCS during this period. To do so would require substantially more complex modeling, including equations to account for the conservation of momentum so that the natural circulation flow rate could be determined. Instead, it is assumed that the coolant is homogeneous, and the code calculates an average system void fraction, which is then used for the effluent from breaks, the flow of coolant between nodes, heat transfer calculations, and so on. When the average void fraction exceeds an input value, <i>Model</i> parameter VFSEP, it is assumed that water can no longer be carried over the highest point in the reactor coolant system and the phases then separate into a relatively stagnant, gas-over-water configuration. (Non-global two-phase natural circulation in the form of countercurrent reflux cooling between the steam generators and the core can continue.) The assumption of a homogenous mixture with a single void fraction during the natural circulation phase is suitable for PRA applications, but</p> |

**Table 8-2 (continued)**  
**MAAP4 PWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis**

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
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|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| All PWR sequences, continued              |                                   |                                 |                                                   |           | <p>this limits the use of the code for determining details of the conditions in the primary system during this phase. More importantly, the value of VFSEP can significantly influence the progression of a sequence because of its impact on the timing of the switch from circulating to stagnant (separated) conditions, which in turn impacts the thermal-hydraulic phenomena in the primary system and the properties of break flow. SLOCA sequences with injection can be particularly sensitive to the value of VFSEP because the system can remain in a steady-state natural circulation mode with a moderate average void fraction for a substantial period of time if it does not hit the VFSEP separation value during the initial period of boiling. That is, a small difference in the value of VFSEP can lead to a large difference in the time of the switch to stagnant conditions. In these cases, lower values of VFSEP can result in significantly later core uncover times. The impact of the time of the switch on sequences can be complicated and will vary as a function of the size of breaks, the availability of systems, and so on. It is strongly recommended that users evaluate the sensitivity of their sequences to the value of VFSEP. See Section 6.5.1 of this report for more information. [from expert team recommendations]</p> <p><b>Precaution:</b> The natural circulation flow rate of the coolant is required to mechanistically calculate the heat transfer from the primary system to the steam generators during the period after the RCPs have stopped but before the coolant becomes stagnant. As noted in the limitation related to determining when the phases separate, the code does not calculate the natural circulation flow rate because it does not account for the conservation of momentum, so it can not mechanistically calculate the heat transfer. Instead, the code uses an input heat transfer coefficient, <i>Model</i></p> |

**Table 8-2 (continued)**  
**MAAP4 PWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis**

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
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|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| All PWR sequences, continued              |                                   |                                 |                                                   |           | parameter HTSTAG, when the primary system is in the natural circulation mode. This simplification is acceptable for PRA applications because the temperature differences between the RCS and the steam generators will quickly transition to quasi-steady-state values sufficient to remove the decay heat from the core. The heat transfer and the conditions in the primary system and the generators, both during the natural circulation period and subsequent to it, are generally not very sensitive to the value of HTSTAG. However, sequences in which thresholds are just missed or just reached might be sensitive to the value of HTSTAG. For example, the value will have a slight impact on the energy of the effluent from a break, which will then have an impact on the pressure in the containment. One value might lead to the containment spray pressure setpoint being reached while a slightly higher value might lead to the spray setpoint being missed. If the sprays are activated, there will be much less water in the RWST for injection, leading to substantially earlier accumulator discharge, core uncover, and so on. This sensitivity to the value of HTSTAG represents the potential impact of thresholds in the progression of accidents rather than a purely numerical issue related to the use of a simplistic heat transfer calculation during the natural circulation phase. Because of the potential impact and the uncertainty associated with the heat transfer, users are encouraged to evaluate the sensitivity of their sequences to the value of HTSTAG. It is to be noted that the nominal value in the sample parameter files might be conservative or non-conservative for a full sequence, depending on the particular results of interest. Similarly, the use of HTSTAG compared to more mechanistic calculations has not been shown to be consistently conservative or non-conservative. See Section 6.5.5 of this report for more information. [from expert team recommendations] |



**Table 8-2 (continued)**  
**MAAP4 PWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis**

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
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|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| All PWR sequences, continued              |                                   |                                 |                                                   |           | <p><b>Note:</b> An extended RCP coastdown curve can be used to simulate natural circulation flow. The heat transfer to the steam generators will then be calculated with the prescribed flow and the forced convection heat transfer correlation. This is an alternative to the use of HTSTAG for at least a portion of the natural circulation period. Using the RCP coastdown curve did not consistently yield better agreement with benchmark data compared to using HTSTAG. The void fraction to trip the RCPs, parameter VFCPMX, should be the same as the void fraction for phase separation, parameter VFSEP, if the coastdown curve is used in this manner. [from benchmarks PE5 and IC4]</p> <p><b>Recommendation for users:</b> The code does not include a coastdown curve for MFW. The coastdown flow as a function of time will vary depending on the particular plant conditions and signals that caused the feedwater trip. The addition of a nontrivial amount of cold water into the steam generators over the coastdown period can have a significant impact on the conditions in the generators later in time. Therefore, users should consider including input file components to model the MFW coastdown logic on a sequence-specific basis. (This is discussed further in Appendix C.) [from expert team recommendations]</p> |

**Table 8-2 (continued)**  
**MAAP4 PWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis**

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
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|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| All PWR sequences, continued              |                                   |                                 |                                                   |           | <p><b>Precaution:</b> When using the steam generator level as an indicator or setpoint, such as for tripping the reactor, the level should be calibrated such that the calculated value corresponds to the actual mass (water volume) in the generator at that level. This is because of inherent simplifications in the code and applies to both the one-region and two-region steam generator model options. The one-region model uses a volume versus height input parameter array to determine the collapsed water level in the downcomer, which allows the user to specify the change in cross-sectional area with height in some detail. The two-region model uses other geometric input parameter values to determine the level in the downcomer. The resulting level calculations are more accurate because the two-region model accounts for differences in the hydrostatic head resulting from flow resistance. For U-tube steam generators with the two-region model the calculations are based on constant cross-sectional areas in the lower and upper downcomer subsections. Users with steam generators that have a varying cross-sectional area in the transition from the lower to the upper downcomer should pay particular attention to the water mass versus calculated level at these elevations because this portion generally corresponds to the span of the narrow-range level instrumentation. [from expert team recommendations]</p> <p><b>Precaution:</b> The calculated level in the steam generators with the one-region model will be under-predicted before reactor trip (that is, when there is high heat transfer from the RCS to the secondary side) because the code does not model the void distribution in the tube bundle region and the flow resistance. Users should reduce the target downcomer water level control system setpoints, parameters ZWCTLB and ZWCTLU, from their actual values to avoid adding too much feedwater at the beginning of an accident sequence. [from expert team recommendations]</p> |

**Table 8-2 (continued)**  
**MAAP4 PWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis**

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
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|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| All PWR sequences, continued              |                                   |                                 |                                                   |           | <p><b>Precaution:</b> The accumulator tanks and the piping to the primary system are not modeled as thermal-hydraulic control volumes. Combined with this is the positive-feedback coupling of a higher accumulator discharge rate with a lower primary system pressure (which allows more discharge). Therefore, the accumulator model has inherent uncertainties that can influence the results of a sequence. Users should evaluate the sensitivity of their results to the accumulator input parameters, including the polytropic constants, the head loss coefficients, and the dimensions of the piping. Note that the larger the value of the polytropic constant, the slower the rate of discharge. [from benchmark IC7]</p> <p><b>Recommendation for users:</b> When initiating a sequence at significantly less than full power and with heat transfer to the steam generators (that is, not a mid-loop sequence), it is important to determine that the initial water levels in the steam generators are correct. This particularly applies to the two-region steam generator model because the dynamic head is not fully developed. It is also necessary to decrease the value of the calculated steam generator resistance correction factor, FKSEC, to 1.0 after time zero because the code will calculate an unreasonably high value due to the nonstandard conditions. [from benchmark IE1]</p> |

**Table 8-2 (continued)**  
**MAAP4 PWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis**

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
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|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| All PWR sequences, continued              |                                   |                                 |                                                   |           | <p><b>Limitation:</b> The code does not model individual loops for three- and four-loop designs. Instead, the broken and/or unbroken sides represent more than one actual loop. This limits the modeling of such things as feedwater flow, safety injection, and pressure control on a loop-by-loop basis. [from expert team recommendations]</p> <p><b>Limitation:</b> Early, temporary primary system pressure drops might not be calculated because the behavior in each loop is not determined individually. Therefore, low primary system pressure setpoints for ECCS injection might not be hit early in a sequence (on the order of 30 minutes). [from benchmark IC8]</p> <p><b>Precaution:</b> For sequences involving feed and bleed operator actions, the results can be very sensitive to the input values of delivered flow as a function of primary system pressure (that is, the pump curves). Users should assess the sensitivity of their results to uncertainties in the injection flow. [from expert team recommendations]</p> <p><b>Limitation:</b> MAAP4 does not model condensation on the secondary side of the steam generators, which can occur when there is substantial cooling on the primary side because of injection. The code will not predict the resulting increase in the water level and decrease in the pressure on the secondary side. This is a minor limitation. [from benchmark IC4]</p> <p><b>Recommendation:</b> Users should be aware of the default logic in the code that applies to the modeling of plant systems. Of particular interest are code logic features related to initiating events. These are discussed in Section 6.3 of this report. Users should adjust input values and/or add input components so that the logic represents their plant. [from expert team recommendations]</p> |

Table 8-2 (continued)

MAAP4 PWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis

| Sequence Type or Particular Plant Feature                | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
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|                                                          | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| PWR transients (including SBOs, LOFW, and turbine trips) | Yes                               | —                               | Yes                                               | Yes       | <p><b>Precaution:</b> LOFW sequences are particularly sensitive to mismatches between the core power, feedwater flow, and secondary side volume versus height input values. It is important to accurately determine the time of the reactor trip, which in turn means determining appropriate secondary side water level setpoints if the water level is the trigger for the trip. [from benchmark IC1]</p> <p><b>Limitation:</b> Calculations for PWR sequences without makeup or loss from the primary system in which the primary system is cooling down by heat transfer to the steam generators can result in a minor over-prediction of the rate of depressurization of the primary system at the time that the pressurizer drains completely. This is due to the fact that steam flow from the pressurizer into the water-filled RCS condenses in the water, which is in a homogenous, subcooled state. In actuality, the water in the reactor vessel dome is somewhat hotter than the rest of the RCS, and a portion of that water flashes into steam as the RCS depressurizes, keeping the system at a higher pressure. The calculated faster depressurization might lead to slightly earlier pressure activation of safety systems, such as accumulator injection. This is a minor limitation and affects only the detailed behavior of the primary system. [from benchmark PE5]</p> <p><b>Recommendation for users:</b> For non-LOCA sequences in which the results are particularly sensitive to the RCS pressure (for example, where injection is triggered by pressure setpoints), users should investigate the impact of the value of the maximum time step prior to vessel failure, TDCORE. [from expert team recommendations]</p> |

**Table 8-2 (continued)**

**MAAP4 PWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis**

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
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|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| PWR transients, continued                 |                                   |                                 |                                                   |           | <p><b>Limitation:</b> MAAP4 models one primary system water temperature before the phases separate. This is adequate when all of the steam generators are behaving similarly or when all of the RCPs are operating to keep the water circulating. However, in cases in which the pressures in the steam generators are very different and the primary system is in a single-phase natural circulation mode, the code will over- or under-predict the heat transfer to the secondary side. Under these circumstances, the code should not be used to calculate detailed results such as the time to steam generator dryout. Note that an asymmetry in the steam generators is different from an asymmetry in the primary system loops, which can be handled with the MAAP4 models. (This limitation was identified in a benchmark sequence in which three of four steam generators were not vented, causing the code to over-predict the heat transfer to the vented steam generator. This is a highly improbable sequence because all of the valves on three of the generators are assumed to have failed, and it exaggerates the impact of the limitation.) [from benchmark IC2]</p> |

Table 8-2 (continued)

MAAP4 PWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
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|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| PWR LLOCAs (excluding MSLBs)              | No                                | Yes, due to limitation          | No                                                | Yes       | <p><b>Limitation:</b> MAAP4 should not be used to determine the plant response in any LLOCA sequence <b>during the period before the initial recovery of the core</b> by injection (reflooding). This limitation on the pre-recovery phase of an LLOCA is due to the fact that several potentially influential thermal-hydraulic phenomena are not included in the primary system model, such as reverse flow through the core, departure from nucleate boiling, and condensation on safety injection flow. In LLOCAs that would in actuality have flow reversal, such as a large break in the cold leg, MAAP4 will initially under-predict the amount of mass and energy discharged through the break. After recovery with adequate injection (including accumulator discharge) to prevent core damage, as determined by alternative analysis methods, MAAP4 can be used for the remainder of an LLOCA. The effects of the early under-prediction of the mass and energy release and the lack of detail in the thermal-hydraulic modeling do not have a significant impact on the code results beyond the initial recovery. In particular, the under-prediction of mass through the break is somewhat self-correcting because the break flow is a function of the primary system inventory. The period before recovery is most likely less than three minutes, so this limitation meshes with the overall scope limitation listed at the top of this table. [from expert team recommendations and benchmark IC10]</p> |

**Table 8-2 (continued)**  
**MAAP4 PWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis**

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
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|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| PWR LLOCAs, continued                     |                                   |                                 |                                                   |           | <p><b>Note and recommendation for users:</b> Injection into the “cold leg” in MAAP4, as designated by setting the value of input parameter IDISCH to 1 for the hardwired ESF model or by setting the pump discharge location parameters to 2 for the generalized ESF model, is actually into the intermediate leg water pools, which extend from the outlets of the steam generators to the RCPs. Users might misinterpret injection into the “cold leg” as going into the horizontal portions of the cold legs. The water in the horizontal portions of the cold legs is part of the downcomer water pool. This distinction is important for cold leg break sequences because it affects whether injection goes directly out of the break or into the downcomer. The fraction of the injected water that goes out of the break before it is heated in the vessel can influence the progression of a sequence. It is recommended that users investigate the sensitivity of their results to the injection location for cold leg break sequences. See Sections 6.4.3 and 6.6.1 of this report for discussions of break locations and water pools. [from benchmark IC7 and expert team recommendations]</p> |



Table 8-2 (continued)

MAAP4 PWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
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|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| PWR LLOCAs, continued                     |                                   |                                 |                                                   |           | <p><b>Limitation:</b> In sequences with a break in the cold leg, MAAP4 can over-predict the amount of injected water that goes into the downcomer—and therefore into the core—prior to going out of the break if the injection is designated as being into the downcomer water pool. This occurs because the code does not apportion the injection into that which flows to the downcomer and that which flows out of the break. Users should determine the injection location relative to the break location and then define the sequence such that the injected water goes into the appropriate water pool. Individual scenarios can be bracketed with one sequence that includes a break in the cold leg and injection into the cold leg (the downcomer water pool) and one that includes a break in the intermediate leg and injection into the intermediate leg at the same elevation as the cold leg break. A workaround for the code limitation is to reduce the amount of injection (including the inventory in the cold leg accumulators) and add the portion of the water that would go out of the break directly into the containment. Note that the discharge location of the accumulators is always the downcomer water pool. [from benchmark IC7]</p> <p><b>Precaution:</b> The break area should be the chokepoint—that is, the minimum area—in the path from the primary system to the containment. [from expert team recommendations]</p> <p><b>Recommendation for users:</b> The sensitivity of LLOCA sequence results to a spectrum of effective break sizes and locations should be evaluated. [from expert team recommendations]</p> <p><b>Recommendation for users:</b> The sensitivity of LLOCA sequence results to <i>Model</i> parameters FCDDC, FELOCA, and FNOMIX should be evaluated. [from expert team recommendations]</p> |

**Table 8-2 (continued)**  
**MAAP4 PWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis**

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
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|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| PWR MLOCAs and SLOCAs                     | No                                | Yes                             | Yes                                               | Yes       | <p><b>Limitation:</b> Because of the potentially large impact of the value of <i>Model</i> parameter VFSEP (as discussed in the general PWR portion of this table), S/MLOCA sequences should be routinely run in an augmented mode to determine the sensitivity of the results to the time of phase separation—that is, by running sets of cases, each with a different value of VFSEP. Running a series of break sizes can also be an aid in quantifying the uncertainty. In addition, if the break is large enough to cool the primary system below the steam generators—that is, the heat transfer to the steam generators, variable QSGTOT, becomes negative—users should consider decreasing the value of VFSEP to trigger the switch to stagnant conditions and limit the prediction of nonphysical natural circulation in the primary system. The value of VFSEP can be decreased when QSGTOT becomes negative using an intervention condition in the input file. See Section 6.5.1 of this report for more information about the impact of VFSEP. For small LOCA sequences with injection, a relatively low value of VFSEP might result in a more realistic primary system inventory but a somewhat higher primary system pressure. [from expert team recommendations and benchmark IC6]</p> |

Table 8-2 (continued)

MAAP4 PWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
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|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| PWR MLOCAs and SLOCAs, continued          |                                   |                                 |                                                   |           | <p><b>Limitation:</b> When the RCS is circulating (that is, the phases have not separated), the coolant has a uniform temperature and a uniform void fraction. Therefore, the heat and mass changes to the fluid, such as those associated with injection and break flow, are distributed evenly through the RCS. When there is actually a nontrivial temperature gradient, such as would be the case early in a LOCA, the temperature of the fluid leaving the break will be slightly in error. This will lead to an under-prediction of the mass flow from cold leg breaks and an over-prediction of the mass flow from hot leg breaks until the phases separate. [from expert team recommendations]</p> <p><b>Limitation:</b> A single pressure is used for all water pools and gas volumes in the RCS, even when the phases are separated. Therefore, the code does not calculate the difference in the collapsed levels in the core and the downcomer. The collapsed level in the downcomer will be negligibly higher than the collapsed level in the core when the pump bowls are clear. When there is water in the pump bowls and the water blocks gas flow, the core water level can be much lower than in the downcomer because of the hydrostatic head in the vertical section of the RCP suction pipe. Note that in this case, steam cooling is sufficient to remove the decay heat in the uncovered portion of the core, preventing excessive increases in the fuel temperatures. For a small cold leg LOCA with injection, the under-prediction of the downcomer level can cause MAAP4 to under-predict the water discharge through the break and over-predict the time to core uncover. [from expert team recommendations]</p> <p><b>Note:</b> When the fluid in the RCS is circulating, injected water is uniformly mixed in the downcomer water node. This might have a minor impact on mass and energy flow through breaks. [from expert team recommendations]</p> |

**Table 8-2 (continued)**  
**MAAP4 PWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis**

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
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|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| PWR MLOCAs and SLOCAs, continued          |                                   |                                 |                                                   |           | <p><b>Note and recommendation for users:</b> Injection into the “cold leg” in MAAP4, as designated by setting the value of input parameter IDISCH to 1 for the hardwired ESF model or by setting the pump discharge location parameters to 2 for the generalized ESF model, is actually into the intermediate leg water pools, which extend from the outlets of the steam generators to the RCPs. Users might misinterpret injection into the “cold leg” as going into the horizontal portions of the cold legs. The water in the horizontal portions of the cold legs is part of the downcomer water pool. This distinction is important for cold leg break sequences because it affects whether injection goes directly out of the break or into the downcomer. The fraction of the injected water that goes out of the break before it is heated in the vessel can influence the progression of a sequence. It is recommended that users investigate the sensitivity of their results to the injection location for cold leg break sequences. See Sections 6.4.3 and 6.6.1 of this report for discussions of break locations and water pools. [from benchmark IC7 and expert team recommendations]</p> |

Table 8-2 (continued)

MAAP4 PWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
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|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| PWR MLOCAs and SLOCAs, continued          |                                   |                                 |                                                   |           | <p><b>Limitation:</b> In sequences with a break in the cold leg, MAAP4 can over-predict the amount of injected water that goes into the downcomer—and therefore into the core—prior to going out of the break if the injection is designated as being into the downcomer water pool. This occurs because the code does not apportion the injection into that which flows to the downcomer and that which flows out of the break. Users should determine the injection location relative to the break location and then define the sequence such that the injected water goes into the appropriate water pool. Individual scenarios can be bracketed with one sequence that includes a break in the cold leg and injection into the cold leg (the downcomer water pool) and one that includes a break in the intermediate leg and injection into the intermediate leg at the same elevation as the cold leg break. A workaround for the code limitation is to reduce the amount of injection (including the inventory in the cold leg accumulators) and add the portion of the water that would go out of the break directly into the containment. Note that the discharge location of the accumulators is always the downcomer water pool. [from benchmark IC7]</p> |

**Table 8-2 (continued)**  
**MAAP4 PWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis**

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
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|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| PWR MLOCAs and SLOCAs, continued          |                                   |                                 |                                                   |           | <p><b>Limitation:</b> The portion of condensation on the primary side of the steam generator tubes that flows into the hot legs is added to the core water pool and will not flow directly out a hot leg break. This is a concern only if just one steam generator is depressurized and the break is in that loop. An approximate workaround is to locate the break in the intermediate leg such that the portion of the condensate that goes into the intermediate leg water pool is potentially discharged out of the break. [from benchmark IC7]</p> <p><b>Precaution:</b> The break area should be the chokepoint—that is, the minimum area—in the path from the primary system to the containment. [from expert team recommendations]</p> <p><b>Recommendation for users:</b> The sensitivity of S/MLOCA sequence results to a spectrum of effective break sizes and locations should be evaluated. [from expert team recommendations]</p> <p><b>Recommendation for users:</b> The sensitivity of S/MLOCA sequence results to <i>Model</i> parameters FCDDC and FELOCA should be evaluated. [from expert team recommendations]</p> |
| PWR interfacing system LOCAs              | No                                | Yes                             | Yes                                               | Yes       | <p><b>Precaution:</b> Because the run of pipe between the primary system and the discharge location outside of the containment will be substantial, the specified area of the break and the discharge coefficient should include the equivalent length of the pipe. [from expert team recommendations]</p> <p>The entries in this table for LLOCAs and for S/MLOCAs also apply to interfacing system LOCAs, depending on the size.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |

Table 8-2 (continued)

MAAP4 PWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
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|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| PWR stuck-open pressurizer PORVs          | Yes                               | —                               | Yes                                               | Yes       | —                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| PWR SGTRs                                 | Yes                               | —                               | Yes                                               | Yes       | <b>Note:</b> The code calculates induced SGTRs using the material creep model as well as SGTRs that are initiating events. [from expert team recommendations]                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| PWR MSLBs                                 | No                                | Yes, due to limitations         | Yes                                               | Yes       | <p><b>Limitation:</b> A MSLB leads to rapid cooling in the steam generators and therefore rapid cooling of the RCS. This can lead to a spike in reactivity. The MAAP4 predictions for the initial MSLB transients will not be correct if this return-to-power condition occurs because the code does not have a model for calculating the power under these conditions. Users can approximate the power by using the power versus time input rather than the decay heat correlation. In addition, the early response of the plant to a MSLB is particularly sensitive to the detailed response of the control systems and the balance-of-plant components. This can be addressed by extending the feedwater injection to add the correct integrated mass of water to the steam generators. The time of the initial transient will be shorter than three minutes, so this limitation meshes with the overall scope limitation listed at the top of this table. [from expert team recommendations]</p> <p><b>Limitation:</b> The one-region steam generator model does not calculate the reversal of water flow in the steam generators that would occur in a large MSLB. It is calculated in the two-region model (as of Rev. 4.0.6). The reversal of water leads to the accumulation of water in the downcomer and steam dome and overflow into the main steam line. In small and medium MSLBs, the impact of flow reversal is short term and not significant, so it does not limit MAAP4's applicability. [from expert team recommendations]</p> |

Table 8-2 (continued)

MAAP4 PWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis

| Sequence Type or Particular Plant Feature    | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|----------------------------------------------|-----------------------------------|---------------------------------|---------------------------------------------------|-----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                              | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| PWR MSLBs, continued                         |                                   |                                 |                                                   |           | <p><b>Recommendation for users:</b> The two-region steam generator model should be used instead of the one-region model for large MSLBs because the one-region model will predict only steam blowdown while the two-region model can predict the two-phase blowdown that would occur in the first portion of the transient. [from expert team recommendations]</p> <p><b>Note:</b> The effect of flow restrictors in the main steam line should be considered when defining the area of the break. [from expert team recommendations]</p>                                                                                                                                                                                                                             |
| PWR feedwater line breaks                    | Yes                               | —                               | Yes                                               | Yes       | —                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| PWR mid-loop operation                       | Yes                               | —                               | Yes                                               | Yes       | —                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| PWR ATWS                                     | —                                 | Yes, per note                   | Yes                                               | Yes       | <p><b>Note:</b> The code does not contain a model for power versus level for PWRs in an ATWS condition. Users must supply the power as a function of the primary system conditions, for example, water level or time. [from expert team recommendations]</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| PWR plants with hot water in the vessel dome | —                                 | —                               | —                                                 | —         | <p><b>Limitation:</b> Through Rev. 4.0.6, the code models the water in the vessel dome as cold water, representing <i>T-cold</i> plants. The code might under-predict the decrease in the water volume in the primary system as the plant depressurizes for plants with hot water in the vessel dome, <i>T-hot</i> plants, resulting in a smaller predicted pressure drop. Rev. 4.0.7 contains a code modification that allows the user to select whether the water in the dome is modeled as hot water or cold water using <i>Control</i> parameter IDOMEHOT, removing this limitation. One impact of the limitation is that emergency system low pressure setpoints might not be hit in T-hot plants if they are modeled as T-cold plants. [from benchmark PE6]</p> |



Table 8-2 (continued)

MAAP4 PWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|-------------------------------------------|-----------------------------------|---------------------------------|---------------------------------------------------|-----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Ice condenser plants                      | —                                 | —                               | —                                                 | —         | <p><b>Recommendation for users:</b> The review team recommends that users with ice condenser plants evaluate the sensitivity of their sequence results to the ice condenser input parameters. Of particular importance for ice condensers is the time at which the ice melts and the properties of the gas and condensate exiting the ice condenser compartment because of their impact on the overall energy balance and on the hydrogen concentration in the containment. [from benchmark IE6; also noted in Table 4-6]</p> <p><b>Issue for code development and user support:</b> The review team recommends that investigations be done to determine which parameters have the most influence on the heat transfer in the ice condenser and how sensitive the results are to the parameter values. The important output variables, particularly those that define the energy balance around the condenser (for example, temperatures and steam partial pressures), should be communicated to the users. These investigations should tie in to the existing benchmarks as well as any potential new benchmarks. A particular item of interest is how does the condensate temperature, which is an input to the benchmarks, affect the results. The large sensitivity of the input heat transfer coefficient HTADDI on the gas exit temperatures is also of interest. [from benchmark IE6]</p> |

Table 8-2 (continued)

MAAP4 PWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis

| Sequence Type or Particular Plant Feature                                 | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|---------------------------------------------------------------------------|-----------------------------------|---------------------------------|---------------------------------------------------|-----------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| PWR plants with injection driven solely by gravity (including the AP1000) | —                                 | —                               | —                                                 | —         | <p><b>Issue for code development and user support:</b> A code change was made to the subroutine that calculates the heat transfer within the covered nodes of the core (subroutine COVER) for AP600 benchmark sequences. The change allows oscillations in the two-phase level swell associated with steaming due to injection followed by subcooling, which then allows more injection. In the standard version of the code, these oscillations are suppressed to avoid numerical difficulties. The model deficiency affects only those plants with injection that is driven solely by a gravity head (versus a differential gas pressure) such as the AP1000; it was appropriate to model the oscillations in the benchmark sequences. The code change improved the detailed primary system water level agreement late in the transients after the primary system depressurized. Incorporating the change into the standard version of the code, primarily to improve calculations for sequences in which there is repeated core uncover with injection intermittent injection, is under consideration. [from benchmark IE4]</p> <p><b>Note:</b> In addition to using the various accumulator models and the makeup tank model, a gravity-driven system can be modeled with a containment node and a generalized opening to the primary system with an appropriate discharge coefficient. [from expert team recommendations]</p> |

**Table 8-2 (continued)**  
**MAAP4 PWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis**

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|-------------------------------------------|-----------------------------------|---------------------------------|---------------------------------------------------|-----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| PWR miscellaneous                         | —                                 | —                               | —                                                 | —         | <p><b>Limitation:</b> The ILOCK flag is intended to prevent the automatic opening of a PWR PORV in relief mode. Because of a logic error in the code, this feature does not operate as intended (it has been corrected for Rev. 4.0.8). Users can work around this issue either by setting the area of the valve, ASRV(<i>i</i>), to 0.0 or setting the relief mode opening pressure, PSETRV(<i>i</i>), to a large value.</p> <p><b>Limitation:</b> The code treats values assigned to MAAP4 variables in action blocks within user-defined event blocks in British parameter and input files as if they are in British units, even if explicit SI units labels are included with the values. This is the result of a code error that has been corrected in Rev. 4.0.7. Therefore, values should be in British units in action blocks when the default system of units is British.</p> <p><b>Limitation:</b> Input file components that incorporate parentheses or units labels might not be successfully processed, preventing the calculations from starting. Adding spaces before and after the parentheses and labels will generally resolve the difficulty. (Examples of this limitation are presented in Section 3.3.1.2 of this report.)</p> <p><b>Recommendation for users:</b> MAAP4 mechanistically calculates HLCR. There are significant uncertainties associated with the conditions leading to rupture, so users should treat rupture as an uncertainty rather than relying on the code predictions. They should also consider the sensitivity of the prediction of HLCR to the accumulator input parameters.</p> |

**Table 8-2 (continued)**  
**MAAP4 PWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis**

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|-------------------------------------------|-----------------------------------|---------------------------------|---------------------------------------------------|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| PWR miscellaneous, continued              |                                   |                                 |                                                   |           | <p><b>Precaution:</b> The values of the target steam generator downcomer water level control system setpoints, parameters ZWCTLB and ZWCTLU, and the steam generator geometry parameters can have a significant impact on the mass of water in the steam generators when AFW is available for a limited period during a sequence.</p> <p><b>Note:</b> The code does not model systems downstream of the MSIVs or upstream of the feedwater heater outlet. The feedwater temperature is an input parameter. For sequences in which the transient properties of the feedwater are important, users should include logic to adjust the temperature using input file components. This is relevant for sequences in which the feedwater pumps can continue to operate but steam to the feedwater heaters is not available and a refined heat balance is desired.</p> <p><b>Note:</b> The values of parameters for injection systems should reflect delivered flow for the systems and should not be based solely on pump performance.</p> <p><b>Limitation:</b> The code does not model the discharge of nitrogen into the primary system from the accumulators following the discharge of the water. The nitrogen can be detrimental to the heat transfer to the steam generators.</p> <p><b>Limitation:</b> The code can model a solid containment volume (that is, a water-filled volume) provided that it is connected by an open junction to a non-solid volume—not just to another solid volume. Additional junctions can be added for solid volumes to work around this limitation.</p> |

Table 8-2 (continued)

MAAP4 PWR Applicability, Limitations, Precautions, and Issues for Level 1 Analysis

| Sequence Type or Particular Plant Feature | Mode of Application for Sequences |                                 | Applicability for Success Criteria and HRA Timing |           | Limitations, Precautions, Notes, Recommendations, and Issues for Further Code Development and User Support                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|-------------------------------------------|-----------------------------------|---------------------------------|---------------------------------------------------|-----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                           | Standard Mode                     | Standard Mode with Augmentation | 3–10 min                                          | Long Term |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| PWR miscellaneous, continued              | DD                                |                                 |                                                   |           | <p><b>Note:</b> The containment model does not account for the entrainment of water from the surface of water pools or from heat sinks (condensation films) resulting from the blowdown from the primary system. This is conservative because the entrained water would reduce the superheat in the containment atmosphere, which would lead to a lower pressure and temperature.</p> <p><b>Note:</b> For long-term sequences with recirculating injection into the cold leg, boron can concentrate in the core and eventually precipitate such that it blocks the coolant channels. The code does not model this phenomenon.</p> <p><b>Note:</b> The event codes that indicate that the steam generators are dry, events 151 and 161, are set when the mass of water in the generators is less than 100 kg (220 lb). This might be considerably lower than plant criteria for defining steam generator dryout.</p> <p>[miscellaneous entries from expert team recommendations or from documentation on the code web site]</p> |
| Benchmark sequences                       | —                                 | —                               | —                                                 | —         | <p><b>Recommendation for users:</b> Comparisons of MAAP4 results with other codes or plant data should include a comparative assessment of the time of the plant trip and the water inventory at that time. This is important for establishing consistent initial conditions. [from expert team recommendations]</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |



# 9

## REFERENCES

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# A

## UNITS AND USER-DEFINED CALCULATIONS

### A.1 MAAP4 Units Labels and Conversion Factors

The explicit units labels used in the MAAP4 code, along with the corresponding factors to convert from British to SI units, are listed in Table A-1.

**Table A-1**  
**MAAP4 Units Labels and Conversion Factors**

| Quantity                  | British Units Labels | SI Units Labels | Conversion Factor for British to SI Units (multiply by factor) |
|---------------------------|----------------------|-----------------|----------------------------------------------------------------|
| Area                      | FT**2                | M**2            | 9.290e-2                                                       |
| Density                   | LB/FT**3             | KG/M**3         | 16.018                                                         |
| Differential temperature  | DEG-F                | DEG-K           | 0.5556                                                         |
| Enthalpy                  | BTU/LB               | J/KG            | 2326.0                                                         |
| Energy                    | BTU                  | J               | 1055.0                                                         |
| Heat transfer coefficient | BTU/FT**2-HR-F       | W/M**2-C        | 5.6782                                                         |
| Length                    | FT                   | M               | 0.3048                                                         |
| Mass                      | LB                   | KG              | 0.4536                                                         |
| Mass flow                 | LB/HR                | KG/S            | 1.260e-4                                                       |
| Power                     | BTU/HR               | W               | 0.2931                                                         |
| Pressure                  | PSI                  | PA              | 6894.8                                                         |
| Specific energy           | BTU/LB               | J/KG            | 2326.0                                                         |
| Specific heat             | BTU/LB-F             | J/KG-C          | 4186.7                                                         |
| Specific power            | BTU/HR-LB            | W/KG            | 0.6461                                                         |
| Specific volume           | FT**3/LB             | M**3/KG         | 6.243e-2                                                       |
| Temperature               | F                    | K               | 0.5556 * (T + 459.7) <sup>a</sup>                              |
| Thermal conductivity      | BTU/FT-HR-F          | W/M-C           | 1.7307                                                         |
| Thermal resistance        | FT**2-HR-F/BTU       | M**2-C/W        | 0.1761                                                         |
| Time                      | HR                   | S               | 3600.                                                          |
| Velocity                  | FT/HR                | M/S             | 8.470e-5                                                       |
| Viscosity                 | LB/FT-S              | KG/M-S          | 1.4881                                                         |
| Volume                    | FT**3                | M**3            | 2.832e-2                                                       |
| Volumetric flow           | GPM, FT**3/HR        | M**3/S          | 6.309e-5, 7.866e-6                                             |

<sup>a</sup>T is temperature in Fahrenheit.

## A.2 British Units in Input Files

The following points regarding units should be kept in mind when constructing input files with British units and when evaluating the output. Volume I, Section 3 of the User's Manual contains detailed information on how to construct input files, including the options, structure, and syntax rules for the input statements and blocks. It is helpful to consult that section when reviewing these points and examples. The log file should always be reviewed to confirm that units were correctly addressed in the input file and handled by the code. Another useful method for checking if the units were handled correctly is to plot the values of functions, user-defined variables, and MAAP4 variables whose values are adjusted in the input file.

- When MAAP4 variables (versus user-defined variables) are used in expressions in the input file, the values used when the expressions are evaluated by the code are in SI units.

An example of this in a statement that sets the value of a parameter is as follows. The BWR low-level scram setpoint is parameter ZSCRAM. It is to be set to 2 ft above the value of the parameter that is the top of the core, ZTOAF. The code will use the value of ZTOAF in meters, not feet, in the calculation. Therefore, the correct assignment statement is

$$\text{ZSCRAM} = \text{ZTOAF} + (2 * 0.3048)$$

where 0.3048 is the factor for converting feet to meters. If ZTOAF is 180.0 ft, ZSCRAM will be set to 182.0 ft. If the expression does not contain the conversion factor, that is,

$$\text{ZSCRAM} = \text{ZTOAF} + 2$$

ZSCRAM will be incorrectly set to  $(180 \text{ ft} = 54.9 \text{ m}) + 2 \text{ m}$ , which equals 56.9 m or 186.7 ft.

- The code treats numerical values in the condition statements in operator intervention blocks as if they are in SI units unless explicit British units labels are used. This is true even if the entire input file is in British units.

An example of this is an intervention when the primary system pressure, variable PPS, is greater than 1000 psia. The intervention statement must contain the PSI label:

WHEN PPS > 1000 PSI

If the statement is incorrectly written as

WHEN PPS > 1000

the code will intervene when the pressure is greater than 1000 pascals, not 1000 psi.

- The code converts the numerical values in the intervention action statements from British to SI units if they are being assigned to MAAP4 variables (using the naming convention to determine the conversion factor). The code does not convert the values if they are being assigned to user-defined variables and no units labels have been included.

For example, ZSCRAM is a MAAP4 variable. In accordance with the naming convention, ZSCRAM has units of length. ZSCRAMNEW is a user-defined variable; therefore, the code does not use the naming convention to identify a conversion factor. The assignment statement

ZSCRAM = 50

will assign a value of 50 ft, which equals 15.24 m, to ZSCRAM. But the statement

ZSCRAMNEW = 50

will simply assign a value of 50 to ZSCRAMNEW. If it is intended that ZSCRAMNEW should be used the same way as ZSCRAM and the value is to be the equivalent of 50 ft, the statement should be

ZSCRAMNEW = 50 \* 0.3048

where 0.3048 converts the value from feet to meters.

- The code treats values assigned to MAAP4 variables in action blocks within user-defined event blocks in British parameter and input files as if they are in British units, even if explicit SI units labels are included with the values. This is the result of a code error that has been corrected in Rev. 4.0.7. Therefore, values should be in British units in action blocks when the default system of units is British.

For example, the action block will assign TDAFW, the time delay for AFW, to 200 hours instead of 200 seconds in Rev. 4.0.6.

```
ACTION #4
  TDAFW = 200 S
END
```

The value of 200 seconds, which is equal to 0.0556 hours, will be correctly assigned if entered as

```
ACTION #4
  TDAFW = 0.0556
END
```

- It is not possible to specify the type of units for user-defined variables. If explicit units labels are added to lines in which user-defined variables are assigned values or in intervention conditions that depend on user-defined variables, the code will convert the values from British to SI units. However, the code will not register that the user-defined variable has units, which is relevant if it is used in subsequent input file components or if it is written to an output file.

For example, if user-defined variable XYZ is set to 100 ft

XYZ = 100 FT

the code will assign a value of 30.48 to XYZ for the calculations. But if XYZ is also included in a plot file, the code will not convert its value from meters back to feet for the output. The units label in the plot file will be \*\*\*, signifying that no units were identified and no conversion was done. Similarly, the intervention condition  $XYZ > 50$  will not be true, but the condition  $XYZ > 50 \text{ FT}$  will be true because the code will convert the value of 50 to 15.24 and then compare the value of 30.48 to it.

To avoid errors related to this point and the preceding one, it is recommended that users do not include units labels in input file components that contain user-defined variables. Rather, comment lines can be added to keep track of the assumed units.

- The code does not check the appropriateness of a British units label that is used in the input file. If the label is valid (that is, it appears in the list in Table A-1), the code will use the corresponding conversion factor, even if it is not appropriate for the particular parameter.

For example, if the initial pool water level XWRB0(3) is assigned to 4.00 ft

$$\text{XWRB0(3)} = 4.00 \text{ FT}$$

the code will convert the value to 1.22 using the conversion factor for length, 0.3048. But if the area units label is used by mistake

$$\text{XWRB0(3)} = 4.00 \text{ FT}^2$$

the code will convert the value to 0.372 using the conversion factor for area, 0.0929. This can be seen in the log file.

If the value is then written to an output file in British units, it will be converted as if the value is a length based on the variable naming convention. The resulting value will be  $0.372 / 0.3048 = 1.219$  ft, which is incorrect.

### A.3 User-Defined Input Calculations

Users can set up calculations in the input file using function statements and blocks. If these are included, users should remember that the functions will be evaluated twice each time step. This will affect only recursive calculations such as  $A = A + B$  or  $C = C * D$ . (Note that this does not apply to expressions in other input file components such as operator intervention blocks.) In addition, if the time step is used in a function, the variable TDOLD (the time step from the previous integration) and not TD should be used. Both of these points are important if user-defined functions are created to obtain integrated output such as total mass (versus mass flow). The appropriate ways to set up functions to address these items are demonstrated next.

As discussed in Section 3, it is important to test all input file components. A useful method for testing user-defined calculations is to write all of the variables used in the calculations to sequence-specific plot files and force the values to be written every time step by setting the values of plot frequency parameters TDFQMN and TDFQMX to values that are less than the minimum time step, TDMIN. This should be done only for select periods of interest to prevent excessively large plot files. In addition, it is sometimes helpful to test the calculations with a set value of the time step, which can be achieved by setting the minimum and maximum time step parameters to essentially the same value (for example,  $\text{TDMIN} = 0.099$  s and  $\text{TDMAX} = 0.101$  s).

#### A.3.1 Simple Recursive Calculations

To correctly add a value each time step, define the function to add one half of the value. For example, if the value of 5 is to be added to user-defined variable AAAA each time step, the correct expression is  $\text{AAAA} = \text{AAAA} + 5 / 2$ , not  $\text{AAAA} = \text{AAAA} + 5$ .

To correctly multiply by a value each time step, define the function to multiply by the square root of the value. For example, if user-defined variable BBBB is to be multiplied by 1.25 each time step, the correct expression is  $\text{BBBB} = \text{BBBB} * (1.25)^{0.5}$ , not  $\text{BBBB} = \text{BBBB} * 1.25$ .

### A.3.2 BWR Integration Examples

To calculate the total mass of SLC injection water in SI units, first initialize user-defined variables for the mass added in the current time step and for the cumulative mass using the parameter change block entries

```
SLC_MASS = 0
SLC_MASS_TOT = 0
```

Then include the additive equations in a function block

```
FUNCTION
  SLC_MASS = WWSLC * TDOLD           // KG
  SLC_MASS_TOT = SLC_MASS_TOT + (SLC_MASS / 2)
END
```

To calculate the total mass of makeup water added to the isolation condenser (using the hardwired isolation condenser model) and convert it to British units, first initialize user-defined variables for the mass added in the current time step and for the cumulative mass using the parameter change block entries

```
MAKEUP_M = 0
MAKEUP_TOT = 0
```

Then include the additive equations in a function block

```
FUNCTION
  MAKEUP_M = (WWMAK1 * TDOLD) * 2.205 // LBM
  MAKEUP_TOT = MAKEUP_TOT + (MAKEUP_M / 2)
END
```

### A.3.3 PWR Integration Examples

To calculate the total energy released through the pressurizer relief and safety valves in SI units, first initialize user-defined variables for the energy released in the current time step and for the cumulative energy using the parameter change block entries

```
UTRVSV = 0
UTOTRVSV = 0
```

Then include the additive equations in a function block

```
FUNCTION
  UTRVSV = (QWRV + QGRV) * TDOLD           // Joules
  UTOTRVSV = UTOTRVSV + (UTRVSV / 2)
END
```

To calculate the total mass of water added by the auxiliary pressurizer sprays and convert it to British units, first initialize user-defined variables for the mass added in the current time step and for the cumulative mass using the parameter change block entries

```
ALT_PZR_SP = 0
ALT_PZR_TOT = 0
```

Then include the additive equations in a function block

```
FUNCTION
  ALT_PZR_SP = (WWEBSP * TDOLD) * 2.205 // LBM
  ALT_PZR_TOT = ALT_PZR_TOT + (MAKEUP_M / 2)
END
```

# B

## BWR SYSTEMS AND EVENTS

---

This appendix contains information and guidance on the MAAP4 modeling of individual BWR systems. It includes descriptive information about the input parameters, the calculated variables, and the event codes that control the system logic. It also includes descriptions of unique features of the individual models that might be of particular interest to users. The contents are grouped by system for easy reference. This appendix is intended to complement the information in the MAAP4 User's Manual and the sample parameter files, and to be used in conjunction with these other references. Users should also refer to Section 5 of this report for guidance on BWR code applications.

The information in this appendix is consistent with Rev. 4.0.6 of the code. Changes made for Rev. 4.0.7 that relate to BWR systems are noted. Also, some of the information applies only to plants that have Mark I, II, or III containments—that is, parameter IBWR is set to 1, 2, or 3—and might not be applicable to plants with other containment types. The lists of calculated variables for each system are not exhaustive; additional variables are listed in the *Pltmap* section of the sample parameter files and in the lists of plottable variables on the MAAP4 web site.

### Events

MAAP4 uses event codes to control the high-level logic during an accident simulation. The three types of event codes—automatic, external, and user-defined—are discussed in Section 3.1.1.3. The BWR automatic and external events are described in detail in the *Evtmes* section of the sample parameter files and in the GENEVT/USEVT subroutine description in Volume II of the MAAP4 User's Manual. The descriptions include the conditions that cause the automatic events to change state. The entries in the sample parameter files are in numerical order. In this appendix, they are grouped with the other input and output for each system. The MAAP4 variables for the events are the elements in the array IEVNT; the variable for event number  $i$  is IEVNT( $i$ ).

### Systems

The following BWR systems are addressed in this appendix:

- Condensate storage tank (CST)
- Suppression pool
- Supply power
- Feedwater

- Main steam isolation valves (MSIVs), turbine stop valves, and turbine bypass valves
- Recirculation pumps
- Reactor protection system
- Anticipated transient without scram (ATWS) and standby liquid control (SLC)
- Control rod drive flow (CRD)
- Safety and relief valves (SRVs)
- High pressure coolant injection (HPCI)
- Reactor core isolation cooling (RCIC)
- High pressure core spray (HPCS)
- Low pressure core spray (LPCS)
- Residual heat removal (RHR) and low pressure coolant injection (LPCI)
- Alternate injection, referred to as high pressure service water (HPSW)
- Isolation condenser
- Shutdown cooling system (SCS)
- Reactor water cleanup system (RWCU)
- Drywell (containment) coolers and chillers
- Containment air coolers
- Drywell and containment purge systems
- Additional BWR events and logic control
  - Primary system
  - Containment
  - Miscellaneous



## **Condensate Storage Tank**

The water in the CST feeds CRD, HPCI, RCIC, and HPCS. It also provides makeup water to the isolation condenser if the hardwired isolation condenser model is used and parameter IMAKE is set to 1 (otherwise the makeup water is assumed to be from an external source). The CST model assumes a single tank.

### **Input Parameters**

|        |                                                                                                                          |
|--------|--------------------------------------------------------------------------------------------------------------------------|
| VCSTO  | Initial volume of water in the CST                                                                                       |
| VWCST  | Specific volume of the water                                                                                             |
| HCST   | Enthalpy of the water                                                                                                    |
| VMNCST | Minimum water volume in the CST to automatically switch HPCI, RCIC, and HPCS suction to the suppression pool             |
| FBACST | Mass fraction of the boric acid ( $\text{H}_3\text{BO}_3$ ) in the CST (used to track pH in the containment water pools) |

### **Calculated Variables**

|          |                                                                                                         |
|----------|---------------------------------------------------------------------------------------------------------|
| VLCSTP   | Volume of water in the CST (actually one time step behind the volume variable used in the code, VLWCST) |
| Event 37 | Low water level in the CST                                                                              |

### **Features of the CST water supply model to note:**

- CRD will operate as long as there is water in the CST, assuming that all other CRD flags are set appropriately. If the CRD suction tap is the lowest tap in the tank, the initial water volume, VCSTO, should be set to include only the water above the tap.
- HPCI, RCIC, and HPCS will automatically switch to suction from the suppression pool when the water level is less than parameter VMNCST (sets event 37), assuming that all other flags are set appropriately.
- If one tap is above another tap, it might be necessary to create user-defined events to shut a system off or switch the water source to the pool using events 249 and 254 plus the calculated volume of water in the CST, VLCSTP, such that each system uses the appropriate water volume. For example, if the CRD tap is above the minimum for HPCI, RCIC, and/or HPCS, CRD should be turned off when the CST level drops below the CRD tap. This can be done using the following user-defined event:

```
606 VLWCST < 4511.73 FT**3 LOCKOUT
606 ACTION #6
606 TRUE CST LEVEL BELOW HEADER FOR CRD SUCTION
ACTION #6
    278 TRUE    ! TURN OFF CRD
END
```

- The code uses pre-pump versus post-pump fluid properties for HPCI and RCIC injection. That is, the code will use the value of HCST in the calculation of the energy added to the primary system rather than the higher enthalpy of the water at the pump discharge locations. The impact is relatively small and can be compensated for by setting HCST to a higher value.

## **Suppression Pool**

The water in the suppression pool feeds HPCI, RCIC, HPCS, LPCS, and RHR. It also receives the discharge from the SRVs and/or the HPCI and RCIC turbines if the appropriate pointer parameters are set to the containment node that contains the pool.

### **Input Parameters**

|             |                                                                                                        |
|-------------|--------------------------------------------------------------------------------------------------------|
| JNSP        | Containment node that contains the suppression pool                                                    |
| TWRB0(JNSP) | Initial water temperature                                                                              |
| XWRB0(JNSP) | Initial water height                                                                                   |
| ZHISP       | Maximum pool water level above which HPCI, RCIC (Mark III only), and HPCS suction switches to the pool |
| TCHPCI      | Maximum pool temperature above which the HPCI pump can not operate if suction is from the pool         |
| TCRCIC      | Maximum pool temperature above which the RCIC pump can not operate if suction is from the pool         |
| Event 249   | Force HPCI and HPCS to take suction from the pool versus from the CST                                  |
| Event 254   | Force RCIC to take suction from the pool versus from the CST                                           |

### **Calculated Variables**

|              |                                                                                                  |
|--------------|--------------------------------------------------------------------------------------------------|
| MWRB(JNSP)   | Mass of water in the pool                                                                        |
| TWRB(JNSP)   | Temperature of water in the pool                                                                 |
| ZWRB(JNSP)   | Collapsed water level of the pool                                                                |
| FPHVAL(JNSP) | pH of the water in the pool                                                                      |
| Event 18     | High water level in the pool, causing a switch in high pressure suction from the CST to the pool |

### **Features of the suppression pool water supply model to note:**

- Suction for HPCI and/or HPCS will be automatically transferred from the CST to the suppression pool if the water level in the pool exceeds ZHISP (sets event 18). This is also true for RCIC if the plant is a Mark III (IBWR = 3).
- HPCI and RCIC are not operational if suction is from the pool and the water temperature exceeds TCHPCI and TCRCIC, respectively (sets events 128 and 164).
- The code uses pre-pump versus post-pump fluid properties for HPCI, RCIC, HPCS, LPCS, and RHR injection. That is, the code will use the value of HWSP (the enthalpy of the suppression pool water) in the calculation of the energy added to the primary system or removed by RHR heat exchangers rather than the higher enthalpy of the water at the pump discharge locations. The impact is relatively small.

## **Supply Power**

The supply power variables in MAAP4 are used to determine the potential operability of the various systems.

### **Input Parameters**

|           |                                                              |
|-----------|--------------------------------------------------------------|
| TDBATT    | Duration of battery power following the loss of all AC power |
| Event 250 | Loss of offsite AC power                                     |
| Event 251 | Loss of onsite AC (diesel power)                             |
| Event 290 | Igniters forced on even if AC power is not available         |

### **Calculated Variables**

|           |                                                                                                                                                               |
|-----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|
| IPOWER    | Flag to indicate availability of AC power:<br>= 1: if either offsite or onsite AC power is available<br>= 0: if offsite and onsite AC power are not available |
| Event 63  | Offsite AC power is lost                                                                                                                                      |
| Event 156 | Igniters have power (AC power or available using event 290)                                                                                                   |
| Event 159 | DC (battery) power is unavailable                                                                                                                             |

### **Features of the supply power logic to note:**

- The initial assumption in the BWR code is that both offsite and onsite AC power are available. The onsite AC power source is diesel power.
- If both sources of AC power are not available, DC power from batteries is used to supply some systems.
- AC power can be recovered during a sequence by setting events 250 and/or 251 back to false. The DC (battery) power failure time is reset to a value larger than the problem time when either the offsite or onsite AC power is recovered.
- See Section 5.3.7 of this report for more information on system power requirements, including a table of requirements for quick reference.

## **Feedwater**

Feedwater is considered to be turbine-driven unless specified by the user as motor-driven. The flow is adjusted to control the collapsed downcomer level at its initial value until feedwater is automatically tripped on high downcomer level or, if turbine-driven, on loss of steam flow (MSIV or bypass closure). Feedwater may also be manually tripped.

*MAAP4 power requirement: none*

### **Input Parameters**

|                        |                                                                                         |
|------------------------|-----------------------------------------------------------------------------------------|
| WFWMAX                 | Maximum feedwater mass flow rate                                                        |
| HFW                    | Specific enthalpy of the feedwater                                                      |
| ZWSHO                  | Initial absolute elevation of the water in the downcomer                                |
| ZHFW                   | High collapsed downcomer level setpoint to trip feedwater (absolute elevation)          |
| WFWCD vs. TIFWCD array | Feedwater coastdown flow versus time since trip (represents the coastdown curve)        |
| Events 208 and 209     | Feedwater is forced on, locked off, or automatically controlled                         |
| Event 294              | Feedwater is not tripped by MSIV or bypass closure (motor-driven versus turbine-driven) |

### **Calculated Variables**

|          |                             |
|----------|-----------------------------|
| WFW      | Mass flow rate of feedwater |
| Event 19 | Feedwater pumps are tripped |

### **Features of the feedwater model to note:**

- The calculated water level that is compared to the initial water level in the feedwater flow algorithm and to the high level trip setpoint ZHFW is ZWSHC, the collapsed level in the downcomer.
- The feedwater coastdown array contains eight sets of elements for the flow versus the time since the pumps were tripped. The last value for the flow in the array, WFWCD(8), should **always** be 0.0 (versus a small “trailing” value) to prevent extraneous flow.
- Usually the only plant-specific information about the coastdown that is readily available is the time that it takes for the flow to go to zero. This yields only two points in the coastdown curve: 1) the full flow when the time is zero and 2) zero flow at the end time. In this case, the two sets of values should be entered in the parameter file, with the second set of values repeated to fill up the eight points in the curve. This is necessary because the default values in the code are 0.0 for both the flow and the time. Otherwise, the code will incorrectly calculate the coastdown.

