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Guidelines for Performance of Internal Flooding Probabilistic Risk Assessment

UPDATE AND ERRATUM

August 5, 2020

1019194

Equation 6-4 in EPRI report 1019194 provides a method to calculate pipe flow rates. The definition of density originally provided for this equation is:

ρ = weight density of fluid (pounds-force per cubic foot)

This has been interpreted to mean that the density of water, 62.4 lb/ft^3, should be multiplied by the acceleration due to gravity, 32.2 ft/s^2. This approach results in non-conservatively low flow rates. Accordingly, the definition of density has been revised on page 6-5 as follows:

ρ = density of fluid = 62.4 lb/ft^3 for water at standard temperature and pressure

In addition, to calculate flow rates for use in internal flooding PRAs or related analyses, EPRI recommends, as the preferred approach, Equation 2-10 in report 3002000079, *Pipe Rupture Frequencies for Internal Flooding Probabilistic Risk Assessments*, Revision 3. EPRI, Palo Alto, CA: 2013.

Guidelines for Performance of Internal Flooding Probabilistic Risk Assessment

1019194

Final Report, December 2009

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This report describes research sponsored by the Electric Power Research Institute (EPRI).

The report is a corporate document that should be cited in the literature in the following manner:

Guidelines for Performance of Internal Flooding Probabilistic Risk Assessment. EPRI, Palo Alto, CA: 2009. 1019194.

REPORT SUMMARY

This report provides guidance for the performance of an Internal Flood Probabilistic Risk Assessment (IFPRA). The scope of IFPRA tasks supported by this guidance also includes the treatment of High Energy Line Breaks (HELB) which can produce floods as well as other unique challenges to Systems, Structures, and Components (SSCs) important to the prevention and mitigation of a core damage accident. The guidance includes step-by-step procedures for performing a complete IFPRA, specific examples of approaches for performing specific tasks, and meets specific technical requirements for IFPRA in the ASME/ANS PRA Standard. This guidance is intended for use in conjunction with a pipe failure rate database that was developed by EPRI to support IFPRA as documented in EPRI Report 1013141 published in 2006.

Background

Probabilistic Risk Assessments (PRAs) are used in day-to-day decisions in design, operations, and maintenance and to support risk-informed applications to the Nuclear Regulatory Commission (NRC) for beneficial changes to plant operations. Internal Flood events can be a significant contributor to the risk profile at nuclear plants. It is important to analyze Internal Flood events in a consistent manner across the nuclear industry that conforms to existing standards. There have been significant improvements to the methods and databases available to support IFPRA since the initial IFPRAs were performed in the early 1980s as part of the Individual Plant Examinations (IPE). These advances as well as the continuing improvements to the supporting PRA standards and regulatory guides provide a basis for documenting industry best practices in the performance of IFPRA.

Objectives

- To provide guidance on Internal Flood PRA implementation that encourages consistency across the industry and saves resources in the development, maintenance, and review of these models
- To provide guidance regarding acceptable approaches that is sufficient to meet the requirements of the ASME/ANS RA-Sa-2009 associated with Internal Flood

Approach

A draft version of these guidelines was prepared in 2006 based on industry practice current at the time. Although these guidelines had widespread industry input, they lacked the benefit of a pilot application. Subsequently lessons were learned from pilot studies. The project team also used an industry questionnaire in preparing the final version of the guidance. The technical issues identified in these pilot studies and the questionnaire are documented in this report.

The technical approach was to divide the IFPRA into eleven tasks performed in an iterative fashion. These included four tasks associated with information gathering, plant partitioning, walkdowns, and qualitative screening of flood areas; six tasks that covered defining and quantifying accident scenarios initiated by internal floods; and a task on documentation requirements.

Results

This guidance in the document has been applied in a number of pilots. This guidance will help users perform an Internal Flood PRA in a consistent manner that meets the requirements of ASME/ANS RA-Sa-2009 while saving resources in development, maintenance, and review.

EPRI Perspective

Industry standards such as ASME/ANS RA-Sa-2009 provide minimal requirements that should be followed to meet various applications of PRA. By design, the standard leaves open the specific methods of implementation. Following the best practices in this guide provides a vehicle to develop consistent high quality analyses with a minimal amount of resources. EPRI continues to work with industry leaders to document such practices in a number of PRA guidance documents.

This report contains recommended guidelines to satisfying the ASME/ANS combined standard requirements as they apply to Internal Flood. This self-consistent approach has been developed with significant support from EPRI members, vendors, owner’s groups, and other PRA experts. The main improvement to the earlier draft guidelines include:

- Improved definition of scenarios
- Treatment of flood barriers and high energy line breaks (HELB)
- Refinement of severity levels and flood categories
- Incorporation of updated RA-Sa requirements

PRA technology and methodologies continue to improve and new information continues to become available. Furthermore, field experience and identification of new vulnerabilities will necessitate additions or changes to the methods. Therefore, although this document represents the current state of the art, it is intended to be “living guidance” for PRA practitioners; and, as more feedback is obtained from additional trials, it is expected to be updated to support the conclusions of those applications.

Keywords

Probabilistic risk assessment (PRA)
PRA Standard
PRA Scope and Quality
High Energy Line Break (HELB)
Internal Flood PRA (IFPRA)

EXECUTIVE SUMMARY

Purpose and Scope

The purpose of this report is to provide guidance for the performance of an Internal Flood probabilistic risk assessment (IFPRA) for existing and advanced light water reactor (LWR) plants. The guidance includes step-by-step procedures for performing a complete IFPRA, specific examples of approaches for performing specific tasks, and meets specific technical requirements for IFPRA in the ASME/ANS PRA Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications [1] [2].

This guidance is intended for performance of a complete IFPRA for new plants as well as for updates and upgrades of PRAs for existing plants. Such upgrades may be necessary to increase the capabilities of the PRA to support risk informed applications; address changes to the design and operator procedures, repair, and replacement of equipment that may be the source of flooding; to account for trends in plant and industry service experience with floods and piping system failure mechanisms; or to account for enhancements to piping system integrity management programs to reduce the frequency of pipe ruptures.

The scope of IFPRA evaluations included in this guide includes the treatment of pressure boundary failures in low pressure and temperature as well as high energy systems, i.e. systems containing water and steam with pressure and temperature above saturated conditions, commonly referred to as HELBs. The inclusion of high-energy systems is necessary because HELBs can lead to flooding and is desirable because both Internal Flood events and HELB can be caused by pipe failures and can result in spatial dependencies. Inclusion of the HELB within the scope of an IFPRA guide is also consistent with the ASME/ANS PRA Standard [1]. Finally, a large fraction of the guidance on how to perform an IFPRA is also applicable to HELBs.

The scope of this guidelines is internal flood during power operation. Low power and shutdown applications are not the current focus of this guide nor did the pilots of this guide perform any detailed low power evaluations of this method. These methods, with modification, could be applied to low power and shutdown conditions as long as factors unique to these conditions are taken into account.

Perspective on Internal Flood and HELB

Internal Flood and HELB events differ from other initiating events in several ways. These differences are described below:

- Flooding and HELB events are the results of passive component pressure boundary failure; inadvertent system actuations (for example, Fire Protection water system sprinkler-caused spraying/flooding); or human error induced during system operation or maintenance (for example, freeze seal failures).
- Internal Flood and/or HELB events may simultaneously impact multiple structures, redundant systems, and components at a plant. Mitigation of the event may therefore require a combination of plant system responses and manual interventions not considered in accident sequence models for other causes of an initiating event.
- The evaluation of recovery actions from Internal Flood and HELB events requires detailed consideration of unique challenges in detecting impending flooding and responding to it in a timely manner. Depending on break size and location, certain plant areas may not be accessible, further complicating timely gathering of diagnostic information and corrective actions by plant personnel. Furthermore, risk of electrocution is yet another complicating factor in the assessment and evaluation of flooding response by operators.

The Internal Flood and HELB hazards have several characteristics that strongly influence the identification, quantification, and treatment of the initiators. These characteristics include the following:

- The design, quantity, type, and routing of piping systems varies substantially from plant to plant. Therefore, the identification of internal flood hazards is highly plant specific thereby limiting the usefulness of generic approaches to hazard characterization.
- HELB, flood, and spray events may have a spectrum of adverse impacts such as submergence, jet impingement, spray, pipe whip, increased humidity, condensation, high temperature, excessive structural loads, and electrocution concerns. Hence a given event has the potential for extensive impacts as well as many different resulting scenarios.
- The timely operating crew response to a flood or HELB initiator may be challenged by diagnostic difficulties as well as communications difficulties between auxiliary operators and main control room operators. Furthermore, internal flood response procedures may be less well developed than Abnormal Operating Procedures and Emergency Operating Procedures developed for response to active equipment malfunction or engineered safety feature actuations in response to reactor trip.
- Internal Flood and HELB initiating event quantification includes consideration of piping and non-piping passive component pressure boundary failures. This is an area of equipment reliability analysis that continues to evolve. A challenge for the IFPRA analysts is to account for the current state-of-knowledge and to correctly account for plant-specific aging management programs and pressure boundary integrity inspection plans.
- Considering the number of different flood sources, system failure modes, propagation paths, and possible plant impacts from floods, a very large number of different flood scenarios need to be considered and dispositioned in the IFPRA. Hence the processes of identifying, enumerating, grouping, and screening the flood scenarios need to be carefully managed and documented.

Technical Approach to IFPRA

The Internal Flood PRA (IFPRA) guideline has been organized into three major phases of analysis, which are further subdivided into eleven tasks as shown in Figure E-1. In the first phase of IFPRA, Qualitative Evaluation, the information that is needed for the IFPRA is collected and the initial qualitative analysis tasks are performed. The major outputs of this phase include the screening out of plant flood areas based on criteria associated with flood sources, flood propagation pathways, and potential impacts of floods on SSCs and the selection of flood areas for quantitative evaluation. There are four key tasks that are completed in this phase for the collection of information, performance of a plant walkdown, and completion of a qualitative screening evaluation of plant locations.

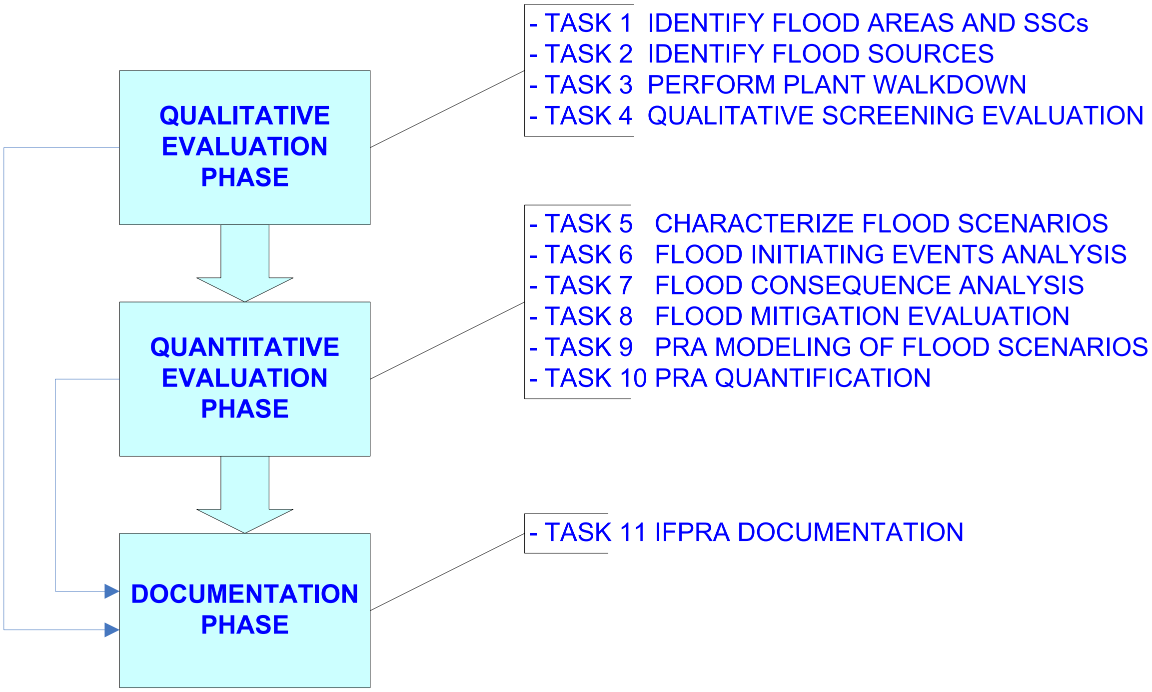

Figure E-1
Major Phases and Tasks of IFPRA

Pipe Pressure Boundary Failure Modes

Performing a detailed, comprehensive, and well-structured flood hazard evaluation is a key to achieving a realistic, plant-specific IFPRA model. At each level of the flood hazard evaluation, different types of passive component pressure boundary failure are considered including the following categories of loss-of-fluid events:

Spray

Spray events are defined as pipe leaks that result in sprays that may damage susceptible SSCs due to spray impact. In most cases such events will not result in accumulation of water on the floor of the associated flood area. An underlying assumption in this definition is that a spill rate from a pressure boundary through-wall flaw is within the capacity of a floor drain system and that the drain system is functioning properly. Otherwise, spray events can result in flooding, albeit at a slower rate than events classified as floods or major floods as defined below. The resulting leak or spill rate is defined as well in excess of 1 gpm but usually no larger than 100 gpm.

Flood

Flood events are characterized as pressure boundary failures involving large through-wall flow rates and with accumulation of water on a building floor. In the flood hazard evaluation the upper bound for a resulting spill rate is chosen in such a way that it remains within a plant-specific flood design basis. The spill rate resulting from this type of pressure boundary failure may or may not challenge the capacity of a floor drain system depending on the design. The resulting spill rate is defined as in excess of 100 gpm but no larger than•2,000 gpm. This spill rate range is typically within the flood design basis in safety related structures. Note that the upper bound flow rate for a flood event in a given pipe is limited by the flow capacity of that pipe.

Major Flood

Major flood event are characterized as pressure boundary structural failure with a resulting spill rate beyond the flood design basis. A resulting spill rate is likely to exceed the capacity of a floor drain system. The result of a major structural failure is a rapid release of a large volume of process medium with a spill rate in excess of 2,000 gpm. Note that some pipes may not be capable of producing a flood rate as high as 2,000gpm depending on the break size and capacity of the piping system. When it applies, the upper bound flow rate for this category is limited by the flow capacity of that pipe.

High Energy Line Break (HELB)

HELB is characterized by a large through-wall flow rate caused by a major structural failure in a high-energy line. A piping system is defined as high-energy if the maximum operating temperature exceeds 200 ºF or the maximum operating pressure exceeds 275 psig. By contrast, a piping system is defined as moderate energy if the maximum operating temperature is less than below 200 ºF of the maximum operating pressure is less than 275 psig. Consequential effects of HELB as well as Moderate-Energy Line Break (MELB) events are considered in IFPRA.

Scope of Flood Sources

All fluid sources outside of the containment structure that have a potential to cause flooding and/or HELB impacts are to be considered in IFPRA. Included for consideration in IFPRA are the following system groups with associated piping and non-piping passive components:

- Safety Injection & Recirculation System (for example, High and Low Pressure Safety Injection, Core Spray, Recirculation, and Residual Heat Removal).
- Containment Spray System (only piping and tanks external to containment structure)
- Reactor Auxiliary Systems (for example, Component Cooling Water, Reactor Water Cleanup, Chilled Water, Chemical and Volume Control, Boric Acid, Standby Liquid Control, Spent Fuel Pool Cooling, and Radwaste)
- Auxiliary Cooling Systems (for example, safety related and non-safety related Service Water Systems)
- Feedwater and Condensate Systems (Main Feedwater, Auxiliary Feedwater, and Condensate)
- Main and Auxiliary Steam Systems
- Fire Protection Water System
- Utility systems (domestic/potable water systems and hot water/steam systems that are part of a building heating system).

These systems include high-energy, moderate-energy, and low-energy piping. Excluded from the above system scope are systems within the reactor coolant system pressure boundary whose failure would represent a loss of coolant accident (LOCA) as these events are addressed as part of the internal events analysis scope of the PRA.

Report Guide

The methodology of Internal Flood PRA is summarized in Section 2. In Section 3 the first four tasks comprising the qualitative phase of IFPRA are described, and guidance in the performance of these tasks is provided. The remaining sections of this guideline track the remaining seven tasks comprising the quantitative and documentation phases of IFPRA with one section for each task.

Details on the lessons learned from the Fort Calhoun Pilot Study and IFPRA survey that was performed by the PWR Owners Group are found in Appendix A and B, respectively. Appendix C includes an example of how to calculate maximum flow rates for different combinations of pressure boundary failure (“spray”, “flood” and “major flood”), piping system and pipe size. A sample evaluation of the capacity of a flood door to retain various flood heights is provided in Appendix D. Appendix E includes examples of Internal Flood plant walkdown checklists. Finally, Appendix F includes a description of the EPRI computer program FRANX for analyzing Internal Flood plant risk.

ACKNOWLEDGMENTS

The authors extend special recognition to the PWR Owners Group for their participation in providing valuable input and in reviewing this document during the preparation process.

The authors would also like to acknowledge the valuable input from Entergy Services Inc. on flood door capacity evaluation.

The authors provide a special thanks to Vesna Dimitrijevic (AREVA NP, Inc.) for developing the early draft versions of the IFPRA Guidelines. Valuable peer review comments were provided by Lonnie Bullington (APS), Anthony Sarrack (Nuclear Management Company), and Ian Wall (Private Consultant). Rupert Weston and Ray Schneider of Westinghouse provided significant input in terms of lessons learned from a pilot study performed at Fort Calhoun and the results of a questionnaire sent out to the PWR Owners Group, which provided feedback from users of the preliminary draft of this report, and recent Internal Flood PRA insights and were responsible for producing Appendices A and B of this report.

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INTRODUCTION

1.1 Purpose

The purpose of this report is to provide guidance for the performance of an Internal Flood probabilistic risk assessment (IFPRA) for existing and advanced light water reactor (LWR) plants. This guidance describes procedures and approaches for the performance of an IFRA that is intended to meet the technical requirements defined in Part 3 (Requirements for Internal Flood At-Power PRA) of the ASME/ANS Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications [1] [2]. This guidance is intended for performance of a complete IFPRA for new plants as well as for updates and upgrades of PRAs for existing plants. Such upgrades may be necessary to increase the capabilities of the PRA to support risk informed applications; address changes to the design and operator procedures, repair and replacement of equipment that may be the source of flooding; to account for trends in plant and industry service experience with floods and piping system failure mechanisms; or to account for enhancements to piping system integrity management programs to reduce the frequency of pipe ruptures.

The purpose of IFPRA is to identify potential flood and high energy sources and mechanisms and to perform an assessment that identifies all the risk significant flood and high energy line break propagation pathways and scenarios in a manner that accounts for plant-specific spatial dependencies. Pressure boundary failure of piping or other passive, non-piping components, and inadvertent or spurious system or component actuations could lead to localized or global flooding, or high energy line break (HELB) impacts that could lead to failures that affect plant operability and safety. An objective of IFPRA is to evaluate flood-induced and HELB impacts on structures, systems, and components (SSCs) important to safety in such a way that:

- Flooding and high-energy sources within the plant that have the potential to create adverse conditions and affect the plant mitigating equipment are identified.
- The flood and HELB scenarios that contribute to CDF or LERF are identified and quantified.

Internal Flood and HELB events differ from other initiating events in several ways. These differences are described below:

- Flooding and HELB events are the results of passive component pressure boundary failure, inadvertent system actuations (for example, Fire Protection water system sprinkler-caused spraying/flooding), or human error induced during system operation or maintenance (for example, freeze seal failures).

- Internal Flood and/or HELB events may simultaneously impact multiple structures, redundant systems, and components at a plant. Mitigation of the event may therefore require a combination of plant system responses and manual interventions not considered in accident sequence models for other causes of an initiating event.
- The evaluation of recovery actions from Internal Flood and HELB events requires detailed consideration of unique challenges in detecting impending flooding and responding to it in a timely manner. Depending on break size and location, certain plant areas may not be accessible, further complicating timely gathering of diagnostic information and corrective actions by plant personnel. Furthermore, risk of electrocution is yet another complicating factor in the assessment and evaluation of flooding response by operators.

Internal Flood and HELB hazards have several characteristics that strongly influence the identification, quantification, and treatment of the initiators. These characteristics include the following:

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- Internal Flood and HELB initiating event quantification includes consideration of piping and non-piping passive component pressure boundary failures. This is an area of equipment reliability analysis that continues to evolve. A challenge for the IFPRA analysts is to account for the current state-of-knowledge and to correctly account for plant-specific aging management programs and pressure boundary integrity inspection plans.
- Considering the number of different flood sources, system failure modes, propagation paths, and possible plant impacts from floods, a very large number of different flood scenarios need to be considered and dispositioned in the IFPRA. Hence the processes of identifying, enumerating, grouping, and screening the flood scenarios needs to be carefully managed and documented.

The scope of IFPRA evaluations included in this guide includes the treatment of pressure boundary failures in low pressure and temperature as well as high-energy systems—systems containing water and steam with pressure and temperature above saturated conditions, commonly referred to as HELBs. The inclusion of high-energy systems is necessary because HELBs can lead to flooding and is desirable because both Internal Flood events and HELB can be caused by pipe failures and can result in spatial dependencies. Inclusion of the HELB within the scope of an IFPRA guide is also consistent with the ASME/ANS PRA Standard [1]. Finally, a large fraction of the guidance on how to perform an IFPRA is also applicable to HELBs.

1.2 Background

The treatment of internal floods is regarded as a key element of a PRA as reflected in the ASME/ANS PRA Standard [1] and Regulatory Guide 1.200 [4]. Internal floods are important to consider in a PRA because they represent an important class of *common cause initiating events*. As noted in the ANS/IEEE PRA Procedures Guide [5] common cause-initiating events are defined as:

> "…external and internal events that have the potential for initiating a plant transient and (to) increase the probability of failure in multiple systems. These events usually, but not always, cause sever environmental stresses on components and structures. Examples include fires, floods, earthquakes, losses of offsite power, aircraft crashes, and gas clouds."

The insight that Internal Flood events are potentially risk significant and should be addressed in a PRA has long been recognized. One of the first PRAs that identified Internal Flood as a significant contributor to core damage frequency (CDF) was the PRA completed for Oconee in 1984 [6]. A number of PRAs that have been completed since then have identified Internal Flood as either a dominant or significant risk contributor. The need to consider Internal Flood in a PRA is evident upon review of the reactor industry service experience with significant flooding events. A representative sample of some of the more severe Internal Flood events that have occurred is presented in Table 1-1 [7].

Table 1-1
Selected Nuclear Power Plant Events Involving Internal Flood

Plant	Date	Plant Building	Spill Rate [gpm]	Flood Volume [gallons]	Description
Quad Cities-1	6/72	Turbine Building	150,000	1,000,000	Rubber expansion joint rupture, RHR SW pumps and EDG cooling water pumps flooded out
Surry-2	12/86	Turbine Building	80,000	>> 100,000	18-inch diameter elbow in Feedwater System ruptured. Within minutes of the pipe rupture the Fire Protection System activated opening 62 sprinklers. The water from the sprinklers seeped into electrical panels and shorted out several electrical circuits.
Palo Verde-1	6/87	Turbine Building	40,300	500,000	Condenser outlet pipe ruptured, stairwell flooded
Foreign, PWR	5/88	Auxiliary Building	7,000	21,000	During refueling outage, LHSI pump suction valve inadvertently opened; both LHSI pump rooms flooded
FitzPatrick	9/96	Reactor Building	212	140,000	Fire Protection water system pipe rupture, MCC flooded causing HPCI system to be unavailable

Table 1-2
Selected Nuclear Power Plant Events Involving Internal Flood (cont'd)

Plant	Date	Plant Building	Spill Rate [gpm]	Flood Volume [gallons]	Description
Columbia River	6/98	Reactor Building	6,500	163,000	Fire Protection water system header ruptured due to water hammer, significant flooding RHR/LPCS pump rooms
South Texas-1	11/02	Turbine Building	3,300	300,000	Circ. Water pump casing ruptured, instrument cabinet knocked over, water up to 4 ft.

As seen in this table, floods have been caused by failures of safety and non-safety piping as well as other piping system components and also may occur as a result of human error in which no passive component has failed. The range of observed flood rates and flood volumes has been responsible for producing significant plant damage. Although none of these events resulted in a serious accident, all may be regarded as potential accident precursors.

1.3 Development of IFPRA Guidelines

A draft of this guideline was created for trial use in 2006. The draft guideline was used to support a number of Internal Flood PRA updates and upgrades, including one performed on the Fort Calhoun station. Lessons learned from these PRAs have been factored into the preparation of this version of the guide. Specific feedback from the Fort Calhoun study that was helpful in the preparation of this version is summarized in Section 1.3.1 below.

In addition to the lessons learned from IFPRAs, this guide has also benefited from the results of a survey that was performed by the PWR Owners Group to identify areas where additional guidance is needed. A summary of those areas is provided in Section 1.3.2 below.

1.3.1 Lessons Learned from Fort Calhoun IFPRA

The following key points summarize the lessons learned from the Ft. Calhoun pilot study that were especially useful in the preparation of this guide. A more complete summary is found in Appendix A.

Overall, the EPRI draft guidelines were found to be useful in initially structuring the IFPRA effort and identifying important flooding considerations at a high level; but there were a number of areas outlined below that would benefit from additional guidance. These technical areas are identified below together with a description of how the finalized IFPRA Guidelines address the recommendations for enhanced guidance:

- Additional guidance is needed to consider the dynamic effects of flooding such as the time dependent flood propagation effects that are difficult to analyze using a static model.
  - A new Section 4.4 (Example Problem for Flood Scenario Identification) has been added to expand on scenario aspects of this issue. Section 8.3.1 includes an example of an integrated flood isolation assessment that account for uncertainty in flood rates that are produced from a range of possible pipe break sizes.
- More guidance is needed to consider different responses of barriers such as doors and walls whose success or failure can influence the flood propagation and resulting damage to SSCs inside and outside the flood area.
  - Additional guidance has been added for the consideration of different flood barrier responses and the need to justify assumptions about barrier integrity. A new Appendix D has been added to provide an example of a flood door capacity evaluation from a recent IFPRA update.
- Additional guidance is needed to evaluate low-pressure stagnant water systems as well as the treatment of piping system components other than pipes.
  - Clarification was provided that low-pressure stagnant water conditions can indeed influence pipe failure rates and in fact this possibility has been considered in the partitioning of systems in the supporting failure rate report (EPRI report 1013141).

Future updates to EPRI report 103141 may provide additional guidance on the treatment of these water systems.

- The use of three general leak rate categories for flood modes—spray, flood, and major flood—was found to be useful to categorize the different possibilities for flood severity. Additional guidance is needed on the enumeration of different scenarios with different flood leak rates and pipe sizes.
- Additional insights to improve the criteria for qualitative screening, the treatment of maintenance-induced floods, and procedures to utilize databases and to optimize the timing and planning of the walk-down(s) were identified.
  - A new Section 5.6 (Maintenance Induced Floods) provides examples of qualitative and quantitative screening criteria for consideration of maintenance- induced floods.
- More guidance on how far away from a pipe failure to consider spray effects on equipment was requested.
  - Section 5.4 includes an example of flood initiating event analysis with spray impact considerations. The general guidance in Section 6.2.4.2 (Spray) has been expanded. The revised guidance considers potential spray effects by through-wall defects in moderate energy and high energy piping systems.
- A recommendation was made to incorporate roadmaps in the IFPRA documentation to enable peer reviewers to track compliance with ASME/ANS PRA Standard requirements.
  - Table 2-1 has been updated to reflect the requirements for IFPRA according ASME/ANS RA-Sa-2009. Section 9.3 (Roadmap to Support Peer Reviews) includes recommendations for IFPRA documentation
- Based on insights from plant operating experience, the possibility for flood propagation through cracks in concrete floors was identified, a possibility likely to have been overlooked in the absence of this experience.
  - Section 1.4.4 (Scope of Flood Sources) has been expanded to address failure of buried and concrete floor embedded piping and the potential for water to propagate through cracks in a concrete floor.

An effort was made to incorporate changes into this version of the guidance to address these useful insights as explained in the above sub-bullets. Future updates to this IFPRA guideline will be considered as improved treatments become available.

1.3.2 Results of 2009 Survey on IFPRA

The following highlights from the IFPRA Survey performed by the PWR Owners Group were found to be very useful in the preparation of this version of the guide.

- A total of nine PRA teams provided written responses to the survey, and each of these had recently performed an update or upgrade to their respective IFPRAs. Of these nine, six found internal floods to make either a significant or dominant contributor to CDF and/or LERF.
- About half of the respondents used the EPRI draft IFPRA guidelines, and most of the respondents used the companion EPRI report on pipe failure rates [7] as an input to the derivation of flood event frequencies.
- Most of the issues identified in the Fort Calhoun Pilot Study also appeared in the results of the survey, including such issues as distance for damage from sprays and treatment of barriers such as doors.
- There was a lack of consensus among respondents about whether the pipe failure rates reported in Reference [7] accounted for such non-pipe components as valve bodies, pump bowls, and heat exchanger vessels, even though that reference clearly states that such components are in fact included in those rates.
- Most of the respondents adopted the flood categories suggested in the current guidance, namely sprays, floods, and major floods.
- All the respondents included pressure boundary failures that cause flooding whereas about half of the respondents included human or maintenance-induced flooding.
- There was an indication in the responses that the rules of thumb given in the draft guidance for consideration of flood depth capacity of non-flood proof doors may have been misinterpreted in the sense that the rules were applied deterministically with no possibility given in the definition of flood scenarios that doors could fail or not fail at different flood heights.
- Some plants included the treatment of HELB events within the context of the IFPRA upgrade or update whereas other plants relied on assumptions based on the design basis HELB evaluation.
- There seemed to be a large variance among the respondents in the treatment of floor drains both as a means to mitigate the accumulation of water in a flood area and as a propagation path into sump tanks and rooms that could overfill and propagate into other areas.
- Most respondents did not take credit for equipment protection against moisture for spray events. There is a wide variation in the zone of influence that was used for spray effects. The zones ranged from the entire room to the implied 10-feet mentioned in the EPRI draft guideline.
- The respondents described varying approaches to the treatment of human actions to avert damage that would preclude an initiating event and those taken to mitigate the consequences of flood scenario in the PRA model.

1.3.3 Improvements to the Earlier Draft Guideline

Based on pilot applications and results from other industry feedback, the preliminary draft of this guidance was updated. Some of the significant changes that have been made include:

- Additional guidance is provided for the definition of a reasonably complete set of flood scenarios for each flood area for consideration in the screening, grouping, and PRA modeling of flood-induced initiating events.
- Additional guidance is provided for the treatment of flood barriers such as flood proof doors, non-water tight doors, and fire doors including application of “rules of thumb” for assumed door failure depth, deterministic evaluation of flood depth capacity of doors, and considerations for different flood door states in the development and evaluation of scenarios.
- Additional guidance is provided on the definition of flood severity categories—spray, flood, major flood—including application of “rules of thumb” for distance in consideration of spray damage effects on SSCs, need to incorporate insights from walkdowns to confirm spray damage assumptions, and the capability to refine the boundaries between flood severity categories based on plant specific and flood area specific factors.
- Appropriate updates were made to conform to the 2009 Addendum (RA-Sa-2009) version of the ASME/ANS PRA Standard.
- Additional guidance and clarification that the IFPRA guideline and the supporting technical requirements from the ASME/ANS PRA standard are applicable to pipe failures involving High Energy Line Breaks that may result in flooding and other adverse effects on the capability of plant SSCs to prevent and mitigate core damage events.

1.4 Scope

1.4.1 Scope of Plant Operating States

The scope of common cause initiating events covered in this guideline is limited to floods that are initiated from flooding sources within the nuclear power plant as well as flood initiating events while the reactor is at power. It is expected that the guidance that is provided herein will also be useful in the PRA of high energy line breaks (HELBs) which are difficult to separate from the events considered in an Internal Flood PRA. This difficulty is due to the facts that such events also involve the need to address the risk impacts of piping system failures and that Internal Flood is one of the possible consequences of a HELB. Indeed, some of the requirements in the ASME/ANS PRA standard for Internal Flood PRA address the consequences of a HELB. HELB events may cause floods either directly, or indirectly (e.g., by setting off the fire suppression sprinklers) but may also cause additional consequences due to the energy associated with the event such as thermally induced failures, pipe whip, and structural damage not associated with the flooding. The pipe failure data that is available to support Internal Flood PRA is also available to support HELBs.

The scope of this guideline is internal flood during power operation. Low power and shutdown applications are not the current focus of this guide nor did the pilots of this guide perform any detailed low power evaluations of this method. These methods, with modification, could be applied to low power and shutdown conditions as long as factors unique to these conditions are taken into account. In low power shutdown additional considerations would apply and would need to be addressed. Some of these considerations are, but are not limited to, the following:

- The PRA models for initiating events, success criteria, and accident sequences that interface with the flood scenarios would be specialized for different plant operating states
- Fewer piping systems are commissioned and pressurized.
- Large number of concurrent maintenance actions with systems opened up for various maintenance activities. Inadvertent spills of water may occur as a result of these activities.
- Low or no exposure to a potential high-energy line breaks in piping systems.
- Operating experience data show that about one third of all recorded significant Internal Flood events have occurred during shutdown operations [7].

The term “Internal Flood” implies an inadvertent or accidental release and accumulation of process medium within plant building structure. IFPRA is limited to consideration of impacts from releases or spills of cold/warm raw cooling water, wastewater, borated water, potable water, condensate, and steam flashing into hot water. The scope of these IFPRA guidelines excludes the following event types:

- Inadvertent actuation of containment spray systems or any pressure boundary failure within a containment structure. The containments and the equipment therein are designed to accommodate effects of loss-of-coolant accidents (LOCAs). Containment structures are not addressed in IFPRA.
- Any pressure boundary failure or inadvertent equipment actuation resulting in the release of lubricating oils or electro-hydraulic control (EHC) fluids. These types of events typically result in localized spraying of adjacent equipment, sometimes with a resulting fire, and should be addressed within the scope of an internal fire PRA.

1.4.2 Level of Detail

Depending on the objectives of a study and the plant-specific design characteristics including building and equipment arrangements, IFPRA can be performed at different levels of scope and detail. Flood areas are defined by dividing the plant into physically separated areas where flooding effects can be viewed as independent. A critical flood area is one that contains equipment determined to be important to plant safety (critical SSCs) as included in an internal events PRA model. Thus, a list of critical SSCs includes those modeled in the PRA as part of the success criteria and those that could challenge normal plant operation.

1.4.3 Pipe Pressure Boundary Failure Modes

Performing a detailed, comprehensive and well-structured flood hazard evaluation is a key to achieving a realistic, plant-specific IFPRA model. At each level of the flood hazard evaluation different types of passive component pressure boundary failure are considered including the following categories of loss-of-fluid events:

Sprays

Spray events are defined as pipe leaks that result in sprays that may damage susceptible SSCs due to spray impact. In most cases such events will not result in accumulation of water on the floor of the associated flood area. An underlying assumption in this definition is that a spill rate from a pressure boundary through-wall flaw is within the capacity of a floor drain system and that the drain system is functioning properly. Otherwise, spray events can result in flooding, albeit at a slower rate than events classified as floods or major floods as defined below. Local spray impacts are considered by identifying the equipment in each flood zone and determining the range of a potential spray zone and the effectiveness of spray shields. A detailed evaluation of potential spray impacts needs to acknowledge type of spray source and an engineering calculation of estimated spray pattern (angle and range) may be required. The resulting leak or spill rate is defined as well in excess of 1 gpm but usually no larger than 100 gpm. The lower bound is based on a criterion used in screening data for flood event frequencies; events with lower through-wall leak rates are screened out from this data. The upper bound flow rate is based on engineering judgment and insights accumulated by the authors in the review of service data and licensing basis flood level calculations. This upper bound flow rate of 100 gpm also corresponds to a typical capacity of a floor drain system. Hence, if the consequences of a flood event are limited to spray impact, the submergence of equipment in the area need not be considered. Spray event should therefore be assumed to fall in the range of 1 to 100 gpm unless the results of a site-specific design basis evaluation indicate otherwise.

Floods

Flood events are characterized as pressure boundary failures involving large through-wall flow rates and with accumulation of water on a building floor. In the flood hazard evaluation the upper bound for a resulting spill rate is chosen in such a way that it remains within a plant-specific flood design basis as defined in Standard Review Plan 3.4.1 [8]. The spill rate resulting from this type of pressure boundary failure may or may not challenge the capacity of a floor drain system depending on the design. The resulting spill rate is defined as in excess of 100 gpm but no larger than . 2000 gpm). This spill rate range is typically within the flood design basis in safety related structures. Note that the upper bound flow rate for a flood event in a given pipe is limited by the flow capacity of that pipe.

Major Floods

Major flood event are characterized as pressure boundary structural failure with a resulting spill rate beyond the flood design basis. A resulting spill rate is likely to exceed the capacity of a floor drain system. The result of a major structural failure is a rapid release of a large volume of process medium and with a spill rate in excess of 2,000 gpm. Note that some pipes may not be capable of producing a flood rate as high as 2,000gpm depending on the break size and capacity of the piping system. When it applies, the upper bound flow rate for this category is limited by the flow capacity of that pipe.

High Energy Line Break (HELB)

HELB is characterized by a large through-wall flow rate caused by a major structural failure in a high-energy line. A piping system is defined as high-energy if the maximum operating temperature exceeds 200 ºF or the maximum operating pressure exceeds 275 psig. By contrast, a piping system is defined as moderate energy if the maximum operating temperature is less than below 200 ºF of the maximum operating pressure is less than 275 psig. Consequential effects of HELB as well as Moderate-Energy Line Break (MELB) events are considered in an IFPRA.

1.4.4 Scope of Flood Sources

All fluid sources outside of the containment structure that have a potential to cause flooding and/or HELB impacts are to be considered in IFPRA. Included for consideration in IFPRA are the following system groups with associated piping and non-piping passive components:

- Safety Injection & Recirculation System (for example, High and Low Pressure Safety Injection, Core Spray, Recirculation, and Residual Heat Removal).
- Containment Spray System (only piping and tanks external to containment structure)
- Reactor Auxiliary Systems (for example, Component Cooling Water, Reactor Water Cleanup, Chilled Water, Chemical and Volume Control, Boric Acid, Standby Liquid Control, Spent Fuel Pool Cooling, and Radwaste)
- Auxiliary Cooling Systems (for example, safety related and non-safety related Service Water System)
- Feedwater and Condensate Systems (Main Feedwater, Auxiliary Feedwater, and Condensate)
- Main and Auxiliary Steam System
- Fire Protection Water System
- Utility systems (domestic/potable water systems, hot water/steam systems that are part of a building heating system).
- Buried piping: a pressure boundary failure of below-ground piping may result in water propagating through cracks in concrete floor. Plant aging management program documentation includes buried piping reliability considerations including degradation mechanism assessments of potential relevance to IFPRA.

These systems include high-energy, moderate-energy, and low-energy piping. Excluded from the above system scope are systems within the reactor coolant system pressure boundary whose failure would represent a loss of coolant accident (LOCA) as these events are addressed as part of the internal events analysis scope of the PRA.

Justification shall be provided for excluding pressure boundary failure of piping of a certain size. It is recommended that a flood hazard evaluation initially account for all potential spray/flood sources as well as the impact on adjacent equipment. Small-bore piping (less than 3-inch diameter) carrying cold, warm, or hot water is typically found in enclosed areas of plant buildings rather than in large open areas. Hence a blanket screening out of flood sources from small-bore pipe may not be justified. A requirement for a more detailed evaluation of small-bore piping needs to account for the different influence factors on the structural integrity, including type of system (moderate- vs. high-energy piping), degradation susceptibility (if any), inspection program, and routing of piping.

1.5 Objectives

The objectives of this guideline are to:

- Provide guidance on Internal Flood PRAs implementation that encourages consistency across the industry and saves resources in the development, maintenance, and review of these models.
- Provide guidance regarding acceptable approaches that are sufficient to meeting the requirements of the ASME/ANS PRA Standard (2009 Addendum A) associated with Internal Flood.