For example, if the normal feedwater flow is 1800 kg/s and the feedwater coasts down over 5 s, the array can be entered as

|           |     |          |           |
|-----------|-----|----------|-----------|
| TIFWCD(1) | 0 S | WFWCD(1) | 1800 KG/S |
| TIFWCD(2) | 5 S | WFWCD(2) | 0 KG/S    |
| TIFWCD(3) | 5 S | WFWCD(3) | 0 KG/S    |
| TIFWCD(4) | 5 S | WFWCD(4) | 0 KG/S    |
| TIFWCD(5) | 5 S | WFWCD(5) | 0 KG/S    |
| TIFWCD(6) | 5 S | WFWCD(6) | 0 KG/S    |
| TIFWCD(7) | 5 S | WFWCD(7) | 0 KG/S    |
| TIFWCD(8) | 5 S | WFWCD(8) | 0 KG/S    |

But it should **not** be entered with just two sets of values because the default for TIFWCD(8) is 0.0, which will then become the coastdown time. That is, it should not be entered as just

|           |     |          |           |
|-----------|-----|----------|-----------|
| TIFWCD(1) | 0 S | WFWCD(1) | 1800 KG/S |
| TIFWCD(2) | 5 S | WFWCD(2) | 0 KG/S    |

- The plant-specific feedwater coastdown curve might be a function of the initiator that leads to the feedwater trip. Because the progression of the sequence can be sensitive to the coastdown time, the appropriate coastdown curve should be used for individual sequences. For example, the coastdown time might be significantly shorter if the initiator is a feedwater pump trip versus an MSIV closure. This is discussed further in Sections 5.3.3 and 5.4.1.
- The code does not contain a model for the feedwater supply so it does not account for any limitations on the water source. It also does not contain a model for the feedwater heater. For sequences in which the transient properties of the feedwater are important, users should include logic to adjust the enthalpy using components in the input file. This is relevant for sequences in which the feedwater pumps continue to operate but steam to the feedwater heaters is not available, and a refined heat balance is desired.

## **Main Steam Isolation Valves, Turbine Stop Valves, and Turbine Bypass Valves**

The MSIVs are modeled as one set of valves. Their effective flow area is calculated based on the initial core power and the thermodynamic conditions. The turbine stop valves are not explicitly modeled; the code uses only their status (open or closed) in the calculations. The turbine bypass valves are modeled as a second set of valves. Their effective flow area is determined from the maximum bypass flow rate.

*MAAP4 power requirement for MSIVs: none*

*MAAP4 power requirement for turbine stop valves: offsite AC power*

*MAAP4 power requirement for turbine bypass valves: none*

### **Input Parameters**

|                    |                                                                                               |
|--------------------|-----------------------------------------------------------------------------------------------|
| PLMSIV             | Low primary system pressure setpoint that initiates MSIV closure                              |
| ZLMSIV             | Low collapsed downcomer water level setpoint that initiates MSIV closure (absolute elevation) |
| TDMSIV             | Time period over which the MSIVs close                                                        |
| WBPMAX             | Maximum main turbine bypass mass flow rate                                                    |
| TDMSSV             | Time period over which the turbine stop valves close                                          |
| TDMSBPV            | Time period over which the turbine bypass valves close                                        |
| Event 212          | Close turbine stop valves                                                                     |
| Event 213          | Close turbine bypass valves                                                                   |
| Events 214 and 215 | MSIVs are forced open, locked closed, or automatically controlled                             |

### **Calculated Variables**

|          |                                                                 |
|----------|-----------------------------------------------------------------|
| WSTMSL   | Total mass flow of water and gas through the main steam line    |
| AMSL0    | Initial minimum effective flow area through the main steam line |
| AMSBP0   | Initial minimum flow area through the turbine bypass line       |
| AMSL     | Minimum flow area through the main steam line                   |
| Event 62 | MSIV closure is initiated                                       |
| Event 66 | Turbine stop valves are closed                                  |

**Features of the steam line valve models to note:**

- The MSIVs close on low primary system pressure or low downcomer water level, or when they are locked closed. The turbine stop valves close on loss of offsite AC power or when they are locked closed. The turbine bypass valves close when they are locked closed.
- The calculated water level that is compared to the low level setpoint ZLMSIV is ZWSHC, the collapsed level in the downcomer.
- The effective flow area through the MSIVs decreases linearly over the input time period TDMSIV. Similarly, the flow area decreases linearly over the turbine stop valve and bypass valve time periods TDMSSV and TDMSBPV. TDMSSV and TDMSBPV were added to the code in Rev. 4.0.6 but were not included in the sample parameter files until Rev. 4.0.7.
- MSIV closure leads directly to initiating scram and tripping feedwater. The latter can be prevented by setting event 294 to true (for modeling motor-driven feedwater systems).
- MAAP4 does not model the following features that are applicable for most plants:
  - The flow area through the turbine stop valves or the bypass valves will be reduced to maintain pressure in the primary system.
  - The MSIVs will not close on low primary system pressure after a certain time period has passed since a scram signal was received (the scram signal having been generated by a condition other than MSIV closure).
  - The main turbines will be tripped when the steam flow has been reduced following a scram.

These features can have a moderate impact on results. The logic for these features can be added to the input files; sample input file components and the impacts of including the logic are presented in Sections 5.3 and 5.4.1.



## Recirculation Pumps

MAAP4 models four different primary system recirculation configurations: natural circulation (no pumps), jet pumps, internal recirculation pumps, and external recirculation pumps.

*MAAP4 power requirement:* offsite AC power

### Input Parameters

|                     |                                                                                                    |
|---------------------|----------------------------------------------------------------------------------------------------|
| IJET                | Specifies recirculation configuration (type of pumps)                                              |
| NJET–VRRMIN         | Geometry terms as a function of recirculation configuration                                        |
| ZLRPT               | Low collapsed downcomer water level setpoint for recirculation pump trip                           |
| PHRPT               | High reactor pressure setpoint for recirculation pump trip                                         |
| TDRPT               | Time delay for the recirculation pumps to trip after the trip signal has been received             |
| FWRR vs. TIRR array | Recirculation pump coastdown flow fraction versus time since trip (represents the coastdown curve) |

### Calculated Variables

|                 |                                                                                                                                         |
|-----------------|-----------------------------------------------------------------------------------------------------------------------------------------|
| WJETO and WJETI | Recirculating water mass flow rate to the lower plenum and into either the jet pump or the lower plenum, depending on the configuration |
| Event 65        | Recirculation pumps have tripped                                                                                                        |
| Event 70        | Recirculation pump trip signal has been received                                                                                        |

### Features of the recirculation model to note:

- The recirculation coastdown array contains eight sets of elements for the fraction of flow versus the time since the pumps were tripped. The first terms in the array, TIRR(1) and FWRR(1), should **always** be 0 and 1, respectively. The last flow value in the array, FWRR(8), should **always** be 0 (versus a small “trailing” value) to prevent extraneous flow.
- If fewer than eight sets of plant-specific values are available, the points can be repeated. Because the default values in the code are 0 for both the fraction of flow and the time, users should **always** enter a value for TIRR(8) unless the coastdown is intended to be instantaneous. Otherwise, the code will incorrectly calculate the coastdown. (See the example in the feedwater system section of this appendix.)
- The coastdown starts at the time that the pumps are tripped, not when the trip signal is received.
- The calculated water level that is compared to the low level setpoint ZLRPT is ZWSHC, the collapsed level in the downcomer.

## **Reactor Protection System—Scram**

In MAAP4, a scram signal is generated if any of the following has occurred:

- High primary system pressure
- MSIV closure signal
- Turbine stop valve closure signal
- Low downcomer water level
- High drywell pressure
- Manual initiation

*MAAP4 power requirement:* loss of offsite AC power causes closure of the turbine stop valves, which results in a scram signal

### **Input Parameters**

|           |                                                                                                                  |
|-----------|------------------------------------------------------------------------------------------------------------------|
| QCR0      | Initial core power                                                                                               |
| ZSCRAM    | Low collapsed downcomer water level scram setpoint (absolute elevation)                                          |
| PSCRAM    | High reactor pressure scram setpoint                                                                             |
| PDWSCM    | High drywell pressure scram setpoint                                                                             |
| TDSCRM    | Time delay between the reactor scram signal and the onset of scram                                               |
| TDPOWR    | Time period over which the core power ramps linearly from full power to decay power following the onset of scram |
| Event 255 | Reactor manually scrambled                                                                                       |

### **Calculated Variables**

|           |                                                                               |
|-----------|-------------------------------------------------------------------------------|
| QCORE     | Core power (equals variable QDECAY for non-ATWS sequences)                    |
| Event 9   | Scram due to high vessel pressure                                             |
| Event 10  | Scram signal received                                                         |
| Event 64  | Reactor has scrambled (at the time the scram signal was received plus TDSCRM) |
| Event 160 | Scram due to low water level                                                  |
| Event 161 | Scram due to high drywell pressure                                            |

**Features of the reactor protection system model to note:**

- Event 10 is set to true when one of the conditions to scram has been met. The core remains at full power for an additional time specified by input parameter TDSCRM.
- The decay power is calculated according to the ANSI/ANS decay heat correlation [9]. The exception is an ATWS scenario, which is discussed next.
- If TDPOWR is non-zero, the power will ramp down linearly to the decay power over that time period. After that, the power will be equal to the decay power (which is calculated based on the time since scram and does not account for TDPOWR).
- The calculated water level that is compared to the low level setpoint ZSCRAM is ZWSHC, the collapsed level in the downcomer. The definition of ZSCRAM in the sample parameter files is the Level 2 trip for scram. At some plants, the scram signal corresponds to Level 3.
- The definitions of parameters TDSCRM and TDPOWR have been changed for Rev. 4.0.7, and users should reevaluate their values for these parameters when transitioning to that version of the code.
- The time it takes to receive a scram signal is an appropriate value for TDSCRM, and the time it takes to fully insert the control rods is an appropriate value for TDPOWR.

## **Anticipated Transient Without Scram and Standby Liquid Control**

The SLC system injects borated water into the primary system to reduce the core power in the event of an ATWS condition.

*MAAP4 power requirement: none*

### **Input Parameters**

|                        |                                                                                                                             |
|------------------------|-----------------------------------------------------------------------------------------------------------------------------|
| FQATWS vs. XATWS array | Fractional core power as a function of the collapsed downcomer water level, or flag to select the Chexal-Layman correlation |
| TDSLCL                 | Time period for the reactor to shut down after the initiation of SLC                                                        |
| HSLC                   | Specific enthalpy of the SLC inlet flow                                                                                     |
| VWSLC                  | Specific volume of the SLC inlet flow                                                                                       |
| WVSLC vs. PSLC array   | Volumetric flow of SLC as a function of primary system pressure                                                             |
| FBASLC                 | Mass fraction of boric acid ( $H_3BO_3$ ) in the SLC system flow (used to track pH in the containment water pools)          |
| Event 257              | ATWS sequence                                                                                                               |
| Event 258              | Start SLC injection                                                                                                         |

### **Calculated Variables**

|       |                                 |
|-------|---------------------------------|
| QCORE | Core power                      |
| WWSLC | Mass flow rate of SLC injection |

### **Features of the ATWS power and SLC models to note:**

- The ATWS power is calculated according to the Chexal-Layman correlation [10] or using input values of the power versus downcomer water level array; the user selects the option by assigning corresponding values to the input parameters.
- If the option to use input values of the power versus the downcomer water is selected, the values of  $XATWS(i)$  are compared to the collapsed water level in the downcomer relative to the bottom of the core plate (ZWSHC - ZCPL), not to the water level relative to the bottom of the active core as stated in the sample parameter files.
- The core power in an ATWS sequence is the initial core power multiplied by the maximum of the recirculation pump flow fraction (determined using the time of the recirculation pump trip and the FWRR versus TIRR array), the calculated ATWS power fraction, and the decay power fraction (referenced to the time of the recirculation pump trip).

- For plants that do not have recirculation pumps—that is, parameter IJET is equal to 0—it is necessary for the user to specify the time at which the ATWS conditions begin by setting variable TIRPT equal to that time in the input file.
- When SLC is injected, the power decreases in an approximately linear manner to the decay power over the time period specified by TDSLCL. Because the decay power is referenced to the time of the recirculation pump trip, there can be a slight under-prediction of the decay power. The code does not use the calculated SLC flow to determine the core power; the flow is used only to determine the additions to the primary system water mass and energy.
- The elements of the input array that represents the SLC injection flow curve do not need to be in the order of highest to lowest pressure or vice versa. To avoid the possibility of inadvertently using default values for elements of the array, users should always include all eight sets of values. This can be accomplished by repeating values.
- The SLC flow does not stop after the time period TDSLCL. It can be stopped by setting event 258 to false.
- Actuating the SLC system will disable the RWCU system.
- Appendix A contains an example of how to calculate the total mass of SLC that has been injected.

## **Control Rod Drive Flow**

CRD takes suction from the CST and injects it into the CRD water control volume, which feeds into the lower plenum. The default in the code is that CRD flow is on.

*MAAP4 power requirement:* offsite AC power unless an alternative source is specified

### **Input Parameters**

|                       |                                                                                               |
|-----------------------|-----------------------------------------------------------------------------------------------|
| HCRD                  | Enthalpy of CRD water                                                                         |
| VWCRDI                | Specific volume of CRD water                                                                  |
| WVCRDI vs. PCRD array | Volumetric flow versus primary system pressure (absolute pressure, not differential pressure) |
| ZWL8                  | High downcomer level used to limit CRD injection (also limits LPCS, LPCI, and HPSW injection) |
| Events 277 and 278    | CRD is forced on, locked off, or automatically controlled                                     |

### **Calculated Variables**

|          |                                                                                                                                  |
|----------|----------------------------------------------------------------------------------------------------------------------------------|
| WCRD     | CRD mass flow                                                                                                                    |
| Event 71 | CRD pumps are on (does not necessarily mean that there is flow, which is dependent on the flow versus pressure parameter values) |

### **Features of the CRD flow model to note:**

- Because the code assumes that there is a single CRD system, the flow parameters should be set accordingly if there are multiple pumps (that is, they should correspond to the total flow).
- The enthalpy and specific volume parameters can be set equal to the corresponding values of the CST parameters, HCST and VWCST, or they can be set to the post-pump properties. The code does not calculate the change in properties due to the energy added by the pumps. The impact of using pre- versus post-pump properties is small.
- Event 277 will force the system on regardless of the availability of offsite AC power; therefore, it can be used to specify an alternative power source for CRD.
- The CRD pump will not be operational if the collapsed water level in the downcomer, ZWSHC, is greater than the Level 8 value, ZWL8, plus 1 m (3.048 ft).
- If the tap in the CST for CRD suction is above the taps for other systems, logic should be added to stop CRD when the volume of the CST falls below the tap. This is discussed further in the CST section of this appendix.

## ***Safety and Relief Valves***

MAAP4 models up to 30 individual valves that vent the primary system to the containment. Each valve can operate in relief or safety mode; the modes are distinguished by the power requirements and setpoints. The valves can discharge to one of two locations, specified by the signs of their area terms.

*MAAP4 power requirement for valves in relief mode:* offsite AC power, onsite AC power, or DC (battery) power

*MAAP4 power requirement for valves in safety mode:* none

### **Input Parameters (for valve *i*)**

|                    |                                                                                                                                                                                                                                             |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| JNRV               | Pointer that identifies one of the two compartments that receive valve discharge (nominally from the relief and/or combined SRV valves)                                                                                                     |
| JNSV               | Pointer that identifies the other of the two compartments that receive valve discharge (nominally from the safety valves)                                                                                                                   |
| ASRV( <i>i</i> )   | Effective flow area; if positive, the flow discharges to compartment JNRV; if negative, the flow discharges to compartment JNSV                                                                                                             |
| PSETRV( <i>i</i> ) | Opening set pressure in relief mode                                                                                                                                                                                                         |
| PDRV( <i>i</i> )   | Deadband associated with the relief mode set pressure                                                                                                                                                                                       |
| PSETSV( <i>i</i> ) | Opening set pressure in safety mode                                                                                                                                                                                                         |
| PDSV( <i>i</i> )   | Deadband associated with the safety mode set pressure                                                                                                                                                                                       |
| ISTUCK( <i>i</i> ) | Stick open the valve by setting the parameter equal to 1, simulating a mechanical failure                                                                                                                                                   |
| IFAILC( <i>i</i> ) | Stick closed the valve by setting the parameter equal to 1, simulating a mechanical failure                                                                                                                                                 |
| ILOCK( <i>i</i> )  | Inhibit automatic opening in relief mode by setting the parameter equal to 1 (to be used only with code Rev. 4.0.8 and higher; the option does not work properly because of a code error that was not successfully corrected in Rev. 4.0.7) |
| IMANON( <i>i</i> ) | Manually open the valve in relief mode by setting the parameter equal to 1                                                                                                                                                                  |

**Calculated Variables (for valve  $i$ )**

|               |                                                                                                 |
|---------------|-------------------------------------------------------------------------------------------------|
| WWRV and WGRV | Mass flow of water and gas through the SRVs to compartment JNRV                                 |
| WWSV and WGSV | Mass flow of water and gas through the SRVs to compartment JNSV                                 |
| IOPEN( $i$ )  | Valve status:<br>= 0: valve is closed<br>= 1: valve is open                                     |
| NCYCLE( $i$ ) | Count of the number of times the valve cycles (opening counts as 0.5 and closing counts as 0.5) |
| PHIGRV        | High setpoint closest to current pressure                                                       |
| PLOWRV        | Low setpoint closest to current pressure                                                        |
| ARV           | Total open flow area of valves to compartment JNRV                                              |
| ASV           | Total open flow area of valves to compartment JNSV                                              |

**Features of the valve model to note:**

- The valve areas,  $ASRV(i)$ , are effective areas. That is, they are not multiplied by a discharge coefficient in the code calculations. The sample parameter files provide two methods for calculating the areas; only the second method, which is based on the code's critical flow model, is recommended.
- The use of a high value for the relief mode set pressure,  $PSETRV(i)$ , will prevent the valve from opening in relief mode. This value should be less than  $1e8$  Pa ( $1e4$  psi) if it is to be opened manually using parameter  $IMANON(i)$ . If the set pressure is above this value, the valve will be treated only as a safety valve (that is, it will be opened only in safety mode).
- Because of a code limitation, parameter  $ILOCK(i)$  will not lock a valve closed. Therefore, to lock a valve closed, set the area to 0.0 as an operator action,  $ASRV(i) = 0.0$ , or set the opening pressure  $PSETRV(i)$  to a large value. This limitation will be removed in Rev. 4.0.8 (it was not successfully fixed in Rev. 4.0.7).
- Some valves have the characteristic that if manually opened they will close on a low pressure differential between the primary system and containment, causing them to cycle. The valves might also close on high containment pressure. These attributes can have a significant effect on fission product distributions in the containment and releases to the environment. The logic for these features can be added to the input files. Sample input file components are included in Section 5.3.8.
- Some valves have the characteristic that their relief mode pressure setpoints will be reduced after the valves open the first time. This reduces valve cycling, which improves valve operability and reduces containment fatigue. In addition, some valves are prevented from rapid cycling to improve operability. The logic for these features can be added to input files. Sample input file components are included in Section 5.3.8.



## **High Pressure Coolant Injection**

HPCI takes water from either the CST or the suppression pool and injects it into the RPV downcomer. The pump is turbine-driven, extracting steam from the vessel and exhausting it to the pool.

*MAAP4 power requirement:* offsite AC power, onsite AC power, or DC (battery) power

### **Input Parameters**

|                         |                                                                                                                                                                             |
|-------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| XSPARG                  | HPCI (and RCIC) spray droplet diameter                                                                                                                                      |
| ZLHPCI and ZHHPCI       | Low and high downcomer levels used to turn on and off HPCI injection, including auto-initiation (absolute elevations)                                                       |
| ZWSHCD                  | Target water level in the downcomer used for HPCI (and RCIC) level control if the option to throttle the flow is selected (absolute elevation)                              |
| PHPCI vs. WVHPCI array  | Head-flow curve (differential pressure versus injected flow)                                                                                                                |
| WSTHPI vs. PTURHP array | Steam extraction curve for the HPCI turbine as a function of the differential pressure                                                                                      |
| FHPCIS vs. FHPCIW array | Reduced steam extraction as a function of the reduced HPCI flow if the flow is throttled (compared to non-throttled flow at the differential pressure, added in Rev. 4.0.7) |
| PSHPCI                  | High drywell pressure to auto-initiate HPCI                                                                                                                                 |
| TDHPCI                  | Time delay for starting HPCI injection after the system initiation signal has been activated (applies for both auto-initiation and when HPCI is forced on)                  |
| PHHPCI                  | Minimum vessel pressure to operate HPCI                                                                                                                                     |
| TCHPCI                  | Maximum water temperature to operate HPCI if suction is from the pool                                                                                                       |
| PHTURH                  | Maximum wetwell pressure to operate HPCI (maximum for turbine exhaust)                                                                                                      |
| ZCLHPI                  | Pump NPSH reference elevation for HPCI                                                                                                                                      |
| Events 200 and 201      | HPCI is forced on, locked off, or automatically controlled                                                                                                                  |
| Event 295               | Option to throttle HPCI (and RCIC) flow to match the target level                                                                                                           |

### **Calculated Variables**

|          |                                             |
|----------|---------------------------------------------|
| WWHPCI   | HPCI injection rate                         |
| WGTUR    | Total flow of gas to HPCI and RCIC turbines |
| XHHPCI   | NPSH at the HPCI pump                       |
| Event 7  | HPCI is operational                         |
| Event 34 | HPCI suction is from the pool               |

**Calculated Variables (continued)**

|           |                                                                     |
|-----------|---------------------------------------------------------------------|
| Event 40  | HPCI flow can be initiated                                          |
| Event 45  | HPCI has tripped                                                    |
| Event 78  | HPCI has initiated on low downcomer water level                     |
| Event 79  | HPCI has initiated on high drywell pressure                         |
| Event 128 | HPCI has tripped on high pool temperature                           |
| Event 129 | HPCI has tripped on high wetwell pressure                           |
| Event 130 | HPCI has tripped on low primary system pressure                     |
| Event 178 | HPCI initiation signal has been generated                           |
| Event 185 | High water level reset signal for HPCI operation has been generated |

**Features of the HPCI model to note:**

- HPCI is not modeled for Mark III plants (that is, when  $IBWR = 3$ ).
- The input parameters that control the switch between suction from the CST and the suppression pool are discussed in earlier sections of this appendix.
- The water level control input parameters are compared to the calculated collapsed water level in the downcomer, ZWSHC.
- Contrary to the ZWL8 entry in the sample parameter files, the HPCI high level trip setpoint is parameter ZHHPCI, not ZWL8. HPCI will not inject when the water level exceeds ZHHPCI, even if the system is forced on using event 200.
- The default mode of level control is “bang-bang” mode, in which the flow cycles on and off based on ZLHPCI and ZHHPCI. The user can select the throttling option, in which the flow is controlled to match the target level, ZWSHCD.
- The HPCI system is automatically initiated on high drywell pressure or low downcomer level, setting event 178. If the throttling option **is not selected**, the flow initiation signal (event 40) will not be set until the level falls below ZLHPCI, even if the system is auto-initiated on high drywell pressure. However, if the throttling option **is selected**, the flow initiation signal is set independent of the downcomer water level, which can lead to the flow initiation signal being set much earlier. Because the actual flow will depend on the water level relative to ZWSHCD, the earlier initiation does not necessarily mean earlier injection.
- If the throttling option **is not selected**, the code will calculate steam extraction only when the water level in the downcomer is such that HPCI can inject. The extraction of steam will cycle with the cycling of HPCI operation. If the throttling option **is selected**, the code will calculate steam extraction regardless of the water level in the downcomer, which will lead to significantly more steam extraction. This essentially models the operator action of depressurizing the primary system using HPCI, with the pumped water being recirculated back to the source. Therefore, the time at which event 295 is set to true to select throttling can have a significant impact on sequences. It is important that users understand when

the code will calculate steam extraction so that their sequences are defined appropriately. (As of Rev. 4.0.7, the steam extraction curve can be modified for throttled injection.)

- To throttle injection flow based on level without extracting steam when the system is not injecting, the throttling can be simulated by adjusting the high and low water level setpoints, ZLHPCI and ZHHPCI, to values just below and just above the target level rather than using event 295.
- The time delay, TDHPCI, applies for each HPCI cycle when the flow is controlled by the high and low water level setpoints.
- The turbine-driven HPCI pump will trip on high pool temperature (if suction is from the pool), high wetwell pressure, or low primary system pressure. If the pump has tripped but the condition(s) that caused the trip are no longer met, the code will allow HPCI injection to resume. In actuality, after the pump has tripped it will not restart without operator intervention. The following logic can be added to either input or parameter files to prevent automatic restarting of HPCI:
  - This logic is applicable to input files. It is recommended that it be part of an include file that is used with every sequence. The logic can be overridden by setting user variable ITRIP to 1 if restarting is to be allowed for a particular sequence. Note that the operator action will be invoked only once unless the repeat option is added.

INITIATORS

ITRIP = 0

END

IF IEVNT(45) > 0.0 AND ITRIP == 0

HPCI LOCKED OFF

END

- This logic is applicable to the *Userevt* section of the parameter file. It can be overridden by setting MAAP4 variable PLT(92) to 1.0 if restarting is to be allowed for a particular sequence. Note that this logic can be invoked more than once unless the keyword LOCKOUT is added to the definitions of the events (refer to the examples in the sample parameter files).

502 EVENT 45 TRUE AND PLT(92) < 1.0 !HPCI TRIP

502 ACTION 302

502 TRUE HPCI LOCKED OUT ON PUMP TRIP

502 FALSE HPCI NOT LOCKED OUT ON PUMP TRIP

ACTION 302

201 TRUE

END

512 EVENT 201 TRUE AND PLT(92) >= 1.0

512 ACTION 312

512 TRUE LET HPCI RESTART

512 FALSE HPCI CAN LOCK OUT ON PUMP TRIP

ACTION 312

201 FALSE  
END

- The elements of the input arrays that represent the head-flow curve and the steam extraction curve do not need to be in the order of highest to lowest pressure or vice versa. (However, in the following discussion, it is assumed that the pressure terms,  $PHPCI(i)$  and  $PTURHP(i)$ , are ordered from highest to lowest.) To avoid the possibility of inadvertently using default values for elements of the arrays, users should always include all eight sets of values. This can be accomplished by repeating values. The head-flow curve should represent delivered flow, so it should be the system curve rather than the pump curve, if possible.
- Low pressure issues:
  - The code calculates the flow based on the pressure difference between the primary system and the water source, but the low primary system pressure setpoint,  $PHHPCI$ , is an absolute pressure. Therefore, if the injection source is the suppression pool and the wetwell pressure has increased significantly above the ambient pressure, the code can calculate injection and not trip on low pressure even though the differential pressure is low. To prevent injection in this situation, the last flow term in the head-flow curve,  $WVHPCI(8)$ , should be set to 0.0, and the last pressure term,  $PHPCI(8)$ , should be set to the low differential pressure at which there would be no flow (approximately  $PHHPCI$  minus the ambient pressure or the anticipated pressure in the containment). The code will interpolate between the last two sets of values in the array to calculate the injected flow at low pressure. Information on the actual HPCI system performance in this range is unlikely to be readily available for inclusion in the head-flow curve, but it is expected that the system will deliver a reduced flow at low pressure. (This guidance is based on the entries in the array going from high pressure to low pressure.)
  - Contrary to the guidance in the sample parameter files, the points in the steam extraction curve do not need to match one-to-one with the points in the head-flow curve. In addition, the code will calculate steam extraction based on the steam curve even if the injection rate is 0.0, which it would be at low primary system pressure. To prevent this, the last terms in the extraction array should be set such that  $PTURHP(8)$  is equal to  $PHPCI(8)$  and  $WSTHPI(8)$  is 0. A minor item to note is that in the event that 1) the HPCI flow is from the CST, 2) the primary system pressure is low, and 3) the pressure in the wetwell is significantly above the ambient pressure, the differential pressure to calculate extraction might be less than  $PTURHP(8)$ , while the differential pressure to calculate injection flow might be above  $PHPCI(8)$ . This leads to injection with no steam extraction. It is expected that the impact of this mismatch would be minor. (This guidance is based on the entries in the arrays going from high pressure to low pressure.)
- High pressure issues:
  - There is no logic in the code to limit HPCI operation at high primary system pressure. The code does not extrapolate beyond the input values in the arrays for the injection flow and steam extraction values. If the differential pressures exceed those in the arrays, the code will use the injection and steam extraction values that correspond to the highest respective differential pressures. Information on actual HPCI system performance at pressures beyond the required range is unlikely to be readily available for inclusion in the head-flow curve, but it is expected that HPCI will be able to inject at its required flow

rate at pressures somewhat beyond the required maximum. On the other hand, the turbine will experience an overspeed trip if the pressure is too high. MAAP4 does not model this trip. It can be addressed in the input file as part of the sequence definition.

- The NPSH at the HPCI pump is calculated by the code but is not compared to a required NPSH. It is assumed that the height of the CST or the height of the water in the pool provides sufficient NPSH when HPCI is required, and an increase in the temperature of the pool would limit the operation of the pump before the pool height becomes insufficient.
- The maximum wetwell pressure to operate HPCI, parameter PHTURH, is compared to the gas pressure in the wetwell, PRB(JNTUR). The pressure at the exit of the exhaust line is the gas pressure plus the head of water corresponding to the submergence of the pipe. Users may choose to account for the submergence when setting the value of PHTURH.
- Users should refer to the guidance in Section 5.4.2 for information on the impact of cycled versus throttled injection.
- The HPCI (and RCIC) turbine exhaust steam enthalpy is not calculated prior to adding the exhaust to the receiving compartment, designated with pointer JNTUR, because of a code error. In Revs. 4.0.6 and earlier, the value of the enthalpy used for the steam is the enthalpy of another effluent stream from the primary system calculated during the previous time step, so the impact of the error is minor. In Rev. 4.0.7, the value that is used for the enthalpy is essentially 0.0 (because of a change in a compiler setting). This leads to a significant over-prediction of pressure and temperature in compartment JNTUR, causing the premature shutoff of the injection systems and the over-prediction of the pressure and temperature in the primary system. This error has been corrected for Rev. 4.0.8. It is discussed in MAAP FLAASH 70. Users should incorporate the following workaround using generalized opening 3 for applicable sequences run with Rev. 4.0.7.

```
PARAMETER CHANGE
  JNGO(3) = JNTUR
  AGO(3) = 1.E-8 M**2
END
```

- The code does not calculate the impact of a condenser on the HPCI turbine exhaust prior to its discharge to the suppression pool. A condenser can be simulated with the generalized isolation condenser model. The power requirement for the condenser should be taken into account when determining whether it is appropriate to include the model for particular sequences.
- Additional information regarding the modeling of the HPCI system is contained in the GENEVT/USEVT subroutine description in Volume II of the User's Manual.

## **Reactor Core Isolation Cooling**

RCIC takes water from either the CST or the suppression pool and injects it into the RPV downcomer. The pump is turbine-driven, extracting steam from the vessel and exhausting it to the pool.

*MAAP4 power requirement:* offsite AC power, onsite AC power, or DC (battery) power

### **Input Parameters**

|                         |                                                                                                                                                                             |
|-------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| XSPARG                  | RCIC (and HPCI) spray droplet diameter                                                                                                                                      |
| ZLRCIC and ZHRCIC       | Low and high downcomer levels used to turn on and off RCIC injection, including auto-initiation (absolute elevations)                                                       |
| ZWSHCD                  | Target water level in the downcomer used for RCIC (and HPCI) level control if the option to throttle the flow is selected (absolute elevation)                              |
| PRCIC vs. WVRCIC array  | Head-flow curve (differential pressure versus injected flow)                                                                                                                |
| WSTRCI vs. PTURRI array | Steam extraction curve for the RCIC turbine as a function of the differential pressure                                                                                      |
| FRCICS vs. FRCICW array | Reduced steam extraction as a function of the reduced RCIC flow if the flow is throttled (compared to non-throttled flow at the differential pressure, added in Rev. 4.0.7) |
| PSRCIC                  | High drywell pressure to auto-initiate RCIC                                                                                                                                 |
| TDRCIC                  | Time delay for starting RCIC injection after the system initiation signal has been activated (applies for both auto-initiation and when RCIC is forced on)                  |
| PHRCIC                  | Minimum vessel pressure to operate RCIC                                                                                                                                     |
| TCRCIC                  | Maximum water temperature to operate RCIC if suction is from the pool                                                                                                       |
| PHTURR                  | Maximum wetwell pressure to operate RCIC (maximum for turbine exhaust)                                                                                                      |
| ZCLRCI                  | Pump NPSH reference elevation for RCIC                                                                                                                                      |
| Events 210 and 211      | RCIC is forced on, locked off, or automatically controlled                                                                                                                  |
| Event 295               | Option to throttle RCIC (and HPCI) flow to match the target level                                                                                                           |

### **Calculated Variables**

|          |                                             |
|----------|---------------------------------------------|
| WWRCIC   | RCIC injection rate                         |
| WGTUR    | Total flow of gas to HPCI and RCIC turbines |
| XHRCIC   | NPSH at the RCIC pump                       |
| Event 29 | RCIC is operational                         |
| Event 44 | RCIC flow can be initiated                  |

**Calculated Variables (continued)**

|           |                                                                     |
|-----------|---------------------------------------------------------------------|
| Event 49  | RCIC has tripped                                                    |
| Event 82  | RCIC has initiated on low downcomer water level                     |
| Event 83  | RCIC has initiated on high drywell pressure                         |
| Event 92  | RCIC has tripped on high wetwell pressure                           |
| Event 110 | RCIC suction is from the pool                                       |
| Event 164 | RCIC has tripped on high pool temperature                           |
| Event 165 | RCIC has tripped on low primary system pressure                     |
| Event 181 | RCIC initiation signal has been generated                           |
| Event 186 | High water level reset signal for RCIC operation has been generated |

**Features of the RCIC model to note:**

- The input parameters that control the switch between suction from the CST and the suppression pool are discussed in earlier sections of this appendix.
- The water level control input parameters are compared to the calculated collapsed water level in the downcomer, ZWSHC.
- Contrary to the ZWL8 entry in the sample parameter files, the RCIC high level trip setpoint is parameter ZHRCIC, not ZWL8. RCIC will not inject when the water level exceeds ZHRCIC, even if the system is forced on using event 210.
- The default mode of level control is “bang-bang” mode, in which the flow cycles on and off based on ZLRCIC and ZHRCIC. The user can select the throttling option, in which the flow is controlled to match the target level, ZWSHCD.
- The RCIC system is automatically initiated on high drywell pressure or low downcomer level, setting event 181. If the throttling option **is not selected**, the flow initiation signal (event 44) will not be set until the level falls below ZLRCIC, even if the system is auto-initiated on high drywell pressure. However, if the throttling option **is selected**, the flow initiation signal is set independent of the downcomer water level, which can lead to the flow initiation signal being set much earlier. Because the actual flow will depend on the water level relative to ZWSHCD, the earlier initiation does not necessarily mean earlier injection.
- If the throttling option **is not selected**, the code will calculate steam extraction only when the water level in the downcomer is such that RCIC can inject. The extraction of steam will cycle with the cycling of RCIC operation. If the throttling option **is selected**, the code will calculate steam extraction regardless of the water level in the downcomer, which will lead to significantly more steam extraction. This essentially models the operator action of depressurizing the primary system using RCIC, with the pumped water being recirculated back to the source. Therefore, the time at which event 295 is set to true to select throttling can have a significant impact on sequences. It is important that users understand when the

code will calculate steam extraction so that their sequences are defined appropriately.  
(As of Rev. 4.0.7, the steam extraction curve can be modified for throttled injection.)

- To throttle injection flow based on level without extracting steam when the system is not injecting, the throttling can be simulated by adjusting the high and low water level setpoints, ZLRCIC and ZHRCIC, to values just below and just above the target level rather than using event 295.
- The time delay, TDRCIC, applies for each RCIC cycle when the flow is controlled by the high and low water level setpoints.
- The turbine-driven RCIC pump will trip on high pool temperature (if suction is from the pool), high wetwell pressure, or low primary system pressure. If the pump has tripped but the condition(s) that caused the trip are no longer met, the code will allow RCIC injection to resume. In actuality, after the pump has tripped it will not restart without operator intervention. The following logic can be added to either input or parameter files to prevent automatic restarting of RCIC:
  - This logic is applicable to input files. It is recommended that it be part of an include file that is used with every sequence. The logic can be overridden by setting user variable ITRIP to 1 if restarting is to be allowed for a particular sequence. Note that the operator action will be invoked only once unless the repeat option is added.

INITIATORS

ITRIP = 0

END

IF IEVNT(49) > 0.0 AND ITRIP == 0

RCIC LOCKED OFF

END

- This logic is applicable to the *Userevt* section of the parameter file. It can be overridden by setting MAAP4 variable PLT(93) to 1.0 if restarting is to be allowed for a particular sequence. Note that this logic can be invoked more than once unless the keyword LOCKOUT is added to the definitions of the events (refer to the examples in the sample parameter files).

503 EVENT 49 TRUE AND PLT(93) < 1.0 !RCIC TRIP

503 ACTION 303

503 TRUE RCIC LOCKED OUT ON PUMP TRIP

503 FALSE RCIC NOT LOCKED OUT ON PUMP TRIP

ACTION 303

211 TRUE

END

513 EVENT 211 TRUE AND PLT(93) >= 1.0

513 ACTION 313

513 TRUE LET RCIC RESTART

513 FALSE RCIC CAN LOCK OUT ON PUMP TRIP



ACTION 313  
211 FALSE  
END

- The elements of the input arrays that represent the head-flow curve and the steam extraction curve do not need to be in the order of highest to lowest pressure or vice versa. (However, in the following discussion it is assumed that the pressure terms,  $PRCIC(i)$  and  $PTURRI(i)$ , are ordered from highest to lowest.) To avoid the possibility of inadvertently using default values for elements of the arrays, users should always include all eight sets of values. This can be accomplished by repeating values. The head-flow curve should represent delivered flow, so it should be the system curve rather than the pump curve, if possible.
- Low pressure issues:
  - The code calculates the flow based on the pressure difference between the primary system and the water source, but the low primary system pressure setpoint,  $PHRCIC$ , is an absolute pressure. Therefore, if the injection source is the suppression pool and the wetwell pressure has increased significantly above the ambient pressure, the code can calculate injection and not trip on low pressure even though the differential pressure is low. To prevent injection in this situation, the last flow term in the head-flow curve,  $WVRCIC(8)$ , should be set to 0.0, and the last pressure term,  $PRCIC(8)$ , should be set to the low differential pressure at which there would be no flow (approximately  $PHRCIC$  minus the ambient pressure or the anticipated pressure in the containment). The code will interpolate between the last two sets of values in the array to calculate the injected flow at low pressure. Information on the actual RCIC system performance in this range is unlikely to be readily available for inclusion in the head-flow curve, but it is expected that the system will deliver a reduced flow at low pressure. (This guidance is based on the entries in the array going from high pressure to low pressure.)
  - Contrary to the guidance in the sample parameter files, the points in the steam extraction curve do not need to match one-to-one with the points in the head-flow curve. In addition, the code will calculate steam extraction based on the steam curve even if the injection rate is 0.0, which it would be at low primary system pressure. To prevent this, the last terms in the extraction array should be set such that  $PTURRI(8)$  is equal to  $PRCIC(8)$  and  $WSTRCI(8)$  is 0. A minor item to note is that in the event that 1) the RCIC flow is from the CST, 2) the primary system pressure is low, and 3) the pressure in the wetwell is significantly above the ambient pressure, the differential pressure to calculate extraction might be less than  $PTURRI(8)$ , while the differential pressure to calculate injection flow might be above  $PRCIC(8)$ . This leads to injection with no steam extraction. It is expected that the impact of this mismatch would be minor. (This guidance is based on the entries in the arrays going from high pressure to low pressure.)
- High pressure issues:
  - There is no logic in the code to limit RCIC operation at high primary system pressure. The code does not extrapolate beyond the input values in the arrays for the injection flow and steam extraction values. If the differential pressures exceed those in the arrays, the code will use the injection and steam extraction values that correspond to the highest respective differential pressures. Information on actual RCIC system performance at pressures beyond the required range is unlikely to be readily available for inclusion in the

head-flow curve, but it is expected that RCIC will be able to inject at its required flow rate at pressures somewhat beyond the required maximum. On the other hand, the turbine will experience an overspeed trip if the pressure is too high. MAAP4 does not model this trip. It can be addressed in the input file as part of the sequence definition.

- The NPSH at the RCIC pump is calculated by the code but is not compared to a required NPSH. It is assumed that the height of the CST or the height of the water in the pool provides sufficient NPSH when RCIC is required and that an increase in the temperature of the pool would limit the operation of the pump before the pool height becomes insufficient.
- The maximum wetwell pressure to operate RCIC, parameter PHTURR, is compared to the gas pressure in the wetwell, PRB(JNTUR). The pressure at the exit of the exhaust line is the gas pressure plus the head of water corresponding to the submergence of the pipe. Users may choose to account for the submergence when setting the value of PHTURR.
- Users should refer to the guidance in Section 5.4.2 for information on the impact of cycled versus throttled injection.
- The RCIC (and HPCI) turbine exhaust steam enthalpy is not calculated prior to adding the exhaust to the receiving compartment, designated with pointer JNTUR, because of a code error. In Revs. 4.0.6 and earlier, the value of the enthalpy used for the steam is the enthalpy of other effluent stream from the primary system calculated during the previous time step, so the impact of the error is minor. In Rev. 4.0.7, the value that is used for the enthalpy is essentially 0.0 (because of a change in a compiler setting). This leads to a significant over-prediction of pressure and temperature in compartment JNTUR, causing the premature shutoff of the injection systems and the over-prediction of the pressure and temperature in the primary system. This error has been corrected for Rev. 4.0.8. It is discussed in MAAP FLAASH 70. Users should incorporate the following workaround using generalized opening 3 for applicable sequences run with Rev. 4.0.7.

```
PARAMETER CHANGE
  JNGO(3) = JNTUR
  AGO(3) = 1.E-8 M**2
END
```

- The code does not calculate the impact of a condenser on the RCIC turbine exhaust prior to its discharge to the suppression pool. A condenser can be simulated with the generalized isolation condenser model. The power requirement for the condenser should be taken into account when determining whether it is appropriate to include the model for particular sequences.
- Additional information regarding the modeling of the RCIC system is contained in the GENEVT/USEVT subroutine description in Volume II of the User's Manual.

## **High Pressure Core Spray**

HPCS is a motor-driven system that takes water from the CST or the suppression pool and sprays it directly onto the core. The pump is assumed to have a dedicated independent power supply.

*MAAP4 power requirement: none*

### **Input Parameters**

|                        |                                                                                                                                                               |
|------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|
| PHPCS vs. WVHPCS array | Head-flow curve (differential pressure versus injected flow)                                                                                                  |
| ZLHPCS and ZHHPCS      | Low and high downcomer levels used to turn on and off HPCS injection, including auto-initiation                                                               |
| PSHPCS                 | High drywell pressure to auto-initiate HPCS                                                                                                                   |
| TDHPCS                 | Time delay for starting HPCS injection after the system initiation signal has been activated (applies for both auto-initiation and when HPCS is forced on)    |
| ZCLHPS                 | Pump NPSH reference elevation for HPCS                                                                                                                        |
| ZHDHPS array           | Required NPSH that corresponds to the head-flow curve                                                                                                         |
| XSPRCS                 | HPCS spray droplet diameter (also used for LPCS and LPCI to the core)                                                                                         |
| FOVER                  | Fraction of core spray that goes into the core bypass area (versus the core) and consequently into the lower plenum (also used for LPCS and LPCI to the core) |
| Events 204 and 205     | HPCS is forced on, locked off, or automatically controlled                                                                                                    |

### **Calculated Variables**

|           |                                                            |
|-----------|------------------------------------------------------------|
| WWHPCS    | Flow rate of HPCS                                          |
| XHHPCS    | NPSH at the HPCS pump                                      |
| Event 26  | HPCS is operational                                        |
| Event 34  | HPCS suction is from the pool                              |
| Event 41  | HPCS flow can be initiated                                 |
| Event 46  | HPCS has tripped on low NPSH (if suction is from the pool) |
| Event 80  | HPCS has initiated on low downcomer water level            |
| Event 81  | HPCS has initiated on high drywell pressure                |
| Event 180 | HPCS initiation signal has been generated                  |

**Features of the HPCS model to note:**

- The input parameters that control the switch between suction from the CST and the suppression pool are discussed in earlier sections of this appendix.
- Because the code assumes that there is a single HPCS system, the flow parameters should be set accordingly if there are multiple pumps.
- The water level control input parameters are compared to the calculated collapsed water level in the downcomer, ZWSHC.
- If HPCS is initiated on low downcomer level, the flow will be cycled so that the level will cycle between ZLHPCS and ZHHPCS. If HPCS is initiated on high drywell pressure or if it is forced on, the flow will turn on and off based on whether the water level is below or above ZHHPCS. Therefore, the level will hover around ZHHPCS.
- Contrary to the ZWL8 entry in the sample parameter files, the HPCS high level trip setpoint is parameter ZHHPCS, not ZWL8. HPCS will not inject when the water level exceeds ZHHPCS, even if the system is forced on using event 204.
- The time delay, TDHPCS, applies for each HPCS cycle.
- The elements of the input arrays that represent the head-flow curve and the required NPSH curve do not need to be in the order of highest to lowest pressure or vice versa. To avoid the possibility of inadvertently using default values for elements of the arrays, users should always include all eight sets of values. This can be accomplished by repeating values.
- The head-flow curve should represent delivered flow, so it should be the system curve rather than the pump curve, if possible.
- The HPCS pump can trip on low NPSH if suction is from the pool. After this happens, the code will not let the pump restart even if sufficient NPSH is restored or suction is switched to the CST.
- The value of FOVER is fixed for a particular plant; however, there is uncertainty in its value. It is suggested that the sensitivity of the results to FOVER be evaluated (it will most likely affect LOCA sequences and hydrogen generation).
- Users should refer to the guidance in Section 5.4.2 for information on the impact of cycled versus throttled injection. Additional information regarding the modeling of the HPCS system is contained in the GENEVT/USEVT subroutine description in Volume II of the User's Manual.

## **Low Pressure Core Spray**

LPCS is a motor-driven system that takes water from the suppression pool and sprays it directly onto the core.

*MAAP4 power requirement:* offsite or onsite AC power

### **Input Parameters**

|                          |                                                                                                                                                               |
|--------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NLPCSP                   | Number of LPCS pumps                                                                                                                                          |
| PLPCS vs. WWLPCS array   | Head-flow curve (per pump, differential pressure versus injected flow)                                                                                        |
| ZLLPCS and ZWL8          | Low and high downcomer levels used to turn on and off LPCS injection, including auto-initiation (ZWL8 also limits CRD, LPCI, and HPSW injection)              |
| PSLPCS                   | High drywell pressure to auto-initiate LPCS                                                                                                                   |
| TDLPCS                   | Time delay for starting LPCS injection after the system initiation signal has been activated (applies for both auto-initiation and when LPCS is forced on)    |
| TDDG3                    | Time delay to start LPCS injection following actuation of emergency diesel (onsite AC) power (includes time to start diesels as well as load LPCS)            |
| PHLPCS                   | Maximum reactor vessel pressure above which LPCS will not operate (as of Rev. 4.0.7, it prevents initiation only on low level)                                |
| ZCLLPS                   | Pump NPSH reference elevation for LPCS                                                                                                                        |
| ZHDLPS array             | Required NPSH that corresponds to the head-flow curve                                                                                                         |
| XSPRCS                   | LPCS spray droplet diameter (also used for HPCS and LPCI to the core)                                                                                         |
| FOVER                    | Fraction of core spray that goes into the core bypass area (versus the core) and consequently into the lower plenum (also used for HPCS and LPCI to the core) |
| Events 206 and 207       | LPCS is forced on, locked off, or automatically controlled                                                                                                    |
| Events 271, 272, and 273 | Set number of LPCS pumps to 0, 2, or 4, respectively (changes the value of NLPCSP)                                                                            |

### **Calculated Variables**

|          |                                                                  |
|----------|------------------------------------------------------------------|
| WWLPCS   | Flow rate of LPCS                                                |
| XHLPCS   | NPSH at the LPCS pumps                                           |
| Event 28 | LPCS is operational                                              |
| Event 33 | AC power is available for LPCS                                   |
| Event 39 | Downcomer water level is greater than or equal to Level 8 (ZWL8) |
| Event 43 | LPCS initiation signal has been generated                        |
| Event 48 | LPCS has tripped on low NPSH                                     |

**Calculated Variables (continued)**

|          |                                                 |
|----------|-------------------------------------------------|
| Event 87 | LPCS flow is greater than 0.0                   |
| Event 90 | LPCS has initiated on low downcomer water level |
| Event 91 | LPCS has initiated on high drywell pressure     |

**Features of the LPCS model to note:**

- The water level control input parameters are compared to the calculated collapsed water level in the downcomer, ZWSHC.
- If LPCS is initiated based on low downcomer level or high drywell pressure, the flow will turn on and off based on whether the water level is below or above Level 8, ZWL8. Therefore, the level will hover around ZWL8. If LPCS is forced on using event 206, the flow will not turn off when the level goes above ZWL8. This can lead to water flow out the SRVs. LPCS does not cycle between the low and high level setpoints, ZLLPCS and ZWL8.
- The user can simulate operator control between two levels using the following input file components:

```
C ONCE LPCS TURNED ON MANUALLY,  
C CONTROL LEVEL BETWEEN 193.0 FT AND ZWL8
```

```
PARAMETER CHANGE  
C Initialize user variable  
  LPCSLVL = 0  
END
```

```
WHEN IEVNT(206) > 0.5  
  LPCSLVL = 1  
END
```

```
WHEN LPCSLVL > 0.5 AND ZWSHC > ZWL8  
  IEVNT(207) = 1  
  REPEAT  
END
```

```
WHEN LPCSLVL > 0.5 AND ZWSHC < 193.0 ft  
  IEVNT(207) = 0  
  REPEAT  
END
```

- The time delay, TDLPCS, applies for each LPCS cycle.

- The elements of the input arrays that represent the head-flow curve and the required NPSH curve do not need to be in the order of highest to lowest pressure or vice versa. To avoid the possibility of inadvertently using default values for elements of the arrays, users should always include all eight sets of values. This can be accomplished by repeating values.
- The head-flow curve should represent delivered flow, so it should be the system curve rather than the pump curve, if possible.
- The number of pumps can be used to modify the amount of injected flow if appropriate for a particular sequence. It does not need to be an integer value.
- The LPCS pumps can trip on low NPSH. After this happens, the code will not let the pumps restart even if sufficient NPSH is restored.
- The value of FOVER is fixed for a particular plant; however, there is uncertainty in its value. It is suggested that the sensitivity of the results to FOVER be evaluated (it will most likely affect LOCA sequences and hydrogen generation).
- Additional information regarding the modeling of the LPCS system is contained in the GENEVT/USEVT subroutine description in Volume II of the User's Manual.

## **Residual Heat Removal and Low Pressure Coolant Injection**

The RHR/LPCI system is a motor-driven system that takes water from the suppression pool and discharges it to one of five locations:

- Reactor vessel as LPCI
- Drywell sprays
- Wetwell or Mark III containment sprays
- Back to the suppression pool (pool recirculation)
- Radwaste tank

There are three independent loops. Two of the loops can discharge to any of the five locations and can have heat exchangers. The third loop can discharge only to the vessel and does not have a heat exchanger.

*MAAP4 power requirement:* offsite or onsite AC power

### **Input Parameters**

|                        |                                                                                                                                                                          |
|------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| IILPCI                 | LPCI location:<br>= 0: to the downcomer<br>= 1: to the lower plenum<br>= 2: to the core                                                                                  |
| NLPCI1                 | Number of pumps in Loop 1                                                                                                                                                |
| NLPCI2                 | Number of pumps in Loop 2                                                                                                                                                |
| NLPCI3                 | Number of pumps in Loop 3                                                                                                                                                |
| PLPCI vs. WVLPCI array | Head-flow curve (per pump, differential pressure versus injected/delivered flow)                                                                                         |
| ZLLPCI and ZWL8        | Low and high downcomer levels used to turn on and off LPCI, including auto-initiation (ZWL8 also limits CRD, LPCS, and HPSW injection)                                   |
| PSLPCI                 | High drywell pressure to auto-initiate LPCI                                                                                                                              |
| TDLPCI                 | Time delay for starting RHR operation (not just LPCI) after the system initiation signal has been activated (applies for both auto-initiation and when RHR is forced on) |
| TDDG2                  | Time delay to start RHR operation following actuation of emergency diesel (onsite AC) power (includes time to start diesels as well as load RHR)                         |
| PHLPCI                 | High RPV pressure to prevent LPCI from being initiated on high drywell pressure (as of Rev. 4.0.7, it prevents initiation on low level instead)                          |
| ZCLLPI                 | Pump NPSH reference elevation for RHR                                                                                                                                    |
| ZHDLPI array           | Required NPSH that corresponds to the head-flow curve                                                                                                                    |
| JNDWS                  | Identification number of the compartment that contains the drywell sprays                                                                                                |



**Input Parameters (continued)**

|                                  |                                                                                                                                                   |
|----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|
| JNWWS                            | Identification number of the compartment that contains the wetwell or Mark III containment sprays                                                 |
| XHSPDW                           | Height of the drywell spray headers above the floor of compartment JNDWS                                                                          |
| XHSPWW                           | Height of the wetwell or Mark III spray headers above the floor of compartment JNWWS                                                              |
| XDSP                             | Spray droplet diameter for the drywell, wetwell, and Mark III containment sprays                                                                  |
| XSPRCS                           | Spray droplet diameter for LPCI injection to the core (also used for HPCS and LPCS)                                                               |
| FOVER                            | Fraction of core spray that goes into the core bypass area (versus the core) and consequently into the lower plenum (also used for HPCS and LPCS) |
| PDWSPR and<br>PWWSPPR            | High drywell and high wetwell or dome (as of Rev. 4.0.7) pressure setpoints to auto-initiate Mark III containment sprays                          |
| TDSPR                            | Time delay for Mark III containment spray pump alignment                                                                                          |
|                                  |                                                                                                                                                   |
| Heat Exchangers                  | _____                                                                                                                                             |
| NHX1, NHX2                       | Number of heat exchangers in RHR Loops 1 and 2                                                                                                    |
| FHX                              | Type of heat exchanger (straight tube or U-tube)                                                                                                  |
| WSWHX                            | Service water mass flow per heat exchanger                                                                                                        |
| TWSW                             | Service water inlet temperature                                                                                                                   |
| NTUHX1 and<br>NTUHX2             | NTU values                                                                                                                                        |
| NTHX–XSTHX                       | Input for detailed heat exchanger model                                                                                                           |
|                                  |                                                                                                                                                   |
| Events                           | _____                                                                                                                                             |
| Events 202, 203,<br>231, and 232 | Loop 1 or Loop 2 is forced on, locked off, or automatically controlled                                                                            |
| Events 227–230                   | Heat exchanger in Loop 1 or Loop 2 is turned on or locked off                                                                                     |
| Events 233–236                   | Loop 1 or Loop 2 alignment to drywell sprays is locked open or locked closed                                                                      |
| Events 237–240                   | Loop 1 or Loop 2 alignment to wetwell sprays or Mark III containment sprays is locked open or locked closed                                       |
| Events 241–244                   | Loop 1 or Loop 2 alignment to LPCI is locked open or locked closed                                                                                |
| Events 245–248                   | Loop 1 or Loop 2 alignment to the suppression pool is locked open or locked closed                                                                |
| Events 259 and 260               | Loop 3 is forced on, locked off, or automatically controlled                                                                                      |
| Events 301–304                   | Loop 1 or Loop 2 alignment to radwaste is locked open or locked closed                                                                            |

### Calculated Variables

|                    |                                                                                                                                                                              |
|--------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| WLPCI0             | Injection flow rate of LPCI into the downcomer (IILPCI = 0)                                                                                                                  |
| WLPCI1             | Injection flow rate of LPCI into the lower plenum (IILPCI = 1)                                                                                                               |
| WLPCI2             | Injection flow rate of LPCI into the core (IILPCI = 2)                                                                                                                       |
| WSPDW              | Flow rate of drywell sprays                                                                                                                                                  |
| WSPWW              | Flow rate of wetwell or Mark III containment sprays                                                                                                                          |
| WRHRSP             | Suppression pool recirculation flow rate                                                                                                                                     |
| WWASTE             | Flow rate of water to radwaste                                                                                                                                               |
| QHXRHR             | Energy extracted by the heat exchangers                                                                                                                                      |
| XHLPCI             | NPSH at the RHR pumps                                                                                                                                                        |
| Events 27 and 13   | Loop 1 or Loop 2 is on                                                                                                                                                       |
| Events 14 and 15   | Heat exchanger in Loop 1 or Loop 2 is on                                                                                                                                     |
| Events 42 and 23   | Initiation signal has been received for Loop 1 or Loop 2 for LPCI and for Mark III containment sprays                                                                        |
| Events 47 and 24   | Loop 1 or Loop 2 has tripped on low NPSH                                                                                                                                     |
| Event 32           | Diesel loading permissible for RHR                                                                                                                                           |
| Event 39           | Downcomer water level is greater than or equal to Level 8 (ZWL8)                                                                                                             |
| Events 50 and 51   | Loop 1 or Loop 2 is aligned to drywell sprays                                                                                                                                |
| Events 52 and 53   | Loop 1 or Loop 2 is aligned to wetwell or Mark III containment sprays                                                                                                        |
| Events 54 and 55   | Loop 1 or Loop 2 is aligned to LPCI injection                                                                                                                                |
| Events 56 and 57   | Loop 1 or Loop 2 is aligned to the suppression pool                                                                                                                          |
| Event 58           | Loop 3 is on                                                                                                                                                                 |
| Event 59           | An initiation signal has been received for Loop 3                                                                                                                            |
| Event 60           | Loop 3 has tripped on low NPSH                                                                                                                                               |
| Event 67           | Pump permissible for Mark III containment sprays                                                                                                                             |
| Event 68           | Mark III containment sprays are on                                                                                                                                           |
| Event 84           | Low water level initiation for LPCI                                                                                                                                          |
| Event 85           | High drywell pressure initiation for LPCI                                                                                                                                    |
| Event 86           | LPCI injection flow is on                                                                                                                                                    |
| Events 162 and 163 | High drywell and high wetwell or dome (as of Rev. 4.0.7) pressure to auto-initiate Mark III containment sprays (both events must be set to true to auto-initiate the sprays) |
| Events 183 and 184 | Loop 1 or Loop 2 is aligned to radwaste                                                                                                                                      |

### **Features of the RHR/LPCI model to note:**

- The MAAP4 logic that controls RHR operation is relatively complex because of the number of options for the different loops. Therefore, it is strongly suggested that users pay particular attention to testing the RHR components of their input files to ensure that they have constructed their files appropriately and that they understand how the code is modeling their RHR systems.
- Additional information regarding the modeling of the RHR system is contained in the GENEVT/USEVT subroutine description in Volume II of the User's Manual.

### *Flow and NPSH; Time Delay*

- The elements of the input arrays that represent the head-flow curve and the required NPSH curve do not need to be in the order of highest to lowest pressure or vice versa. To avoid the possibility of inadvertently using default values for elements of the arrays, users should always include all eight sets of values. This can be accomplished by repeating values.
- The head-flow curve should represent delivered flow, so it should be the system curve rather than the pump curve, if possible.
- The same head-flow curve is used for all discharge locations. For LPCI, the pressure terms are compared to the difference in pressure between the primary system and the wetwell (PPS – PRB(JNSP)). For all other discharge locations, the assumed pressure difference is zero, so the largest flow term is used.
- The number of pumps, NLPCIX, can be used to modify the amount of injected flow. It does not need to be an integer value.
- The RHR pumps can trip on low NPSH. After this happens, the code will not let the pumps restart even if sufficient NPSH is restored.
- The time delay, TDLPCI, applies for each RHR cycle and to each RHR alignment, not just LPCI.

### *Alignment*

- The default alignment for the loops is LPCI; the code sets events 241 and 243 to true at the beginning of a sequence to establish that the initial RHR alignment for Loops 1 and 2 is LPCI alignment. There is no code logic to switch alignment on any particular condition; changing the alignment requires entries in the input file or user-defined events in the parameter file. The exception for automatic switching of the alignment is for Mark III containment sprays, which are auto-aligned and auto-initiated on high containment pressure—which is defined as both event 162 and event 163 set to true.
- For plants with jet pumps and LPCI discharge into the recirculation loops, IILPCI should be set so that the water goes into the lower plenum water node rather than into the downcomer water node. That is, IILCPI should be set to 1 instead of 0. This will most closely represent injection at the top of the jet pumps, which passes quickly to the lower plenum and does not mix with the water in the downcomer outside the jet pumps. The water in the recirculation loops and in the jet pumps is part of the downcomer water control volume in MAAP4.

However, setting injection to the downcomer node would cause the water to flow directly out of recirculation line breaks, which is not appropriate.

- For sequences with breaks in a recirculation line, users should consider whether part of the injected flow would go directly out of the break. This can be modeled by reducing the number of RHR pumps or reducing the flow in the head-flow curve, and then modeling the part that would go immediately out of the break into the drywell using drywell sprays with zero fall height. It can also be addressed through the choice of the LPCI injection location using parameter IILPCI.
- The value of FOVER is fixed for a particular plant; however, there is uncertainty in its value. If LPCI is aligned to the core, it is suggested that the sensitivity of the results to FOVER be evaluated (it will most likely affect LOCA sequences and hydrogen generation).
- The drywell and wetwell sprays will be directed to the compartments identified by pointers JNDWS and JNWWS, respectively. These compartments do not need to be the drywell and wetwell—that is, the model can be used to calculate the impact of sprays in other compartments.
- The variables in the code that are used to model Mark III containment sprays are the same as those used to model wetwell sprays for Mark I and II containments; they do not relate to the Mark III wetwell. Note that in the Mark III sample parameter file, the pointer for the containment sprays, JNWWS, should be to the dome, compartment 7, but it is set to the wetwell, compartment 4. This has been corrected for Rev. 4.0.7.
- The containment spray droplets in the Mark III upper dome will fall as spray droplets into other compartments. Users should use non-zero values for the compartment-to-compartment spray parameters—NSPS, NSPR, FSPR, and XHSPRB—in parameter files for Mark III plants. Note that the XHSPRB array is included with the constant flow fire spray parameters. The value of XHSPRB(JNWWS) should be the same as the value of XHSPWW.

#### *Automatic and Forced Initiation*

- There are two auto-initiation setpoints for LPCI: PSLPCI for high drywell pressure and ZLLPCI for low downcomer water level. An RHR loop will be activated based on the LPCI initiation setpoints even if it is aligned to a location other than to the vessel. That is, if the downcomer water level is below ZWL8 and one of the LPCI setpoints is reached, the system will be turned on regardless of the alignment. To prevent the loops from being inadvertently controlled by conditions in the primary system when they are aligned elsewhere, events 202 and 203 for Loop 1 and events 231 and 232 for Loop 2 should be used to manually force the pumps on or off. (The event codes that indicate that Loops 1 and 2 are on are 27 and 13, respectively.) This characteristic of the code logic can present difficulties if the user sets up the alignment along with criteria for starting the loop and the criteria are not immediately met. The logic has been changed for Rev. 4.0.7 so that the LPCI initiation signals apply to the loops only when they are aligned to LPCI.
- To force the RHR flow to a different discharge location, it is necessary to force the applicable loop on using event 202 or 231 as well as set the alignment to the desired location. Merely setting the alignment is not sufficient. If the loop is not forced on, the flow will be turned on and off based on the water level in the vessel even though the loop is not aligned to LPCI. This logic has been corrected for Rev. 4.0.7.

- The code logic for Loops 1 and 2 is symmetrical with one exception: the code uses a Loop 1 event (203) to reset the high drywell auto-initiation signal for LPCI and Mark III containment sprays, regardless of whether Loop 1 or 2 is aligned to LPCI. That is, if event 203 is true (which means that Loop 1 is locked off), event 85 (which indicates that the drywell pressure is greater than PSLPCI) will be reset to 0. This prevents the auto-initiation of Loop 2 (either as LPCI or as Mark III containment sprays). One workaround is to always use Loop 1 for LPCI and Loop 2 for other discharge locations in addition to LPCI. Another workaround is to set the number of Loop 1 pumps, NLPCI1, to 0 rather than locking out Loop 1. Note that this asymmetry does not impact Loop 2 operation if it is forced on using event 231. The logic has been corrected for Rev. 4.0.7 so that event 85 does not incorrectly prevent the auto-initiation of Loop 2.
- To force Mark III containment sprays it is necessary to set the parameter PWWSPR to a small value; if using Loop 2, it is also necessary to set NLCPI1 to 0 if Loop 1 is not to be operational.
- The auto-initiation of Mark III containment sprays is partially dependent on the initiation of LPCI, so users should ensure that the related input values are consistent with the plant logic. The timer, TDSPR, is used in conjunction with the events that indicate that the loops are on, events 27 and 13, versus those that indicate that an initiation signal has been received, events 42 and 23.
- For Mark III containment sprays, the wetwell pressure, PRB(JNSP), is compared to parameter PWWSPR to set event 163, but the calculated pressure used in the comparison should actually be the pressure in the compartment that contains the containment sprays, PRB(JNWS). The difference between the wetwell pressure and the pressure in the compartment with the sprays is not expected to be significant. This has been corrected for Rev. 4.0.7.
- The LPCI high primary system pressure setpoint, PHLPCI, prevents auto-initiation only on high drywell pressure. It does not prevent auto-initiation on low primary system level, and it does not prevent manual activation using event codes 202, 231, and 259. As of Rev. 4.0.7, PHLPCI prevents auto-initiation on low primary system level but not on high drywell pressure.
- Parameter PDWSPR is inadvertently used to reset the event codes that control drywell sprays, events 50 and 51, for Mark III plants. This will have an adverse effect on sequences if drywell sprays are modeled for a Mark III plant. This has been corrected for Rev. 4.0.7.

#### *LPCI Water Level Control*

- The primary system water level control input parameters are compared to the calculated collapsed water level in the downcomer, ZWSHC.
- If LPCI is initiated based on low downcomer level or high drywell pressure, the flow will turn on and off based on whether the water level is above or below Level 8, ZWL8. Therefore, the level will hover around ZWL8. If LPCI is forced on using events 201, 231, and 259, the flow will not turn off when the level goes above ZWL8. This can lead to water flow out the SRVs. LPCI does not cycle between the low and high level setpoints, ZLLPCI and ZWL8.

- The user can simulate operator control of LPCI between two levels using the following input file components:

```
C ONCE LPCI TURNED ON MANUALLY,  
C CONTROL LEVEL BETWEEN 193.0 FT AND ZWL8
```

```
PARAMETER CHANGE  
C Initialize user variable  
  LPCILVL = 0  
END
```

```
WHEN IEVNT(202) > 0.5  
  LPCILVL = 1  
END
```

```
WHEN LPCILVL > 0.5 AND ZWSHC > ZWL8  
  IEVNT(203) = 1  
  REPEAT  
END
```

```
WHEN LPCILVL > 0.5 AND ZWSHC < 193.0 ft  
  IEVNT(203) = 0  
  REPEAT  
END
```

### *Heat Exchangers*

- It is strongly recommended that users evaluate the sensitivity of their results to the RHR heat exchanger input for sequences in which the heat exchangers are operational and the performance of the heat exchangers and/or the response of the containment are of interest, for example, sequences in which the heat-up of the suppression pool is important. This recommendation applies regardless of whether the detailed heat exchanger model or the NTU method is selected. Users are also encouraged to benchmark the heat transfer predicted by the code with plant data and adjust the heat exchanger input values accordingly.
- The energy extracted by the heat exchangers that can be used to determine the heat exchanger performance is QHXRHR. The temperatures of the RHR water and the cooling water after they have passed through the heat exchangers are not available for output.
- The description of subroutine HTEXCH in Volume II of the User's Manual provides equations that can be used to calculate NTU values. An NTU value is essentially a function of the effectiveness of the heat exchanger. Because of the forms of the equations used to calculate the effectiveness, the most direct way to determine the NTU value is to iterate on its value until the calculated effectiveness matches the effectiveness determined using data from plant tests or benchmarks.

### ***Alternate Injection, Referred to as High Pressure Service Water***

The HPSW system is a manually activated system that takes water from an external source and discharges it to one of three locations:

- Reactor vessel downcomer
- Drywell sprays
- Suppression pool

The pump is assumed to have a dedicated independent power supply.

*MAAP4 power requirement: none*

#### **Input Parameters**

|                        |                                                                                                                                                                                               |
|------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| PHPSW vs. WVHPSW array | Head-flow curve (absolute pressure versus injected/delivered flow)                                                                                                                            |
| HWHPSW                 | Enthalpy of the source water                                                                                                                                                                  |
| VWHPSW                 | The absolute value is the specific volume of the source water: if the value is positive, flow is to the vessel; if the value is negative, flow is to the containment (drywell sprays or pool) |
| IHPSW                  | Selects option for containment discharge location:<br>= 0: to discharge to drywell sprays<br>= 1: to discharge to suppression pool                                                            |
| ZWL8                   | High downcomer water level to turn off HPSW if flow is to the downcomer (also limits CRD, LPCS, and LPCI injection)                                                                           |
| Events 274 and 275     | HPSW injection turned on or locked off                                                                                                                                                        |

#### **Calculated Variables**

|          |                                                                  |
|----------|------------------------------------------------------------------|
| WWHPSW   | HPSW flow to the vessel                                          |
| WSPDW    | HPSW flow to drywell sprays                                      |
| WHPWEW   | HPSW flow to the suppression pool                                |
| Event 39 | Downcomer water level is greater than or equal to Level 8 (ZWL8) |
| Event 69 | HPSW system is on                                                |

**Features of the HPSW model to note:**

- The elements of the input array that represents the head-flow curve do not need to be in the order of highest to lowest pressure or vice versa. To avoid the possibility of inadvertently using default values for elements of the array, users should always include all eight sets of values. This can be accomplished by repeating values.
- The head-flow curve should represent delivered flow, so it should be the system curve rather than the pump curve, if possible.
- Unlike the head-flow curves for the other BWR engineered safeguards systems, the HPSW curve is based on an absolute pressure (primary system or containment) rather than on a differential pressure. In addition, the model does not incorporate an NPSH calculation or requirement.
- If HPSW is injecting to the vessel downcomer, the injection will stop and then resume based on whether the calculated collapsed water level in the downcomer, ZWSHC, is above or below ZWL8. Therefore, when the water reaches ZWL8 it will hover around it (assuming that the values in the head-flow curve allow injection). Event 69 will cycle with the cycling of HPSW flow to the downcomer.
- The code does not contain logic to stop HPSW injection on high pressure. It can be incorporated into the head-flow curve by setting the flow to 0.0 at the shutoff pressure.
- The code does not model simultaneous discharge to the drywell sprays by HPSW and RHR.
- HPSW can be sprayed into a compartment other than the drywell by setting the pointer JNDWS to the desired compartment. The code will still use the pressure in the drywell rather than the pressure in the other compartment to calculate the flow rate, but this is expected to have a minimal impact.
- The variables MWHPSW and MESFI are the integrated masses of HPSW injection into the vessel and ESF discharge into the containment (by both the HPSW and RHR systems), respectively. These variables are useful if there is a need to monitor the water consumption from the external source.



## **Isolation Condenser**

The isolation condenser extracts steam from the upper plenum region of the primary system, transfers heat from the steam to water and gas on the secondary (shell) side of the condenser, and returns the condensate to the downcomer region of the primary system. The steam is on the tube side of the condenser. There are two options for modeling the condenser in MAAP4:

1. The hardwired isolation condenser model
2. The generalized containment model (GCM) with user-specified compartments for the tube and shell sides of the condensers and corresponding interfaces with the primary system

The choice of model might be influenced by the fact that the GCM option uses mechanistic equations for calculating the heat transfer, while the hardwired model uses a lookup table for that purpose. The choice might also depend on the plant-specific data that are available for characterizing the isolation condenser.

*MAAP4 power requirement:* none

### **Hardwired Isolation Condenser Option**

The hardwired isolation condenser option models a single condenser.

#### **Input Parameters**

|                       |                                                                                                                                |
|-----------------------|--------------------------------------------------------------------------------------------------------------------------------|
| VOLIC                 | Total free volume on the shell side                                                                                            |
| PHY315 and TD315      | High primary system pressure and the required duration of the high pressure to auto-initiate the isolation condenser           |
| ZLY315                | Low downcomer level setpoint to auto-initiate the isolation condenser                                                          |
| IMAKE                 | Specifies the source of water for the makeup of the shell side of the isolation condenser:<br>= 0: external source<br>= 1: CST |
| MWICI                 | Initial mass of water on the shell side                                                                                        |
| PICI                  | Initial pressure on the shell side                                                                                             |
| TWICI                 | Initial water temperature on the shell side                                                                                    |
| XWIC1 vs. FCOV1 array | Fraction of tubes covered as a function of water level on the shell side                                                       |
| XWIC2 vs. VOLW2 array | Volume versus height on the shell side                                                                                         |
| QIC1 vs. PPSIC array  | Heat removal rate versus partial pressure of primary system steam                                                              |
| AVEN                  | Area of vents on the shell side                                                                                                |
| HWMAKE                | Enthalpy of the makeup water if from an external source                                                                        |

### Input Parameters (Continued)

|                    |                                                                                                   |
|--------------------|---------------------------------------------------------------------------------------------------|
| WWMAKE             | Maximum flow rate of makeup water                                                                 |
| ZWMAKE             | Target level for makeup water on the shell side relative to the bottom of the isolation condenser |
| ARUPIC             | Effective area of the tube rupture (not multiplied by a discharge coefficient in the code)        |
| XZRUP              | Height of tube rupture above the floor of the isolation condenser                                 |
| Events 285 and 286 | Isolation condenser is forced on, locked off, or automatically controlled                         |
| Event 305          | A tube is ruptured                                                                                |
| Event 312          | Makeup water is turned on                                                                         |

### Calculated Variables

|                    |                                                                                 |
|--------------------|---------------------------------------------------------------------------------|
| WST315             | Steam flow rate into the isolation condenser                                    |
| QIC                | Heat removal rate                                                               |
| PIC                | Pressure on the shell side                                                      |
| WWICR              | Condensation rate on the tube side                                              |
| TWIC               | Water temperature on the shell side                                             |
| MWIC               | Mass of water on the shell side                                                 |
| XWIC               | Water level on the shell side relative to the bottom of the isolation condenser |
| TGIC               | Gas temperature on the shell side                                               |
| WWMAK1             | Makeup water flow rate                                                          |
| WSTVEN             | Steam flow through the vent                                                     |
| WGRUP              | Flow through the tube rupture (only gas flow is calculated)                     |
| MFPI( <i>i</i> ,3) | Mass of fission product group <i>i</i> in the shell side water                  |
| Event 96           | Isolation condenser is on                                                       |
| Event 97           | High RPV pressure initiation for the isolation condenser                        |

### Features of the hardwired isolation condenser model to note:

- The calculated water level that is compared to the setpoint ZWMAKE is the collapsed water level in the downcomer, ZWSHC.

- If makeup water is from the CST (IMAKE is set to 1), the code will continue to calculate flow from the CST if it is empty (it will calculate a negative water volume). This can be prevented with the following input file component:

```
WHEN VLCSTP < 0.0
  ISO. COND. MAKEUP WATER - MAN OFF    // event 312
END
```

This has been corrected for Rev. 4.0.7. In addition, Appendix A contains an example of how to calculate the total mass of water that has been added as makeup.

- The model does not account for evaporation from the secondary side water pool, which results in excess energy being stored in the water until the bulk pool temperature exceeds saturation. At this point, the pool begins to flash in order to maintain saturation conditions, and the rapid flashing results in a pressure spike in the shell side. This anomaly has a minimal impact on the heat transfer between the primary system fluid and the isolation condenser. In addition, the code does not allow reverse flow of air from the environment into the shell side of the condenser, which can yield trivial non-physical behavior, manifested in a “sawtooth” shell side pressure. Both of these issues have been addressed by code changes for Rev. 4.0.7.
- It is recommended that the maximum time step, TDMAX, be set to 1.0 s when the hardwired isolation condenser model is removing heat to reduce numerical oscillations in the calculated shell side conditions that result from the numerical stiffness of the model. These oscillations have only a minimal impact on the heat transfer between the primary system fluid and the isolation condenser.
- To avoid the possibility of inadvertently using default values for elements of the geometry and heat removal arrays, users should always include all sets of values. This can be accomplished by repeating values.
- The impact of small leaks should be considered in sequences that might otherwise predict long-term success due to heat removal by the isolation condenser (see Section 5.6.3 of this report).
- Additional information regarding the hardwired isolation condenser model is contained in the ISOCON subroutine description in Volume II of the User’s Manual.

## GCM Isolation Condenser Option

Two isolation condensers can be modeled with the GCM model.

### Input Parameters

|                   |                                                                                                              |
|-------------------|--------------------------------------------------------------------------------------------------------------|
| JNIC( <i>i</i> )  | Compartment that is the tube side of isolation condenser <i>i</i>                                            |
| JNSIC( <i>i</i> ) | Compartment that is the shell side of isolation condenser <i>i</i>                                           |
| —                 | Compartment and generalized opening input (according to instructions in the sample parameter files)          |
| FGCHX             | Maximum allowed gas mass change fraction per time step for compartments used to model an isolation condenser |

**Calculated Variables for Isolation Condenser  $i$**

|                                  |                                                                                                                            |
|----------------------------------|----------------------------------------------------------------------------------------------------------------------------|
| WWIC( $i$ )                      | Rate of condensate return to the primary system                                                                            |
| QWIC( $i$ )                      | Energy of the returning condensate                                                                                         |
| QOGIC( $i$ )                     | Tube-to-shell-side gas heat transfer for uncovered tubes                                                                   |
| QIGIC( $i$ )                     | Tube side gas-to-tube sensible heat transfer rate                                                                          |
| WCDIC( $i$ )                     | Condensation rate                                                                                                          |
| QCDIC( $i$ )                     | Energy of the condensate flow                                                                                              |
| QSHIC( $i$ )                     | Tube-to-shell-side water heat transfer rate                                                                                |
| TIGIC( $i$ ) and<br>TOGIC( $i$ ) | Temperatures of the inner and outer surfaces of the tubes                                                                  |
| HTICI( $i$ )                     | Heat transfer coefficient at the inner surface of the tubes                                                                |
| WSTGO( $j$ )                     | Steam flow rate from the primary system into the isolation condenser tubes through the $j^{th}$ generalized opening        |
| QSTGO( $j$ )                     | Energy of the gas flow from the primary system into the isolation condenser tubes through the $j^{th}$ generalized opening |

**Features of the GCM isolation condenser model to note:**

- There are no hardwired events that control the GCM isolation condenser model. Information on how to construct the input and create logic to control the operation of the condensers is included in the sample parameter files and in the PRHRIC subroutine description in Volume II of the User's Manual.
- The GCM isolation condenser model can be used to represent other passive containment cooling systems because of its capability to include the impact of noncondensable gas on the tube side of the system.

## **Shutdown Cooling System**

The SCS is a manually activated, closed-loop system that circulates primary system water from the downcomer region through heat exchangers and back to the downcomer.

*MAAP4 power requirement:* offsite or onsite AC power

### **Input Parameters**

|                    |                                                                                     |
|--------------------|-------------------------------------------------------------------------------------|
| NSCSP              | Number of SCS pumps                                                                 |
| WVSCS(1)           | Constant volumetric SCS flow rate (per pump)                                        |
| TDSCS              | Time delay for SCS operation following initiation                                   |
| TCSCS              | Maximum downcomer water temperature for SCS operation                               |
| PHSCS              | Minimum primary system pressure for SCS operation                                   |
| NHXSC              | Number of SCS heat exchangers (total)                                               |
| FSCHX              | Type of heat exchanger (straight tube or U-tube)                                    |
| WRBCC              | SCS heat exchanger service water mass flow (per heat exchanger, also used for RWCU) |
| TWRBCC             | SCS heat exchanger service water inlet temperature (also used for RWCU)             |
| NTUSC              | NTU value                                                                           |
| NTSCHX–XSTSC       | Input for the detailed SCS heat exchanger model                                     |
| Events 288 and 289 | SCS is forced on or locked off                                                      |

### **Calculated Variables**

|           |                                                  |
|-----------|--------------------------------------------------|
| QSCS      | Heat transfer from the primary system by the SCS |
| WSCS      | Flow rate of primary system water to the SCS     |
| Event 196 | SCS is on                                        |

### **Features of the SCS model to note:**

- The description of subroutine HTEXCH in Volume II of the User's Manual provides equations that can be used to calculate NTU values. An NTU value is essentially a function of the effectiveness of the heat exchanger. Because of the forms of the equations used to calculate the effectiveness, the most direct way to determine the NTU value is to iterate on its value until the calculated effectiveness matches the effectiveness determined using data from plant tests or benchmarks.

## **Reactor Water Cleanup System**

The RWCU system is a manually activated, closed-loop system that circulates primary system water from the downcomer region through heat exchangers and back to the downcomer.

*MAAP4 power requirement:* none

### **Input Parameters**

|              |                                                                                     |
|--------------|-------------------------------------------------------------------------------------|
| NRWCU        | Number of RWCU heat exchanger and pump systems (one heat exchanger per pump)        |
| WVRWCU       | Constant RWCU volumetric flow rate (per pump)                                       |
| TDRWCU       | Time delay for RWCU operation following initiation                                  |
| ZLRWCU       | Low downcomer water level setpoint to trip off the RWCU system                      |
| FRCHX        | Type of heat exchanger (straight tube or U-tube)                                    |
| WRBCC        | RWCU heat exchanger service water mass flow (per heat exchanger, also used for SCS) |
| TWRBCC       | RWCU heat exchanger service water inlet temperature (also used for SCS)             |
| NTURC        | NTU value                                                                           |
| NTRCHX-XSTRC | Input for the detailed RWCU heat exchanger model                                    |
| Event 293    | RWCU is turned on                                                                   |

### **Calculated Variables**

|           |                                                          |
|-----------|----------------------------------------------------------|
| QRWCU     | Heat transfer from the primary system by the RWCU system |
| Event 176 | RWCU is on                                               |
| Event 177 | Initiation signal received for RWCU                      |

### **Feature of the RWCU system to note:**

- The calculated water level that is compared to the setpoint ZLRWCU is the collapsed water level in the downcomer, ZWSHC.
- The description of subroutine HTEXCH in Volume II of the User's Manual provides equations that can be used to calculate NTU values. An NTU value is essentially a function of the effectiveness of the heat exchanger. Because of the forms of the equations used to calculate the effectiveness, the most direct way to determine the NTU value is to iterate on its value until the calculated effectiveness matches the effectiveness determined using data from plant tests or benchmarks.

## ***Drywell (Containment) Coolers and Chillers***

The drywell coolers and chillers each take suction from a containment compartment gas space, remove heat from the gas using a heat exchanger, and discharge the cooled gas to the same or a different compartment. The code uses identical equations for the drywell cooler and chiller calculations. The models can also be used to calculate gas exchange through containment fans by disabling the heat exchangers.

*MAAP4 power requirement: offsite or onsite AC power*

### **Input Parameters**

|                                |                                                                                                                                                                                                                                                                           |
|--------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NFN and NCHILL                 | Number of drywell coolers and chillers                                                                                                                                                                                                                                    |
| JNFCS, JNFCD, JNCHS, and JNCHD | Identification numbers of the compartments the drywell coolers and chillers take suction from and discharge to                                                                                                                                                            |
| WVFN0 and WVCH0                | Constant volumetric gas flow rate per drywell cooler and chiller                                                                                                                                                                                                          |
| TDFAN and TDCHR                | Time delays for drywell coolers and chillers to become operational after the initiation signals have been received (applies for both auto-initiation and when the systems are forced on)                                                                                  |
| PFAN0 and PCHRO                | High compartment pressure setpoints in the compartments from which the fan coolers and chillers take suction that lead to auto-initiation                                                                                                                                 |
| WCWFC and WCWCH                | Service water mass flow per drywell cooler and chiller                                                                                                                                                                                                                    |
| TCWHX and TCWCH                | Drywell cooler and chiller inlet service water temperature                                                                                                                                                                                                                |
| NTFC–NREGFC<br>NTCH–NREGCH     | Input for detailed heat exchanger model for drywell coolers and chillers                                                                                                                                                                                                  |
| Event 284                      | Heat exchangers are not operational, causing the drywell coolers, chillers, and, as of Rev. 4.0.7, containment air coolers to operate as fans (the area of the tubes, ATFC or ATCH, can be set to 0.0 to disable heat transfer from just the drywell coolers or chillers) |
| Events 291, 292, 313, and 314  | Drywell coolers and chillers are forced on, locked off, or automatically controlled                                                                                                                                                                                       |

### **Calculated Variables**

|                   |                                                                                 |
|-------------------|---------------------------------------------------------------------------------|
| WGFNA and WGCHR   | Mass flow rate of gas into the drywell coolers and chillers                     |
| WCDFC and WCDCH   | Mass flow rate of condensate from the drywell coolers and chillers              |
| QGFNIN and QGFNCH | Energy flow rate into the drywell coolers and chillers by the containment gas   |
| QGFN and QGCHR    | Energy flow rate out of the drywell coolers and chillers by the containment gas |
| QCDFC and QCDCH   | Energy flow rate out of the drywell coolers and chillers by the condensate      |

### Calculated Variables (continued)

|                    |                                                                                                  |
|--------------------|--------------------------------------------------------------------------------------------------|
| QTOTFC and QTOTCH  | Rate of energy transfer from the containment gas by the drywell cooler and chiller service water |
| Events 170 and 171 | Drywell coolers and chillers are on                                                              |
| Events 175 and 174 | Drywell coolers and chillers are initiated (auto-initiation or forced on)                        |

### Features of the drywell cooler and chiller models to note:

- The drywell coolers and chillers are initiated if the pressures in the compartments from which they take suction—PRB(JNFCS) and PRB(JNCHS), respectively—exceed the setpoint pressures, PFAN0 and PCHR0, or if they are manually forced on.
- The energy balances around the drywell coolers and chillers are as follows:

$$QGFNIN - QGFN - QCDFC = QTOTFC$$

$$QGFNCH - QGCHR - QCDCH = QTOTCH$$

Each of these terms is in the hash table, so their values can be written to output files.

- The terms for the energy transfer from the containment to the service water, QTOTFC and QTOTCH, are not recalculated if the heat exchangers are no longer in operation or if the drywell coolers or chillers are forced off. Because these are output variables only and are not used in the calculations, the fact that their values are not reset to 0.0 does not affect the code results. They are reset as of Rev. 4.0.7.
- It is strongly recommended that users benchmark the performance of the drywell cooler and chiller models against plant data and adjust the values of the input as necessary, particularly if these systems are being credited in analyses. This recommendation is due in part to the fact that the values for the detailed heat exchanger parameters can be difficult to obtain from plant drawings and system descriptions. In addition, it is suggested that users evaluate the sensitivity of their results to the heat exchanger input for sequences in which the drywell coolers or chillers are operational and their performance and/or the response of the containment are of interest. Steady-state sequences with the drywell coolers or chillers running can be used for the benchmarking (without the temporary changes to the JNPS pointers that are used in the steady-state testing discussed in Section 3.2.1). The following information might be useful for the benchmarking:
  - The total heat load to the containment, which is then removed by the systems, is the sum of the QGPSHC(*i*) variables, where QGPSHC(*i*) is the heat transfer from the primary system heat sinks to the gas in compartment *i*. This heat load is calculated using several primary system parameters, and it corresponds both to the through-insulation and the not-through-insulation losses. Users might find that the calculated heat load differs from the plant value for normal operation. In this case, it might be necessary to adjust the value of the not-through-insulation heat loss, parameter QC0, to obtain the proper heat load. (The not-through-insulation heat loss is intended to be an input parameter whose value is obtained directly from plant documentation. However, if the calculated total heat load differs substantially from the plant value for normal operation, users may consider using



the adjusted value for all sequences.) This can be done through an analysis of the percentage error calculated using the input file components that follow.

- It might be necessary to make temporary adjustments to some of the containment parameter values to match test conditions.
- The detailed heat exchanger input values should be adjusted so that QTOTFC or QTOTCH equals the target heat transfer rate. Ultimately, it might be necessary to increase the number of drywell coolers or chillers because these parameters tend to have more impact than reasonable changes to the geometry and heat transfer parameters. Non-integer values of NFN and NCHILL can be used.
- Useful input file components for determining the value of QC0 are:

FUNCTION

QLOAD\_TOT = QGPSHC(1) + QGPSHC(2) + QGPSHC(3) // etc.

QLOAD\_BR = QLOAD\_TOT / 0.2931 // convert from W to BTU/hr

QHLKNOWN = { } //Plant Calculated Heat Load for Normal  
//Operation in Btu/Hr

PER\_ERR = (QHLKNOWN+(-1\* QLOAD\_BR))/QHLKNOWN \* 100

END

PLOTFIL 88

QC0, QGPSHC(1), QGPSHC(2), QGPSHC(3), QLOAD\_TOT,  
QLOAD\_BR, PER\_ERR

END

- If the coolers operate in normal and emergency modes, different sets of input should be tested and adjusted as necessary. When the appropriate values are determined, users can construct automatic switches from normal to emergency mode by creating user-defined events or intervention conditions and corresponding parameter changes.
- The code does not contain the option for specifying NTU values for the drywell coolers or chillers; the detailed heat exchanger model is always used for these systems.

## Containment Air Coolers

The containment air coolers take gas from containment compartments, remove heat from the gas using heat exchangers, and discharge the cooled gas to the same or different compartments. The code uses the same equations for the mass and energy exchange that are used for the drywell cooler and chiller calculations. The containment air coolers are manually activated and are assumed to have a dedicated independent power supply. The model can be used to calculate gas exchange through containment fans by disabling the heat exchangers.

*MAAP4 power requirement:* none

### Input Parameters (for cooler $i$ )

|                               |                                                                                                                                                                                                                                                              |
|-------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NFNAC( $i$ )                  | Number of air cooler units in the air cooler                                                                                                                                                                                                                 |
| JNACS( $i$ ) and JNACD( $i$ ) | Identification numbers of the compartments the air coolers take suction from and discharge to                                                                                                                                                                |
| WVAC0( $i$ )                  | Constant volumetric gas flow per air cooler unit in air cooler                                                                                                                                                                                               |
| WCWAC( $i$ )                  | Service water mass flow per air cooler unit in air cooler                                                                                                                                                                                                    |
| TCWAC( $i$ )                  | Air cooler inlet service water temperature                                                                                                                                                                                                                   |
| NTAC( $i$ )–NREGAC( $i$ )     | Input for detailed heat exchanger model for the air cooler                                                                                                                                                                                                   |
| Event 284                     | Heat exchangers are not operational, causing the drywell coolers, chillers, and, as of Rev. 4.0.7, containment air coolers to operate as fans (the area of the tubes, ATAC( $i$ ), can be set to 0.0 to disable the heat transfer from just the air coolers) |
| Events 331–340                | Air coolers are forced on                                                                                                                                                                                                                                    |

### Calculated Variables (for cooler $i$ )

|               |                                                                                  |
|---------------|----------------------------------------------------------------------------------|
| WGAC( $i$ )   | Mass flow rate of gas into the air cooler                                        |
| WCDAC( $i$ )  | Mass flow rate of condensate from the air cooler                                 |
| QGIAC( $i$ )  | Energy flow rate into the air cooler by the containment gas                      |
| QGAC( $i$ )   | Energy flow rate out of the air cooler by the containment gas                    |
| QCDAC( $i$ )  | Energy flow rate out of the air cooler by the condensate                         |
| QTOTAC( $i$ ) | Rate of energy transfer from the containment gas by the air cooler service water |

**Features of the containment air cooler model to note:**

- A containment air cooler is operational if the number of air cooler units is greater than 0 and it is manually forced on.
- The heat exchangers in the air coolers should be disabled by setting the area of the tubes,  $ATAC(i)$ , to 0.0 rather than by using event 284 because of a minor error in the BWR code. The error has been corrected for Rev. 4.0.7, allowing the event to be used to disable the heat exchangers.
- Refer to features of the drywell cooler and chiller models for information on how to verify that the values of the input parameters will yield the appropriate heat transfer.

## **Drywell Purge**

The drywell purge system takes gas from one containment compartment and discharges it to a different compartment. It is intended to model a Mark III system that takes gas from the middle compartment and discharges it to the drywell to reduce a post-accident hydrogen buildup in the drywell.

*MAAP4 power requirement:* offsite or onsite AC power

### **Input Parameters**

|                      |                                                                                                                                                                                         |
|----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NPURP                | Number of drywell purge fans                                                                                                                                                            |
| PPUR vs. WVPUR array | Head-flow curve (per fan)                                                                                                                                                               |
| ZLPUR                | Low downcomer water level setpoint for drywell purge, used for both auto-initiation and isolation                                                                                       |
| PDWPUR               | High drywell pressure for drywell purge, used for both auto-initiation and isolation                                                                                                    |
| PDPUR                | Maximum differential pressure between the discharge compartment and the suction compartment to allow the system to become operational when an auto-initiation signal has been generated |
| TDPUR                | Time delay for the drywell purge system to start when an auto-initiation signal has been received (does not apply if the system is forced on)                                           |
| JNDPS and JNDPD      | Identification numbers of the compartments the drywell purge takes suction from and discharges to                                                                                       |
| Events 265 and 266   | Drywell purge is forced on, locked off, or automatically controlled                                                                                                                     |
| Event 309            | Prevent the drywell purge from operating if one of the isolation criteria is met                                                                                                        |

### **Calculated Variables**

|           |                                              |
|-----------|----------------------------------------------|
| Event 152 | Drywell purge is on                          |
| Event 157 | An auto-initiation signal has been generated |

### **Features of the drywell purge model to note:**

- The calculated water level that is compared to the setpoint ZLPUR is the collapsed water level, ZWSHC.
- The low downcomer water level and the high drywell pressure setpoints are used for both auto-initiation and isolation. The system will isolate when one of these setpoints is reached if event 309 is set to true by the user. This option has been provided to model the impact of

containment isolation on the drywell purge system if there is a dependence at a particular plant. The intent is to allow the drywell to be isolated while conditions that correspond to a LOCA exist such that the potential bypass of the suppression pool is explicitly avoided. The user can set event 309 to false when the water level in the RPV is recovered and the drywell pressure is reduced to allow the drywell purge system to operate. Isolating the system with event 309 supersedes forcing the system on with event 265.

- The elements of the input array that represents the head-flow curve do not need to be in the order of highest to lowest pressure or vice versa. Because the pressure terms are compared to the difference between the pressures in the suction and discharge compartments, the terms should be negative numbers to coincide with the suction pressure being less than the discharge pressure. To avoid the possibility of inadvertently using default values for elements of the array, users should always include all eight sets of values. This can be accomplished by repeating values.
- The mass and energy transfer induced by the drywell purge system are not accessible output variables.

## **Containment Purge**

The containment purge system takes gas from one containment compartment and discharges it to a different location. It is intended to model a Mark III system that takes gas from the upper compartment (dome) and discharges it to the environment to maintain a negative pressure in the upper compartment during normal operation.

*MAAP4 power requirement: none*

### **Input Parameters**

|                       |                                                                                                       |
|-----------------------|-------------------------------------------------------------------------------------------------------|
| PCPUR vs. WVCPU array | Head-flow curve                                                                                       |
| JNCPs and JNCPD       | Identification numbers of the compartments the containment purge takes suction from and discharges to |
| Events 269 and 270    | Containment purge is forced on or locked off                                                          |

### **Calculated Variables**

|           |                         |
|-----------|-------------------------|
| Event 155 | Containment purge is on |
|-----------|-------------------------|

### **Features of the containment purge model to note:**

- The elements of the input array that represents the head-flow curve do not need to be in the order of highest to lowest pressure or vice versa. Because the pressure terms are compared to the difference between the pressures in the suction and discharge compartments, the terms should be negative numbers to coincide with the suction pressure being less than the discharge pressure. To avoid the possibility of inadvertently using default values for elements of the array, users should always include all eight sets of values. This can be accomplished by repeating values.
- The mass and energy transfer induced by the containment purge system are not accessible output variables.
- The modeling of the mass and energy exchange associated with the containment purge system includes an equal volume return flow, which prevents the pulling of a large vacuum in the suction compartment. This component is not included in the modeling associated with the drywell purge system.

## **Additional Primary System Events**

### **Input Events**

|           |                                    |
|-----------|------------------------------------|
| Event 256 | Break in the primary system (LOCA) |
|-----------|------------------------------------|

### **Calculated Events**

|                          |                                                                                                            |
|--------------------------|------------------------------------------------------------------------------------------------------------|
| Events 11, 12, and 75    | Downcomer, lower plenum, or core water is saturated or subcooled                                           |
| Event 16                 | Relocation of core materials to the lower plenum has started                                               |
| Event 30                 | Core is uncovered (boiled-up level of the core water pool, ZWV, is less than the top of active fuel, ZCRU) |
| Event 35                 | Corium in the lower plenum is quenched                                                                     |
| Events 36 and 38         | Corium or water is present in the lower plenum                                                             |
| Event 39                 | Water level is greater than or equal to Level 8 (ZWL8, used to limit LPCI, LPCS, and HPSW)                 |
| Event 111                | Primary system fluids are thermodynamically coupled                                                        |
| Event 112                | Mass of water in the lower plenum is above a threshold                                                     |
| Events 125, 126, and 127 | Primary system natural circulation paths are open                                                          |
| Event 167                | Core has collapsed during reflooding                                                                       |
|                          |                                                                                                            |
| Vessel Failure           | _____                                                                                                      |
| Events 1, 2, and 89      | Vessel failed by heat-up of instrument tubes, CRD tubes, or drain line                                     |
| Events 4, 5, and 6       | Vessel failed by ejection of instrument tubes, CRD tubes, or drain line                                    |
| Event 8                  | Vessel has failed                                                                                          |
| Event 61                 | Extensive vessel failure                                                                                   |
| Event 72                 | Vessel failed by lower head rupture                                                                        |
| Event 73                 | Vessel failed by molten corium jet erosion                                                                 |
| Event 74                 | Vessel failed by overlying metal layer attacking the wall                                                  |

## **Additional Containment Events and Junction Control**

### **Input Events**

|                    |                                                                 |
|--------------------|-----------------------------------------------------------------|
| Events 276 and 287 | Constant flow (fire) sprays or CO <sub>2</sub> system turned on |
| Event 290          | Igniters turned on (does not require AC power)                  |

### **Calculated Events**

|                    |                                                              |
|--------------------|--------------------------------------------------------------|
| Event 21           | Corium has contacted the pedestal floor                      |
| Event 22           | Corium and water interaction in the pedestal                 |
| Events 76 and 77   | Corium or water entrained in the pedestal                    |
| Event 118          | Reverse flow through suppression pool vents                  |
| Events 139 and 150 | Constant flow (fire) spray water or CO <sub>2</sub> depleted |
| Event 140          | Suppression pool level below vent pipe                       |
| Event 199          | Containment failed                                           |

### **Conditions in the Containment and Auxiliary Building Compartments**

|                                           |                                                                    |
|-------------------------------------------|--------------------------------------------------------------------|
| Events 1001, 1016, and so on <sup>a</sup> | Water pool is present                                              |
| Events 1002, 1017, and so on              | Water pool is saturated                                            |
| Events 1003, 1018, and so on              | Volumetric burn is in progress                                     |
| Events 1004, 1019, and so on              | Corium pool is present                                             |
| Events 1005, 1020, and so on              | Corium pool is frozen                                              |
| Events 1006, 1021, and so on              | Compartment is solid (that is, filled with water)                  |
| Events 1008, 1023, and so on              | Corium pool is quenched                                            |
| Events 1009, 1024, and so on              | Corium pool temperature is greater than the concrete melting point |
| Events 1010, 1025, and so on              | Constant flow (fire) sprays are on                                 |
| Events 1011, 1026, and so on              | Fire suppression system (CO <sub>2</sub> ) is on                   |
| Events 1013, 1028, and so on              | Water is entrained                                                 |
| Events 1014, 1029, and so on              | Corium is entrained                                                |
| Events 1015, 1030, and so on              | Jet burn is in progress                                            |

<sup>a</sup> The event codes that correspond to the conditions in the containment compartments are determined using an algorithm that is a function of the condition number and the compartment number.



The following containment junction input parameters and calculated variables are useful for constructing logic to control the operation of junctions and for evaluating the status of junctions.

**Input Junction Control**

|                              |      |                                                                                           |
|------------------------------|------|-------------------------------------------------------------------------------------------|
| JFRB( $j$ ) for junction $j$ | = 1  | Manually force the junction open                                                          |
|                              | = 0  | Manually force the junction closed                                                        |
|                              | = -1 | Restore the junction to its original state (open or closed based on the type of junction) |

**Calculated Junction Variables**

|                              |          |                    |
|------------------------------|----------|--------------------|
| IFRB( $j$ ) for junction $j$ | > 0      | Junction is open   |
|                              | $\leq 0$ | Junction is closed |

## ***Miscellaneous Logic Events***

### **Input Events**

|                |                                                             |
|----------------|-------------------------------------------------------------|
| Event 300      | Reset cumulative figures-of-merit                           |
| Events 320–323 | Write to log, restart, tabular, print, or plot output files |

### **Calculated Events**

|           |                                                                   |
|-----------|-------------------------------------------------------------------|
| Event 100 | Iodine model is on                                                |
| Event 115 | Start to call fission product routines                            |
| Event 198 | Automatic plot spacing is on (versus equally spaced plot spacing) |

# C

## PWR SYSTEMS AND EVENTS

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This appendix contains information and guidance on the MAAP4 modeling of individual PWR systems. It includes descriptive information about the input parameters, the calculated variables, and the event codes that control the system logic. It also includes descriptions of unique features of the individual models that might be of particular interest to users. The contents are grouped by system for easy reference. This appendix is intended to complement the information in the MAAP4 User's Manual and the sample parameter files, and to be used in conjunction with these other references. Users should also refer to Section 6 of this report for guidance on PWR code applications.

The information in this appendix is consistent with Rev. 4.0.6 of the code. Changes made for Rev. 4.0.7 that relate to PWR systems are noted. The lists of calculated variables for each system are not exhaustive; additional variables are listed in the *Pltmap* section of the sample parameter files and in the lists of plottable variables on the MAAP4 web site.

### Events

MAAP4 uses event codes to control the high-level logic during an accident simulation. The three types of event codes—automatic, external, and user-defined—are discussed in Section 3.1.1.3. The PWR automatic and external events are described in detail in the *Evtmes* section of the sample parameter files and in the EVENTS subroutine description in Volume II of the MAAP4 User's Manual. The descriptions include the conditions that cause the automatic events to change state. The entries in the sample parameter files are in numerical order. In this appendix, they are grouped with the other input and output for each system. The MAAP4 variables for the events are the elements in the array IEVNT; the variable for event number  $i$  is IEVNT( $i$ ).

### Systems

The following PWR systems are addressed in this appendix:

- Supply power
- Refueling water storage tank (RWST)
- Condensate storage tank (CST)
- Containment sumps
- Reactor coolant pumps (RCPs)
- Makeup and letdown flow

- Reactor protection system
- Pressurizer PORVs and safety valves
- Pressurizer sprays and heaters
- Accumulators (including upper head injection and core reflood systems)
- Core makeup tanks and passive heat removal system
- Quench tank
- Main feedwater (MFW)
- Auxiliary feedwater (AFW)
- Steam generator MSIVs, PORVs and safety valves
- Hardwired and generalized ESF models—general information
- High pressure injection (HPI)—hardwired ESF model
- Charging pumps (CHP)—hardwired ESF model
- Low pressure injection (LPI)—hardwired ESF model
- RHR sprays and heat exchangers—hardwired ESF model
- Lower and upper compartment sprays—hardwired ESF model
- Generalized ESFs
- Fan coolers and chillers
- Containment air coolers
- Additional PWR events and logic control
  - Primary system
  - Steam generator
  - Containment
  - Miscellaneous

## **Supply Power**

The supply power variables in MAAP4 are used to determine the potential operability of the various systems. The power requirements of each system are listed in Table C-1.

### **Input Parameters**

|           |                                                      |
|-----------|------------------------------------------------------|
| Event 205 | Loss of AC power                                     |
| Event 206 | Loss of DC power                                     |
| Event 207 | Igniters forced on even if AC power is not available |

### **Calculated Variables**

|           |                                                                                  |
|-----------|----------------------------------------------------------------------------------|
| IPOWER    | Flag to indicate availability of AC power (is set to 1 if AC power is available) |
| Event 170 | Igniters have power (AC power or available using event 207)                      |

### **Features of the supply power logic to note:**

- The initial assumption in the PWR code is that AC and DC power are available.
- The PWR code does not distinguish between offsite and onsite (emergency-diesel-generated) AC power. The code assumes that all systems that need AC power are diesel-backed. For this reason, if a user wishes to run a sequence in which only offsite AC is lost, it is necessary manually disable those systems that are not diesel-backed instead of using event 205, which will disable all AC-powered systems.
- DC power (battery power) in the PWR code applies only to the pressurizer PORVs (see the pressurizer section that follows). DC power is assumed to be unlimited; if the PORVs require DC power, logic should be included in the input files to disable DC power when the power supply would be drained.

**Table C-1**  
**MAAP4 PWR Power Requirements**

| <b>System</b>                                     | <b>Requires AC Power</b>                                | <b>Requires AC or DC Power</b> | <b>No Power Requirement</b> |
|---------------------------------------------------|---------------------------------------------------------|--------------------------------|-----------------------------|
| RCPs                                              | X                                                       |                                |                             |
| Makeup and letdown flow                           | X                                                       |                                |                             |
| Pressurizer PORVs                                 | User selected                                           | User selected                  |                             |
| Pressurizer safety valves                         |                                                         |                                | X                           |
| Pressurizer sprays and heaters                    | X                                                       |                                |                             |
| Accumulators, UHI, and core flood tanks           |                                                         |                                | X                           |
| Core makeup tanks and passive heat removal system |                                                         |                                | X                           |
| Quench tank                                       |                                                         |                                | X                           |
| MFW                                               | X                                                       |                                |                             |
| AFW—motor-driven                                  | X                                                       |                                |                             |
| AFW—turbine-driven                                |                                                         |                                | X                           |
| Steam generator MSIVs                             |                                                         |                                | X                           |
| Steam generator PORVs                             | X                                                       |                                |                             |
| Steam generator safety valves                     |                                                         |                                | X                           |
| HPI, LPI, and CHP                                 | X                                                       |                                |                             |
| RHR sprays and heat exchangers                    | X                                                       |                                |                             |
| Containment sprays                                | X                                                       |                                |                             |
| Fan coolers and chillers                          | X                                                       |                                |                             |
| Containment air coolers                           |                                                         |                                | X                           |
| Igniters                                          | X or alternative power source available using event 207 |                                |                             |

## **Refueling Water Storage Tank**

The water in the RWST feeds the hardwired ESF HPI, LPI, CHP, and containment spray systems. For the generalized ESF model, the RWST can be selected by the user as the source of water for individual systems. The RWST also feeds the auxiliary pressurizer sprays. The RWST can be refilled from an external source.