1.6 Approach

The Internal Flood PRA (IFPRA) guideline has been organized into three major phases of the analysis as shown in Figure 1-1. In the first phase of IFPRA, Qualitative Evaluation, the information that is needed for the IFPRA is collected and the initial qualitative analysis tasks are performed. The major outputs of this phase include the screening out of plant flood areas based on criteria associated with flood sources, flood propagation pathways, and potential impacts of floods on SSCs and the selection of flood areas for quantitative evaluation. There are four key tasks that are completed in this phase for the collection of information, performance of a plant walkdown, and completion of a qualitative screening evaluation of plant locations.

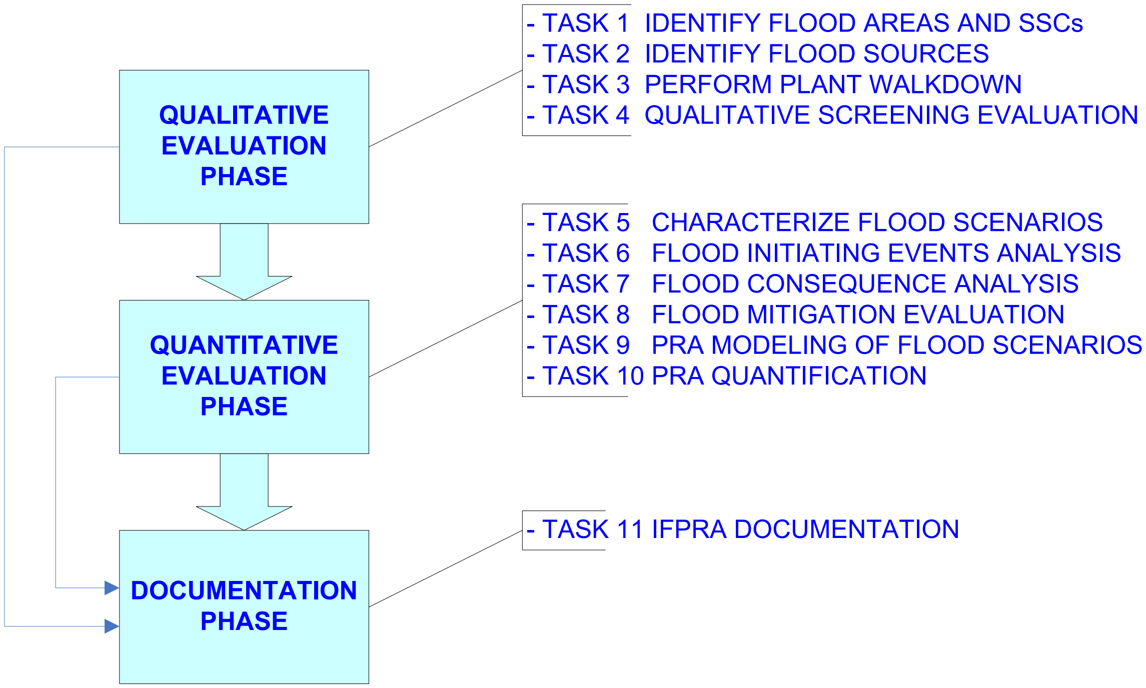


Figure 1-1
Major Phases and Tasks of IFPRA

Quantitative evaluations of flood areas, which have not been screened out, are addressed in six separate tasks that comprise the Quantitative Evaluation phase of IFPRA. These tasks are organized around the key steps in defining flood scenarios and quantifying their impacts in the PRA model in terms of their contributions to CDF and large early release frequency (LERF). These steps include the definition of flood scenarios in terms of flood initiating events, the consequences of the flood on SSCs, human actions to mitigate the consequences of the flood and to control the plant, and the interfacing of the flood scenario with the internal events PRA model. Once the scenarios have been properly characterized, this phase also addresses the quantification of the flood initiating event frequency, CDF, and LERF. The documentation phase, while being described in this guideline as separate task, is an ongoing effort that is being performed with each of the first 10 tasks.

1.7 Report Guide

The methodology of Internal Flood PRA is summarized in Section 2. In Section 3 the first four tasks comprising the qualitative phase of IFPRA are described and guidance in the performance of these tasks is provided. The remaining sections of this guideline track the remaining seven tasks comprising the quantitative and documentation phases of IFPRA with one section for each task.

Details on the lessons learned from the Fort Calhoun Pilot Study and IFPRA survey that was performed by the PWR Owners Group are found in Appendix A and B, respectively. Appendix C includes an example of how to calculate maximum flow rates for different combinations of pressure boundary failure (“spray”, “flood” and “major flood”), piping system, and pipe size. A sample evaluation of the capacity of a flood door to retain various flood heights is provided in Appendix D. Appendix E includes examples of Internal Flood plant walkdown checklists. Finally, Appendix F includes a description of the EPRI computer program FRANX for analyzing Internal Flood plant risk. This software requires a CAFTA PRA model to perform the flood risk evaluations.

2
OVERVIEW OF IFPRA METHODOLOGY

This chapter presents the purpose and scope of the EPRI Guideline for Internal Flood PRA (IFPRA). It defines the IFPRA process and the specific analysis steps and iterations between analysis steps. Included in this chapter is a description of how this IFPRA guideline relates to the ASME/ANS PRA Standard.

2.1 Internal Flood PRA Methodology Overview

Depending on the starting point (e.g., previous flood hazard evaluations, known plant specific vulnerabilities), a flood hazard evaluation may be performed in four levels of detail, each level of evaluation more refined than the previous one:

- Level 1. At the first level of analysis, a plant is divided into broad areas, generally corresponding to the major plant buildings that can be identified as having a significant degree of independence with respect to Internal Flood. In combination with any pre-existing information on plant vulnerabilities, plant walkdowns are performed to document flood areas, equipment inventories, and potential flood propagation pathways.
- Level 2. At the second level of evaluation, the examination of flood locations may focus on a particular building such as the Auxiliary Building for a pressurized water reactor (PWR) or Reactor Building for a boiling water reactor (BWR). Each elevation is systematically reviewed for flood source and safety related equipment. Plant features that could mitigate possible floods would be identified. Qualitative screening of flood areas could commence by identifying those areas where further evaluation is not needed.
- Level 3. Building elevation specific flood scenarios are defined by flood source, consequence of flood isolation, and flood impact. Next, a set of distinct flood damage states are defined, each corresponding to a progressively increased severity of equipment loss. These flood damage states should differentiate between successful and unsuccessful flood isolation and the local and global impact on equipment and plant operability.
- Level 4. In the final level of analysis, the flood scenario definitions are subjected to a detailed technical review to ensure consistency and realism. This stage of the evaluation includes refined assessments of different flood mitigation strategies and would include operator interviews (licensed and non-licensed personnel, training staff, and procedure writers) to ascertain the validity of the scenario.

These levels can be translated into eleven tasks. The guidance identifies each of the tasks and the actions that should be taken to complete the task. The major phases of IFPRA are expanded into the key steps of the methodology in Figures 2-1, which describes the qualitative elements, and 2-2, which describes the quantitative elements. These figures identify the major tasks of IFPRA and some of the key outputs and decisions made in each phase of the approach. The methodology begins by collecting key information that is needed to define flood areas for the evaluation as described in Figure 2-1. It should be noted that performance of an IFPRA is highly iterative, and the tasks are not necessarily performed in this sequence. In addition, updates and upgrades of existing IFPRAs will not need to necessarily repeat all the tasks for all flood areas, sources, and scenarios. For these reasons, prospective users of this guide are encouraged to review the entire guide prior to planning the work in order to optimize the allocation of resources and sequencing of activities.

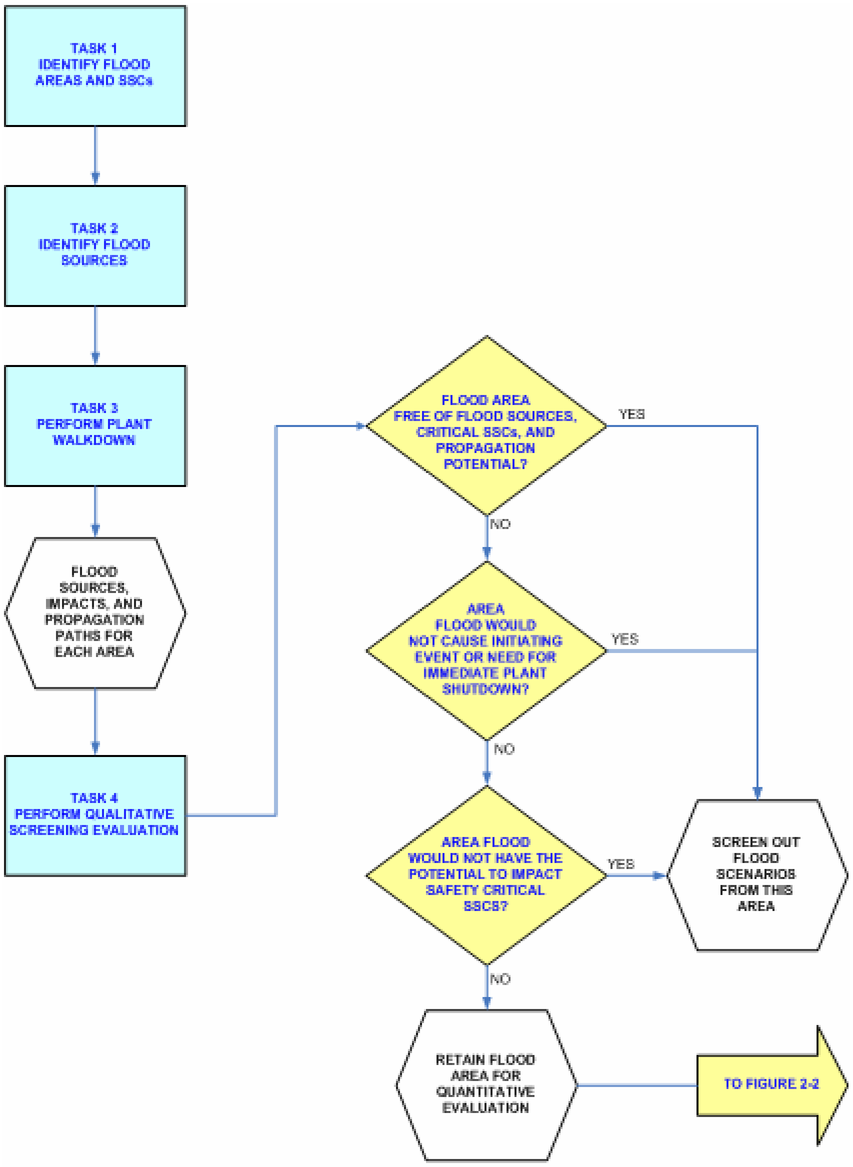


Figure 2-1
Major Steps and Tasks in the Qualitative Phase of IFPRA

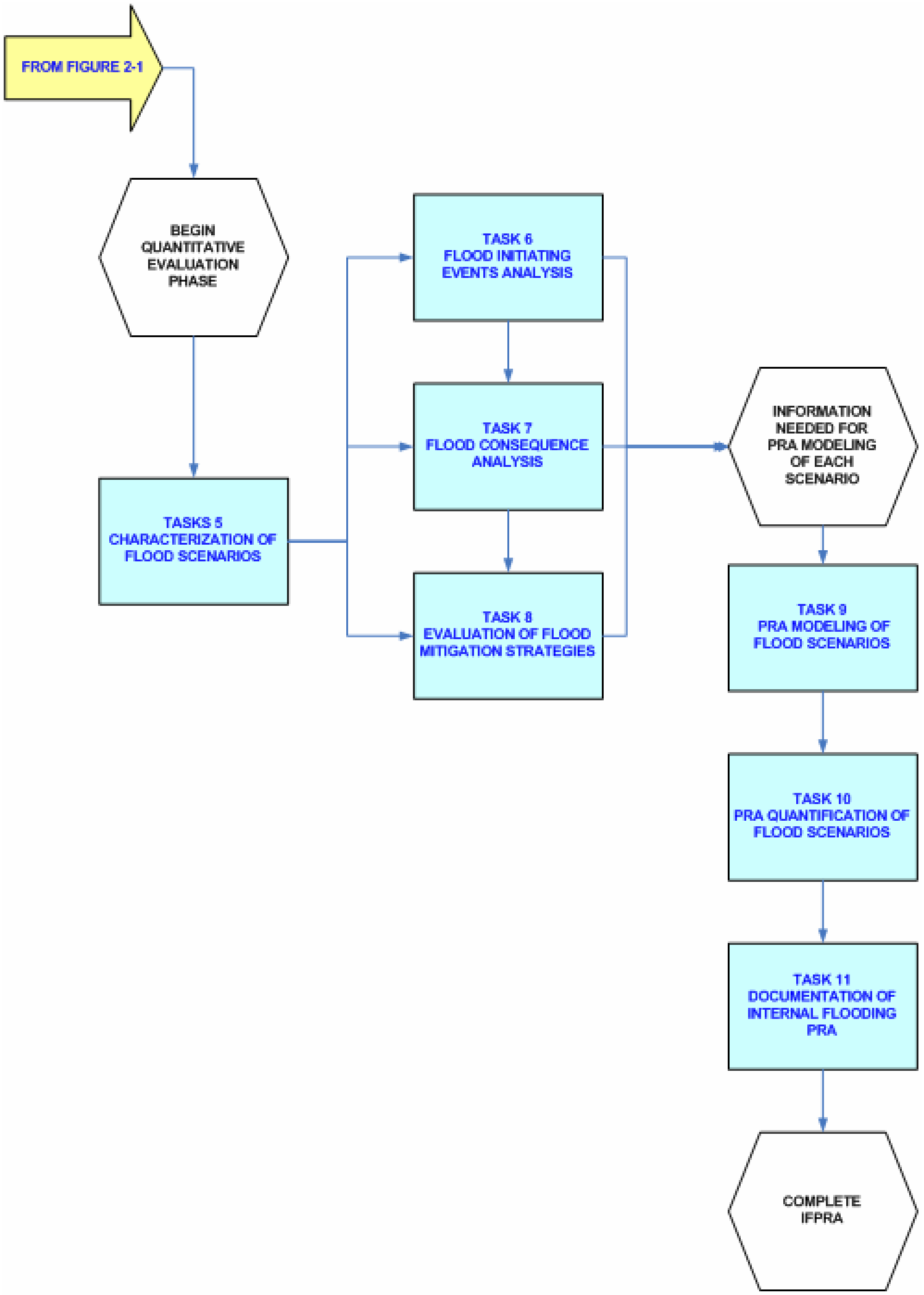


Figure 2-2
Major Steps and Tasks in the Quantitative and Documentation Phases of IFPRA

Qualitative Tasks

In Task 1, existing plant information sources are used to support the definition of flood areas and to identify the SSCs located within each flood area. For example, flood areas are defined with three considerations in mind: First, flood areas facilitate the identification of areas where a flood may impact SSCs that could cause an initiating event or need for immediate plant shutdown, damage equipment needed to respond to an initiating event, or both. Second, flood areas facilitate the identification of sources of flooding as well as flood failure mechanisms that need to be considered; and this is the focus of Task 2. And finally, flood areas are defined to characterize the different flood propagation pathways that need to be considered. Examples of existing information sources include Appendix R fire areas along with the safe shutdown equipment identified for each zone, information compiled in support of RI-ISI program development, and spatial information contained in Standard Review Plan 3.4.1 [8] flood level calculations. Before pursuing any screening of flood areas, existing spatial information must be confirmed and augmented through plant walk-downs including detailed reviews of plant arrangement drawings as delineated in Task 3.

Note that although the plant walkdown is listed in Figure 2-1 as part of the qualitative evaluation, the purposes of the walkdown also support several critical aspects of the quantitative evaluation as well. The primary purposes of the walkdown include verifying assumptions regarding the plant partitioning into flood areas, identification of flood sources, and development of key inputs for the formulation of flood scenarios. One or more walkdowns may be needed to complete all these tasks.

On the basis of the information collected in the first three tasks, flood areas are screened based on criteria that consider the potential for flood initiation and propagation, potential for an initiating event or need for immediate plant shutdown, and damage to SSCs that may be needed to prevent core damage or large early release in response to the initiating event or plant shutdown.

Quantitative Tasks

As shown in Figure 2-2, the quantitative phase begins with the development of flood scenarios for all the unscreened plant locations as accomplished in Task 5. Each location will typically have multiple scenarios as defined by the different flood sources, piping system failure modes (e.g., spray, flood, and major flood), and different possibilities for flood propagation and mitigation. The definition of the flood scenarios is actually started in the qualitative phase and in particular during the plant walkdowns in Task 3. In Task 6 the possible plant initiating events that could be caused by the flood are identified and modeled to the extent needed to support quantification of the initiating event frequency. The initiating events are defined within the scope of the IFPRA. Even if the flood does not directly cause an initiating event, if there is a need for an immediate plant shutdown (e.g. a manual plant shutdown required by the technical specifications) from a power operation mode, the scenario is still considered because the possible damage to SSCs from the flood could increase the probability of core damage or large early release.

The definition and the modeling of the consequences of the plant flooding initiating event are accomplished in Task 7. This task includes an evaluation of the susceptibility of SSCs to each of the flood failure modes and mechanisms included in the scenario definition. This evaluation may include the effects of sprays, submergence, or energetic phenomena if the event is associated with a HELB. The modeling of the human actions involved in the flood scenarios and quantification of the associated human error probabilities are accomplished in Task 8. These actions include the possibility of human-caused flooding, actions to terminate and mitigate the consequences of the flood, as well as actions taken to control the plant in response to the initiating event or plant shutdown. The treatment of dependencies among the various actions that are going on concurrently in coping with the flood and managing the abnormal and emergency operating procedures is a critical issue for this task.

The ultimate goal of the IFPRA is to calculate the contribution of Internal Flood to CDF and LERF. This calculation requires an interface between the definition of the flood scenario and its initiating event frequency and the plant PRA model. This modeling interface is performed in Task 9. In Task 10, the event sequences associated with Internal Flood are quantified. Quantification is normally done in stages including a screening stage where conservative assumptions are used to identify the most important flood scenarios and a detailed quantification phase where the modeling and quantification of the unscreened scenarios are brought up to the appropriate ASME/ANS PRA standard requirements.

The documentation process for IFPRA is described in Task 11. Actually, it is highly advisable to document the IFPRA as each task is performed so that by the time that Task 10 is completed, only the results of the evaluation need to be documented.

Detailed guidance in the performance of each of the eleven tasks is provided in the remaining sections of this guide. Brief task descriptions are provided below.

2.2 IFPRA Task Overview

These IFPRA guidelines address the eleven tasks required for performance of a comprehensive IFPRA study. The defined tasks, including objectives, sequence of analysis steps, and input/output requirements are consistent with the ASME/ANS PRA Standard [1]. The tasks to perform a comprehensive IFPRA study are:

Task 1 Identify Flood Areas and SSCs

The purpose of this task is to identify the independent flood areas of the plant and the SSCs located within these areas High Level Requirement (HLR), HLR-IFPP-A, and HLR-IFPP-B. Guidance for this task is provided in Section 3. In the ASME/ANS PRA Standard, this activity is referred to as plant partitioning.

Task 2 Identify Flood Sources

The purpose of this task is to identify the potential flood sources in the plant and their associated flooding mechanisms (HLR-IFSO-A and HLR-IFSO-B). Guidance for this task is provided in Section 3.

Task 3 Perform Plant Walkdown

The purpose of this task is to conduct walkdowns to verify information used in the above tasks and to support the development and quantification of flood scenarios (ASME/ANS PRA Standard Supporting Requirements IFPP-A5, IFSO-A6, IFSN-A17, and IFQU-A11). The output from this task includes all the necessary information for flood scenario development, flood consequence assessment, flood mitigation, flood initiating event characterization, and flood scenario quantification. The information collected during walkdowns and the way it is assembled very strongly influences the way subsequent tasks are performed and the effectiveness by which they are executed. Guidance for this task is provided in Section 3. Since the walkdown supports both qualitative and quantitative aspects of the IFPRA the time of the walkdown is best postponed until after a preliminary set of flood scenarios has been identified. Alternatively, multiple walkdowns may be performed to support different phases of the IFPRA

Task 4 **Perform Qualitative Screening Evaluation**

The purpose of this task is to perform an exhaustive screening evaluation of all areas of the plant based on criteria provided in this report that consider three aspects of flood area importance in IFPRA: 1) the sources of flooding; 2) the flood propagation pathways; and 3) the consequences of flooding in terms of flood initiating events and the impacts on SSCs that are needed to prevent core damage and large early release in response to the initiating events. Guidance for this task is provided in Section 3.

Task 5 **Characterize Flood Scenarios**

The purpose of this task is to develop the potential flooding scenarios for each flooding source by identifying the flood source and associated failure mode, the propagation paths of the fluid, and the affected SSCs (HLR-IFSN-A and HLR-IFSN-B). The effects of spraying, local, or global flooding on plant operability and safety and the manual and automatic responses to an impending or imminent flood event are considered. Guidance for this task is provided in Section 4.

Task 6 **Flood Initiating Events Analysis**

The purpose of this task is to identify the flooding induced initiating events and estimate their frequencies (HLR-IFEV-A and HLR-IFEV–B) and supporting requirements). The majority of flood induced-initiating events involves some form of passive component failure, but maintenance-induced and other human error induced events are also considered. This report provides guidance on the development of internal flooding analysis at power conditions. It should be noted that internal flood analysis may also be applicable during other modes of operation that are not currently addressed in this report. Hence, there is not necessarily a one-to-one correspondence between the flood scenarios and the PRA modeled event sequences. Even when the flood does not directly cause an initiating event, if there is a need for immediate plant shutdown from a plant operating state, then the plant shutdown event constitutes the initiating event. Guidance for this task is provided in Section 5.

Task 7 Flood Consequence Analysis

The purpose of this task is to evaluate the impact on equipment, including failures by submergence, jet impingement, spray, pipe whip, humidity, condensation and temperatures (HLR-IFSN-A and HLR-IFSN-B). In view of the range of consequences that must be considered, this guidance is also useful for the PRA modeling of HELBs. For multi-unit sites with shared systems or structures, include multi-unit impacts. Guidance for this task is provided in Section 6.

Task 8 Evaluate Flood Mitigation Strategies

This evaluation consists of human reliability analysis (HRA) of actions taken by Main Control Room operators as well as by auxiliary operators out in the plant to terminate the flood and secure the plant. The evaluation must include considerations of equipment access restrictions, risk of electrocution, additional workload and stress, and uncertainty in event progression (HLR-IFSN-A and HLR-IFSN-B). For example the flood may trigger the plant emergency operating procedures as well as additional abnormal operating procedures to recover systems lost during the flood. Hence, the treatment of dependency among multiple concurrent human actions that must be performed to prevent core damage is a major challenge for some of the more severe types of flooding. Recovery actions are defined as operator actions that have the ability to terminate the flood impacts and propagation. Include evaluation of available times and identify existing flood alarms and procedures (IFSN-A14). Guidance for this task is provided in Section 7.

Task 9 PRA Modeling of Flood Scenarios

The results of Tasks 5 through 8 are integrated into the PRA model to support the calculation of flood induced CDF and LERF in this Task 9. This task includes the finalization of flood scenario development by modifying or developing new fault trees and completing IF accident sequence models and the performance of evaluations by examining potential propagation paths, giving credit for appropriate flood mitigation systems and operator actions, and identifying susceptible SSCs that are included in the PRA model (HLR-IFSN-A and HLR-IFSN–B and their supporting requirements). Guidance for this task is provided in Section 8.

Task 10 PRA Quantification of Flood Scenarios

The purpose of this task is to perform quantification of flooding-induced accident sequences. This task includes the performance of quantitative screening analysis to manage a potentially large number of scenarios and locations that have not been screened out previously. Another key purpose of this task is to develop IFPRA results and insights, and perform uncertainty and sensitivity analysis (HLR-IFQU-A and HLR-IFQU-B). Guidance for this task is provided in Section 8.

Task 11 Documentation of IFPRA

The purpose of this task is to capture all the requirements associated with the preparation of the IFPRA report and supporting documentation including peer review (HLR-IFPP-B, IFSO-B, IFSN-B, IFEV-B, and IFQU-B and their supporting requirements). Actually, the documentation of each task should be performed when that task is performed, so by the time that Task 10 is completed, the remaining documentation is limited to the documentation of the results and risk insights. As a general rule, the documentation should be sufficient to demonstrate that each of the relevant requirements of the ASME/ANS PRA standard for IFPRA has been met. A roadmap for peer reviewers to locate documentation of meeting each HLR and SR is recommended for inclusion into the documentation.

2.3 ASME/ANS PRA Standard Requirements for IFPRA

Part 3 of the ASME/ANS PRA Standard (ASME/ANS RA-Sa-2009 [1], addenda to the ASME/ANS PRA Standard ASME/ANS RA-S-2008), includes requirements for performing IFPRA. These requirements are reproduced in Table 2-1 and are broken down into the following elements of an IFPRA:

Internal Flood Plant Partitioning (IFPP)

Internal Flood Source Identification and Characterization (IFSO)

Internal Flood Scenarios (IFSN)

Internal Flood Induced Initiating Events (IFEV)

Internal Flood Induced Accident Sequences and Quantification (IFQU)

For each of these IFPRA elements, the Standard and Table 2-1 have a set of High Level and Supporting Requirements. Note that in previous versions of the Standard, IFPRA was a single PRA element within the scope of an internal events full power PRA. In the current version of the

PRA Standard, Internal Floods is defined as a separate "hazard group" and has been subdivided into the above IFPRA elements. However, at the Supporting Requirement level there is a consistent set of requirements between the different versions of the standard. The primary difference is that instead of having one high level requirement for the entire IFPA documentation as done in the previous version of the Standard, the current Standard has different high level and supporting documentation requirements for each of the above IFPRA elements. These changes helped to organize the standard to include additional requirements for internal hazards and external events.

Included in Table 2-1 are references to corresponding Tasks and section(s) of this guideline that include IFPRA task descriptions and guidance. While the tasks in this guideline are organized a little differently, there is available guidance in this report for each of the technical issues addressed in both the High Level and Supporting Requirements. To help the analyst, the appropriate ASME requirements are identified at the beginning of each of the guide's sections.

This table does not include descriptions of the actual supporting requirements from the PRA Standard, which can be obtained from the PRA Standard itself; but the general topics of each of the requirements are included.

When using this guidance and the ASME/ANS PRA Standard, care must be used in the definition of the terms "Flood Scenario" and "Initiating Event." The term Initiating Event does not refer to the occurrence of the flood per se, but rather the plant disturbance or transient that begins an accident sequence. If a flood leads to a reactor trip, the reactor trip transient is the initiating event that is induced by the flood. As illustrated in Figure 2-3, the ASME/ANS PRA Standard includes requirements for treatment of flood scenarios that cover only part of the entire flood scenario as the term is used in this guideline. The ASME/ANS PRA Standard includes additional requirements for the treatment and quantification of flood induced initiating events and accident sequences. In this guideline, all of these elements are regarded as part of the flooding scenario.

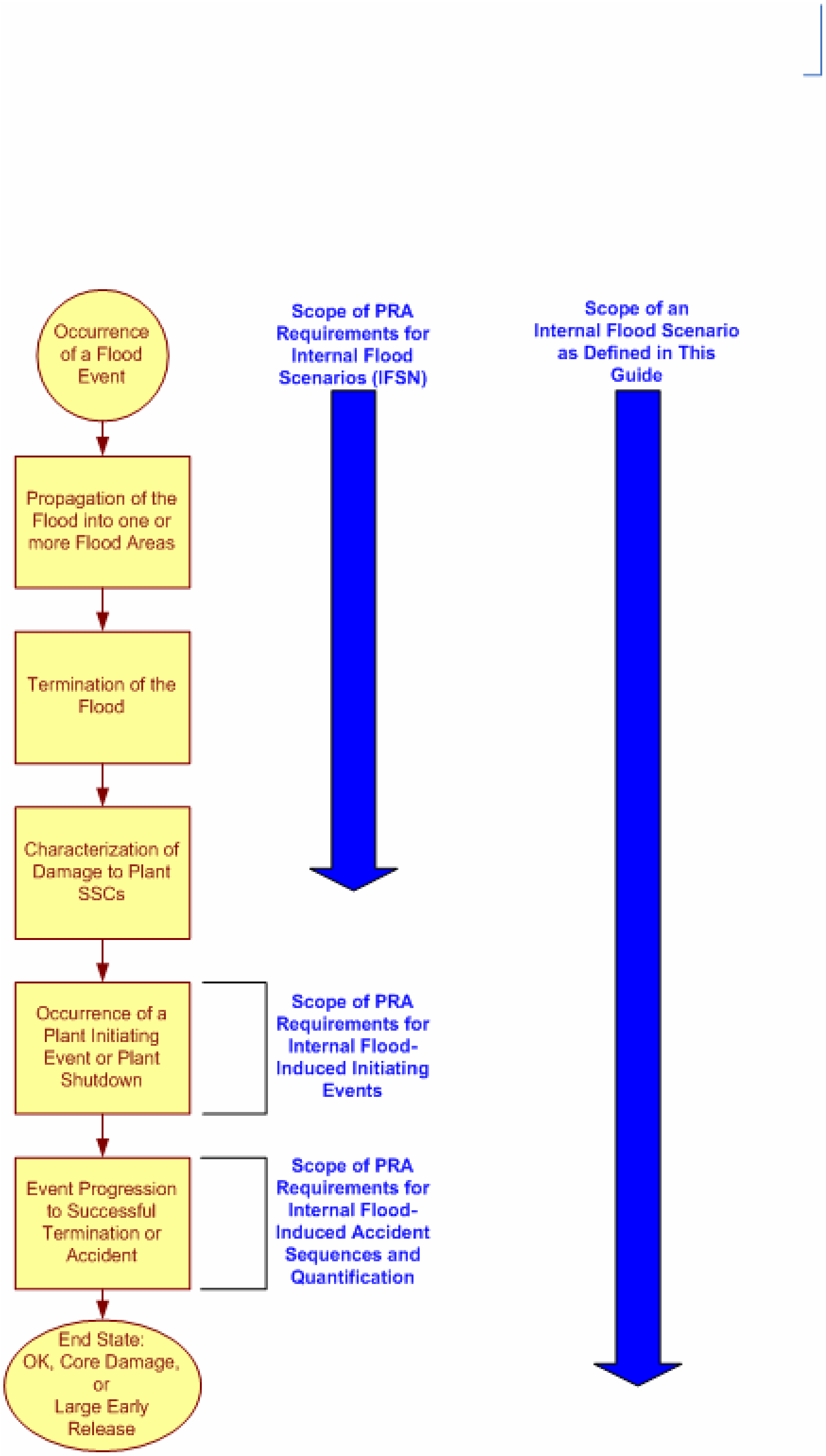


Figure 2-3
Comparison of ASME/ANS PRA Standard and this Guidance Concept of Flood Scenarios

Table 2-1
Requirements for IFPRA According to ASME/ANS RA-Sa-2009

Designator	Requirement Topic	Task and Section in This Document
INTERNAL FLOOD PLANT PARTITIONING - IFPP		
HLR-IFPP-A	A reasonable complete set of flood areas of the plant shall be identified	Task 1, Sec. 3
Supporting Requirements for HLR-IFPP-A		
IFPP-A1	Requirement to define physically separate areas	Task 1, Sec. 3
IFPP-A2	Requirement to consider propagation paths and barriers	Task 1, Sec. 3
IFPP-A3	Requirement for multi-unit site areas	Task 1, Sec. 3
IFPP-A4	Requirement for use of plant information sources	Task 1, Sec. 3
IFPP-A5	Requirement for plant walk-down to confirm areas	Task 3, Sec. 3
HLR-IFPP-B	Documentation of the internal flood plant partitioning shall be consistent with the applicable supporting requirements.	Task 11, Sec. 11
Supporting Requirements for HLR-IFPP-B		
IFPP-B1	Documentation requirement for PRA applications, upgrades, and peer review.	Task 11, Sec. 9
IFPP-B2	Documentation requirement for the process to define areas	Task 11, Sec. 9
IFPP-B3	Documentation requirement to address uncertainties in plant area definition	Task 11, Sec. 9
INTERNAL FLOOD SOURCE IDENTIFICATION AND CHARACTERIZATION - IFSO		
HLR-IFSO-A	The potential flood sources in the flood areas, and their associated Internal Flood mechanisms, shall be identified and characterized	Task 2, Sec. 3
Supporting Requirements for HLR-IFSO-A		
IFSO-A1	Requirement to consider types of sources	Task 2, Sec. 3
IFSO-A2	Requirement for multi-unit site sources	Task 2, Sec. 3
IFSO-A3	Requirement for screening out based on sources	Task 2, Sec. 3
IFSO-A4	Requirement to address flooding mechanisms	Task 2, Sec. 3
IFSO-A5	Requirement to address flood source characteristics	Task 2, Sec. 3
IFSO-A6	Requirement for a plant walk-down to confirm sources	Task 3, Sec. 3
HLR-IFSO-B	Documentation of the internal flood sources shall be consistent with the applicable supporting requirements.	Task 11, Sec. 9

Table 2-1 (continued)
Requirements for IFPRA According to ASME/ANS RA-Sa-2009

Designator	Requirement Topic	Task and Section in This Document
Supporting Requirements for HLR-IFSO-B		
IFSO-B1	Documentation requirement for PRA applications, upgrades, and peer review.	Task 11, Sec. 9
IFSO-B2	Documentation requirement for the process to define sources	Task 11, Sec. 9
IFSO-B3	Documentation requirement to address uncertainties in flood source identification	Task 11, Sec 9
INTERNAL FLOOD SCENARIO DEVELOPMENT - IFSN		
IFSN-A	The potential Internal Flood scenarios shall be developed for each flood source by identifying the propagation path(s) of the source and the affected systems, structures, and components (SSCs).	Task 4, Sec. 3 Task 5, Sec. 4 Task 7, Sec. 6 Task 8, Sec 7
Supporting Requirements for HLR-IFSN-A		
IFSN-A1	Requirement to identify propagation path	Task 4, Sec. 3
IFSN-A2	Requirement to identify plant design features important for flood propagation	Task 4, Sec. 3 Task 8, Sec. 7
IFSN-A3	Requirement to identify factors that could terminate the flood	Task 4, Sec. 3 Task 8, Sec. 7
IFSN-A4	Requirement to assess the capability of barriers and flood mitigation measures	Task 4, Sec. 3 Task 5, Sec. 4
IFSN-A5	Requirement to identify SSCs modeled in the PRA that could be damaged by the flood	Task 4, Sec. 3 Task 7, Sec. 6
IFSN-A6	Requirement to assess the susceptibility of SSCs to various flood mechanisms	Task 4, Sec. 3 Task 7 Sec. 6
IFSN-A7	Requirement to justify credit for SSCs to mitigate the flood	Task 4, Sec. 3 Task 7, Sec. 6
IFSN-A8	Requirement to consider inter-area flood propagation	Task 4, Sec. 3 Task 7 Sec. 6

Table 2-1 (continued)
Requirements for IFPRA According to ASME/ANS RA-Sa-2009

Designator	Requirement Topic	Task and Section in This Document
Supporting Requirements for HLR-IFSN-A		
IFSN-A9	Requirement to justify barrier capabilities with supporting analyses	Task 4, Sec. 3 Task 7, Sec. 6
IFSN-A10	Requirements for factors to address in defining flood scenarios	Task 4, Sec. 3 Task 5, Sec. 4
IFSN-A11	Requirement to consider unique scenarios for multi-unit sites with shared systems or structures	Task 4, Sec. 3 Task 7, Sec. 6
IFSN-A12	Requirement for application of screening criteria for flood scenarios	Task 4, Sec 3
IFSN-A13	Additional requirements for screening of flood scenarios	Task 4, Sec. 3
IFSN-A14	Requirement for use of human recovery action consideration to screen out flood scenarios	Task 4, Sec. 3 Task 8, Sec. 7
IFSN-A15	Requirements for considerations regarding insufficiency of flood potential, adequacy of mitigation means, and subsuming floods into systems analysis as reasons for screening out flood scenarios.	Task 4, Sec. 3
IFSN-A16	Additional requirements for using recovery action considerations for screening out flood scenarios	Task 4, Sec. 3 Task 8, Sec. 7
IFSN-A17	Requirement for a plant walkdown to verify flood scenarios	Task 3, Sec. 3
HLR-IFSN-B	Documentation of the internal flood scenarios shall be consistent with the applicable supporting requirements.	Task 11, Sec 9
Supporting Requirements for HLR-IFSN-B		
IFSN-B1	Documentation requirement for PRA applications, upgrades, and peer review.	Task 11, Sec. 9
IFSN-B2	Documentation requirement for process used to identify applicable flood scenarios.	Task 11, Sec. 9
IFSN-B3	Documentation requirement for treatment of uncertainty	Task 11, Sec. 9
INTERNAL FLOOD INDUCED INITIATING EVENT ANALYSIS - IFEV		
IFEV-A	Plant Initiating events caused by Internal Flood shall be identified and their frequencies estimated.	Task 6, Sec. 5

Table 2-1 (continued)
Requirements for IFPRA According to ASME/ANS RA-Sa-2009

Designator	Requirement Topic	Task and Section in This Document
Supporting Requirements for HLR-IFEV-A		
IFEV-A1	Requirement to associated flood initiating event with internal initiating event group	Task 6, Sec. 5
IFEV-A2	Requirement for grouping of flood scenarios into initiating event groups	Task 6, Sec. 5
IFEV-A3	Requirement that limits subsuming and grouping of flood scenarios	Task 6, Sec. 5
IFEV-A4	Requirement for grouping flood scenarios that involve multi-unit impacts	Task 6, Sec. 5
IFEV-A5	Requirement to estimate the flood initiating event frequency	Task 6, Sec. 5
IFEV-A6	Requirement for the approach used to estimate the flood initiating event frequency	Task 6, Sec. 5
IFEV-A7	Requirement to include human induced flood initiating events	Task 6, Sec. 5
IFEV-A8	Requirement for screening out flood initiating events based on frequency and impact considerations	Task 4, Sec. 3 Task 10, Sec.9
HLR-IFEV-B	Documentation of the internal flood-induced initiating events shall be consistent with the applicable supporting requirements.	Task 11, Sec. 9
Supporting Requirements for HLR-IFEV-B		
IFSN-B1	Documentation requirement for PRA applications, upgrades, and peer review.	Task 11, Sec. 9
IFSN-B2	Documentation requirement for process used to estimate flood initiating event frequencies	Task 11, Sec. 9
IFSN-B3	Documentation requirement for treatment of uncertainty	Task 11, Sec. 9
INTERNAL FLOOD ACCIDENT SEQUENCES AND QUANTIFICATION - IFQU		
IFQU-A	Internal Flood-induced accident sequences shall be quantified.	Task 10, Sec. 9
Supporting Requirements for HLR-IFQU-A		
IFQU-A1	Requirement to select and confirm the correct modeling of flood induced accident sequences	Task 10, Sec. 9
IFQU-A2	Requirement to model the dependent failures of the SSCs damaged by the flood in the system models	Task 9, Sec. 8
IFQU-A3	Requirement for screening out flood induced accident sequences based on frequency and impact considerations	Task 10, Sec. 9
IFQU-A4	Requirement for the performance of additional data analyses that may be introduced by the flood	Task 10, Sec. 9

Table 2-1 (continued)
Requirements for IFPRA According to ASME/ANS RA-Sa-2009

Designator	Requirement Topic	Task and Section in This Document
Supporting Requirements for HLR-IFQU-A		
IFQU-A5	Requirement for the performance of additional human reliability analyses that may be introduced by the flood	Task 8, Sec. 7
IFQU-A6	Requirement to consider additional performance shaping factors that are introduced by the flood	Task 8, Sec 7
IFQU-A7	Requirement to invoke requirements defined for internal initiating event sequence quantification for floods	Task 10, Sec. 9
IFQU-A8	Requirement that the internal flood induced event sequences account for SSC failures resulting from and independent of the flood	Task 10, Sec. 9
IFQU-A9	Requirement to include both direct and indirect causes of SSC failures from the flood	Task 10, Sec. 9
IFQU-A10	Requirement to incorporate flood induced accident sequences in the evaluation of LERF	Task 10, Sec. 9
IFQU-A11	Requirement for a walkdown to verify proper modeling and quantification of event sequences	Task 3, Sec. 1
HLR-IFQU-B	Documentation of the internal flood accident sequences and quantification shall be consistent with the applicable supporting requirements.	Task 11, Sec. 9
Supporting Requirements for HLR-IFQU-B		
IFQU-B1	Documentation requirement for PRA applications, upgrades, and peer review.	Task 11, Sec. 9
IFQU-B2	Documentation requirement for process used to model and quantify event sequences	Task 11, Sec. 9
IFQU-B3	Documentation requirement for treatment of uncertainty	Task 11, Sec. 9

3

TASKS 1-4 ASSOCIATED WITH QUALITATIVE FLOOD PHASE OF IFPRA

This chapter describes the IFPRA tasks associated with the qualitative phase of Internal Flood evaluation and the approach to meeting High Level (HLR) and Supporting Requirements (SRs) of the following ASME/ANS Internal Flood Hazard Group Elements:

- Plant Partitioning HLRs: HLR-IFPP-A and HLR-IFPP-B
- Internal Flood Source Identification and Characterization HLRs: HLR-IFSO-A and HLR-IFSO-B
- Internal Flood Scenarios HLRs: HLR-IFSN-A and HLR-IFSN-B

Closely interrelated, Tasks 1 through 3 of the IFPRA methodology provide for a systematic identification and evaluation of flood *areas*, *sources*, and *mechanisms*. The information compiled and evaluated in Tasks 1 through 3 provides the required input for definition of flood pathways, flood scenarios, and operator actions to isolate floods. Task 1 (flood area definition) and Task 2 (flood source definition) may be performed concurrently. Task 3 (plant walkdown) verifies the results of previous tasks. This phase is completed by Task 4 in which a qualitative screening evaluation of flood areas is performed; and potentially risk significant areas are selected for the subsequent quantitative evaluation phase, which is covered in the remaining sections of this guideline.