### **Input Parameters**

|           |                   |                                                                            |
|-----------|-------------------|----------------------------------------------------------------------------|
| MRWST0    | Both <sup>a</sup> | RWST initial water mass                                                    |
| TRWST     | Both              | RWST liquid temperature                                                    |
| ARWST     | Both              | Area of the base of the RWST                                               |
| ZESPRW    | Hardwired         | Height of the bottom of the RWST above the ESF pumps                       |
| ZLP1RW    | Generalized       | Height of the bottom of the RWST above the LPI train 1 pumps               |
| ZLP2RW    | Generalized       | Height of the bottom of the RWST above the LPI train 2 pumps               |
| ZHPIRW    | Generalized       | Height of the bottom of the RWST above the HPI pumps                       |
| ZCHPRW    | Generalized       | Height of the bottom of the RWST above the CHP pumps                       |
| ZSPARW    | Generalized       | Height of the bottom of the RWST above the upper compartment spray pumps   |
| ZSPBRW    | Generalized       | Height of the bottom of the RWST above the lower compartment spray pumps   |
| ZSPCRW    | Generalized       | Height of the bottom of the RWST above the containment spray train C pumps |
| WRWSTX    | Both              | Mass flow rate of the external RWST replacement water                      |
| FBARWS    | Both              | Mass fraction of the boron in the RWST                                     |
| Event 237 | Both              | External RWST source is available                                          |

<sup>a</sup> Indication of whether the input parameter applies to the hardwired ESF model only, the generalized ESF model only, or both.

### **Calculated Variables**

|           |                                                            |
|-----------|------------------------------------------------------------|
| ZRWST     | Water level in the RWST relative to the bottom of the tank |
| MRWST     | Mass of water in the RWST                                  |
| Event 187 | RWST water is depleted                                     |

## **Condensate Storage Tank**

The water in the CST feeds the motor-driven and turbine-driven AFW systems.

### **Input Parameters**

|        |                                                                   |
|--------|-------------------------------------------------------------------|
| MWCST0 | CST initial water mass                                            |
| ACST   | Area of the CST                                                   |
| ZCSTAF | Elevation of the bottom of the CST relative to the AFW pump inlet |
| TAFW   | Temperature of the AFW water                                      |

### **Calculated Variables**

|           |                          |
|-----------|--------------------------|
| MWCST     | Mass of water in the CST |
| Event 191 | CST water depleted       |

### **Feature of the CST model to note:**

- AFW will terminate upon depletion of the CST inventory. Users should specify a large initial CST mass (for example, 1.e10 lbs) to simulate the refilling of the CST from an external source.



## Containment Sumps

The water in the containment sumps provides a source for the ESF systems. For the hardwired ESF model, depending on the user-specified recirculation lineup, the HPI, LPI, CHP, and containment spray systems can take suction from the main sump (usually in the lower compartment and referred to as the *containment sump*) following the operator action to enable recirculation. For the generalized ESF systems, the user can select the main or secondary sump (usually in the annular compartment) as the source in either the normal or recirculation mode.

### Input Parameters

|                        |                                                                                                   |
|------------------------|---------------------------------------------------------------------------------------------------|
| JNCSMP                 | Containment node containing the containment sump                                                  |
| JNASMP <sup>a</sup>    | Containment node containing the secondary (annular) containment sump                              |
| VRBLK vs. XRBLK arrays | Water volume versus height tables for the containment and annular sumps                           |
| ZESPCS <sup>b</sup>    | Height of the bottom of the containment sump above the ESF pumps                                  |
| ZSPACS                 | Height of the bottom of the containment sump above the upper containment spray pumps              |
| ZSPBCS                 | Height of the bottom of the containment sump above the lower containment spray pumps              |
| ZLP1CS <sup>a</sup>    | Height of the bottom of the containment or annular sump above the LPI train 1 pumps               |
| ZLP2CS <sup>a</sup>    | Height of the bottom of the containment or annular sump above the LPI train 2 pumps               |
| ZHPICS <sup>a</sup>    | Height of the bottom of the containment or annular sump above the HPI pumps                       |
| ZCHPCS <sup>a</sup>    | Height of the bottom of the containment or annular sump above the CHP                             |
| ZSPCCS <sup>a</sup>    | Height of the bottom of the containment or annular sump above the containment spray train C pumps |
| ACS and ZCS            | Area and depth of the containment sump (used only for MAAP4-GRAAPH)                               |
| Event 220              | Switch to recirculation mode                                                                      |

<sup>a</sup> These are used only with the generalized ESF model.

<sup>b</sup> This is used only with the hardwired ESF model.

### Calculated Variables

|              |                                                                |
|--------------|----------------------------------------------------------------|
| ZWRB(JNCSMP) | Water level in the containment sump node                       |
| MWRB(JNCSMP) | Mass of water in the containment sump node                     |
| ZWRB(JNASMP) | Water level in the secondary (annular) containment sump node   |
| MWRB(JNASMP) | Mass of water in the secondary (annular) containment sump node |
| WCS          | Total water flow pumped out of the containment sump            |
| WDSCS        | Total water flow pumped out of the secondary (annular) sump    |
| Event 181    | Operator has switched to recirculation mode                    |

## **Reactor Coolant Pumps**

The RCPs, also referred to as *main coolant pumps (MCPs)*, circulate water in the primary system. There is one pump per cold leg.

*MAAP4 power requirement: AC power*

### **Input Parameters**

|                       |                                                                                                                                                                                                      |
|-----------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NWPST                 | Number of points in the RCP coastdown curve                                                                                                                                                          |
| WPST vs. TIWPST array | RCP coastdown flow per pump versus time since pump trip (represents the coastdown curve)                                                                                                             |
| QCP0                  | Energy input from one RCP at full flow                                                                                                                                                               |
| VFCEPMX               | Maximum primary system void fraction for RCP operation                                                                                                                                               |
| PDCR0                 | Pressure rise across the RCPs during full-power operation                                                                                                                                            |
| Event 204             | Prevent clearing of the pump bowls by the bumping of the pumps when they would be bumped because of the depressurization resulting from vessel failure (does not affect bumping due to other causes) |
| Event 208             | Force the unbroken loop pump bowls to be cleared by bumping the pumps                                                                                                                                |
| Event 215             | Manually trip off the RCPs                                                                                                                                                                           |
| Events 244 and 247    | Idle and bump the broken loop pumps to clear the loop of water for the TMI-2 accident simulation                                                                                                     |
| Event 258             | Force the broken loop pump bowls to be cleared by bumping the pumps                                                                                                                                  |

### **Calculated Variables**

|           |                                                           |
|-----------|-----------------------------------------------------------|
| WWBL      | Pumped mass flow of water through the broken loop         |
| WWUL      | Pumped mass flow of water through the unbroken loop       |
| QPBL      | Rate of energy addition by one RCP in broken loop         |
| QPUL      | Rate of energy addition by one RCP in unbroken loop       |
| QMCPMP    | Rate of energy addition by all RCPs                       |
| Event 4   | RCPs tripped off                                          |
| Event 165 | RCPs bumped in the unbroken loops to clear the pump bowls |
| Event 166 | RCPs bumped in the broken loops to clear the pump bowls   |

**Features of the RCP model to note:**

- The pumps are assumed to be on initially and will trip off if any of the following conditions is met:
  - Loss of AC power
  - High primary system void fraction
  - Manually forced off
- The pumps will coast down according to the coastdown curve if they are tripped off by loss of AC power or by manually forcing them off. They will not coast down if they are tripped off by the high void fraction criterion; in this case, the pumped flow will be set to 0.0 immediately.
- It is not necessary that the last flow term in the coastdown curve be 0.0. The flow will be set to 0.0 after the time since the trip exceeds TIWPST(NWPST). However, a smoother coastdown can be achieved by setting the last flow term to 0.0 or a small value.
- Unlike the coastdown of steam generator feedwater pumps, the coastdown of RCPs is not a function of the initiator that leads to the pump trip. (The exception is a locked rotor event, but this would apply to only one pump—and MAAP4 does not model the pumps individually.)
- There is no automatic RCP trip signal based on void fraction at a plant. The high void fraction trip logic is included in the code to prevent the pumps from continuing to run at high void fraction, simulating the operators shutting off the pumps according to the plant's EOPs. The calculated void fraction that is compared to VFPMX is VFPS. Event 215 will be set to true when the high void fraction criterion is reached. This is an exception to the rule that external events are set by the user with input components versus being set by the code.
- The energy added to the primary system water from the pumps is a significant contributor to the conditions in the primary system, and the value of QCP0 can affect the timing of key events. The energy is proportional to the pumped flow during the coastdown period.
- Users should include additional sequence-specific logic to trip the RCPs in order to simulate operator actions in the EOPs. Without this logic, code results might be impacted by inappropriately-extended RCP operation.
- The bumping of the pumps causes the inventory in the cold legs to be rapidly discharged to the downcomer. The pumps will be bumped if they have been tripped and the forced flow through the pumps is greater than 0.0 (that is, during the pump coastdown), or when the primary system depressurizes as a result of vessel failure. The pumps can also be bumped manually (to simulate the pump start during the TMI-2 accident). If the volume of water that would be moved is greater than the open volume in the vessel, the action to bump the pumps is overridden.
- The RCP coastdown curve can be modified to simulate natural circulation flow. This allows the code to mechanistically calculate the heat transfer to the steam generators rather than use the *Model* parameter HTSTAG, which is the coefficient for the primary side to secondary side heat transfer when single- or two-phase natural circulation is occurring in the coolant loops. This is discussed further in Table 8-2.

## **Makeup and Letdown Flow**

The makeup and letdown flow systems add water to and remove water from the primary system; the source and sink are not modeled.

*MAAP4 power requirement: AC power*

### **Input Parameters**

|           |                                                      |
|-----------|------------------------------------------------------|
| WWLET0    | Letdown mass flow rate                               |
| WWMU0     | Maximum makeup mass flow rate                        |
| TWMU      | Temperature of makeup water                          |
| ZWPZMU    | Pressurizer level setpoint for makeup control system |
| Event 242 | Makeup flow is locked off                            |
| Event 243 | Letdown flow is locked off                           |

### **Calculated Variables**

|          |                                                                                                                                      |
|----------|--------------------------------------------------------------------------------------------------------------------------------------|
| WESFCL   | Mass flow rate of injection to the intermediate leg, including makeup flow, referred to as the <i>cold leg</i> in code documentation |
| Event 24 | Makeup is not operational                                                                                                            |
| Event 46 | Letdown is not operational                                                                                                           |

### **Features of the makeup and letdown flow models to note:**

- Makeup and letdown flow are on by default.
- To prevent flow, the systems can be forced off using events 242 and 243, or the mass flow rates can be set to 0.0.
- Makeup flow is injected into the primary system through the intermediate legs. It is split evenly among the loops.
- Letdown flow is removed from the unbroken loop intermediate leg unless Spanish-specific coding is used (ISPAIN = 1), in which case the water is removed from the broken loop intermediate leg.
- The makeup and letdown models are compatible with both the hardwired and generalized ESF models.
- Because the source of makeup flow is a balance-of-plant component that is not modeled, there is no limit on the amount of water that can be added to the primary system, and the added water does not influence the boron concentration in the primary system.

- Makeup flow is throttled using the target level ZWPZMU. If the pressurizer water level is greater than ZWPZMU, there will be no makeup flow. Event 24 is not set to false if the flow is 0.0 because of high pressurizer water level.
- The letdown mass flow rate is a constant; the code does not adjust letdown flow as a function of pressurizer water level. The flow can be controlled as a function of the water level using the following input file component:

```
PARAMETER CHANGE
C Saves original value of WWLET0
  WWLETSAB = WWLET0
C Sequence has not begun
  IWATCHLET = 0
END

FUNCTION ZWPZLET = X //Letdown level setpoint in meters
                      //where X is input lower level shutoff trip
WHEN ZWPZ < ZWPZLET and IWATCHLET /= 1
  IWATCHLET = 1
  WWLET0 = 0
  REPEAT
END

WHEN ZWPZ > ZWPZLET AND IWATCHLET /= 2
  IWATCHLET = 2
  WWLET0 = WWLETSAB
  REPEAT
END
```

- Typically, one safety injection pump (usually a charging pump) is used for makeup flow. MAAP4 does not contain logic to account for the fact that one pump can be used for both systems. As a result, if makeup and the corresponding injection system are both operational, makeup should be turned off. Logic that can be added to the input file to turn off makeup when CHP is operational is as follows (for HPI instead of CHP, use event 5 instead of event 11):

```
PARAMETER CHANGE
C Saves original value of WWMU0
  WWMU0SAV = WWMU0
C Sequence has not begun
  IWATCHMK = 0
END

WHEN IEVNT(11) == 1
  IWATCHMK = 1
  WWMU0 = 0
  REPEAT
END
```

```
WHEN IEVNT(11) == 0  
  IWATCHMK = 2  
  WWMU0 = WWMU0SAV  
  REPEAT  
END
```

## ***Reactor Protection System—Scram***

In MAAP4 a reactor trip (scram) signal is generated if any of the following has occurred:

- High or low primary system pressure
- High or low pressurizer water level
- High water temperature difference across the loops
- Low steam generator water level
- Loss of AC power
- RCPs are tripped
- CHPs are on (unless overridden with event 257)
- High containment pressure (as of Rev. 4.0.7)
- Manual initiation

*MAAP4 power requirement:* loss of AC power causes a reactor trip signal

### **Input Parameters**

|                       |                                                                                                                     |
|-----------------------|---------------------------------------------------------------------------------------------------------------------|
| QCR0                  | Initial core power                                                                                                  |
| PPSL                  | Low primary system pressure reactor trip setpoint                                                                   |
| PPSH                  | High primary system pressure reactor trip setpoint                                                                  |
| ZWPZL                 | Low pressurizer water level reactor trip setpoint (also used for Spanish-specific plants to control HPI)            |
| ZWPZH                 | High pressurizer water level reactor trip setpoint                                                                  |
| TDIFPS                | High loop water temperature difference reactor trip setpoint                                                        |
| ZWSGL                 | Low steam generator water level reactor trip setpoint                                                               |
| PRBHI                 | High containment pressure reactor trip setpoint (as of Rev. 4.0.7)                                                  |
| TDSCRM                | Time delay between the reactor trip signal and the onset of the trip                                                |
| TDPOWR                | Time period over which the core power ramps linearly from full power to decay power following the onset of the trip |
| FQINHF                | Selects option for decay power calculation:<br>= 0: use ANSI/ANS decay power correlation<br>= 1: use input array    |
| NFQHF                 | Number of points in the decay power input array                                                                     |
| FQHF vs. TIFQHF array | Core power fraction (relative to full power) versus time since reactor trip                                         |
| HALFLP                | Flag to indicate that a sequence is simulating mid-loop (half-loop) operation                                       |

### Input Parameters (continued)

|           |                                                                         |
|-----------|-------------------------------------------------------------------------|
| TIHALF    | Time elapsed since reactor trip at the beginning of a mid-loop sequence |
| Event 227 | Reactor manually tripped                                                |
| Event 245 | MFW remains on at reactor trip                                          |
| Event 257 | Reactor does not trip when charging pumps are on                        |

### Calculated Variables

|           |                                                                                 |
|-----------|---------------------------------------------------------------------------------|
| QDECAY    | Core power                                                                      |
| TISCRM    | Reactor trip time (onset of reactor trip after TDSCRM)                          |
| Event 13  | Reactor trip signal received                                                    |
| Event 109 | Reactor trip due to low primary system pressure                                 |
| Event 110 | Reactor trip due to high primary system pressure                                |
| Event 111 | Reactor trip due to high loop temperature difference                            |
| Event 112 | Reactor trip due to low pressurizer water level                                 |
| Event 113 | Reactor trip due to high pressurizer water level                                |
| Event 114 | Reactor trip due to loss of AC power                                            |
| Event 115 | Reactor trip due to loss of RCPs                                                |
| Event 116 | Reactor trip due to charging pump initiation (can be disabled with event 257)   |
| Event 117 | Reactor trip due to low water level in the steam generator in the broken loop   |
| Event 118 | Reactor trip due to low water level in the steam generator in the unbroken loop |
| Event 131 | Reactor trip due to high containment pressure                                   |

### Features of the reactor protection system model to note:

- Event 13 is set to true when one of the conditions to trip the reactor has been met. The core remains at full power for an additional time specified by input parameter TDSCRM.
- The decay power is calculated according to a) the ANSI/ANS decay power correlation [9] or b) the table of input values specified by the FQHF versus TIFQHF array. The table is used if the parameter FQINHF is set to 1, regardless of whether the sequence is a mid-loop (half-loop) sequence. Users should set the number of points in the array, NFQHF, to the appropriate value and set the initial power, parameter QCR0, to the full power when the table is used.
- If the option to use the input array of the decay power versus time is selected, the code will interpolate only within the values of the array and will not extrapolate beyond the time range. Therefore, users should set the first fraction and time values to 1.0 and 0.0, respectively.



- If TDPOWER is non-zero, the power will ramp down linearly to the decay power over that time period. After that time period has ended, the power will be equal to the decay power (which is calculated based on the time since the reactor trip and does not account for TDPOWER).
- The definitions of parameters TDSCRM and TDPOWER have been changed for Rev. 4.0.7, and users should reevaluate their values for these parameters when transitioning to that version of the code.
- The time it takes to receive a reactor trip signal is an appropriate value for TDSCRM, and the time it takes to fully insert the control rods is an appropriate value for TDPOWER.
- If the sequence is simulating a plant in mid-loop operation, the decay power is calculated using the value of parameter TIHALF, the time since the reactor has scrammed. This is the case regardless of whether the ANSI/ANS correlation or the input table is used for the decay power. In addition, the code will set external event 227 to true to force a manual scram. However, events 227 and 13 will not be noted in the summary file in this instance. See Section 6.6.10 of this report for more information about the modeling of mid-loop sequences.
- The calculated primary system pressure, pressurizer water level, temperature difference between the water in the hot and cold legs, and steam generator water levels that are compared to the setpoints are PPS, ZWPZ, the quantity TWHPS minus TWLPS, ZWBS, and ZWUS, respectively.
- The logic to initiate a reactor trip on high containment pressure has been added in Rev. 4.0.7. The calculated containment pressure that is compared to the setpoint is either the pressure in the compartment containing the upper or RHR sprays (pointer JNUCS) or the third compartment if the spray pointer JNUCS is not set.
- Because of an error in the logic, the code will calculate a reactor trip on initiation of the charging pumps even if they have been locked off using event 232. Setting the number of pumps, NCHP, to 0.0 when they are locked off will avoid this error.
- Care should be taken to determine a value for the low steam generator water level setpoint that is consistent with the code models, particularly if the one-region steam generator model is used. Because of inherent simplifications in the steam generator models, the calculated water level is not a precise value. **Users should calibrate the calculated water level against the water mass and then use a value for the setpoint that is consistent with the actual water mass at the plant setpoint.**
- The MSIVs will close on a reactor trip unless they are locked open with event 236.

## Pressurizer PORVs and Safety Valves

The pressurizer model includes a representation of up to five relief valves for pressure control. Each valve can be represented either as a power-operated relief valve (PORV) or a safety valve.

*MAAP4 power requirement for PORVs:* AC or DC power as selected by the user

*MAAP4 power requirement for safety valves:* none

### Input Parameters (for valve *i*)

|                    |                                                                                                                                                                                                                                     |
|--------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NPZRV              | Total number of PORVs and safety valves modeled in the pressurizer                                                                                                                                                                  |
| NIPORV( <i>i</i> ) | Flag indicating whether the valve is a PORV or a safety valve<br>= 0: the valve is a safety valve<br>= 1: the valve is a PORV                                                                                                       |
| FPPORV             | Flag indicating how the PORVs are powered<br>= 0: AC powered<br>= 1: DC powered<br>= 2: AC or DC powered                                                                                                                            |
| IQT                | = 1: valves discharge to a quench tank<br>= 0: valves discharge to a containment node (which can be used to model a tank)                                                                                                           |
| JNRV               | Containment node containing the quench tank (if IQT = 1) or receives the relief valve discharge (if IQT = 0)                                                                                                                        |
| ZNRV               | Elevation of the valve discharge above the floor of the quench tank or the receiving containment node                                                                                                                               |
| AINPUT             | Flag indicating how the PORV and safety valves flow areas are calculated<br>= 0: the code calculates the effective areas using the flow rate and pressure (recommended option)<br>≠ 0: the code uses the values of ASRV( <i>i</i> ) |
| WPORV0             | Rated (nameplate) flow of a PORV at PPORVL (used when AINPUT = 0)                                                                                                                                                                   |
| PPORVL             | Reference opening pressure of the PORV (absolute pressure, not gauge pressure)                                                                                                                                                      |
| WPZSV0             | Rated (nameplate) flow for a safety valve at PPZSVL (used when AINPUT = 0)                                                                                                                                                          |
| PPZSVL             | Reference opening pressure of the safety valve (absolute pressure, not gauge pressure)                                                                                                                                              |
| ASRV( <i>i</i> )   | Effective flow area of the valve (used when AINPUT ≠ 0)                                                                                                                                                                             |
| FCDPRV             | Discharge coefficient for valves (used when AINPUT ≠ 0; should be set to 1.0)                                                                                                                                                       |
| PSETRV( <i>i</i> ) | Relief mode opening pressure setpoint for the PORV                                                                                                                                                                                  |
| PDRV( <i>i</i> )   | Relief mode deadband for the PORV; the difference between PSETRV( <i>i</i> ) and PDRV( <i>i</i> ) is the closing pressure for the PORV                                                                                              |
| PSETSV( <i>i</i> ) | Safety mode opening pressure setpoint for the safety valve                                                                                                                                                                          |

**Input Parameters (for valve  $i$ ) (continued)**

|               |                                                                                                                                                                                                                  |
|---------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| PDSV( $i$ )   | Safety mode deadband for the safety valve; the difference between PSETSV( $i$ ) and PDSV( $i$ ) is the closing pressure for the safety valve                                                                     |
| ISTUCK( $i$ ) | Flag to stick open the valve; represents a mechanical failure                                                                                                                                                    |
| IFAILC( $i$ ) | Flag to stick closed the valve; represents a mechanical failure                                                                                                                                                  |
| ILOCK( $i$ )  | Flag to prevent the automatic opening of the PORV (to be used only with code Rev. 4.0.8 and higher; the option does not work properly because of a code error that was not successfully corrected in Rev. 4.0.7) |
| IMANON( $i$ ) | Flag to manually open the PORV                                                                                                                                                                                   |

**Calculated Variables (for valve  $i$ )**

|               |                                                                |
|---------------|----------------------------------------------------------------|
| IOPEN( $i$ )  | Valve status flag:<br>= 0: closed<br>= 1: open                 |
| NCYCLE( $i$ ) | Total count of the number of times the valve has cycled        |
| WWRV          | Flow rate of water through all the valves                      |
| WGRV          | Flow rate of gas through all the valves                        |
| WSTRV         | Total flow of steam through the valves                         |
| ARVPZ         | Total open flow area of the valves                             |
| TDPZR         | Largest allowed time step size for pressurizer rates of change |
| Event 42      | Pressurizer safety valves are open                             |
| Event 44      | Pressurizer relief valves are open                             |

**Features of the pressurizer PORV and safety valve model to note:**

- The pressurizer pressure, PPZ, is compared to the PORV and safety valve setpoint pressures to determine which valves are to be opened.
- The value of NIPORV( $i$ ) is used to indicate if the valve can be manually opened with IMANON( $i$ ) and, if parameter AINPUT is set to 0, which terms are used to calculate the flow area. It is not used to determine whether the relief or safety mode opening pressure setpoints are used (the setpoints always apply). Therefore, to prevent the valve from opening in relief mode the opening setpoint pressure, PSETRV( $i$ ), should be set to a large value and the corresponding deadband, PDRV( $i$ ), should be set to 0. Similar values should be used for PSETSV( $i$ ) and PDSV( $i$ ) to prevent the valve from opening in safety mode.
- Because of a code limitation, parameter ILOCK( $i$ ) will not lock a valve closed. Therefore, to lock a valve closed, set the area to 0.0 as an operator action, ASRV( $i$ ) = 0.0, or set the opening pressure PSETRV( $i$ ) to a large value. This limitation will be removed in Rev. 4.0.8 (it was not successfully fixed in Rev. 4.0.7).

- The value of FCDPRV should be set to 1.0. It is used only when the areas are specified as input, and these are defined to be the effective areas, not the actual areas. FCDPRV is not used when the code calculates the areas (when AINPUT = 0).
- The sample parameter files provide two methods for the user to calculate the values of ASRV(*i*); only the second method, which is based on the code's critical flow model, is recommended. This method is identical to the algorithm used by the code when it calculates the areas (when AINPUT = 0).

## Pressurizer Sprays and Heaters

Pressurizer sprays and heaters maintain pressure in the pressurizer.

MAAP4 power requirement for pressurizer sprays and heaters: AC power

### Input Parameters

|                    |                                                                             |
|--------------------|-----------------------------------------------------------------------------|
| <b>Sprays</b>      |                                                                             |
| PPZSP0             | Pressurizer spray pressure setpoint                                         |
| WPZSP0             | Pressurizer spray mass flow rate                                            |
| ZPZSP              | Elevation of the spray header above the bottom of the pressurizer           |
| XDPZSP             | Nominal diameter of the spray droplet                                       |
| WVEBS              | Volumetric flow rate of water from the RWST to auxiliary pressurizer sprays |
| Events 223 and 246 | Pressurizer sprays are forced on, locked off, or automatically controlled   |
| <b>Heaters</b>     |                                                                             |
| PPZHT0             | Pressurizer heater pressure setpoint                                        |
| QPZHT0             | Pressurizer heater total energy output rate                                 |
| ZPZHT              | Pressurizer heater low water level trip point                               |
| Event 226          | Pressurizer heaters are locked off or automatically controlled              |

### Calculated Variables

|          |                                                                                |
|----------|--------------------------------------------------------------------------------|
| QPZHT    | Energy added by pressurizer heaters                                            |
| WPZSP    | Normal pressurizer spray mass flow output (does not apply to auxiliary sprays) |
| Event 30 | Pressurizer heaters on                                                         |
| Event 31 | Pressurizer sprays are on (does not apply to auxiliary sprays)                 |

### Features of the pressurizer sprays and heaters to note:

- Pressurizer sprays are turned on if all of the following conditions are met:
  - The flow rate of water in the unbroken loops (in the broken loop for a one-loop configuration), WWUL or WWBL, is non-zero.
  - The collapsed water level in the pressurizer, ZWPZ, is below the spray header elevation, ZPZSP
  - The pressurizer water is saturated—not subcooled (event 38 is false).

- The operator has manually switched on the pressurizer sprays or the spray system is in automatic mode and the pressure in the primary system, PPS, is above the spray pressure setpoint, PPZSP0.
- Pressurizer heaters are turned on if both of the following conditions are met:
  - The pressure in the primary system, PPS, is less than the heater pressure setpoint, PPZHT0.
  - The collapsed water level in the pressurizer, ZWPZ, is above the heater low water level trip setpoint, ZPZHT.
- The standard pressurizer sprays are fed from the unbroken intermediate water pool. If there is only one loop, the sprays are fed from the broken intermediate loop.
- Auxiliary pressurizer sprays are fed from the RWST and are turned on if the auxiliary spray flow rate and the mass in the RWST are greater than 0.0.
- The code will not operate successfully with both normal and auxiliary pressurizer sprays turned on.
- Sprays will turn on if the RCPs are on. If the RCPs are turned off, sprays will turn off after the RCP flow has coasted down to 0.0.

## Accumulators

MAAP4 models passive injection of water into the primary system from four different sources:

- Cold leg accumulators: discharge to the downcomer water node
- Upper head injection (UHI) tanks: discharge to the core water node
- Core reflood tanks: discharge to the downcomer water node, for the AP600 and AP1000 plants
- Hot leg accumulators: the Spanish-specific model allows for the diversion of injection flows from the hot or cold leg to the core upper head region and for the diversion of injection flows from the hot leg to the cold leg.

MAAP4 power requirement: none

### Input Parameters

| Input Quantity                                | Cold Leg   | UHI                         | Core Reflood Tanks | Hot Leg<br>(for plants with<br>ISPAIN = 1) |
|-----------------------------------------------|------------|-----------------------------|--------------------|--------------------------------------------|
| Initial water mass in each tank               | MACUM0     | MUHI0 (total for all tanks) | MCRTK0             | MACUM0                                     |
| Number of operational tanks                   | NACUM      | 1                           | NCRTK              | NHLAC                                      |
| Initial pressure of the tanks                 | PACUM0     | PUHI0                       | PCRTK0             | PACUM0                                     |
| Differential failure pressure of rupture disk | —          | PDUHI                       | —                  | —                                          |
| Water temperature                             | TACUM      | TACUM                       | TCRTK              | TACUM                                      |
| Total fluid (water and gas) volume            | VACUM      | VUHI                        | VCRTK              | VACUM                                      |
| Inside diameter of pipe from the tank         | XDACUM     | XDUHI                       | XDCRTK             | XDACUM                                     |
| Equivalent length of pipe from the tank       | XLACUM     | XLUHI                       | —                  | XLACUM                                     |
| Equivalent length-to-diameter ratio           | —          | —                           | LDCRTK             | —                                          |
| Head loss coefficient                         | FKLOSSACUM | FKLOSSUHI                   | FKLOSSCRTK         | FKLOSSACUM                                 |
| Polytropic constant                           | NKPROCACUM | NKPROCUHI                   | NKPROCRTK          | NKPROCACUM                                 |

### Input Parameters

| Input Quantity                                                                               | Cold Leg  | UHI       | Core Reflood Tanks | Hot Leg<br>(for plants with<br>ISPAIN = 1) |
|----------------------------------------------------------------------------------------------|-----------|-----------|--------------------|--------------------------------------------|
| Mass fraction of the boron in the tanks<br>(used to track pH in the containment water pools) | FBAACU    | FBAACU    | FBACRT             | FBAACU                                     |
| Divert injection flow to the upper head and cold leg                                         | —         | —         | —                  | FDIVUH,<br>FDIVCL                          |
| Disable (block) tanks                                                                        | Event 214 | Event 230 | ICRTBL             | Event 264                                  |

### Calculated Variables

| Output Quantity                             | Cold Leg            | UHI                 | Core Reflood Tanks  | Hot Leg             |
|---------------------------------------------|---------------------|---------------------|---------------------|---------------------|
| Flow rate of water                          | WACUM               | WWUHI               | WCRTK               | WWHLAC              |
| Remaining mass of water in the tanks, total | MACUM               | MUHI                | MCRTK               | MHLAC and<br>MHLAC1 |
| Flow included in ESF variable               | WESFDC <sup>a</sup> | WUPSPR <sup>b</sup> | WESFDC <sup>a</sup> | WESFHL <sup>c</sup> |
| Pressure in the tanks                       | PACUM               | PUHI                | PCRTK               | PHLAC               |
| Tanks are depleted                          | Event 188           | Event 190           | —                   | —                   |
| Tank is disabled or depleted                | Event 7             | Event 48            | —                   | —                   |
| Rupture disk is broken                      | —                   | Event 47            | —                   | —                   |

<sup>a</sup>WESFDC, total water injection rate from the ESF pumps to the RPV downcomer.

<sup>b</sup>WUPSPR, core spray/injection rate.

<sup>c</sup>WESFHL, total water injection rate from the ESF pumps to the hot leg.

### Features of the accumulator models to note:

- The lengths of pipe from the accumulators and UHI to the injection nozzles, XLACUM and XLUHI, should include the equivalent lengths of elbows, restrictions, and so on. The corresponding friction losses can have a significant impact on sequences because of the positive feedback effect of injection and primary system pressure.



- The UHI system uses a rupture disk as a barrier for injection into the primary system, whereas the other accumulators use valves. The rupture disk opens when the pressure difference between the primary system and the UHI pressure equals the rupture disk setpoint, PDUHI.
- The *Model* parameter FOVER is the fraction of UHI water that goes into the core bypass region versus into the core.
- The Spanish-specific MAAP4 subroutine, SPNINJ, is invoked if the parameter ISPAIN is set to 1. This subroutine models the diversion of injection flow from the hot leg accumulators to the upper head and to the cold leg. In the subroutine, the cold leg and hot leg accumulators are represented as two separate tanks. The subroutine also models an additional borating system and emergency feedwater system.
- The calculated ESF injection flow rate, WSI, does not include flow from the accumulators, core reflood tanks, or UHI.
- MAAP4 does not model the discharge of nitrogen into the primary system from the accumulators following the discharge of the water. The nitrogen can be detrimental to the heat transfer to the steam generators.
- The accumulator tanks are a possible source of injection of boron ( $H_3BO_3$ ) into the reactor vessel. The actuation of an accumulator with boric acid will result in boric acid injection into the primary system.

### **Core Makeup Tanks and Passive RHR System**

Two core makeup tanks are part of the AP1000 advanced reactor design. The top of each tank is connected to the pressurizer and to the cold legs for gas flow. Water is discharged from the bottom of each tank to the primary system downcomer. The tank model in the code may be used for other plant designs.

A passive RHR system is also part of the AP1000 design. The system model calculates heat transfer between the primary system coolant inside the passive RHR tubes and the containment water pool outside the tubes (the IRWST).

*MAAP4 power requirement: none*

#### **Input Parameters for Core Makeup Tank *i***

|                    |                                                                                                          |
|--------------------|----------------------------------------------------------------------------------------------------------|
| ICMTK( <i>i</i> )  | Flag that indicates whether the tank is to be modeled                                                    |
| ICMT( <i>i</i> )   | Number of the cold leg node that is connected to the top of the tank                                     |
| VCMT( <i>i</i> )   | Total volume (water + gas) of the tank                                                                   |
| ACMT( <i>i</i> )   | Cross-sectional area of the tank                                                                         |
| MWMT0( <i>i</i> )  | Initial mass of water in the tank                                                                        |
| TWMT0( <i>i</i> )  | Initial temperature of the water in the tank                                                             |
| ZBCMT( <i>i</i> )  | Elevation of the bottom of the tank relative to the bottom of the reactor vessel                         |
| ZCMTDC( <i>i</i> ) | Elevation of the injection nozzle in the downcomer relative to the bottom of the reactor vessel          |
| ZTCLMT( <i>i</i> ) | Elevation of the top of the cold leg balance line relative to the bottom of the reactor vessel           |
| AMTDC( <i>i</i> )  | Cross-sectional area of the piping from the tank to the downcomer                                        |
| AMTCL( <i>i</i> )  | Cross-sectional area of the piping from the top of the tank to the cold leg                              |
| AMTPZ( <i>i</i> )  | Cross-sectional area of the piping from the tank to the pressurizer                                      |
| LDCMT( <i>i</i> )  | Equivalent length-to-diameter ratio for the piping from the tank to the downcomer                        |
| LDCLMT( <i>i</i> ) | Equivalent length-to-diameter ratio for the piping from the tank to the cold leg                         |
| LDTDVI( <i>i</i> ) | Equivalent length-to-diameter ratio for the piping from the direct vessel injection tee to the downcomer |

**Calculated Variables for Core Makeup Tank  $i$**

|                    |                                                                                   |
|--------------------|-----------------------------------------------------------------------------------|
| MWMT( $i$ )        | Mass of water in the tank                                                         |
| WGPSMT( $i$ )      | Gas flow from the primary system to the tank                                      |
| WWCLMT( $i$ )      | Water flow from the cold leg to the tank                                          |
| WWMT( $i$ )        | Water flow from the tank to the downcomer                                         |
| ZWMT( $i$ )        | Height of water in the tank                                                       |
| PMT( $i$ )         | Pressure in the tank                                                              |
| TWMT( $i$ )        | Temperature of the water in the tank                                              |
| TGMT( $i$ )        | Temperature of the gas in the tank                                                |
| Events 275 and 277 | Open the valves on the lines connecting the bottoms of the tanks to the downcomer |
| Events 276 and 278 | Open the valves on the lines connecting the tops of the tanks to the cold legs    |

**Input Parameters for Passive RHR System**

|               |                                                               |
|---------------|---------------------------------------------------------------|
| JNPRHR        | Containment compartment containing the water pool (the IRWST) |
| NTPRHR        | Number of tubes in the heat exchanger                         |
| XIDPRH–FQPRHR | Geometry and heat transfer properties for the heat exchanger  |
| Event 274     | Passive RHR valve is open                                     |

**Calculated Variables for Passive RHR System**

|       |                                                          |
|-------|----------------------------------------------------------|
| QPRHR | Heat transfer from the primary system by the passive RHR |
|-------|----------------------------------------------------------|

## Quench Tank

Effluent from the pressurizer PORV and safety valves may be discharged into a quench tank (also referred to as the *pressurizer relief tank*). If the quench tank rupture disk fails, the effluent can then discharge into the containment.

The quench tank can be simulated using a hardwired model or with the generalized containment model (GCM). The hardwired model does not include fission product scrubbing, but it had the advantage for code revisions through Rev. 4.0.5 of being better able to calculate the physical processes resulting from large gas and water flows through the relatively small volume of the tank compared to the GCM. The GCM includes fission product scrubbing and, with changes made to Rev. 4.0.6 to handle water-solid containment volumes, it can handle the large gas and water flows.

*MAAP4 power requirement:* none

### Input Parameters

|                             |                                                                                                                          |
|-----------------------------|--------------------------------------------------------------------------------------------------------------------------|
| IQT                         | = 1: valves discharge to a quench tank<br>= 0: valves discharge to a containment node, which can represent a quench tank |
| JNRV                        | Containment node containing the quench tank (if IQT = 1) or receives the relief valve discharge (if IQT = 0)             |
| Hardwired quench tank model | _____                                                                                                                    |
| VQT                         | Total fluid volume within the quench tank                                                                                |
| MWQT0                       | Initial water mass in the quench tank                                                                                    |
| PQTRD                       | Differential pressure required to fail the quench tank rupture disk                                                      |
| ZQTRD                       | Height of the quench tank rupture disk relative to compartment floor                                                     |
| ASEDQT                      | Sedimentation area for aerosol fission product settling in the quench tank                                               |

### Calculated Variables

|        |                                                 |
|--------|-------------------------------------------------|
| PQT    | Pressure in the quench tank                     |
| TWQT   | Temperature of the water in the quench tank     |
| TGQT   | Temperature of the gas in the quench tank       |
| MH2QT  | Mass of hydrogen in the quench tank             |
| MWQT   | Mass of water in the quench tank                |
| VWQT   | Specific volume of the water in the quench tank |
| VOLGQT | Volume of gas in the quench tank                |

**Calculated Variables (continued)**

|          |                                                                     |
|----------|---------------------------------------------------------------------|
| WWRD     | Flow rate of water out of the quench tank rupture disk              |
| WSTRD    | Flow rate of steam out of the quench tank rupture disk              |
| WVWRD    | Fractional rate of change of the quench tank water mass due to flow |
| WVVRD    | Fractional rate of change of the quench tank gas mass due to flow   |
| QWRD     | Energy of water through the rupture disk                            |
| QGRD     | Energy of gas through the rupture disk                              |
| Event 92 | Quench tank rupture disk has failed                                 |
| Event 93 | Quench tank rupture disk is covered                                 |
| Event 94 | Quench tank rupture disk is overflowing                             |
| Event 95 | Quench tank contains water                                          |
| Event 96 | Quench tank water is saturated or subcooled                         |

**Features of the quench tank model to note:**

- With the hardwired quench model, when the tank is overflowing and the rupture disk has failed, water will flow out the tank through the disk.
- If the GCM is used to model the quench tank, a failure junction is needed to simulate the rupture disk.

## Main Feedwater

The MFW system provides water to the steam generators.

*MAAP4 main feedwater power requirement: AC power*

### Input Parameters

|                   |                                                                                                                                                        |
|-------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|
| WFWMX             | Maximum MFW mass flow rate per steam generator                                                                                                         |
| TFW               | MFW inlet temperature to the steam generator                                                                                                           |
| TDMFW             | Delay time between receiving the main feedwater isolation signal and actual isolation                                                                  |
| ZWCTLB            | Target collapsed water level in the broken steam generator downcomer for feedwater control                                                             |
| ZWCTLU            | Target collapsed water level in the unbroken steam generator downcomer for feedwater control                                                           |
| ZDEADB and ZDEADU | Deadband for the “bang-bang” mode of steam generator water level control in the broken and unbroken loops; primarily for the TMI-2 accident simulation |
| AFWBB             | Actual area of a feedwater line break (multiplied by FCDFWB in the code to obtain the effective area)                                                  |
| FCDFWB            | Discharge coefficient for a feedwater line break                                                                                                       |
| ZFWSG             | Elevation of a feedwater line break relative to the top of the tubesheet                                                                               |
| INSGFW            | = 0: do not bypass the feedwater model<br>= 1: bypass the feedwater model                                                                              |
| WFWBSE and WFWUSE | Externally supplied total feedwater flow rate to the broken and unbroken steam generators; used only when INSGFW is set to 1                           |
| HSGFWE            | Enthalpy of externally supplied feedwater; used only when INSGFW is set to 1                                                                           |
| Event 228         | MFW is locked off or automatically controlled                                                                                                          |
| Event 245         | MFW remains on at reactor trip                                                                                                                         |

### Calculated Variables

|           |                                                                                                   |
|-----------|---------------------------------------------------------------------------------------------------|
| QSGTOT    | Total heat transfer from the primary system fluid to the secondary side                           |
| WWFWBS    | Feedwater flow (main or auxiliary) to the broken steam generator                                  |
| WWFWUS    | Feedwater flow (main or auxiliary) to the unbroken steam generators (total flow)                  |
| WWFWBB    | Water flow through a feedwater line break                                                         |
| WGFWBB    | Gas flow through a feedwater line break                                                           |
| ZWBS      | Collapsed water level in the broken steam generator downcomer                                     |
| ZWUS      | Collapsed water level in the unbroken steam generator downcomer                                   |
| Event 157 | MFW has tripped (flow continues for the additional time period TDMFW unless AFW flow has started) |

**Feature of the MFW model to note:**

- Because MFW is supplied by balance-of-plant components that are not modeled in the code, there is no limit to the amount of feedwater that can be added to the primary system.
- MFW to the steam generators is assumed to be on initially and will trip off if any of the following conditions is met:
  - Reactor trip (unless overridden with event 245)
  - Loss of AC power
  - Manually forced off
- MFW will continue to run after the system is tripped (event 157 is set to true) for an elapsed time specified by parameter TDMFW unless the AFW system has started (event 154, indicating AFW initiation, has been set to true and the time for the system to actuate, TDAFW, has elapsed). That is, the AFW flow calculation takes precedence over the MFW flow calculation if the two time delays, TDMFW and TDAFW, overlap. (If AFW is tripped off prior to TDMFW expiring, MFW will resume; this can be avoided by locking off MFW or using a smaller value of TDMFW.)
- The code does not include a coastdown curve for MFW. If the trip of MFW is intended to simulate system isolation with immediate cessation of flow, input parameter TDMFW should be set to 0.0. If the trip is associated with another type of event that results in a MFW coastdown, TDMFW should be set to the duration of the coastdown and WFWMX should be adjusted to simulate the reduced flow during the coastdown. The flow as a function of time will vary depending on the particular plant conditions and signals that caused the feedwater trip. The addition of a nontrivial amount of cold water into the steam generators over the coastdown period can have a significant impact on the conditions in the generators later in time. **Therefore, users should consider including coastdown logic on a sequence-specific basis.** Sample input file components that can be used to simulate the coastdown are as follows. They should be used in conjunction with event 236, which will force the MSIVs to remain open, and with high values for the target water levels during the coastdown period; these additional input components will prevent the feedwater flow from being inhibited by water level. Alternative input file components that adjust the flow in a more continuous manner using a lookup variable block are available on the code web site.

SET TIMER # 1 // include this line with the initiator of the MFW trip

```
WHEN TIMER #1 > 1. S
  WFWMX = 400 KG/S
END
```

```
WHEN TIMER #1 > 2. S
  WFWMX = 200 KG/S
END
```

```
WHEN TIMER #1 > 3. S
  WFWMX = 0 KG/S
END
```

- The default logic in the code is such that MFW is tripped directly by a reactor trip. Typically, this is not the actual case; the MFW trip after reactor trip is a result of the average temperature of the water in the primary system dropping below a setpoint because of reduced core power with continued heat removal by the steam generators. The code does not account for the additional time that cold water is pumped into the steam generators by the MFW system after reactor trip before the MFW trip on low primary system temperature. As with the coastdown, the addition of cold water into the generators over several seconds after a reactor trip can have a significant impact on the conditions in the generators. **Users can address this feature by setting TDMFW to the expected time required for the water temperature to reach the MFW trip setpoint.**
- The algorithm in subroutine SGWLC (steam generator water level control) for MFW flow as a function of the target water level was modified for Rev. 4.0.6 to more appropriately model plant feedwater systems. Rev. 4.0.6 calculates less feedwater following a reactor trip than Rev. 4.0.5. Users might notice minor differences in overall results between Rev. 4.0.5 and Rev. 4.0.6 because of the differences in the amount of cold water feed to the generators very early in the sequences. The calculated water levels that are compared to the target levels, ZWCTLB and ZWCTLU, are ZWBS and ZWUS, respectively.
- A feedwater line break can be simulated using the one-region steam generator model in Rev. 4.0.6; the capability has been added to the two-region model in Rev. 4.0.7. A feedwater line break is initiated by setting the value of the break area, AFWBB, to a non-zero value.
- The code does not contain a model for the feedwater heater. For sequences in which the transient properties of the feedwater are important, users should include logic to adjust the temperature using components in the input file. This is relevant for sequences in which the feedwater pumps can continue to operate but steam to the feedwater heaters is not available, and a refined heat balance is desired.



## Auxiliary Feedwater

AFW, also referred to as *emergency feedwater (EFW)*, provides water to the steam generators. The code models motor-driven and turbine-driven AFW pumps. Both types of pumps are fed by the CST.

*MAAP4 motor-driven AFW power requirement: AC power*

*MAAP4 turbine-driven AFW power requirement: none*

### Input Parameters

|                                  |                                                                                                                                                      |
|----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
| TDAFW                            | Time delay for AFW actuation (applies to both motor-driven and turbine-driven AFW)                                                                   |
| TAFW                             | AFW inlet temperature to the steam generator                                                                                                         |
| NAFWPT                           | Number of points in the motor-driven AFW pump head-flow curve                                                                                        |
| WVAFW vs. ZHDAFW array           | Head-flow curve for motor-driven AFW per steam generator                                                                                             |
| WAFWXB                           | Throttled motor-driven AFW mass flow rate per steam generator in the broken loop                                                                     |
| WAFWXU                           | Throttled motor-driven AFW mass flow rate per steam generator in the unbroken loop                                                                   |
| ZWCTLB                           | Target collapsed water level in the broken steam generator downcomer for feedwater control                                                           |
| ZWCTLU                           | Target collapsed water level in the unbroken steam generator downcomer for feedwater control                                                         |
| ZDEADB and ZDEADU                | Deadband for the bang-bang mode of steam generator water level control in the broken and unbroken loops; primarily for the TMI-2 accident simulation |
| WBATMN                           | Minimum AFW mass flow rate per steam generator when the water level controller is in the bang-bang mode                                              |
| ZCSTAF                           | Elevation of bottom of CST relative to AFW pump inlet                                                                                                |
| ZSGAFW                           | Elevation of the AFW spray header within the steam generator relative to the AFW pump outlet                                                         |
| ZAFW                             | Elevation of the AFW spray header relative to the top of the lower tubesheet (only for OTSGs)                                                        |
| NIPTS                            | Number of points in the turbine-driven AFW pump head-flow curve and the steam extraction flow curve                                                  |
| WWTDFW and WSTSGT vs. PSG arrays | Head-flow curve and steam extraction curve for turbine-driven AFW per steam generator                                                                |
| INSGFW                           | = 0: do not bypass the feedwater model<br>= 1: bypass the feedwater model                                                                            |

### Input Parameters (continued)

|                   |                                                                                                                              |
|-------------------|------------------------------------------------------------------------------------------------------------------------------|
| WFWBSE and WFWUSE | Externally supplied total feedwater flow rate to the broken and unbroken steam generators; used only when INSGFW is set to 1 |
| HSGFWE            | Enthalpy of externally supplied feedwater; used only when INSGFW is set to 1                                                 |
| Event 224         | Motor-driven AFW is locked off or automatically controlled                                                                   |
| Event 251         | Unbroken loop turbine-driven AFW is turned on                                                                                |
| Event 252         | Broken loop turbine-driven AFW is turned on                                                                                  |

### Calculated Variables

|           |                                                                                                                                   |
|-----------|-----------------------------------------------------------------------------------------------------------------------------------|
| QSGTOT    | Total heat transfer from the primary system fluid to the secondary side                                                           |
| TIAFW     | Time at which AFW will start (the time that event 224 is set to true plus TDAFW)                                                  |
| WWFWBS    | Feedwater flow (main or auxiliary) to the broken steam generator                                                                  |
| WWFWUS    | Feedwater flow (main or auxiliary) to the unbroken steam generators (total flow)                                                  |
| ZWBS      | Collapsed water level in the broken steam generator downcomer                                                                     |
| ZWUS      | Collapsed water level in the unbroken steam generator downcomer                                                                   |
| Event 134 | Unbroken loop turbine-driven AFW is on                                                                                            |
| Event 135 | Broken loop turbine-driven AFW is on                                                                                              |
| Event 154 | Motor-driven AFW has been initiated (flow will not start until the time period TDAFW has elapsed after this event is set to true) |

### Features of the AFW model to note:

- MAAP assumes that there is one motor-driven and one turbine-driven AFW pump per steam generator.
- Motor-driven AFW is automatically initiated when the MFW is tripped off and AC power is available. The flow does not start until the time period TDAFW has elapsed; TDAFW takes precedence over the MFW isolation delay time, TDMFW, if the two overlap.
- Turbine-driven AFW must be manually turned on. It can not be initiated if motor-driven AFW is operational; event 224 must be set to true to use turbine-driven AFW.
- Equal amounts of flow are injected into the steam generators in the broken and in the unbroken loops. It is not possible to align AFW such that the system preferentially feeds one steam generator in a loop that has more than one generator. For example, if there are three steam generators in the unbroken loop, AFW to the unbroken loop is split evenly among the three generators. The flow split to the broken and unbroken loops can be adjusted with the throttling or target level parameters.
- The calculated water levels that are compared to the target levels, ZWCTLB and ZWCTLU, are ZWBS and ZWUS, respectively.

- AFW can be operated in “bang-bang” mode, in which the flow cycles on and off based on the steam generator water levels relative to the target water levels. This mode is invoked by setting ZDEADB and/or ZDEADU to a non-zero value.
- AFW will be shut off when the water in the CST is depleted. Events 134, 135, and 154 will be reset to false when this occurs, depending on which AFW systems were in operation.
- The code does not include logic to shut off turbine-driven AFW when the steam generator pressure falls below a minimum value. A sequence can have numerical difficulties if turbine-driven AFW is on and the pressure becomes too low. The following input file component can be added to trip off turbine-driven AFW on low broken and unbroken steam generator pressure, PBS and PUS, respectively.

```
IF PBS < 500 PSI and IEVNT(252) == 1 // 500 psia is minimum value
  IEVNT(252) = 0
  REPEAT
END
```

```
IF PUS < 500 PSI and IEVNT(251) == 1 // 500 psia is minimum value
  IEVNT(251) = 0
  REPEAT
END
```

## **Steam Generator MSIVs, PORVs, and Safety Valves**

The steam generator model includes a representation of the MSIVs. In addition, it includes representations of the PORVs and safety valves for pressure control. The PORVs are also referred to as the *steam dump valves*.

*MAAP4 power requirement for MSIVs: none*

*MAAP4 power requirement for PORVs: AC power*

*MAAP4 power requirement for safety valves: none*

### **Input Parameters**

|                    |                                                                                                                  |
|--------------------|------------------------------------------------------------------------------------------------------------------|
| TDMSIV             | Time period over which MSIVs close                                                                               |
| NSGRV              | Number of PORVs per steam generator                                                                              |
| PSGRV              | Opening pressure for all steam generator PORVs                                                                   |
| WSGRV0             | Rated flow for a single PORV at the opening pressure, PSGRV                                                      |
| FARVBX and FARVUX  | Scaling factors applied to the total computed flow area of the PORVs in the broken and unbroken steam generators |
| NSGSV              | Number of safety valves per steam generator                                                                      |
| PSGSVH             | Highest opening pressure for all steam generator safety valves                                                   |
| PSGSVL             | Lowest opening pressure for all steam generator safety valves                                                    |
| WSGSV0             | Rated flow for a single safety valve at the opening pressure PSGSVL                                              |
| Event 233          | Manually open the broken loop steam generator PORVs                                                              |
| Events 235 and 236 | MSIVs are locked closed, forced open, or automatically controlled                                                |
| Event 239          | Manually open the broken loop steam generator safety valves                                                      |
| Event 249          | Manually open the unbroken loop steam generator PORVs                                                            |

### **Calculated Variables**

|        |                                                                                                                                           |
|--------|-------------------------------------------------------------------------------------------------------------------------------------------|
| ASGSL0 | Initial effective flow area through MSIVs in one steam generator                                                                          |
| ASGRV  | Effective flow area of one steam generator PORV                                                                                           |
| ASGSV  | Effective flow area of one steam generator safety valve                                                                                   |
| PBS    | Pressure in the broken loop steam generator                                                                                               |
| PUS    | Pressure in the unbroken loop steam generator                                                                                             |
| WWBST  | Combined flow rate of water from PORVs, safety valves, main steam line, and main steam line breaks out of the broken loop steam generator |

**Calculated Variables (continued)**

|           |                                                                                                                                                                                               |
|-----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| WGBST     | Combined flow rate of gas from PORVs, safety valves, main steam line, and main steam line breaks out of the broken loop steam generator                                                       |
| WWUST     | Combined flow rate of water from PORVs, safety valves, main steam line, and main steam line breaks out of the unbroken loop steam generator (available for input and output as of Rev. 4.0.7) |
| WGUST     | Combined flow rate of gas from PORVs, safety valves, main steam line, and main steam line breaks out of the unbroken loop steam generator                                                     |
| Event 152 | Broken loop steam generator PORVs are open                                                                                                                                                    |
| Event 153 | Broken loop steam generator safety valves are open                                                                                                                                            |
| Event 156 | MSIVs are closed (initiated by a reactor trip unless they are forced open with event 236)                                                                                                     |
| Event 162 | Unbroken loop steam generator PORVs are open                                                                                                                                                  |
| Event 163 | Unbroken loop steam generator safety valves are open                                                                                                                                          |

**Features of the steam generator MSIV, PORV, and safety valve model to note:**

- The MSIVs will close on a reactor trip signal unless they are forced open with event 236. They can also be closed manually with event 235. The flow area through the MSIVs decreases linearly over the time period TDMSIV. (Closing of the MSIVs as an initiator leads to a reactor trip by over-pressurization of the primary system.)
- The effective flow areas ASGRV and ASGSV are calculated only during the initialization phase of a sequence. The PORV areas can be adjusted during a sequence by modifying the values of the scaling factors FARVBX and FARVUX. The safety valve areas can be adjusted during a sequence by modifying the number of valves, NSGSV; the value does not have to be an integer. (Adjusting the values of the rated flows during a calculation will not change the flow areas.)
- The code does not include logic to individually control the MSIVs in the broken and unbroken loops. Independent operation of the MSIVs in the two loops can be approximated by using the PORVs to simulate the MSIVs, adjusting the PORV input as needed.
- The PWR code does not explicitly model the turbine bypass. To model flow through the turbine bypass, the MSIVs can be kept open with event 236 and the initial flow area, ASGSL0, can be adjusted to the appropriate value after the initialization phase of the calculation.
- The effluent from the steam generator valves discharges outside the MAAP4 control volume.

## ***Hardwired and Generalized ESF Models***

Users choose one of two ESF models. The *hardwired* (or *specific*) model is selected by setting parameter NESF to 0 in the *Generalized Engineered Safeguards* section of the parameter file. The hardwired model limits the control the user has over the pump system configurations because it incorporates specific pump lineups (for example, suction and discharge locations) and recirculation configurations (including the presence of heat exchangers). The user specifies the appropriate lineup and recirculation configuration using *Control* parameters IDISCH and IRECIR. The hardwired model is usually adequate for typical PWRs.

The *generalized engineered safeguards* model is selected by setting parameter NESF to 1. The model allows the user to select from a series of pump lineups and recirculation configurations for each ESF system. It also incorporates options for NPSH enhancement flows and degraded system operation. The relatively large number of possible alignments and operating modes makes the generalized ESF model appropriate for all PWRs, particularly those with atypical configurations.

Many of the parameters in the *Engineered Safeguards* section of the parameter file are used by both ESF models. The remaining parameters in that section are used only by the hardwired model. In addition, the generalized model uses parameters in the *Generalized Engineered Safeguards* and *Pump* sections of the parameter file.

Additional information about the ESF models are the descriptions of subroutines ENGSAF, SI, and GENESF in Volume II of the User's Manual. Figures showing the lineups that correspond to the values of IDISCH and IRECIR are included in the ENGSAF description.

## High Pressure and Charging Pump Injection—Hardwired Model

The HPI and CHP systems inject water from the RWST into the primary system. In recirculation mode, they inject water from the containment sump.

*MAAP4 power requirement:* AC power

### Input Parameters

|                              |                                                                                                                                                                                                                                                                                                                                                                                                               |
|------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NESF                         | Flag to select the ESF model<br>= 0: hardwired model<br>= 1: generalized model                                                                                                                                                                                                                                                                                                                                |
| NHPI and NCHP                | Number of operational HPI and CHP pumps                                                                                                                                                                                                                                                                                                                                                                       |
| IDISCH                       | Specifies the ESF pump discharge alignment<br>= 1: all ESF systems, except accumulators, discharge to the intermediate leg water node; referred to as <i>discharge into the cold leg</i> in code documentation<br>= 2: all ESF systems, except accumulators, discharge to the hot leg<br>= 3: all ESF systems, including the cold leg accumulators, discharge to the downcomer before filling up the cold leg |
| IRECIR                       | Specifies the ESF pump lineup in the recirculation model (see the ENGSAF subroutine description for figures showing the configuration options)<br>= 1: Zion-like plant; no containment spray heat exchangers<br>= 2: Sequoyah-like plant; all pumped systems have heat exchangers<br>= 3: Calvert Cliffs-like plant; only the containment spray has a heat exchanger                                          |
| NPZCT                        | Selects option for pressurizer level control<br>= 0: no injection control of pressurizer level<br>= 1: control pressurizer level in bang-bang mode using HPI<br>= 2: control pressurizer level in bang-bang mode using CHP                                                                                                                                                                                    |
| ZWPZCL                       | Pressurizer low water level setpoint for bang-bang mode of level control                                                                                                                                                                                                                                                                                                                                      |
| ZWPZCH                       | Pressurizer high water level setpoint for bang-bang mode of level control                                                                                                                                                                                                                                                                                                                                     |
| PHPI0 and PCHP0              | Low primary system pressure setpoints for auto-initiation of HPI and CHP (PPS is the primary system pressure compared to the setpoints)                                                                                                                                                                                                                                                                       |
| TDHPI and TDCHP              | Time delays for system operation after the initiation signals have been received for HPI and CHP                                                                                                                                                                                                                                                                                                              |
| WHPIX and WCHPX              | Total limiting mass flow rates for HPI and CHP                                                                                                                                                                                                                                                                                                                                                                |
| NHPIPT and NCHPPT            | Number of points in the pump head-flow curves                                                                                                                                                                                                                                                                                                                                                                 |
| ZHDHPI vs. W VHPI and ZHDRHP | Head-flow curve for HPI and the required NPSH                                                                                                                                                                                                                                                                                                                                                                 |
| ZHDCHP vs. W VCHP and ZHDRCH | Head-flow curve for CHP and the required NPSH                                                                                                                                                                                                                                                                                                                                                                 |
| ZESPRW                       | Height of the bottom of the RWST above the pumps                                                                                                                                                                                                                                                                                                                                                              |

### Input Parameters (continued)

|                    |                                                                |
|--------------------|----------------------------------------------------------------|
| ZESPCS             | Height of the bottom of the containment sump above the pumps   |
| ZESPSI             | Height of the reactor vessel injection nozzles above the pumps |
| JNCSMP             | Containment node containing the containment sump               |
| Events 212 and 216 | HPI is forced on, locked off, or automatically controlled      |
| Events 231 and 232 | CHP is forced on, locked off, or automatically controlled      |
| Event 220          | Switch to recirculation mode                                   |

### Calculated Variables

|           |                                                                                                                                      |
|-----------|--------------------------------------------------------------------------------------------------------------------------------------|
| WESFCL    | Mass flow rate of injection to the intermediate leg, including makeup flow, referred to as the <i>cold leg</i> in code documentation |
| WESFDC    | Mass flow rate of injection to the downcomer                                                                                         |
| WESFHL    | Mass flow rate of injection to the hot leg                                                                                           |
| Event 5   | HPI is on (the flow might be 0.0 if the head is greater than the shutoff head in the pump curve)                                     |
| Event 148 | HPI pumps are disabled because of insufficient NPSH                                                                                  |
| Event 185 | HPI pumps have insufficient NPSH                                                                                                     |
| Event 11  | CHP is on (the flow might be 0.0 if the head is greater than the shutoff head in the pump curve)                                     |
| Event 149 | CHP pumps are disabled because of insufficient NPSH                                                                                  |
| Event 183 | CHP pumps have insufficient NPSH                                                                                                     |
| Event 181 | Operator has switched to recirculation mode                                                                                          |

### Features of the hardwired HPI and CHP models to note:

- MAAP4 models one HPI train and one CHP train.
- HPI and CHP are initiated if the primary system pressure, PPS, is less than the pressure setpoints, PHPI0 and PCHP0, or if they are manually forced on.
- In addition, HPI or CHP will be initiated if pressurizer level control is selected using NPZCT and the pressurizer water level, ZWPZ, drops below ZWPZCL. HPI or CHP will then be used in “bang-bang” mode to control the level. That is, the system will inject when the pressurizer level is below the low water level setpoint, ZWPZCL, and will turn off when the level is above the high water level setpoint, ZWPZCH. Contrary to the entry in the sample parameter files, the pressurizer water level control option can be used with both the hardwired and the generalized ESF models. However, with the hardwired model, the injection flow is calculated using the system curve rather than the limiting equation noted in the sample parameter files.



- Once HPI or CHP has been turned on, it will remain on unless forced off using event 216 or 232 or by the loss of AC power. If pressurizer level control is not selected, the injection will not be limited by level and the pressurizer can become solid with water. In this case, water will be discharged through the pressurizer PORVs and safety valves.
- The descriptions of the pump head-flow curves in the *Engineered Safeguards* section of the parameter file incorrectly refer to the head arrays, ZHDHPI(*i*) and ZHDCHP(*i*), as being the highest, or shutoff, heads. The first term in the arrays, ZHDHPI(1) and ZHDCHP(1), are used as the shutoff heads in the code. Therefore, the order of the values for ZHDHPI, WVHPI, ZHDCHP, and WVCHP is critical for proper operation and should start with the highest head and lowest flow.
- The pump head-flow curves should be based on the flow that corresponds to the head across the pump plus friction losses in the suction and discharge lines (not based on the pressure difference from suction to discharge). It should not include the gravity head associated with the difference in the suction and discharge elevations. The gravity head is incorporated into the calculations in the code. System curves that include the gravity head can be included; in that case, the suction and discharge locations should be set to the same elevation, and the required NPSH should be adjusted accordingly.
- When HPI and CHP are in recirculation mode and are fed by LPI, the LPI pumps must be manually turned on using event 213. Refer to the figures in the ENGSAF subroutine description in Volume II of the User's Manual for information regarding the possible lineups for suction and discharge, including piggybacking with LPI.
- Injection flow is split evenly to the primary system loops.
- The value of injection flow to the intermediate/cold leg, WESFCL, is not equal to 0.0 for the first time step because of the code logic for initializing conditions; this anomaly can be ignored.
- Typically, one safety injection pump (usually a charging pump) is used for makeup flow during normal plant operation. In MAAP4, HPI and CHP refer only to emergency injection, with suction from either the RWST or the containment sump. Their code models should not be used to represent normal makeup because that will lead to inappropriate draining of the emergency injection source. An independent code model is provided for makeup and letdown.

## Low Pressure Injection—Hardwired Model

The LPI system injects water from the RWST into the primary system. In recirculation mode, it injects water from the containment sump.

MAAP4 power requirement: AC power

### Input Parameters

|                             |                                                                                                                                                                                                                                                                                                                                                                                                               |
|-----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NESF                        | Flag to select the ESF model<br>= 0: hardwired model<br>= 1: generalized model                                                                                                                                                                                                                                                                                                                                |
| NLPI                        | Number of operational LPI pumps                                                                                                                                                                                                                                                                                                                                                                               |
| IDISCH                      | Specifies the ESF pump discharge alignment<br>= 1: all ESF systems, except accumulators, discharge to the intermediate leg water node; referred to as <i>discharge into the cold leg</i> in code documentation<br>= 2: all ESF systems, except accumulators, discharge to the hot leg<br>= 3: all ESF systems, including the cold leg accumulators, discharge to the downcomer before filling up the cold leg |
| IRECIR                      | Specifies the ESF pump lineup in the recirculation model (see the ENGSAF subroutine description for figures showing the configuration options)<br>= 1: Zion-like plant; no containment spray heat exchangers<br>= 2: Sequoyah-like plant; all pumped systems have heat exchangers<br>= 3: Calvert Cliffs-like plant; only the containment spray has a heat exchanger                                          |
| PLPIO                       | Low primary system pressure setpoint for auto-initiation of LPI (PPS is the primary system pressure compared to the setpoint)                                                                                                                                                                                                                                                                                 |
| TDLPI                       | Time delay for system operation after the initiation signal has been received for LPI                                                                                                                                                                                                                                                                                                                         |
| WLPIX                       | Total limiting mass flow rates for LPI                                                                                                                                                                                                                                                                                                                                                                        |
| NLPIPT                      | Number of points in the pump head-flow curve                                                                                                                                                                                                                                                                                                                                                                  |
| ZHDLPI vs. WVLPI and ZHDRLP | Head-flow curve for LPI and the required NPSH                                                                                                                                                                                                                                                                                                                                                                 |
| ZESPRW                      | Height of the bottom of the RWST above the pumps                                                                                                                                                                                                                                                                                                                                                              |
| ZESPCS                      | Height of the bottom of the containment sump above the pumps                                                                                                                                                                                                                                                                                                                                                  |
| ZESPSI                      | Height of the reactor vessel injection nozzles above the pumps                                                                                                                                                                                                                                                                                                                                                |
| JNCSMP                      | Containment node containing the containment sump                                                                                                                                                                                                                                                                                                                                                              |
| NLPSP0                      | Number of LPI pumps used for RHR sprays when system is aligned for sprays                                                                                                                                                                                                                                                                                                                                     |
| Events 213 and 217          | LPI is forced on, locked off, or automatically controlled                                                                                                                                                                                                                                                                                                                                                     |
| Event 220                   | Switch to recirculation mode                                                                                                                                                                                                                                                                                                                                                                                  |

### Calculated Variables

|           |                                                                                                                                      |
|-----------|--------------------------------------------------------------------------------------------------------------------------------------|
| WESFCL    | Mass flow rate of injection to the intermediate leg, including makeup flow, referred to as the <i>cold leg</i> in code documentation |
| WESFDC    | Mass flow rate of injection to the downcomer                                                                                         |
| WESFHL    | Mass flow rate of injection to the hot leg                                                                                           |
| Event 6   | LPI is on (the flow might be 0.0 if the head is greater than the shutoff head in the pump curve)                                     |
| Event 184 | LPI pumps have insufficient NPSH                                                                                                     |
| Event 193 | LPI pumps are disabled because of insufficient NPSH                                                                                  |
| Event 181 | Operator has switched to recirculation mode                                                                                          |

### Features of the hardwired LPI model to note:

- MAAP4 models one LPI train with the hardwired ESF model.
- LPI is initiated if the primary system pressure, PPS, is less than the pressure setpoint, PLPIO, or if it is manually forced on.
- Once LPI has been turned on, it will remain on unless forced off using event 217 or by the loss of AC power.
- The description of the pump head-flow curve in the *Engineered Safeguards* section of the parameter file incorrectly refers to the head array, ZHDLPI(*i*), as being the highest, or shutoff, head. The first term in the array, ZHDLPI(1), is used as the shutoff head in the code. Therefore, the order of the values for ZHDLPI and WVLPI is critical for proper operation and should start with the highest head and lowest flow.
- The pump head-flow curve should be based on the flow that corresponds to the head across the pump plus friction losses in the suction and discharge lines. It should not include the gravity head associated with the difference in the suction and discharge elevations. The gravity head is incorporated into the calculations in the code. System curves that include the gravity head can be included; in that case, the suction and discharge locations should be set to the same elevation, and the required NPSH should be adjusted accordingly.
- When HPI and CHP are in recirculation mode and are fed by LPI, the LPI pumps must be manually turned on using event 213. Refer to the figures in the ENGSAF subroutine description in Volume II of the User's Manual for information regarding the possible lineups for suction and discharge, including piggybacking with LPI.
- Injection flow is split evenly to the primary system loops.

- The value of injection flow to the intermediate/cold leg, WESFCL, is not equal to 0.0 for the first time step because of the code logic for initializing conditions; this anomaly can be ignored.
- The RHR heat exchangers are operational only when the ESF systems are in recirculation mode and LPI is on.
- The RHR sprays are operational only when LPI is on.

## ***RHR Sprays and Heat Exchangers—Hardwired Model***

The RHR sprays take suction from the RWST or the containment sump and discharge into one containment compartment through spray headers. The RHR heat exchangers can remove heat from the LPI and RHR spray water when the system is in recirculation mode.

*MAAP4 power requirement: AC power*

### **Input Parameters**

|                  |                                                                                                                                                                                                                                                                                                                                                                      |
|------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NESF             | Flag to select the ESF model<br>= 0: hardwired model<br>= 1: generalized model                                                                                                                                                                                                                                                                                       |
| IRECIR           | Specifies the ESF pump lineup in the recirculation model (see the ENGSAF subroutine description for figures showing the configuration options)<br>= 1: Zion-like plant; no containment spray heat exchangers<br>= 2: Sequoyah-like plant; all pumped systems have heat exchangers<br>= 3: Calvert Cliffs-like plant; only the containment spray has a heat exchanger |
| NLPSP0           | Number of LPI pumps used for RHR sprays when system is aligned for sprays                                                                                                                                                                                                                                                                                            |
| JNUCS            | Identification number of the compartment containing the RHR sprays (and upper compartment sprays)                                                                                                                                                                                                                                                                    |
| XDSP             | Nominal diameter of the spray droplets exiting the spray header nozzles                                                                                                                                                                                                                                                                                              |
| ZSPA2            | Height of the RHR spray header above the receiving compartment                                                                                                                                                                                                                                                                                                       |
| WLSPSX           | Limiting mass flow rate of RHR sprays                                                                                                                                                                                                                                                                                                                                |
| FHXRH            | RHR heat exchanger selection flag<br>= -1: no heat exchanger; the water temperature is set to the RWST water temperature<br>= 0: no heat exchanger; the water temperature is set to the containment sump water temperature<br>= 1: straight tube heat exchanger<br>= 2: U-tube heat exchanger                                                                        |
| NTURH            | NTU value for the RHR heat exchanger                                                                                                                                                                                                                                                                                                                                 |
| NTHX–XSTRH       | Input for the detailed heat exchanger model for the RHR heat exchanger                                                                                                                                                                                                                                                                                               |
| WCWRH            | Mass flow rate of the cooling water                                                                                                                                                                                                                                                                                                                                  |
| TCWRH and TCWLSP | Temperature of the cooling water if RHR is aligned to LPI injection and RHR sprays, respectively                                                                                                                                                                                                                                                                     |
| Event 203        | Disable RHR heat exchangers (also disables heat exchangers in containment sprays, fan coolers, chillers, and air coolers)                                                                                                                                                                                                                                            |
| Event 234        | Manually align RHR heat exchangers and sprays                                                                                                                                                                                                                                                                                                                        |

**Calculated Variables**

|           |                                                       |
|-----------|-------------------------------------------------------|
| WLPSPT    | Mass flow rate of RHR sprays                          |
| QGSPRH    | Energy removal from the containment gas by RHR sprays |
| Event 193 | LPI pumps are disabled                                |

**Features of the hardwired RHR spray model to note:**

- The RHR heat exchangers are operational only when the ESF systems are in recirculation mode and LPI is on.
- The RHR sprays are operational only when LPI is on and when event 234 is set to true.
- Users should refer to the figures in the ENGSAF subroutine in Volume II of the User's Manual to determine the appropriate recirculation configuration option for the plant. There is the potential for confusion with regard to RHR sprays and heat exchangers. The code models only one RHR spray train.
- The description of subroutine HTEXCH in Volume II of the User's Manual provides equations that can be used to calculate an NTU value. This value is essentially a function of the effectiveness of the heat exchanger. Because of the forms of the equations used to calculate the effectiveness, the most direct way to determine the NTU value is to iterate on its value until the calculated effectiveness matches the effectiveness determined using data from plant tests or benchmarks.
- The containment spray droplets in the upper compartment might fall as spray droplets into other compartments. Users should use non-zero values for the compartment-to-compartment spray parameters—NSPS, NSPR, FSPR, and XHSPRB—to model this condition. Note that the XHSPRB array is included with the constant flow fire spray parameters. The value of the XHSPRB parameter for compartment JNUCS should be the same as the value of ZSPA2.

## **Lower and Upper Compartment Sprays—Hardwired Model**

The containment sprays take suction from the RWST or the containment sump and discharge into the lower or upper compartments through spray headers.

*MAAP4 power requirement:* AC power

### **Input Parameters**

|                           |                                                                                                                                                                                                                                                                                                                                                                      |
|---------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NESF                      | Flag to select the ESF model<br>= 0: hardwired model<br>= 1: generalized model                                                                                                                                                                                                                                                                                       |
| IRECIR                    | Specifies the ESF pump lineup in the recirculation model (see the ENGSAF subroutine description for figures showing the configuration options)<br>= 1: Zion-like plant; no containment spray heat exchangers<br>= 2: Sequoyah-like plant; all pumped systems have heat exchangers<br>= 3: Calvert Cliffs-like plant; only the containment spray has a heat exchanger |
| NSPA and NSPB             | Number of operating spray pumps for the upper (A) and lower (B) compartment sprays                                                                                                                                                                                                                                                                                   |
| PSP0                      | High containment pressure setpoint for auto-initiation of the containment sprays                                                                                                                                                                                                                                                                                     |
| JNUCS                     | Identification number of the compartment containing the upper compartment sprays (and RHR sprays)                                                                                                                                                                                                                                                                    |
| JNLCS                     | Identification number of the compartment containing the lower compartment sprays                                                                                                                                                                                                                                                                                     |
| ZSPA and ZSPB             | Height of the upper and lower compartment spray headers above the receiving compartments                                                                                                                                                                                                                                                                             |
| TDSPA and TDSPB           | Time delays for the upper and lower compartment sprays                                                                                                                                                                                                                                                                                                               |
| XDSP                      | Nominal diameter of the spray droplets exiting the spray header nozzles                                                                                                                                                                                                                                                                                              |
| WSPNZ0                    | Mass flow rate through one containment spray pump at the differential pressure specified for parameter PSPNZ0                                                                                                                                                                                                                                                        |
| PSPNZ0                    | Differential pressure across the containment spray nozzles                                                                                                                                                                                                                                                                                                           |
| WSPAX and WSPBX           | Total limiting mass flow rate for the upper and lower spray systems                                                                                                                                                                                                                                                                                                  |
| NSPPT                     | Number of points in the spray pump head-flow curve                                                                                                                                                                                                                                                                                                                   |
| ZHDSP vs. WVSP and ZHDRSP | Head-flow curve for the spray pump and the required NPSH                                                                                                                                                                                                                                                                                                             |
| FHXSP                     | Containment spray heat exchanger selection flag<br>= -1: no heat exchanger; the water temperature is set to the RWST water temperature<br>= 0: no heat exchanger; the water temperature is set to the containment sump water temperature<br>= 1: straight tube heat exchanger<br>= 2: U-tube heat exchanger                                                          |

### Input Parameters (continued)

|                    |                                                                                                         |
|--------------------|---------------------------------------------------------------------------------------------------------|
| NTUSP              | NTU value for the containment spray heat exchanger                                                      |
| NTSP–XSTSP         | Input for the detailed heat exchanger model for the containment spray heat exchanger                    |
| WCWSP              | Inlet cooling water mass flow rate to the containment spray heat exchanger                              |
| TCWSPA and TCWSPB  | Temperatures of the cooling water for the upper compartment and lower compartment spray heat exchangers |
| Events 219 and 222 | Upper and lower compartment sprays are forced on, locked off, or automatically controlled               |
| Event 220          | Switch to recirculation mode                                                                            |

### Calculated Variables

|           |                                                      |
|-----------|------------------------------------------------------|
| WSPTA     | Mass flow rate of upper compartment sprays           |
| WSPTB     | Mass flow rate of lower compartment sprays           |
| TSPA      | Temperature of water in upper compartment spray flow |
| TSPB      | Temperature of water in lower compartment spray flow |
| Event 86  | Lower compartment spray pumps are on                 |
| Event 103 | Upper compartment spray pumps are on                 |
| Event 181 | Operator has switched to recirculation mode          |

### Features of the hardwired containment spray model to note:

- Containment sprays are automatically initiated if the pressure in the upper or lower compartment, PRB(JNUCS) and PRB(JNLCS), is above the pressure setpoint for the containment sprays, PSP0, or if they are manually forced on.
- Users should refer to the figures in the ENGSAF subroutine in Volume II of the User's Manual to determine the appropriate recirculation configuration option for the plant.
- The description of the pump head-flow curve in the *Engineered Safeguards* section of the parameter file incorrectly refers to the head array, ZHDSP(*i*), as being the highest, or shutoff, head. The first term in the array, ZHDSP(1), is used as the shutoff head in the code. Therefore, the order of the values for ZHDSP and WVSP is critical for proper operation and should start with the highest head and lowest flow.
- The pump head-flow curve should be based on the flow that corresponds to the head across the pump plus friction losses in the suction and discharge lines (not based on the pressure difference from suction to discharge). It should not include the gravity head associated with the difference in the suction and discharge elevations. The gravity head is incorporated into the calculations in the code. System curves that include the gravity head can be included; in that case, the suction and discharge locations should be set to the same elevation, and the required NPSH should be adjusted accordingly.



- The description of subroutine HTEXCH in Volume II of the User's Manual provides equations that can be used to calculate an NTU value. This value is essentially a function of the effectiveness of the heat exchanger. Because of the forms of the equations used to calculate the effectiveness, the most direct way to determine the NTU value is to iterate on its value until the calculated effectiveness matches the effectiveness determined using data from plant tests or benchmarks.
- The containment spray droplets in the upper compartment might fall as spray droplets into other compartments. Users should use non-zero values for the compartment-to-compartment spray parameters—NSPS, NSPR, FSPR, and XHSPRB—to model this condition. Note that the XHSPRB array is included with the constant flow fire spray parameters. The value of the XHSPRB parameters should be the same as the ZSPA and ZSPB parameters for the JNUCS and JNLCS compartments, as appropriate.

## Generalized ESFs

The generalized ESF model represents the following pump systems:

- HPI
- CHP
- LPI train 1 (LP1)
- LPI train 2 (LP2)
- Upper compartment containment spray pumps, train A (SPA)
- Lower compartment containment spray pumps, train B (SPB)
- Containment spray pumps, train C (SPC)

The model allows the user to specify suction and discharge locations, flow curves, NPSH requirements, heat exchange characteristics, and other attributes for each system. (The model is an alternative to the hardwired ESF model described previously.)

*MAAP4 power requirement: AC power*

### Input Parameters

|                                                              |                                                                                                                                                             |
|--------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NESF                                                         | Flag to select the ESF model<br>= 0: hardwired model<br>= 1: generalized model                                                                              |
| NHPIG, NCHPG,<br>NLP1G, NLP2G,<br>NSPAG, NSPBG,<br>and NSPBG | Number of operational pumps for the HPI, CHP, LPI trains 1 and 2, and spray trains A, B, and C systems                                                      |
| PHPI0, PCHP0, and<br>PLPI0                                   | Low primary system pressure setpoints for auto-initiation of HPI, CHP, and LPI (PPS is the primary system pressure compared to the setpoints)               |
| PSP0                                                         | High containment pressure setpoint for auto-initiation of containment spray systems                                                                         |
| JNCSMP                                                       | Containment node containing the containment sump                                                                                                            |
| JNASMP                                                       | Containment node containing the secondary (annular) containment sump                                                                                        |
| JNUCS and JNLCS                                              | Containment nodes containing the upper and lower compartment sprays                                                                                         |
| TDHPI, TDCHP,<br>TDLPI, TDLP2,<br>TDSPA, TDSPB, and<br>TDSPC | Time delays for system operation after the initiation signals have been received for the HPI, CHP, LPI trains 1 and 2, and spray trains A, B, and C systems |
| WHPIX, WCHPX,<br>WLPIX, WLP2X,<br>WSPAX, WSPBX,<br>and WSPCX | Total limiting mass flow rates for the HPI, CHP, LPI trains 1 and 2, and spray trains A, B, and C systems                                                   |

**Input Parameters (continued)**

|                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|---------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| System lineups                                                      | _____                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| NSHPI, NSCHP,<br>NSLP1, NSLP2,<br>NSSPA, NSSPB, and<br>NSSPC        | Water source selection flags for normal pump lineup for the HPI, CHP, LPI trains 1 and 2, and spray trains A, B, and C systems<br>= 0: No source (that is, system not functional)<br>= 1: hot leg<br>= 2: cold leg<br>= 3: RWST<br>= 4: lower compartment sump (compartment JNCSMP)<br>= 5: annular compartment sump (compartment JNASMP)<br>= 6: LPI 1 (only for HPI and CHP)<br>= 7: LPI 2 (only for HPI and CHP)<br>= 8: SPA discharge (only for HPI and CHP)                                                                                                                                                                                                                                                                                                                                                                                             |
| NDHPI, NDCHP,<br>NDLP1, NDLP2,<br>NDSPA, NDSPB, and<br>NDSPC        | Pump discharge location selection flags for normal pump lineup for the HPI, CHP, LPI trains 1 and 2, and spray trains A, B, and C systems<br>= 1: hot leg<br>= 2: cold leg; actually the intermediate leg water pool<br>= 3: downcomer (includes the water pool in the horizontal cold leg)<br>= 4: upper compartment spray, first header (compartment JNUCS)<br>= 5: lower compartment spray header (compartment JNLCS)<br>= 9: upper compartment spray, second header (compartment JNUCS)<br><br>Additional locations for LPI trains 1 and 2 and spray train A<br>= 6: HPI pump inlet<br>= 7: CHP pump input<br>= 8: HPI and CHP pump inlets<br>= 10: HPI pump inlet and upper compartment spray, first header<br>= 11: HPI pump inlet and cold leg<br>= 12: CHP pump inlet and upper compartment spray, first header<br>= 13: CHP pump inlet and cold leg |
| NORHPI, NORCHP,<br>NORLP1, NORLP2,<br>NORSPA, NORSPB,<br>and NORSPC | Identification numbers of the sets of pump characteristics for recirculation lineup for the HPI, CHP, LPI trains 1 and 2, and spray trains A, B, and C systems                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| RSHPI, RSCHP,<br>RSLP1, RSLP2,<br>RSSPA, RSSPB, and<br>RSSPC        | Water source selection flags for recirculation pump lineup for the HPI, CHP, LPI trains 1 and 2, and spray trains A, B, and C systems<br>= 0: no source (that is, system not functional)<br>= 1: hot leg<br>= 2: cold leg<br>= 3: RWST<br>= 4: lower compartment sump (compartment JNCSMP)<br>= 5: annular compartment sump (compartment JNASMP)<br>= 6: LPI 1 (only for HPI and CHP)<br>= 7: LPI 2 (only for HPI and CHP)<br>= 8: SPA discharge (only for HPI and CHP)                                                                                                                                                                                                                                                                                                                                                                                      |

**Input Parameters (continued)**

|                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|---------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| RDHPI, RDCHP,<br>RDLP1, RDLP2,<br>RDSPA, RDSPB, and<br>RDSPC        | <p>Pump discharge location selection flags for normal pump lineup for the HPI, CHP, LPI trains 1 and 2, and spray trains A, B, and C systems</p> <p>= 1: hot leg<br/>= 2: cold leg; actually the intermediate leg water pool<br/>= 3: downcomer (includes the water pool in the horizontal cold leg)<br/>= 4: upper compartment spray, first header (compartment JNUCS)<br/>= 5: lower compartment spray header (compartment JNLCS)<br/>= 9: upper compartment spray, second header (compartment JNUCS)</p> <p>Additional locations for LPI trains 1 and 2 and spray train A</p> <p>= 6: HPI pump inlet<br/>= 7: CHP pump input<br/>= 8: HPI and CHP pump inlets<br/>= 10: HPI pump inlet and upper compartment spray, first header<br/>= 11: HPI pump inlet and cold leg<br/>= 12: CHP pump inlet and upper compartment spray, first header<br/>= 13: CHP pump inlet and cold leg</p> |
| RECHPI, RECCHP,<br>RECLP1, RECLP2,<br>RECSPA, RECSPB,<br>and RECSPC | Identification numbers of the sets of pump characteristics for recirculation lineup for the HPI, CHP, LPI trains 1 and 2, and spray trains A, B, and C systems                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| NPSH enhancement                                                    | _____                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| SNPHPI, SNPCHP,<br>SNPLP1, SNPLP2,<br>SNPSA, SNPSB,<br>and SNSPC    | <p>NPSH enhancement flow source selection flags for the HPI, CHP, LPI trains 1 and 2, and spray trains A, B, and C systems</p> <p>= 0: no enhancement flow<br/>= 1: flow is drawn from the discharge side of the pump, downstream of the heat exchanger outlet if applicable, and recirculated to the inlet side of pump<br/>= 2: flow is from the SPA outlet<br/>= 3: NPSH enhancement flow from the external water storage tank</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| WEHPI, WECHP,<br>WELP1, WELP2,<br>WESPA, WESPB,<br>and WESPC        | NPSH enhancement flow rates for the HPI, CHP, LPI trains 1 and 2, and spray trains A, B, and C systems                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| MWEXT0                                                              | Initial water mass in the external storage tank                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| TWEXT                                                               | Temperature of the water in the external storage tank                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| NPSH and degraded performance                                       | _____                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| TDNHPI, TDNCHP,<br>TDNLP1, TDNLP2,<br>TDNSA, TDNSPB,<br>and TDNSPC  | Times to pump failure after insufficient NPSH for the HPI, CHP, LPI trains 1 and 2, and spray trains A, B, and C systems; pumps operate in degraded mode during this time                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |

**Input Parameters (continued)**

|                                                            |                                                                                                                                                                                        |
|------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| DEGHPI, DEGCHP, DEGLP1, DEGLP2, DEGSPA, DEGSPB, and DEGSPC | Identification numbers of the sets of pump characteristics for degraded performance for the HPI, CHP, LPI trains 1 and 2, and spray trains A, B, and C systems                         |
| Source and discharge elevation differences                 | _____                                                                                                                                                                                  |
| ZHPIRW, ZCHPRW, ZLP1RW, ZLP2RW, ZSPARW, ZSPBRW, and ZSPCRW | Height of the bottom of the RWST above the pumps for the HPI, CHP, LPI trains 1 and 2, and spray trains A, B, and C systems                                                            |
| ZHPICS, ZCHPCS, ZLP1CS, ZLP2CS, ZSPACS, ZSPBCS, and ZSPCCS | Height of the bottom of the containment (lower or annular) sump above the pumps for the HPI, CHP, LPI trains 1 and 2, and spray trains A, B, and C systems                             |
| ZHPISI, ZCHPSI, ZLP1SI, ZLP2SI, ZSPASI, ZSPBSI, and ZSPCSI | Height of the reactor vessel injection nozzles above the pumps for the HPI, CHP, LPI trains 1 and 2, and spray trains A, B, and C systems                                              |
| ZSPA, ZSPA2, and ZSPB                                      | Height of the spray headers above the receiving compartments                                                                                                                           |
| Miscellaneous                                              | _____                                                                                                                                                                                  |
| BYPASS                                                     | Option flag for excess flow from LPI during piggybacking<br>= 0: no accounting for bypass flow<br>= 1: bypass flow to the hot leg<br>= 2: bypass flow to the cold leg                  |
| NPZCT                                                      | Selects option for pressurizer level control<br>= 0: no injection control of pressurizer level<br>= 1: control pressurizer level using HPI<br>= 2: control pressurizer level using CHP |
| ZWPZCL                                                     | Pressurizer low water level setpoint for bang-bang mode of level control                                                                                                               |
| ZWPZCH                                                     | Pressurizer high water level setpoint for bang-bang mode of level control                                                                                                              |
| XDSP                                                       | Nominal diameter of containment spray droplets exiting the spray header nozzles                                                                                                        |
| WSPNZ0                                                     | Mass flow rate through one containment spray pump at the differential pressure specified for parameter PSPNZ0                                                                          |
| PSPNZ0                                                     | Differential pressure across the containment spray nozzles                                                                                                                             |
|                                                            |                                                                                                                                                                                        |

### Input Parameters (continued)

|                                     |                                                                                                            |
|-------------------------------------|------------------------------------------------------------------------------------------------------------|
| Pump characteristics<br>(for set x) | _____                                                                                                      |
| NPOIx                               | Number of points in the pump head-flow curve                                                               |
| ZHDPx vs. WVPMx                     | Head-flow curve                                                                                            |
| FHXPx–WCWPx                         | Heat exchanger parameters                                                                                  |
|                                     |                                                                                                            |
| Events 212 and 216                  | HPI is forced on, locked off, or automatically controlled                                                  |
| Events 231 and 232                  | CHP is forced on, locked off, or automatically controlled                                                  |
| Events 213 and 217                  | LPI train 1 is forced on, locked off, or automatically controlled                                          |
| Events 253 and 254                  | LPI train 2 is forced on, locked off, or automatically controlled                                          |
| Events 219 and 222                  | Upper and lower compartment sprays (trains A and B) are forced on, locked off, or automatically controlled |
| Events 252 and 256                  | Containment sprays (train C) are forced on, locked off, or automatically controlled                        |
| Event 220                           | Switch to recirculation mode                                                                               |

### Calculated Variables

|                                                                     |                                                                                                                                      |
|---------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|
| WESFCL                                                              | Mass flow rate of injection to the intermediate leg, including makeup flow, referred to as the <i>cold leg</i> in code documentation |
| WESFDC                                                              | Mass flow rate of injection to the downcomer                                                                                         |
| WESFHL                                                              | Mass flow rate of injection to the hot leg                                                                                           |
| WSPTA                                                               | Mass flow rate of upper compartment sprays (combined flow for both headers)                                                          |
| WSPTB                                                               | Mass flow rate of lower compartment sprays                                                                                           |
| WHPIXX                                                              | Mass flow rate delivered by HPI pumps                                                                                                |
| WCHPXX                                                              | Mass flow rate delivered by CHP pumps                                                                                                |
| WLPI1X and WLPI2X                                                   | Mass flow rates delivered by LPI pumps in trains 1 and 2                                                                             |
| WSPAXX, WSPBXX,<br>and WSPCXX                                       | Mass flow rates delivered by spray pumps in trains A, B, and C                                                                       |
| TSPA                                                                | Temperature of the water in the upper compartment spray flow                                                                         |
| TSPB                                                                | Temperature of the water in the lower compartment spray flow                                                                         |
| NPHPIA, NPCHPA,<br>NPLP1A, NPLP2A,<br>NPSHAA, NPSHBA,<br>and NPSHCA | Available NPSH for the HPI, CHP, LPI trains 1 and 2, and spray trains A, B, and C systems                                            |

**Calculated Variables (continued)**

|                                                            |                                                                                                                                                         |
|------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|
| NPHPIR, NPCHPR, NPLP1R, NPLP2R, NPSHAR, NPSHBR, and NPSHCR | Required NPSH for the HPI, CHP, LPI trains 1 and 2, and spray trains A, B, and C systems                                                                |
| Event 5                                                    | HPI is on (the flow might be 0.0 if the head is greater than the shutoff head in the pump curve)                                                        |
| Event 148                                                  | HPI pumps are disabled                                                                                                                                  |
| Event 185                                                  | HPI pumps have insufficient NPSH                                                                                                                        |
| Event 11                                                   | CHP is on (the flow might be 0.0 if the head is greater than the shutoff head in the pump curve)                                                        |
| Event 149                                                  | CHP pumps are disabled                                                                                                                                  |
| Event 183                                                  | CHPs have insufficient NPSH                                                                                                                             |
| Events 6 and 142                                           | LPI trains 1 and 2 are on (the flows might be 0.0 if the head is greater than the shutoff head in the pump curves)                                      |
| Events 184 and 143                                         | LPI pumps in trains 1 and 2 have insufficient NPSH                                                                                                      |
| Events 146 and 147                                         | LPI pumps in trains 1 and 2 are disabled                                                                                                                |
| Events 103, 86, and 139                                    | Upper, lower, and containment sprays (trains A, B, and C) are on (the flow might be 0.0 if the head is greater than the shutoff head in the pump curve) |
| Events 182, 189, and 140                                   | Upper, lower, and containment sprays (trains A, B, and C) have insufficient NPSH                                                                        |
| Events 144, 145, and 150                                   | Upper, lower, and containment sprays (trains A, B, and C) are disabled                                                                                  |
| Event 181                                                  | Operator has switched to recirculation mode                                                                                                             |

**Features of the generalized ESF model to note:**

- The discharge location identified as the *cold leg* is actually the intermediate (cross-over) leg water pool, and the discharge location identified as the *downcomer* includes the water in the horizontal portion of the cold leg. The downcomer location should be specified if injection into the cold leg is desired.
- The head-flow curves,  $ZHDP_x(i)$  versus  $WVPM_x(i)$ , should represent delivered flow, so they should be system curves rather than pump curves. They should be based on the flow that corresponds to the head across the pump plus friction losses in the suction and discharge lines (not based on the pressure difference from suction to discharge). They should not include the gravity head associated with the difference in the suction and discharge elevations. The gravity head is incorporated into the calculations in the code. System curves that include the gravity head can be included; in that case, the suction and discharge locations should be set to the same elevation, and the required NPSH should be adjusted accordingly.

- The order of the values of the entries in the pump head-flow curve arrays is critical for proper operation and should start with the highest head and lowest flow. This is because the code uses the first head term, ZHDPx(1), as the shutoff head. If the head is higher than the shutoff head, there will be no flow—even if the system is manually forced on.
- Once a system has been initiated, it will be operational until it is forced off with the appropriate external event or by the loss of AC power.
- If parameter NPZCT is set to 1 or 2, HPI or CHP injection will be used in “bang-bang” mode to control the pressurizer water level. That is, the selected system will inject when the pressurizer level, ZWPZ, is below the low water level setpoint, ZWPZCL, and will turn off when the level is above the high water level setpoint, ZWPZCH. (Contrary to the entry in the sample parameter files, the pressurizer water level control option can be used with both the hardwired and the generalized ESF models. However, with the hardwired model, the injection flow is calculated using the system curve rather than the limiting equation noted in the sample parameter files.)
- A system can use the same or different sets of pump characteristics for normal, recirculation, and degraded modes of operation. After a system’s pumps have operated in degraded mode (because of a loss of NPSH) for the time period specified by the input parameter, the pumps are considered inoperable for the remainder of the sequence.
- The system lineup parameters can be changed during a sequence. Intervention conditions and actions can be added to input files to customize the lineups as a function of plant-specific conditions and features. For example, a delay in the switch to recirculation mode for one group of pumps can be modeled by setting the recirculation suction location to the RWST and then changing it to the containment sump based on RWST level.
- The description of subroutine HTEXCH in Volume II of the User’s Manual provides equations that can be used to calculate NTU values for the heat exchangers. An NTU value is essentially a function of the effectiveness of the heat exchanger. Because of the forms of the equations used to calculate the effectiveness, the most direct way to determine the NTU value is to iterate on its value until the calculated effectiveness matches the effectiveness determined using data from plant tests or benchmarks.
- Injection flow is split evenly to the primary system loops.
- The value of the flow to the intermediate/cold leg, WESFCL, is not equal to 0.0 for the first time step because of the code logic for initializing conditions; this anomaly can be ignored.
- When a low pressure system is aligned in a piggybacked configuration to feed both HPI and CHP (lineup number 8), the HPI pump head might not be high enough to inject water into the primary system. Because of a logic error, the code will not calculate the flows correctly in this situation. This has been corrected in Rev. 4.0.7.
- During piggyback mode, the downstream (high pressure) pump inherits the NPSH requirements of the upstream (low pressure) pump. The code does not individually evaluate the downstream pump’s NPSH requirements because the code treats the two pumps as essentially one pump. If the NPSH for the upstream pump is inadequate, there will be no flow, and only the event message corresponding to the upstream pump will be written to the summary file.



- Typically, one safety injection pump (usually a charging pump) is used for makeup flow during normal plant operation. In MAAP4, HPI and CHP refer only to emergency injection. The ESF model should not be used to represent normal makeup because that will lead to inappropriate draining of the emergency injection source. An independent code model is provided for makeup and letdown.
- The containment spray droplets in the upper compartment might fall as spray droplets into other compartments. Users should use non-zero values for the compartment-to-compartment spray parameters—NSPS, NSPR, FSPR, and XHSPRB—to model this condition. Note that the XHSPRB array is included with the constant flow fire spray parameters. The values of the XHSPRB parameters should be the same as the ZSPA, ZSPA2, and ZSPB parameters for the JNUCS and JNLCS compartments, as appropriate.

## Fan Coolers and Chillers

The fan coolers and chillers each take suction from a containment compartment gas space, remove heat from the gas through a heat exchanger, and discharge the cooled gas to the same or a different compartment. The code uses identical equations for the fan cooler and chiller calculations. The models can be used to calculate gas exchange through containment fans by disabling the heat exchangers.

*MAAP4 power requirement: AC power*

### Input Parameters

|                                |                                                                                                                                                                                                                                                                                   |
|--------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NFN and NCHILL                 | Number of fan coolers and chillers                                                                                                                                                                                                                                                |
| JNFCS, JNFCD, JNCHS, and JNCHD | Identification numbers of the compartments the fan coolers and chillers take suction from and discharge to                                                                                                                                                                        |
| WVFN0 and WVCH0                | Constant volumetric gas flow rates per fan cooler and chiller                                                                                                                                                                                                                     |
| TDFAN and TDCHR                | Time delays for fan coolers and chillers to become operational after the initiation signals have been received (applies for auto-initiation and when the systems are forced on)                                                                                                   |
| PFAN0 and PCHR0                | High compartment pressure setpoints in the compartments from which the fan coolers and chillers take suction that lead to auto-initiation                                                                                                                                         |
| WCWFC and WCWCH                | Service water mass flow per fan cooler and chiller                                                                                                                                                                                                                                |
| TCWHX and TCWCH                | Fan cooler and chiller inlet service water temperature                                                                                                                                                                                                                            |
| NTFC–NREGFC<br>NTCH–NREGCH     | Input for detailed heat exchanger model for fan coolers and chillers                                                                                                                                                                                                              |
| INFANC                         | = 0: do not bypass the fan cooler and chiller models<br>= 1: bypass fan cooler and chiller models                                                                                                                                                                                 |
| Event 203                      | Heat exchangers are not operational, causing the fan coolers and chillers to operate as fans (the area of the tubes, ATFC or ATCH, can be set to 0.0 to disable heat transfer from only one of the systems); also disables RHR, containment spray, and air cooler heat exchangers |
| Events 218, 221, 210, and 225  | Fan coolers and chillers are forced on, locked off, or automatically controlled                                                                                                                                                                                                   |

### Calculated Variables

|                   |                                                                           |
|-------------------|---------------------------------------------------------------------------|
| WGFNA and WGCHR   | Mass flow rate of gas into the fan coolers and chillers                   |
| WCDFC and WCDCH   | Mass flow rate of condensate from the fan coolers and chillers            |
| QGFNIN and QGFNCH | Energy flow rate into the fan coolers and chillers by the containment gas |

### Calculated Variables (continued)

|                   |                                                                                              |
|-------------------|----------------------------------------------------------------------------------------------|
| QGFN and QGCHR    | Energy flow rate out of the fan coolers and chillers by the containment gas                  |
| QCDFC and QCDCH   | Energy flow rate out of the fan coolers and chillers by the condensate                       |
| QTOTFC and QTOTCH | Rate of energy transfer from the containment gas by the fan cooler and chiller service water |
| Events 77 and 76  | Fan coolers and chillers are on                                                              |
| Events 79 and 78  | Fan coolers and chillers are initiated (auto-initiation or forced on)                        |

### Features of the fan cooler and chiller model to note:

- The fan coolers and chillers are initiated if the pressures in the compartments from which they take suction—PRB(JNFCS) and PRB(JNCHS), respectively—exceed the setpoint pressures, PFAN0 and PCHRO, or if they are manually forced on.
- The energy balances around the fan coolers and chillers are as follows:

$$QGFNIN - QGFN - QCDFC = QTOTFC$$

$$QGFNCH - QGCHR - QCDCH = QTOTCH$$

Each of these terms is in the hash table, so their values can be written to output files.

- The terms for the energy transfer from the containment to the service water, QTOTFC and QTOTCH, are not recalculated if the heat exchangers are no longer in operation or if the fan coolers or chillers are forced off. Because these are output variables only and are not used in the calculations, the fact that their values are not reset to 0.0 does not affect the code results. They are reset as of Rev. 4.0.7.
- It is strongly recommended that users benchmark the performance of the fan cooler and chiller models against plant data and adjust the values of the input as necessary, particularly if these systems are being credited in analyses. This recommendation is due in part to the fact that the values for the detailed heat exchanger parameters can be difficult to obtain from plant drawings and system descriptions. In addition, it is suggested that users evaluate the sensitivity of their results to the heat exchanger input for sequences in which the fan coolers or chillers are operational and their performance and/or the response of the containment are of interest. Steady-state sequences with the fan coolers or chillers running can be used for the benchmarking. The following information might be useful for the benchmarking:
  - The total heat load to the containment, which is then removed by the systems, is the sum of the QGPSHC(*i*) variables, where QGPSHC(*i*) is the heat transfer from the primary system heat sinks and the PWR pressurizer, steam generators, and surge line to the gas in compartment *i*. This heat load is calculated using several primary system parameters, and it corresponds both to the through-insulation and the not-through-insulation losses. Users might find that the calculated heat load differs from the plant value for normal operation. In this case, it might be necessary to adjust the value of the not-through-insulation heat loss, represented by parameter QC0, to obtain the proper heat load. (The not-through-

insulation heat loss is intended to be an input parameter whose value is obtained directly from plant documentation. However, if the calculated total heat load differs substantially from the plant value for normal operation, users may consider using the adjusted value for all sequences.) This can be done through an analysis of the percentage error calculated using the input file components that follow.

- It might be necessary to make temporary adjustments to some of the containment parameter values to match test conditions.
- The detailed heat exchanger input values should be adjusted so that QTOTFC or QTOTCH equals the target heat transfer rate. Ultimately, it might be necessary to increase the number of fan coolers or chillers because these parameters tend to have more impact than reasonable changes to the geometry and heat transfer parameters. Non-integer values of NFN and NCHILL can be used.
- Useful input file components for determining the value of QC0 are

```
FUNCTION
  QLOAD_TOT = QGPSHC(1) + QGPSHC(2) + QGPSHC(3) // etc.
  QLOAD_BR = QLOAD_TOT / 0.2931 // convert from W to BTU/hr
  QHLKNOWN = { } //Plant Calculated Heat Load for Normal
                //Operation in Btu/Hr
  PER_ERR = (QHLKNOWN+(-1* QLOAD_BR))/QHLKNOWN * 100
END
```

```
PLOTFIL 88
  QC0, QGPSHC(1), QGPSHC(2), QGPSHC(3), QLOAD_TOT,
  QLOAD_BR, PER_ERR
END
```

- If the coolers operate in normal and emergency modes, different sets of input should be tested and adjusted as necessary. When the appropriate values are determined, users can construct automatic switches from normal to emergency mode by creating user-defined events or intervention conditions and corresponding parameter changes.
- The code does not contain the option for specifying NTU values for the fan coolers or chillers; the detailed heat exchanger model is always used for these systems.

## Containment Air Coolers

The containment air coolers take gas from containment compartments, remove heat from the gas using heat exchangers, and discharge the cooled gas to the same or different compartments. The code uses the same equations for the mass and energy exchange that are used for the fan cooler and chiller calculations. The containment air coolers are manually activated and are assumed to have a dedicated independent power supply. The model can be used to calculate gas exchange through containment fans by disabling the heat exchangers.

MAAP4 power requirement: none

### Input Parameters (for air cooler $i$ )

|                               |                                                                                                                                                                                                                                                                           |
|-------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NFNAC( $i$ )                  | Number of air cooler units in the air cooler                                                                                                                                                                                                                              |
| JNACS( $i$ ) and JNACD( $i$ ) | Identification numbers of the compartments the air cooler takes suction from and discharges to                                                                                                                                                                            |
| WVAC0( $i$ )                  | Constant volumetric gas flow per air cooler unit                                                                                                                                                                                                                          |
| WCWAC( $i$ )                  | Service water mass flow per air cooler unit                                                                                                                                                                                                                               |
| TCWAC( $i$ )                  | Air cooler inlet service water temperature                                                                                                                                                                                                                                |
| NTAC( $i$ )–NREGAC( $i$ )     | Input for detailed heat exchanger model for air cooler                                                                                                                                                                                                                    |
| Event 203                     | Disable heat exchangers in the air coolers (also RHR and containment spray heat exchangers and heat exchangers in the containment fan coolers and chillers; the area of the tubes, ATAC( $i$ ), can be set to 0.0 to disable the heat transfer from just the air coolers) |
| Events 331–340                | Air cooler is forced on                                                                                                                                                                                                                                                   |

### Calculated Variables (for air cooler $i$ )

|               |                                                                                  |
|---------------|----------------------------------------------------------------------------------|
| WGAC( $i$ )   | Mass flow rate of gas into the air cooler                                        |
| WCDAC( $i$ )  | Mass flow rate of condensate from the air cooler                                 |
| QGIAC( $i$ )  | Energy flow rate into the air cooler by the containment gas                      |
| QGAC( $i$ )   | Energy flow rate out of the air cooler by the containment gas                    |
| QCDAC( $i$ )  | Energy flow rate out of the air cooler by the condensate                         |
| QTOTAC( $i$ ) | Rate of energy transfer from the containment gas by the air cooler service water |

### Features of the containment air cooler model to note:

- A containment air cooler is operational if the number of air cooler units is greater than 0 and it is manually forced on.
- Refer to features of the fan cooler and chiller models for information on how to verify that the values of the input parameters will yield the appropriate heat transfer.