3.1 Task 1 - Define Flood Areas

ASME/ANS PRA Standard HLRs HLR-IFPP-A and HLR-IFPP-B and SRs IFPP-A1 through IFPP-A5 and IFPP-B1 through IFPP-B3 specify the requirements for identifying and documenting a reasonable complete set of flood areas.

An iterative process is used for the definition of flood areas to be included in the IFPRA work scope. This process starts by identifying those plant structures and areas where equipment identified as important to the PRA model as either having a mitigating function of an initiating function is located, including structures and areas potentially acting as flood water source and conduits for flood water.

The scope of the IFPRA and general knowledge of plant building design and equipment locations determine the overall approach to flood area definition and which structures and areas to include and exclude for further consideration. Invariably the IFPRA scope includes potential flood areas and flood sources in Auxiliary Buildings and Reactor Buildings. Flood propagation pathways from other building structures may or may not be considered because of plant-specific arrangements and layouts, as indicated below:

- Containment. During routine power operation the containment is closed and independent of other buildings from a flooding standpoint. The equipment inside this structure is qualified for post-accident environment, which includes the effects of containment spray system actuation. Any adverse effects of water accumulation due to loss of primary coolant are considered within the loss-of-coolant accident (LOCA) models. Therefore, flooding is not a unique threat to the operability of equipment in the containment, and the structure is not included in IFPRA.
- Auxiliary Building for PWR. This is a multi-story building housing equipment and piping associated with systems for residual heat removal, chemical and volume control, safety injection, closed-loop, cooling and radioactive waste systems, plus necessary air handling and cooling equipment for the building. The building consists of open areas and enclosed areas for certain equipment to provide biological shielding for operating personnel. The building also includes electrical switchgear rooms, cable spreading rooms, and a control room for radioactive waste system. Some dual reactor unit sites have a shared auxiliary building structure. Since the auxiliary building includes equipment important to plant safety, it requires room-by-room and area-by-area assessment of the possibility of a flood-induced core damage scenario. It is generally expected that few if any areas within this structure will be screened out from an evaluation. Potential flood pathways from adjacent buildings into the Auxiliary Building are included in the work scope.
- Reactor Building for BWR. The reactor building is either a square or circular limited leakage building that entirely surrounds containment and has multiple stories. The top floor (i.e., refueling floor) has a spent fuel storage pool, refueling equipment, and a reactor service crane. The remainder of the building houses the following systems:
    - Control rod drive hydraulic system
    - Reactor water cleanup system
    - Standby liquid control system
    - High-pressure core spray system
    - Low-pressure core spray system
    - Automatic blowdown system
    - Residual heat removal system
    - Reactor core isolation system
    - Spent fuel cooling system
    - Closed loop cooling system
    - Standby gas treatment system
    - Ventilation system

The reactor building requires room-by-room and area-by-area assessment of the possibility of a flood-induced core damage scenario. It is generally expected that few if any areas within this structure will be screened out from an evaluation. Potential flood pathways from adjacent buildings into the Reactor Building are included in the work scope.

- Fuel Handling Building. The fuel handling building typically does not contain any equipment related to reactor protection. However, some designs may have potential interfaces with other buildings where a flood may be risk-significant.
- Turbine Building. The turbine building contains potential flood sources and some equipment modeled in a PRA model, including any emergency diesel generators that may be located in this building, main feedwater system, condensate system, and instrument air compressors. The building must be evaluated for potential flood pathways into the auxiliary building or reactor building. Equipment in the immediate vicinity of leakage could be adversely affected, and some equipment could be wetted by spray/flow from higher elevations. HELB evaluations may need special attention within an IFPRA work scope. For some plants, the turbine building is an open-air design and is not susceptible to large-scale flooding. Equipment must be evaluated for local spray-effects, however.
- Service Water Intake, Circulating Water Intake, and Other Structures. The service water and circulating water pumps may be located within the Turbine Building or within separate closed or open-air structures. No water accumulation is possible in the latter case; but other locations should be considered for evaluation since these systems are important to plant operation and safety; and flood rates may be significant given a pressure boundary failure.

The auxiliary building for PWR and reactor building for BWR is always subject to room-by-room and area-by-area assessment of the possibility of flooding and flood propagation pathways. Other buildings may or may not be excluded from an evaluation depending on site specific building characteristics and the equipment housed within these structures. It is important to note that screening structures, rooms, or areas from future evaluation early in the IFPRA process may lead to omission of key Internal Flood scenarios. As discussed later in this chapter, screening should be performed at the flood scenario definition level rather than on a location basis alone.

The identification of flood areas uses existing plant information sources and is augmented with walkdowns and/or interviews of operations staff, system engineers, and fire protection engineers to verify the as-built and as-operated SSC configurations. It is recommended that the information on potential flood areas and equipment locations be in some kind of organized format such as a spreadsheet or database. Appendix B contains sample sheets for capturing pertinent data. The analyst could also use the EPRI software “FLANX” (see Appendix C) to develop each flood area’s information. During the walkdown, piping inventories and routing can be verified for each flood area. Examples of plant information sources used to plan and perform the evaluations include:

- Plant architectural drawings
- Piping & Instrumentation Diagrams and isometric drawings
- Design Basis Flood Calculations (per Standard Review Plan 3.4.1)

- Barrier Programs
- Appendix R (or Fire PRA) Fire Areas
- High Energy Line Break (HELB) Areas
- IPE Documentation
- Risk-Informed In-service Inspection (RI-ISI) documentation. Applies to plants for which full-scope RI-ISI programs have been developed
- Flow accelerated corrosion (FAC) inspection program plans

The above information sources have identified various plant areas by using a certain naming or numbering convention. It is recommended that any existing naming or number convention be carried over to an IFPRA for ease in conveying the information to other organizations and industry groups. For each flood area, an analyst should identify the precise plant location by building elevation and column number as identified on architectural drawings. If no flood area is adjacent to the area of interest, for example, an outer wall of a building or the floor of the lowest elevation room, this fact should be indicated.

Flood mitigation features such as curbs, spray shields, and drains will impact the definition of flood areas. Such mitigating features need to be considered when defining propagation paths or estimating SCC impacts from flooding. It is recommended that a “flood pathway diagram” be developed from the walkdown information collected to support the flood scenario development. The example in Figure 3-1 shows potential flood pathways for a fictitious auxiliary building for which some common areas are shared by two reactor units (IFSN-A11).

If there are doors within the boundaries of the area, then the following guidance can be applied:

- For both water-tight doors and non-water tight doors, the possible door states of remaining closed, failing open, or being inadvertently left open should be considered in the enumeration of scenarios Factors that may influence the probability or likelihood of door failure may be considered in the screening and quantification of the resulting flood scenarios.
- For scenarios in which credit is taken for the integrity of a flood barrier such as a flood proof door, engineering calculations should be available to justify such integrity. An example of a flood door integrity calculation is provided in Appendix D.
- Watertight doors should be considered as failing through human actions such as leaving or propping the doors open to perform maintenance and leaving them in this position. The possibility that the door is closed but not fully latched should also be considered. If the door is alarmed, its non-detected failure probability can be considered to be negligible. If the door is not alarmed, then assume the normal egress failure condition of a door opening out of the flood area if the watertight door opens out of the area. If the water-tight door opens into the area, then consider the failure probability to be zero.
- For non-water tight doors and fire doors, credit for door flood barrier integrity needs to be justified. In no cases should normal egress and door closure be credited above 3 foot of flood level if the door opens into the area or above 1 foot if the door opens out of the flood area.

Even when continued door closure can be justified, leakage of water around the door perimeter needs to be considered as a flood propagation path.

Flood area information should be verified by a walkdown, which is described in Section 3.3. Information needed to define each area and corresponding information sources are summarized in Table 3-1, below.

Table 3-1
Examples of Information Needed to Identify Flood Areas

Information Needed	Information Sources
(a) Name of area with unique identifier (b) Identify each of the boundaries (i.e., North, South, East, West, Top and Bottom) (c) Identify the adjoining areas using the naming convention set up in Step (a).	• Plant architectural drawings • Design Basis Flood Calculations • Barrier Programs • Appendix R Fire Areas • HELB Areas • IPE Documentation • "Other" plant-specific Flooding Analysis Information • Plant-specific Service Experience • RI-ISI walkdown information and pressure boundary failure impact assessment
For each area boundary, identify barriers and propagation paths: (d) Doors / door types (e) Pipe penetrations (f) Cable penetrations (g) HVAC duct routing & openings (h) Drains (i) Berms (j) Sumps (k) Walls For each of the above barriers, identify the elevation, the size, whether it is opened or sealed. Determine direction of door opening (into or out of area) and door dimension.	
(l) Determine the dimension of the area (m) Estimate how much of the room is filled with equipment	

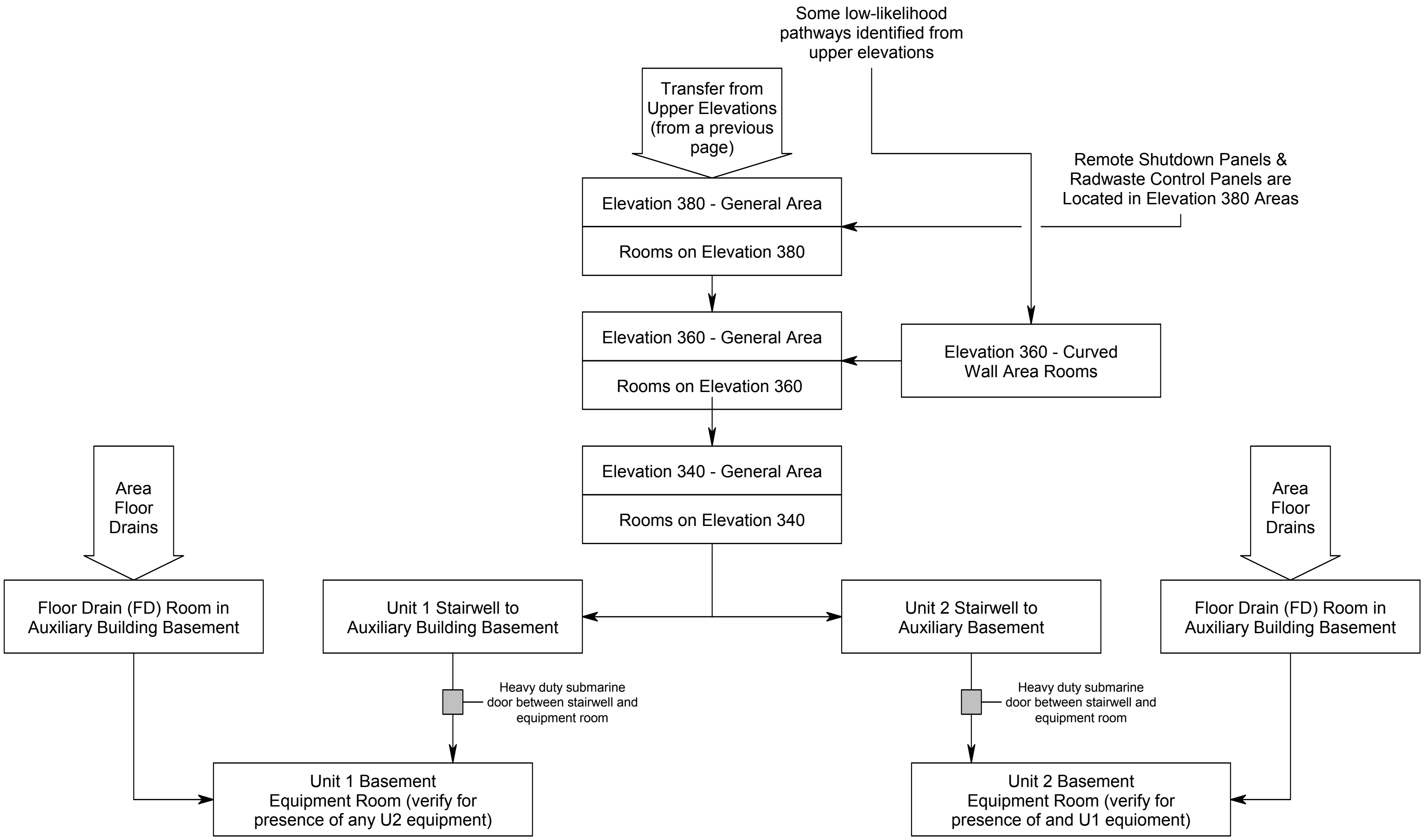


Figure 3-1
Example of Flood Propagation Diagram for a Fictitious Auxiliary Building

3.2 Task 2 - Identify Flood Sources, Flood Mechanisms & SSCs

ASME/ANS PRA Standard HLRs HLR-IFSO-A and IFSO-B and SRs IFSO-A1 through IFSO-A6 and IFSO-B1 through IFSO-B3 specify the requirements for the identification, characterization, and documentation of internal flood sources and their associated mechanisms.

For a selected plant building structure, Task 2 involves a systematic identification of the flood sources and flood mechanisms. A natural extension of work related to Task 2 is to identify the potentially affected SSC within each flood area or along flood propagation pathways.

3.2.1 Flood Sources

Plant systems that transport fluid through any area are considered as potential flood sources. For each selected flood area, the following flooding sources should be included in the analysis:

a) Equipment (e.g., piping, valves, pumps, tanks) located in the area. A fluid system can either be in operational or standby mode. Examples of the normally operating fluid systems in the plant include Circulating Water, Essential and Non-Essential Service Water, Component Cooling, Chemical and Volume Control, Main Steam, Feedwater, and Condensate systems.

   Although not specifically identified in the ASME/ANS PRA Standard, the Internal Flood analysis should also include standby (non-operating) systems, like Emergency Core Cooling System or Emergency Feedwater System. A significant breach in a standby system, depending upon its volume of fluid, may cause a plant transient; or, even if it does not directly cause one, it could require a manual shutdown of the plant. Alternatively, another initiating event may initiate start up of a standby system. The start up process would result in valve repositioning, rapid pressurization, and additional stresses, which may cause a breach. For the above reasons, the analyst should consider standby systems as potential flooding sources

b) Plant internal sources of flooding (e.g. tanks or pools) located in the flood area

c) Plant external sources of water (i.e., ultimate heat sinks such as reservoirs or rivers) that are connected to the area through some system or structure

d) In-leakage from other flood areas (e.g. back flow through drains, doorways, etc)

e) Potential sources with multi-unit or cross-unit impact, for multi-unit sites with shared systems and structures

Sources of flooding are typically expected to be water; and the ASME/ANS PRA Standard requirements are generally written in terms of sources of water; but other fluid sources could also be considered. Section 1.3 of this guideline provides justifications for the scope of an IFPRA.

For flood sources in each flood area that contain PRA modeled equipment, identify the system, the type of source (tank, pipe, valve, etc.), the flood source boundaries on the upstream and downstream sides, the source component ID, and the proximity of the flood source to any modeled equipment. Information needed to define each flooding source and corresponding information sources are summarized in Table 3-2, below. This information needs to be confirmed in a walkdown (Section 3.3).

Table 3-2
Examples of Information Needed to Identify Flooding Sources

Information Needed	Information Sources
(a) System (b) Type of source (pipe, valve, tank) (c) Source boundaries (d) Source ID (e) Sources of floodwater (tank, river, ocean) (f) Source size (g) Source elevation (h) Source pressure and temperature (i) Floodwater elevation (j) For pipes: size, number of welds, pipe length or pipe sections. Include piping material and degradation susceptibilities	• Plant-Specific Equipment Database • Plant architectural drawings • General arrangement drawings • Pipe isometric drawings • Piping & Instrumentation Diagrams • Design Basis Flood Calculations • ISI and Pipe Performance Data • RI-ISI information • Industry operating history • Plant Systems Description and Operating Procedures

3.2.2 Flood Mechanisms

ASME/ANS PRA Standard SR IFSO-A4 specifies various ways of breaching a fluid system pressure boundary that must be included in the identification of flooding mechanisms.

Breaches of a fluid system pressure boundary could result from various types of failure modes often associated with different degradation mechanisms. They could also be a result of human actions, often related to maintenance activities, which lead to piping and/or equipment failure.

In addition to pressure boundary failures due to internal/external degradation or pressure transients, flooding can also occur as a result of inadvertent manual or spurious automatic actions associated with maintenance on equipment. These causes include equipment failure related or human error related events. An example of maintenance-induced flooding related to equipment failure involves failure of freeze seal applied to enable valve repair/replacement or pipe replacement. The flood experience review in Reference [7] includes examples of freeze seal failures. Another example of maintenance-induced flooding related to equipment failure involves the spurious opening of a value that is relied to maintain the fluid system pressure boundary during the maintenance activity.

As evidenced by the event at Surry in 1983, flooding from actuation of the Fire Protection System spray nozzles can be caused by occurrence of a High Energy Line Break (HELB).

An example of maintenance-induced failure related to manual (human) action would be inadvertent actuation of the wrong system train while a pressure boundary is open to perform repair/replacement or routine preventive maintenance. Again, the flood experience review in Reference [7] includes examples of this type of flooding.

Information needed to identify flooding mechanisms and corresponding information sources are summarized in Table 3-3. This information needs to be confirmed in a walkdown (Section 3.3).

Table 3-3
Examples of Information Needed to Identify Flooding Mechanisms

Information Needed	Information Sources
Flood Mechanisms - Equipment (a) Identify specific equipment failure modes which could lead to the release of a fluid for: pipes, tanks, valves, gaskets, expansion joints, fittings (b) Identify the elevation of the equipment (c) Determine opening size (d) Identify failure mechanisms for pipes	• Plant-Specific Equipment Database • Plant architectural drawings • General arrangement drawings • Pipe isometric drawings • Piping & Instrumentation Diagrams • Design Basis Flood Calculations • ISI and Pipe Performance Data • RI-ISI information • Industry operating history • System engineers • Plant history
Flood Mechanisms - Maintenance (e) Identify maintenance activities which could open the fluid system (f) Identify the location of the maintenance activity (g) Determine opening size	

3.2.3 Identification of SSCs Affected by Flooding

ASME/ANS PRA Standard HLRs IFSN-A and IFSN-B and SRs IFSN-A5, IFSN-A6, IFSN-A7, and IFSN-B1 through IFSN-B3 require the identification of SSCs located in each of the flood areas and along the propagation paths. The spatial location of each SSC in the flood area and any mitigation feature must also be identified. These SRs also require the identification of the susceptibility of each SSC in a flood area. Note that since the evaluation of SSCs affected by flooding is dependent on the propagation path of the flood, this task is done in parallel with Task 6 regarding the evaluation of flood consequences, which includes the definition of the flood propagation paths as discussed more fully in Section 6.2.1.

These SRs apply only to the flood areas that are not screened out as a result of applying Section 3.4 actions. These SSCs should be the ones that are modeled in internal events PRA model as being required to respond to an initiating event or whose failure would challenge normal plant operation. The identified SSCs should be considered susceptible to flood. Refer to Sections 6.2.4 and 6.2.5 for additional information on the evaluation of SSC flood susceptibility.

The complete list of SSCs to be considered is the listing contained in the internal events PRA since, by definition, they are associated with initiating events, preventing core damage, or a large early release. In general, most equipment included in the PRA model is associated with a basic event identifier. However, some equipment boundaries, as defined for the PRA models, may encompass multiple components. For example, a pump failure event may include not only the pump, but also the associated circuit breaker, junction boxes, and instrumentation and control circuitry. When identifying equipment that is included in the PRA models, it is important to include components subsumed within the PRA model boundary. The maintenance rule equipment list could be a good starting selection.

For each identified SSC, it is necessary to define its spatial location in the area and any associated mitigating features (e.g., shielding, flood or spray capability ratings). Additional discussion on mitigating features is provided in Sections 6.2.2 and 6.2.3. The exact location of SSCs and their related mitigating features should be confirmed in the plant walkdown. For spray consideration and assumed sphere of influence will be a minimum 10 horizontal feet for liquid flood sources and a minimum of 20 horizontal feet for high-energy flood sources. These distances, presented here as rules of thumb, should be verified based on the results of the walkdown. For additional guidance see U.S. NRC Generic Issue 156.6.1 “Pipe Break Effects on Systems and Components Inside Containment” for perspectives on spray impact assessment. The spray impact assessment should include consideration of system operating pressure, assumed piping through-wall flaw size, as well as the potential spray pattern (e.g., spray angle and orientation). Perform an engineering analysis as necessary to account for the range of through-wall flow rates for spray events. Information needed to define SSCs in each area and corresponding information sources are summarized in Table 3-4.

Table 3-4
Information Needed to Identify SSCs

Information Needed	Information Sources
(a) Identify SSC list to be considered. (b) Identify the location of the equipment by area identifier (c) Identify the elevation and orientation to the source of the equipment (d) Identify possible susceptibility to spray, flood and major flood (e) Identify any flooding mitigating features associated with the component: e.g. shielding, flooding or spray capability rating	• PRA model • Maintenance Rule Equipment List • Out of Service Model • Plant architectural drawings • General Arrangement Drawings
(f) Identify whether the failure of the SSC will cause the trip and/or loss of mitigation capability.	• PRA model • Plant Technical Specifications

3.3 Task 3 - Conduct Plant Walkdowns

ASME/ANS PRA Standard HLRs IFPP-A, IFPP-B, IFSO-A, IFSO-B, IFSN-A, IFSN-B, IFQU-A, and IFQU-B and SRs IFPP-A5, IFSO-A6, IFSN-A17, IFQU-A11, IFPP-B2, IFSO-B2, IFSN-B2, and IFQU-B2 specify the need to conduct plant walkdown and the documentation of such walkdown.

Previous sections described the work required to define critical flood areas and to identify flood sources and SSCs located in each flood area. This definition and identification are based upon available plant information. Walkdowns are required to verify the accuracy of this information.

A team that, as a minimum, includes the flooding PRA analysts; a PRA analyst familiar with the existing internal events analysis; and engineers or operators familiar with the plant layout, systems and flooding sources should perform these walkdowns. It is recommended that walkdowns use a top-down approach starting at the highest floor elevation and then progressing floor elevation by elevation down to the basement.

The scope of the walkdown should include documentation that validates identified information in Tasks 1 and 2 and provides additional information not obtained from the original plant documents. The scope also includes the collection and verification of information needed to construct and quantify flood scenarios in the subsequent tasks. Appendix E contains samples of walkdown forms that can be used to organize the information gathered during the walkdown. It should be noted that walkdown tasks can be combined and completed at the same time if the analyst so wishes.

Included in the walkdown documentation should be insights obtained from interviews of licensed and non-licensed operations personnel, systems engineers, and fire protection engineers. The purpose of the interviews is to address procedure and training issues as they relate to flood response. The information so obtained will support flood scenario development and the human reliability analysis.

SSCs within each flood area should be identified. During the walkdown, these SSCs and their spatial location should be verified. For each SSC, the height to which water would need to rise to cause its failure, (i. e., the critical flood height), should be noted. For all flood areas, the volume of the area occupied by equipment in the room should be confirmed.

The following subsections contain particular guidance for verifying the information for each of the tasks identified in the previous subsections.

3.3.1 Flood Areas

For flood areas verify the accuracy of information obtained from the plant information sources used in Task 1 and obtain or verify:

a) Spatial information needed for the development of flood areas

b) Plant design features credited in defining flooding areas

3.3.2 Flooding Sources

For flood sources verify the accuracy of the plant information sources used in Task 2 and determine or verify the location of flood sources and in-leakage pathways.

In this walkdown, the presence of the flooding sources, including piping, valves, pumps, and tanks in each area, must be determined or verified. The possibility of connection to the plant external sources of flooding (reservoirs or rivers) or in-leakage from other flood areas (back flow through drains, doorways, etc) must also be evaluated and verified.

3.3.3 Equipment Location, Flood Mitigation & Flood Propagation Pathways

For equipment location, flood mitigation, and flood propagation pathways, verify the accuracy of the plant information sources used in Task 2 for:

a) SSCs located within each defined flood area

b) Flood/spray/other applicable mitigating features for the SSCs located within each defined flood area (e.g., drains, shields, flood level alarms, etc.)

c) Flood propagation pathways

d) Flood source(s): piping system defined by size, material, length (or number or welds or number of sections as discussed in Chapter 5)

3.4 Task 4 – Qualitative Screening of Flood Areas

ASME/ANS PRA Standard HLRs IFSO-A, IFSO–B, IFSN-A, and IFSN–B stipulate the identification and characterization of flood sources within each flood area. The documentation of the flood sources is required for each of the flood sources. Qualitative screening is allowed as part of the identification and characterization of the flood sources. To accomplish the screening aspects of the HLRs, SRs IFSO-A3, IFSO-B2, IFSN-A12, IFSN-A13, IFSN-A14, IFSN-A15, and IFSN A16 specify the criteria that are allowed for screening flood sources qualitatively from further evaluation. SR IFSN-B2 specifies the documentation of the screening criteria and process that are used to accomplish the screening of flood sources.

The purpose of this task is to perform a qualitative screening analysis to demonstrate completeness in the identification of all credible, safety-significant flood scenarios. The starting point for the screening evaluation is the complete list of flood areas and flood sources from Tasks 1 and 2 together with the flood impact evaluation results from Tasks 3 through 5. Each flood area must be reviewed to determine if it can be screened out from further evaluation by various screening criteria. Any screening performed must consider flood *source* if any and potential effects of any *propagation pathways* and the results of flood impact assessment. Document the results of the screening. Documentation should include what criteria were used to screen out the area. If the below listed criteria are not used, provide justification for why the area can be screened from further flood evaluation.

The criteria included in the ASME/ANS PRA Standard Supporting Requirement for screening flood areas are as follows:

Criterion IFSO-A3: SCREEN OUT flood areas with none of the potential sources of flooding listed in IFSO-A1 and IFSO-A2:

IFSO-A1 is a requirement to identify all significant flood sources in the plant, and IFSO-A2 is a requirement to identify sources in multi-unit sites that could propagate from one unit to the other.

Criterion IFSN-A12: A flood area may be screened out where flooding of the area does not cause an initiating event or a need for immediate plant shutdown, and either of the following conditions applies:

a) the flood area (including adjacent areas where flood sources can propagate) contains no mitigating equipment modeled in the PRA; OR
b) the flood area has no flood sources sufficient (e.g., through spray, immersion, or other applicable mechanism) to cause failure of the equipment identified in IFSO-A1 or –A2.

Failure of a barrier against inter-area propagation does not justify screening (i.e., for the purposes of screening, do not credit such failures as a means of beneficially draining the area).

Use of any other screening criteria needs to be justified and documented.

For many significant floods, a manual plant shutdown should be assumed; and these areas should be retained for the further evaluation. For localized floods, the termination and mitigation of the flood could occur without a plant shutdown. A failure of a barrier against inter-area propagation should not be used to justify screening.

Criterion IFSN-A13: According to this criterion, any area may be screened out if the postulated flooding of the area neither causes an initiating event nor a need for an immediate plant shutdown; and both of the following conditions apply:

- The flood area contains flooding mitigation systems (e.g., drains or sump pumps) capable of preventing unacceptable flood levels, and the nature of the flood does not cause equipment failure (e.g., through spray, immersion, or other applicable failure mechanisms).
- A technical basis is provided to justify that the mitigation systems credited for screening out flood areas have sufficient capability.

In this screening step, an analyst is cautioned not to credit flood-mitigating systems for the screening purposes unless there is a definitive basis for crediting their capability and reliability. In addition, taking credit for barrier failures as a means of beneficially draining the area is not a valid basis for screening.

The ASME/ANS PRA Standard allows screening out flood areas and sources based on the potential human mitigating actions. The screening criteria are different for different capability categories as described below.

Criteria IFSN-A14 and IFSN A16: For Capability Category I, potential human mitigating actions could be used as additional criteria for screening out flood areas and sources if all the following could be shown:

a) Flood indication is available in the control room.

b) Flood sources in the area can be isolated.

c) The time to the damage of safe shutdown equipment is significantly greater than the expected time for human mitigating actions to be performed, for the worst flooding initiator.

Criteria IFSN-A14 and IFSN A16: For Capability Category II, potential human mitigating actions could be used as additional criteria for screening out flood areas and sources if all the following could be shown:

a) Flood indication is available in the control room.

b) Flood sources in the area can be isolated.

c) The mitigating actions can be performed with high reliability for the worst flooding initiator. High reliability is established by demonstrating, for example, that the actions are procedurally directed, that adequate time is available for response, that the area is accessible, and that there is sufficient manpower available to perform the action.

The screening of flood areas and sources, based on reliance on operator action to prevent challenges to normal plant operation, is not allowed in Capability Category III per IFSN-A14. The next screening criterion and Supporting Requirement applies to the screening of <u>the flood sources.</u>

<u>Criterion IFSN-A15</u>: Any flood source can be screened out if it can be shown that:

a) The flood source is insufficient (e.g., through spray, immersion, or other applicable mechanism) to cause failure of equipment; OR

b) The area flooding mitigation systems (e.g., drains or sump pumps) are capable of preventing unacceptable flood levels; and the nature of the flood does not cause failure of equipment through spray, immersion, or other applicable failure mechanism; OR

c) The flood only affects the system that is the flood source, and the system analysis addresses this type of the failure and need not be treated as a separate Internal Flood initiating event.

4

CHARACTERIZATION OF FLOODING SCENARIOS (TASK 5)

Using the information generated in Tasks 1 through 4, Task 5 of the IFPRA Guideline structures the flood scenarios for the quantitative phase of the IFPRA. Decision event trees are developed to identify the types of floods in the remaining flood areas. Those branches that identify a plausible flood scenario are assigned a flood damage state. The results of this task define the requirements for initiating event frequency calculation (Task 6), evaluation of flood consequences (Task 7), and evaluation of the relevant flood mitigation strategies (Task 8).

4.1 Elements of Flood Scenarios for Quantification

Flood scenarios must be carefully defined to support the estimation of their contributions to CDF and LERF during the quantitative phase of IFPRA. The primary elements of the flood scenario must contain:

- Definition of the plant operating state at the time of the flood
- A definition of the flood area, source, and failure mode
- A definition of the type of initiating event (e.g., spray, flood, or major flood)
- An assessment of the consequences of the flood including flood propagation and SSCs damaged by the flood and the initiating event for the purpose of formulating event sequences leading to core damage or large early release. The initiating event could be the direct consequence of the flood or an immediate plant shutdown that could trigger an adverse event sequence.
- An evaluation of the operator actions and mitigation system responses to terminate the flood and limit the damage to plant SSCs and to recover the plant from the initiating event. This evaluation must consider time-windows for operator response that account for different flood volumes.
- An interface with the event tree and fault tree logic of the PRA that links the occurrence of the flood to a plant initiating event and damage state for calculating the probability that the flood leads to core damage or large early release.

In Task 5 a preliminary list of flood scenarios is developed for the flood areas not screened out in the previous step. This list is used to scope out the remaining tasks. The definition of the flood scenarios is further refined during Tasks 6, 7, 8, and 9 during which the analysis of flood initiating events, flood consequences, flood mitigation, and interfaces with the PRA model are completed. Each flood scenario retained for detailed analysis is characterized by flood area, flood source, potentially impacted equipment, successful or unsuccessful flood isolation, and plant impact. Associated with each scenario is a flood damage state (FDS). As the analyst progresses through the list of flood areas, scenarios with a similar impact can be identified with a common FDS.

4.2 Development of Flood Damage Decision Tree

It is recommended that a decision tree be developed to document the flood scenario evaluation process. Such a tree can be useful in screening and grouping the flood scenarios prior to full PRA modeling. Developing a decision tree involves addressing four questions for each flood source:

- Which of the three types of flooding—spray, flood, or major flood— are applicable?
- Is it possible to isolate the flood source before losing the system the flood source is a part of?
- Is isolation of the flood source possible prior to loss of the SSC being impacted?
- Did the damage produced by the flood and the direct system effects of the pipe break lead directly to core damage or would additional equipment failures need to occur?

Decision branches are assigned to each question. The yes/no questions would have two branches. The type of flood question would have three branches. Determine if the end state would be OK or should be flagged as a plausible flood scenario. Do this for each of the flood areas remaining from the completion of Tasks 1 through 4. Documentation of your decisions is important. During this process there may be locations that will be eliminated from further analysis because of a finer inspection of the conclusions and determinations that originally resulted in a conclusion that equipment damage or flood initiator could occur.

4.3 Definition of Flood Damage States

Flood damage states (FDSs) can be combined if the effects of the scenarios are similar or can be bounded by a set of conditions. Review each of the FDS scenarios to determine if such grouping is possible. Assign a common FDS name to the group. Figure 4-1 includes an example of FDS definitions. The idea of using flood damage states is recommended as a technique to organize, screen, and group the flood scenarios prior to full PRA modeling. Alternatively, each flood scenario may be modeled separately. The optimum approach is a function of the capabilities of the PRA software and the nature of the results.

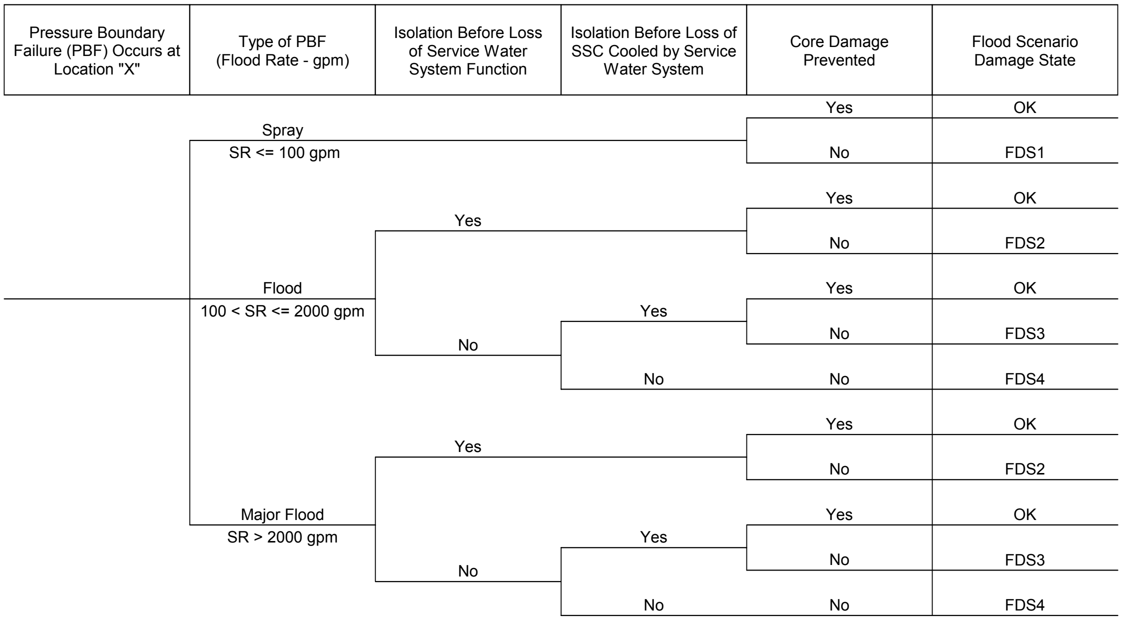


Figure 4-1
Example of Flood Damage States

The decision tree in Figure 4-1 includes the possibility of aligning an alternate source of equipment cooling should a pressure boundary failure disable the normal cooling source. Flood damage state #1 (FDS1) represents scenarios involving local spray effects only. Since a spray event is within the capacity of a floor drain system, isolation of the spray source is not credited. FDS2 accounts for flood and major flood scenarios with successful isolation of a pressure boundary failure in such a way that a plant shutdown is required. FDS3 represents global flooding in such a way that the normal cooling of safety-related equipment is disabled but an alternate cooling source is successfully aligned followed by a plant shutdown. Finally, FDS4 represents a global flooding, which incapacitates the normal and alternate sources of equipment cooling.

4.4 Example Problem for Flood Scenario Identification

The following example is taken from the EPRI Training Course for Risk Professionals to illustrate some basic considerations in the identification and enumeration of flood scenarios. This example uses two flood areas involving two Essential Service Water pump rooms that are separated by walls and a watertight door as illustrated in Figure 4-2.

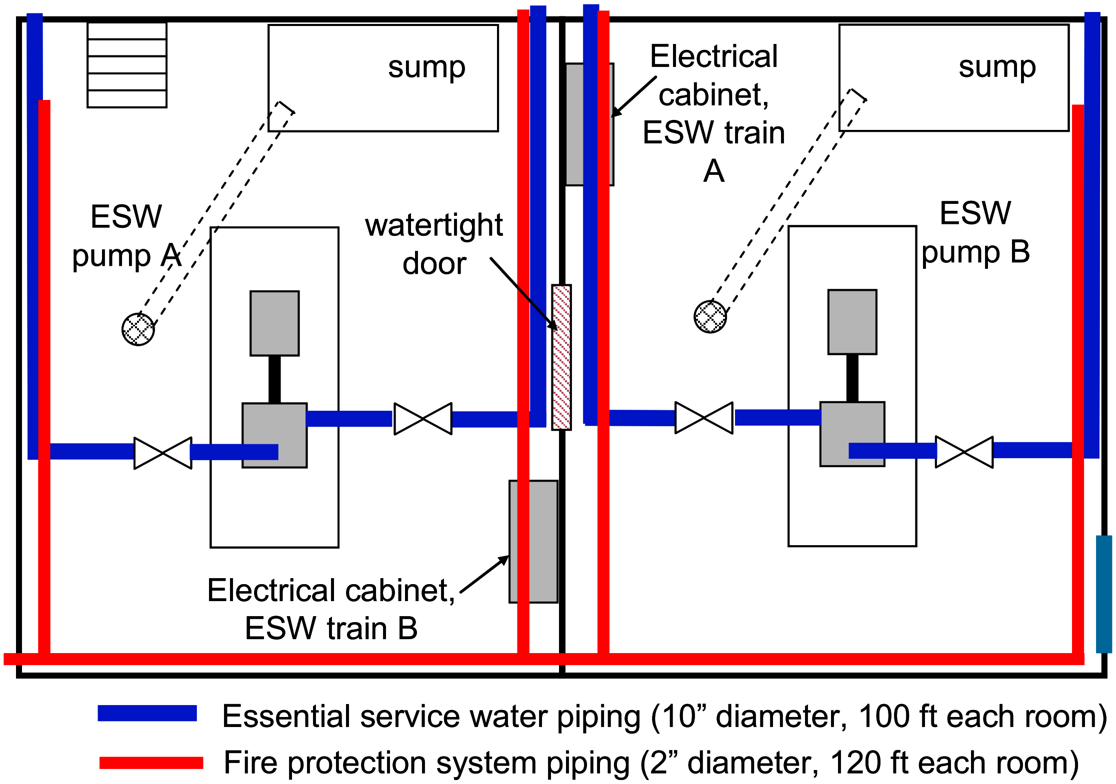


Figure 4-2
Example Food Areas Involving Two Essential Service Water Pump Rooms

The ESW pump rooms in this example are adjacent, essentially identical and are separated by a watertight door that is designed to contain a flood in either room without leaking into the other room if it is closed at the time of a postulated flood. Each room is 30' x 50' x 10' and contains one emergency service water (ESW) pump—train A in one room, train B in the other. Each pump is mounted on a concrete pedestal, with motor windings starting about 3' above floor level. There is about 100 ft of 10-inch ESW piping and about 120 ft of piping of 2" fire-protection system piping in each room. In each room there is an electrical cabinet for the opposite train that is located about 7' off the floor. (This obvious design flaw does not meet normal separation requirements but is included in this example to illustrate the need to consider various dependencies in the formulation of scenarios. In each room there is a floor drain with 100-gpm flow capacity draining into a 600 gal sump. Each sump has a flood level indicator that alarms in the control room to notify the operator to take corrective actions in the event of a flood.