## **Additional Primary System Events**

### **Input Events**

|           |                                                                 |
|-----------|-----------------------------------------------------------------|
| Event 209 | Initiate break (LOCA) in the primary system                     |
| Event 229 | Manually open reactor vent (system not modeled in current code) |
| Event 280 | ESF injection to the intermediate leg (for TMI-2 benchmark)     |

### **Calculated Events**

|                   |                                                                                    |
|-------------------|------------------------------------------------------------------------------------|
| Events 1 and 197  | Broken and unbroken loop breaks are uncovered                                      |
| Event 2           | Relocation of core materials to the lower plenum has started                       |
| Event 8           | All corium discharged during initial blowdown                                      |
| Event 9           | Gas blowdown through vessel failure can occur                                      |
| Event 10          | Only the core water mass is in equilibrium with the primary system gas             |
| Event 12          | Water in the core is saturated                                                     |
| Events 15 and 171 | Unbroken and broken loops are homogeneous                                          |
| Events 16 and 29  | Reactor vent line is uncovered and open (system not modeled in current code)       |
| Event 17          | Corium is in the lower plenum pool                                                 |
| Event 19          | Corium is quenched in the vessel                                                   |
| Event 20          | Primary system is saturated                                                        |
| Event 21          | Primary system has voids, and pressure is calculated with primary system inventory |
| Event 22          | Surge line nozzle is uncovered                                                     |
| Event 23          | Downcomer node has no water                                                        |
| Event 25          | Primary system is not in thermodynamic equilibrium                                 |
| Event 26          | Primary system pools are isolated                                                  |
| Events 27 and 45  | Unbroken and broken loops are not blocked at the pump bowls                        |
| Event 28          | Core downcomer not blocked for gas transport                                       |
| Event 32          | Pressurizer is empty                                                               |
| Events 33 and 34  | Unbroken and broken hot legs have ruptured                                         |
| Event 35          | Void fraction in the pressurizer is <0.1                                           |
| Event 38          | Water in the pressurizer is saturated                                              |
| Event 40          | Pressurizer is solid                                                               |

**Calculated Events (continued)**

|                       |                                                                                                            |
|-----------------------|------------------------------------------------------------------------------------------------------------|
| Event 49              | Core is uncovered (boiled-up level of the core water pool, ZWV, is less than the top of active fuel, ZCRU) |
| Events 51, 52, and 53 | Generalized containment opening 1, 2, or 3 is uncovered                                                    |
| Events 155 and 164    | Broken and unbroken loops are stagnant                                                                     |
| Event 160             | SGTR is uncovered on the primary side                                                                      |
| Event 196             | Fast steam table used for primary system properties                                                        |
| Event 198             | Core has collapsed                                                                                         |
| Event 199             | Primary system has depressurized                                                                           |
|                       |                                                                                                            |
| Vessel Failure        | _____                                                                                                      |
| Event 3               | Vessel has failed                                                                                          |
| Events 39             | Vessel failed by ejection of instrument tubes                                                              |
| Event 41              | Vessel failed by molten corium jet erosion                                                                 |
| Event 43              | Vessel failed by overlying metal layer attacking the wall                                                  |
| Event 56              | Vessel cylinder failed due to creep                                                                        |
| Events 57             | Vessel failed by heat-up of instrument tubes                                                               |
| Event 61              | Extensive vessel failure                                                                                   |
| Event 80              | Vessel failed by lower head rupture                                                                        |
| Event 81              | 1000 seconds since vessel failure                                                                          |

### ***Additional Steam Generator Events***

#### **Calculated Events**

|                    |                                                                                        |
|--------------------|----------------------------------------------------------------------------------------|
| Events 37 and 63   | Unbroken and broken steam generator tubes have ruptured                                |
| Events 151 and 161 | Broken and unbroken steam generators are dry (mass of water less than 100 kg [200 lb]) |
| Events 158 and 167 | Broken and unbroken steam generators are in thermodynamic equilibrium                  |
| Event 159          | Broken steam generator is solid                                                        |
| Event 169          | Broken SGTR is uncovered on the secondary side                                         |
| Events 172 and 173 | Broken steam generator is saturated or subcooled                                       |



### ***Additional Containment Events and Junction Control***

#### **Input Events**

|            |                                                |
|------------|------------------------------------------------|
| Events 240 | Constant flow (fire) sprays turned on          |
| Event 207  | Igniters forced on (does not require AC power) |
| Event 241  | Turn on cavity injection system pump           |

#### **Calculated Events**

|                    |                                                              |
|--------------------|--------------------------------------------------------------|
| Events 58 and 59   | Corium or water entrained in the cavity                      |
| Event 66           | Steaming in cavity limited by flooding                       |
| Event 69           | Steam explosion occurred in the cavity                       |
| Event 70           | Corium has contacted the cavity floor                        |
| Event 104          | Containment failed                                           |
| Event 106          | Neutron shield bags ruptured                                 |
| Event 132          | Ice depleted                                                 |
| Events 177 and 178 | Constant flow (fire) spray water or CO <sub>2</sub> depleted |
| Event 192          | Cavity injection system water depleted                       |

### Conditions in the Containment and Auxiliary Building Compartments

|                                           |                                                                    |
|-------------------------------------------|--------------------------------------------------------------------|
| Events 1001, 1016, and so on <sup>a</sup> | Water pool is present                                              |
| Events 1002, 1017, and so on              | Water pool is saturated                                            |
| Events 1003, 1018, and so on              | Volumetric burn is in progress                                     |
| Events 1004, 1019, and so on              | Corium pool is present                                             |
| Events 1005, 1020, and so on              | Corium pool is frozen                                              |
| Events 1006, 1021, and so on              | Compartment is solid (that is, filled with water)                  |
| Events 1008, 1023, and so on              | Corium pool is quenched                                            |
| Events 1009, 1024, and so on              | Corium pool temperature is greater than the concrete melting point |
| Events 1010, 1025, and so on              | Constant flow (fire) sprays are on                                 |
| Events 1011, 1026, and so on              | Fire suppression system (CO <sub>2</sub> ) is on                   |
| Events 1013, 1028, and so on              | Water is entrained                                                 |
| Events 1014, 1029, and so on              | Corium is entrained                                                |
| Events 1015, 1030, and so on              | Jet burn is in progress                                            |

<sup>a</sup> The event codes that correspond to the conditions in the containment compartments are determined using an algorithm that is a function of the condition number and the compartment number.

The following containment junction input parameters and calculated variables are useful for constructing logic to control the operation of junctions and for evaluating the status of junctions.

### Input Junction Control

|                                        |      |                                                                                           |
|----------------------------------------|------|-------------------------------------------------------------------------------------------|
| JFRB( <i>j</i> ) for junction <i>j</i> | = 1  | Manually force the junction open                                                          |
|                                        | = 0  | Manually force the junction closed                                                        |
|                                        | = -1 | Restore the junction to its original state (open or closed based on the type of junction) |

### Calculated Junction Variables

|                                        |     |                    |
|----------------------------------------|-----|--------------------|
| IFRB( <i>j</i> ) for junction <i>j</i> | > 0 | Junction is open   |
|                                        | ≤ 0 | Junction is closed |

### ***Miscellaneous Logic Events***

#### **Input Events**

|                |                                                             |
|----------------|-------------------------------------------------------------|
| Event 248      | Force execution stop                                        |
| Event 250      | Reset cumulative figures-of-merit                           |
| Events 320–323 | Write to log, restart, tabular, print, or plot output files |

#### **Calculated Events**

|           |                                                                   |
|-----------|-------------------------------------------------------------------|
| Event 100 | Iodine model is on                                                |
| Event 14  | Start to call fission product routines                            |
| Event 180 | Automatic plot spacing is on (versus equally spaced plot spacing) |



# ***D***

## **SAMPLE MAAP4 ANALYST CERTIFICATION GUIDE**

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This appendix contains a sample guide that can be used for the certification of a MAAP4 analyst. The guide serves as a checklist and documentation tool for the testing of a trainee by a MAAP4 mentor. It can be customized to meet an organization's particular needs. The applicant should demonstrate, preferably to a mentor, that he or she knows the required information and can perform the required tasks. Additional suggestions about the certification process are included in Section 3.5 of this report.

## Sample Engineering Training Certification Guide for a MAAP4 Analyst

Completion of the requirements of this certification guide is required to independently perform the following activities:

1. Prepare and/or revise a MAAP4 parameter file and prepare the documentation for review.
2. Perform a peer review of a new parameter file or changes to a previously reviewed file.
3. Create an input file for a MAAP4 sequence.
4. Execute MAAP4 using the input file, verify that the sequence executed successfully, and prepare the documentation for review.
5. Perform a peer review of the MAAP4 sequence.

### Trainee Information

Name:

Employee number:

Department:

### Mentor Information

Name:

Employee number:

Department or outside organization:

### Certification Process

Start date:

Due date (if applicable):

Completion date:

## CERTIFICATION VERIFICATION

### Trainee Verification

I have completed the Knowledge and Performance Requirements for this certification guide (see the corresponding sections on the subsequent pages). I am prepared to perform the MAAP4 activities listed above.

Signature:

---

Date:

---

### Mentor Verification

I have verified that the trainee has satisfactorily completed the Knowledge and Performance Requirements. The trainee is qualified to perform the MAAP4 activities independently.

Signature:

---

Date:

---

### Manager Approval

I accept the qualification of the trainee. The trainee is now certified to perform the MAAP4 activities independently.

Name:

---

Signature:

---

Date:

---

### Training and Certification Coordinator Approval

I have verified that the appropriate completion data for the certification of the trainee have been documented in the certification documentation system.

Name:

---

Signature:

---

Date:

---

## KNOWLEDGE REQUIREMENTS

The trainee should demonstrate knowledge of the following topics. The trainee should have access to the MAAP4 User's Manual, the MAAP4 User's Guides, the transmittal document for the current code revision, and the MAAP4 Applications Guide (if available) during the demonstration.

### I. OVERALL PURPOSES AND STRUCTURE OF MAAP4

- A. DESCRIBE the overall purposes of the MAAP4 code and the types of applications to which the results can be applied.

Mentor initial when requirement completed: \_\_\_\_\_

- B. IDENTIFY the physical and chemical processes (both pre- and post-core damage) that are modeled by MAAP4 within the following safety barriers:

- a. Fuel
- b. Primary system
- c. Containment

IDENTIFY the MAAP4 documentation that contains descriptions of the processes.

Mentor initial when requirement completed: \_\_\_\_\_

- C. IDENTIFY the types of sequences that MAAP4 is designed to simulate.

Mentor initial when requirement completed: \_\_\_\_\_

- D. DESCRIBE the following within the context of MAAP4:

- a. Time step
- b. State variables
- c. Driving forces
- d. Code execution/integration scheme, given the above terms

Mentor initial when requirement completed: \_\_\_\_\_



E. DESCRIBE the purpose of MAAP4 “events.” DESCRIBE what is meant by the following:

- a. MAAP4 automatic events
- b. MAAP4 external events
- c. Containment events
- d. User-defined events

IDENTIFY where the definitions and additional information about events can be found.

Mentor initial when requirement completed: \_\_\_\_\_

F. DESCRIBE the nodalization of the volumes and heat sinks in the following:

- a. Primary system
- b. Steam generator
- c. Containment

Mentor initial when requirement completed: \_\_\_\_\_

G. DESCRIBE the different types of containment junctions that can be specified and what they represent.

Mentor initial when requirement completed: \_\_\_\_\_

H. DESCRIBE the engineered safeguards systems that are modeled. DESCRIBE the differences between the hardwired and generalized ESF models in the PWR code.

Mentor initial when requirement completed: \_\_\_\_\_

I. DESCRIBE the key input and output files and their purposes.

Mentor initial when requirement completed: \_\_\_\_\_

J. DISCUSS the code’s limitations in terms of the plant’s systems, sequence types, and transient phenomena.

Mentor initial when requirement completed: \_\_\_\_\_

Section completed:

Signature: \_\_\_\_\_

Date: \_\_\_\_\_

## II. PARAMETER FILES

A. IDENTIFY the MAAP4 sample parameter files.

Mentor initial when requirement completed: \_\_\_\_\_

B. IDENTIFY the sections of a parameter file. DESCRIBE the format of the different parameter file sections.

Mentor initial when requirement completed: \_\_\_\_\_

C. DESCRIBE how the units for the parameter values are specified.

Mentor initial when requirement completed: \_\_\_\_\_

D. INDICATE whether your organization has any plant-specific MAAP parameter files. If so, IDENTIFY the location of the files, references for the values in the files, and the code revisions with which the parameter files are compatible (MAAP3B or MAAP4 and specific revision).

Mentor initial when requirement completed: \_\_\_\_\_

E. DESCRIBE the MAAP4 nodalization scheme for the following:

- a. Core
- b. Primary system
- c. Containment and reactor/auxiliary building

SHOW how the nodalization is specified using a plant-specific or sample parameter file.

Mentor initial when requirement completed: \_\_\_\_\_

F. DISCUSS the steps for finalizing and testing a parameter file.

Mentor initial when requirement completed: \_\_\_\_\_

Section completed:

Signature: \_\_\_\_\_

Date: \_\_\_\_\_

### III. SEQUENCE INPUT FILES

A. IDENTIFY the different components of an input file.

Mentor initial when requirement completed: \_\_\_\_\_

B. DISCUSS the syntax rules for each component. INDICATE where the syntax rules are documented.

Mentor initial when requirement completed: \_\_\_\_\_

C. INDICATE how parameters and event messages in the parameter file are used in input files.

Mentor initial when requirement completed: \_\_\_\_\_

D. INTERPRET several input files and describe the scenarios being modeled. (Note: The input files should not have explanatory comments in them.)

Mentor initial when requirement completed: \_\_\_\_\_

E. DISCUSS the benefits of documenting the intention of a sequence and how the written intention is used by both the MAAP4 analyst and the end user of the results.

Mentor initial when requirement completed: \_\_\_\_\_

F. DISCUSS the steps for testing an input file.

Mentor initial when requirement completed: \_\_\_\_\_

G. DISCUSS problems that users can encounter when creating input files.

Mentor initial when requirement completed: \_\_\_\_\_

Section completed:

Signature: \_\_\_\_\_

Date: \_\_\_\_\_

#### IV. CODE INSTALLATION AND EXECUTION

- A. DESCRIBE how to install MAAP4 and how to verify the installation using the sample problems.

Mentor initial when requirement completed: \_\_\_\_\_

- B. EXPLAIN how to verify that a sequence executed successfully.

Mentor initial when requirement completed: \_\_\_\_\_

- C. DISCUSS problems that users can encounter when executing MAAP4 as well as potential solutions to those problems.

Mentor initial when requirement completed: \_\_\_\_\_

- D. DISCUSS the impact of thresholds on the code results and how to investigate the impact of thresholds.

Mentor initial when requirement completed: \_\_\_\_\_

- E. DESCRIBE the elements of the documentation of a sequence.

Mentor initial when requirement completed: \_\_\_\_\_

Section completed:

Signature: \_\_\_\_\_

Date: \_\_\_\_\_

V. UNCERTAINTY AND SENSITIVITY ANALYSES

- A. DESCRIBE the reasons for assessing uncertainty and performing sensitivity analyses with MAAP4.

Mentor initial when requirement completed: \_\_\_\_\_

- B. IDENTIFY the input that should be adjusted for Level 1 and Level 2 PRA sequences.

Mentor initial when requirement completed: \_\_\_\_\_

- C. DISCUSS how to determine if the uncertainty in a phenomenon significantly affects a sequence or set of sequences.

Mentor initial when requirement completed: \_\_\_\_\_

Section completed:

Signature: \_\_\_\_\_

Date: \_\_\_\_\_

**VI. PEER REVIEW**

A. DESCRIBE the objectives of the peer review of MAAP4 parameter files and sequences.

Mentor initial when requirement completed: \_\_\_\_\_

B. DESCRIBE the documentation that the analyst should provide for review.

Mentor initial when requirement completed: \_\_\_\_\_

C. DISCUSS methods for reviewing a parameter file and a sequence.

Mentor initial when requirement completed: \_\_\_\_\_

Section completed:

Signature:

Date:

\_\_\_\_\_  
\_\_\_\_\_

**VII. CODE DOCUMENTATION, MAINTENANCE, AND THE MAAP USERS GROUP (MUG)**

A. DESCRIBE the MAAP4 documentation components. IDENTIFY their locations.

Mentor initial when requirement completed: \_\_\_\_\_

B. DESCRIBE the purposes and activities of the MUG and the types of work it sponsors.

Mentor initial when requirement completed: \_\_\_\_\_

C. DESCRIBE the code maintenance process from a user's perspective, including how to communicate questions and problems regarding the code and how revisions to the code are obtained and used.

Mentor initial when requirement completed: \_\_\_\_\_

D. DESCRIBE both how to obtain access to the MAAP web site and the content of the web site.

Mentor initial when requirement completed: \_\_\_\_\_

Section completed:

Signature:

Date:

\_\_\_\_\_  
\_\_\_\_\_

## PERFORMANCE REQUIREMENTS

The trainee should demonstrate that he or she can install and execute the code, create parameter and input files, and interpret the results. The trainee should use the MAAP4 User's Manual, the MAAP4 User's Guides, the transmittal document for the current revision, and the MAAP4 Applications Guide (if available) to perform these tasks. The tasks can be completed on a computer that either has MAAP4 installed or will have it installed as part of this process.

### VIII. INSTALLATION AND SAMPLE PROBLEM EXECUTION

- A. DEMONSTRATE the installation of the MAAP4 code on the computer. If the code has already been installed on the computer, DESCRIBE the process. If the code has not been installed on the computer, PERFORM the installation.

Mentor initial when requirement completed: \_\_\_\_\_

- B. VERIFY the installation by executing the code with the sample input and comparing the results with the sample output provided with the code. INDICATE the circumstances under which the results should yield digit-for-digit agreement and when the results should be similar but not identical. EXPLAIN how to determine whether the agreement between the generated results and those provided with the code is adequate for concluding that the code has been properly installed.

Mentor initial when requirement completed: \_\_\_\_\_

Section completed:

Signature: \_\_\_\_\_

Date: \_\_\_\_\_



## IX. PARAMETER AND INPUT FILE CREATION

- A. DISCUSS the creation of a parameter file using a sample parameter file as a template. INDICATE which parameters require plant-specific values. INDICATE how the references for the values in the file are to be cited and documented.

Mentor initial when requirement completed: \_\_\_\_\_

- B. DESCRIBE how to update a parameter file to be compatible with a new code revision. DESCRIBE how to update a file to represent a change in the plant or in the modeling (for example, in response to information provided by the maintenance contractor). INDICATE how the changes should be documented and the versions of the file maintained.

Mentor initial when requirement completed: \_\_\_\_\_

- C. PREPARE descriptions of several sequences that can be used with a parameter file that represents a plant or a sample parameter file. These sequences should include a blackout, a LOCA, and, for PWRs, a feed and bleed. They should also include a variety of intervention conditions and corresponding plant responses or operator actions.

Mentor initial when requirement completed: \_\_\_\_\_

- D. CREATE input files that represent the sequences in the descriptions.

Mentor initial when requirement completed: \_\_\_\_\_

- E. DEMONSTRATE how to test user-defined events and other elements of an input file.

Mentor initial when requirement completed: \_\_\_\_\_

Section completed:

Signature: \_\_\_\_\_

Date: \_\_\_\_\_

**X. CODE EXECUTION AND DOCUMENTATION OF SEQUENCES**

- A. EXECUTE the code using the input files created for requirement IX D above. EVALUATE the results to determine if the sequences ran without numerical difficulties and if the elements of the input files were interpreted as intended. GENERATE plots of key results using the plot files. EXPLAIN the progression of each sequence.

Mentor initial when requirement completed: \_\_\_\_\_

- B. DEMONSTRATE how to validate the results using other sequences run with other parameter files or by adjusting the input and doing sensitivity analyses.

Mentor initial when requirement completed: \_\_\_\_\_

- C. DEMONSTRATE how pertinent results should be documented. DEMONSTRATE how the descriptions, input files, parameter file(s), and results should be identified in sequence documentation.

Mentor initial when requirement completed: \_\_\_\_\_

Section completed:

Signature:

\_\_\_\_\_

Date:

\_\_\_\_\_

# E

## ASME REQUIREMENTS FOR PROBABILISTIC RISK ASSESSMENTS APPLICABLE TO MAAP4

---

The requirements in the ASME standard for PRAs are organized into the following nine technical elements [7]:

- Element 1: Initiating events analysis (IE)
- Element 2: Accident sequence analysis (AS)
- Element 3: Success criteria (SC)
- Element 4: Systems analysis (SY)
- Element 5: Human reliability analysis (HR)
- Element 6: Data analysis (DA)
- Element 7: Internal flooding (IF)
- Element 8: Quantification (QU)
- Element 9: LERF analysis (LE)

The standard lists objectives and a set of minimum high level requirements (HLRs) for each element. It also lists supporting requirements (SRs) to meet each HLR. Each SR might be subdivided into three capability categories; the higher the category, the more rigorous the requirement in terms of the scope, level of detail, plant specificity, and realism.

High level and corresponding supporting requirements that are directly applicable to MAAP4 analysis were identified in five of the nine technical elements: accident sequence analysis, success criteria, human reliability analysis, quantification, and LERF analysis. These requirements are listed next. For SRs that differ as a function of capability category, the entries are for Categories II and III. Included in the lists are the corresponding NRC staff positions for the identified requirements as they appear in RG 1.200 [8]. **Note:** Only the portions applicable to MAAP4 are reproduced in the lists that follow; omissions are indicated with ellipses (“...”).

The lists of applicable requirements fall into five general categories. These are presented in Table 3-5 along with a cross-reference to the portions of this report that provide applicable guidance.

## E.1 Element 2: Accident Sequence Analysis (AS)

**Objectives:** The objectives of the accident sequence element are to ensure that the response of the plant's systems and operators to an initiating event is reflected in the assessment of CDF and LERF ...

*[per RG 1.200 – references to LERF are not appropriate for this element]*

**HLR-AS-A:** The accident sequence analysis shall describe the plant-specific scenarios that can lead to core damage following each modeled initiating event. These scenarios shall address system responses and operator actions, including recovery actions that support the key safety functions necessary to prevent core damage.

**AS-A9: Capability Category III:** USE realistic, plant-specific thermal hydraulic analyses to determine the accident progression parameters (e.g., timing, temperature, pressure, steam) that could potentially affect the operability of the mitigating systems.

**Capability Category II:** USE realistic, applicable (i.e., from similar plants) thermal hydraulic analyses ...

*[per RG 1.200 for both categories – (See SC-B4.)]*

**HLR-AS-C:** The accident sequence analysis shall be documented consistent with the applicable supporting requirements.

**AS-C1:** DOCUMENT the accident sequence analysis in a manner that facilitates PRA applications, upgrades, and peer review.

**AS-C2:** DOCUMENT the processes used to develop accident sequences and treat dependencies in accident sequences, including the inputs, methods and results. For example, this documentation typically includes:

(b) the success criteria established for each modeled initiating event including the bases for the criteria (i.e., the system capacities required to mitigate the accident and the necessary components required to achieve these capacities);

(c) a description of the accident progression for each sequence or group of similar sequences (i.e., descriptions of the sequence timing, applicable procedural guidance, expected environmental or phenomenological impacts, dependencies between systems and operator actions, end states, and other pertinent information required to fully establish the sequence of events);

(d) the operator actions reflected in the event trees, and the sequence-specific timing and dependencies that are traceable to the HRA for these actions.

**AS-C3:** DOCUMENT the key assumptions and key sources [*per RG 1.200 – the assumptions and sources*] of uncertainty associated with the accident sequence analysis.

## **E.2 Element 3: Success Criteria (SC)**

**Objectives:** The objectives of the success criteria element are to define the plant-specific measures of success and failure that support the other technical elements of the PRA ... [*per RG 1.200 – references to LERF are not appropriate for this element*]

**HLR-SC-B:** The thermal hydraulic, structural, and other supporting engineering bases shall be capable of providing success criteria and event timing sufficient for quantification of CDF and LERF, determination of the relative impact of success criteria on the SSCs and human actions, and the impact of uncertainty on this determination.

**SC-B1: Capability Category III:** USE realistic, plant-specific models for thermal hydraulic, structural, and other supporting engineering bases in support of success criteria requiring detailed computer modeling. DO NOT USE assumptions that could yield conservative success criteria.

**Capability Category II:** Use appropriate realistic generic analyses/evaluations that are applicable to the plant for thermal hydraulic... modeling. Realistic models or analyses may be supplemented with plant-specific/generic FSAR or other conservative analysis applicable to the plant, but only if such supplemental analyses do not affect the determination of which combinations of systems and trains of systems are required to respond to an initiating event.

*[per RG 1.200 for both categories – (See SC-B4.)]*

**SC-B3:** When defining success criteria, USE thermal hydraulic, structural, or other analyses/evaluations appropriate to the event being analyzed, and accounting for a level of detail consistent with the initiating event grouping (HLR-IE-B) and accident sequence modeling (HLR-AS-A and HLR-AS-B).

**SC-B4:** USE analysis models and computer codes that have sufficient capability to model the conditions of interest in the determination of success criteria for CDF, and that provide results representative of the plant. A qualitative evaluation of a relevant application of codes, models, or analyses that has been used for a similar class of plant (e.g., Owner's Group generic studies) may be used. USE computer codes and models only within known limits of applicability.

**SC-B5:** CHECK the reasonableness and acceptability of the results of the thermal hydraulic, structural, or other supporting engineering bases used to support the success criteria. Examples of methods to achieve this include:

- (a) comparison with results of the same analyses performed for similar plants, accounting for differences in unique plant features
- (b) comparison with results of similar analyses performed with other plant-specific codes
- (c) check by other means appropriate to the particular analysis

**HLR-SC-C:** Success criteria shall be documented consistent with the applicable supporting requirements.

**SC-C1:** DOCUMENT the success criteria in a manner that facilitates PRA applications, upgrades, and peer review.

**SC-C2:** DOCUMENT the processes used to develop overall PRA success criteria and the supporting engineering bases, including the inputs, methods, and results. For example, this documentation typically includes:

- (b) calculations (generic and plant-specific) or other references used to establish success criteria, and identification of cases for which they are used
- (c) identification of computer codes or other methods used to establish plant-specific success criteria
- (d) a description of the limitations (e.g., potential conservatisms or limitations that could challenge the applicability of computer models in certain cases) of the calculations or codes
- (g) the basis for establishing the time available for human actions
- (h) descriptions of processes used to define success criteria for grouped initiating events or accident sequences

**SC-C3:** DOCUMENT the key assumptions and key sources [*per RG 1.200 – the assumptions and sources*] of uncertainty associated with the development of success criteria.

### **E.3 Element 5: Human Reliability Analysis (HR)**

**Objectives:** The objectives of the human reliability element of the PRA are to ensure that the impacts of plant personnel actions are reflected in the assessment of risk ...

#### *Post-Initiator HRA*

**HLR-HR-G:** The assessment of the probabilities of the post-initiator HFEs shall be performed using a well-defined and self-consistent process that addresses the plant-specific

and scenario-specific influences on human performance, and addresses potential dependencies between human failure events in the same accident sequence.

**HR-G4: Capability Category III:** BASE the time available to complete actions on plant-specific thermal hydraulic analysis, or simulations. SPECIFY the point in time at which operators are expected to receive relevant indications.

**Capability Category II:** BASE the time available to complete actions on appropriate realistic generic thermal hydraulic analyses, or simulation from similar plants (e.g., plant of similar design and operation). SPECIFY ...

*[per RG 1.200 for both categories – (See SC-B4.)]*

#### *Pre- and Post-Initiator HRA*

**HLR-HR-I:** The human reliability analysis shall be documented consistent with the applicable supporting requirements.

**HR-I1:** DOCUMENT the human reliability analysis in a manner that facilitates PRA applications, upgrades, and peer review.

**HR-I2:** DOCUMENT the processes used to identify, characterize, and quantify the pre-initiator, post-initiator, and recovery actions considered by the PRA, including the inputs, methods, and results. For example, this documentation typically includes:

(c) factors used in the quantification of the human action, how they were derived (their bases), and how they were incorporated into the quantification process

**HR-I3:** DOCUMENT the key assumptions and key sources *[per RG 1.200 – the assumptions and sources]* of uncertainty associated with the human reliability analysis.

## **E.4 Element 8: Quantification (QU)**

**Objectives:** The objectives of the quantification element are to provide an estimate of CDF *[per RG 1.200 – and support the quantification of LERF]* based upon the plant-specific scenarios ...

**HLR-QU-E:** Uncertainties in the PRA results shall be characterized. Key sources of model uncertainty and key assumptions shall be identified, and their potential impact on the results understood.

*[per RG 1.200 – Uncertainties in the PRA results shall be characterized. Sources of model uncertainty and assumptions shall be identified, and their potential impact on the results understood.]*

**QU-E1:** IDENTIFY key sources [*per RG 1.200 – IDENTIFY sources*] of model uncertainty.

**QU-E2:** IDENTIFY key assumptions [*per RG 1.200 – IDENTIFY assumptions*] made in the development of the PRA model.



**QU-E4: Capability Category III:** EVALUATE the sensitivity of the results to uncertain model boundary conditions and other key assumptions *[per RG 1.200 – other assumptions]* using sensitivity analyses except where such sources of uncertainty have been adequately treated in the quantitative uncertainty analysis. For specific applications, key assumptions and parameters should be examined both individually and in logical combinations.

**Capability Category II:** EVALUATE the sensitivity of the results to key model *[per RG 1.200 – to model]* uncertainties and key assumptions using sensitivity analyses. For specific applications ...

**HLR-QU-F:** The quantification shall be documented consistent with the applicable support requirements.

**QU-F4:** DOCUMENT key assumptions and key sources of uncertainty, such as: possible optimistic or conservative success criteria, suitability of the reliability data, possible modeling uncertainties (modeling limitations due to the method selected), degree of completeness in the selection of initiating events, possible spatial dependencies, etc.  
*[per RG 1.200 – DOCUMENT the assumptions and sources of uncertainty associated with the quantification analysis.]*

## **E.5 Element 9: LERF Analysis (LE)**

**Objectives:** The objectives of the LERF analysis element are to identify and quantify the contributors to large early releases, based upon the plant-specific core damage scenarios ...

**HLR-LE-A:** Core damage sequences shall be grouped into plant damage states based on their accident progression attributes.

**LE-A1:** IDENTIFY those physical characteristics at the time of core damage that can influence LERF. Examples include:

- (a) RCS pressure (high RCS pressure can result in high pressure melt ejection)
- (b) status of emergency core coolant systems (failure in injection can result in a dry cavity and extensive core concrete interaction)
- (c) status of containment isolation (failure of isolation can result in an unscrubbed release)
- (d) status of containment heat removal
- (e) containment integrity (e.g., vented, bypassed, or failed)
- (f) steam generator pressure and water level (PWRs)

(g) status of containment inerting (BWRs)

**LE-A2:** IDENTIFY the accident sequence characteristics that lead to the physical characteristics identified in LE-A1. Examples include:

(a) type of initiator

(1) Transients can result in high RCS pressure

(2) LOCAs usually result in lower RCS pressure

(3) ISLOCAs, SGTRs can result in containment bypass

(b) status of electric power: loss of electric power can result in loss of ECC injection

(c) status of containment safety systems such as sprays, fan coolers, igniters, or venting systems: operability of containment safety systems determines status of containment heat removal

**HLR-LE-B:** The accident progression analyses shall include an evaluation of contributors (e.g., phenomena, equipment failures, and human actions) to a large early release.

**LE-B2: Capability Category III:** DETERMINE the containment challenges (e.g., temperature pressure loads, debris impingement) resulting from contributors identified in LE-B1 in a realistic manner. CONSIDER differential pressure loadings on the RCS, and vessel support capabilities during vessel failure and blowdown, in order to address whether RCS motions may impact containment integrity.

**Capability Category II:** DETERMINE the containment challenges (e.g., temperature, pressure loads, debris impingement) resulting from contributors identified in LE-B1 using applicable generic or plant-specific analyses for significant containment challenges. USE conservative treatment or a combination of conservative and realistic treatment for non-significant containment challenges. IF generic calculations are used in support of the assessment, JUSTIFY applicability to the plant being evaluated.

**HLR-LE-C:** The accident progression analysis shall include identification of those sequences that would result in a large early release.

**LE-C1: Capability Category III:** DEVELOP accident sequences to a level of detail to account for the potential contributors identified in LE-B1 and analyzed in LE-B2. Compare the containment challenges analyzed in LE-B with the containment structural capability analyzed in LE-D and identify accident progressions that have the potential for a large early release. CALCULATE

source terms for accident progressions that have the potential for large early releases.

**Capability Category II:** DEVELOP ... large early release. JUSTIFY any generic or plant-specific calculations or references used to categorize releases as non-LERF contributors based on release magnitude or timing. NUREG/CR-6595, App. A provides an acceptable definition [*per RG 1.200 – provides a discussion and examples*] of LERF source terms.

**LE-C3: Capability Category III:** INCLUDE model logic necessary to provide a realistic estimation of the accident progression sequences resulting in a large early release. INCLUDE mitigating actions by operating staff, effect of fission product scrubbing on radionuclide release, and expected beneficial failures. PROVIDE technical justification (by plant-specific or applicable generic calculations demonstrating the feasibility of the actions, scrubbing mechanisms, or beneficial failures) for the inclusion of any of these features.

**Capability Category II:** INCLUDE ... estimation of the significant accident progression ... beneficial failure in significant accident progression sequences... beneficial failures) supporting the inclusion of any of these features.

**LE-C4: Capability Category III:** USE appropriate realistic plant-specific system success criteria.

**Capability Category II:** USE appropriate realistic generic or plant-specific analyses for system success criteria for the significant accident progression sequences. USE conservative or a combination of conservative and realistic system success criteria for non-risk significant accident progression sequences.

**LE-C10:** PERFORM a containment bypass analysis in a realistic manner. JUSTIFY any credit taken for scrubbing (i.e., provide an engineering basis for the decontamination factor used).

**HLR-LE-D:** The accident progression analysis shall include an evaluation of the containment structural capability for those containment challenges that would result in a large early release.

**LE-D5: Capability Category III:** PERFORM a realistic analysis of thermally-induced SG tube rupture that includes plant-specific procedures and key design features. Use appropriate computer codes to calculate the plant-specific conditions.

**Capability Category II:** PERFORM an analysis of thermally-induced SG tube rupture that includes plant-specific procedures and design features and conditions that could impact tube failure. An acceptable approach is one that

arrives at plant-specific split fractions by selecting the SG tube conditional failure probabilities based on NUREG-1570 or similar evaluation for induced SG failure of a similarly designed SG and loop piping. SELECT failure probabilities based on

(a) RCS and SG post-accident conditions sufficient to describe the important risk outcomes

(b) secondary side conditions including plant-specific treatment of MSSV and ADV failures

JUSTIFY key assumptions and selection of key inputs. An acceptable justification can be obtained by the extrapolation of the information in NUREG-1570 to obtain plant-specific models, use of reasonably bounding assumptions, or performance of sensitivity studies indicating low sensitivity to changes in the range in question.

**HLR-LE-E:** The frequency of different containment failure modes leading to a large early release shall be quantified and aggregated.

**LE-E2: Capability Category III:** USE realistic parameter estimates to characterize accident progression phenomena.

**Capability Category II:** USE realistic parameter estimates to characterize accident progression phenomena for significant accident progression sequences resulting in a large early release. USE conservative or a combination of conservative and realistic estimates for non-significant accident progression sequences resulting in a large early release.

**HLR-LE-G:** The LERF analysis shall be documented consistent with the applicable supporting requirements.

**LE-G1:** DOCUMENT the LERF analysis in a manner that facilitates PRA applications, upgrades, and peer review.

**LE-G2:** DOCUMENT the process used to identify plant damage states and accident progression contributors, define accident progression sequences, evaluate accident progression analyses of containment capability, and quantify and review the LERF results. For example, this documentation typically includes:

(c) the containment failure modes, phenomena, equipment failures, and human actions considered in the development of the accident progression sequences and the justification for their inclusion or exclusion from the accident progression analysis

(f) the accident progression analysis sequences considered in the containment event trees

**LE-G4:** DOCUMENT key assumptions and key sources [*per RG 1.200 – assumptions and sources*] of uncertainty associated with the LERF analysis, including results and important insights from sensitivity studies.



# **F**

## **SUMMARIES OF MAAP BENCHMARKS**

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This appendix contains summaries of benchmarks that pertain to the MAAP4 modeling of Level 1 phenomena. The benchmarks fall into the following categories:

- Comparisons to plant events (PE entries)
- Comparisons to integral codes (IC entries)
- Comparisons to integral experiments (IE entries)
- Comparisons to separate effects experiments (SE entries)

The summaries contain identifying information about the benchmarks, including the authors, plant types, PRA levels, time frames, MAAP4 code versions, comparison codes and experiments, number and types of sequences, and references for the documentation. The summaries also contain the degree of agreement for the major code models and the validation of code capabilities, as determined by the team of MAAP4 experts introduced in Section 7 of this report. Related notes, exemplified limitations and precautions, recommendations for users, and issues for further code development identified by the team are included, as are the documented conclusions drawn by the authors of the benchmarks. The summaries are presented in a common format to facilitate the drawing of conclusions regarding the overall extent and success of the benchmarking of MAAP4; only relevant components are included in each individual summary. Copies of the benchmark documentation and the references in the report will be maintained by EPRI and made available under separate cover.

**Comparison to Plant Event:**

**PE1. TMI-2 LOFW with Stuck-Open PORV**

| Author | Plant Type | PRA Level | Time Frame | MAAP4 Code Versions        | Principal Sources of Documentation                                                                      |
|--------|------------|-----------|------------|----------------------------|---------------------------------------------------------------------------------------------------------|
| FAI    | PWR, B&W   | 1 and 2   | 5 hr       | 4.0.0, 4.0.2, 4.0.6, 4.0.7 | MAAP4 User's Manual (1994), conference proceedings (1995); also code transmittal documents (2005, 2007) |

**Major Code Models Compared and Review of Agreement**

| Model                                 | Indicator                      | Agreement Based on Expert Review                                                                                                       | Notes                                                                                                                                      |
|---------------------------------------|--------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|
| Overall code                          | —                              | Very good agreement given that there are uncertainties in some of the boundary conditions and corresponding assumptions had to be made | —                                                                                                                                          |
| PWR primary system thermal hydraulics | Pressure                       | Good agreement                                                                                                                         | —                                                                                                                                          |
|                                       | Water level in the pressurizer | Good agreement                                                                                                                         |                                                                                                                                            |
| Steam generator: one-region OTSG      | Pressure                       | Fair agreement                                                                                                                         | Does not uncover any issue that calls the model into question                                                                              |
|                                       | Water level                    | Not applicable (boundary condition)                                                                                                    |                                                                                                                                            |
| Core heat-up                          | Core temperature               | Core temperature is not available; however, agreement indirectly supported by the timing of hydrogen generation                        | Code predicts that hydrogen was generated early enough to shut off condensation in the steam generators, which is consistent with the data |



**Comparison to Plant Event:****PE1. TMI-2 LOFW with Stuck-Open PORV, continued**

| <b>Model</b> | <b>Indicator</b> | <b>Agreement Based on Expert Review</b>              | <b>Notes</b>                                                                                                            |
|--------------|------------------|------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------|
| Containment  | Pressure         | Qualitative agreement; overall trends are reasonable | Boundary conditions and plant details are uncertain (for example, fan cooler performance and flow from the quench tank) |

**Conclusions from the Authors of the Benchmark**

*Conference proceedings:* “Comparisons of the MAAP4 model predictions with the TMI-2 data show that the MAAP4 code calculations are in good agreement with the overall plant response during the accident. ... MAAP4 provided a reasonable simulation of the TMI-2 system response in terms of the behavior before the core was uncovered, the response of the primary system while the core degraded, the response of the RCS when the core was reflooded at 174 minutes as well as the lower head response after 224 minutes.”

**Documentation**

|                                                                                                                                                                                                                                                                              |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| MAAP4 User’s Manual [1]: Volume III, Section 4, Rev. 0, May 1994. (using Rev. 4.0.0, includes predicted containment response)                                                                                                                                                |
| C. Paik, R. Henry, and M. McCartney, “MAAP4.0 Benchmarking with the TMI-2 Experience,” <i>Proceedings of the International Conference on Probabilistic Safety Assessment Methodology and Applications, PSA ’95</i> . Seoul, Korea (November 26–30, 1995). (using Rev. 4.0.2) |
| MAAP4 transmittal documents for Rev. 4.0.6 and Rev. 4.0.7 [12, 13]. (plotted results only, 2005 and 2007)                                                                                                                                                                    |

**Comparison to Plant Event:**  
**PE2. Davis-Besse LOFW**

| Author | Plant Type | PRA Level | Time Frame | MAAP4 Code Versions | Principal Sources of Documentation                                       |
|--------|------------|-----------|------------|---------------------|--------------------------------------------------------------------------|
| FAI    | PWR, B&W   | 1         | 0.5 hr     | 4.0.3, 4.0.6, 4.0.7 | MAAP4 User's Manual (1996); also code transmittal documents (2005, 2007) |

**Major Code Models Compared and Review of Agreement**

| Model                                 | Indicator                      | Agreement Based on Expert Review | Notes                                                                                                                                |
|---------------------------------------|--------------------------------|----------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|
| Overall code                          | —                              | Fair agreement                   | Steam generator terms (pressure and water level) are boundary conditions, so this benchmark does not test the steam generator model. |
| PWR primary system thermal hydraulics | Pressure                       | Fair agreement                   | There is evidence that the code overestimates the heat transfer to the pressurizer sprays.                                           |
|                                       | Water level in the pressurizer | Good agreement                   |                                                                                                                                      |

**Conclusions from the Authors of the Benchmark**

“MAAP4 agrees with the measured data over the entire duration of the incident. ... There are some differences in the pressurizer response, but all of the appropriate trends are observed in terms of the initial level increase, a decrease in the level and a subsequent increase as the system overheats and the pressure increases. Once the auxiliary feedwater has been reestablished to the steam generators and the RCS depressurizes, the pressurizer level also decreases. ... Given the secondary side conditions, the MAAP4 models follow the dynamic response of the RCS.”

**Comparison to Plant Event:**  
**PE2. Davis-Besse LOFW, continued**

**Documentation**

|                                                                      |
|----------------------------------------------------------------------|
| MAAP4 User's Manual [1]: Volume III, Section B, Rev. 0, August 1996. |
|----------------------------------------------------------------------|

|                                                                                                           |
|-----------------------------------------------------------------------------------------------------------|
| MAAP4 transmittal documents for Rev. 4.0.6 and Rev. 4.0.7 [12, 13]. (plotted results only, 2005 and 2007) |
|-----------------------------------------------------------------------------------------------------------|

**Comparison to Plant Event:**  
**PE3. Oyster Creek LOFW**

| Author | Plant Type                   | PRA Level | Time Frame | MAAP4 Code Version | Principal Source of Documentation |
|--------|------------------------------|-----------|------------|--------------------|-----------------------------------|
| FAI    | BWR with isolation condenser | 1         | 0.5 hr     | 4.0.7              | MAAP4 User's Manual (2007)        |

**Major Code Models Compared and Review of Agreement**

| Model                                 | Indicator                 | Agreement Based on Expert Review                                                                                                       | Notes |
|---------------------------------------|---------------------------|----------------------------------------------------------------------------------------------------------------------------------------|-------|
| Overall code                          | —                         | Very good agreement given that there are uncertainties in some of the boundary conditions and corresponding assumptions had to be made | —     |
| BWR primary system thermal hydraulics | Pressure                  | Good agreement                                                                                                                         | —     |
|                                       | Water level in the vessel | Good agreement                                                                                                                         |       |

**Validation of Code Capabilities**

|                                                    |                                                                        |
|----------------------------------------------------|------------------------------------------------------------------------|
| Isolation condenser heat transfer: hardwired model | Validated based on pressure in the primary system being well predicted |
|----------------------------------------------------|------------------------------------------------------------------------|

**Note**

The extent of steam voiding in the core and the resulting water displacement into the downcomer are somewhat under-predicted during the early portion of the sequence (the first 4 minutes in this benchmark). The calculated water level has the expected trend, but it rises more slowly than the data during this period. This might also be because the model for water circulation between the downcomer, core, and core bypass is somewhat simplified, with only one node for the combined downcomer, jet pump, and recirculation pump water and one node for the combined core, core bypass, shroud head, riser, and separator water.

**Comparison to Plant Event:**

**PE3. Oyster Creek LOFW, continued**

**Conclusions from the Authors of the Benchmark**

“With some reasonable sensitivities included to refine boundary conditions that are either absent or in conflict with plant data, the MAAP4 model provides an excellent characterization of the RCS pressure response following the reactor scram and loss-of-feedwater initiators. The downcomer level response provides good long-term agreement, so total water mass and energy in the vessel are properly represented. However, additional improvement in the short-term dynamic level response is necessary. Specifically, the model for core voiding and subsequent displacement of water from the core to the downcomer needs improvement. Given the simplified model for water (one combined node for downcomer, jet pump and recirculation loop water and one combined node for core and core bypass water), this may be the best agreement possible in the context of the current model.”

**Documentation**

MAAP4 User’s Manual [1]: Volume III, Section B, Rev. 0.1, March 2007.

**Comparison to Plant Event:**  
**PE4. Prairie Island SGTR**

| Author | Plant Type | PRA Level | Time Frame | MAAP4 Code Versions | Principal Sources of Documentation                                       |
|--------|------------|-----------|------------|---------------------|--------------------------------------------------------------------------|
| FAI    | PWR, WLD   | 1         | 8 min      | 4.0.4, 4.0.6, 4.0.7 | MAAP4 User's Manual (1997); also code transmittal documents (2005, 2007) |

**Major Code Models Compared and Review of Agreement**

| Model                                 | Indicator                      | Agreement Based on Expert Review | Notes                                                                                                                               |
|---------------------------------------|--------------------------------|----------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|
| Overall code                          | —                              | Good agreement                   | Steam generator terms (pressure and water level) are boundary conditions, so this benchmark does not test the steam generator model |
| PWR primary system thermal hydraulics | Pressure                       | Good agreement                   | —                                                                                                                                   |
|                                       | Water level in the pressurizer | Not available                    |                                                                                                                                     |

**Validation of Code Capabilities**

|                                     |                                                                                                                |
|-------------------------------------|----------------------------------------------------------------------------------------------------------------|
| PWR ECCS injection: hardwired model | Validated based on the effect of injection on the pressure in the primary system being appropriately predicted |
|-------------------------------------|----------------------------------------------------------------------------------------------------------------|

**Comparison to Plant Event:**

**PE4. Prairie Island SGTR, continued**

**Conclusions from the Authors of the Benchmark**

*Primary system pressure:* “Agreement is excellent between transient initiation and the time of reactor scram. ... Post-scram depressurization and the subsequent pressurization due to safety injection (HPI) flow were predicted well for the remainder of the benchmark.”

*Primary system water temperatures:* “Agreement is quite good during the period prior to scram. ... MAAP4 predicted well the hot and cold leg temperatures.... After the 10% power reduction, MAAP4 properly predicted the slight decrease in the hot leg temperature and the corresponding increase in the cold leg temperature. Upon scram initiation, MAAP4 properly predicted the substantial decrease in the hot leg temperature and subsequent convergence with the cold leg temperature in response to the step change in thermal power. ... Initial post-scram cooling rate was somewhat higher than that in the actual transient, which was probably due to a secondary side boiling heat transfer coefficient that was larger than expected. However, as the primary side temperature approached the secondary side saturation temperature, boiling was diminished due to the decrease [in] tube wall superheat. Consequently, while the initial cooldown was too rapid, the total energy removed from the RCS during the entire post-scram period was similar, as reflected in the average temperature prediction that was only a few degrees lower than that for the actual transient.”

*Overall:* “MAAP4 provides a reasonable characterization of the reactor coolant system response to the steam generator tube rupture given the synchronized boundary conditions for the thermal power runback, reactor scram, feedwater flow rate, and steam generator secondary side pressure.”

**Documentation**

MAAP4 User’s Manual [1]: Volume III, Section B, Rev. 0, October 1997.

MAAP4 transmittal documents for Rev. 4.0.6 and Rev. 4.0.7 [12, 13]. (plotted results only, 2005 and 2007)

**Comparison to Plant Event:**  
**PE5. Maanshan SBO**

| Author                           | Plant Type | PRA Level | Time Frame | MAAP4 Code Version | Principal Source of Documentation |
|----------------------------------|------------|-----------|------------|--------------------|-----------------------------------|
| FAI, also INER, Taiwan Power Co. | PWR, WLD   | 1         | 3 hr       | 4.0.5              | Presentation to the NRC (2004)    |

**Major Code Models Compared and Review of Agreement**

| Model                                 | Indicator                      | Agreement Based on Expert Review                                                                                                                                                                                                                                                 | Notes                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|---------------------------------------|--------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Overall code                          | —                              | Good agreement                                                                                                                                                                                                                                                                   | —                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| PWR primary system thermal hydraulics | Pressure                       | Very good agreement                                                                                                                                                                                                                                                              | Sensitivity cases consisted of 1) using a lower value of HTSTAG and 2) simulating natural convection with the RCP coastdown curve. Using the coastdown curve instead of HTSTAG means that the code will calculate the primary side to secondary side heat transfer coefficient using the forced convection heat transfer correlation instead of HTSTAG. These sensitivity cases were selected because the sequence starts 23 hours after reactor trip. |
|                                       | Water level in the pressurizer | <p>Good agreement</p> <p>Very good agreement with a value of HTSTAG<sup>a</sup> that is appropriate for the sequence (lower than the nominal value because the initial power is low)</p> <p>Very good agreement with natural convection simulated by the RCP coastdown curve</p> |                                                                                                                                                                                                                                                                                                                                                                                                                                                        |

<sup>a</sup> HTSTAG is the coefficient for the primary side to secondary side heat transfer when single- or two-phase natural circulation is occurring in the coolant loops.



**Comparison to Plant Event:**

**PE5. Maanshan SBO, continued**

**Notes**

The benchmark includes MELCOR code predictions of the event as well as the MAAP4 predictions.

The steam generator terms (pressure and water level) are boundary conditions, so this benchmark does not test the steam generator model.

Using the RCP coastdown curve did not yield better agreement with the data than using the smaller value for input parameter HTSTAG. The smaller value was selected because the power is relatively low due to the long elapsed time since reactor trip.

**Exemplified Limitation**

PWR sequences without makeup or loss from the primary system in which the primary system is cooling down by heat transfer to the steam generators can result in a minor over-prediction of the rate of depressurization in the primary system at the time that the pressurizer drains completely. This is due to the fact that steam flow from the pressurizer into the water-filled RCS condenses in the water, which is in a homogenous, subcooled state. In actuality, the water in the reactor vessel dome is somewhat hotter than the rest of the RCS, and a portion of that water flashes into steam as the RCS depressurizes, keeping the system at a higher pressure. The calculated faster depressurization might lead to slightly earlier pressure activation of safety systems, such as accumulator injection. This is a minor limitation and affects only the detailed behavior of the primary system.

**Conclusions from the Authors of the Benchmark**

“MAAP4 results generally agree with the plant data for the SBO sequence. With adjustments of MAAP input parameters (sensitivity studies), comparisons with the details of the plant data can be improved. In this case, this is primarily a result of the low decay heat.... These sensitivity parameters have very little effect on overall time to when the core is uncovered.”

**Comparison to Plant Event:**  
**PE5. Maanshan SBO, continued**

**Documentation**

|                                                                                |
|--------------------------------------------------------------------------------|
| Presentation to the NRC by FAI, September 2004. (supersedes 2001 presentation) |
| Presentation to the MAAP Users Group by INER and Taiwan Power Co., May 2001.   |

**Comparison to Plant Event:**  
**PE6. Oconee Plant Trip**

| Author                                                                                                                                          | Plant Type | PRA Level | Time Frame | MAAP4 Code Versions           | Principal Source of Documentation |
|-------------------------------------------------------------------------------------------------------------------------------------------------|------------|-----------|------------|-------------------------------|-----------------------------------|
| Duke                                                                                                                                            | PWR, B&W   | 1         | 15 min     | 4.0.5, 4.0.6 plus code change | Presentation to the MUG (2006)    |
| Code change made regarding the option for specifying if the water in the PWR vessel dome region is considered hot or cold (added in Rev. 4.0.7) |            |           |            |                               |                                   |

**Major Code Models Compared and Review of Agreement**

| Model                                 | Indicator                      | Agreement Based on Expert Review                                                 | Notes |
|---------------------------------------|--------------------------------|----------------------------------------------------------------------------------|-------|
| Overall code                          | —                              | Good agreement                                                                   | —     |
| PWR primary system thermal hydraulics | Pressure                       | Very good agreement after change made to model plants with hot water in the dome | —     |
|                                       | Water level in the pressurizer | Not available                                                                    |       |

**Exemplified Limitation**

Through Rev. 4.0.6, the code always models the water in the vessel dome as cold water, representing *T-cold* plants. The code might under-predict the decrease in the water volume in the primary system as the plant depressurizes for plants with hot water in the vessel dome, *T-hot* plants, resulting in a smaller predicted pressure drop. One impact of this limitation is that emergency system low pressure setpoints might not be hit in T-hot plants if they are modeled as T-cold plants.