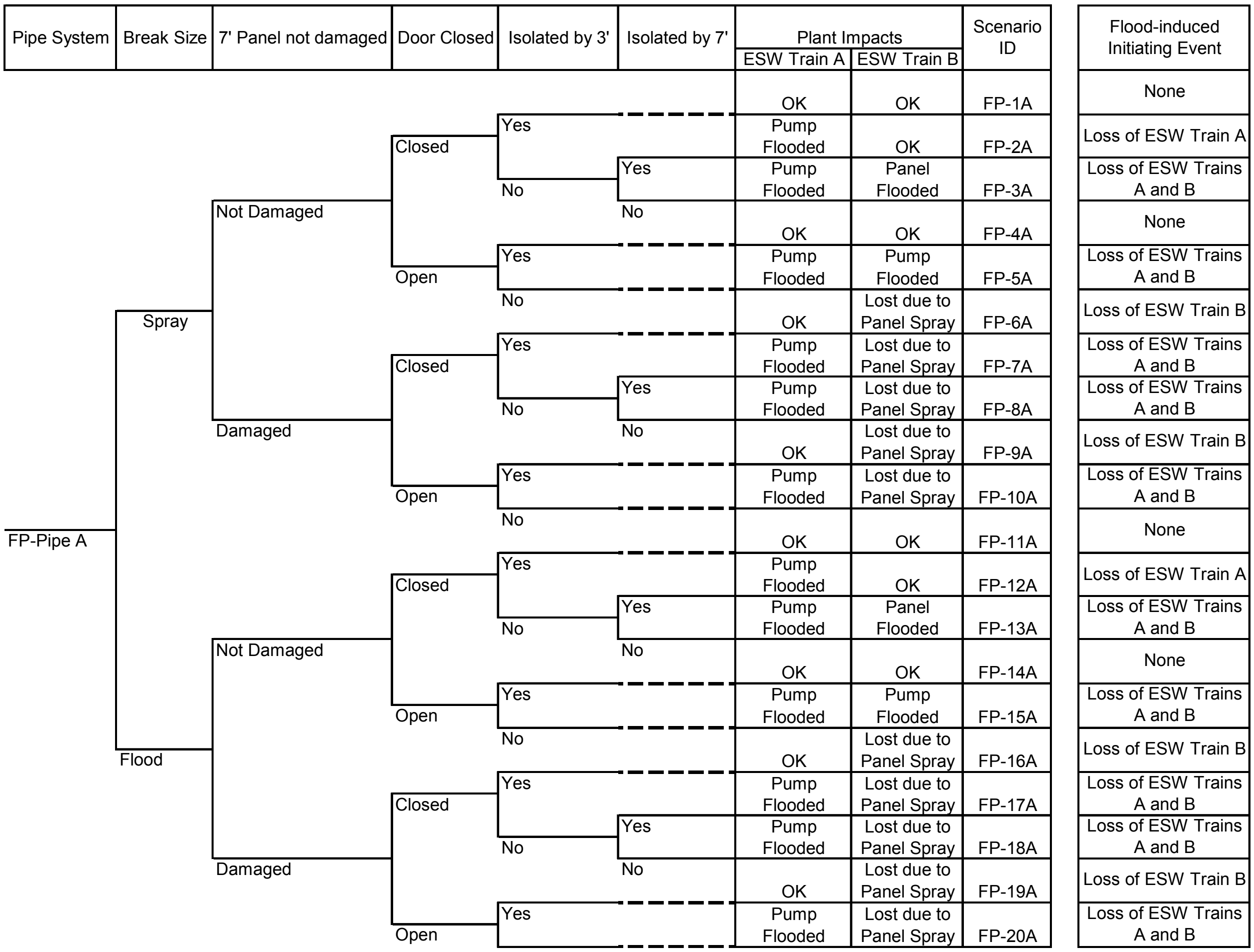
The first problem that we address with this example is the problem of identifying a reasonably complete set of flood scenarios based on flood sources within each ESW room as well as the potential for scenarios propagating into other areas.

The objective of the flood scenario identification step is to identify a reasonably complete set of scenarios with unique plant impacts and defined with sufficient clarity to support subsequent steps such as grouping and screening of scenarios and estimating flood initiating event frequencies. Some considerations that need to be taken into account in the identification of scenarios in this example include:

- The flood may be initiated by a breach in the piping system of each system: FP and SW.
- The pipe failure may occur in any location within the room.
- The pipe failure mode may vary – in this example we shall consider three flood modes including spray, flood, and major flood.
- The watertight door may be open or closed at the time of the flood event. There may be administrative controls to make an open door very unlikely; but this does not prevent the scenario, but rather alters its probability. Quantification and screening out of flood scenarios comes in a later step of the process.
- The operator may take steps to isolate the source of the flood and terminate the flow of water into room at any time following the arrival of indications in the control room and diagnosis of the cause of the event.

This problem of defining flood scenarios is fundamentally the same problem faced in the development of accident sequences from an internal or external initiating event. Hence the event tree provides a useful tool for enumerating the possible combinations of factors that define the different scenarios in a logical manner. In Figures 4-3 and 4-4 event trees are presented to show examples of flood scenarios that can be defined for this problem. Figure 4-3 defines the scenarios for floods in ESW Pump Room A originating from failures of the fire protection system piping, whereas Figure 4-4 shows the scenarios that arise from piping failures in the ESW piping in this same room. There would also be a symmetric set of scenarios for pipe failures originating in ESW Pump Room B. Approximately 100 scenarios are defined by these event trees assuming a symmetric set for each pipe system in ESW Pump Room B. This set of scenarios was reduced by several assumptions including:

- The 2” FP piping is not capable of providing flood rates in excess of 2,000gpm
- The water tight door and the floors, walls, and ceiling of the ESW Pump rooms have sufficient structural and leak tight capability to preclude flood propagation beyond these areas

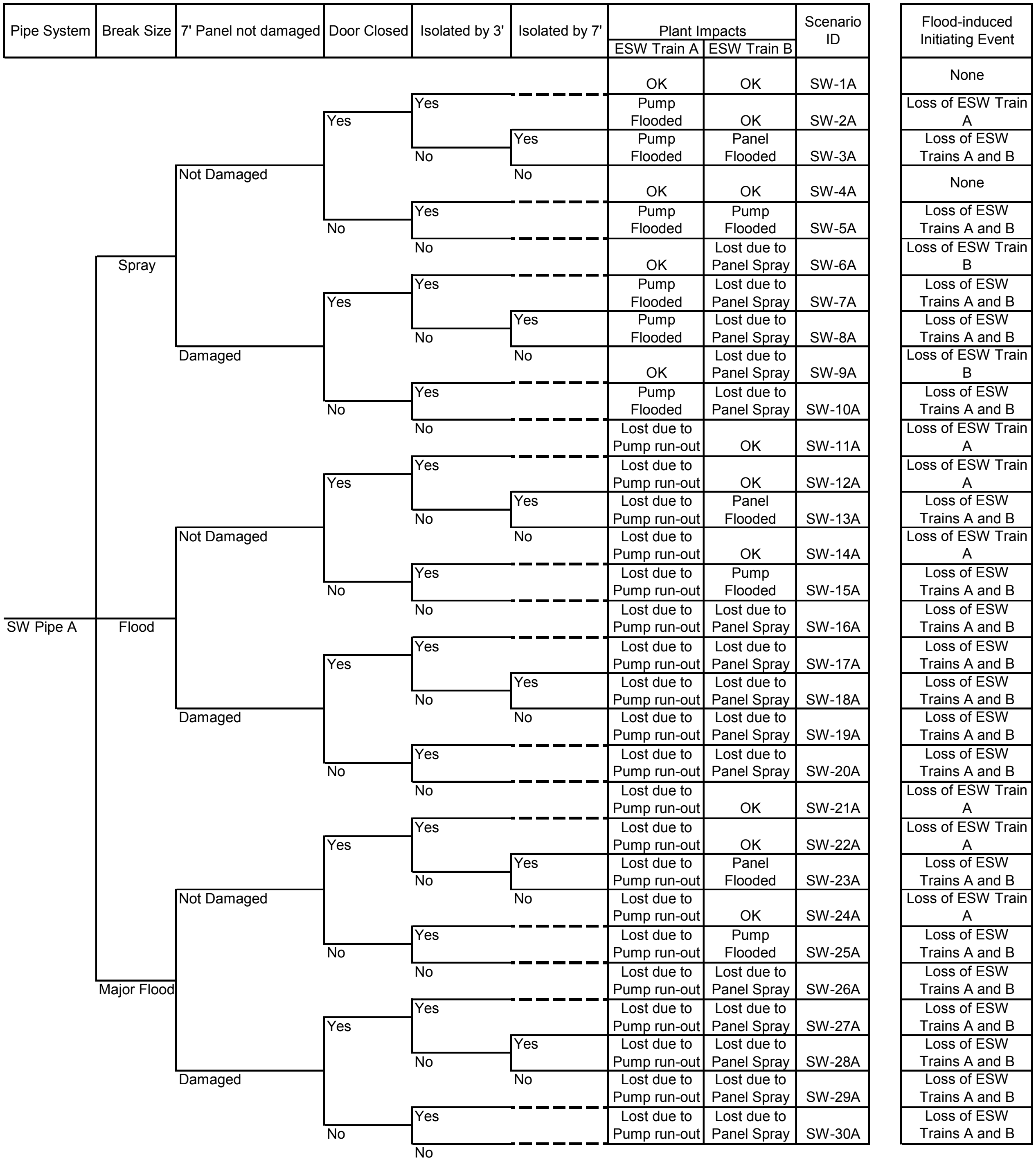


Plant Impacts		Scenario ID	Flood-induced Initiating Event
ESW Train A	ESW Train B		
OK	OK	FP-1A	None
Pump Flooded	OK	FP-2A	Loss of ESW Train A
Pump Flooded	Panel Flooded	FP-3A	Loss of ESW Trains A and B
OK	OK	FP-4A	None
Pump Flooded	Pump Flooded	FP-5A	Loss of ESW Trains A and B
OK	Lost due to Panel Spray	FP-6A	Loss of ESW Train B
Pump Flooded	Lost due to Panel Spray	FP-7A	Loss of ESW Trains A and B
Pump Flooded	Lost due to Panel Spray	FP-8A	Loss of ESW Trains A and B
OK	Lost due to Panel Spray	FP-9A	Loss of ESW Train B
Pump Flooded	Lost due to Panel Spray	FP-10A	Loss of ESW Trains A and B
OK	OK	FP-11A	None
Pump Flooded	OK	FP-12A	Loss of ESW Train A
Pump Flooded	Panel Flooded	FP-13A	Loss of ESW Trains A and B
OK	OK	FP-14A	None
Pump Flooded	Pump Flooded	FP-15A	Loss of ESW Trains A and B
OK	Lost due to Panel Spray	FP-16A	Loss of ESW Train B
Pump Flooded	Lost due to Panel Spray	FP-17A	Loss of ESW Trains A and B
Pump Flooded	Lost due to Panel Spray	FP-18A	Loss of ESW Trains A and B
OK	Lost due to Panel Spray	FP-19A	Loss of ESW Train B
Pump Flooded	Lost due to Panel Spray	FP-20A	Loss of ESW Trains A and B

Figure 4-3
Example Flood Scenarios for FP Pipe Failures in ESW Pump Room A

- The ESW system is capable of continued operation indefinitely with leaks in progress up to 100gpm

Note that when identifying scenarios in this example, the flood door is considered to have two possible states, open or closed. In subsequent steps the probability the door is open or fails open may be considered in determining whether any scenarios can be screened out. However, when the scenarios are initially identified, the goal is to systematically enumerate a complete set of scenarios. We shall return to this example to illustrate subsequent steps of the IFPRA procedure.



Pipe System	Break Size	7' Panel not damaged	Door Closed	Isolated by 3'	Isolated by 7'	Plant Impacts ESW Train A	Plant Impacts ESW Train B	Scenario ID	Flood-induced Initiating Event
SW Pipe A	Spray	Not Damaged	Yes	Yes		OK	OK	SW-1A	None
				No	Yes	Pump Flooded	OK	SW-2A	Loss of ESW Train A
					No	Pump Flooded	Panel Flooded	SW-3A	Loss of ESW Trains A and B
			No	Yes		OK	OK	SW-4A	None
				No		Pump Flooded	Pump Flooded	SW-5A	Loss of ESW Trains A and B
		Damaged	Yes	Yes		OK	Lost due to Panel Spray	SW-6A	Loss of ESW Train B
				No	Yes	Pump Flooded	Lost due to Panel Spray	SW-7A	Loss of ESW Trains A and B
					No	Pump Flooded	Lost due to Panel Spray	SW-8A	Loss of ESW Trains A and B
			No	Yes		OK	Lost due to Panel Spray	SW-9A	Loss of ESW Train B
				No		Pump Flooded	Lost due to Panel Spray	SW-10A	Loss of ESW Trains A and B
	Flood	Not Damaged	Yes	Yes		Lost due to Pump run-out	OK	SW-11A	Loss of ESW Train A
				No	Yes	Lost due to Pump run-out	OK	SW-12A	Loss of ESW Train A
					No	Lost due to Pump run-out	Panel Flooded	SW-13A	Loss of ESW Trains A and B
			No	Yes		Lost due to Pump run-out	OK	SW-14A	Loss of ESW Train A
				No		Lost due to Pump run-out	Pump Flooded	SW-15A	Loss of ESW Trains A and B
		Damaged	Yes	Yes		Lost due to Pump run-out	Lost due to Panel Spray	SW-16A	Loss of ESW Trains A and B
				No	Yes	Lost due to Pump run-out	Lost due to Panel Spray	SW-17A	Loss of ESW Trains A and B
					No	Lost due to Pump run-out	Lost due to Panel Spray	SW-18A	Loss of ESW Trains A and B
			No	Yes		Lost due to Pump run-out	Lost due to Panel Spray	SW-19A	Loss of ESW Trains A and B
				No		Lost due to Pump run-out	Lost due to Panel Spray	SW-20A	Loss of ESW Trains A and B
	Major Flood	Not Damaged	Yes	Yes		Lost due to Pump run-out	OK	SW-21A	Loss of ESW Train A
				No	Yes	Lost due to Pump run-out	OK	SW-22A	Loss of ESW Train A
					No	Lost due to Pump run-out	Panel Flooded	SW-23A	Loss of ESW Trains A and B
			No	Yes		Lost due to Pump run-out	OK	SW-24A	Loss of ESW Train A
				No		Lost due to Pump run-out	Pump Flooded	SW-25A	Loss of ESW Trains A and B
		Damaged	Yes	Yes		Lost due to Pump run-out	Lost due to Panel Spray	SW-26A	Loss of ESW Trains A and B
				No	Yes	Lost due to Pump run-out	Lost due to Panel Spray	SW-27A	Loss of ESW Trains A and B
					No	Lost due to Pump run-out	Lost due to Panel Spray	SW-28A	Loss of ESW Trains A and B
			No	Yes		Lost due to Pump run-out	Lost due to Panel Spray	SW-29A	Loss of ESW Trains A and B
				No		Lost due to Pump run-out	Lost due to Panel Spray	SW-30A	Loss of ESW Trains A and B

Figure 4-4
Example Flood Scenarios from SW Pipe Failures in ESW Pump Room A

5
FLOOD INITIATING EVENTS ANALYSIS (TASK 6)

This chapter includes guidance for flood-induced initiating event frequency quantification, especially as it relates to passive component failures. It complements the results of a companion report, EPRI 1012301 Revision 1 [7], which provides piping system failure rates for use in IFPRA. This report is in the process of being updated. These failure rates were developed with the intention of satisfying the supporting requirements associated with the ASME/ANS PRA Standard Internal Flood Hazard Group element: Internal Flood Induced Initiating Events (IFEV) [1].

5.1 Task 6 – Flood Initiating Event Frequency Quantification

ASME/ANS PRA Standard High Level Requirements IFEV-A and –B, and Supporting Requirements IFEV-A1 through –A8, and IFEV-B1 through –B3.

The flood initiating event frequency for each flood scenario group is governed by the applicable requirements of the ASME/ANS PRA Standard. The ASME/ANS PRA Standard gives examples of different categories of data sources. To satisfy ASME/ANS PRA Standard Capability Category I, the analyst is directed to use the following information in determining the flood initiating event frequencies for flood scenario groups:

a) Generic operating experience

b) Piping and non-piping passive component (heat exchanger shell, pump casing, tank, valve body, and tank) rupture failure rates from generic data sources

c) Combination of (a) or (b) with engineering judgment

For Capability Categories II & III, the standard directs an analyst to gather plant-specific information on plant design, operating practices, and conditions that may impact flood likelihood (i.e., material condition of piping and other non-piping passive components and experience with water hammer and maintenance-induced floods). After collecting this information, the analyst determining the flood initiating event frequencies for flood scenario groups is directed to use a combination of:

a) Generic and plant-specific operating experience

b) Pipe, component, and tank rupture failure rates from generic data sources and plant-specific experience

c) Data specializations using engineering judgment and other techniques for consideration of any plant-specific information collected

ASME/ANS PRA Standard requires inclusion of maintenance errors in the calculation of the Internal Flood frequency. For Capability Requirements I and II the application of generic data is acceptable. For Capability Category III an analyst is required to evaluate plant-specific maintenance activities for potential human-induced floods using human reliability analysis techniques. It is noted that such an evaluation would require consideration of human errors of commission. This aspect of HRA methodology is still evolving, and the estimation of plant-specific maintenance errors is beyond the current state-of-the-art. Chapter 7 of these guidelines elaborates on this and other HRA-related topics.

The estimation of piping reliability analysis has evolved considerably, and methods and data exist to support plant-specific estimation of piping pressure boundary failure rates that account for unique combinations of material, chemical treatment of process water, and inspection strategies. Selection of an approach that is best suited to a plant-specific IFPRA is a function of many factors, including:

- Plant-specific service-experience and known degradation susceptibilities
- Aging management strategies, including non-destructive examination and piping replacements using materials that are resistant to degradation
- Analyses performed in support of full-scope RI-ISI program development. Results obtained may be directly applicable to the initiating event frequency quantification
- Experience with earlier IFPRA work (e.g., IPE-era and subsequent reassessments or updates)
- Known Internal Flood vulnerability and need for highly specialized IE frequency
- Intended uses of plant-specific IFPRA

Different options are available for calculating piping failure rates and internal flood initiating event frequencies. Many factors influence how initiating event frequency quantification is pursued. Examples of considerations include insights from any previous IFPRA work together with knowledge of plant-specific flood vulnerabilities, existing plant-specific structural integrity evaluations (e.g., in support of RI-ISI evaluations), and familiarity with a certain data option. Examples of different data sources for initiating event frequency quantification are included in Section 5.2.

5.1.1 Baseline Initiating Event Frequencies

A first step in the task to quantify IF initiating event frequencies is to select an appropriate data source for pressure boundary failure rates. Depending on the scope of an IFPRA and the overall risk significance of Internal Flood, further modification and specialization of baseline IF initiating event frequencies may be required.

The flood sources considered in this chapter are for in-plant fluid systems and in cases in which the cause of an Internal Flood event in a particular flood area originates from a pressure boundary failure. The way an initiating event is characterized and its frequency quantified are closely related to the definition of flooding "source terms," where a flood source term is defined as the total amount or volume of passive components within a specified flood area that theoretically can generate a spray, flood, or major flood event. Where a flood area includes a certain pipe run, a corresponding flood source term can be characterized in terms of number of welds, linear feet of piping, or sections (or segments) of piping. This last characterization may correspond to a pipe segment as defined by RI-ISI [12] or other analyst-defined pipe section. Exactly how this characterization is done should be addressed during the flood walkdown planning and performance (Tasks 1 through 3 of the IFPRA methodology) *and* is also a function of which data source is ultimately selected for quantifying flood initiating events. In general, a flood initiating event frequency, IE_{IF} is quantified as follows:

$$IE_{IF} = \rho System\ i \times \{System\ \text{“}i\text{”}\ Flood\ Source\ Term\} Equation \qquad \textbf{Equation 5-1}$$

Where,

$\rho_{\text{System “i”}}$ = Frequency of spray, flood, or major flood as obtained from a data source. The units of the pipe rupture frequency are events per reactor calendar year and per unit quantity of pipe as defined in the flood source term.

System "i" Flood Source Term = Linear feet of piping in system *i* within a specified flood area, number of welds, or number of pipe segments/sections as obtained from the walkdown information

The next section provides examples of different data sources. A selected approach for quantifying initiating event frequencies is closely related to the types of information on flood sources and "flood source terms" assembled in Task 1 through 3 of an IFPRA project and the data source on pressure boundary failure rates.

5.2 Data Sources for Initiating Event Frequency Quantification

There are multiple published data sources on passive component pressure boundary failure rates. Not all data sources support the requirements of ASME/ANS PRA Standard Capability Category II or III, however. The focus of these data sources is on piping components (e.g., bends, elbows, pipes, socket welded fittings, and welds). Only very limited failure data exist for non-piping passive components, however. Included below is a representative set of published failure rate data sources. Not all data sources support the requirements of ASME/ANS PRA Standard Capability Category II or III, however.

5.2.1 INEL Report EGG-SSRE--9639

Under a contract with the U.S. Department of Energy, the Idaho National Engineering Laboratory (INEL) developed passive component external leakage and rupture frequency estimates for use in IFPRA. This work is documented in Report EGG-SSRE--9639 [13], which was published in 1991. The Nuclear Power Experience (NPE) was searched for relevant service experience covering the period September 1960 through June 1990. The search distinguished between primary coolant system (PCS, which is the term used in the subject report) and non-PCS passive components. A "rupture" is defined as any pressure boundary failure producing a through-wall flow rate greater than 50 gpm. The dimension of calculated frequencies is "per linear foot and hour" for piping and "per component and hour" for the non-piping passive components. Leakage and "rupture" frequencies are presented for the following types of passive components:

- Piping
- Valve body
- Pump casing
- Flange
- Heat exchanger shell
- Tank

For each component type uncertainty distributions are included (lognormal mean values and corresponding range factors). No updates of this work have been performed to date. An application of this data source to a current IFPRA project would require a considerable amount of interpretation and adaptation to account for new service experience data and the current state-of-knowledge with respect to piping reliability analysis. The NPE database is no longer a supported source of service experience data.

5.2.2 EPRI TR-100380

EPRI report TR-100380 [15] includes results of a project to develop a pipe failure event database and estimate BWR- and PWR-specific pipe leak and rupture frequencies by using the service experience data for four system groups: 1) reactor coolant system, 2) safety injection & recirculation system, 3) feedwater & condensate system, and 4) "other" safety-related systems. The service experience data covers the period 1960 through 1986. A "rupture" is defined as any pressure boundary failure producing a through-wall flow rate greater than 50 gpm. The leak and rupture frequency estimates are presented in terms of pipe sections, which are defined as runs of piping between major components that range from 10 feet to 100 feet in length. An updated study [16] was published in 1993 and includes pipe failure rates that account for U.S. service experience for the period 1960 through 1991.

In this EPRI-sponsored work, a "section" is used to define a piping component boundary for the purpose of calculating failure rates. Estimates of the number of pipe sections in a given system are obtained from reviews of piping and instrumentation diagrams (P&IDs). The intent was to simplify the analyst's work to obtain appropriate piping component populations. The statistical analysis of the service experience data uses an analysis-of-variance (ANOVA) technique to account for influences by material type (e.g., carbon steel vs. stainless steel), pipe size (below 2-inch inside diameter (ID), 2" ≤ ID < 6", and 6-inch diameter or greater), system group, and NSSS vendor.

Given the availability of more recent data, it is not recommended that References [15] or [16] be used for performing contemporary IFPRAs.

5.2.3 EPRI 1013141

EPRI report 1013141 [7] was specifically structured to address the applicable requirements of the ASME/ANS PRA Standard for internal flood initiating event frequencies (See High Level and Supporting Requirements for IFEV). This EPRI report includes pipe failure rates for three different pressure boundary failure modes ("spray," "flood," and "major flood") and seven different systems (ASME Class 3 Service Water, Safety Injection & Recirculation outside containment or drywell, Component Cooling Water, Fire Protection, Feedwater & Condensate, and Circulating Water). The U.S. service experience for the period 1970 through 2004 is accounted for in this study. The failure parameter estimation uses a Bayesian analysis framework together with a comprehensive treatment of uncertainties. The dimension of all calculated failure rates is "per linear foot of piping system and reactor calendar year." For raw water piping systems this study accounts for the influence of water quality (fresh water, river water or salt water) on pipe failure rate. All metallic components of the pressure boundary are included in the failure rates and hence separate estimates for components such as valve bodies and pump bowls do not need to be applied for the purpose of calculating flood induced initiating event frequencies from piping systems.

Unlike EPRI report TR-100380 [15] (and the updated report, TR-102266 [16]), this more recent effort explicitly accounts for the degradation and damage mechanisms that are unique to specific system groups. Chapter 6 of EPRI report 1013141 [7] includes information regarding how the failure rates derived in EPRI report 1013141 compare with TR-100380. An example of the results comparison is given in Figure 5-1 for failure rates and rupture frequencies in 2" to 6" service water pipes. In most cases the estimates from the most recent study (denoted as SW) exceed the corresponding estimates from TR-100380 (denoted as GE-OSR) by one to two orders of magnitude.

There area two key reasons for these differences, one being the significantly larger pipe failure event population used in EPRI report 1013141, and another being different pipe population exposure terms. In Figure 5-1 a "rupture" in the case of TR-100380 corresponds to pressure boundary failure producing a through-wall flow rate greater than 50 gpm; and, in the case of EPRI report 1013141, it is a through-wall flow rate greater than 100 gpm.

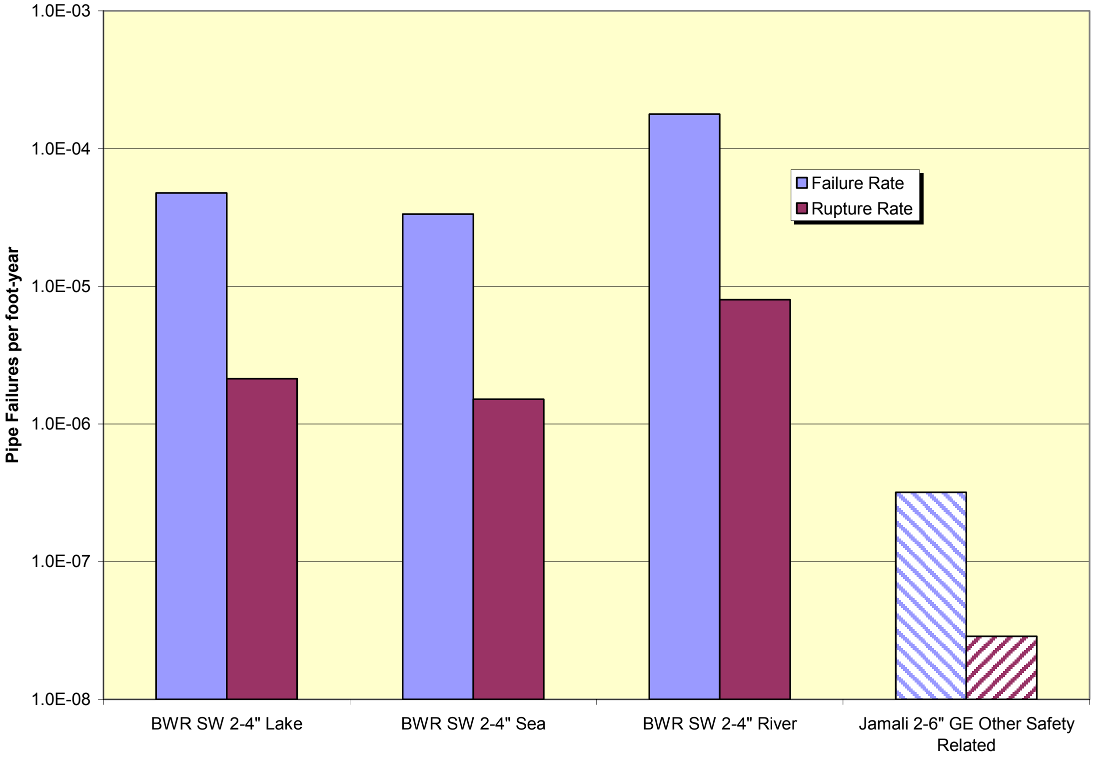


Figure 5-1
Comparison of Failure Rate Estimates for BWR Service Water Piping

With the benefit of hindsight and these comparisons, the authors do not recommend the use of the earlier EPRI pipe failure data (TR-100380 and TR-102266) for IFPRAs or upgrades. Given the availability of more recent data, it is unlikely that continued use of the older data would be able to meet the ASME/ANS requirements for using the most currently available and recently applicable data. For those IFPRAs performed previously using this earlier data, the screening and final quantification of internal flood induced accident sequences should be reviewed to determine whether application of more recent data would alter the results or conclusions regarding the risk significance of internal flood-induced accident sequences.

5.2.4 "Other" Data Sources

Full-scope RI-ISI program development reports may include pipe failure rate estimates applicable to an IFPRA. From the point of supporting ASME/ANS PRA Standard requirements for Capability Category II or III, any RI-ISI related data may require further processing and specialization for use in IFPRA. Rupture frequencies used in RI-ISI evaluations do not necessarily represent realistic estimates of pipe failure rates for Internal Flood. Hence, before applying these values, it should be confirmed that the frequencies represent realistic estimates of pipe failures as a function of pipe failure severity as assumed in the IFPRA. For example, the resolution of the break size or leak rate from pipe failures was not required to perform the RI-ISI application. For many RI-ISI evaluations, pipe failures were only resolved to determine whether they were less than or greater than 50gpm in leak rate. To ensure such estimates can be used, make sure that the applicable requirements in the ASME/ANS PRA Standard for IFEV are met.

5.3 Data Specializations

Initiating event frequencies can be modified by the method of “data specialization.” The term “data specialization” entails re-scaling or re-base-lining a published pipe failure rate and then factoring in new influence factors not accounted for by the original analyses. An example of an influence factor would be the effect of replacing a section of carbon steel piping with stainless steel to enhance resistance to degradation. Failure mechanisms that do not apply to stainless steel but do apply to carbon steel could be removed from the service data in order to specialize the failure rates for this application. Another example would be the effect of implementing an augmented inspection program using non-destructive examination of specific piping locations where no inspections have been previously made.

Examples of data specializations that have been applied in a recent IFPRA for the Columbia Generating Station include the following strategies that were applied to reduce the frequency of Fire Protection System (FPS) pipe failures. These strategies included:

- Design changes to reduce the susceptibility of the FPS piping to water hammer
- Improved leak detection and surveillance procedures to identify pipe leaks and repair them prior to further degradation
- Application of periodic non-destructive examinations (NDE) to FPS piping to identify pipe flaws prior to occurrence of a leak or rupture

The impact of the design strategy to address water hammer was evaluated by eliminating the water hammer events from the service data used to develop the pipe failure rates. The impact of improved leak detection and NDE to reduce the likelihood of pipe failures was evaluated using the Markov model that was developed to support EPRI RI-ISI programs. As shown in Figure 5-2, each of these strategies is seen to make a significant reduction in the FPS failure rate.

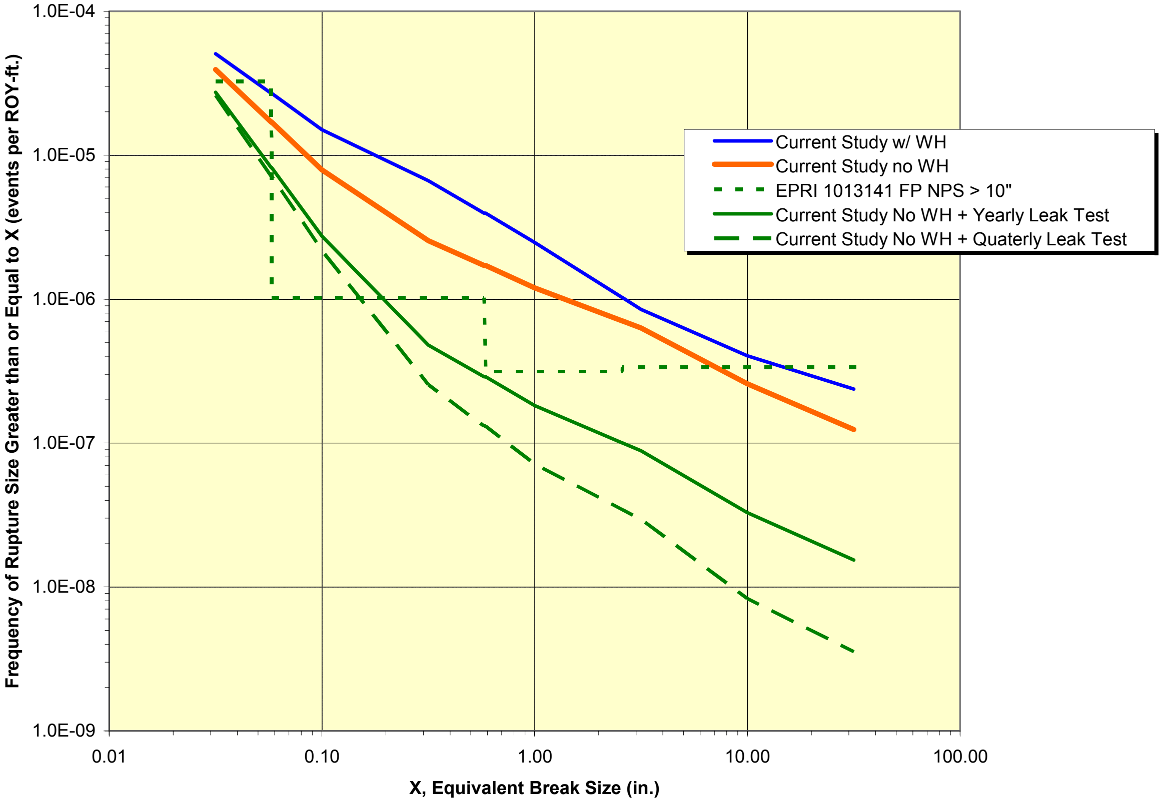


Figure 5-2
Impact of Design and Inspection Strategies to Reduce the Frequency of Fire Protection Header Pipe Ruptures

5.4 Flood Initiating Events from ESW Pump Room Example of Section 4.4

The flood scenarios in the example of Section 4.4 give rise to three distinct flood-initiating events as illustrated in Figures 4-3 and 4-4:

- Flood Induced Loss of ESW Pump A
- Flood Induced Loss of ESW Pump B
- Flood Induced Loss of ESW Pumps A and B

Referring to these as “flood initiating events” presumes that for this plant, loss of either train of ESW or loss of both trains would represent an initiating event, i.e. cause a plant trip or shutdown and challenge the safety functions of the plant that need to be maintained to prevent core damage and a large early release. If a flood event does not cause an initiating event for purposes of the PRA model development, it is simply a flood and not a flood-initiating event as this terminology is used in the ASME/ANS PRA Standard. By quantifying the event trees of Figures 4-3 and 4-4 for ESW Pump Room A and a similar set of event trees for ESW Pump Room B, the frequency of each initiating event above can be quantified. This procedure will require the calculation of pipe failure frequencies for the lengths of pipe and failure modes considered in the event tree for the ESW and FP system piping, quantification of the probabilities that the spray from the pipe failure will lead to failure of the electrical panels at the 7’ elevation in the rooms, quantification of the probability that the flood proof door is left open at the time of the pipe break, and evaluation of the human recovery actions to isolate and terminate the flood before reaching one or both pump pedestals or reaching one or both electrical panels depending on whether the door is open or closed.

Returning to this example, suppose the follow parameters apply to the pump rooms:

Room Dimensions:	30’ width x 50’ length x 10’ height = 15,000ft^3 room volume
Sump Capacity	600gal
Free Volume Fraction	.75
Water density	7.48 gal/ft^3

Based on this information the data in Table 5-1 is easily developed to help quantify the event trees in Figures 4-3 and 4-4.

Table 5-1
Data for Evaluation of Flood Recovery Actions

Parameter		Door Closed	Door Open
Free Volume Sump		80.2 ft^3	160.4 ft^3
Free Volume Room		11,250 ft^3	22500 ft^3
Free Volume to 3'		3375 ft^3	6750 ft^3
Free Volume to 7'		7875 ft^3	15750 ft^3
Time to 3'	Spray @100gpm	258.5 min	516.9 min
	Flood @ 2,000 gpm	12.9 min	25.8 min
	Major Flood @ 10,000 gpm	2.6 min	5.2 min
Time to 7'	Spray @100gpm	595.1 min	1190.1 min
	Flood @ 2,000 gpm	29.8 min	59.5 min
	Major Flood @ 10,000 gpm	6.0 min	11.9 min

5.5 Floods from HELB-Induced Fire Protection System Actuation

The following example is based on an Internal Flood evaluation that was performed as part of a "Significance Determination Process" at an existing PWR power plant [22]. The example is selected to show how to address several technical issues and associated requirements in the ASME/ANS PRA Standard regarding internal flood initiating event frequency development.

The flood initiating events developed in this example are for PWR Turbine Building floods that are caused by the fire protection system deluge sprinklers, which are actuated by high energy line breaks (HELB) in the Turbine Building.

The HELB event initially considers breaks in any pipe containing main turbine working fluid above saturation conditions and includes all piping from the outlet of second feedwater heaters (Numbers 12A and 12B at this plant). Engineering calculations to evaluate the consequences of HELB in the Turbine Building showed that breaks upstream of the fourth feedwater heaters (Numbers 14A and 14B at this plant) do not actuate any fire protection systems. In addition, the volume of water released from such breaks is less than the 185,000 gallons needed to threaten any equipment in safeguards alley, which was determined to be the critical flood volume for these Internal Flood events. Therefore, all breaks upstream of the fourth feedwater heaters can be excluded from further consideration.

In this example, it is interesting to note that the flood volume resulting from the systems producing the HELB is insufficient to reach this critical volume, so the HELB induced fire protection system actuation is a necessary condition to produce the flood consequences of interest.

For piping between the 14 and 15 feedwater heaters, breaks smaller than four inches equivalent diameter actuate no sprinklers. A six-inch equivalent diameter break in these lines would actuate about 100 fire protection sprinklers, and a nine-inch equivalent break would actuate enough sprinklers so that the fire pumps could be assumed to be providing full flow to the system.

For piping after the 15 feedwater heaters, a two-inch or smaller equivalent diameter break would actuate no fire protection systems. A four-inch break would actuate enough sprinklers so that the fire pumps could be assumed to be providing full flow to the system.

Based on these results, two initiating events are analyzed for flooding events. The first is a feedwater or condensate line break that actuates enough fire sprinklers to result in full flow from both fire pumps to the Turbine Building. This event includes any break between the 14 and 15 feedwater heaters with an equivalent diameter of greater than six inches or any break downstream of the 15 feedwater heaters with an equivalent diameter greater than two inches.