**Conclusions from the Authors of the Benchmark**

“The additional shrinkage that results when the reactor vessel upper head water is designated as hot causes the pressure to drop to the emergency system setpoint.”

**Comparison to Plant Event:**  
**PE6. Oconee Plant Trip, continued**

**Documentation**

|                                                              |
|--------------------------------------------------------------|
| Presentation to the MAAP Users Group by Duke, November 2006. |
|--------------------------------------------------------------|

**Comparison to Plant Event:****PE7. 1992 MAAP3B Qualification Studies–LOOP and Plant Trip**

| <b>Author</b> | <b>Plant Type</b>                                             | <b>PRA Level</b> | <b>Time Frame</b> | <b>MAAP4 Code Version</b> | <b>Principal Source of Documentation</b> |
|---------------|---------------------------------------------------------------|------------------|-------------------|---------------------------|------------------------------------------|
| GKA           | PWR, Westinghouse four-loop plant (ice condenser containment) | 1                | 3, 5 min          | MAAP3B Rev. 16            | EPRI technical report (1992)             |

**Major Code Models Compared and Review of Agreement**

| <b>Model</b> | <b>Indicator</b> | <b>Agreement Based on Expert Review</b>                                                                                                               | <b>Notes</b>                                                                                         |
|--------------|------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|
| Overall code | —                | Good agreement with MAAP3B plus code changes that were identified as part of the MAAP3B benchmark activity. The changes were incorporated into MAAP4. | The benchmark is generally but not specifically applicable to MAAP4 because it was done with MAAP3B. |

**Documentation**

|                                                           |
|-----------------------------------------------------------|
| 1992 MAAP Thermal-Hydraulic Qualification Studies [2, 5]. |
|-----------------------------------------------------------|

**Comparison to Integral Codes:**

**IC1. SBO and LOFW with Feed and Bleed for CE Plants; CENTS Code**

| Author                                                                                                                                          | Plant Type | PRA Level | Time Frame | MAAP4 Code Version                          | Comparison Code Version | Number of Sequences | Principal Source of Documentation                             |
|-------------------------------------------------------------------------------------------------------------------------------------------------|------------|-----------|------------|---------------------------------------------|-------------------------|---------------------|---------------------------------------------------------------|
| Westinghouse                                                                                                                                    | PWR, CE    | 1         | 3 hr       | 4.0.6 plus code change, also 4.0.5 for LOFW | CENTS Version 06100     | 1 SBO, 1 LOFW       | Conference proceedings (2009), presentation to the MUG (2006) |
| Code change made regarding the option for specifying if the water in the PWR vessel dome region is considered hot or cold (added in Rev. 4.0.7) |            |           |            |                                             |                         |                     |                                                               |

**Major Code Models Compared and Review of Agreement**

| Model                                 | Indicator                      | Agreement Based on Expert Review                        | Notes                                                                                                                                                                                                                                                                                                                                                                    |
|---------------------------------------|--------------------------------|---------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Overall code                          | —                              | Good agreement                                          | The cases demonstrate the need to check the secondary side water mass versus level and adjust the geometry terms as needed. The 4.0.5 LOFW case also demonstrates the importance of checking that the input parameter values result in accurate, self-consistent initial conditions by testing with a steady-state sequence.                                             |
| PWR primary system thermal hydraulics | Pressure                       | Good agreement                                          | The RCP coastdown curve was used to simulate single-phase primary side natural convection in the LOFW sequence. There are differences in the predicted quality of the fluid flowing through the surge line and therefore through the PORVs. These differences do not indicate problems with the MAAP4 model, and they do not affect the agreement of the key quantities. |
|                                       | Water level in the pressurizer | Good agreement (available in MUG presentation for LOFW) |                                                                                                                                                                                                                                                                                                                                                                          |

**Comparison to Integral Codes:****IC1. SBO and LOFW with Feed and Bleed for CE Plants; CENTS Code, continued**

| Model                              | Indicator                         | Agreement Based on Expert Review | Notes                                                                                                                                                                                                                                                                                                                                                         |
|------------------------------------|-----------------------------------|----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Steam generator: two-region U-tube | Pressure                          | Very good agreement              | The MAAP4 steam generator level model is more simplified than the one in CENTS. Secondary side benchmarking was performed to ensure consistency between the two codes for the timing of the reactor trip signal and the initiation of feed and bleed. This involved adjusting the MAAP4 setpoints to correspond to the appropriate steam generator inventory. |
|                                    | Water level (represented by mass) | Fair to good agreement           |                                                                                                                                                                                                                                                                                                                                                               |

**Validation of Code Capabilities**

|                                       |                                                                           |
|---------------------------------------|---------------------------------------------------------------------------|
| Critical flow: pressurizer PORVs      | Qualitative agreement inferred from primary system response               |
| PWR ECCS injection: generalized model | Validated based on the effect of injection on the primary system response |

**Exemplified Precaution**

Loss-of-feedwater sequences are particularly sensitive to mismatches between the core power, feedwater flow, and secondary side volume versus height input values. It is important to accurately determine the time of reactor trip, which in turn means determining appropriate secondary side water level setpoints if the water level is the trigger for reactor trip.

**Comparison to Integral Codes:**

**IC1. SBO and LOFW with Feed and Bleed for CE Plants; CENTS Code, continued**

**Conclusions from the Authors of the Benchmark**

*Conference proceedings:* “The results of the analyses presented in this paper provide several useful insights. The simplified single-phase natural circulation model utilized by MAAP4 drives differences in the thermal-hydraulic response of the SGs as well as the RCS. It should be noted that older generators of MAAP4, such as MAAP 4.0.5, have been known to skew the RCS pressure responses for feed and bleed and SBO transients. MAAP versions 4.0.6 and beyond include a number of enhancements that yield more consistent results for the pressure traces of the SBO and the feed and bleed transients. It is recommended that the user be cautious in the selection of the code version that is employed for SBO and LOFW event analyses.

This paper demonstrates that when care is taken to normalize the MAAP4 and CENTS primary side natural circulation flow rate and SG modeling behaviors, the trends of MAAP4 and CENTS, while not in precise agreement, are sufficiently close to predict similar equipment sets required for mitigation. Although the timings and durations of key occurrences and actuations vary, MAAP4 predictions of core uncover time tend to be conservatively biased. It should also be noted that the use of thermal-hydraulic results in PRA should consider the uncertainties inherent in key models employed in the computer codes.”

*Minutes and viewgraphs:* “MAAP is successful in predicting feed and bleed success criteria with integrated containment response.”

*Viewgraphs:* “Incorporating mass-based secondary side setpoints and steam generator pressure control: earlier SG dryout times, less time for operators to initiate feed and bleed, more realistic SG mass vs. level predictions; ... Low PORV quality predictions lead to: increased RCS coolant loss, earlier core uncover times; ... MAAP generated success criteria: accurate in terms of minimum requirement equipment set, different in terms of detailed transient response; ... MAAP is successful in predicting feed and bleed success criteria with integrated containment response: important to understand potential MAAP modeling uncertainties.”



**Comparison to Integral Codes:**

**IC1. SBO and LOFW with Feed and Bleed for CE Plants; CENTS Code, continued**

**Documentation**

N. LaBarge, R. Schneider, B. Baron, and M. Jacob, “Comparison of Thermal Hydraulic Simulations of Beyond Design Basis Events Using the MAAP4 and CENTS Computer Codes,” *Proceedings of the 17<sup>th</sup> International Conference on Nuclear Engineering (ICONE17)*. Brussels, Belgium (July 12–16, 2009).

Presentation to the MAAP Users Group by Westinghouse, November 2006. (preliminary to the 2009 paper, used Rev. 4.0.5, proprietary to Westinghouse)

**Comparison to Integral Codes:**

**IC2. LOFW and S/MLOCAs for U.S. EPR; S-RELAP5 Code**

| Author   | Plant Type    | PRA Level | Time Frame | MAAP4 Code Version | Comparison Code Version          | Number of Sequences       | Principal Source of Documentation |
|----------|---------------|-----------|------------|--------------------|----------------------------------|---------------------------|-----------------------------------|
| AREVA NP | PWR, U.S. EPR | 1         | 2 hr       | 4.0.7              | S-RELAP5 (version not specified) | 3 LOFWs, 1 SLOCA, 1 MLOCA | Conference proceedings (2008)     |

**Major Code Models Compared and Review of Agreement**

| Model        | Indicator | Agreement Based on Expert Review | Notes                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|--------------|-----------|----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Overall code | —         | Good agreement                   | The agreement between the codes for the various sequences is sensitive to the timing of the RCP trip and the subsequent onset of natural circulation in the primary system, which influences primary to secondary side heat transfer. The MAAP4 model primary system model is less mechanistic than the S-RELAP5 model; the differences in the results due to differences in the modeling are the most pronounced for Case 3c (LOFW with three unvented steam generators) because of the particularly asymmetric conditions in the steam generators. |

**Comparison to Integral Codes:****IC2. LOFW and S/MLOCAs for U.S. EPR; S-RELAP5 Code, continued**

| <b>Model</b>                          | <b>Indicator</b>               | <b>Agreement Based on Expert Review</b>                                                                                 | <b>Notes</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|---------------------------------------|--------------------------------|-------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| PWR primary system thermal hydraulics | Pressure                       | Very good agreement (pressure comparison provided for only one sequence, a LOCA)                                        | Plots of the water level in the vessel are not included in the paper. However, periods of core uncover were inferred from plots of the cladding temperatures. One LOFW sequence (Case 4g) shows a higher core temperature in MAAP4 compared with S-RELAP5, and the paper contains a postulated explanation of why MAAP4 predicts the more conservative result—that MAAP4 does not explicitly model the “sucking” of water into the core due to the pressurizer PORV being open—which contributes to the homogenization of the two-phase fluid and, therefore, improved heat transfer. Based on the information provided, the review team that assessed the benchmark suspects that the reason for the differences in results is that the RCPs have tripped on a high void fraction condition in MAAP4, while the RCPs continue to run in S-RELAP5, and is not primarily due to differences in the thermal-hydraulic models. |
|                                       | Water level in the pressurizer | Not available                                                                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|                                       | Water level in the vessel      | Good agreement, with the exception of one LOFW sequence (Case 4g), which is suspected to be due to differences in input |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Steam generator: one-region U-tube    | Pressure                       | Not available                                                                                                           | The review team surmised that the pressures agree well based on the other information provided in the paper. Differences in water level are suspected to be in part due to differences in RCP operation, as noted in the primary system thermal hydraulics discussion.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|                                       | Water level                    | Fair to good agreement                                                                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Core heat-up                          | Core temperature               | Fair to very good agreement                                                                                             | Differences in core temperatures are suspected to be in part due to differences in RCP operation, as noted in the primary system thermal hydraulics discussion.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |

**Comparison to Integral Codes:**

**IC2. LOFW and S/MLOCAs for U.S. EPR; S-RELAP5 Code, continued**

**Exemplified Limitation**

MAAP4 models one primary system water temperature before the phases separate. This is adequate when all of the steam generators are behaving similarly or when all the RCPs are operating to keep the water circulating. However, in cases where the pressures in the steam generators are very different and the primary system is in a single-phase natural circulation mode, the code will over- or under-predict the heat transfer to the secondary side. Under these circumstances, the code should not be used to calculate detailed results such as the time to steam generator dryout. (This is the situation in Case 3c in this benchmark, in which three of the steam generators are not vented and the code over-predicts the heat transfer to the vented steam generator. This is a highly improbable sequence because all of the valves on three of the generators are assumed to have failed, and it exaggerates the impact of the code limitation.) Note that an asymmetry in the steam generators is different than an asymmetry in the primary system loops, which can be handled with the MAAP4 models. (This limitation relates to the first code-to-code discrepancy noted in the conclusions from the authors, presented below.)

**Validation of Code Capabilities**

|                                          |                                                                                            |
|------------------------------------------|--------------------------------------------------------------------------------------------|
| Critical flow: pressurizer safety valves | Qualitative support with one LOFW sequence                                                 |
| Critical flow: break flow                | Validated based on good agreement between the calculated break flows for one LOCA sequence |

**Comparison to Integral Codes:****IC2. LOFW and S/MLOCAs for U.S. EPR; S-RELAP5 Code, continued****Conclusions from the Authors of the Benchmark**

“The results of the benchmark between MAAP4 and S-RELAP5 provided insight into the capabilities and limitations of MAAP4 to simulate plant thermal-hydraulic behavior prior to core damage. Overall, the MAAP4 results show a very good agreement to the S-RELAP5 results as summarized in [a table in the paper]. However, two significant discrepancies were identified.

This first significant discrepancy is related to the simulation of primary to secondary side heat transfer. Specifically, this discrepancy is associated with the onset of fully developed natural circulation in the RCS coolant loops. MAAP4 consistently predicts this occurring shortly after the RCPs have tripped, while S-RELAP5 typically showed the development of this loop flow within 20 minutes following the RCP trips. As such, the onset of natural circulation has been identified as a major uncertainty associated with using the MAAP4 code. This only impacts those events in which RCPs are tripped early in an event simulation.

The second significant discrepancy appeared in Case 13d [actually Case 4g, a LOFW] in which the RCPs were allowed to remain operating for the duration of the simulation. Due to the lack of explicit interfacial drag and other code limitations, MAAP4 results exhibited unphysical phase separation. As a result, when a significant amount of RCS coolant is lost, the heat transfer benefits of entrained liquid are absent and in the situation in which the core becomes uncovered, a subsequent clad temperature excursion occurs earlier and lasts longer than that predicted by the best-estimate S-RELAP5 code. As such, in those scenarios MAAP4 results should be considered as being very conservative relative to a best-estimate representation.

Based on the results from the benchmark study, MAAP4 has demonstrated that it is a rather good simulator of nuclear plant transient trends; however, MAAP4’s prediction of clad temperature magnitude is not sufficiently accurate to accept without compensation. As such, the following bases for success criteria are to be applied when using MAAP4 for the U.S. EPR: MAAP4 cases resulting in a PCT (peak cladding temperature) of 1400°F or less will be considered a success; cases resulting in a PCT of 1800°F or greater will be considered a failure; and cases resulting in a PCT between 1400°F and 1800°F will be examined in detail, possibly with a corresponding S-RELAP5 calculation.”

**Documentation**

J. Butler, D. Kapitz, R. Martin, F. Seifae, and R. Sundaram, “MAAP4.0.7 Analysis and Justification for PRA Level 1 Mission Success Criteria,” *Proceedings of the 2008 International Congress on Advances in Nuclear Power Plants (ICAPP’08)*. Anaheim, CA (June 8–12, 2008).

**Comparison to Integral Codes:**

**IC3. LOOP with LLOCA for BWR Plants; TRACG02 Code**

| Author                                                                                                                                                   | Plant Type | PRA Level | Time Frame | MAAP4 Code Version     | Comparison Code Version | Number of Sequences | Principal Source of Documentation |
|----------------------------------------------------------------------------------------------------------------------------------------------------------|------------|-----------|------------|------------------------|-------------------------|---------------------|-----------------------------------|
| GE                                                                                                                                                       | BWR        | 1         | 8 min      | 4.0.4 plus code change | TRACG02                 | 2 LOOP with LLOCAs  | GE technical report (2006)        |
| Code change made for a more mechanistic transition between nuclear and film boiling heat transfer from the cladding to the coolant (added to Rev. 4.0.6) |            |           |            |                        |                         |                     |                                   |

**Major Code Models Compared and Review of Agreement**

| Model                                 | Indicator                 | Agreement Based on Expert Review | Notes                                                                                                                                                                                                                                                                         |
|---------------------------------------|---------------------------|----------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Overall code                          | —                         | Good agreement                   | Benchmark required careful attention to ensure that the core peaking factors were the same in both codes so that they would calculate the same linear heat generation rates.                                                                                                  |
| BWR primary system thermal hydraulics | Pressure                  | Good agreement                   | Code change results in a higher heat transfer coefficient during the early part of the film boiling phase.                                                                                                                                                                    |
|                                       | Water level in the vessel | Good agreement                   |                                                                                                                                                                                                                                                                               |
| Core heat-up                          | Core temperature          | Fair agreement                   | There is good agreement in the magnitude of the predicted temperatures with an “adder” of ~200°F added to the TRACG02 results to account for known model uncertainties. However, MAAP4 predicts an early temperature increase, and the reason for this difference is unknown. |

**Comparison to Integral Codes:****IC3. LOOP with LLOCA for BWR Plants; TRACG02 Code, continued****Validation of Code Capabilities**

|                           |                                                                          |
|---------------------------|--------------------------------------------------------------------------|
| Critical flow: break flow | Validated based on good agreement between the calculated break flows     |
| BWR ECCS injection        | Validated based on good agreement between the calculated injection flows |

**Conclusions from the Authors of the Benchmark**

*Report:* “In the generic analysis, the MAAP4 code was used to identify the most challenging set of plant changes, and subsequently TRACG02 analyses were carried out for these conditions to show that the peak cladding temperature was below the defined criteria. With the benchmark complete, it is shown that the MAAP4 code is adequate for analyzing the large break LOCA/LOOP events. It is also expected that as long as the parameters used in the generic MAAP4 analysis bound the corresponding parameters for the individual licensee’s plants, the results of the generic MAAP4 analyses ... are applicable for those individual plants.”

“The benchmark analyses documented in [the report] showed that the TRACG02 and MAAP4 PCT (peak cladding temperature) values compared reasonably well. ... The TRACG02 results showed that MAAP4 results are relatively conservative, i.e., they over-predict the PCT values.”

“Sections B.4.2 and B.4.3 compare MAAP4 and TRACG02 predictions of reactor power, reactor vessel pressure, break flow rate, ECCS flow rate, and peak cladding temperature, for the selected BWR4 case and BWR6 case, respectively. Overall, the results compare favorably given the differences in methodology between the two codes. The results of these benchmark analyses conclude that MAAP4 is an acceptable tool for performing the thermal-hydraulic analyses required for the large break LOCA/LOOP exemption for the specific cases analyzed here.”

**Documentation**

GE Nuclear Energy. *Guidance for Separation of Loss of Offsite Power from Large Break LOCA*. Licensing Topical Report, 2006. NEDO-33148, Rev. 2.

Presentation to the MAAP Users Group by NPPD, May 2004. (preliminary to the licensing report)

**Comparison to Integral Codes:****IC4. SBO with Feed and Bleed for Palisades CE Plant; RELAP5 Code**

| <b>Author</b>                                                                                                                                   | <b>Plant Type</b> | <b>PRA Level</b> | <b>Time Frame</b> | <b>MAAP4 Code Versions</b> | <b>Comparison Code Version</b> | <b>Number of Sequences</b> | <b>Principal Sources of Documentation</b>                  |
|-------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|------------------|-------------------|----------------------------|--------------------------------|----------------------------|------------------------------------------------------------|
| Erigo Technologies                                                                                                                              | PWR, CE           | 1                | 5, 10 hr          | 4.0.5 plus code change     | RELAP5 Ver. 3 Mod. 2           | 2 SBOs                     | Erigo letter report (2006), presentation to the MUG (2006) |
| FAI                                                                                                                                             | PWR, CE           | 1                | 5, 10 hr          | 4.0.6 plus code change     | RELAP5 Ver. 3 Mod. 2           | 2 SBOs                     | Presentation to the MUG (2008)                             |
| Code change made regarding the option for specifying if the water in the PWR vessel dome region is considered hot or cold (added in Rev. 4.0.7) |                   |                  |                   |                            |                                |                            |                                                            |

**Major Code Models Compared and Review of Agreement**

| <b>Model</b>                          | <b>Indicator</b>               | <b>Agreement Based on Expert Review</b>                                                                                                                  | <b>Notes</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|---------------------------------------|--------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Overall code                          | —                              | Good agreement                                                                                                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| PWR primary system thermal hydraulics | Pressure                       | Fair agreement using HTSTAG, <sup>a</sup> good agreement simulating natural circulation with the RCP coastdown curve (results in a later pressurization) | Sensitivity case consisted of simulating natural convection with the RCP coastdown curve. This resulted in a better match for the timing of the primary system pressurization (the pressurization is later with the RCP coastdown). The lumped treatment of natural convection using HTSTAG is conservative with respect to heat transfer from the primary system for this benchmark. It might be conservative or non-conservative for the full sequence depending on the particular results of interest. |
|                                       | Water level in the pressurizer | Good agreement, taking into account earlier pressurization due to reduced heat transfer to SGs in base case (trends are good in both cases)              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |



**Comparison to Integral Codes:****IC4. SBO with Feed and Bleed for Palisades CE Plant; RELAP5 Code, continued**

| Model                                 | Indicator                 | Agreement Based on Expert Review | Notes                                                                                                                                                                                                                                                                                                                                                                                                                       |
|---------------------------------------|---------------------------|----------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| PWR primary system thermal hydraulics | Water level in the vessel | Good agreement                   | See previous note                                                                                                                                                                                                                                                                                                                                                                                                           |
| Steam generator: one-region U-tube    | Pressure                  | Good agreement except as noted   | Due to cooling on the primary side because of injection, RELAP5 calculates condensation on the secondary side of the steam generator tubes, and MAAP4 does not model condensation on the secondary side. This is a minor limitation in MAAP4, and is the reason that at the end of the first sequence RELAP5 predicts a water level increase and a pressure decrease in the steam generator that is not predicted by MAAP4. |
|                                       | Water level               | Good agreement                   |                                                                                                                                                                                                                                                                                                                                                                                                                             |

<sup>a</sup> HTSTAG is the coefficient for the primary side to secondary side heat transfer when single- or two-phase natural circulation is occurring in the coolant loops.

**Validation of Code Capabilities**

|                                       |                                                                          |
|---------------------------------------|--------------------------------------------------------------------------|
| Critical flow: pressurizer PORVs      | Qualitative agreement inferred from primary system response              |
| PWR ECCS injection: generalized model | Validated based on good agreement between the calculated injection flows |

**Comparison to Integral Codes:**

**IC4. SBO with Feed and Bleed for Palisades CE Plant; RELAP5 Code, continued**

**Exemplified Limitation**

MAAP4 does not model condensation on the secondary side of the steam generators, which can occur when there is substantial cooling on the primary side because of injection. The code will not predict the resulting increase in the water level and decrease in the pressure on the secondary side. This is a minor limitation.

**Conclusions from the Authors of the Benchmark**

*Report:* “The trends exhibited by both codes are considered quite consistent for both sequences, and similar conclusions would be made regarding key timing and the adequacy of operator actions in preventing core damage. [The authors] expect that differences in plant models remain, and that these are probably more responsible for the remaining differences than are different thermal-hydraulic modeling approaches. Taken at face value, MAAP exhibited a somewhat faster and more severe response in each of these two sequences. The results from this effort should help resolve concerns about the use of MAAP for non-severe accident sequences, particularly those involving feed and bleed.”

*Erigo viewgraphs:* “Generally good agreement on SBO-001: users can improve agreement by modeling natural circulation heat transfer with a nominal flow rate rather than HTSTAG;” “For SBO-003, differences exist in SG inventory predictions which can partly be attributed to smaller decay heat in RELAP;” “MAAP generally predicts slightly more severe behavior”

*FAI viewgraphs:* “MAAP4 is in general agreement with RELAP;” “MAAP4 provides a conservative assessment of the potential for core overheating”

**Documentation**

Presentation to the MAAP Users Group by Erigo, May 2006.

M. Kenton, *Comparison of MAAP and RELAP Predictions for Two Postulated Station Blackout Accidents in Palisades*. Erigo Technologies (2006). FR-0512-01.

Presentation to the MAAP Users Group by FAI, May 2008.

**Comparison to Integral Codes:****IC5. LLOCA for Kuosheng BWR Plant and SBO for Maanshan WLD Plant;  
SCDAP/RELAP5 and MELCOR Codes**

| Author                  | Plant Type | PRA Level | Time Frame | MAAP4 Code Version | Comparison Code Versions              | Number of sequences | Principal Sources of Documentation                 |
|-------------------------|------------|-----------|------------|--------------------|---------------------------------------|---------------------|----------------------------------------------------|
| INNER, Chung Yuan Univ. | BWR        | 1         | 4 hr       | 4.0.4              | SCDAP/RELAP5 Mod. 3.3 and MELCOR1.8.5 | 1 LLOCA             | Journal paper (2005), doctoral dissertation (2006) |
|                         | PWR, WLD   | 1         | 5 hr       |                    |                                       | 1 SBO               |                                                    |

**Major Code Models Compared and Review of Agreement**

| Model                                                | Indicator                      | Agreement Based on Expert Review          | Notes                                                                                                                                                                   |
|------------------------------------------------------|--------------------------------|-------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Overall code                                         | —                              | Good agreement for both BWR and PWR cases | —                                                                                                                                                                       |
| BWR primary system thermal hydraulics                | Pressure                       | Good agreement                            | There are discrepancies in the boil off of the water in the lower plenum, but there is not enough information to determine the reason.                                  |
|                                                      | Water level in the vessel      | Fair agreement as noted                   |                                                                                                                                                                         |
| PWR primary system thermal hydraulics                | Pressure                       | Good agreement                            | Trends in the water level are the same, but different reference elevations inhibit the drawing of conclusions. The levels track well after they are in the same regime. |
|                                                      | Water level in the pressurizer | Not available                             |                                                                                                                                                                         |
|                                                      | Water level in the vessel      | Fair agreement as noted                   |                                                                                                                                                                         |
| Steam generator: U-tube (region model not specified) | Pressure                       | Good agreement                            | —                                                                                                                                                                       |
|                                                      | Water level                    | Good agreement                            |                                                                                                                                                                         |
| BWR and PWR core heat-up                             | Core temperature               | Good agreement                            | —                                                                                                                                                                       |

**Comparison to Integral Codes:**

**IC5. LLOCA for Kuosheng BWR Plant and SBO for Maanshan WLD Plant;  
SCDAP/RELAP5 and MELCOR Codes, continued**

**Note**

The paper includes Level 2 phenomena, but the extraction of information for benchmarking purposes is limited to Level 1 phenomena (consistent with the scope of this document).

**Conclusions from the Authors of the Benchmark**

*Journal paper:* “The important severe accident phenomena including core uncover, cladding oxidation, ... give similar results with SR5, MAAP, and MELCOR.”

**Documentation**

T. Wang, S. Wang, and J. Teng, “Comparison of Severe Accident Results Among SCDAP/RELAP5, MAAP, and MELCOR Codes,” *Nuclear Technology*. Vol. 150, p. 145–152 (2005).

T. Wang, *Study on Severe Accident Codes and Their Applications*. Chung Yuan Christian University (Taiwan) Doctoral Dissertation, etd-0725107-155243 (2006).

**Comparison to Integral Codes:****IC6. MLOCA for Palo Verde WLD Plant; CENTS Code**

| Author                                                                                                                                               | Plant Type | PRA Level | Time Frame | MAAP4 Code Version     | Comparison Code Version       | Number of Sequences | Principal Source of Documentation |
|------------------------------------------------------------------------------------------------------------------------------------------------------|------------|-----------|------------|------------------------|-------------------------------|---------------------|-----------------------------------|
| FAI                                                                                                                                                  | PWR, WLD   | 1         | 5 hr       | 4.0.5 plus code change | CENTS (version not specified) | 1 MLOCA             | Presentation to the MUG (2005)    |
| Code change for venting separated liquid and gas flow with subcooled water (will be added to Rev. 4.0.8, results in a marginally lower RCS pressure) |            |           |            |                        |                               |                     |                                   |

**Major Code Models Compared and Review of Agreement**

| Model                                                | Indicator                      | Agreement Based on Expert Review | Notes                                                                                                                                                                                                                                                                                                                                                                                                   |
|------------------------------------------------------|--------------------------------|----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Overall code                                         | —                              | Inconclusive                     | CENTS predicts that the pressurizer and steam generators depressurize at a much higher rate than the MAAP4 predictions. Significant effort failed to resolve the issue; the differences are associated with small differences in the mass and energy, which make it difficult to find the root cause of the discrepancies. It is suspected that the critical flow model in CENTS might need refinement. |
| PWR primary system thermal hydraulics                | Pressure                       | Inconclusive                     | Due to pressure discrepancies                                                                                                                                                                                                                                                                                                                                                                           |
|                                                      | Water level in the pressurizer | Not available                    |                                                                                                                                                                                                                                                                                                                                                                                                         |
| Steam generator: U-tube (region model not specified) | Pressure                       | Inconclusive                     | Due to pressure discrepancies                                                                                                                                                                                                                                                                                                                                                                           |
|                                                      | Water level                    | Not available                    |                                                                                                                                                                                                                                                                                                                                                                                                         |

**Comparison to Integral Codes:**

**IC6. MLOCA for Palo Verde WLD Plant; CENTS Code, continued**

**Validation of Code Capabilities**

|                           |                                                                                                                |
|---------------------------|----------------------------------------------------------------------------------------------------------------|
| Critical flow: break flow | Validated based on generally good agreement between the code predictions for mass and energy through the break |
|---------------------------|----------------------------------------------------------------------------------------------------------------|

**Exemplified Limitation**

The code uses a single value of VFSEP, the void fraction above which the primary system inventory is no longer modeled as a homogeneous two-phase mixture, during any sequence. For small to medium LOCA sequences with injection, a relatively low value might result in a more realistic primary system inventory but a somewhat higher primary system pressure. The sensitivity of the primary system response to the value of VFSEP should be evaluated routinely, as noted in Sections 4 and 8 of this document.

**Conclusions from the Authors of the Benchmark**

“Agreement between MAAP4 and CENTS on break flow is generally good, but differences in RCS and SG depressurization could not be resolved, despite significant effort. (It was identified that there might be a need for Henry-Fauske implementation refinement in CENTS.) Despite these differences, both codes reach the same basic conclusion of no core overheating.”

**Documentation**

Presentation to the MAAP Users Group by FAI, May 2005.

**Comparison to Integral Codes:****IC7. S/M LOCAs for EDF/Framatome PWR 900 Plant; CATHARE Code**

| Author | Plant Type                             | PRA Level | Time Frame | MAAP4 Code Version | Comparison Code Version | Number of Sequences | Principal Source of Documentation |
|--------|----------------------------------------|-----------|------------|--------------------|-------------------------|---------------------|-----------------------------------|
| EDF    | PWR, 900 MWe CPY series, EDF/Framatome | 1         | 2–12 hr    | 4.0.4              | CATHARE v1.5            | 6 S/MLOCAs          | EDF technical report (2004)       |

**Major Code Models Compared and Review of Agreement**

| Model        | Indicator | Agreement Based on Expert Review                    | Notes                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|--------------|-----------|-----------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Overall code | —         | Good agreement after adjustments to the MAAP4 input | Initially, MAAP4 predicted a faster discharge rate from the accumulators than CATHARE. The differences were resolved by reducing the diameter of the accumulator piping in the MAAP4 parameter file, thereby increasing the flow resistance. Recommendations were made to allow the accumulators to discharge in an adiabatic (isentropic) manner as well as in an isothermal manner; this option was added to MAAP4.0.6 along with a coefficient to increase the piping resistance. Also, there were differences in the initial designations of the water pools associated with the cold leg breaks that were resolved by moving the breaks in MAAP4 to the intermediate leg. |

**Comparison to Integral Codes:**

**IC7. S/MLOCAs for EDF/Framatome PWR 900 Plant; CATHARE Code, continued**

| Model                                 | Indicator                      | Agreement Based on Expert Review                                        | Notes                                                                                                                                                                                                                           |
|---------------------------------------|--------------------------------|-------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| PWR primary system thermal hydraulics | Pressure                       | Very good agreement                                                     | The agreement in the water level in the vessel is inferred from the mass of water in the primary system plus pressurizer; the calculated levels were not plotted.                                                               |
|                                       | Water level in the pressurizer | Not available                                                           |                                                                                                                                                                                                                                 |
|                                       | Water level in the vessel      | Good agreement given the noted differences in the accumulator injection |                                                                                                                                                                                                                                 |
| Steam generator: one-region U-tube    | Pressure                       | Very good agreement                                                     | The agreement in the heat transfer to the steam generators is very good. It is surmised that the agreement in the water levels in the steam generators is very good because of the agreement in the pressure and heat transfer. |
|                                       | Water level                    | Not available                                                           |                                                                                                                                                                                                                                 |

**Validation of Code Capabilities**

|                           |                                                                          |
|---------------------------|--------------------------------------------------------------------------|
| Critical flow: break flow | Validated based on moderate agreement between the calculated break flows |
|---------------------------|--------------------------------------------------------------------------|



**Comparison to Integral Codes:**

**IC7. S/MLOCAs for EDF/Framatome PWR 900 Plant; CATHARE Code, continued**

**Notes**

Injection into the “cold leg” in MAAP4, as designated by setting the value of input parameter IDISCH to 1 for the hardwired ESF model or by setting the pump discharge location parameters to 2 for the generalized ESF model, is actually into the intermediate leg water pools, which extend from the outlets of the steam generators to the RCPs. Users sometimes misinterpret injection into the “cold leg” as going into the horizontal portions of the cold legs. The water in the horizontal portions of the cold legs is part of the downcomer water pool. This distinction is important for cold leg break sequences because it affects whether injection goes directly out of the break or into the downcomer. See Sections 6.4.3 and 6.6.1 of this report for discussions of break locations and water pools.

It is suggested in this benchmark that the evacuation of water plugs in the cross-over legs be improved. The water plugs affect the pressure calculations such that the code can over-predict the pressure in the core relative to the pressure in the downcomer by the amount of the water head in the legs, potentially leading to a brief period of core uncover, but this condition is minor and self-correcting.

**Exemplified Precaution**

The accumulator tanks and the piping to the primary system are not modeled as thermal-hydraulic control volumes. Combined with this is the positive-feedback coupling of a higher accumulator discharge rate with a lower primary system pressure (which allows more discharge). Therefore, the accumulator model has inherent uncertainties that can influence the results of a sequence. Users should evaluate the sensitivity of their results to the accumulator input parameters, including the polytropic constants, the head loss coefficients, and the dimensions of the piping. The largest impact of the parameter values on the results occurs for small LOCA sequences. Note that the larger the value of the polytropic constant the slower the rate of discharge.

**Comparison to Integral Codes:**

**IC7. S/MLOCAs for EDF/Framatome PWR 900 Plant; CATHARE Code, continued**

**Exemplified Limitations**

In sequences with a break in the cold leg, MAAP4 can over-predict the amount of injected water that goes into the downcomer—and therefore into the core—prior to going out of the break if the injection is designated as being into the downcomer water pool (see the note). This occurs because the code does not apportion the injection into that which flows to the downcomer and that which flows out of the break. Users should determine the injection location relative to the break location, and then define the sequence such that the injected water goes into the appropriate water pool. Individual scenarios can be bracketed with one sequence that includes a break in the cold leg and injection into the cold leg (the downcomer water pool) and one that includes a break in the intermediate leg and injection into the intermediate leg at the same elevation as the cold leg break. A workaround for the code limitation is to reduce the amount of injection (including the inventory in the cold leg accumulators), and add the portion of the water that would go out of the break directly into the containment. (Note that the discharge location of the accumulators is always the downcomer water pool.)

A similar but less encountered limitation is that the portion of condensation on the primary side of the steam generator tubes that flows into the hot legs is added to the core water pool and will not flow directly out a hot leg break. This is only a concern if just one steam generator is depressurized and the break is in that loop. An approximate workaround is to locate the break in the intermediate leg such that the portion of the condensate that goes into the intermediate leg water pool is potentially discharged out of the break.

**Comparison to Integral Codes:****IC7. S/MLOCAs for EDF/Framatome PWR 900 Plant; CATHARE Code, continued****Conclusions from the Authors of the Benchmark**

“Response to the objectives: An initial comparison with CATHARE showed the limits of the modeling of the primary thermo-hydraulics in MAAP. However, following the modifications made to the parameter file to overcome these limits, the difference with CATHARE is greatly reduced in a second comparison. We solved the problems of: excessively fast letdown of the accumulators; evacuation of the condensates in the cold leg; evacuation in the break of part of the injection of the accumulators on scenario B4BF [4" cold leg break]. However, on the other hand, the evacuation of the condensates on the break scenarios in the hot leg [two sequences] is not always modeled. On the other hand, the improvements made are not viable in the long term: it is necessary to take these physical phenomena into account in the models of the code. The comparison with CATHARE only enabled us to assess the validity of the MAAP results on the thermo-hydraulics of the primary system before uncovering of the core. MAAP, the reference code for the study of serious accidents at EDF, is a scenario code representing the nuclear unit as a whole (including the containment).

Prospects: It is necessary to make the following improvements to envisage the use of MAAP as a crisis tool: the injection of the accumulators should be carried out in the cold leg and not directly to the downcomer; for the cold leg break scenarios, the letdown of part of the safety injection in the break should be taken into account; the accumulator letdown routine should be modified: the current isothermic letdown should be replaced by a polytropic letdown with a coefficient that may be modified by the user; the evacuation in the break of condensates produced in the SG tubes in heat pipe operation should be modeled; the modeling of the evacuation of water plugs in the crossover leg should be improved. In addition, this validation of the modeling of the primary thermo-hydraulics in MAAP should be extended to other types of accident scenarios (H2, RTGV ...)

**Documentation**

EDF Branche Energies, Service Études et Projets Thermiques et Nucléaires. *Intercomparison of the MAAP/CATHARE codes on 2" and 4" break scenarios*. Design note, 2004.  
ENTEAG040227 A Prel.

Presentation to the MAAP Users Group by EDF, November 2004.

**Comparison to Integral Codes:**

**IC8. TMLB' for WLD Plant; SCDAP/RELAP5 and MELCOR Codes**

| Author                            | Plant Type | PRA Level | Time Frame | MAAP4 Code Version | Comparison Code Versions              | Number of Sequences                 | Principal Source of Documentation                    |
|-----------------------------------|------------|-----------|------------|--------------------|---------------------------------------|-------------------------------------|------------------------------------------------------|
| Purdue Univ., Exelon, Creare, SNL | PWR, WLD   | 1 and 2   | 5 hr       | 4.0.5              | SCDAP/RELAP5 Mod. 3.3 and MELCOR1.8.5 | 1 TMLB' (SBO with no RCP seal leak) | Journal paper (2004), presentation to the MUG (2004) |

**Major Code Models Compared and Review of Agreement**

| Model                                 | Indicator                      | Agreement Based on Expert Review                                        | Notes                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|---------------------------------------|--------------------------------|-------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Overall code                          | —                              | Good agreement                                                          | —                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| PWR primary system thermal hydraulics | Pressure                       | Good agreement except as noted                                          | A pressurizer pressure initial dip of about 1.5 MPa (corresponding to 0.5 m in level) is not calculated in MAAP4. The reason is unclear and is atypical for MAAP4. It might be due to the fact that the code does not calculate the behavior in each loop individually, so it does not calculate a much larger natural circulation flow in the loop that is venting compared to the other loops. The other two codes model this level of detail. The effect of this difference is minor. |
|                                       | Water level in the pressurizer | Good agreement prior to core damage, fair agreement after core damage   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|                                       | Water level in the vessel      | Fair agreement inferred from core uncover time                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Steam generator: one-region U-tube    | Pressure                       | Good agreement                                                          | —                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                                       | Water level                    | Not available                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Core heat-up                          | Core temperature               | Good agreement supported by timing and magnitude of hydrogen generation | Core temperature is not available.                                                                                                                                                                                                                                                                                                                                                                                                                                                       |

**Comparison to Integral Codes:****IC8. TMLB' for WLD Plant; SCDAP/RELAP5 and MELCOR Codes, continued****Validation of Code Capabilities**

|                                  |                                                             |
|----------------------------------|-------------------------------------------------------------|
| Critical flow: pressurizer PORVs | Qualitative agreement inferred from primary system response |
|----------------------------------|-------------------------------------------------------------|

**Note**

Models typically used in MAAP4 analysis were disabled for code consistency, including 1) the steam generator/hot leg recirculation flow ratio calculation, 2) the pressure drop caused by cross-flow in the core, 3) thermal radiation between gases and structures in the hot leg and surge line, and 4) hot leg to containment heat transfer.

**Exemplified Limitation**

Early, temporary primary system pressure drops might not be calculated with MAAP4 because the code does not calculate the behavior in each loop individually. Therefore, low primary system pressure setpoints for ECCS injection might not be hit early in a sequence (on the order of 30 minutes).

**Conclusions from the Authors of the Benchmark**

*Journal paper:* “Detailed plots show that the thermal-hydraulic phenomena and major in-vessel severe accident phenomena are in good agreement for the three codes. The integral effect of diversified core models in terms of total hydrogen production and total core debris mass slumping into the reactor vessel lower head are consistent for the three codes. ... There are several discrepancies that could be termed as minor and that are possibly due to uncertainties in the numerics and physics models. Several key assumptions were made to account for known differences in heat transfer modeling and the representation of counter-current natural circulation of hot gasses. Given these assumptions, the three codes predict similar temperatures in the various reactor coolant system components.”

**Comparison to Integral Codes:**

**IC8. TMLB' for WLD Plant; SCDAP/RELAP5 and MELCOR Codes, continued**

**Documentation**

|                                                                                                                                                                                                                                           |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| K. Vierow, Y. Liao, J. Johnson, M. Kenton, and R. Gauntt, "Severe Accident Analysis of PWR Station Blackout with the MELCOR, MAAP4 and SCDAP/RELAP5 Codes," <i>Nuclear Engineering and Design</i> . Vol. 234, No. 1–3, p. 129–145 (2004). |
| Presentation to the MAAP Users Group by ERIN for Purdue University, May 2004.                                                                                                                                                             |
| Presentation to the NRC staff by Creare, March 2002. (preliminary to the 2004 paper)                                                                                                                                                      |
| M. Kenton, <i>A Comparison of MAAP and SCDAP/RELAP5 Calculations for a High Pressure PWR Severe Accident</i> . Creare Incorporated: 2000. 8200.7 TM-2048. (preliminary to the 2004 paper)                                                 |

**Comparison to Integral Codes:****IC9. LOOP with Feed and Bleed for Millstone CE Plant; RELAP5 Code**

| <b>Author</b> | <b>Plant Type</b> | <b>PRA Level</b> | <b>Time Frame</b> | <b>MAAP4 Code Version</b> | <b>Comparison Code Version</b> | <b>Number of Sequences</b> | <b>Principal Source of Documentation</b> |
|---------------|-------------------|------------------|-------------------|---------------------------|--------------------------------|----------------------------|------------------------------------------|
| Dominion      | PWR, CE           | 1                | 3 hr              | Not specified             | RELAP5 (version not specified) | 1 LOOP                     | Presentation to the MUG (2003)           |

**Major Code Models Compared and Review of Agreement**

| <b>Model</b>                          | <b>Indicator</b>               | <b>Agreement Based on Expert Review</b>                           | <b>Notes</b> |
|---------------------------------------|--------------------------------|-------------------------------------------------------------------|--------------|
| Overall code                          | —                              | Good agreement                                                    | —            |
| PWR primary system thermal hydraulics | Pressure                       | Good agreement                                                    | —            |
|                                       | Water level in the pressurizer | Not available                                                     |              |
|                                       | Water level in the vessel      | Fair agreement                                                    |              |
| Steam generator: one-region U-tube    | Pressure                       | Good agreement, taking into account range of RELAP output         | —            |
|                                       | Water level                    | Good agreement                                                    |              |
| Core heat-up                          | Core temperature               | Good agreement, taking into account slightly higher initial value | —            |

**Validation of Code Capabilities**

|                                                 |                                                                                  |
|-------------------------------------------------|----------------------------------------------------------------------------------|
| Critical flow: pressurizer PORVs                | Validated based on good agreement between the calculated vent flows              |
| PWR ECCS injection (model option not specified) | Validated based on fair to good agreement between the calculated injection flows |

**Comparison to Integral Codes:**

**IC9. LOOP with Feed and Bleed for Millstone CE Plant; RELAP5 Code, continued**

**Conclusions from the Authors of the Benchmark**

“Comparison shows excellent agreement.”

**Documentation**

Presentation to the MAAP Users Group by Dominion, November 2003.



**Comparison to Integral Codes:****IC10. Various Sequences for BWR and WLD PWR Plants; MELCOR Code**

| Author                                                                                                   | Plant Type | PRA Level | Time Frame | MAAP4 Code Version | Comparison Code Version | Number of Sequences | Principal Source of Documentation |
|----------------------------------------------------------------------------------------------------------|------------|-----------|------------|--------------------|-------------------------|---------------------|-----------------------------------|
| ITS, SNL, NUPEC                                                                                          | PWR, WLD   | 1 and 2   | 40 hr      | 4.0.2              | MELCOR 1.8.3            | 4 PWRs              | Conference proceedings (1996)     |
|                                                                                                          | BWR, MI    | 1 and 2   | 40 hr      |                    |                         | 5 BWRs              |                                   |
| PWR Sequences: TMLB (SBO with RCP seal leak), 2 LLOCAs, SLOCA<br>BWR Sequences: SBO, 3 transients, LLOCA |            |           |            |                    |                         |                     |                                   |

**Major Code Models Compared and Review of Agreement**

| Model                                                                   | Indicator   | Agreement Based on Expert Review                                                                | Notes |
|-------------------------------------------------------------------------|-------------|-------------------------------------------------------------------------------------------------|-------|
| Overall code                                                            | —           | Good agreement based on core uncover times for sequences within range of applicability of MAAP4 | —     |
| PWR primary system thermal hydraulics (only available for SBO sequence) | Pressure    | Good agreement                                                                                  | —     |
|                                                                         | Water level | Good agreement, based on core uncover time                                                      |       |

**Note**

Comparisons are primarily for Level 2 phenomena. This is a minor supporting benchmark for Level 1 applications given its emphasis on severe accidents and the fact that there is not a large amount of information on specific sequences in the paper.

**Comparison to Integral Codes:**

**IC10. Various Sequences for BWR and WLD PWR Plants; MELCOR Code, continued**

**Exemplified Limitation**

MAAP4 does not predict the appropriate primary system response during the early blowdown phase of a large LOCA in a PWR, and should not be used in this context. This is because the code might over-predict the amount of water retained in the primary system; the phases are separated and the code can under-predict the water flow through the break (more gas flow versus water flow). The water in the primary system is assumed to be in the core region versus partly in the legs, which adversely affects the calculations. Also, the code can over-predict the rate of accumulator discharge because the pressure is under-predicted, contributing to the non-physical response.

**Conclusions from the Authors of the Benchmark**

None applicable for Level 1.

**Documentation**

M. Leonard, S. Ashbaugh, R. Cole, K. Bergeron, and K. Nagashima, "A Direct Comparison of MELCOR 1.8.3 and MAAP4 Results for Several PWR and BWR Accident Sequences," *Proceedings of the International Topical Meeting on Probabilistic Safety Assessment, PSA '96*. Park City, UT (September 29–October 3, 1996).

**Comparison to Integral Codes:**

**IC11. 1992 MAAP3B Qualification Studies—Various BWR Sequences; SAFE Code**

| Author | Plant Type           | PRA Level | Time Frame | MAAP4 Code Version | Comparison Code Version      | Number of Sequences           | Principal Source of Documentation |
|--------|----------------------|-----------|------------|--------------------|------------------------------|-------------------------------|-----------------------------------|
| GKA    | BWR (MI containment) | 1         | 7 min–2 hr | MAAP3B Rev. 6      | SAFE (version not specified) | 4 transients, 1 SLOCA, 1 MSLB | EPRI technical report (1992)      |

**Major Code Models Compared and Review of Agreement**

| Model        | Indicator | Agreement Based on Expert Review | Notes                                                                                                |
|--------------|-----------|----------------------------------|------------------------------------------------------------------------------------------------------|
| Overall code | —         | Good agreement with MAAP3B       | The benchmark is generally but not specifically applicable to MAAP4 because it was done with MAAP3B. |

**Documentation**

1992 MAAP Thermal-Hydraulic Qualification Studies [2, 5].

**Comparison to Integral Codes:**

**IC12. 1992 MAAP3B Qualification Studies—Various PWR Sequences; RELAP and RETRAN Codes**

| <b>Author</b> | <b>Plant Type</b>                             | <b>PRA Level</b> | <b>Time Frame</b> | <b>MAAP4 Code Version</b> | <b>Comparison Code Versions</b>           | <b>Number of Sequences</b>                                               | <b>Principal Source of Documentation</b> |
|---------------|-----------------------------------------------|------------------|-------------------|---------------------------|-------------------------------------------|--------------------------------------------------------------------------|------------------------------------------|
| GKA           | PWR, Westinghouse (ice condenser containment) | 1                | 5 min–1.4 hr      | MAAP3B Rev. 16            | RELAP and RETRAN (versions not specified) | 8 total: 2 transients, 1 failed-open PORV, 2 SGTRs, 2 SLOCAs, and 1 MSLB | EPRI technical report (1992)             |

**Major Code Models Compared and Review of Agreement**

| <b>Model</b> | <b>Indicator</b> | <b>Agreement Based on Expert Review</b>                                                                                                               | <b>Notes</b>                                                                                         |
|--------------|------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|
| Overall code | —                | Good agreement with MAAP3B plus code changes that were identified as part of the MAAP3B benchmark activity. The changes were incorporated into MAAP4. | The benchmark is generally but not specifically applicable to MAAP4 because it was done with MAAP3B. |

**Documentation**

1992 MAAP Thermal-Hydraulic Qualification Studies [2, 5].

**Comparison to Integral Experiments:****IE1. BETHSY LOFW with F&B and SLOCA**

| Author | Plant Type                  | PRA Level | Time Frame | MAAP4 Code Version | Scale/Scope of Experiment                                                                                 | Number of Sequences | Principal Source of Documentation |
|--------|-----------------------------|-----------|------------|--------------------|-----------------------------------------------------------------------------------------------------------|---------------------|-----------------------------------|
| FAI    | PWR, 900 MWe, EDF/Framatome | 1         | 1, 2 hr    | 4.0.7              | Primary system with 3 loops and steam generators, full height, full pressure, 1/100 power-to-volume ratio | 2 LOFWs, 1 SLOCA    | Presentation to the MUG (2008)    |

**Major Code Models Compared and Review of Agreement**

| Model                                       | Indicators                                | Agreement Based on Expert Review | Notes                                                                                                                         |
|---------------------------------------------|-------------------------------------------|----------------------------------|-------------------------------------------------------------------------------------------------------------------------------|
| Overall code                                | —                                         | Very good agreement              | Agreement obtained with minimal adjustment of input parameters.                                                               |
| PWR primary system thermal hydraulics       | Pressure                                  | Very good agreement              | Very good agreement was obtained for the primary system inventory.                                                            |
|                                             | Water level in the pressurizer and vessel | Very good agreement              |                                                                                                                               |
| Steam generator: one- and two-region U-tube | Pressure                                  | Very good agreement              | The one-region model was used for the LOFW cases because the power was low; the two-region model was used for the SLOCA case. |
|                                             | Water level                               | Very good agreement              | —                                                                                                                             |

**Comparison to Integral Experiments:**

**IE1. BETHSY LOFW with F&B and SLOCA, continued**

**Note for PWR Benchmarking**

When initiating a sequence at significantly less than full power and with heat transfer to the steam generators (that is, not a mid-loop sequence), it is important to determine that the initial water levels in the generators are correct. This particularly applies to the two-region steam generator model because the dynamic head is not fully developed. It is also necessary to decrease the value of the calculated steam generator resistance correction factor, FKSEC, to 1.0 after time zero because the code will calculate an unreasonably high value due to the non-standard conditions.

**Validation of Code Capabilities**

|                                       |                                                                                                                                                                                                        |
|---------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Critical flow: pressurizer PORVs      | Validated based on the good agreement of the primary system inventory.                                                                                                                                 |
| Critical flow: break flow             | Validated based on the good agreement of the primary system inventory. There is a slight under-prediction of the break flow due to the MAAP4 modeling of the water distribution in the primary system. |
| PWR ECCS injection: generalized model | Validated based on the good agreement of the primary system inventory.                                                                                                                                 |
| Voiding in the core                   | Qualitative validation based on core temperature and core collapsed water level, which implicitly support the void fraction calculations.                                                              |

**Conclusions from the Authors of the Benchmark**

“Good agreement with the experimental results for both the loss of feed with feed-and-bleed, and 2-inch small LOCA sequences. For 2-inch small LOCA, MAAP4 under-predicted overall break flow mass which is mostly due to MAAP4 modeling of water distribution in RCS.”

**Documentation**

Presentation to the MAAP Users Group by FAI, May 2008.

**Comparison to Integral Experiments:**  
**IE2. IIST SBO**

| Author | Plant Type | PRA Level | Time Frame | MAAP4 Code Version | Scale/Scope of Experiment                                                             | Number of Sequences | Principal Source of Documentation |
|--------|------------|-----------|------------|--------------------|---------------------------------------------------------------------------------------|---------------------|-----------------------------------|
| FAI    | PWR, WLD   | 1         | 3 hr       | 4.0.6              | Primary system with 3 loops and steam generators, reduced height and reduced pressure | 1 SBO               | Conference proceedings (2005)     |

**Major Code Models Compared and Review of Agreement**

| Model                                 | Indicators                     | Agreement Based on Expert Review | Notes                                                                                                                                                                                                                                                                                          |
|---------------------------------------|--------------------------------|----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Overall code                          | —                              | Very good agreement              | Two values of the volume of the primary system were used because of uncertainties in the data. The specific input parameters that were adjusted to obtain agreement were not identified in the paper. The effect of heat loss is substantial because of the small scale of the test apparatus. |
| PWR primary system thermal hydraulics | Pressure                       | Very good agreement              | —                                                                                                                                                                                                                                                                                              |
|                                       | Water level in the pressurizer | Very good agreement              |                                                                                                                                                                                                                                                                                                |
|                                       | Water level in the vessel      | Not available                    |                                                                                                                                                                                                                                                                                                |

**Comparison to Integral Experiments:**  
**IE2. IIST SBO, continued**

| Model                               | Indicators       | Agreement Based on Expert Review | Notes                                                                                       |
|-------------------------------------|------------------|----------------------------------|---------------------------------------------------------------------------------------------|
| Steam generator: one-region, U-tube | Pressure         | Not available                    | —                                                                                           |
|                                     | Water level      | Very good agreement              |                                                                                             |
| Core heat-up                        | Core temperature | Very good agreement              | The onset of core heat-up is influenced by the defined initial volume of the primary system |

**Conclusions from the Authors of the Benchmark**

“The comparison ... with the integral experiment ... demonstrates that the MAAP4 code provides a good, yet conservative representation of the timing over which inventory would be lost from both the secondary and RCS under station blackout conditions. In particular, the MAAP4 code, with its geometric representation of the IIST facility, shows agreement with the boildown of water level on the secondary side. The representation for the RCS pressure history is also in good agreement with the measured response. It is noted that one aspect of this and all analyses for reduced size test facilities is to properly represent the heat losses from the scaled RPV, cold legs, hot legs and pressurizer.”