The second event is a feedwater or condensate line break that actuates approximately 100 sprinklers. The Turbine Building HELB models show that 100 sprinklers are representative of moderate releases. This event includes breaks in the lines between the 14 and 15 feedwater heaters with an equivalent diameter between two and six inches.

5.5.1 Initiating Event Frequency Model

5.5.1.1 Feedwater and Condensate Line Breaks Causing Large Fire Protection System Actuation

Large fire protection system actuations are those that result in the opening of sufficient fire suppression sprinklers to result in the full flow of the fire protection system pumps into the Turbine Building. As discussed above, this event includes any break with an equivalent diameter greater than two inches in piping downstream of the 15 feedwater heaters and any break with an equivalent diameter greater than six inches between the 14 and 15 feedwater heaters. For feedwater piping located downstream of the 15 feedwater heaters, a total of 331.56 feet of pipe was identified. For piping between the 14 and 15 feedwater heaters, a total of 696.55 feet of pipe was identified.

The frequency of a large FP actuation due to HELB downstream of the 15 FW heater can be expressed as:

$$F_{FL15} = L_{FWC15}(\rho_{FWC2} + \rho_{FWC6}) = L_{FWC15}(\lambda_{FWC2}P\{2-6|F_{FWC2}\} + \lambda_{FWC6}P\{>6|F_{FWC6}\}) \qquad \textbf{Equation 5-2}$$

For piping between the 14 and 15 feedwater heaters, only pipe breaks greater than 6-inch equivalent diameter are included. The large FP actuation frequency for these size breaks in this piping is calculated to be:

$$F_{F45L} = L_{FWC45}\rho_{FWC6} = L_{FWC45}(\lambda_{FWC6}P\{>6|F_{FWC6}\} \qquad \textbf{Equation 5-3}$$

The frequency of large FP actuation due to HELB in the feeedwater and condensate system is the sum of the two values above or:

$$F_{FLBL} = F_{FLB15} + F_{FLB45L} \qquad \textbf{Equation 5-4}$$

Where,

L_{XY} = Length of pipe in system X (e.g. FW) and location Y (e.g. FW heater 15)

ρ_{Xj} = Pipe Rupture Frequency for system X and pipe rupture size j (e.g. 2" to 6" break size)

λ_{Xj} = Pipe Failure Rate for system X and pipe rupture size j

$P\{2-6|F_{Xj}\}$ = Conditional probability of pipe rupture of size 2" to 6" given pipe failure in system X and pipe size j

$P\{>6|F_{Xj}\})=$ Conditional probability of pipe rupture of size > 6” given pipe failure in system X and pipe size j

In the above models it is necessary to have different terms for pipe breaks ≥ 2 in. and those ≥ 6 inches because of the fact that pipe breaks greater than 6 inches in break size cannot occur in pipes smaller than 6 inches in pipe size. In the failure rate development shown below, the pipe failure and exposure data must be segregated into different pipe size ranges to support this type of model.

5.5.1.2 Feedwater and Condensate Line Breaks Causing Intermediate Fire Protection System Actuations

Intermediate fire protection system actuations are those that result in the opening of approximately 100 fire suppression sprinklers based on the results of engineering calculations to evaluate the consequences of HELB in the Turbine Building. As discussed above, this event includes any break with an equivalent diameter between two and six inches between the 14 and 15 feedwater heaters.

The Intermediate FP actuation frequency for these size breaks in this piping is calculated to be:

$$F_{FL45M}=L_{FWC45}\rho_{FWC2}=L_{FWC45}\lambda_{FWC2}P\{2-6|F_{FWC2}\}$$ **Equation 5-5**

With the terms defined as above.

5.5.2 Database Development

5.5.2.1 Database Insights

As discussed more fully in Reference [22], the dominant failure mechanism in HELB piping is flow-accelerated corrosion (FAC). The piping systems in the Turbine Building were put into 4 major categories based on their general susceptibility to FAC. The systems in the HELB category that are susceptible to FAC include the feedwater and condensate systems and the steam systems with relatively wet steam conditions with carbon steel pipe. Based on insights from service experience and the piping design parameters, the high-pressure steam piping between the steam generators and the inlet of the high-pressure turbine is generally not susceptible to FAC. The reasons for this lack of susceptibility include the use of thick walled pipe, dry steam conditions, and relatively straight bend free runs of pipe. In the PIPExp database there have been no instances of FAC in this part of the main steam system. Hence the high-pressure steam piping is set aside as one category so that the remaining categories represent the FAC sensitive pipe. The FAC sensitive pipe was further broken down into 3 categories based on the relative susceptibility to FAC: two categories for steam and one for feedwater and condensate. The two steam categories include the low-pressure steam pipe downstream of the HP turbine outlet and the extraction steam. These insights were used to decide how to specialize the data treatment for this Internal Flood initiating event frequency development.

For each of the four system categories described in the preceding paragraphs, rupture frequencies were developed for two rupture size cases: ruptures with equivalent break sizes between 2-inches and 6-inches diameter and ruptures with equivalent break sizes greater than 6-inches in diameter. The estimation of the rupture frequencies for each of these break size cases required the estimation of two parameters: a failure rate and a conditional probability that the break would be in the specified size range. The failure rate for each break size range is different because only pipes with a pipe diameter of at least 6-inches can produce a break size greater than 6-inches, whereas pipes as small as 2-inches in diameter can produce break sizes of 2-inches and greater (for example, a double ended break of a 2-inch pipe creates an equivalent break size that is the square root of two times the pipe diameter). To support the estimation of these parameters, separate queries of the pipe failure database had to be made for pipe failures (cracks, leaks, wall-thinning, and ruptures) and ruptures in the prescribed break size ranges. Then, these queries had to be matched up against the appropriate estimate of the pipe component population exposure terms. The parameter estimation for these failure rates and conditional rupture probabilities is documented in Section 4.

Consideration was given to the development of system-specific failure rates and rupture frequencies separately for the feedwater system and for the condensate system. It was decided to develop a composite set of failure rates and rupture frequencies for both systems combined for several reasons:

- First, there are inconsistencies in the way in which system boundaries are established between feedwater and condensate that would give rise to inconsistencies between how the data was classified and how it is applied to the plant being subjected to Internal Flood PRA.
- Second, there are a variety of different operating conditions within the condensate system and the feedwater system that give rise to different susceptibilities to the predominant damage mechanism, flow accelerated corrosion. For example, there are normally several stages of feedwater heating in the condensate and additional stages in the feedwater system. Feedwater drains and heater and main feedwater and condensate lines have much different conditions.
- Third, there is no noticeable trend in the failure and rupture service experience between the two systems that would suggest different underlying failure rates and rupture frequencies.
- Finally, breaking up the data into separate systems reduces the statistical quality of each data cell. Subdividing the data cells too finely would produce statistically insignificant event frequencies within each data cell.

A review of the piping service data with systems susceptible to FAC as discussed more fully in Reference [22] reveals a significant improvement in piping system performance around 1988. It is reasonable to assume that this trend in performance is due to industry and NRC efforts to improve plant performance in general and in particular to augmented inspection, repair, and replacement programs for FAC. For the base case analysis, only the service data since 1988 was used to calculate the failure rates as this data is viewed to be representative of current industry practice in managing piping system performance. As a contrast, the second case considered only the service data up to and including 1988. A third case was defined by screening out all the FAC related pipe failures. The purpose of the third case was to understand the importance of the prevailing failure mechanism for experienced high-energy line breaks. This set of cases is useful when addressing the issue of the appropriateness of using historical industry data regarding FAC induced pipe failures to predict the future performance of piping susceptible to FAC.

Failure rates were specialized for the wet and dry steam systems and for the feedwater and condensate systems by specializing the data analysis for the failure rates. The data from the FAC sensitive steam, feedwater, and condensate systems were combined for the purposes of estimating the conditional rupture size probabilities. The justification for this procedure is that essentially all the pipe ruptures in these systems are due to FAC and occur in similar carbon steel pipes. The system-specific factors that influence the rupture frequencies are judged to be adequately reflected in the specialized failure rates. The conditional probability of rupture size is viewed to be primarily related to properties of the pipe material and the damage mechanism and less related to other properties of the system. The piping system materials for all the FAC sensitive piping are very similar. This approach to pooling data is consistent with the data treatment in References [7], and [23].

5.5.2.2 Feedwater and Condensate System Failure Data

The source of the failure data that was used in Reference [22] is known as PIPExp-2009 [24], and it is the same source of data used to develop Internal Flood initiating event frequency data in Reference [7] and to support the estimation of Loss of Coolant Accident Frequencies in Reference [23]. This database covers more than 2,500 reactor calendar years of service experience with PWR plants. The results of the failure data query to support this example are shown in Table 5-2taken from Reference [22]. Failures include all events leading to pipe repair or replacement and are broken down into failure mode in this table.

5.5.2.3 Feedwater and Condensate Exposure Term Data

The exposure terms needed for this analysis include feedwater and piping system exposures that correspond with the failure data in Table 5-3. The exposure data must be structured to be able to estimate failure rates for two pipe size ranges to support this model; pipe sizes ≥ 2 in. and sizes ≥ 6 in. In addition, due to the observed trends in the failure data resulting from industry programs to address FAC, different exposure term estimates are needed for two different time intervals including 1970-2004 and 1988-2004. This level of detail is needed to support the sensitivity analyses mentioned previously. The exposure term estimates from Reference [22] are summarized in Table 5-3

In the uncertainty analysis to be discussed below, the exposure estimates in Table 5- 3are taken to be median values of an uncertainty distribution that assigns a 25% chance that the true exposure is 50% higher and 25% chance that is 50% lower than the point estimates in Table 5-2.

This accounts for the uncertainty due to the fact that the pipe exposure lengths are estimated from a limited population of plants and the exposure term accounts for all the plants in the industry. The uncertainty in the failure rate terms was developed using the same methodology as was used to develop the Internal Flood initiating event data in Reference [7]. A lognormal distribution is assumed based on engineering judgment with a mean value of 1.5×10^{-4} per ft-yrs and an assumed range factor of 100. This lognormal distribution is subjected to Bayes' updating based on the number of failures in Table 5-2 and each of the three exposure term hypotheses (best estimate in Table 5-3 assigned a probability of 50%, 25% probability that Table 5-3 is high by 50% and 25% probability that Table 5-3 is too high by 50%. The 3 Bayes' posterior distributions are then combined using a Bayes' posterior weighting technique as explained more fully in Reference [7].

5.5.2.4 Feedwater and Condensate Conditional Rupture Probability

For FAC-susceptible piping the likelihood of rapid or unexpected flaw propagation given wall thinning is quite high and can be estimated directly from service data. In the case of pipe materials or systems that are not susceptible to FAC such as the high-pressure main steam system at Kewaunee, there are much fewer events from which to derive the conditional rupture probability. In this case the estimation of the likelihood of sudden pipe failure relies on insights from service experience with different piping systems and materials under different loading conditions in combination with engineering judgment and fracture mechanics evaluations.

Table 5-2
Feedwater and Condensate System Pipe Failures 1970-2004

Nominal Pipe Size (NPS) [Inch]	**1970-1987**				**1988-2004**			
	Total	Wall Thinning	Leak	Rupture	Total	Wall Thinning	Leak	Rupture
2” < NPS ≤ 6”	14	5	6	3	18	7	7	4
NPS > 6”	300	275	17	8	52	30	15	7
Total:	314	280	23	11	70	37	22	11

Notes:

Service experience in Table 5-1 derived from 2524 reactor-years of PWR operation worldwide; 858 reactor-years pre-1988 and 1666 reactor-years post-1987

Failure data includes contributions from FAC (dominant degradation mechanism), vibration-fatigue and water hammer

Table 5-3
Exposure Term Data for FWC Pipe Failure Rates

Parameter	1970-2004	1988-2004
Reactor Operating Years (ROY)	2,524	1,666
Length of FWC Pipe ≥ 2 in.	14,037 ft	
Length of FWC Pipe ≥ 6 in.	9,358 ft.	
Exposure (ROY-ft) ≥ 2 in.	35,429,388 ft-yr.	23,385,642 ft-yr.
Exposure (ROY-ft) ≥ 6 in.	23,619,592 ft-yr.	15,590,428 ft-yr.

The likelihood of a through-wall flaw propagating to a significant structural failure is expressed by the conditional rupture size probability $P\{R|F\}$. It is determined from service experience; insights from reviewing service data; and engineering judgment, with the uncertainty treated using the Beta Distribution.

The beta distribution takes on values between 0 and 1 and is defined by two parameters, A and B (some texts refer to these as "Alpha" and "Beta"). It is often used to express the uncertainty in the estimation of dimensionless probabilities such as MGL common cause parameters and failure rates per demand. The mean of the Beta Distribution is given by:

$$Mean = \frac{A}{A+B}$$ **Equation 5-6**

If A = B = 1, the beta distribution takes on a flat distribution between 0 and 1. If A = B = ½, the distribution is referred to as a Jeffery's non-informative prior and is a U shaped distribution with peaks at 0 and 1. Expert opinion can be incorporated by selecting A and B to match up with an expert estimate of the mean probability. For example, to represent an expert estimate of 10^{-2}, A=1 and B=99 can be selected. These abstract parameters A and B can be associated with the number of failures and the number of successes in examining service data to estimate a failure probability on demand. A + B represents the number of trials.

The beta distribution has some convenient and useful properties for use in Bayes' updating. A prior distribution can be assigned by selecting the initial parameters for A and B, denoted as A_{Prior} and B_{Prior}. Then when looking at the service data, if there are N failures and M successes observed, the Bayes updated or posterior distribution is also a Beta distribution with the following parameters:

$$A = A_{\Pr ior} + N$$ **Equation 5-7**

$$B = B_{Prior} + M$$ **Equation 5-8**

The above explains how the Beta distribution is used in this study to estimate conditional rupture probabilities. The priors are selected to represent engineering estimates of the probabilities "prior" to the collection of evidence. Equations (5-7) and (5-8) are used to compute the parameters of the Bayes' updated distribution after applying the results of the data queries to determine N and M. N corresponds to the number of ruptures in the specified size range, and M corresponds to the number of pipe failures that do not result in a rupture in the specified size range.

The "A" parameter of the Beta Distribution corresponds to a significant consequence (spray, internal flood. or major flooding event) and the "B" parameter corresponds to the remaining failure experience (significant wall thinning or through-wall flaw). The total number of failures in the database is equal to A+B. Table 5-5 is a summary of the prior and posterior Beta Distribution parameters for non-Code FWC used in this example. The posterior distribution parameters are derived by performing a Bayes' update of the assumed prior distributions using service data from PIPExp and the conjugate properties of the Beta Distribution. The prior distribution parameters were developed in an expert elicitation sponsored by the NRC to develop loss of coolant accident initiating event frequencies. That elicitation included estimates for FAC sensitive piping.

Part of the information presented in Table 5-4 is the screening of pipe ruptures in different break size ranges in the FAC sensitive piping. The 26 events with equivalent break sizes between 2" and 6" are listed in Table 5-5, and the 33 events with break sizes greater than 6-inches are in Table 5-6. Recall that for the failure rate estimates, only the data from the FWC systems are used; but for the conditional rupture probability, all systems with FAC susceptible piping are used, including feedwater, condensate, and various steam systems.

5.4.2.5 Feedwater and Condensate Failure Rates and Rupture Frequencies

The results for the quantification of the failure rate and rupture frequency parameters used in the initiating event frequency Equations (5-2) through (5-5) are shown in Table 5-7.

To support sensitivity calculations that are summarized in the next section, comparisons were made among three different cases selected to investigate the trends in the failure data before and after 1988 and the impact of FAC on the estimates. As seen in Figure 5-3, the results for the case using only data from prior to 1988 before FAC programs became effective would increase by more than an order of magnitude. Stated another way, the failure rates and rupture frequencies based on the service data before 1988 are more than an order of magnitude greater than those considering only data from events after 1988 when the FAC programs were in effect.

Conversely, if all the FAC-related events were precluded by some type of plant change to introduce FAC resistant piping, an order of magnitude reduction in the relevant pipe failure rates and rupture frequencies would be expected.

Table 5-4
Parameters Selected to Quantify Conditional Rupture Probabilities

Analysis Case		Prior Beta Parameters			Posterior Beta Parameters(3)		
Piping Material	Equivalent Break Size (EBS)(1), (2)	Constraint	A_{Prior}	B_{Prior}	A_{Post}	B_{Post}	Mean
Carbon Steel and FAC-susceptible	2” < EBS ≤ 6”	1.0E-2	1	99	27 (1)	1254	2.11E-02
	EBS > 6”	1.0E-2	1	99	34 (2)	1072	3.07E-02
Stainless Steel or FAC-resistant(4)	2” < EBS ≤ 6”	1.0E-3	1	999	10	1062	9.33E-03
	EBS > 6”	1.0E-3	1	999	8	1036	7.66E-03

Notes:

(1) A through-wall flaw of size 2” < EBS ≤ 6” can occur in any FAC-susceptible piping of nominal pipe size (NPS) > 2”. The database screening criteria include consideration of NPS and through-wall flaw size.

(2) A through-wall flaw of size EBS > 6” can occur in any FAC-susceptible piping of NPS > 6”.

- EBS = Equivalent Break Size
- NPS = Nominal Pipe Size [inch]

(3) The posterior Beta distribution parameters are obtained from PIPExp database (accounts for service experience applicable to non-Code FWC and steam piping in Light Water Reactors):

- $B_{Post} = B_{Prior} + (B_{Evidence} – A_{Evidence})$
- $A_{Evidence}$ = Total number of ruptures in specified size range
- $B_{Evidence}$ =Total number of failure records =1181 records (carbon steel FWC piping of nominal pipe size greater than 2”. There are 1006 records for piping > 6” NPS.
- $A_{Post\text{-}Large\ Leak} = A_{Prior} + A_{Evidence}$; the evidence is 26 records for which the through-wall defect is sufficient to create a significant outflow of steam/condensate corresponding to 2” < EBS ≤ 6” (Table 5-4).
- $A_{Post\text{-}MSF} = A_{Prior} + A_{Evidence}$; the evidence is 33 records involving major structural failure of FAC-susceptible piping corresponding to EBS > 6-inch diameter (Table 5-5)

(4) The Beta distribution parameters for ‘stainless steel or FAC resistant case’ are obtained by screening out any data record involving degradation or failure caused by FAC. A total of 72 records involve non-FAC failures and of these, 44 records involve piping > NPS6.

Table 5-5
Summary of FAC-Susceptible Piping Rupture Events with Equivalent Break Size Between 2-inch Diameter and 6-Inch Diameter (EBS1)

Event Date	Plant Name	Country	Plant Type	System	System Group	Nominal Pipe Size [Inch]
4/22/1995	Almaraz-1	ES	PWR	COND	FWC	6
2/13/2001	Balakovo-2	RU	PWR	FW	FWC	3.2
7/27/1993	Bohunice-3	SK	PWR	MS	STEAM	6
9/28/1983	Browns Ferry-1	US	BWR	MSR	STEAM	6
11/1/1977	Browns Ferry-3	US	BWR	EXT-Steam	STEAM	6
8/10/1999	Callaway	US	PWR	FW	FWC	6
9/25/1985	Dresden-2	US	BWR	COND	FWC	6
11/17/1986	Fermi-2	US	BWR	FW	FWC	6
4/28/1970	H.B. Robinson-2	US	PWR	MS	STEAM	6
3/1/1977	Hatch-1	US	BWR	COND	FWC	4
9/26/1989	Indian Point-2	US	PWR	MS	STEAM	4
4/3/1987	Indian Point-2	US	PWR	FW	FWC	6
11/24/1993	Kola-4	RU	PWR	MS	STEAM	4
1/1/1972	Millstone-1	US	BWR	MS	STEAM	4
12/30/1973	Millstone-1	US	BWR	COND	FWC	4
12/31/1990	Millstone-3	US	PWR	MSR	STEAM	6
12/31/1990	Millstone-3	US	PWR	MSR	STEAM	6
3/19/1983	Oconee-2	US	PWR	MSR	STEAM	3
12/15/1996	Paks-3	HU	PWR	EXT-STEAM	STEAM	6
7/29/1986	R.E. Ginna	US	PWR	MS	STEAM	6
11/18/1977	Ringhals-2	SE	PWR	FW	FWC	6
3/23/1990	Surry-1	US	PWR	MSR	STEAM	4
8/7/1972	Surry-1	US	PWR	MSR	STEAM	4
1/9/1982	Trojan	US	PWR	EXT-STEAM	STEAM	6
8/1/1983	Zion-1	US	PWR	EXT-STEAM	STEAM	6
7/28/1991	Zion-2	US	PWR	FW	FWC	3
MSR = Moisture Separator Reheater System						

Table 5-6
Summary of FAC-Susceptible Piping Rupture Events with Equivalent Break Size > 6-inch Diameter (EBS2)

Event Date	Plant Name	Country	Plant Type	System	System Group	Pipe Size [Inch]
12/18/1991	Almaraz-1	ES	PWR	MS	STEAM	8
4/18/1989	ANO-2 (Arkansas-2)	US	PWR	MS	STEAM	14
9/29/1982	Browns Ferry-1	US	BWR	MS	STEAM	8
6/24/1982	Browns Ferry-1	US	BWR	MSR	STEAM	8
8/15/1983	Browns Ferry-1	US	BWR	MS	STEAM	8
11/20/1984	Calvert Cliffs-1	US	PWR	EXT-STEAM	STEAM	16
1/15/1988	Catawba-1	US	PWR	COND	FWC	8
9/25/1987	Doel-1	BE	PWR	COND	FWC	8
4/10/1993	Fermi-2	US	BWR	EXT-STEAM	STEAM	8
4/21/1997	Fort Calhoun-1	US	PWR	FW	FWC	12
4/25/1986	Hatch-2	US	BWR	FW	FWC	20
6/27/1985	Mülheim-Kärlich	DE	PWR	FW	FWC	18
12/29/1984	Krsko	SLO	PWR	FW	FWC	14
5/6/1991	Kuosheng-2	TW	BWR	COND	FWC	12
5/28/1990	Loviisa-1	FI	PWR	FW	FWC	12
2/25/1993	Loviisa-2	FI	PWR	FW	FWC	8
6/14/1996	Maanshan-21	TW	PWR	MS	STEAM	16
8/9/2004	Mihama-3	JP	PWR	FW	FWC	20
11/6/1991	Millstone-2	US	PWR	MSR	STEAM	8
8/8/1995	Millstone-2	US	PWR	Heater-Drain	FWC	8
6/23/1982	Oconee-2	US	PWR	EXT-STEAM	STEAM	24
1/1/1985	Oconee-2	US	PWR	FW	FWC	10
9/24/1996	Oconee-2	US	PWR	MSR	STEAM	18
9/17/1986	Oconee-3	US	PWR	Heater-Drain	FWC	10
6/10/1974	Quad Cities-2	US	BWR	FW	FWC	18
1/1/1989	Santa Maria de Garona	ES	BWR	FW	FWC	16
2/9/1980	Santa Maria de Garona	ES	BWR	EXT-STEAM	STEAM	16
3/1/1993	Sequoyah-2	US	PWR	MS	STEAM	10
10/15/1983	Surry-1	US	PWR	FW	FWC	26
12/9/1989	Surry-1	US	PWR	Heater-Drain	FWC	10
12/9/1986	Surry-2	US	PWR	FW	FWC	18
3/9/1985	Trojan	US	PWR	FW	FWC	14
12/2/1971	Turkey Point-3	US	PWR	MS	STEAM	12
MSR = Moisture Separator Reheater System						

Table 5-7
Results for FWC Mean Failure Rates and Rupture Frequencies

Case	Data Used	FAC Events	Equivalent Break Size	Failure Rate [1/ft.-yr.]	Rupture Frequency [1/ft.-yr.]
1	1988-2004	Included	EBS1: 2” to 6”	3.19E-06	6.72E-08
			EBS2: ≥ 6”	3.56E-06	1.09E-07
2	1970-1987	Included	EBS1: 2” to 6”	2.78E-05	5.85E-07
			EBS2: ≥ 6”	3.98E-05	1.22E-06
3	1988-2004	Excluded	EPS1: 2” to 6”	9.21E-07	8.60E-09
			EPS2: ≥ 6”	8.29E-07	6.35E-09

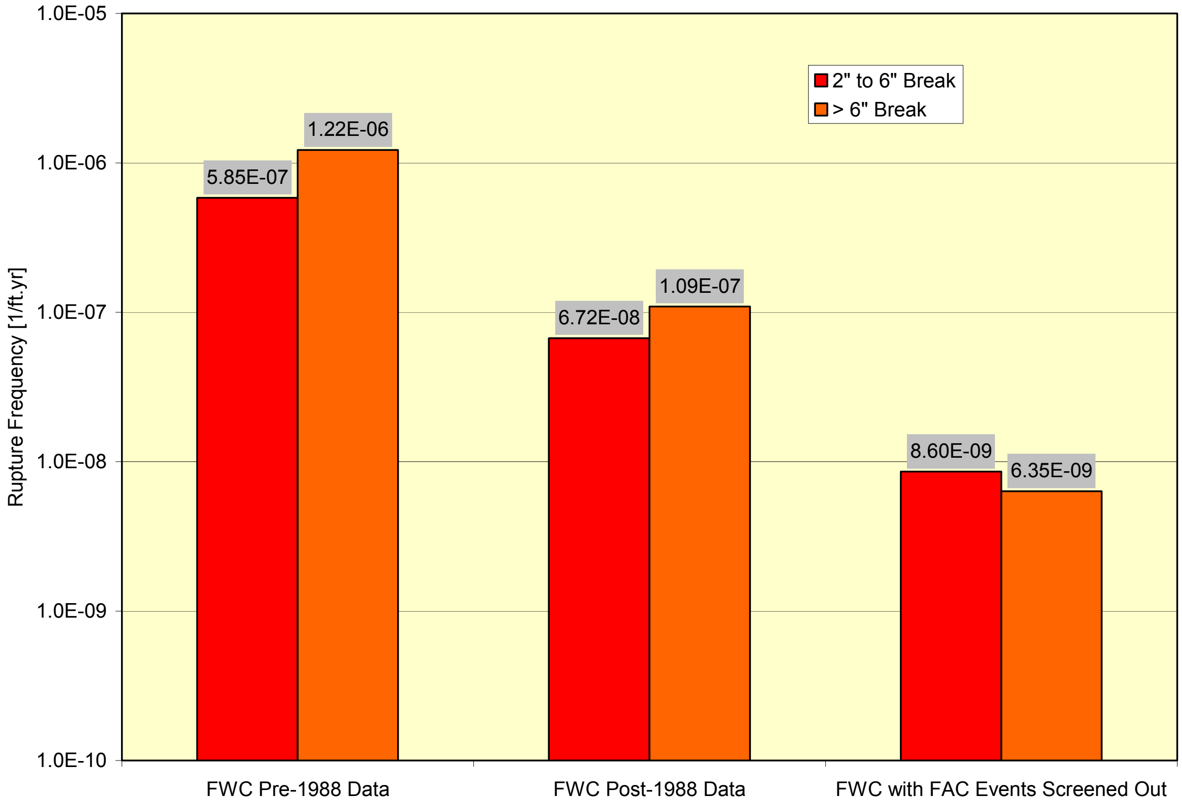


Figure 5-3
Comparison of FWC Failure Rates and Rupture Frequency Cases

5.4.2.6 Internal Flood Initiating Event Frequency Results

The results for each of the failure rate parameters were propagated through the initiating event frequency equations of Equations (5-2) through (5-5) via Monte Carlo simulation to obtain uncertainty distributions for each initiating event frequency and analysis case. The following steps summarize all the calculations made through this point:

1. A prior distribution for the FWC failure rate was obtained from Reference [25]. The prior is a lognormal distribution with a mean value of 1.50×10^{-4} failures per foot of pipe per year with a range factor of 100.
2. For each of the failure rate and rupture frequency cases listed in Table 5-7 Bayes' updates were performed using the prior from Step 1, the number of failures obtained from the PIPExp database for each case, and estimates of the piping population exposures that are documented in Table 5-3. Bayes' updates were performed using the program BART™ developed by ERIN Engineering and Research, Inc.
3. To account for uncertainty in the population exposure estimates the Bayes' updates were performed for three estimates of the exposure: a best estimate with a probability weight of 50% and a high (1.5 times that of the best estimate) and low (0.5 times that of the best estimate) estimate with weights of 25% each.
4. A composite uncertainty distribution was developed for each of the 6 cases of failure rates of table 5-7 using a posterior weighting procedure using Crystal Ball and Microsoft Excel.
5. The process listed in Steps 1-4 was repeated for two ranges of pipe size: one for pipes greater than or equal to 2", which could produce ruptures of size 2" and greater, and one for pipes sizes greater than 6", which could produce rupture sizes exceeding 6". Hence a total of 6 failure rate distributions were developed: one for 2" and greater and one for 6" and greater pipe size ranges for each of the 3 cases of failure data periods in Table 5-7.
6. A Beta distribution was developed to represent the conditional probability of rupture for two rupture sizes: 2" to 6" and greater than 6" equivalent break size using the data described in Section 4. These beta distributions include prior distribution parameters that represent the authors' expert judgment on the values of these probabilities, and service data experience that is documented in Table 5-4 Two sets of distributions were developed: one for FAC sensitive carbon steel pipe in systems subject to FAC and the other for FAC resistant pipe or systems that are not susceptible to FAC, e.g., the high-pressure main steam piping upstream of the turbine throttle valves.
7. The rupture frequencies for rupture sizes between 2" and 6" were obtained by combining the failure rates for 2" and greater pipes and the conditional rupture probabilities developed in Step 6. The rupture frequencies for greater than 6" breaks were obtained by combining the failure rates for greater than 6" pipe sizes with the appropriate conditional rupture probability.
8. Uncertainty in the estimates of the pipe lengths that are used to compute the initiating event frequencies as defined in Equations (5-2) through (5-5) due to uncertainty in the measurements that were taken was treated by using a normal distribution with a mean value

corresponding to the point value measurements and assigning a standard deviation that is 10% of the mean value.

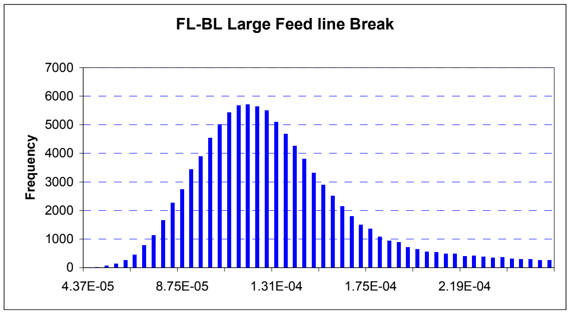
9. The HELB-initiated Internal Flood initiating event frequencies were obtained by propagating the uncertainties in the appropriate rupture frequencies through the Equations (5-2) through (5-5) using the Monte Carlo process using Crystal Ball™ and Microsoft Excel. To properly treat the state of knowledge dependencies all the uncertainty calculations from the output of the Bayes' updates through Step 8 were performed in a single integrated Monte Carlo procedure. In each Monte Carlo trial, a failure rate was sampled for each case and pipe size by sampling from either a high, best estimate, or low exposure term estimate. A conditional rupture probability for each rupture mode was sampled for each pipe size, and a sample initiating event frequency was calculated by propagating these samples through the equations for the pipe rupture frequencies and the equations for the HELB-initiated Internal Flood initiating event frequencies. This process also made it unnecessary to perform a series of Monte Carlo calculations in which the results from each step would be fitted to a distribution for sampling in the next stage.

The results for the initiating event uncertainty analysis resulting from the above calculational steps are shown in Table 5-8. The sources of uncertainty include the scarcity of failure data, uncertainty in the average number of FWC components per reactor year in the PWR plant population in the database (exposure term data), uncertainty in the estimates of FWC piping system lengths in each of the terms of the equations, and the modeling uncertainty that was used to characterize the results of the expert elicitation performed in Reference [23] that was used to form the Bayes' prior distribution for the conditional probability of pipe rupture in different size ranges. In this particular example, however, there were so many actual pipe rupture events used in the Bayes' updating procedure due to the relative high frequency of pipe ruptures in the FWC system due to FAC that the final results are insensitive to the Bayes' prior distribution assumptions.

It should be noted that the results in these exhibits are expressed in terms of events per reactor operating year, because the exposure term data for the failure rates was developed in these terms to avoid introducing an uncertainty about the availability of the plants in the service data from which the failures are derived. In order to meet an ASME Requirement for initiating events analysis, these results should be converted to events per reactor calendar year by multiplying by the plant's predicted availability factor for future plant operation. We speak here about the plant that is being subjected to the Internal Flood PRA. Moreover, the availability factor is that which is predicted to occur and not the historical plant average availability factor, which in most cases is lower than what is expected in future operation due to improvements in plant performance since the mid-1990s.

Table 5-8
Results of the Uncertainty Analysis for FWC Break Initiating Events

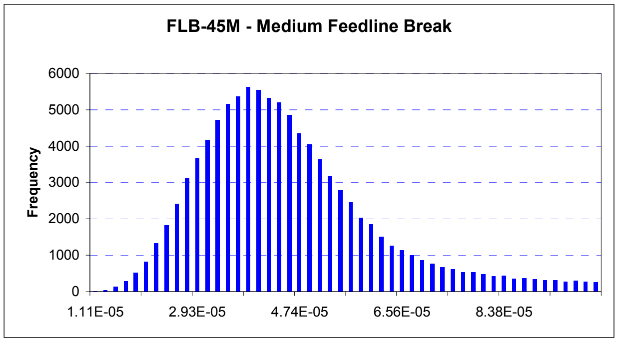
Event	Events per Reactor Operating Year			
	Mean	5%tile	50%tile	95%tile
F_{FL15}, Large FLB downstream of FWH15	5.85E-05	3.67E-05	5.52E-05	9.40E-05
F_{FL45}, Large FLB between FWH14 and FWH15	7.67E-05	4.15E-05	7.01E-05	1.42E-04
F_{FLBL}, Large FLB Initiating Event	1.35E-4	8.19E-05	1.26E-04	2.27E-04
F_{FL45M}, Moderate FLB Initiating Event	4.69E-05	2.47E-05	4.29E-05	8.63E-05



Percentiles:	Forecast values
0%	4.15E-05
5%	8.19E-05
10%	9.04E-05
15%	9.65E-05
20%	1.02E-04
25%	1.06E-04
30%	1.10E-04
35%	1.14E-04
40%	1.18E-04
45%	1.22E-04
50%	1.26E-04
55%	1.30E-04
60%	1.34E-04
65%	1.39E-04
70%	1.44E-04
75%	1.50E-04
80%	1.58E-04
85%	1.69E-04
90%	1.87E-04
95%	2.27E-04
100%	4.90E-04

Statistics:	Forecast values
Trials	100,000
Mean	1.35E-04
Median	1.26E-04
Mode	---
Standard Deviation	4.50E-05
Variance	2.02E-09
Skewness	1.76
Kurtosis	10.76
Coeff. of Variability	0.33
Minimum	4.15E-05
Maximum	4.90E-04
Range Width	4.49E-04
Mean Std. Error	1.42E-07

Figure 5-3
Crystal Ball Results for “Large FP Actuation”



Percentiles:	Forecast values
0%	1.02E-05
5%	2.47E-05
10%	2.81E-05
15%	3.05E-05
20%	3.27E-05
25%	3.45E-05
30%	3.62E-05
35%	3.79E-05
40%	3.95E-05
45%	4.11E-05
50%	4.29E-05
55%	4.46E-05
60%	4.65E-05
65%	4.86E-05
70%	5.09E-05
75%	5.36E-05
80%	5.70E-05
85%	6.17E-05
90%	6.96E-05
95%	8.63E-05
100%	2.16E-04

Statistics:	Forecast values
Trials	100,000
Mean	4.69E-05
Median	4.29E-05
Mode	---
Standard Deviation	1.94E-05
Variance	3.75E-10
Skewness	1.83
Kurtosis	11.10
Coeff. of Variability	0.41
Minimum	1.02E-05
Maximum	2.16E-04
Range Width	2.06E-04
Mean Std. Error	6.12E-08

Figure 5-4
Crystal Ball Results for "Intermediate FP Actuation"

5.4.2.7 Sensitivity Study

As a sensitivity study, the initiating event frequencies were recalculated using different assumptions regarding how the data was screened as discussed in the previous section. This study was performed by propagating the results for the pipe failure rates and rupture frequencies for the different data screening strategies through the equations for the initiating event frequencies in Equations (5-2) through (5-5). The results are summarized in Table 5-9 and Figure 5-6. As seen in these exhibits, the impact of using the service data from 1988 to represent the current industry practice and as a basis to predict the HELB-initiated Internal Flood frequencies is approximately an order of magnitude greater compared with the case of using pre-1988 data. This shows the impact of industry improvement programs, particularly the FAC augmented inspection programs, which were responsible for reducing the frequency of pipe breaks due to this damage mechanism since about 1988. Although these programs were effective in reducing the pipe break frequencies, as seen in the third case in which all the FAC related failures since 1988 were removed, FAC is still a dominant failure mechanism for these systems. The initiating event frequencies would be an order of magnitude lower if all the FAC related failures were removed from the data analysis. This assumption simulates the impact of replacing the FWC piping with FAC resistant material such as stainless steel.

In summary, this example provides guidance in addressing the following issues for Internal Flood initiating event frequency development including:

- Initiating event frequency models
- Calculation of HELB frequencies that lead to floods by actuation of the fire protection system sprinklers
- Analysis of service data to calculate initiating event frequencies based on success criteria derived from engineering calculations, such as those to identify the break sizes needed to produce the desired consequences
- Performance of Bayes' updating of failure data and the analysis of trends in the industry data that could be masked by careless application of too many years of data
- Performance of uncertainty analysis and sensitivity analysis for flood initiating event frequencies

Table 5-9
Results of Sensitivity Study to Explore Alternative FAC Data Treatments

Initiating Event	Mean Initiating Event Frequency per Reactor Operating Year		
	Base Case Data after 1988 only	Data up to 1988 only	Data after 1988 with FAC events removed
F_{FL15}, Large FLB downstream of FWH15	5.85E-05	5.98E-04	4.96E-06
F_{FL45}, Large FLB between FWH14 and FWH15	7.67E-05	8.50E-04	4.42E-06
F_{FLBL}, Large FLB Initiating Event	1.35E-04	1.45E-03	9.38E-06
F_{FL45M}, Moderate FLB Initiating Event	4.69E-05	4.07E-04	4.29E-05

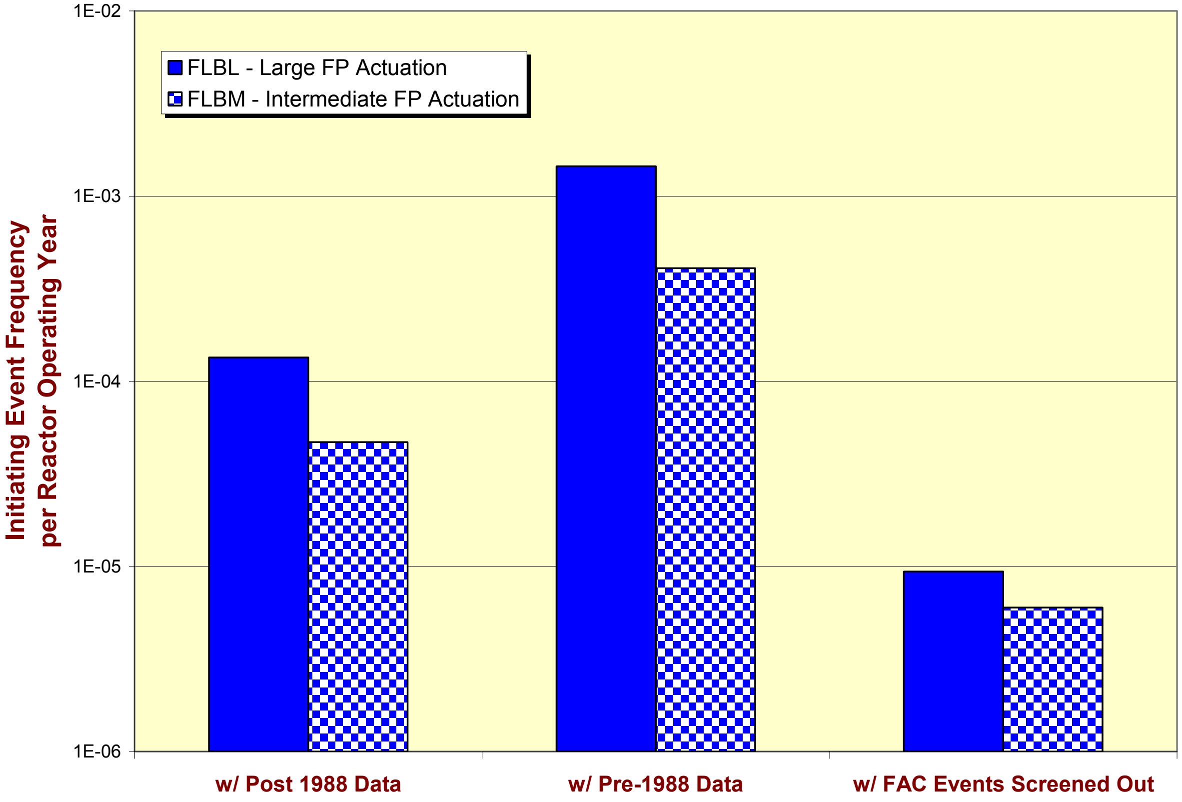


Figure 5-5
Sensitivity Study Results to Show Impact of Alternative FAC Data Handling

5.6 Maintenance-Induced Floods

During full-power operation, certain maintenance activities are performed on major equipment within the plant. Prior to the initiation of such activities, valves in the inlet and outlet flow path of the equipment are closed to provide isolation protection. In the event that the isolation protection fails, a breach in the system boundary will occur and caused the flooding of equipment within the room. Equipment located in rooms in the flood propagation path may also be impacted.

Qualitative screening can be performed to develop a complete and realistic list of maintenance-induced flood scenarios for further evaluation. Several factors must be considered in performing the screening of maintenance-induced flood events. A review of plant maintenance activities and procedures must be conducted to identify major equipment that is taken out-of-service for maintenance during full-power operation. The review should focus on maintenance activities that temporarily re-configure the system pressure boundary and have the potential for breaching the system boundary. The re-configuration of the pressure boundary may rely on the repositioning of valves or installation of freeze seals to establish the required protection. The number of barriers used to establish inlet and outlet isolation for the removed equipment will determine the likelihood of breaching the pressure boundary. The elevation of the inlet and outlet points may also influence the likelihood of breaching the pressure boundary. This consideration implies that the use of multiple valves for isolation at the inlet and outlet points will provide greater protection against pressure boundary failure. The failure rate of a valve or other equipment used for isolation can be factored into the screening process. Data from NUREG/CR-6928 [1] suggests that the failure rate of a motor-operated valve is relatively low. Use of these data indicates that the failure probability of a re-configured pressure boundary that uses two or more motor-operated valves for isolation is expected to be very low. The failure probability of a re-configured pressure boundary that uses two or more manual valves instead of motor-operated valves is expected to be much lower. This suggests that re-configured pressure boundaries that rely on multiple barriers for isolation can be screened as maintenance-induced flood scenarios.

Additional quantitative screening can be performed by taking into consideration the number of isolation barriers, the likelihood of performing maintenance activity during full power operation, the duration of the maintenance, and the feasibility of mitigation. It is generally recognized that during maintenance activities, there are roving operators or security personnel in the vicinity of where the maintenance is being performed. With maintenance or other personnel in the vicinity, it is likely that detection of a re-configured pressure boundary failure will occur before it progresses to a catastrophic event. Depending on plant-specific maintenance procedures and practices, these factors may be considered in performing a qualitative and/or quantitative screening of maintenance-induced flood scenarios.

In general, a maintenance activity is screened if:

- No plant trip would occur from flood
- The frequency of occurrence can be subsumed by a non-flood initiating event and no resulting damage occurs to PRA SSCs due to the flood.
- The opening is isolated by two or more means
- The opening is isolated by a blind flange or manual valve because of low transfer open probability (3E-7)
- The maintenance can be shown to be unlikely or very infrequent during full-power operation
- Failure of additional equipment such as sump pumps would be required in addition to isolations to result in damaging flood
- A flood would be readily detected by roving operations or security personnel well before PRA SSCs would be affected.
- The following information on “Maintenance-induced Flooding” was obtained from the FCS Internal Flood Analysis Notebook:

> “During full-power operation, certain maintenance activities are performed on major equipment within the plant. Prior to the initiation of such activities, valves in the inlet and outlet flow path of the equipment are closed to provide isolation protection. In the event that the isolation protection fails, a breach in the system boundary will occur and caused

> the flooding of equipment within the room. Equipment located in rooms in the flood propagation path may also be impacted.
>
> A review of the flood sources at FCS was conducted to identify major equipment that may be taken out-of-service for maintenance during full-power operation. The review focused on maintenance activities that have the potential for breaching the system boundary. The review revealed that raw water strainers, heat exchangers, pumps, and the condenser are the major types of equipment that may be taken out-of-service for maintenance and pose the potential for a maintenance-induced flood. A qualitative evaluation was performed to identify maintenance activities that can be screened from further assessment. The following elements were taken into consideration in performing the evaluation:
>
> - Number of valves or flanges used for inlet isolation
> - Number of valves used for outlet isolation
> - The likelihood of performing the maintenance activity during full-power operation
> - Duration of the maintenance activity
> - Detection capability by roving operations or security personnel
>
> The qualitative evaluation is summarized in Appendix J. Generally, the potential for a maintenance-induced flood reduces significantly when multiple isolations are used in the inlet and outlet flow paths. It is realistic to assume that an isolation barrier would exhibit signs of leakage prior to catastrophic failure. The ability of roving operations or security personnel to detect and identify leakage of isolation barriers would also reduce the likelihood of a maintenance-induced flooding."

Table 5-10 provides a template that can be used for documenting the qualitative assessment of maintenance-induced flooding events.

Table 5-10
Qualitative Assessment of Maintenance-Induced Flooding

System	Component ID	Component Type	Location	Maintenance-Induce Flood	Inlet Isolation	Outlet Isolation	Flood Source	Flood Likelihood	Maintenance Frequency	Notes
Circulating Water System	CW-1A	Circulating water pump	Intake pump station	N/A	Drain the cell, close sluice gates for double isolation	FCV-1904A check valve FCV-1904A and HCV-1905A motor operate valve	Cell or intake tunnel	**Screen:** Opening pump is usually only done during plant outages. The cell is drained and isolated. Portable pumps are in the cell to keep it dry and frequent inspections are made on backshifts.	Multiple years between maintenance events.	1, 2, 3, 4, 5, 6, 7, 8

Notes

1	Short duration event
2	Maintenance opening pressure boundary rarely performed
3	Not normally performed on-line
4	Double isolation
5	Manual valve transfer open low prob event: 3E-7/hr
6	If valve is not fully closed, will be readily detected
7	Suction pressure is low
8	Roving security and operations staff make detection likely

6
FLOODING CONSEQUENCE ANALYSIS (TASK 7)

This chapter addresses Task 7 of the IFPRA Guidelines. The steps to characterize the consequences for each of flood-induced initiating event are described by considering the type of flood source, spill rate, flood location, time to reaching a critical flood volume, and the impact on the SSCs modeled in the PRA.

6.1 Characterization of Flood Mechanisms

ASME/ANS PRA Standard High Level Requirement IFSO-A and –B; Supporting Requirement IFSO-A4 and –A5

The characteristic of a potential water release and the capacity of the source should be identified, including:

- A characterization of the type of pressure boundary failure (e.g., spray, large leak, or major structural failure)
- Through-wall flow rate or spill rate.
- Capacity of the flood source (e.g., gallons of water)
- Pressure and temperature of the source

6.1.1 Types of Pressure Boundary Failures

An IFPRA should consider any pressure boundary failure potentially causing local spraying or flooding or global flooding of multiple equipment areas. In defining potential flood sources a differentiation should be made on the basis of type of source. For example, a finite source of flood water (e.g., limited to piping system inventory of process medium or a specific storage tank) as apposed to a theoretically infinite source of floodwater (e.g., Service Water System for which the Ultimate Heat Sink, UHS, provides the cooling medium).

6.1.2 Information on the Flooding Source

In order to evaluate characteristics of the water release, it is necessary to determine the extent by which a potential flood source can inflict localized or global flood impact. As defined in ASME/ANS PRA Standard this information must include:

- A characterization of the breach, including type (e.g., spray, flood, major flood)

- Flow rate
- Capacity of the source, which determines the maximum flood level to be reached in a specific area
- Pressure of the source and the pressure boundary flaw size determine the through-wall flow rate and the potential for different flood effects such as spray or jet stream impingement. Potential dynamic effects from a major pipe failure would normally only be a consideration given a postulated high-energy line break.
- Temperature of the source determines the conditions of the release. Some equipment adjacent to a potential flood source may not be qualified for sustained operation in a high-temperature environment. Also, a high-temperature release may complicate flood recovery actions by plant operators.

6.1.3 Flood Rate

A flood can be characterized by its volumetric flow rate and the quantity of the fluid that has been discharged from a fluid system to a specific area. These characteristics dictate the behavior of a flood and are important in modeling flooding scenarios.

Not all flood sources within the various plant areas are of concern. The basic criterion is that the flood should be of sufficient quantity and occur at a fast enough flow rate such that accumulation will lead to critical component failure if not mitigated. The following additional instructions are provided to assist an analyst in performing the screening process:

- Determine the ability of a fluid system to be a potential flood source of significance.
- Estimate the potential through-wall flow rate and flood volume resulting from a postulated pressure boundary failure within a flood area of concern. Utilize information from the system configuration, mode of operation, system flow requirements, pump curves, etc. It is generally assumed that a postulated pressure boundary failure causes a release to atmospheric conditions.
- Calculate the total head loss associated with flow through a hole in the pressure boundary by determining: (a) the length of constant area piping between the two reference sections within the fluid system and (b) the number of fittings (i.e., valves, bends, elbows, etc.) within the referenced piping sections.
- Estimate the break area and the associated volumetric flow rate.

Approach 1

The rate at which flooding takes place can be obtained from the break flow rate, the rate at which inventory is lost from the break location. Engineering handbooks include methods and techniques for flood rate calculation. For a known piping configuration, the following expression can be used to calculate the flow characteristics between any two points in a piping system.

$$\left(\frac{P_1}{\gamma} + Z_1 + \frac{V_1^2}{2g}\right) - \left(\frac{P_2}{\gamma} + Z_2 + \frac{V_2^2}{2g}\right) = h_T$$ **Equation 6-1**

Where:

P_1, P_2 = System pressure at sections 1 and 2, respectively

V_1, V_2 = Average velocity of the fluid at sections 1 and 2, respectively

Z_1, Z_2 = Vertical distance from a reference point at sections 1 and 2, respectively

γ = Specific weight of the fluid

g = Acceleration due to gravity

h_T = Total head loss, considered as friction or resistance factors

The total head loss is regarded as the sum of major losses due to frictional effects in the fully developed flow in constant area piping and minor losses due to fluid flow through pipe fittings such as elbows, valves, couplings, and sudden pipe contractions and expansions. The following expression can be used to calculate the frictional effects due to major losses [9].

$$h_l = f \frac{L}{D} \frac{V^2}{2g}$$ **Equation 6-2**

Where:

h_l = major head loss in constant area piping (feet of fluid)

f = friction factor, which is a function of the Reynolds number, Re, and the relative roughness for the pipe, e/D

D = internal pipe diameter (feet)

L = length of pipe (feet) over which the pressure drop occurs

e = roughness factor for the pipe

V = average flow velocity (feet per second)

g = acceleration of gravity (32.2 feet per second per second)

To estimate the major head losses, the analyst should determine the Reynolds number and relative roughness of the piping material. These values are then used to determine the corresponding value for the friction factor. The Moody diagram, which provides frictional factors versus Reynolds number for various values of relative pipe roughness, is available in engineering handbooks including Reference [9]. The major head losses can then be estimated using Equation (6-2).

Piping systems also generally contain a variety of fittings, bends, and sudden pipe contractions and expansions, which cause additional minor head losses. Exit losses associated with a postulated pipe break also need to be considered in the head loss determination. Similar to the major head loss, the following expression can be used to estimate the friction factor for the variety of fittings in a piping system [9].

$$hl = K \times V^2/2g \qquad \textbf{Equation 6-3}$$

Where:

h_l = minor head losses resulting from fittings, bends, contractions, and expansions (feet of fluid)

K = resistance coefficient

V = average flow velocity (feet per second)

g = acceleration of gravity (32.2 feet per second per second)

Specific fittings have resistance coefficients (K), which, in most cases, have been determined experimentally and published in available sources. The analyst may consult available textbook sources or information from the equipment manufacturer to determine the coefficient values for the fittings of concern. The sum of the major and minor head losses, as defined in Equations (6.2) and (6.3), represents the total head loss for the piping system. Once the friction factor, *f*, and/or loss coefficient, C, are determined by the analyst for the piping configuration of concern, the flow characteristics in terms of pressure drop and average velocity can then be calculated.

For the various systems, the volumetric flow rate resulting from a break located upstream of a pump should be determined by the difference in elevation between tanks and the break location. Similarly, the volumetric flow rate resulting from a break located downstream of a pump should be determined by both the elevation difference between the tanks and the break location and the pressure difference between the pump discharge and the break location (which is assumed to be atmospheric).

The total head loss must be calculated assuming a range of postulated flow rates. The point at which the total calculated head loss (system resistance) and break flow are equal to the system capacity (e.g. pump capacity curve or gravity elevation head of a tank) identifies the break flow rate that can be supplied by the system.

Approach 2

Given the variety of piping systems seen throughout each facility and the range of piping sizes even within each system, another approach is to estimate leak rates based on binning the leaks as spray, flood, and major flood events and determining the flow rate by the size of the break.

Flow (Q) (gallons per minute) through a leak of equivalent diameter d (inches) from a pipe that is maintained at a pressure P (psig) and can continue to maintain this pressure during the postulated break scenario can be estimated by the following equation [9]:

$$Q = 236 \cdot d^2 \cdot \sqrt{\Delta P / K\rho}$$ **Equation 6-4**

Where:

Q = flow rate (gallons per minute)

d = equivalent internal pipe diameter (inches)

ΔP = pressure differential between internal pipe pressure and break (atmosphere) (psi)

K = resistance coefficient for exit loss and other head losses as applicable

ρ = density of fluid = 62.4 lb/ft^3 for water at standard temperature and pressure

Depending on the time and resources available some simplifying assumptions may be used to determine the consequence of a pressure boundary failure. Two examples are:

- Estimate leak rates based on system pressure and break size. As a rule-of-thumb, a spray event results from ½-inch equivalent flaw size; a flood results from a 1.5-inch equivalent flaw size; and a major flood results from a full-pipe rupture.
- Spray is assumed to generate a spill rate (SR) ≤ 100 gpm; a flood results from 100 < SR ≤ 2.000 gpm; and Major Flood corresponds to maximum flow, based on system pressure and pumping capacity, given a full-pipe rupture.

Using Equation (6.4), the above postulated break flow rates can be re-estimated and reduced if the maximum flow from a full pipe rupture is less than the suggested amount. For example, a Spray leak from a ½" diameter pipe on a 40 psig system should postulate a break flow rate of approximately 75 gpm instead of 100. Another example using Equation (6.4) is a flood scenario involving a 1" diameter pipe on a 100-psig system should postulate a break flow rate of approximately 320 gpm instead of 1,500. Appendix A provides an example of an application of this methodology.

6.1.4 Calculation of Flood Height

For equipment areas where flooding is considered a possibility, the characterization of flood vulnerabilities will include calculation of flood height. It may be evident that an area is not impacted by flood if the equipment in the area is located at an elevation well above any possible flood height or there are no flooding sources in the area or in adjacent areas. Large open areas can be eliminated if no barriers exist to contain the flooding in the area and if components in that area cannot be damaged from water drip or spray. These areas may be eliminated without performing any formal flood height calculation.

In performing flood height calculations for areas, the maximum flood rates and volumes are assumed for the flooding sources. For pipe breaks, the flood rates calculated in the previous section should be used. For equipment failure initiated floods, catastrophic failure of tank, valve, or other types of equipment can be assumed. An example of tank failure is described in Case 1 given below.

When calculating flood heights in each area, the maximum expected flood should be calculated without considering drainage and other protective features. If a flood in an area is calculated without taking into account propagation pathways and it does not threaten the equipment contained within that area, then that area can be eliminated from further flood analysis. Spray considerations should still be addressed, however. If the calculated flood height threatens the equipment within the area, then additional calculations will have to be performed to account for the mitigation features, such as the drains, sump pumps, and any other pathway out of the area to determine actual failures of the SSCs.

The analyst should document maximum height, maximum flow and drainage rates, the time associated with flooding of equipment in each particular area, and any other assumptions pertinent to the development of the analysis.

Case 1 - Tank Rupture: Two conservative and simplifying assumptions are included in this calculation: 1) the tank ruptures rapidly, spilling all its contents to the floor immediately; and 2) the tank rupture is sufficiently rapid so that drain paths can be ignored.

$$Flood\ Depth = \frac{Tank\ Volume}{Floor\ Area}$$ **Equation 6-5**

Example:

$$Flood\ Depth\ (in.) = \frac{(12\ in./ft.)\ (Tank\ Vol\ (gal.))}{(7.48\ gal./cu.\ ft.)\ (Floodable\ Floor\ Area\ (sq.\ ft.))}$$

Case 2 - Flooding Inside a Curbed Area: For this example, flow over a curb is assumed to be similar to flow over a sharp-edged weir. The flow coefficient used in this equation is that for a sharp-edged weir and is obtained from Reference [10].

$$Q = 3.33 \times L \times H^{3/2}$$ **Equation 6-6**

Where:

Q = Water flow rate (cfs)

L = Length of the weir (curb) (ft.)

H = Water depth above the weir (curb) (ft.)

3.33 = Flow Coefficient

Let us consider the water depth inside the curbed area, which is the sum of the curb height and "H." Therefore,

$$Water\ Depth\ Inside = Curb\ Height\ (in.) + (12\ in./ft.)\ (0.45)\ (Q/L)^{2/3}$$ **Equation 6-7**

Flood Depth in a Room with Drainage Under a Door. For this example, we assume that this situation is analogous to the flow through a sluice gate structure. This approach also conservatively assumes the existence of a large volume flooding source (i.e., tank or large pipe) capable of filling the room with water shortly after the rupture. Flow through the gap is developed in Reference [11], and is defined by the following equation:

$$Q = B\,a\,c\sqrt{2G\,(H_o - \psi\,a)}$$ **Equation 6-8**

Where,

Q = Flow through the gap (cfs)

B = Width of gate (door) (ft.)

a = Gap under gate (door) (ft.)

c = Flow constant

G = Gravitational constant (ft./sec.^{2})

H_o = Upstream water depth (ft.)

Ψ = Vena contracta fraction

Therefore,

$$Ho = \left(\frac{Q}{B\,a\,c\sqrt{2G}}\right)^2 + \psi\,a$$ **Equation 6-9**

This equation assumes that the steady state flow rate into the room is the incoming flood rate, minus any drainage paths other than those under the door. It also assumes that the downstream flow region is wide and the critical flow region just downstream of the door does not flood. This latter assumption is reasonable unless a curb exists outside the door.

6.2 Flood Propagation Pathways & Flood Mitigation

This subsection describes the identification of propagation paths for a flooding source. The means to identify a possible propagation pathway is described below.

6.2.1 Identify Flood Propagation Paths

The ASME/ANS PRA Standard directs an analyst to identify the propagation path from each flooding source in each area to its area of accumulation. Each flood source should be reviewed to determine where the water would propagate. A preliminary evaluation based on drawings can be performed but the plant walkdown (described in Section 3.3) is vital in confirming this assessment. Propagation pathways, not obvious on drawings, can often be identified during the walkdown.

In general, flooding will proceed to the lowest level available in the area or building; but there are many factors influencing its path. For example, in some cases, flooding could extend into areas not directly connected to the original area via backflow through floor drains. Items important in evaluating the potential pathways are:

- Characteristics of floor – Many plant areas contain grating that will not retain floodwater but will let it pass directly to lower elevations. Other areas have floor openings for crane access with kick-plate type protection but no watertight integrity. Other floor penetrations (stairwells, pipe or cable penetrations, floor plugs, HVAC ducts, etc.) should be identified as potential paths. The grading in areas with solid floors is typically toward floor drains, but other features may allow floodwater to progress to areas below the original flood area. All areas where flooding could eventually propagate must be identified.
- Potential backflow through drain lines – A large volume of water coming from a higher elevation will backup in the drain system and could flood lower areas connected through the drains. Check valves may be included in the drain system but may have a high potential failure rate depending on maintenance practice.
- Doors – Watertight doors are designed for anticipated flooding. There is, however, some potential for these doors to fail, especially from inadequate closure. In addition, there may be a significant probability that the door is left open or propped open to perform a maintenance task or as a result of a human error to fail to secure the door. This potential should be considered in possible flooding scenarios. The presence of a watertight door is again an indicator of vulnerability to flooding. Normal access doors will fail once the water level increases to a certain depth. Their capability to retain water and the level at which failure occurs should be determined for use in the propagation timing determination. In RI-ISI a typical assumption (“rule-of-thumb”) is that a normal access door is forced open by 1 foot of water on the floor if the door opening is out of the area. Appendix D includes a technical basis for determining at what level of water buildup against a door it will fail.
- Wall failure – Most walls in a plant are thick solid concrete structures that can withstand the hydraulic pressure due to flooding. Other walls, such as cinder block walls, may not be capable of doing so. Their capacity should be considered in determining the flooding paths. Wall penetrations (pipe or cable penetrations, HVAC ducts, etc.) should be identified as potential propagation paths.
- Flooding from high-energy sources - Steam line or feedwater line breaks will also result in a hazardous environment. This type of flooding is usually already addressed in the original PRA analysis. If new flooding initiators from high-energy lines are added, they should be treated in a manner similar to the original PRA analysis. Environmental considerations should include humidity, condensation, temperature, and any other potential failure causes in addition to flooding effects.

The impact of maintenance events on the propagation of floods should be considered. For Capability Category III PRA models, this is a requirement. Barriers such as doors, penetration seals, and dampers, may be credited with preventing propagation of flood events from one area to another. Maintenance events, however, may render such barriers ineffective. In general, it can be expected that the impact of maintenance events on flood propagation will be minimal for an Internal Flood PRA. However, maintenance that impacts barriers could have a significant impact on configuration-specific risk evaluations. After flood areas have been defined, maintenance on barriers between flood areas should be reviewed to determine if there is a significant probability that maintenance events could change accident sequences by changing propagation effects. In addition to maintenance on barriers, maintenance in the vicinity of flooding barriers can have an effect on flooding propagation. If hoses, electrical cables, or plant rigging devices pass through and block open a normally closed flooding barrier, such as a water-tight door, this can have a major effect on flooding propagation. Also, if plant equipment is being moved by crane through normally closed floor hatches, this can also change the course of flood propagation during the rigging process.

An interview with the Maintenance Departments within a plant can provide insights as to how much impact maintenance practices have on defeating flood and spray barriers. A review of programs which are responsible for tracking when doors are opened and remain open for significant times would also be a source for possible information in determining maintenance impact.

In addition to maintenance events, plant experience with doors and other barriers should be considered to determine if a history of mis-positioned or failed doors exists. If so, these effects should be considered when determining propagation effects.

After all of the potential pathways for each flood source have been identified, the actual propagation scenario can be determined based on the characteristics of these sources. For example, propagation from one area to another area may only be possible for sources large enough to submerge the area to a depth considered to fail a door to the next area. In some cases, propagation may only be possible if a spray source is located in a location that could directly enter an HVAC opening. In each case, propagation paths are flood source specific.

It is recommended that a “flood area pathway diagram” be developed from the results developed in this section and the Flood Damage State data developed in Section 4 for each of the flood areas. The example in Figure 3-1 shows potential flood pathways for a fictitious Auxiliary Building Flood Area. Documentation should include any assumptions and/or conclusions from the development of the diagrams.

6.2.2 Identify Flood Mitigation Features

ASME/ANS PRA Standard Supporting Requirement IFSN-A2, and –A4

These ASME/ANS PRA Standards require an analyst to identify plant design features that have the ability to terminate or contain the flood propagation, for each defined flood area and each flood source. These design features could include the presence of:

a) Flood alarms (also discussed in the next subsection)

b) Flood dikes, curbs, sumps (i.e., physical structures that allow for the accumulation and retention of water)

c) Drains (i.e., physical structures that can function as drains)

d) Sump pumps, spray shields, water-tight doors

e) Blowout panels or dampers, with automatic or manual operation capability

Curbs (berms/dikes) are frequently installed in order to prevent flooding of adjacent areas. The height of these curbs should be considered in order to quantify the volume of water that it is capable of containing. Note that the presence of these protective features may also be an indicator that the adjacent area is vulnerable to damage by flooding.

Floor drains and sumps can be considered in two ways: First, they provide a means to remove water from the flood area being assessed. If not already done in the qualitative IFPRA steps, the number of drains in the area as well as the capacity of the drain system needs to be determined from the relevant plant documentation. Flooding concerns can possibly be eliminated for some small breaks if the floor drain capacity is sufficient. If the drain capacity is not capable of removing the flooding volume, it is still important in determining the rate of increase in flood elevation, in order to evaluate chances for operator intervention prior to reaching critical depths. Potential for plugging of the drains from material stored or potentially left in the area should also be considered.

Second, drains may serve as conduits for moving floodwaters from one flood zone to another. For example, flooding may occur at a floor drain discharge point. Drains usually terminate in a building sump. These sumps may not be capable of holding large quantities of water and may overflow. Many of these areas also contain SSCs important to safety, and a potential for flooding of the sump area should be considered. The presence of sump high-level isolation valves would reduce this potential. Sump pump capacities must also be considered. Sump pumps are sized for intermittent operation and may be incapable of keeping pace with any significant flood volume. In addition, the sumps are frequently discharged to a radwaste system that is not intended to treat large volumes and may isolate at high levels. Performance of the sump pumps during the flooding must be evaluated.

It is also important to address the potential for grates and other openings to provide floor drainage and to propagate water to lower levels. Piping chases, grating, and maintenance access doors are possible pathways for drainage to occur.

A walkdown is required to verify the location and size of drains and sumps and other plant protective features to ensure that they are accurately represented in the Internal Flood analysis.

6.2.3 Identify Plant Features & Operator Actions to Limit Flood Propagation

ASME/ANS PRA Standard Supporting Requirement IFSN-A3

The ASME/ANS PRA Standard directs an analyst to identify those automatic or operator responses that have the ability to terminate or contain the flood propagation, for each defined flood area and each flood source.

The plant design features to terminate flooding are seldom automatic and usually require the operators to become aware of the flooding situation and take action. The isolation capability of the systems also needs to be evaluated in relation to the operators. Isolation from the Control Room versus the need to send an operator to the area should be considered. If the plant is designed with automatic system action, it can be modeled in a fault tree in the same manner as other system capabilities. The plant design features that could alert the operators include such items as:

- Flood alarms – The presence of flood alarms in the area under evaluation will considerably reduce the time to discovery and taking action to isolate the flood. The location of the alarm indicator, usually in the control room, and the need to send operators to investigate should be considered in this timing. Credit should only be taken if availability of the alarm can be proven.
- Flow indicators – Many systems contain flow indicators used for normal system monitoring. The ability of these indicators to identify and possibly alarm high flow conditions should be evaluated. The expected action of the operators on recognition of the high flow indication should also be considered.
- Radwaste Control Panels – These panels provide diagnostic information for locating leaks inside an Auxiliary Building. Communications between Radwaste Operators and Main Control Room Operators can be essential in flood response.
- Radiation detectors – Generally, radiation detectors will not detect flooding because the source is insufficiently radioactive to actuate the alarm. They may be considered, however, in cases such as a steam line break where high radiation can be encountered.

The possibility of isolating a pipe failure, if appropriate, should also be accounted for in assessing the significance of a flooding source. A pipe failure can be isolated by a protective check valve or be automatically isolated following the generation of an isolation signal or by manual operator action. The likelihood of successful manual isolation depends on means of detecting the pipe failure, successful diagnosis, availability and accessibility of the isolation equipment, the amount of time available to prevent specific consequences, and operator performance.

Regularly scheduled operator tours and the presence of personnel in the area could also detect flooding. These scenarios, however, would have to be long-term in nature for mitigation to be effective. Each potential operator action may require a human reliability analysis to determine the potential mitigation. Availability of the alarm response procedures, accessibility to isolation devices, and the time available to perform the actions should be evaluated to justify taking credit for the actions. All these evaluations must be well documented to support the analysis. Human mitigating actions are discussed in more detail in Chapter 7 (Flood Mitigation & Human Reliability Analysis).

Information needed to define flood propagation paths and mitigating design features, with corresponding information sources needs to be confirmed by a walkdown (Section 3.3)

6.2.4 Evaluation of SSC Flood Susceptibilities

ASME/ANS PRA Standard Supporting Requirement IFSN-A6

The ASME/ANS PRA Standard directs an analyst to identify the susceptibility of each SSC in a flood area to flooding induced failure mechanisms. To satisfy the ASME Standard's Capability Category II, it is enough to include failure by submergence and spray in the identification process and to either:

a) Assess qualitatively the impact of flood-induced mechanisms that are not formally addressed (which are defined for Capability Category III, see below), by using conservative assumptions, or

b) Note that these mechanisms are not included in the scope of the evaluation.

To satisfy Capability Category III, it is required to include in the identification process, failure by submergence, spray, jet impingement, pipe whip, humidity, condensation, temperature concerns, and other identified failure modes. There are several flooding effects that could fail equipment including:

- Submergence
- Spray
- Jet impingement
- Pipe whip
- Humidity
- Condensation
- Temperature concerns

The potential impacts of some of these flooding effects are discussed below.

6.2.4.1 Component Submergence

Component submergence is assumed to fail electrical equipment. Failure is generally assumed when the lowest portion of the SSC is submerged, e.g., above the pedestal, unless there is a detailed evaluation to establish continued availability despite partial submergence. However, this assumption should not be applied to passive components such as heat exchangers, check valves, or manual valves, nor to any other components that do not change positions or do not require external motive forces to change position or operate. Motor operated valves are generally assumed to fail in their "as-is" position. For tanks that may be submerged, an assessment of the buoyancy force on the tank and the impact of its failure on initiating events and accident progression is necessary.

6.2.4.2 Spray

The location of the flooding source may make the spray more significant than the actual flooding. Components that are located well above flood level can fail from spray before actual submergence. Water spray is assumed to fail electrical equipment such as switchgear and motor control centers (MCCs), unless protected by suitably installed shields. The evaluation should differentiate between moderate-energy piping systems (maximum operating pressure less than 275 psig) and high-energy piping systems. Insulated, moderate-energy piping may be assumed to drip, but not spray given a small through-wall flaw (e.g., pinhole size). Bare (moderate- or high-energy) piping systems are assumed to be spray sources. As a general guideline, spraying or splashing water should be assumed to affect those electrical components located within a minimum 10-foot horizontal radius and within line-of-sight of a pressurized water source. This guideline needs to be adjusted based on insights from the plant walkdown. This radius needs to be applied along the entire length of pipe in the flood area because the pipe may fail anywhere along the pipe run. Engineering judgment should be exercised in evaluating spatial arrangement (e.g., intervening components, spray direction, effectiveness of spray shields) as identified during the walkdown. With the exception of passive components discussed in the previous section, water spraying or splashing on unprotected equipment is assumed to fail the component unless its design precludes such failure.

In this analysis, only pipe joints (flanges, valves) and tanks will be considered as sources of spraying or splashing. If equipment is located either directly below or within a minimum of a ten-foot radius for one of these sources, then it will be analyzed with respect to failure modes as a result of spraying or splashing.

A special case involves the spray-impact evaluation of fire protection water system actuation. As an example, weld repair operations during a plant outage may accidentally cause an actuation and consequential spray impact on equipment within range. This possibility would be evaluated as part of maintenance-induced flood scenario development.

6.2.4.3 Other Flood Damage Effects

Consideration of dynamic and environmental effects is normally conducted as part of the design process. The original design basis documents can be used to justify availability of equipment related to damage from jet impingement, pipe whip, increased temperature and pressure, humidity, and radiation levels. Normally, dynamic effects of a piping failure would only be considered for high-energy piping or any piping susceptible to water hammer.

6.2.5 Evaluating Equipment Damage

ASME/ANS PRA Standard Supporting Requirements IFSN-A5, -A7, and –A9

All SSCs possibly affected by flooding must be identified. Estimating the flooding effects will often require additional evaluations. For example, it could be necessary to determine if the component is submerged in the water, given the component specific position, area volume, area mitigative features, and source flow rates. The effects of equipment flooding on SSCs outside the flooding zone also should be considered. For example, submergence of a motor control center may not just fault the affected bus. It is possible for the fault to propagate to the power sources that feed the motor control center if incoming leads to the protective breakers become submerged (regardless of the position of these breakers).

There is also a possibility that equipment would survive the flooding conditions because floods from a specific source would not reach critical levels to cause damage. The ASME Standard directs an analyst to perform any necessary engineering calculation for flood rate (see Section 6.1.3), time to reach susceptible equipment, and the structural capacity of SSCs.

Not all equipment modeled in the PRA, however, would be expected to fail when impacted by a flooding event. For example, a heat exchanger would still be functional if subjected to submergence, spray, or steam. Expected flooding impact on the different component types is defined in Table 6-1. Equipment listed as "Not Affected" in Table 6-1 can be expected to function if exposed to a flooding environment and may be excluded from the further evaluation. A provision for this exclusion is given in the ASME/ANS PRA Standard, which states that the identified SSCs are the ones susceptible to flood.

Note that the equipment identified in Table 6-1 as "Possible failure" due to the flooding environment may not necessary fail, and it could be analyzed further. For example, environmental qualification analyses may justify equipment functioning in a flooded environment. As stated in the ASME/ANS PRA Standard, an analyst could take credit for the availability of SSCs, with respect to Internal Flood impacts only if supported by an appropriate combination of:

a) Test or operational data

b) Engineering analysis

c) Expert judgment

Taking credit for any SSCs affected by flooding must be well documented. If susceptibility information is not available, it is recommended to use a conservative approach and consider equipment failed. The walkdown documentation should be consulted when determining SSC susceptibilities together with relevant equipment qualification documentation

Table 6-1
Impact of Flood Environment on Component Operability

Component Type	Impact of Flood Environment
Valve, motor-operated	Possible Failure
Valve, air-operated	Possible Failure
Valve, hydraulic operated	Possible Failure
Valve, solenoid operated	Possible Failure
Valve, manual	Operability may be affected due to access restrictions by spray or flooding
Valve, check	Not Affected
Valve, safety	Not Affected
Pumps	Possible Failure
Compressors	Possible Failure
Fans	Possible Failure
Diesel-Generators	Possible Failure
Electrical Equipment	Possible Failure (including possible fault propagation to other SSCs outside the flood zones)
Cables	Not Affected
Cable Splices	Possible Failure
Junction Boxes	Possible Failure
Instrumentation	Possible Failure
Strainers/Filters	Not Affected
Heat Exchangers	Not Affected
Tanks/Accumulators	Analysis Required (see Subsection 3.7.1)
Piping	Not Affected
Ducting	Possible Failure – Also note that duct work may serve as a flood pathway and needs to be evaluated for spatial dependencies
Room Air Coolers	Possible Failure
Vaporizers/Heaters	Possible Failure

6.2.6 Identify Flood-Induced Initiating Events

Identification of flooding initiators requires a structured, systematic process to identify those flood-induced events that challenge normal plant operation and that require successful mitigation to prevent core damage, including plant precursors, and operating and supporting system alignments. Flood initiating events are grouped in order to facilitate an efficient but realistic estimation of CDF. The Internal Flood hazard has several characteristics that strongly influence the identification, quantification, and treatment of the initiators. For example, the routing of piping varies substantially from plant to plant; and, therefore, the identification of internal flood hazards must be performed on a plant-specific basis.

The relationship between an initiating event and the flooding source is a subtle but important aspect of the analysis. Two general relationships exist and are defined in the cases below:

1. Flood causes the initiator (via equipment damage and/or procedural shutdown).
2. Flood results from the initiator.

Floods that start with a pressure boundary failure of an operating system are more likely to cause an automatic initiating event (Case 1), while floods that result from an independent initiator are more likely to occur in stand-by systems (Case 2). A manual shutdown of the plant (Case 1) is equally likely for breaks in both operating and stand-by systems and is a function of the plant's Technical Specifications, flooding procedures, and provisions for alternate equipment cooling. The two cases are discussed further below.

Flooding events could also be initiated by maintenance actions, which are usually performed on stand-by systems or on the stand-by train of an operating system. Historical licensee event report (LER) data indicate that it is not uncommon for flood barriers to be misaligned, resulting in a flooding event.

6.2.6.1 Flood Causes an Initiator

Depending upon the operational mode, including flow conditions, pressure, and temperature, plant systems are exposed to degradation and damage mechanisms. Depending upon material selections, aging management strategies, and inspection programs, there is some likelihood of pressure boundary failure associated with all plant systems. With respect to IFPRA, systems considered as flood sources include the following:

- Essential (safety-related) and non-essential Service Water System
- Component Cooling Water System
- Circulating Water System
- Feedwater and Condensate Systems (these are high-energy systems)
- Fire Protection Water System

If a rupture or leak were to occur in these operating systems, the resultant flood damage effects would be likely to lead to an initiating event. The specific initiating event depends on the system and the break location. The initiating event may occur due to impacts on equipment or due to prescribed operator actions (i.e., manual scram or shutdown). The impact to the equipment causing the initiator could be a direct (e.g. loss of flow) or an indirect (e.g., equipment damage due to flood related effects such as submersion or spray). The equipment may also lose its function due to a prescribed human action (e.g. isolation of a flood source). The following examples illustrate several different cases:

- Service Water system (SW) or Component Cooling Water (CCW) ruptures or leaks may be appropriately treated as a loss of SW/CCW if the operating crew isolates all of the system or the break is large enough to divert all flow. The initiator may be treated as a reactor trip with a partial loss of SW/CCW if there is a capability to isolate only the specific break location.

- An isolated Fire Protection System (FPS) break in the Reactor Building or Auxiliary Building may be appropriately treated as a reactor trip, i.e., operator induced manual scram per the Emergency Operating Procedures (EOPs).
- An unisolated FPS break in the Turbine Building may be treated as a loss of Feedwater (FW) if the flooding results in the loss of condensate pumps in the condensate pump pit.

The cases described above are given only as examples. A described treatment of the flood events would not be appropriate if the flood effects or flood propagation could lead to a more severe condition that would need to be modeled as separate initiators/scenarios. The IFPRA scope should always include HELB analysis.

Evaluation discussed in this section could also apply to some stand-by system piping that is pressurized in stand-by state even though there is no flow through the pipes. An example of this condition would be a Refueling Water Storage Tank (RWST) discharge pipe, which is under RWST pressure, but where flow occurs only on an accident demand. A rupture or leak in this piping would result in loss of RWST and is likely to result in a plant shutdown as required by Technical Specifications.

6.2.6.2 Initiator Causes a Flood

While pipe rupture frequency is usually modeled as a time related failure rate and not as a failure on demand, it is possible that, in some scenarios for standby systems, a pipe failure may occur on a demand, created by an independent event or by a test. The pipe failure would likely be caused by a demand-induced “shock stress,” which may result from any of the following:

- Water hammer
- Rapid pressurization
- Valves slamming open or closed
- High vibration
- Void collapse

For standby systems with normally unpressurized pipe, a pressure boundary degradation or failure is likely to be revealed only during functional tests or in connection with an actual event response. Examples of pressure boundary failures in standby safety systems include breaks in the Emergency Feedwater System lines, induced by a demand created by a loss of feedwater event, or breaks in the Emergency Core Cooling System lines, induced by a demand created by a LOCA event. These breaks are likely to be screened out early in the analysis, because pipe break probability on demand is expected to be much lower than the other demand-related failure probabilities in a system. For plants with a RI-ISI program, results and insights from evaluations of structural failures of standby systems should be utilized when performing any screening evaluation. Combined with the frequency of the assumed independent initiator, the pipe break probability on demand would produce an initiating sequence with a very low frequency.