**Documentation**

R. Henry, C. Henry, C. Paik, and G. Hauser, “Comparison of the MAAP4 Code with the Station Blackout Simulation in the IIST Facility,” *The 11<sup>th</sup> International Topical Meeting on Nuclear Reactor Thermal-Hydraulics (NURETH-11)*. Avignon, France (October 2–6, 2005), paper 264.

Presentation to the MAAP Users Group by FAI, May 2005.



**Comparison to Integral Experiments:****IE3. MB-2 LOFW and MSLBs with and without SGTR**

| <b>Author</b> | <b>Plant Type</b> | <b>PRA Level</b> | <b>Time Frame</b> | <b>MAAP4 Code Version</b> | <b>Scale/Scope of Experiment</b> | <b>Number of Sequences</b> | <b>Principal Source of Documentation</b> |
|---------------|-------------------|------------------|-------------------|---------------------------|----------------------------------|----------------------------|------------------------------------------|
| FAI           | PWR, WLD          | 1                | 1–15 min          | 4.0.6                     | Steam generator, 0.8% power      | 2 LOFWs, 3 MSLBs           | Conference proceedings (2005)            |

**Major Code Models Compared and Review of Agreement**

| <b>Model</b>                        | <b>Indicators</b> | <b>Agreement Based on Expert Review</b> | <b>Notes</b>                                                                                           |
|-------------------------------------|-------------------|-----------------------------------------|--------------------------------------------------------------------------------------------------------|
| Overall code                        | —                 | Very good agreement                     | The specific input parameters that were adjusted to obtain agreement were not identified in the paper. |
| Steam generator: two-region, U-tube | Pressure          | Very good agreement                     | —                                                                                                      |
|                                     | Water level       | Very good agreement                     |                                                                                                        |

**Validation of Code Capabilities**

|                           |                                        |
|---------------------------|----------------------------------------|
| Critical flow: break flow | Validated based on MSLB flow agreement |
|---------------------------|----------------------------------------|

**Comparison to Integral Experiments:**

**IE3. MB-2 LOFW and MSLBs with and without SGTR, continued**

**Conclusions from the Authors of the Benchmark**

“In general, comparisons of the MAAP4 results with the MB-2 test results show that the MAAP4 code calculation is in agreement with the overall test responses for all five tests. This agreement indicates that a simple lumped volume approach and simple models of internal recirculation and void fraction profile can adequately simulate the response of a steam generator during these accident conditions. This conclusion is particularly relevant for the more challenging test of 100% MSLB. Herein, prediction of the substantial liquid discharge is key to a successful benchmark. The model accommodates the relevant physical processes of flow reversal and dynamic level swell.”

**Documentation**

C. Paik and C. Henry, “Benchmarking of MAAP4 Steam Generator Model Against Westinghouse MB-2 Experiments,” *The 11<sup>th</sup> International Topical Meeting on Nuclear Reactor Thermal-Hydraulics (NURETH-11)*. Avignon, France (October 2–6, 2005), log number 322.

MAAP4 User’s Manual [1]: Volume III-C, Rev. 0, February 2005.

Presentation to the MAAP Users Group by FAI, November 2004.

**Comparison to Integral Experiments:****IE4. AP600 OSU SLOCAs and Failed PORVs**

| Author                                                                                                                                                                                                                                                                                                                                 | Plant Type | PRA Level | Time Frame                                                                        | MAAP4 Code Version     | Scale/Scope of Experiment                                         | Number of Sequences           | Principal Source of Documentation |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|-----------|-----------------------------------------------------------------------------------|------------------------|-------------------------------------------------------------------|-------------------------------|-----------------------------------|
| FAI and Westinghouse                                                                                                                                                                                                                                                                                                                   | PWR, AP600 | 1         | “Short” and “long” but only relative time; actual time frame not in documentation | 4.0.5 plus code change | Primary system with 1 loop and steam generators, 1/4 height scale | 2 SLOCAs, 2 failed-open PORVs | Conference proceedings (2004)     |
| Code change made to the calculations of heat transfer within the covered nodes of the core to allow oscillations in the two-phase level swell associated with steaming due to injection followed by subcooling (not included in the standard code; see the <i>issue for code development and user support</i> discussion that follows) |            |           |                                                                                   |                        |                                                                   |                               |                                   |

**Major Code Models Compared and Review of Agreement**

| Model                                 | Indicators                     | Agreement Based on Expert Review | Notes                                       |
|---------------------------------------|--------------------------------|----------------------------------|---------------------------------------------|
| Overall code                          | —                              | Very good agreement              | —                                           |
| PWR primary system thermal hydraulics | Pressure and level             | Very good agreement              | Detailed agreement dependent on code change |
|                                       | Water level in the pressurizer | Very good agreement              |                                             |
|                                       | Water level in the vessel      | Not available                    |                                             |
| Steam generator: two-region, U-tube   | Pressure                       | Very good agreement              | —                                           |
|                                       | Water level                    | Very good agreement              |                                             |

**Comparison to Integral Experiments:**

**IE4. AP600 OSU SLOCAs and Failed PORVs, continued**

**Validation of Code Capabilities**

|                                                       |                                            |
|-------------------------------------------------------|--------------------------------------------|
| Critical flow: pressurizer PORVs                      | Validated based on primary system response |
| Critical flow: break flow                             | Validated based on primary system response |
| PWR ECCS injection (passive AP600 and AP1000 systems) | Validated based on primary system response |

**Issue for Code Development and User Support**

A code change was made to the subroutine that calculates the heat transfer within the covered nodes of the core (subroutine COVER) to allow oscillations in the two-phase level swell associated with steaming due to injection followed by subcooling, which then allows more injection. In the standard version of the code, these oscillations are suppressed to avoid numerical difficulties. The model deficiency affects only plants with injection that is driven solely by a gravity head (versus a differential gas pressure) such as the AP1000 and the ABWR; it was appropriate to model the oscillations in the benchmark sequences. The code change improved the detailed primary system water level agreement late in the transients after the primary system depressurized. Incorporating the change into the standard version of the code, primarily to improve calculations for sequences in which there is repeated core uncover with intermittent injection, is under consideration.

**Conclusions from the Authors of the Benchmark**

“In general, comparisons of the MAAP4 results with the OSU test results show that the MAAP4 code calculation is in agreement with the overall test response for all four tests. This includes reactor coolant system including pressurizer, core makeup tank, accumulator, steam generators, and the IRWST. These benchmarking results demonstrate the use of MAAP4 to simulate a reactor coolant system response and the passive system performance during small LOCAs. These benchmarking results also show that it is essential to have an integral response of the reactor coolant system and the containment to model the AP600 passive core cooling.”

**Comparison to Integral Experiments:**

**IE4. AP600 OSU SLOCAs and Failed PORVs, continued**

**Documentation**

|                                                                                                                                                                                             |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| C. Paik, R. Hammersley, and J. Scobel, “MAAP4 Benchmarking of AP600 OSU Experiments,” <i>2004 Pacific Basin Nuclear Conference</i> . Honolulu, Hawaii (March 21–25, 2004), ANS paper 93495. |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

|                                                             |
|-------------------------------------------------------------|
| Presentation to the MAAP Users Group by FAI, November 2003. |
|-------------------------------------------------------------|

**Comparison to Integral Experiments:**

**IE5. Waltz Mill Ice Condenser SLOCA, MLOCA, and LLOCAs**

| Author | Plant Type | PRA Level | Time Frame    | MAAP4 Code Versions | Scale/Scope of Experiment | Number of Sequences | Principal Sources of Documentation                                       |
|--------|------------|-----------|---------------|---------------------|---------------------------|---------------------|--------------------------------------------------------------------------|
| FAI    | PWR, WICE  | 1         | No time scale | 4.0.4, 4.0.6, 4.0.7 | Ice condenser containment | 4 LOCAs             | MAAP4 User's Manual (1999); also code transmittal documents (2005, 2007) |

**Major Code Models Compared and Review of Agreement**

| Model       | Indicator | Agreement Based on Expert Review                                                                                                                               | Notes                                                                                                       |
|-------------|-----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------|
| Containment | Pressure  | Fair agreement; difficult to determine the extent and implications of the pressure differences because there are no scales on the plots (they are proprietary) | This benchmark applies to the generic containment model; the heat transfer to the ice is the driving force. |

**Validation of Code Capabilities**

|                      |                                                               |
|----------------------|---------------------------------------------------------------|
| Heat transfer to ice | Validated based on containment pressure response and ice mass |
|----------------------|---------------------------------------------------------------|

**Conclusions from the Authors of the Benchmark**

“Comparing the MAAP4 ice condenser containment model with a spectrum of LOCA experiments shows that the MAAP4 characterization provides good agreement with the behavior for the various size LOCA conditions investigated, including long term decay heat added to the containment atmosphere. Furthermore, it shows that the MAAP4 mechanistic ice melt model provides a good characterization of the ice melt for a wide spectrum of accident conditions, including long term decay heat steam release. The model also provides a good representation of the ice melt drain temperature and lower compartment water temperature.”

**Comparison to Integral Experiments:**

**IE5. Waltz Mill Ice Condenser SLOCA, MLOCA, and LLOCAs, continued**

**Documentation**

|                                                                                                           |
|-----------------------------------------------------------------------------------------------------------|
| MAAP4 User's Manual [1]: Volume III-C, Rev. 0.2, September 1999. (using Rev. 4.0.4)                       |
| MAAP4 transmittal documents for Rev. 4.0.6 and Rev. 4.0.7 [12, 13]. (plotted results only, 2005 and 2007) |

**Comparison to Integral Experiments:**  
**IE6. PNL Ice Condenser Heat Transfer**

| Author | Plant Type | PRA Level | Time Frame | MAAP4 Code Versions | Scale/Scope of Experiment                           | Number of Sequences         | Principal Sources of Documentation                                       |
|--------|------------|-----------|------------|---------------------|-----------------------------------------------------|-----------------------------|--------------------------------------------------------------------------|
| FAI    | PWR, WICE  | 1         | 1 hr       | 4.0.4, 4.0.6, 4.0.7 | Ice condenser containment: heat transfer to the ice | 3 heat transfer experiments | MAAP4 User's Manual (1999); also code transmittal documents (2005, 2007) |

**Major Code Models Compared and Review of Agreement**

| Model | Indicator | Agreement Based on Expert Review | Notes                                                                                                               |
|-------|-----------|----------------------------------|---------------------------------------------------------------------------------------------------------------------|
| None  | —         | —                                | Benchmark applies only to the ice condenser portion of the containment model, not to the generic containment model. |

**Notes and Recommendations for Users**

The values of the heat transfer coefficient for natural convection and radiation in the ice condenser, input parameter HTADDI, that yield a good match between the calculated and experimental gas exit temperatures are relatively small (on the order of  $1 \text{ W/m}^2\text{-K}$  [ $0.176 \text{ Btu/ft}^2\text{-hr-F}$ ]). It is unknown why differences in the values of a factor of four influence the predicted gas temperatures to the large extent seen in the benchmark results.

The review team recommends that users with ice condenser plants evaluate the sensitivity of their sequence results to the ice condenser input parameters. Of particular importance for ice condensers is the time at which the ice melts and the properties of the gas and condensate exiting the ice condenser compartment because of their impact on the overall energy balance and on the hydrogen concentration in the containment.



**Comparison to Integral Experiments:****IE6. PNL Ice Condenser Heat Transfer, continued****Issue for Code Development and User Support**

The review team recommends that investigations be done to determine which parameters have the most influence on the heat transfer in the ice condenser and how sensitive the results are to the parameter values. The important output variables, particularly those that define the energy balance around the condenser (for example, temperatures and steam partial pressures), should be communicated to the users. These investigations should tie in to the existing benchmarks as well as any potentially new benchmarks. A particular item of interest is how the condensate temperature, which is an input to the benchmarks, affects the results. The large sensitivity of the input heat transfer coefficient HTADDI on the gas exit temperatures, as seen in this benchmark, is also of interest.

**Validation of Code Capabilities**

|                      |                                                              |
|----------------------|--------------------------------------------------------------|
| Heat transfer to ice | Validated based on the gas (steam and air) exit temperatures |
|----------------------|--------------------------------------------------------------|

**Comparison to Integral Experiments:**

**IE6. PNL Ice Condenser Heat Transfer, continued**

**Conclusions from the Authors of the Benchmark**

“Comparison of the MAAP ice condenser containment model with a spectrum of inlet conditions to the ice condenser shows good agreement for the thermal-hydraulic response of the test performed. This is true for those experiments utilizing high steam partial pressures as well as those with a low steam partial pressure. Furthermore, the imposed gas flow rate is equivalent to the velocity through the ice bed that would be promoted by a single train of ice condenser recirculation air fans. Therefore, the behavior observed in these experiments and the good agreement observed between the experimental measurements and the MAAP model develop a level of confidence that the MAAP calculation is a good representation of the containment response for a spectrum of accident sequences.”

**Documentation**

MAAP4 User’s Manual [1]: Volume III-C, Rev. 0, June 1999. (using Rev. 4.0.4)

MAAP4 transmittal documents for Rev. 4.0.6 and Rev. 4.0.7 [12, 13]. (plotted results only, 2005 and 2007)

**Comparison to Integral Experiments:****IE7. CSTF Containment Heat Transfer**

| <b>Author</b> | <b>Plant Type</b> | <b>PRA Level</b> | <b>Time Frame</b> | <b>MAAP4 Code Versions</b> | <b>Scale/Scope of Experiment</b>                               | <b>Number of Sequences</b>    | <b>Principal Sources of Documentation</b>                                 |
|---------------|-------------------|------------------|-------------------|----------------------------|----------------------------------------------------------------|-------------------------------|---------------------------------------------------------------------------|
| FAI           | PWR, WICE         | 1 and 2          | 1 hr              | 4.0.4, 4.0.7               | Forced and counter-current (natural) convection in containment | 7 gas circulation experiments | MAAP4 User's Manual (1999); also, code transmittal documents (2005, 2007) |

**Major Code Models Compared and Review of Agreement**

| <b>Model</b> | <b>Indicator</b> | <b>Agreement Based on Expert Review</b> | <b>Notes</b>                                                           |
|--------------|------------------|-----------------------------------------|------------------------------------------------------------------------|
| Containment  | Pressure         | Very good agreement                     | Applies to the generic containment model (not to heat transfer to ice) |

**Conclusions from the Authors of the Benchmark**

“These comparisons of the MAAP Generalized Containment Model with the spectrum of test conditions considered for the simulated ice condenser containment in the CSTF vessel show that the MAAP model provides an effective representation of the containment response under both natural circulation and forced flow conditions. Good agreement between the calculated and measured behaviors is obtained for all of the test conditions examined in the CSTF test program and therefore the user has the confidence that the MAAP model can follow the influences of light gas, such as hydrogen, being released to the containment as a consequence of postulated accident sequences. Furthermore, the sensitivity studies performed illustrate the importance of including representations for both forced and natural circulation flows between the containment compartments, including natural circulation counter-current flows through the partially opened doors in the CSTF simulation. Since the expected ice condenser response to small break LOCA conditions is to have lower inlet doors only partially opened, this potential for examining both the forced flow and natural circulation flow is important. Furthermore, it is particularly important to assess the potential for experiencing “flooding” of the gas flow in the partially opened doors as a result of the imposed recirculation flow by the air return fans.”

**Comparison to Integral Experiments:**

**IE7. CSTF Containment Heat Transfer, continued**

**Documentation**

|                                                                                   |
|-----------------------------------------------------------------------------------|
| MAAP4 User's Manual [1]: Volume III-C, Rev. 0, June 1999. (using Rev. 4.0.4)      |
| MAAP4 transmittal documents for Rev. 4.0.7 [12, 13]. (plotted results only, 2007) |

**Comparison to Integral Experiments:****IE8. HDR Containment Mixing: E11.2 for SLOCA, T31.5 for LLOCA**

| <b>Author</b> | <b>Plant Type</b> | <b>PRA Level</b> | <b>Time Frame</b> | <b>MAAP4 Code Versions</b> | <b>Scale/Scope of Experiment</b> | <b>Number of Sequences</b> | <b>Principal Sources of Documentation</b>                                       |
|---------------|-------------------|------------------|-------------------|----------------------------|----------------------------------|----------------------------|---------------------------------------------------------------------------------|
| FAI           | Generic           | 1 and 2          | 1–22 hr           | 4.0.0, 4.0.2, 4.0.6, 4.0.7 | Large-scale containment mixing   | 1 SLOCA, 1 LLOCA           | Journal paper (1999), MAAP4 User's Manual (1994), conference proceedings (1991) |

**Major Code Models Compared and Review of Agreement**

| <b>Model</b> | <b>Indicator</b> | <b>Agreement Based on Expert Review</b> | <b>Notes</b>                                                             |
|--------------|------------------|-----------------------------------------|--------------------------------------------------------------------------|
| Containment  | Pressure         | Very good agreement                     | The benchmark uses the subnodal physics option in the containment model. |

**Note**

The HDR containment is more highly nodalized and is more vertically oriented than the containments for commercial reactors. The subnodal physics model in MAAP4 is particularly appropriate for this type of configuration, and it contributed to the very good agreement between the code predictions and the data. The subnodal physics model will have a smaller impact for less nodalized containments. MAAP4 is known to slightly over-predict the pressure in the containment. The subnodal physics model will slightly over-predict the pressure even more (essentially another “adder”), which is conservative.

**Comparison to Integral Experiments:**

**IE8. HDR Containment Mixing: E11.2 for SLOCA, T31.5 for LLOCA, continued**

**Conclusions from the Authors of the Benchmark**

*E11.2 paper:* “The MAAP4 code over-predicted the peak pressure by 0.25 bar. On the other hand, the MAAP4 code correctly predicted the thermal and hydrogen stratification observed in the E11.2 test. In addition, the intricate gas turnover phenomena in the dome region during the external spray time period was also correctly predicted by the code. Subnodal physics implemented in the MAAP4 containment model are responsible for the capability to predict the hydrogen and thermal stratification that were observed in the HDR E11.2 test.”

*T31.5 conference proceedings:* “1) MAAP predicted the pressure accurately. 2) MAAP substantially over-predicted the temperature in the source room, indicating a non-homogeneous condition in the source room. MAAP uses lumped parameter models in each node. 3) In general, MAAP did well in predicting temperatures above the break location. However, for lower nodes where natural circulation plays an important role in distributing hot gas into the lower part of the containment, MAAP predicted much steeper temperature gradients. 4) MAAP predicted better mixing than indicated by data. As a consequence, the hydrogen concentration in the lower node rose more rapidly than indicated by data. Also, MAAP predicted complete homogenization after about 18000 sec. Data indicates stratification of hydrogen persisting up to the end of the transient.”

**Documentation**

S. Lee, C. Paik, R. Henry, M. Epstein, and M. Plys, “Benchmark of the Heiss Dampf Reaktor E11.2 Containment Hydrogen-Mixing Experiment Using the MAAP4 Code,” *Nuclear Technology*. Vol. 125, p. 182–196 (1999). (presumed to be Rev. 4.0.2)

MAAP4 User’s Manual [1]: Volume III, Section 2, Rev. 0, May 1994. (using Rev. 4.0.0)

C. Paik, S. Lee, and M. Plys, “MAAP Prediction of the HDR T31.5 Containment Experiment,” *National Heat Transfer Conference*. AIChE, Minneapolis, Minnesota (1991). (presumed to be Rev. 4.0.0)

MAAP4 transmittal documents for Rev. 4.0.6 and Rev. 4.0.7 [12, 13]. (plotted results only, 2005 and 2007)

**Comparison to Integral Experiments:**  
**IE9. ISP-35 Containment Mixing**

| Author              | Plant Type | PRA Level | Time Frame | MAAP4 Code Version                    | Scale/Scope of Experiment | Number of Sequences      | Principal Source of Documentation |
|---------------------|------------|-----------|------------|---------------------------------------|---------------------------|--------------------------|-----------------------------------|
| Japanese consortium | Generic    | 1 and 2   | 30 min     | Not specified (estimated to be 4.0.0) | Containment mixing        | 1 containment experiment | Conference proceedings (1995)     |

**Major Code Models Compared and Review of Agreement**

| Model       | Indicator | Agreement Based on Expert Review | Notes                                                                                                                                                                                        |
|-------------|-----------|----------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Containment | Pressure  | Very good agreement              | The authors identified that the modeling of counter-current flow through junctions in MAAP4 is a primary reason why the code successfully simulates the gas distribution in the containment. |

**Conclusions from the Authors of the Benchmark**

“The international standard problem ISP-35 for hydrogen mixing in a containment vessel has been analyzed using the MAAP4 code. The MAAP4 code has obtained good results for simulating the helium gas concentration in each compartment, even in a dead-end compartment such as the pressurizer compartment. In general, the analytical results for the pressure in the containment vessel, the gas temperature, and the helium concentrations in each compartment agree very well with the test results. Therefore, it has been verified that the MAAP4 code provides a good simulation of the hydrogen mixing problem.”

**Comparison to Integral Experiments:**

**IE9. ISP-35 Containment Mixing, continued**

**Documentation**

H. Iizuka, Y. Furukawa, O. Kawabata, J. Uchida, Y. Narumiya, N. Hayashi, T. Sakai, and T. Yamauchi, “An Analysis of Hydrogen Mixing and Distribution Problem ISP–35 Using the MAAP4 Code,” *International Conference on Probabilistic Safety Assessment Methodology and Applications*. KAERI, Seoul, Korea (1995). (presumed to be Rev. 4.0.0)



**Comparison to Integral Experiments:****IE10. Semiscale in 1992 MAAP3B Qualification Studies—Various PWR Sequences**

| <b>Author</b> | <b>Plant Type</b> | <b>PRA Level</b> | <b>Time Frame</b> | <b>MAAP4 Code Version</b> | <b>Scale/Scope of Experiments</b>                                                | <b>Number of Sequences</b> | <b>Principal Source of Documentation</b> |
|---------------|-------------------|------------------|-------------------|---------------------------|----------------------------------------------------------------------------------|----------------------------|------------------------------------------|
| GKA           | PWR WLD           | 1                | 5 min–5 hr        | MAAP3B Rev. 16            | Primary system with 1 loop and steam generator, full height, 1/1705 volume scale | 4 LOCAs, 2 LOOPs, 3 SGTRs  | EPRI technical report (1992)             |

**Major Code Models Compared and Review of Agreement**

| <b>Model</b> | <b>Indicator</b> | <b>Agreement Based on Expert Review</b> | <b>Notes</b>                                                                                                                                                                  |
|--------------|------------------|-----------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Overall code | —                | Good agreement with MAAP3B              | The benchmark is generally but not specifically applicable to MAAP4 because it was done with MAAP3B, and it is not feasible to extract details from the existing information. |

**Documentation**

|                                                           |
|-----------------------------------------------------------|
| 1992 MAAP Thermal-Hydraulic Qualification Studies [2, 5]. |
|-----------------------------------------------------------|

**Comparison to Integral Experiments:**

**IE11. FIST in 1992 MAAP3B Qualification Studies--Various BWR Sequences**

| Author | Plant Type | PRA Level | Time Frame   | MAAP4 Code Versions | Scale/Scope of Experiments                      | Number of Sequences | Principal Source of Documentation |
|--------|------------|-----------|--------------|---------------------|-------------------------------------------------|---------------------|-----------------------------------|
| GKA    | BWR        | 1         | 8 min–50 min | MAAP3B Rev. 6       | Primary system, full height, 1/624 volume scale | 1 MLOCA, 2 LOFWs    | EPRI technical report (1992)      |

**Major Code Models Compared and Review of Agreement**

| Model        | Indicator | Agreement Based on Expert Review | Notes                                                                                                                                                                         |
|--------------|-----------|----------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Overall code | —         | Good agreement with MAAP3B       | The benchmark is generally but not specifically applicable to MAAP4 because it was done with MAAP3B, and it is not feasible to extract details from the existing information. |

**Documentation**

1992 MAAP Thermal-Hydraulic Qualification Studies [2, 5].

**Comparison to Integral Experiments:****IE12. MIST in 1992 MAAP3B Qualification Studies–PWR SLOCA Sequences**

| <b>Author</b> | <b>Plant Type</b> | <b>PRA Level</b> | <b>Time Frame</b> | <b>MAAP4 Code Version</b> | <b>Scale/Scope of Experiments</b>                                                 | <b>Number of Sequences</b> | <b>Principal Source of Documentation</b> |
|---------------|-------------------|------------------|-------------------|---------------------------|-----------------------------------------------------------------------------------|----------------------------|------------------------------------------|
| GKA           | PWR B&W           | 1                | 1 hr, 12 hr       | MAAP3B Rev. 16            | Primary system with 2 loops and steam generators, full height, 1/817 volume scale | 2 SLOCAs                   | EPRI technical report (1992)             |

**Major Code Models Compared and Review of Agreement**

| <b>Model</b> | <b>Indicator</b> | <b>Agreement Based on Expert Review</b> | <b>Notes</b>                                                                                                                                                                  |
|--------------|------------------|-----------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Overall code | —                | Good agreement with MAAP3B              | The benchmark is generally but not specifically applicable to MAAP4 because it was done with MAAP3B, and it is not feasible to extract details from the existing information. |

**Documentation**

|                                                           |
|-----------------------------------------------------------|
| 1992 MAAP Thermal-Hydraulic Qualification Studies [2, 5]. |
|-----------------------------------------------------------|

**Comparison to Separate Effects Experiments:**

**SE1. MAAP4 Function VFVOL–Void fraction and boiled-up level in the core compared to THTF experiments (with minor comparisons to FLHT4 and IIST)**

| Author | Plant Type | PRA Level | Time Frame     | MAAP4 Code Version           | Principal Source of Documentation |
|--------|------------|-----------|----------------|------------------------------|-----------------------------------|
| FAI    | Generic    | 1 and 2   | Not applicable | All (no change with version) | MAAP4 User's Manual (2007)        |

**Code Model Compared and Validation**

| Model               | Indicator     | Validation                                                                                                                                                                                                                                                                          |
|---------------------|---------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Voiding in the core | Void fraction | Subroutine VFVOL is validated based on good agreement of the calculated average void fraction as a function of steam superficial velocity with values generated from the THTF experiments, using the value of 2 for the drift flux proportionality constant (input parameter FVOL). |

**Conclusions from the Authors of the Benchmark**

*Presentation:* “Benchmarking of the MAAP subroutine VFVOL with the information from all three of these experiments demonstrates good agreement with the data reported from these facilities.”

**Documentation**

MAAP4 User's Manual [1]: Volume III-D, Rev. 0, April 2007.

Presentation to the MAAP Users Group by FAI, December 2005.

**Comparison to Separate Effects Experiments:**

**SE2. MAAP4 Subroutine HLNC–Hot leg circulation flow and heat transfer to the steam generator compared to Westinghouse 1/7<sup>th</sup> scale experiments (also referred to as SF<sub>6</sub> and Stewart experiments)**

| Author                      | Plant Type       | PRA Level | Time Frame     | MAAP4 Code Version      | Principal Source of Documentation                        |
|-----------------------------|------------------|-----------|----------------|-------------------------|----------------------------------------------------------|
| FAI (manual), EPRI (report) | PWR Westinghouse | 1 and 2   | Not applicable | 4.0.5 (4.0.2 in report) | MAAP4 User's Manual (2003), EPRI technical report (1997) |

**Code Model Compared and Validation**

| Model | Indicators                                                                                                     | Validation                                                                                                                                                                                                                                                                                                                                                                                                                         |
|-------|----------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| HLNC  | Combined counter-current and unidirectional flow in the hot leg and heat transfer to the steam generator tubes | Subroutine HLNC is validated based on good agreement of the flow rates, fluid temperatures, and heat transfer to the tubes for various experimental configurations, using the value of 0.115 for the flow correlation coefficient (input parameter FWHL) and values in the range of 0.2 to 0.45 for the fraction of tubes carrying flow from the inlet plenum to the outlet plenum of the steam generator (input parameter FAOUT). |

**Note**

Improvements to the model identified in the Rev. 4.0.2 work were incorporated into Rev. 4.0.3.

**Comparison to Separate Effects Experiments:**

**SE2. MAAP4 Subroutine HLNC–Hot leg circulation flow and heat transfer to the steam generator compared to Westinghouse 1/7<sup>th</sup> scale experiments (also referred to as SF<sub>g</sub> and Stewart experiments), continued**

**Conclusions from the Authors of the Benchmark**

*Paraphrased from manual:* The model and data agree for specific values of  $FA_{out}$ , the fraction of tubes carrying the out-flow from the U-tube steam generators.

*Report:* “Representative comparisons of the predictions of this model to measured flow rates in some of the experiments are given ...[including] results as a function of the fraction of tubes which bear flow in the “out” direction from the inlet plenum to the outlet plenum. The rather good performance of the model, and the relative insensitivity of the flow rates to changes in input parameters such as this fraction, afford confidence in the code’s predictions.”

**Documentation**

MAAP4 User’s Manual [1]: Volume II, HLNC description, Rev. 0.2, January 2003.

*Steam Generator Management Project, Risks from Severe Accidents Involving Steam Generator Tube Leaks or Ruptures, Volume 1: Risk Assessment.* EPRI, Palo Alto, CA: 1997. TR-106194-V1. (prepared by Polestar, Dames & Moore, FAI, and Structural Integrity Associates)

**Comparison to Separate Effects Experiments:****SE3. MAAP4 Subroutine FLOEXP–Pressurizer model compared to Marviken, FAI and GE vessel blowdown experiments**

| Author | Plant Type | PRA Level | Time Frame     | MAAP4 Code Version                                                 | Principal Source of Documentation               |
|--------|------------|-----------|----------------|--------------------------------------------------------------------|-------------------------------------------------|
| FAI    | PWR        | 1         | Not applicable | 4.0.0 with Marviken and FAI experiments; 4.0.7 with GE experiments | MAAP4 User's Manual (2003 and anticipated 2010) |

**Code Model Compared and Validation**

| Model                                                                   | Indicators                              | Validation                                                                                                                                                                                                      |
|-------------------------------------------------------------------------|-----------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Pressurizer control volume, including boiled-up level and critical flow | Pressure, level, gas volume, break flow | Subroutine FLOEXP is validated based on good agreement of the calculated quantities with the experimental data. The validation applies to all of the critical flow calculations because the same model is used. |

**Note**

The discharged water is steam in the Marviken experiment, two-phase in the FAI experiments, and liquid and two-phase in the GE large vessel experiments.

**Conclusions from the Authors of the Benchmark**

*Regarding the Marviken experiments:* “shows the actual and predicted vessel pressure in the Marviken vessel as a function of time. The FLOEXP prediction agrees well with the experimental data.”

*Regarding the FAI experiments:* “the predicted pressure closely matches the actual pressure, and the gas volume is slightly over-predicted.”

*Regarding the GE experiments:* “the calculated pressure and the level swell were well compared against the data.”

**Comparison to Separate Effects Experiments:**

**SE3. MAAP4 Subroutine FLOEXP–Pressurizer model compared to Marviken, FAI and GE vessel blowdown experiments, continued**

**Documentation**

|                                                                                                                        |
|------------------------------------------------------------------------------------------------------------------------|
| MAAP4 User's Manual [1]: Volume II, FLOEXP description, Rev. 0.1, December 2006.<br>(Marviken and FAI experiments)     |
| MAAP4 User's Manual [1]: Volume III, FLOEXP benchmark description, to be published<br>with MAAP4.0.8. (GE experiments) |





# TRANSLATED TABLE OF CONTENTS

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**Electric Power Research Institute (EPRI)**

# **MAAP4-Anwendungshandbuch**

Desktop-Referenz für die MAAP4-Software,  
Revision 2

**1020236**

Schlussfassung, Juli 2010

EPRI Project Manager  
F. Rahn

Dieses Dokument entspricht **NICHT** den Anforderungen gemäß  
10CFR50 Anhang B, 10CFR Teil 21,  
ANSI N45.2-1977 und/oder dem Zweck von ISO-9001 (1994).

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## PRODUKTBESCHREIBUNG

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Die MAAP4-Dokumentation (Modular Accident Analysis Program Version 4) besteht aus dem MAAP4-Benutzerhandbuch, den MAAP4-Benutzerleitfäden für die Eingabevorbereitung sowie begleitenden Dokumenten, in denen die einzelnen Revisionen beschrieben werden. Die einzelnen Dokumente enthalten detaillierte Informationen zum Vorgehen beim Ausführen des Codes sowie detaillierte Beschreibungen der einzelnen Modelle. Nicht enthalten sind jedoch Richtlinien für spezifische Anwendungen. Mit dem vorliegenden Anwendungshandbuch wird diese Lücke geschlossen, indem Benutzern ausreichend Informationen bereitgestellt werden, um akkurate probabilistische Sicherheitsanalysen der Stufe 1 durchzuführen.

### **Ergebnisse und Befunde**

Bei MAAP4 handelt es sich um eine Software, die in Nuklearanlagen zur Vorhersage des Verlaufs von Leichtwasserreaktorstörfällen eingesetzt wird. Dieses Anwendungshandbuch enthält folgende Informationen:

- Beschreibung des MAAP4-Codes
- Richtlinien zur Qualitätssicherung von MAAP4-Analysen
- Anleitung zur Anwendung von MAAP4 für probabilistische Sicherheitsanalysen der Stufe 1
- Aufstellung zusammengefasster Informationen zum Vergleich von Prozessen in MAAP4-Modellen
- Bewertung der Fähigkeit von MAAP4, Phänomene probabilistischer Sicherheitsanalysen der Stufe 1 hinlänglich vorzuberechnen

### **Herausforderungen und Ziele**

Zwei Arbeiten im Zusammenhang mit der vorherigen Version des Codes (MAAP3B) enthalten wertvolle Informationen zur Validierung von thermohydraulischen Modellen, Richtlinien zu Codeanwendungen sowie empfohlene Sensitivitätsanalysen. Bei der ersten Arbeit handelt es sich um eine Reihe von Studien zur thermohydraulischen Qualifikation. Ziel dieser Studien war die Überprüfung des thermohydraulischen Modells in MAAP3B sowie die Bereitstellung von Richtlinien zur Verwendung des Codes. Die Ergebnisbereiche enthalten ausführliche Beschreibungen relevanter Anlagenmerkmale, Unfallabläufe, Vergleichsgrößen und Eingabedateikomponenten sowie Richtlinien zu Anwendungen und Einschränkungen. Bei der zweiten Arbeit handelt es sich um die Erstellung einer Reihe empfohlener Sensitivitätsanalysen für die Überprüfung einer einzelnen Anlage. Das Ergebnisdokument enthält eine Übersicht über

wichtige Unfallabläufe, Phänomene und empfohlene Vorgehensweisen zum Umgang mit phänomenologischen Unsicherheiten bei der Überprüfung einer einzelnen Anlage. Bei den bisherigen Anwendern des Codes findet sich übereinstimmend die Meinung, dass vergleichbare thermohydraulische Bewertungen, Anwendungsrichtlinien und Empfehlungen für Sensitivitätsanalysen mit MAAP4 einen Vorteil darstellen würden. Der vorliegende Bericht dient dazu, die gewünschten Informationen für einen risikobewussten Einsatz von PSA der Stufe 1 bereitzustellen.

### **Anwendungen, Nutzen und Verwendung**

Es gilt die Annahme, dass der vorliegende Bericht von für die Ausführung des Codes verantwortlichen Analysten, Analysten, die die MAAP4-Ergebnisse in PSA-Modelle überführen, und anderen Personen verwendet wird, für die die Funktionen von MAAP4 von Interesse sind (z. B. Anlagenpersonal, Mitarbeiter von Regulierungsbehörden, Reaktorhersteller und Wissenschaftler).

### **Standpunkt von EPRI**

Dieses Anwendungshandbuch enthält hinreichende Informationen, um Benutzern akkurate PSA der Stufe 1 mithilfe von MPPA4 zu ermöglichen.

### **Ansatz**

Die in diesem Bericht enthaltenen Informationen wurden vornehmlich auf Grundlage der umfassenden Erfahrung in der Anwendung des MAAP4-Codes, des MAAP4-Benutzerhandbuchs, bereits vorliegenden thermohydraulischen Qualifizierungsstudien mit MAAP3B und Sensibilitätsrichtlinien, Beschreibungen von Vergleichsgrößen sowie Ergebnissen erläuternder MAAP4-Berechnungen zu bestimmten Themen des vorliegenden Dokuments zusammengestellt.

### **Kernbegriffe**

Probabilistische Sicherheitsanalyse  
ASME PRA-Standard  
PSA-Umfang und -Qualität  
Erfolgskriterien  
Thermohydraulische Analyse  
MAAP4

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## **Directrices para aplicaciones MAAP4**

Referencia de escritorio para el uso de software  
MAAP4, Revisión 2

**1020236**

Informe final, julio de 2010

Director de proyecto de EPRI  
F. Rahn

Este documento **NO** cumple los requisitos 10CFR50  
apéndice B, 10CFR parte 21,  
ANSI N45.2-1977 y/o el propósito de ISO-9001 (1994)

## DESCRIPCIÓN DEL PRODUCTO

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La documentación del programa analítico modular de accidentes versión 4 (Modular Accident Analysis Program, MAAP4) consiste en el Manual del usuario de MAAP4, las guías del usuario para la preparación de la información de MAAP4, y los documentos de transmisión que describen las revisiones individuales. Estos componentes contienen información detallada sobre la mecánica de ejecución del código, así como descripciones detalladas de los modelos individuales, pero no incluyen directrices de aplicación específicas. Este documento de directrices para las aplicaciones tiene como finalidad cubrir ese vacío y proporcionar a los usuarios información suficiente para que puedan optimizar sus esfuerzos y generar análisis de evaluación probabilística del riesgo (PRA) de Nivel 1 de alta calidad.

### **Resultados y conclusiones**

MAAP4 es un código informático utilizado por las centrales nucleares y las organizaciones dedicadas a la investigación para predecir la progresión de los accidentes de los reactores de agua ligera. Este documento de directrices para las aplicaciones incluye lo siguiente:

- Una descripción del código MAAP4
- Directrices para asegurar la calidad de los análisis MAAP4
- Directrices para la aplicación de MAAP4 a los análisis PRA de Nivel 1
- Una recopilación de la información resumida sobre la referenciación de modelos MAAP4
- Una evaluación de la capacidad de MAAP4 para predecir adecuadamente fenómenos significativos de PRA de Nivel 1

### **Desafíos y objetivos**

En dos trabajos anteriores relacionados con la versión anterior del código, MAAP3B, se generó información especialmente útil relativa a la validación de modelos termohidráulicos, así como directrices para la aplicación del código y análisis de sensibilidad recomendados. El primer trabajo consistió en un conjunto de estudios de cualificación termohidráulica. Los objetivos de los estudios fueron evaluar el modelado termohidráulico en MAAP3B y proporcionar directrices para el uso del código. Los informes resultantes contienen descripciones detalladas de características relevantes de la central, secuencias de accidentes, referenciaciones y componentes del archivo de entrada, así como directrices sobre aplicaciones y limitaciones. El segundo trabajo consistió en la creación de un conjunto de análisis de sensibilidad recomendados para el examen individual de la central (Individual Plant Examination, IPE).



El documento resultante contiene una revisión de las secuencias y fenómenos de accidentes clave y los enfoques recomendados para el tratamiento de las incertidumbres fenomenológicas en IPE. Existe un consenso entre los usuarios actuales del código respecto a la ventaja que supondría disponer de evaluaciones termohidráulicas similares, directrices para aplicaciones y recomendaciones de análisis de sensibilidad para MAAP4. Este informe intenta satisfacer estas necesidades para las aplicaciones de PRA de Nivel 1 con información del riesgo.

### **Aplicaciones, valor y uso**

Se prevé que este informe será utilizado por los analistas responsables de la ejecución del código, los analistas responsables de incorporar los resultados de MAAP4 en modelos de PRA, y otras personas interesadas en las posibilidades de MAAP4 (por ejemplo, personal de las centrales, reguladores, proveedores de reactores e investigadores).

### **La perspectiva de EPRI**

Este documento de directrices proporciona a los usuarios información suficiente para que puedan optimizar sus esfuerzos y generar análisis de evaluación probabilística del riesgo (PRA) de Nivel 1 de alta calidad con MAAP4.

### **Enfoque**

La información de este documento se recopiló principalmente a partir de una amplia experiencia en el uso del código MAAP4, del Manual del usuario de MAAP4 y las guías del usuario, de las directrices de sensibilidad y los estudios de cualificación termohidráulica de MAAP3B descritos anteriormente, de descripciones de referenciación y de los resultados de cálculos exploratorios de MAAP4 realizados para investigar cuestiones específicas para este trabajo.

### **Palabras clave**

Evaluación probabilística del riesgo  
Estándar de PRA ASME  
Alcance y calidad del análisis PRA  
Criterios de éxito  
Análisis termohidráulico  
MAAP4

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## **Guide des applications MAAP4**

Référence de bureau pour l'utilisation du logiciel  
MAAP4, Révision 2

**1020236**

Rapport final, Juillet 2010

Responsable de projet EPRI  
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**Ce document ne répond pas aux exigences de 10CFR50  
Annexe B, de 10CFR Partie 21,  
d'ANSI N45.2 -1977 et/ou l'intention de la norme ISO-  
9001 (1994)**

## DESCRIPTION DU PRODUIT

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La documentation existante du programme modulaire d'analyse des accidents Version 4 (MAAP4) se compose du manuel de l'utilisateur MAAP4, des guides de l'utilisateur MAAP4 pour la préparation d'entrée et de documents de transmission qui décrivent les révisions individuelles. Ces composants contiennent des informations détaillées sur la mécanique de l'exécution du code, ainsi que des descriptions détaillées de chaque modèle, mais ils ne comprennent pas de directives spécifiques aux applications. Ce document guide pour les applications est destiné à combler cette lacune en fournissant des informations suffisantes pour permettre aux utilisateurs d'optimiser leurs efforts et de produire des analyses probabilistes d'évaluation du risque (PRA) de niveau 1 de haute qualité.

### **Résultats et conclusions**

MAAP4 est un code informatique utilisé par les sites nucléaires et les organismes de recherche afin de prévoir l'évolution des accidents des réacteurs à eau ordinaire. Ce document guide pour les applications fournit ce qui suit :

- une description du code MAAP4
- des conseils pour assurer la qualité des analyses MAAP4
- des conseils sur la façon d'appliquer MAAP4 pour les PRA de niveau 1
- une compilation des informations récapitulatives sur la référencement des modèles de MAAP4
- une évaluation de la capacité de MAAP4 à prévoir de façon adéquate les phénomènes significatifs de PRA du niveau 1

### **Défis et objectifs**

Deux tentatives antérieures qui ont été liées à la version précédente du code, MAAP3B, ont généré des informations particulièrement utiles en ce qui concerne la validation des modèles thermohydrauliques, le guide d'application du code et les analyses recommandées de sensibilité. La première se composait d'une série d'études de qualification thermohydraulique. Les objectifs de ces études étaient d'évaluer la modélisation thermohydraulique dans MAAP3B et de fournir des conseils sur l'utilisation du code. Les rapports résultant contiennent des descriptions détaillées des caractéristiques des centrales concernées, des séquences d'accident, des référenciations et des composants du fichier d'entrée, ainsi que des conseils sur les applications et les limites. La deuxième tentative fut la création d'un ensemble d'analyses

recommandées de sensibilité pour l'examen d'une centrale individuelle (IPE). Le document résultant contient un examen des séquences d'accident clés, et des phénomènes et des approches recommandées pour le traitement des incertitudes phénoménologique dans les IPE. Le consensus parmi les utilisateurs du code actuel est que des évaluations thermohydrauliques similaires, des conseils pour applications et des recommandations pour des analyses de sensibilité pour MAAP4 seraient bénéfiques. Ce rapport vise à répondre à ces besoins pour les applications fondées sur l'analyse des risques PRA de niveau 1.

### **Applications, valeur et utilisation**

Il est prévu que ce rapport sera utilisé par les analystes chargés de l'exécution du code ainsi que par ceux chargés de l'incorporation des résultats MAAP4 dans des modèles PRA et par d'autres personnes intéressées par les capacités de MAAP4 (par exemple, le personnel des services publics, les organismes de réglementation, les fournisseurs de réacteurs et les chercheurs).

### **Perspective d'EPRI**

Ce document guide fournit des informations suffisantes pour permettre aux utilisateurs d'optimiser leurs efforts et de produire des analyses MAAP4 PRA de niveau 1 de haute qualité.

### **Approche**

Les informations contenues dans ce rapport ont été principalement assemblées à partir de l'expérience de l'utilisation du MAAP4, du manuel et des guides de l'utilisateur de MAAP4, à partir d'études de qualification thermohydraulique et des conseils de sensibilité de MAAP3B décrits précédemment, depuis des descriptions de référence et des résultats de calculs exploratoires de MAAP4 effectués pour enquêter sur des sujets spécifiques de cet effort.

### **Mots clés**

Évaluation probabiliste des risques

Norme ASME PRA

Étendue et qualité des PRA

Critères de réussite

Analyse thermohydraulique

MAAP4

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# MAAP4 適用上の指針

## MAAP4ソフトウェア使用に関するデスクトップ リファレンス第2版

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EPRIプロジェクトマネージャ  
F. Rahn

本書は以下の文書の要件を満たしていません。  
10CFR50付属書B、10CFRパート21、  
ANSI N45.2-1977、またISO-9001(1994)の意図

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## 製品説明

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既存のモジュール事故分析プログラムバージョン4 (MAAP4) には、それぞれの改訂内容を記載した入力準備および転送に関する資料であるMAAP4ユーザマニュアル、MAAP4ユーザガイドが含まれています。これらのコンポーネントには、コード実行のメカニズムに関する詳細情報やそれぞれのモデルに関する詳細な説明が記載されていますが、この中には具体的な適用上の指針は記載されていません。この適用上の指針は、ユーザの作業を最適化し、高度なレベル1確率的危険評価 (PRA) 分析を行えるよう十分な情報を提供することによって、その不足情報を補うためのものです。

### 結果と研究成果

MAAP4は、原子力発電所や研究機関が軽水炉の事故の経過を予測するために使用するコンピュータコードです。この適用上の指針では、以下の内容について説明します。

- MAAP4コードについての説明
- MAAP4解析の質を確保するための指針
- レベル1 PRAにMAAP4を適用する方法についての指針
- MAAP4モデルのベンチマークに関する概要のまとめ
- レベル1 PRAの重大な現象を的確に予測するMAAP4の機能の評価

### 課題と目的

前のバージョンのコードMAAP3Bに関連した2つの優先的な取り組みにより、熱水力モデルの検証、コード適用上の指針、推奨感度解析に関する非常に有用な情報が出てきました。1つ目の取り組みは、熱水力の適格性に関する一連の研究です。この研究の目的は、熱水力モデリングをMAAP3Bで評価し、コードの使用方法に関する指針を定めることでした。結果の報告書には、関連するプラントの特徴、事故の経過、ベンチマーク、入力ファイルコンポーネント、適用および制約に関する指針について詳しい説明が記載されています。2つ目の取り組みは、個別プラント評価 (IPE) を行うために一連の推奨感度解析を構築したことです。結果の資料には、重大な事故や現象の調査や、IPEにおける現象の不確実性を扱う際の推奨手法が記載されています。現在のコードのユーザ間には、類似した熱水力評価、適用上の指針、MAAP4の感度解析の推奨方法は有効であるとの共通認識があります。この報告の目的は、レベル1 PRAの危険を知らせるアプリケーションへのニーズに応えることです。

## **応用、値、および使用**

この報告書は、コード実行の責任を負う専門家、MAAP4の結果をPRAモデルに統合する責任を負う専門家、その他にもMAAP4の機能に興味を持つ人達(例:電力会社社員、監督機関、炉製造企業、研究者)が使用することを想定しています。

## **EPRIの観点**

この指針には、ユーザの作業を最適化し、高度なレベル1 PRA MAAP4解析を行うために十分な情報が掲載されています。

## **方法**

この報告書に記載されている情報は、元はMAAP4コードを使用した多彩な経験、MAAP4ユーザマニュアルおよびユーザガイド、MAAP3B熱水力の適格性に関する研究、および以前作成された感度の指針、ベンチマークの記述、この取り組みに対する特定のトピックを調査するために実行されたMAAP4予備演算の結果をまとめたものです。

## **キーワード**

確率的危険評価

ASME PRA規格

PRAの範囲と質

成功基準

熱水力分析

MAAP4

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# MAAP4 애플리케이션 사용지침

MAAP4 소프트웨어 사용법 데스크탑 레퍼런스,  
제 2 개정판

1020236

최종 보고서, 2010년 7월

EPRI 프로젝트 매니저  
F. Rahn

본 문서는 10CFR50 Appendix B, 10CFR Part 21, ANSI  
N45.2-1977의 요건 및/또는,  
ISO-9001 (1994)의 의도를 충족하지 않습니다

## 제품 설명

기존 Modular Accident Analysis Program Version 4 (MAAP4)의 부속 문서에는 MAAP4 사용자 설명서, 입력(input) 준비를 위한 MAAP4 사용자 설명서, 및 각각의 개정판에 대해 설명한 발신 문서 (transmittal documents)들이 포함됩니다. 이 부속문서들에는 코드 실행에 관한

자세한 정보는 물론 개별 모델에 대한 자세한 설명도 나와 있지만, 특정한 애플리케이션에 대한 사용지침은 포함되지 않습니다. 이 애플리케이션 사용지침은 사용자들이 최대한 효과적으로 작업하여 질 높은 레벨 1 확률적 위험 평가 (PRA) 분석을 수행할 수 있도록, 충분한 정보를 제공함으로써 그와 같은 부족 부분을 보충하기 위한 것입니다.

### 결과와 발견된 사실

MAAP4는 원자력을 이용하는 공공기업과 연구기관에서 경수로 사고 발생을 예측하기 위해 이용하는 컴퓨터 코드입니다. 본 애플리케이션 사용지침서의 내용은 다음과 같습니다:

- MAAP4 코드 설명
- MAAP4 분석 품질 보장을 위한 지침
- 레벨 1 PRA에 MAAP4를 적용하는 방법의 지침
- MAAP4 모델 벤치마킹에 관한 발체된 요약 정보들
- 중대한 레벨 1 PRA 현상을 적절하게 예측하는 MAAP4의 능력에 관한 평가

### 문제점과 목표

이전 버전의 코드 MAAP3B와 관계된 선행한 두 번의 노력에서, 열 유압 (thermal-hydraulic) 모델의 검증, 코드 애플리케이션 지침 및 권장되는 감도 분석 기법에 대한 아주 유용한 정보를 얻어냈습니다. 그 첫 번째 노력은 몇 가지 열-유압 적합성(qualification)에 대한 조사였습니다. 이 조사의 목적은 MAAP3B에서 열-유압 모델 작성을 평가하고 코드 사용에 대한 지침을 제공하는 것이었습니다. 조사 결과 보고서에는 애플리케이션과 한계에 관한 지침은 물론, 관련 플랜트의 특성, 사고발생 시퀀스 (accident sequences), 벤치마크 및 입력 파일 구성요소에 대한 자세한 설명이 포함되어 있습니다. 두 번째 노력은 개별 플랜트 점검 (IPE)을 위한 권장되는 감도 분석 모델을 작성하는 것이었습니다. 결과 서류에는 주요 사고 시퀀스 (key accident sequences) 및 현상에 대한 검토와 IPE에서 현상적 불확실성을 처리하기 위한

권장되는 접근법이 포함됩니다. 현재의 코드 이용자들 사이에는 MAAP4용의 유사한 열-유압 평가, 애플리케이션 지침, 및 감도 분석에 대한 권고사항 등이 유리할 것이라는 데 의견이 모아지고 있습니다. 이 보고서는 레벨 1 PRA 위험이 알려진 용도에서 이런 요구들을 충족시키고자 합니다.

### **용도, 가치 및 사용**

이 보고서는 코드 실행을 담당하는 분석기술자, MAAP4 결과를 PRA 모델에 적용하는 작업을 담당한 분석기술자, 그리고 그 외 MAAP4의 기능에 관심 있는 사람들 (예: 공공기업 직원, 규제기관, 반응로 판매업체, 및 연구자)이 사용할 것으로 예상됩니다.

### **EPRI의 입장**

이 안내 책자에서는 사용자들이 자신들의 노력을 최적화하여 높은 품질의 레벨 1 PRA MAAP4 분석을 하는 데 충분한 정보를 제공합니다.

### **접근방식**

이 보고서에 나오는 정보들은 기본적으로 MAAP4 코드를 사용한 광범위한 경험, MAAP4 사용자 설명서와 사용자 안내, 앞에 설명했던 MAAP3B 열-유압 적합성 조사 및 감도 지침, 벤치마크 설명, 그리고 이 작업의 특정한 주제들을 조사할 목적으로 실시했던 MAAP4 계산 결과들로부터 수집되었습니다.

### **주요 어휘**

확률적 위험 평가

ASME PRA 표준

PRA 범위(scope)와 품질

성공 기준

열-유압 분석

MAAP4



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