These scenarios should still be considered if the flood effects of the break are significant and mitigating ability of the plant is severely affected by the flood. In some cases, the pipe breaks could directly lead to core damage. A good example would be a potential break in the RWST discharge piping, which could lead to a flooding of all emergency feedwater pumps and propagate to a electrical switchgear room, leaving a plant without any secondary heat removal. Even though the frequency of such scenarios is expected to be low, such significant events should be evaluated and documented. A break in the RWST discharge line could also be modeled as an initiator and not a break on demand if the pipe is normally pressurized.

6.2.6.3 Group Flood Scenarios

ASME/ANS PRA Standard Supporting Requirements IFSN-A10, IFEV-A2, -A3, and –A4

The ASME/ANS PRA Standard directs an analyst to develop flood scenarios by examining the equipment and relevant plant features in the flood areas (and potential propagation paths), giving credit for appropriate flood mitigating systems or operator actions, and identifying susceptible SSCs. In developing the flood scenarios, all relevant information, which would form the boundary conditions for the interface with the internal events PRA, is collected by an analyst (affected flooding area, source, flood rate and source capacity, operator actions, SSC damage). The ASME/ANS PRA Standards directs an analyst to group flood scenarios and to subsume flood scenarios with existing plant initiating event groups. It is the effect of flooding and the consequence of successful flood isolation that determine how flood scenarios are grouped and evaluated.

ASME/ANS PRA Standard requires grouping of the flood scenarios. To satisfy the Standard Capability Category I, an analyst is directed to group flooding scenarios only when the following is true:

a) Scenarios can be considered similar in terms of plant response, success criteria, timing, and the effect on the operability and performance of operators and relevant mitigating systems; OR

b) Scenarios can be subsumed into a group and bounded by the worst-case impacts within the "new" group.

To satisfy Capability Category II, an analyst is directed to group flooding scenarios if *(a)* and (b) from above is true and to avoid subsuming scenarios into a group unless:

(i) The impacts are comparable to or less than those of the remaining scenarios in that group; AND

(ii) It is demonstrated that such grouping does not impact significant accident sequences.

To satisfy Capability Category III, an analyst is directed to group flooding scenarios only when *(a)* and (b) from above is true and NOT to add scenarios to a group and NOT to subsume scenarios into a group unless the impacts are comparable to those of the remaining scenarios in that group.

The ASME/ANS PRA Standard defines grouping of the flood initiating scenarios with existing plant initiating event groups. To satisfy ASME/ANS PRA Standard Capability Category I & II, an analyst is directed to group or subsume the flood initiating scenarios with an existing plant initiating event group if the impact of the flood (i.e., plant response and mitigating system capability) is the same as a plant initiating event group already considered in the PRA in accordance with the applicable ASME/ANS PRA Standard requirements for grouping initiating events (see IFPRA element IFEV).

To satisfy ASME/ANS PRA Standard Capability Category III, the analyst is directed to NOT group and NOT subsume flood-initiating scenarios with other plant initiating event groups.

The above requirements allows for separate flood scenarios to be grouped into a single flood scenario if the individual scenarios have similar impacts in terms of plant response, success criteria, timing, and the effect on the operability and performance of operators and relevant mitigation systems. For example, fire protection system (FPS) flooding originating from a number of locations in the upper elevations of a reactor building/auxiliary building may have similar impacts given that the water flows down a common stairwell to flood basement level rooms. In such cases, a single FPS scenario and an initiator may be defined encompassing all the relevant piping in the upper levels. Naturally, the impacts of sprays and effects at intermediate levels must also be considered.

For multi-unit sites with shared systems or structures, a flood in one unit may impact other units. For such sites, the assessment of each unit must address potential floods from other units to determine their impact on that unit. This requirement is addressed in the ASME/ANS PRA Standard, which, for multi-unit sites with shared systems or structures, directs an analyst to include multi-unit impacts on SSCs and plant initiating events caused by internal flood scenario groups.

7
FLOOD MITIGATION & HUMAN RELIABILITY ANALYSIS (TASK 8)

This chapter addresses Task 8 of the IFPRA Guidelines and summarizes analysis considerations associated with the response to internal flood scenarios by plant personnel, including main control room operators and auxiliary operators. Also addressed are equipment operability issues that could impact the ability of plant personnel to terminate flood events. The human reliability analysis (HRA) task of IFPRA is concerned with assessments of the detection, diagnosis, and response to Internal Flood scenarios.

7.1 Perform HRA for IFPRA Scenarios

ASME/ANS PRA Standard Supporting Requirements IFSN-A14, -A16, IFQU-A5, and –A6

The ASME/ANS PRA Standard addresses the need to perform HRA to support quantification of flood scenarios. It also addresses mitigating human actions used in the evaluation of flood areas and flood scenarios.

The ASME/ANS PRA Standard identifies additional human failure events that are required to support quantification of flood scenarios and requires an analyst to perform a human reliability analysis in accordance with the applicable requirements described in the Standard section on the human reliability analysis (Tables 2-2.5.5-1 through Table 2-2.5.5-10 in Part 2 of the ASME/ANS PRA Standard).

The Standard requires an analyst to include, for all human failure events in the internal flood scenarios, the following scenario-specific impacts on Performance Shaping Factors (PSFs) for control room and ex-control room actions, as appropriate to the HRA methodology being used:

a) Additional workload and stress (above that for similar sequences not caused by internal floods)

b) Cue availability

c) Effect of flood on mitigation, required response, timing, and recovery activities (e.g., accessibility restrictions, possibility of physical harm)

d) Flooding-specific job aids and training (e.g., procedures, training exercises)

As indicated in the above requirements, internal flood events can present conditions for operator response that are different from those following internal initiators. Therefore, the operating crew response to a flood initiator may be more challenging than a response to loss-of-coolant accidents or transients as modeled in the internal events PRA. Ultimately the plant procedures and operator training programs specific to flood response determine how well operations personnel respond to Internal Flood conditions.

While there are no universally accepted methods for addressing human reliability analysis (HRA) in the context of internal events, the EPRI HRA Users Group is working to achieve standardization in this area and has produced guidance for conducting HRA for internal events during at-power modes of plant operation [17]. Based on the EPRI approach, guidance is provided below on the definition and evaluation of human failure events (HFEs) following internal flood initiators.

Internal floods present some unique challenges to the ability of the operators to respond reliably. Among these challenges are:

- For large floods, it is likely that combinations of failures not normally expected will occur. These combinations of failures may make it more difficult to respond within the context of the existing emergency operating procedures.
- Floods can impede the operator's efforts to perform mitigating actions, both locally and in the control room. Even if flood damage does not necessarily cause failure of important equipment, it may impede access of operators to needed controls and equipment or cause delays in response due to addressing the flood in addition to the initiator.
- A flood will likely increase the stress level, workload, and complexity of response of the operators. This increase is especially true following a large flood where the stress may be heightened in the period initially following the plant trip.

7.2 Organizing the HRA Task

Performing a realistic HRA of flood response actions involves identifying relevant alarms, indications, procedures, and communications protocols. A starting point for organizing the task is to assemble the associated documentation and to perform interviews of plant personnel familiar with training, procedures, and operations relating to Internal Flood. It is recommended that an operator action tree (OAT) be developed as part of the documentation of the flood-specific operator actions to be subjected to HRA.

The results from previous tasks include evaluations of the various flood mitigation options and flood spill rates. Successful flood mitigation could imply shutting down a system train or entire system or a loss of a support system function as well as one or more supported loads. The relevant alarm response procedures, system malfunction procedures, abnormal operating procedures, emergency operating procedures, and Internal Flood response procedure with associated Job Performance Measures (JPMs) should be identified and reviewed. During the diagnostic phase of flood response, it is highly likely that the plant operator would be working off multiple procedures. The feasibility of manual local isolation of a Fire Protection water system breach may also require further evaluation. Most, if not all, isolation valves in this system are manual, locked-open valves; and valve accessibility should be determined for each flood area.

A practical way of organizing the HRA task is to first develop an OAT, which defines specific situations and unique operator actions to be subjected to more detailed evaluation. Such an OAT should address potential errors in detection, diagnosis, and implementation of flood mitigation actions. As the flood scenario development evolves the OAT may be revised or enhanced to better support the quantification of scenario-specific human error probabilities (HEPs). An example of an OAT for flood response is given in Figure 7-1.

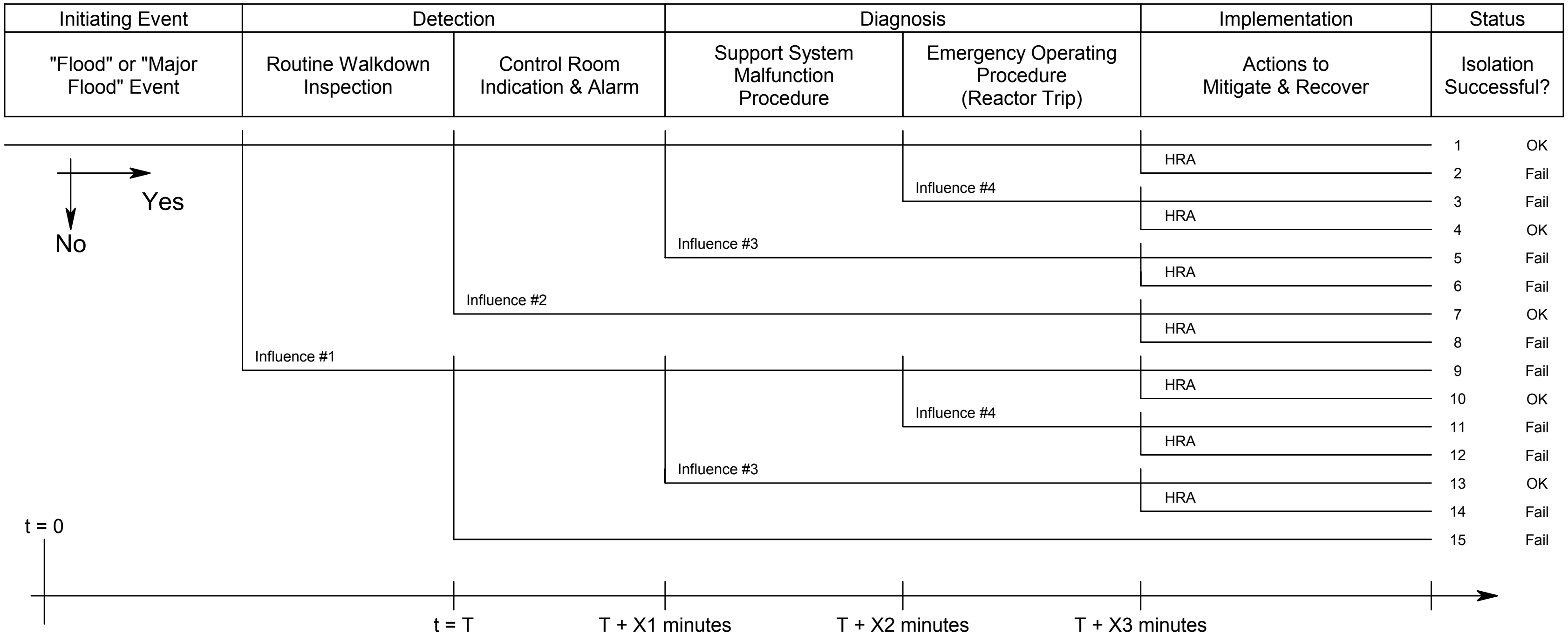


Figure 7-1
Example of an Operator Action Tree (OAT) for Flood Response

The OAT in Figure 7-1 identifies seven (7) unique situations that warrant a detailed flood-specific HRA. Each HRA needs to account for a unique set of influences by potential diagnostic difficulties and time constraints as imposed by flood spill rates:

- Influence #1 relates to method(s) of detecting flooding. The method of detection could be “fortuitous detection” by an Auxiliary Operator performing a routine inspection in an affected building area. The HRA needs to account for the communications between field operators and Main Control Room operators.
- Influence #2 relates to how available control panels, instrumentation, and alarm affect flood detection. Depending on the extent and location of flooding, a partial or complete loss of support system may cause a slow upward trending in equipment heat-up and/or room heat-up, which could challenge a prompt detection by the plant operations personnel.
- Influence #3 addresses the available procedural guidance and related operator expectations. If resulting flood-induced impacts on plant equipment are not well understood or readily recognizable the operator response may be delayed.
- Influence #4 addresses situations that may arise when plant personnel implement multiple procedures concurrently. Depending on the procedures in use, the HRA must address a potentially increased likelihood of not recognizing an impending flooding scenario in a timely manner.

Included in Figure 7-1 is an operator response time-line, which is a function of support system dependencies, the time at which a first symptom of impending flooding appears, and critical flood volumes (CFVs). The latter is the estimated volume of floodwater that would fail the equipment in a given flood area and represents the time window of concern in the HRA. Depending on plant-specific flood vulnerabilities, an assessment of time-window for operator response may have to consider competing CFVs. One CFV may be associated with a failure of a particular SSC, and another CFV may be associated with a particular global flooding scenario. Depending on the flood spill rate and the capacity of a floor drain system, the way one CFV competes with another strongly affects the time available for flood response. The HRA must account for the full range of time-windows.

7.2.1 HRA Insights from Operational Events

Insights from review of actions in response to actual Internal Flood events provide information diagnostic operator performance information that could support assumptions made in HRA. An example of a relatively recent Internal Flood event is the June 1998 event at Columbia River Station where a water hammer in the Fire Protection water system severed a 12-inch header pipe. The resulting floodwater entered the Residual Heat Removal (RHR) “C” pump room through a watertight door, which had been left in an unsecured position. It then propagated to the adjacent Low Pressure Core Spray (LPCS) pump room via a sump isolation valve, which failed to close as designed. The flood completely submerged the RHR pump and motor and the associated keep-fill pump (which also serves as the RHR “B” train). The level in the LPCS pump room rose to just below the pump motor and completely submerged the LPCD keep-fill pump (which also serves as the RHR "A" train).

It took the plant operators approximately 6 minutes to determine that the control room fire alarms annunciated because of a Fire Protection header break and not a fire. During this time on the order of 160,000 gallons of water spilled into the Reactor Building stairways. Due to the remote location of the fire pumps, it took about 12 minutes to stop the water. Approximately 17 minutes into the event the control room received a LPCS pump room "water level high alarm" and almost simultaneously the control room received a report that the water level in the Reactor Building stairwell had stopped rising. About 30 minutes into the event the Technical Support Center was activated. After about 60 minutes the control room received a report that the water level in the RHR "C" room was 8 inches greater than the maximum safe operating limit and the pump breaker was racked out at this time. After another 12 minutes the control room received a report that the LPCS pump room water level was 6 inches greater than the safe operating limit.

7.3 Human Error Rate Quantification Process

For consistency it is recommended that the IFPRA adopt the quantification process used for the internal events PRA. Some methods extensions or adaptations may be needed to account for flood-specific influences on the identified HFEs. Background information for the quantification process is included in References [19, 20 and 21]. Errors of commission are discussed in References [20] and [21].

After initial quantification of the internal flood model, the dominant cutsets are reviewed to identify important post-initiator HFEs that require detailed HRA. In the first phase, the screening HFEs may be used in the evaluation of flooding scenarios, as defined below. If the flooding scenario does not screen out based on the quantitative criteria discussed in Chapter 3 and the scenario is identified as important, the screening values for the considered HFEs should be replaced with the values derived from the detailed HRA.

The following guidelines are suggested for modeling post-initiator HFEs for the flood analysis and for quantifying the post-initiator HFEs that appear in the flood sequences. These guidelines should be applied to the HRA methods used for the non-flood internal events:

1. The flood analysis should address physical plant access during the local mitigation of a flood-initiating event.
2. All actions credited in the non-flood plant response must be revisited to verify that the procedural path is still valid. Because of the large number of failures that potentially occur during a large flood, the event-based abnormal operating procedures (AOPs) may be less relevant than for more straightforward internal events. Discussions with experienced operations personnel should help to determine how the events would be expected to proceed.
3. Screening Values: Human interactions occurring within the period immediately following the flood should have limited credit. It is reasonable to assume that the control room staff will be unable to respond effectively to many events immediately following the flooding event.

Before any local actions are credited, it must be confirmed that no access limitations or restrictions exist. Physical damage to the plant may significantly increase the execution time for local actions. A screening approach is presented below for these events:

3.1 All HFEs that require local action in an area where access would be restricted should be set to a failure probability of 1.0.

3.2 All new HFEs or pre-existing HFEs, where the relevant instrumentation or controls could be impacted by the flood and which are required within 30 minutes after the flood event, should be set to a probability of 1.0

3.3 For HFEs required within 1 hr after the flood event, first check to see if there is a procedure to direct the action and there is sufficient time available to complete the action. If both these conditions are satisfied, then increase the existing internal events HRA for the case with written procedure or, use 0.10 for a new HFE with no procedure and no corresponding internal events HRA.

3.4 Other HFEs (physically not affected by the flood, with more than one hour available to perform the action) can be left at their nominal values.

4. Modifying the Existing HRA: For the human actions where the above screening values will be not used, the following modifications are proposed for the existing HRA:

   4.1 For human actions within an hour after the initiator, the operator response time should be increased significantly [by a factor to be determined]. This increase in the median response time is intended to account for both the effects of stress caused by the flood, which may slow diagnosis and decision-making, and the likelihood of distractions due to flood-induced failures that are not necessarily explicitly reflected in the PRA model.

   4.2 For human actions within an hour after the initiator, an increase in the stress level may be warranted. Recommended increase in stress levels is discussed in Section 4.2. It is recommended that the HRA practitioner make a final determination for how to best account for flood specific stress levels.

   4.3 Other HFEs with more than one hour available to perform the action could be left at their nominal values.

7.4 Plant Recovery Actions

After initial quantification of the internal flood model, typically dominant cutsets are reviewed to identify potential recovery actions. Such recovery actions may include closing a valve to isolate a leak or shutting down pumps to terminate flow. If these actions are not proceduralized, conservative HEPs should be assigned, using recommendations found in the HRA methods documentation; e.g., Reference [17]. For proceduralized recovery actions, a detailed HRA should be performed. Consequential effects of a recovery action on component or system operability need to be accounted for. For the quantitative assessment of recovery actions the following guidelines apply:

1. The isolation action could be credited with a screening value of 0.1 if the following is satisfied and can be documented:

- Flood indication is available in the Control Room.
- Flood can be isolated; isolation equipment is not affected by flood; and the area is accessible (if local action is required).
- Action is procedurally directed.
- There is sufficient time available to perform action, including time needed to detect the break location.

2. If the above conditions are not satisfied, a detailed HRA should be performed. For consistency, the same methods should be applied as in the internal PRA.

7.5 Determination of Time-Windows

The quantification of flood response should account for the three broad categories of pressure boundary failures (spray, flood, major flood). Depending on the scope of an IFPRA, further subdivision of “major flood” may be required to correctly account for how major floods of different magnitudes progress with time and what their effect son the time-window for operator response may be. As an example, while a “major flood” is characterized as a pressure boundary failure producing a spill rate in excess of 2,000 gpm, there is some likelihood that a spill rate could be approaching a theoretical maximum value. The effect on a corresponding time-window would be quite drastic. For a Capability Category III IFPRA, it is recommended that a probabilistic weighting approach be applied to correctly account for the full range of spill rates and time-windows for operator response.

7.6 Flood Risk Sensitivity to Human Reliability

Before finalizing the HRA it is recommended that a sensitivity analysis be performed to evaluate the flood risk as a function of derived human error probabilities. Results from a fictitious sensitivity analysis are shown in Figure 7-2.

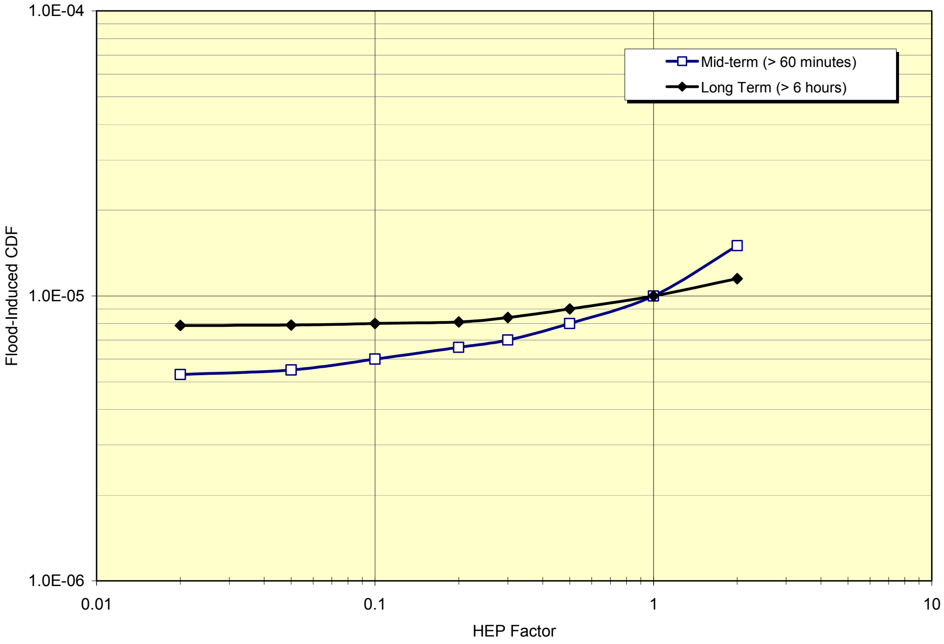


Figure 7-2
Example of Flood-Risk Sensitivity to Human Error

In figure 7-2, a HEP-factor = 1.0 corresponds to a base-line flood-risk model with flood-CDF = 1.0×10^{-5}. According to the example, lowering a flood-mitigation HEP by a factor of 10 has only a modest impact on the CDF for actions in the long term. If the same reduction factor is applied to actions in the mid-term (after the first hour of flood response) the CDF is reduced by almost a factor of 2.

8

PRA MODELING OF FLOOD SCENARIOS AND PRA QUANTIFICATION OF INTERNAL FLOOD SCENARIOS (TASK 9 AND TASK 10)

This chapter includes guidance for the development of the PRA model for flood scenarios (Task 9 of the IFPRA Guidelines) and the process of flood scenario quantification (Task 10 of the IFPRA Guidelines).

8.1 Task 9 - PRA Modeling of Flood Scenarios

Depending on the level of analytical discrimination, an Internal Flood analysis may involve a large number of scenarios that are based on many distinct conditional core damage probability (CCDP) values to reflect a large number of different local and global flooding effects as well as consequences of isolating the systems that cause the flood. Before incorporating these flood scenarios in an existing internal events PRA model, it may be useful to bin the flood scenarios into distinct categories according to type of flood (global vs. local effects) and flood source. As the flood scenarios include operator actions to isolate a flood, the model integration needs to account for possible dependencies with other operator actions modeled in the PRA. Section 8.3 includes an example of how to perform an integrated evaluation of flood scenarios.

8.2 Task 10 - Quantification of Flood-Induced Accident Sequences

8.2.1 Internal Flood Contribution to CDF

ASME/ANS PRA Standard High Level Requirements IFQU-A and –B, Supporting Requirements IFQU-A1 through –A11

The combined effects of flood-induced equipment failures and other non-flood related equipment failures that include hardware failures, unavailability due to maintenance, and operator errors must be accounted for in the quantification process. For example, the direct effects of flooding such as loss of CCW system and indirect effects such as submergence of equipment in the room where the flood originated and/or in the propagation paths must be accounted for in the integration of the flooding sequences into the PRA model to determine the impact on CDF. The impact of flood effects on LERF must also be accounted for in the quantification process.

Once the flood scenarios are identified for quantification, the associated initiator events or equivalent flood scenario initiator logic are incorporated into the baseline PRA model. Generally, the transient event tree can be used to model the plant response to flood events. The quantification can be performed for each sequence of the event tree and then summed to obtain an overall value for CDF. An alternative approach involves the simultaneous quantification of all the sequences to obtain the final CDF. Either approach can be used to quantify LERF. Incorporation of flood scenarios into the baseline PRA model can be accomplished manually by inserting the flood scenario-initiating event or the equivalent flood scenario-initiator logic at the same level as the transient event of concern. To model the flood impact on the affected equipment, the flood scenario-initiating event or equivalent flood scenario-logic must also be inserted at the level where the impacted equipment (i.e., basic event) is included in the model. Depending on the logic structure, the insertion can be made at a higher level in the baseline PRA model where the effect of equipment failure remains the same.

The manual insertion of flood scenarios into the baseline PRA model can be very labor-intensive —verifying the correct treatment of affected equipment can be difficult. In the past, the EPRI XINIT [27] software product was used to automate the process of incorporating flood scenarios. XINIT can insert initiators into the PRA model and can modify the model to incorporate initiator-related events. This capability allows for the easy and reliable quantification of the model including both internal events and the flood scenarios. Subsequent to the pilot, the XINIT features were incorporated in to the EPRI FRANX [28] software as part of a general-purpose fire/flood risk analysis tool. Please see Appendix F for more information on the FRANX tool as applied to IFPRA.

In general, the incorporation of the flooding sequences is similar to the incorporation of other initiating events into the system model. If a flood impact is different, additional modeling may be required. For example, the timing of equipment failure due to flood may be needed. Some equipment may fail prior to a plant transient due to its location; other equipment may not fail until much later in the flood scenario.

When initiating events are incorporated through event trees, the proper event tree path to be followed must be determined. The normal plant transient event tree will usually be used for this purpose, but it is possible to create a new event tree if necessary. Once the tree is defined, appropriate rules are added to identify the impact of the flooding event. The rules must be carefully constructed and placed in the proper order to reflect the appropriate progression of the accident.

Quantification of the Internal Flood-induced accident sequences are defined in High Level requirements HLR-IFQU-A and -B. Supporting Requirements for HLR-IF-E are discussed below:

1. <u>ACCIDENT SEQUENCES</u>: For each flood scenario an analyst is required to review the accident sequences for the associated plant initiating event group to confirm applicability of the accident sequence model. If appropriate accident sequences do not exist, it is required to modify sequences as necessary to account for any unique flood-induced scenarios and/or

phenomena in accordance with the applicable ASME/ANS PRA Standard requirements, described in Tables 2-2.2-1 thru 2-2.2-4 in Part 2 of the Standard.

2. SYSTEM ANALYSIS: An analyst is required to modify the systems analysis results to include flood-induced failures identified by IFSN-A6 (see Chapter 6 of this Guide). The applicable ASME/ANS PRA Standard requirements for system analysis, described in Table 2-2.4-1 through 2-2.4-4 of Part 2 of the Standard are to be followed.
3. DATA: If additional analysis of SSC data is required to support quantification of flood scenarios, perform the analysis in accordance with the applicable ASME/ANS PRA Standard requirements, described in Table 2-2.6-1 through 2-2.6-6 of the Standard for Data Analysis.
4. HUMAN: The human actions and applicable ASME/ANS PRA Standard supporting requirements are discussed in detail in Chapter 7.
5. SEQUENCE QUANTIFICATION: An analyst is required to perform internal flood sequence quantification in accordance with the applicable ASME/ANS PRA Standard requirements, described in Table 2-2.7-1 through 2-2.7-7 of the Standard, for quantification. Two important aspects of the quantification process are discussed below:
    - Combined Effects of Failures: An analyst is required to include in the quantification the combined effects of failures caused by flooding and those coincident with the flooding due to independent causes including equipment failures, unavailability due to maintenance, and other credible causes.
    - Direct and Indirect Effects: An analyst is required to include in the quantification both the direct effects of the flood (e.g., loss of cooling from a service water train due to an associated pipe rupture) and indirect effects such as submergence, jet impingement, and pipe whip.
6. LERF: The LERF analysis is discussed in Subsection 8.2.2.

To confirm all assumptions made in the quantification, the ASME/ANS PRA Standard Supporting Requirement IFQU-A11 requires an analyst to conduct walkdown(s) to verify the accuracy of information obtained from plant information sources and to obtain or verify inputs to:

a) Engineering analyses
b) Human reliability analyses
c) Spray or other applicable impact assessments
d) Screening decisions

Note: Walkdown(s) may be done in conjunction with other requirements, see Section 3.3.

8.2.2 Impact of Internal Floods on LERF

The ASME/ANS PRA Standard requires an analyst to review the LERF analysis to confirm applicability of the LERF sequences for each flood scenario. If appropriate LERF sequences do not exist, an analyst is required to modify the LERF analysis as necessary to account for any unique flood-induced scenarios or phenomena in accordance with the applicable requirements described in the Standard's section on LERF analysis (Table 2-2.8-1 through 2-2.8-9 of the Standard).

In order to determine the impact of Internal Flood on the LERF sequences, the analyst must understand the existing LERF sequences and how they were determined. The LERF sequences receive the input from the core damage analysis in terms of the probability that the plant will end up in one of a number of Plant Damage States (PDSs) when core damage occurs. PDSs describe the plant in a number of ways that are important to the LERF analysis, such as whether the Reactor Coolant System is at high or low pressure, the status of containment isolation, or containment integrity (vented, bypassed, or failed). Internal Flood can affect LERF by changing the probability distribution of the Plant Damage States or by introducing a new Plant Damage State.

The other possible impact of Internal Flood on LERF is the effect that Internal Flood could have on the way the accident sequence progresses through the Containment Event Tree (CET). Internal Flood may change the probability or possibly eliminate one of the functions credited in the CET (e.g. containment heat removal) or could introduce a new failure mode to the CET, depending on the location of the break that leads to the flooding.

A pipe failure that degrades the containment isolation function and introduces a potential LOCA outside containment scenario, not modeled in the internal events PRA, is a good example of the effects Internal Flood analysis may have on the LERF evaluation. Another example is a pipe failure that could flood containment heat removal pumps and disable this function. There are pipe failures that in the recirculation phase could lead to a direct containment bypass; but such a break would occur in a stand-by system on a LOCA demand; and the likelihood of these will be very low.

An additional consideration for the impact of flooding on LERF is the impact that the flooding may have on Operator Actions. Depending on the location of the flooding and the extent of the effects of the flooding event, there is the potential that operator actions credited in the LERF analysis may be prevented. There is also a potential that the flooding event prevents operators from taking actions that the LERF analysis assumes were already performed prior to core damage.

The determination of the impact of internal floods on LERF requires coordination between the flooding analyst and the analysts involved in the LERF analysis in order to closely examine each of the flooding scenarios for their impact to both the Core Damage and Containment Analyses.

8.2.3 Uncertainty & Sensitivity Analysis

An integrated assessment of uncertainties in the quantification of an IFPRA model should account for uncertainty in initiating event frequency and time available for flood isolation. EPRI 1013141 (Reference [7]) addresses uncertainties in pipe failure rates.

Uncertainties in the evaluation of different flood isolation strategies implicitly involve accounting for uncertainties in spill rate distributions and the time to reach a critical flood volume. Discrete probability distributions (DPDs) may be defined to account for these uncertainties. To investigate the impact of subjective probabilities behind a defined DPD, these probabilities may be varied.

In Section 5.5 guidance on the performance of uncertainty and sensitivity analysis in the treatment of flood initiating event frequencies is provided through the use of an example.

8.3 Example of Internal Flood Scenario Quantification

This section includes an example of how results from the initiating event frequency quantification and the human reliability analysis are folded into an integrated quantification of internal flood scenarios. Each flood scenario is defined by:

- Flood area, which is a uniquely defined plant location (for example, building elevation with open areas and confined areas)
- Flood source (for example, a single piping system or storage tank) and a corresponding initiating event frequency characterized according to type of release. A flood zone may include multiple flood sources. Sections 5.4 and 5.5 include examples of initiating event frequency calculations.
- Type of release resulting from a pressure boundary failure (spray, flood, or major flood). Remember that in these guidelines a “flood” is defined as a pressure boundary failure that results in a spill rate in excess of 100 gpm but less than 2000 gpm. Furthermore, a “major flood” assumes that the spill rate exceeds 2000 gpm, which is a lower bound spill rate.
- Flood mitigation as characterized by procedural guidance and operator response as analyzed in the HRA task. Depending on how flood isolation is characterized and quantified in the HRA task, isolation of a pressure boundary failure may or may not consider spray events since these are defined as being within the capacity of a floor drain system.
- Plant response to Internal Flood given successful or unsuccessful mitigation. The plant response is characterized by a CCDP.
- Calculated core damage frequency (CDF) for each uniquely defined flood damage state (FDS).

In quantifying each flood scenario (potentially hundreds of unique scenarios), detailed consideration must be given to relationships between the magnitude of a flood event, the likelihood of flood mitigation given a pressure boundary failure, and the plant response. Results from Task 6 (Initiating Event Frequency) and Task 8 (Human Reliability Analysis) will require further processing or adjustments to account for sequence-specific dependencies. A generalized flood scenario quantification format is shown in Table 8-1.

Table 8-1
Generalized Quantification Format

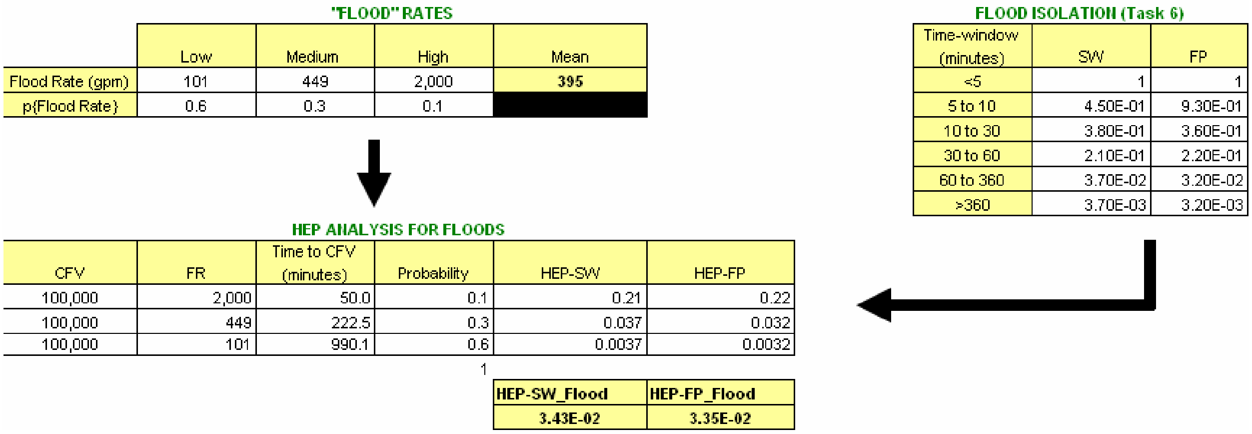
Scenario Description						
1 Flood Zone & Flood Source	**2 Type of Release/ Spill**	**3 IF Frequency (Task 5)**	**4 Flood Isolation (Task 8)**	**5 Flood Scenario Frequency**	**6 CCDP**	**7 CDF_{IF}**
Can be an open or closed area, which is uniquely defined by the SSCs and flood sources.	Differentiate between "spray," "flood," and "major flood." There would be a unique scenario for each zone and spray/flood source	In this step of the quantification process an unmodified IF event frequency is selected (e.g., EPRI 1013141 Rev. 1) and multiplied by the appropriate number of linear feet of piping (or number of welds, or number of pipe segments)	The HRA task produces human error probabilities for flood isolation tasks given certain time-windows for flood response. The output from Task 8 are "unmodified HEPs" that require further specialization depending of the characteristics of each flood scenario. The main objective of such HEP specialization is to account for the uncertainty in the flood frequencies, flood rates and critical flood volumes. Further details are included in the 8.3.1.	The flood scenario frequency is obtained by combining the values in column "3" and "4."	A CCDP catalog is developed to characterize the spray/ flood consequences. The CCDP determination includes an assessment of the potential equipment damage by water spray or submergence, the consequences of loss of functions supported by the system that caused the flood, and the consequences of flood isolation	Each contribution to the overall Internal Flood induced CDF is obtained by combining the values in column "5" and "6. Each unique scenario is assigned a flood damage state (FDS).

8.3.1 Integrated Flood Isolation Assessment

Flood scenario quantification involves a specialization of the results from Task 6 (flood initiating event analysis) and Task 8 (human reliability analysis) to account for the unique characteristics of each flood scenario. An objective of this specialization is to perform an integrated assessment of the uncertainties in flood rates, critical flood volumes, and HEPs. According to EPRI report 1013141 Rev. 1 [7], a "flood" is defined as a pressure boundary failure, which produces a flow rate greater than 100 gpm and less than or equal to 2000 gpm. All pipe failure frequencies in Reference [7] are either interval or threshold values.

The likelihood of successful flood isolation is strongly correlated with the flow rates that result from a pressure boundary failure. Figure 8-1 shows an Excel spreadsheet for a fictitious scenario for which the critical flood volume (CFV) is 100,000 gallons. As is indicated in this figure, there is some uncertainty in the flow rate that results from a pressure boundary failure in Fire Protection (FP) and Service Water (SW) piping. Subjective probabilities are assigned to the "low," "medium," and "high" flow rate.

The HRA task will produce HEP values for different combinations of pressure boundary failures and time-windows; results from a fictitious analysis are summarized under "Flood Isolation HRA (Task 6). Summarized under "HEP Analysis for Floods" are calculations for six different flood scenarios. The values under the HEP-SW and HEP-FP are calculated using MS-Excel "IF formulas." Finally, integrated results for the Service Water case and the Fire Protection case are given under "HEP-SW_FLOOD" and "HEP-FP_FLOOD," respectively; these values are calculated using MS-Excel "SUMPRODUCT."



"FLOOD" RATES

	Low	Medium	High	Mean
Flood Rate (gpm)	101	449	2,000	**395**
p(Flood Rate)	0.6	0.3	0.1	

FLOOD ISOLATION (Task 6)

Time-window (minutes)	SW	FP
<5	1	1
5 to 10	4.50E-01	9.30E-01
10 to 30	3.80E-01	3.60E-01
30 to 60	2.10E-01	2.20E-01
60 to 360	3.70E-02	3.20E-02
>360	3.70E-03	3.20E-03

HEP ANALYSIS FOR FLOODS

CFV	FR	Time to CFV (minutes)	Probability	HEP-SW	HEP-FP
100,000	2,000	50.0	0.1	0.21	0.22
100,000	449	222.5	0.3	0.037	0.032
100,000	101	990.1	0.6	0.0037	0.0032
			1		

HEP-SW_Flood	HEP-FP_Flood
3.43E-02	**3.35E-02**

Figure 8-1
Example of Integrated Flood Isolation Assessment

9

DOCUMENTATION OF INTERNAL FLOOD PRA (TASK 11)

This chapter describes IFPRA documentation and addresses the High Level Requirement IFPP-B and its Supporting Requirements IFPP-B1 through –B3; HLR IFSO-B and its SRs IFSO-B1 through B3; HLR IFSN-B and its SRs; IFSN-B1 through B3; HLR IFEV-B and its SRs IFEV-B1 through B3; and HLR IFQU-B and its SRs IFQU-B1 through B3.

The documentation and presentation of results are dependent on the objectives and scope of an IFPRA, including the planned uses. If a study were to be performed only to conservatively represent Internal Flood risk (Capability Requirement I per the ASME/ANS PRA Standard), then a different set of documentation may be needed than if the study were to be performed to support risk-informed applications (Capability Requirements II and III per the ASME/ANS PRA Standard). Three aspects of IFPRA documentation are addressed: 1) Documentation of qualitative evaluations, 2) documentation of quantitative evaluations including documentation of IFPRA model, and 3) its integration with an overall PRA of internal and external initiating events.

9.1 Documentation of Qualitative IFPRA Evaluations

The documentation of Tasks 1 through 4 needs to be sufficiently comprehensive and systematic to support future applications and updates. It is recommended that the information on potential flood areas and equipment locations be in some kind of organized format such as a spreadsheet or database. The structure of the documentation should be such that relevant flood scenarios are identified by applying data filters and query functions. An intrinsic quality of a good, traceable document design should be its ability to clearly demonstrate how walkdowns, operator interviews, and other field observations are used in IFPRA model development. Appendices B and C include examples of IFPRA documentation.

It is recommended that any existing naming or number conventions for plant building locations and plant equipment be carried over to an IFPRA for ease in conveying the information to other organizations and industry groups. For each plant area, an analyst should identify the precise plant location by building elevation and column number as identified on architectural drawings. It is furthermore recommended that a “flood pathway diagram” be developed from the walkdown information collected to support the flood scenario development.

9.2 Documentation of Quantitative IFPRA Evaluations

Since an IFPRA utilizes existing internal events PRA information, it is essential to implement the appropriate PRA model configuration controls as the flood scenario development evolves. The integration of the IFPRA with the internal event PRA model must be documented in a concise way by utilizing already implemented PRA documentation routines.

9.3 Roadmap to Support Peer Reviews

Peer reviews of IFPRAs can be performed more efficiently if it is easy for the peer reviewers to identify and locate the documentation associated with each HLR and SR in the PRA Standard. Therefore, it is highly recommended that the IFPRA include an easy-to-locate section or table that provides a cross reference between the requirements in the Standard and the location in the IFPRA documentation where objective evidence can be located that each requirement has been addressed. For PRAs performed during a design stage or pre-operational stage, this roadmap should also identify requirements that could not be met or not fully met due to lack of information or design details that were not available.

10

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A

LESSONS LEARNED FROM FORT CALHOUN INTERNAL FLOOD PRA

An IFPRA study was performed at Fort Calhoun Station (FCS) using the 2006 EPRI draft guidance report. As a result, numerous insights and lessons learned were recognized. The lessons learned and insights identified were generally categorized into the following topics:

- Flood Timing Impacts
- Assignment of System Pipe Failure Frequency
- Flood Type Characterization
- Qualitative Screening Methodology
- Spray Scenario Impacts
- Maintenance-Induced Flooding Scenarios
- Walkdown Optimization
- Flooding Modeling Integration
- SSC Considerations
- Documentation

A.1 Flood Timing Impacts

Performing the IFPRA presented an opportunity to investigate potential impact and usefulness of a time-based flooding analysis. A time-based flooding analysis considers flood propagation flowing out of a room in real time while tracking actual flood height in the given room. While this approach is more rigorous, it involves the need to construct simple static hydraulic models of key rooms and the respective propagation paths. Consequently, the use of dynamic models was limited. It is not known how much effort would be required to develop a dynamic model and develop the necessary nodalization and input parameters. However, it is safe to assume the effort could exceed the total level of effort spent on this IFPRA update. Hence, for the most part, room flooding is analyzed statically. Scenario-dependent flood depths were calculated by assuming the room was filled with the total fluid released and components failed based on the resultant flood height and flood propagation path assumptions. This process was repeated for all rooms along the flood propagation pathway. Timing is particularly important for flooding when tied together with operator actions (i.e., flood isolation and recovery).

Estimating the duration of a flood, i.e., the time required to achieve isolation of the flood source, is important in determining the likelihood of component failures due to submergence. Multiple factors must be considered however, when performing this analysis, such as flow rates out of the room through doors, vents, and drains. Additionally, the dynamics of the analysis can rapidly change as doors and walls begin to fail, sump tanks overflow, and the resulting flow rates in-and-out of rooms may dramatically change.

To facilitate equipment repair and removal during routine plant operations and maintenance, several rooms may be separated by removable cinder block walls. The 2006 EPRI IFPRA draft guidance has no specific discussion on the treatment of these barriers beyond the need to justify any credit that is assumed for them for flood barrier integrity. The current analysis conservatively assumes that if a pipe break occurs in a room containing PRA-related equipment and a flood depth greater than a nominal level is expected, two flood scenarios should be considered. The first scenario assumes that the room, where the break initiated, completely fills as a result of the accumulating water. The second scenario assumes a complete failure of any interconnecting barriers (i.e., block walls) and water accumulates in both the originating and adjacent rooms to a height consistent with the combined areas of the rooms and the released inventory..

The above approach results in a relatively conservative treatment. To address this concern, multiple flood scenarios need to be considered and dynamic flood analyses may be used along with realistic wall and door leakage and failure estimates to perform this analysis. Such analyses can be relatively complicated; however, utilizing appropriate software, such as MathCad, can make the study tractable. This level of detail is expected to be restricted to selected scenarios where the additional knowledge is expected to result in improved risk insights or significant expected risk benefits.

Dynamic analyses may also be helpful in establishing the impact of drain interaction. Since room flood rates may significantly exceed the room drain capability (through doors and floor drains), a dynamic model can be used to establish the maximum primary room flood height as well as the flood heights in adjacent and drain-connected rooms. This procedure is particularly useful for identifying flood threats to rooms with electrical equipment located near the floor. This model was not constructed in the present study, and its assessments were conservatively performed using quasi-static arguments.

The timing of flood events becomes particularly important when trying to characterize operator actions and identify and evaluate possible recovery actions. In these cases, identification of time to component loss, time to operator identification, isolation timing, and recovery timing become critical. PRA modeling of these events becomes complicated because of the complexity in identifying observable cues, difficulty in estimating the impact of environmental conditions in the vicinity of mitigating components, and the challenges in evaluating the non-proceduralized recovery actions such as recognizing flooding event and then closing an adjacent valve. Consequently, these events can become very complicated to model and validate. The FCS IFPRA was relatively conservative in its treatment of these events. This approach did not have a major risk impact because the FCS IFPRA demonstrated that unless isolation and recovery can occur within an extremely short time-window (less than an hour), not much could be gained through time-based analysis. Experience at FCS has shown that components fail almost immediately following pipe break, and most isolation and recovery options are either impractical or not significant. It should be noted, however, that these are plant-specific insights and experiences may be entirely different at other plants.

A.2 Assignment of System Pipe Failure Frequency

The EPRI failure frequency report [7] is the recommended source for pipe failure frequency data. The appropriate use of the EPRI failure frequency report has been a topic of discussion for many recently completed IFPRA studies. While the recommended reference represents the most up-to-date compilation of flood frequency data, the report lumps together many types of fluid containing components (tanks, pumps and valves, etc.) and averages their frequency with piping failure rates. This approach is inherently different from earlier approaches where the flood frequency was developed from a composite of floods from different components (see INEL (EG&G) Report [13]). The approach is justified by the observation from service experience that shows that almost all piping system failures occur in pipes or at welds between pipes and components and the fact that the few non-pipe failures have in fact been included in the collected failure data. However, the earlier data set is relatively old and incomplete. There remains an uncertainty for plants that have an unusual distribution of pipe components relative to the amount of piping assumed in estimating industry generic frequencies. This issue was treated in the FCS IFPRA as a model uncertainty issue and addressed via use of sensitivity analyses.

A second issue that arises is associated with low-pressure or unpressurized static piping. Piping frequencies should reflect data from a common type of pipe that is operated under similar flow and pressure and fluid conditions (i.e. chemistry). To a large extent, the EPRI report separates data from pipes operated under different conditions. However, the report does lump data for pipes operated under static or low flow conditions with other failure data for the "Safety Injection and Recirculation (SIR) system group, which is for the most part dominated by systems at low pressure under stagnant conditions. While this lumping may not be a general concern, the fact that such pipes are located in high-risk areas makes the use of the EPRI data problematic for estimating pipe failure frequencies in the absence of alternate sources of information. A survey of literature was performed after the FCS IFPRA was completed to identify a method for estimating failure frequency of static or low pressure piping. The survey results indicated that the approach used to estimate conditional pipe failure probabilities associated with ISLOCA fracture mechanic studies may be more appropriate for establishing such failure frequencies..

While the EPRI report provided guidance on assignment of the piping initiating event frequency, it offered little guidance on how to combine disparate pipe failure frequencies and associated error factors within a flood area.. This process is important to complete the IFPRA uncertainty assessment. For the current effort, a simplified error factor selection scheme was developed. In Section 5.5 of the report, an example is provided that shows how to propagate uncertainties that are initially defined in the pipe failure rate report through models that account for the number of feet of pipe and pipe failure modes associated with each flood-induced initiating event.

A.3 Flood Type Characterization

The EPRI guideline report recommends classifying flood types based upon their potential flow rates following a break. The guideline defines a spray as a pressure boundary breach in which the flow released is less than 100 gpm. The guideline defines a flood as a pressure boundary breach in which the flow released is between 100 and 2000 gpm. Finally, a major flood is defined as one in which the flow released is greater than 2000 gpm.

For the FCS IFPRA study, all pipes from the same system and flood area were grouped together. Each group of piping was then assigned the most limiting flood rate for that system. This practice avoided the need to create separate scenarios for 4 inch and 8-inch pipes from the same room and system; they can be grouped together in the same scenario. Additionally, the EPRI failure rate data provides different failure rates for different pipe sizes, which can then be summed together and treated as a total pipe failure frequency. Furthermore, scenarios were defined by flood rates at the high end of the ranges. However, this was not done for pipe systems that could only support a certain flood rate such as Component Cooling Water (CCW), which can not flood at a rate greater than 2000 gpm, or for major floods, for which there was no upper bound.

For major floods, realistic flow rates were used. Sensitivity studies were performed to demonstrate that the flood-induced plant was not particularly sensitive to small changes to the flow rate. For example the impact of a Raw Water (RW) flood of 5000 gpm was not significantly different from a RW flood of 2500 gpm.

Determination of pipe rupture areas and flows were simplified by the use of the 100 gpm dividing line between spray and flood events. While pragmatic, this division raises two issues. First, if no flow egress is available from an area, for example, because there is no drain or insufficient door leakage, a spray event of 100 gpm can evolve into a flood. Second, most spray events would be expected to be far less than 100 gpm. In fact, early data of Eide [13] used a 50 gpm upper limit on small leaks. As small leaks make a higher frequency contribution to the flood initiating event frequency, better characterizing events through more realistic leak rates and probabilities could make it possible to more realistically characterize threats.

A.4 Qualitative Screening Methodology

Qualitative screening may be performed during the first four tasks as defined by the EPRI draft guideline report. As data are being collected, some sources, rooms, and components may be screened out from further analysis: the rationale for omitting them should be documented. Screening may also overlap into Task 5, as the screening methodology will help in defining the scenarios included in the FCS IFPRA study..

No specific guidance on how to screen rooms or areas from further detailed analysis was provided in the EPRI guideline. However, based on a team evaluation, an example of screening methodology was developed. Its key elements are as follows:

1. The area or room contains no PRA-related components and no plant system within the area or room that stores or transports fluid (flood source).
2. The room does containing flood source(s) but these sources could not cause a direct loss of system and consequential plant trip or emergency plant shutdown if a pressure boundary failure occurred, AND one of the following conditions obtains:
   a) The room contains no flood-susceptible PRA-related components in other systems within the initiating area/room and the flood does not propagate to other areas/rooms
   b) The room contains no flood-susceptible PRA-related components in other systems within the initiating and propagating areas/rooms
   c) The room contains flood-susceptible PRA-related components in other systems within the initiating and propagating areas/rooms, but these components do not fail because of insufficient flood volume. (This criterion is used to screen out small volume flood sources such as eyewash stations that are considered insufficient to result in spray damage to components.
3. The room contains flood-susceptible PRA-related components but no flood source AND is not in a propagation pathway.

Note that all screening methodologies will be plant specific and must be fine-tuned to best utilize plant characteristics.

In the current version of the guideline it has been explained that the IFPRA tasks are not expected to be performed sequentially, but rather in an iterative fashion consistent with the approach taken in the FCS IFPRA.

A.5 Spray Scenario Impacts

Building spray scenarios for implementation into the model requires more information on targets and sources than is required for flood or major flood scenarios. Extra information is needed due to the spatial sensitivities—room location, height, proximity of components to flood sources—for the target as well as the source. To accurately model spray scenarios, the components exact spatial location (including height) must be known in relation to the pipe length within the defined spray distance from the target. The EPRI guideline report recommends 10-feet for the spray zone of influence; however, no formal basis is provided. The FCS internal flood evaluation supports adjusting this distance. Further guidance has been provided in this version of the guideline to address this concern.

Collecting and building this information is very time consuming. A significant amount time can be saved by performing some analysis prior to performing walkdowns. By performing some simple system and component classifications that identify the overall susceptibility or lack of susceptibility of the component to potential spray scenarios, the effort required to establish detailed spray geometries may be reduced. Thus, component susceptibility assessments should be attempted early in the IFPRA and prior to performing any detailed analysis or walkdowns.

Additionally, performing a component susceptibility analysis can help simplify component failure identification. The impact of component failure—for example, does it cause a plant trip? —should also be determined prior to the detailed quantification analysis. Performing this simple qualitative screening can eliminate most, if not all, of the potential spray scenarios from the evaluation, which will in turn save significant time performing plant walkdowns and detailed scenario analysis.

A.6 Maintenance-Induced Flooding Scenarios

Maintenance-induced flooding scenarios need to be included and were analyzed in the FCS IFPRA. This analysis should include an evaluation of maintenance practices and general procedures and can be limited to maintenance activities on the major PRA-related equipment (i.e., pumps, heat exchangers) performed during power operation. To limit the extent of the maintenance procedure reviews, a procedure was developed to screen out maintenance configurations that provide multiple barriers to maintain pressure boundary integrity.

A.7 Walkdown Optimization

Without proper preparation, plant walkdowns can prove to become a burdensome task when performing an Internal Flood PRA analysis. Information sources consulted to aid in preparation will likely include PRA component databases, isometric drawings, and piping and instrumentation drawings. Walkdown sheets provided by the EPRI draft guideline report can serve as a good basis for information needed. These sheets should be updated as necessary to include plant specific information. To increase the walkdown effectiveness, the sheets should be populated as much as practical with information from the previously mentioned sources; and the presence and susceptibility of targets to flood and spray challenges should be considered.

A.8 Flooding Model Integration

One of the final tasks for performing an Internal Flood study requires implementation of the flooding scenarios into the PRA model. This can be done a number of different ways. In the future it will likely be done using the FRANX software product developed by EPRI. The current evaluation tracked flooding scenarios using XINIT [27]. Use of these integration tools allows the creation of an integrated flood model while still maintaining a discrete flood PRA model. Specifically, XINIT allows for initiator implementation along with HRA adjustment and integration.

To facilitate the model integration several databases were helpful. A separate database was used to track initiator mapping, and XINIT was used to map the PRA-related components that are impacted by a flood-induced event. Another database tracked scenario driven flood depths and equipment flooding failure levels and component susceptibilities. Initiator mapping was required to ultimately maintain a model with a reasonable number of initiators. This approach was also used because it reduces the effort required to perform the mapping task. The approach used to build the PRA model will impact the level at which the initiators are put into the model.

A.9 SSC Considerations

In performing the IFPRA, there are a number of potential traps that an analyst may fail to notice without careful considerations. These traps deal with non-conservative treatment of seemingly conservative assumptions. One such case is treatment of door failure. Crediting door failure at a given water height may not always be the most conservative treatment of a flooding scenario and flood propagation. Some analysis and consideration must be given to door treatment and where the flood will potentially back-up to if the door does not fail. Some plants have block walls, which should also be treated similarly to doors in that crediting failure is not always the most conservative treatment.

A second potential IFPRA trap is the treatment of drains. As with door treatment, the analyst must consider all propagation and treatments of the flooding scenario and not just the seemingly conservative propagation pathways. For example, it may not always be conservative to not credit floor drains. Depending on where the drains lead (tanks, other rooms, etc.) flow through the drains could be more significant than flow through rooms and corridors. Typically, however, it is not appropriate to credit drains for any flood greater than 100 gpm, but rather acknowledging the fact that some amount of flow will travel through the drains to another location. Backflow calculations should also be performed to ensure that there are no backflow concerns at the plant.

A.10 Documentation and Standard Compliance

For a flooding model to be used for regulatory activities, it should be developed to meet RG 1.200 [4] and by reference to the ASME PRA Standard. Since flooding PRAs are likely to be peer reviewed, the EPRI guidance should recommend the development of a roadmap that shows compliance with ASME PRA Standard Supporting Requirements (SRs). Such a roadmap was developed for FCS IFPRA study. The follow-up peer review concluded that such a roadmap was useful in identifying key section of the internal flooding document or reports that demonstrated compliance with the ASME PRA SRs for internal flood. The roadmap will be helpful to the development team if it is maintained as a living document.

B
SUMMARY OF RESULTS FROM IFPRA QUESTIONNAIRE

B.1 Introduction

A survey/questionnaire was developed to identify the technical areas of ASME/ANS PRA supporting requirements that needed additional explanation or guidance based on the recently conducted IFPRAs . The questions were developed to capture lessons learned and insights from recent IFPRAs that used the draft EPRI guideline or other utility-developed, plant-specific guidelines. As such, the questions were divided in two parts. Part I of the survey/ questionnaire was geared towards IFPRAs that were recently performed using the draft EPRI guideline to implement the supporting requirements of the ASME/ANS PRA Standard for internal flood events. Part II of the survey/questionnaire was geared towards IFPRAs that did not use the draft EPRI guideline to implement the supporting requirements of the ASME/ANS PRA Standard for Internal Flood events.

Parts I and II of the survey/questionnaire covered the following technical areas:

Initiating Event Impact – The impact of a flood event can manifest itself on plant operation in several ways. This type of event can cause a plant trip, an immediate plant shutdown, or an orderly shutdown because limited conditions of operation cannot be met. The impact on plant operation was not always used consistently to identify flood scenario initiating events.

Reference Sources - Several reference sources could be used in determining the impact of Internal Flood inside a plant. These references would be used for failure frequencies, treatment of barriers, human actions, and many more. Reference sources were not consistently used in flooding PRA studies.

High-energy line breaks (HELB) Initiating event (IE) frequency - HELBs are different from normal breaks due to the different consequences that occur. Some scenarios that may occur from HELB events include: inducing fire suppression systems to come on, thermal induced failures, pipe whip, or structural damage not associated with flooding. Therefore HELB IE guidance is different than flooding IE guidance.

Detail IE Frequency Calculations - Categorizing floods and treatment of plant equipment that have the potential to fail and cause flooding need to be considered in any IF model. For this reason IE details need to be considered. Treatment of gaskets, vales, heat exchangers, and tanks need to be considered along with piping. Spatial orientation for spray events is also considered due to possible failure of equipment from sprays. The consideration of these events and components are not consistently used for detailed IE frequency.

Credit for Human Actions to Avert Flood Scenarios - Operator actions to mitigate or avert floods can occur in several ways. Alarms, indicators, plant personal, or detectors could provide a notification that a flood is occurring. These notifications could either help in mitigating a flood or averting it, and HRA guidance is provided in the draft document.

Break Spectrum - Classifying floods based on the flow rate or the break spectrum allows for a classification of the event and set of consequences to go along with the event to be assigned. At each level of the flood hazard evaluation, different types of components could fail along with different times to failure. Consistent treatment of breaks is needed to insure that the proper assumptions are being used.

Non-Piping Breach - Maintenance induced flooding can impact the plant because it could lead to piping breaches or failure of equipment. It is important to consider maintenance-induced flooding different for other initiating events due to the fact that HRA calculations would be involved. Guidelines to evaluate maintenance-induced flooding need to be developed due to the special nature of this initiating event.

Barrier Failure - Barriers can prevent or allow floods to propagate inside a plant. Barrier failure can be modeled in terms of exceeding the load on the door or assuming a door will fail at a certain water height. Treatment of fire doors, barriers, door cracks, and floors should also be considered. The treatment of such barriers and doors is not consistent.

Flood Depth - Flood depth or height is an important factor when determining the impact of a flood on plant equipment. Flood height relies on several factors that are characteristics of the room such as maximum flow, drainage rates, and the time associated with flooding of the equipment. Empirical equations are provided to give guidance on these issues and to standardize the determination of a flood depth.

Pathways - Flood pathways are important because pathways lead to flood propagation to other areas where the flood did not originate. Characteristics for propagation include floor characteristics, backflow through drains, doors, and wall failures. The evaluation of these characteristics was not always consistent.

Hydraulic Calculations - Drainage propagation is an issue for drains without reverse flow check valves. Due to this propagation, the back flow through drains needs to be determined because of flooding from drain propagation could cause or lead to a plant trip.

Water/Moisture Resistance - HELB events can induce failure in susceptible equipment because of the high probability of sprays being produced. Guidelines for crediting resistance to these events are needed due to the inconsistent ways equipment resistances are accounted for.

Equipment Rating - Equipment resistances to water or moisture is important for flooding or spray events. There is a need to determine which equipment would fail from a spray or flood event and which equipment would not. If the equipment were found to be susceptible to a spray or flooding event, the determination into whether the equipment has any protection against these events would then need to be determined. Treatment of the susceptibility of equipment to these events was not consistent.

B.2 Survey/Questionnaire

The unmodified survey/questionnaire is provided below.

Part I
Internal Flood Survey/Questionnaire

1. In the most recent update of your PRA model, which statement best characterizes the risk significance of Internal Flood events? In answering this question, please use the ASME/ANS Combined PRA Standard definition of significance.

   ☐ Internal floods were significant contributors to risk
   ☐ Internal floods were major or dominant contributors to risk
   ☐ Internal floods were found to be insignificant contributors to risk

2. What was the percent contribution of floods to CDF (if less than 1% simply state <1%)?

   ____

3. What was the percent contribution of floods to LERF (if less than 1% simply state <1%)?

   ____

4. Did you use the draft EPRI Internal Flood PRA (IF-PRA) guideline to support your most recent IF-PRA?

   ☐ Yes ☐ No

   If your response was Yes, continue with questions 5-9 and the questionnaire on Internal Flood in Attachment B.
   If your response was No, continue with the questionnaire on Internal Flood in Attachment B.

5. If the draft EPRI guideline was used, please identify one of the following:

   ☐ The draft guidance was followed closely on a step-by-step basis for floods and high energy line break events
   ☐ The draft guidance was followed closely for floods only
   ☐ The draft guidance was used for only certain aspects, please specify

   ____

   ☐ The draft guidance was used in conjunction with other guidance, please specify

   ____

6. If the draft EPRI guidance was used, please fill out the information requested in Table B-1. Identify specific tasks that were found to be helpful or unhelpful and areas where improved guidance is needed. Please provide an explanation of each issue and suggestions on how improvements can be made.

7. Did you use the companion EPRI report on pipe failure rates (1012302) to support the quantification of HELB events?

   ☐ Yes ☐ No

   If you did not use the companion EPRI report, please specify which source of pipe failure rate data was used.

8. Did you use the companion EPRI report on pipe failure rates (1012302) to support the quantification of flood initiating events?

   ☐ Yes ☐ No

   If you did not use the companion EPRI report, please specify which source of pipe failure rate data was used.

9. If you used the companion EPRI report on pipe failure rates, and the library of failure rates did not cover an adequate set of systems, pipe sizes, and failure modes to support the initiating event quantification, please specify what additional parameters are needed.

Table B-1
Identification of Technical Issue for Specific Tasks for IFPRA

Task No.	Task Description	Rank 1-5: 1=Not Helpful; 5=Most Helpful	Explanation of Technical Issues	Comment/Suggestion for Addressing Technical Issues
Task 1	Identify Flood Areas and SSCs			
Task 2	Identify Flood Sources			
Task 3	Perform Plant Walkdown			
Task 4	Perform Qualitative Screening Evaluation			
Task 5	Characterize Flood Scenarios			
Task 6	Flood Initiating Events Analysis			
Task 7	Flood Consequence Analysis			
Task 8	Evaluate Flood Mitigation Strategies			

Table B-1 (continued)
Identification of Technical Issue for Specific Tasks for IFPRA

Task 9	PRA Modeling of Flood Scenarios			
Task 10	PRA Quantification of Flood Scenarios			
Task 11	Documentation of IFPRA			

Part II
Internal Flood Survey/Questionnaire

A Initiating Events

1 Initiating Event Impact

a Which of the following applies? Please explain the basis for your response to this question.

Initiating events that only resulted in a direct plant trip were included.

Initiating events that resulted in a plant trip or an exigent (emergency) shutdown were included.

Initiating events that resulted in a plant trip or was expected to result in a plant shutdown for any reason were included.

Other, please explain.

b Were sources with automatic makeup capability screened? Please explain the basis for your response.

2 Reference Sources

a Which of the following reference sources were used to determine initiating event (IE) frequency for flood and spray events? Please explain the reason for choosing the reference source.

EPRI-1013141, Rev. 1

EGG-SSRE-9639

NUREG-CR/6928

NUREG-1829

Other, please specify

b What type of inventory was required to support IE frequency calculation (i.e., pipe length, pipe welds, valves, pumps, etc.)?

3 High Energy Line Break (HELB) IE Frequency

a Which references were used to determine IE frequency for HELB events?

b Did the Internal Flood PRA (IF-PRA) relied on existing design basis HELB analyses (Y/N)?

c Did the HELB analyses considered propagation to other rooms/areas?

Part II (cont'd)
Internal Flood Survey/Questionnaire

4 Detail IE frequency Calculations

a How were tank failure frequencies or heat exchanger shell frequencies determined?

b What was the maximum flow rate used for spray events?

c What was the maximum flow rate used for flood and major events?

d How were valve packing and gasket failures accounted for and how were the failure frequencies determined?

e Was any spatial orientation factor taken for sprays and potential targets?

f Was any credit taken for stagnant pipe runs at low pressure?

g Was Bayesian updating used?

h Was any credit taken for leak detection? If so, please explain the basis.

i If water sources existed in the control room, how was the subsequent event treated?

5 Credit for Human Actions to Avert Flood Scenarios

a Were human actions credited in averting a flood initiating scenarios? (i.e., securing the fire protection system prior to evolving into a flood scenario following spurious actuation or response to HELB)

b How?

c Was credit taken for leaks detected in routinely inspected areas?

d How is operator detection and diagnosis credited? (i.e., control room indications or alarms, operator rounds, etc.)

e Was credit taken for inspection programs to screen out low pressure piping in standby systems?

f How was the operator credited for isolating an unlimited flood source?

6 What types of flood initiating events were used (type, categorization, grouping, etc.)?

8 Break Spectrum

a What spectrum of leakage rates were used (i.e., 0-100 gpm, 100-2000 gpm, 2000+ gpm)?

b Was the suggested spectrum in EPRI-1013141 applicable without modification?

B Maintenance Screening

1 Non-piping Breaches

a Were maintenance-induced flood scenarios accounted for? Please explain how such scenarios were screened.

b Were human-induced flood scenarios accounted for? Please explain how such scenarios were screened.

C Flood Propagation

1 Barrier Failure

b Was door failure considered? Please explain the basis for determining door failure.

c Were movable (block) walls considered to fail? Please explain the basis for determining failure.

d Were analyses performed on structures to determine their capacity?

e How were fire barriers treated?

Part II (cont'd)
Internal Flood Survey/Questionnaire

2 Flood Depth
a Were transient models used to establish peak flood depths?
b Was equipment in the flood area accounted for in determining the height of accumulated water?

3 Pathways
a Was leaking through floor plugs or other barriers considered
b Was propagation through floor cracks accounted for? Please explain how impacted equipment was identified.
c How were floor drains treated?
d For elevated equipment, was water impingement or splashing from sources above the equipment accounted for?
f Were shielding effects considered for major equipment located between the source and potential target for spray events?
g Was the location of equipment with respect to water sources considered for both flooding and spray events?

D Hydraulic Calculation

1 Calculations
a Was a drain interaction study performed?
b What reference provided guidance for the study?

E Equipment Susceptibility

1 Water/Moisture Resistance
a Under what circumstances were non-waterproofed enclosures considered resistant to flooding?
b Under what circumstances were non-waterproofed enclosures considered resistant to sprays?
c Was the impact of moisture and humidity considered for flood and spray events?
d Was moisture and humidity considered in consequences of HELB?

2 Equipment Rating
a What factors were considered in establishing susceptibility of equipment to flood or spray?
b Was NEMA rating considered?
c Is voltage rating considered in equipment vulnerability (low vs. high voltage)?
d Were junction boxes explicitly treated / expected to fail when sprayed upon?
e What factors were used to determine if component was resistant to water?
f Was the dripping of water on electrically operated equipment considered a potential cause for component failure?
g Under what circumstances were non-waterproofed and non-water resistant NEMA cabinets considered resistant to flood/spray?
h Was the type of water considered when evaluating equipment fragility?
i Were waves and/or sloshing effects considered when examining flooding?
k What zone of influence was considered for spray events? Please explain how the zone was determined.

B.3 Summary Results

The results identify the extent of additional information and guidance that should be considered in future update(s) to the industry consensus guideline for performing an Internal Flood PRA. This section summarizes the survey results in terms of the technical areas covered.

Characterization of Risk from Internal Flood - In the most recent Internal Flood evaluation, approximately 67% of the respondents indicated that internal floods were not significant contributors the plant risk. The remaining 33% of the respondents indicated internal floods were significant contributors to plant risk.

Contribution to Core Frequency Damage from Internal Flood – The contribution of Internal Flood to plant risk varied widely from plant to plant. The results indicated that contributions to core damage frequency ranged from approximately 1% to50 %. Likewise, the contribution to large early release frequency ranged from approximately 1% to 50%. The dominant contributors to plant risk for internal flood events were not specified by the respondents.

Use of the EPRI Draft Guideline – The respondents relied on several different sources of information (i.e., EPRI-1013141, Rev. 1, EGG-SSRE-9639, PLG-500, NUREG/CR-4407) for estimating pipe break failure rates that were used in the Internal Flood evaluation. Approximately 50% of the respondents used the EPRI draft guideline (EPRI-1013141, Rev. 1) in part or in its entirety in their most recent Internal Flood evaluation.

HELB Initiating Event Frequency - The majority of the respondents relied on existing design basis HELB analyses, and HELB scenarios were not considered within the scope of the Internal Flood evaluation. The respondents that did not rely on design basis for treating HELB impacts used plant-specific analyses that included rupture of high energy lines in the turbine building and the impact on plant areas that have entry doors and/or ventilation openings from the turbine building.

Detail Initiating Event Frequency Calculations - Tank and heat exchanger shell failure frequencies were determined from a number of references. Several methods to determine the failure frequency of these components included the use of IEF apportioning, EPRI-1013141, Rev 1, or EGG-SSRE-9639. The most common method used by respondents was to use EPRI-1013141, Rev 1. Respondents using this document generally used piping failure frequencies for tank and heat exchanger failure rates. Valve and gasket failures were generally accounted for by using the guidance document that was used to determine pipe, tank, and heat exchanger failures. A minority of the respondents did not account for tank, heat exchanger, or gasket failure.

Credit for Human Actions to Avert Flood Scenarios – Sixty percent of the respondents did not credit human actions for averting a flood. Respondents that did credit human actions in averting floods usually credited such actions by tripping equipment or acting before becoming a flood scenario that relies on human mitigation. Inspections were generally not credited unless the room was continuously manned. Though not credited with averting a flood, all the respondents responded that human actions were credited with mitigation of flooding once it occurred. Sixty percent of the respondents used the HRA Calculator to estimate flood-specific HEPs.

Break Spectrum – The respondents indicated that the EPRI-1013141 documented break spectrum was widely used. Almost all respondents used less then one hundred gallons per minute as a spray event, one hundred to two thousand gallons per minute as a flood event, and over two thousand gallons per minute as a major flood event. Respondents that did not use the draft EPRI guideline based break sizes on actual pipe configuration for a more detailed evaluation.

Non-piping Breaches – Maintenance-induced flood scenarios were accounted for by over 70% of the respondents, though how they were incorporated differed. The majority of the plants considered maintenance-induced flooding events to be captured within the frequency of the data used or based on maintenance frequency and HEP. Plants that excluded maintenance-induced flooding did so because it was assumed detection and mitigation would be instant.

Human-induced flood scenarios were also accounted for in a variety of ways. Approximately 40% of the respondents assumed such scenarios were captured within the reference document used. The remaining either did not credit human-induced flooding or gave the same credit used for maintenance-induced flooding.

Barrier Failure - Door failure was considered by all respondents though in differing ways. In many cases stress calculations were performed to find what height of water would cause a failure. One respondent indicated that the door was considered to fail at a certain height and indicated that the height differed depending on which side of the door the flood was and whether the flood caused the door to go against the jam. Only one responded that the door did not fail and they only considered leaks underneath the door.

Movable block walls were widely not considered in the Internal Flood models and were also not considered when trying to determine when structures would fail based on their flooding capacity. Generally, only a few respondents considered fire barriers. Of the respondents who indicated they did account for them, it was indicated that they were either treated as walls or they had a different failure mode then a regular door.

Flood Depth - Two questions were asked on flooding depths: the use of transient models and equipment volume in flooded room. Transient models used to establish peak floods were used by the majority of the respondents, though in varying degrees. Many of the respondents used simplified calculations to apply the transient model. The respondents accounted for equipment in estimating the available volume in the room or flood area. Usually, a certain percentage of the room volume was assumed to be occupied by equipment within the room or flood area.

Propagation Pathways - Leakage through floor plugs or other barriers was considered by approximately 50% of the respondents. Those who did not credit leakage through floor plugs or other barriers indicated that the leak rate would be too low to be of any consequences or that they considered other propagation pathways to be of a more serious nature. Leaks through floor cracks were not widely considered due to the low flow rates that would occur.

Floor drains were accounted for in over 55% of the respondents in some degree. While most credited them in some sort of propagation role, some actually accounted for their draining ability. Some modeling was done to determine their ability to act as flow paths as well. This modeling was mainly based on plant design.

Equipment in the flooding pathway was then considered. For elevated equipment, water impingement and splashing was considered from sources above the equipment. Generally it was accounted for in about 80% of the respondents. Shielding effects for equipment was accounted for by either distance or a physical barrier. Locations of equipment with respect to water sources were considered for both flooding and spray events by over 75% of the respondents. Respondents who provided detailed information indicated that there were some conservative assumptions involved, for example, only considering location for spray events and not on a global basis.

Calculations or Analyses - the majority of the respondents did not perform a drain interaction study. The respondents that did perform this study indicated that they used the Gothic code in supporting their study. Some respondents indicated that the study was performed but screened out due to the fact that it would not be a significant initiating event.

Water/Moisture Resistance – None of the respondents considered non-waterproofed enclosures as resistant to flooding under any circumstances. Non-waterproofed enclosures were considered by only 20% of the respondents to be resistant to sprays. Resistance to sprays was usually credited by spatial orientation rather then by the presence of a physical barrier.

The impact of moisture and humidity was not considered by about 80% of the respondents. These respondents indicated that impact of humidity relied on equipment qualifications to determine if the equipment would fail. For HELB events, the impact of moisture intrusion was credited in some way by 60% of the respondents, taking into account either equipment qualification factors or the parts of the plants where HELB events are more likely to occur.

Equipment Rating - Factors considered in establishing susceptibility of equipment to flood or spray included equipment qualification, height and location, and enclosure sealing. Several respondents indicated that if the component was wetted, it was considered to fail. The NEMA rating was only considered by less than 10% of the respondents who indicated that it had to fall within equipment qualifications. The same response was seen if the PRA model considered voltage ratings in equipment vulnerability. Junction boxes in most cases had little to no resistance and were considered to fail if wetted. While dripping on equipment was almost universally considered to some degree, the adverse effect of the fluid medium on the equipment was not generally considered. Few respondents considered the potential adverse reaction from lake water with chemical addition or other chemical effects. Generally the zone of influence for spray events varied from 10 to 30 ft to the entire room.

C

ALTERNATE APPLICATION OF FLOW RATE AND FLOOD FREQUENCY METHODOLOGY

C.1 Introduction

Chapter 4 offers a practical approach that the analyst can use to determine the flow rate for breaks in piping systems that can lead to flooding scenarios. This approach is based on the following equation and a few rules for its use. Flow (Q) (gallons per minute) through a leak of equivalent diameter D (inches) from a pipe that is maintained at a pressure P (psig) can be estimated by the equation

$$Q = 29.9 \cdot D^2 \cdot \sqrt{P}$$

Equation C-1

To apply this equation, the analyst can either:

- Estimate leak rates, based on system pressure and break size. Break sizes can be estimated as follows: Spray = ½” equivalent diameter, Flood = 1½” equivalent diameter, and Major Flood = full pipe rupture.

or

- Estimate leak rates as follows: Spray = 100 gpm, Flood = 2,000 gpm, and Major Flood = max flow based system pressure and pumping capacity, given a full pipe rupture.

Flows should be reduced if the maximum flow from a full pipe rupture is less than the suggested amount.

C.2 Sample Application

Using this information and the guidance above, the analyst can apply this methodology to determine the maximum flow rates for the three leak categories for the major fluid systems in the analyst’s plant. Table C-1 provides examples to show how this can be done for some typical fluid systems:

Table C-1
Estimated Flow vs. Pipe Size and Failure Category for Different Systems

Estimated flow vs. pipe size and failure category for various systems

			Pipe Size												
press.	***system***	***mode***	***0.5***	***1***	***1.5***	***2***	***3***	***4***	***6***	***8***	***10***	***12***	***14***	***16***	***24***
70	SW	Spray	63	63	63	63	63	63	63	63	63	63	63	63	63
		Flood	63	250	563	563	563	563	563	563	563	563	563	563	563
		Major	63	250	563	1,001	2,251	4,003	9,006	16,010	18,000	18,000	18,000	18,000	18,000
100	FPS	Spray	75	75	75	75	75	75	75	75	75				
		Flood	75	299	673	673	673	673	673	673	673				
		Major	75	299	673	1,196	2,691	4,784	7,000	7,000	7,000				
50	RBCCW	Spray	53	53	53	53	53	53	53	53	53	53			
		Flood	53	211	476	476	476	476	476	476	476	476			
		Major	53	211	476	846	1,903	3,383	7,611	13,531	21,142	30,445			
15	CW	Spray	29	29	29	29	29	29	29	29	29	29	29	29	29
		Flood	29	116	261	261	261	261	261	261	261	261	261	261	261
		Major	29	116	261	463	1,042	1,853	4,169	7,411	11,580	16,676	22,697	29,645	66,702
1,100	FW	Spray	248	248	248	248	248	248	248	248	248	248	248	248	248
		Flood	248	992	2,231	2,231	2,231	2,231	2,231	2,231	2,231	2,231	2,231	2,231	2,231
		Major	248	992	2,231	3,967	8,925	15,867	22,000	22,000	22,000	22,000	22,000	22,000	22,000

Notes

0.5" diameter pipes are assessed as full pipe ruptures, regardless of failure mode.
Spray failures are assessed as 0.5" diameter leaks, regardless of pipe size.
Flood failures are assessed as 1.5" diameter leaks or full pipe ruptures for smaller pipes.
All flows are limited to system capacity at pump runout conditions.

In this example, the maximum system pressure is used as the driving head for the leak flow; and the rules in the notes are applied to each of the systems. In this approach, the sizes of spray and flood failures are defined as 0.5 inches and 1.5 inches, respectively. The flow through a spray or flood leak rises to its maximum value when the pipe size equals the leak size and is not affected by increasing pipe size.

In a different approach, the break size could be defined by a flow rate. ***Sprays*** are defined in this example as those with flow rates less than or equal to the maximum spray flow rate of 100 gpm. ***Floods*** are defined as those with flow rates greater than the maximum spray flow rate of 100 gpm and less than or equal to the maximum flood flow rate of 2,000 gpm. ***Major floods*** are defined as those with flow rates in excess of 2,000 gpm. The analyst can further extend the use of the flow rate methodology to aid in determining the frequency of ***Spray***, ***Flood***, and ***Major flood*** leaks on each system in each area of interest.

In order to accommodate this binning, the analyst could group the data as shows in Table C-2.

Table C-2
Characterization of Leak Rates by Break Type for Various Systems

			Pipe Size												
press.	***system***	***mode***	***0.5***	***1***	***1.5***	***2***	***3***	***4***	***6***	***8***	***10***	***12***	***14***	***16***	***24***
70	SW	Spray	63	63	63	63	63	63	63	63	63	63	63	63	63
		Flood	63	250	563	1,001	1,001	1,001	1,001	1,001	1,001	1,001	1,001	1,001	1,001
		Major	63	250	563	1,001	2,251	4,003	9,006	16,010	18,000	18,000	18,000	18,000	18,000
100	FPS	Spray	75	75	75	75	75	75	75	75	75				
		Flood	75	299	673	1,196	1,196	1,196	1,196	1,196	1,196				
		Major	75	299	673	1,196	2,691	4,784	7,000	7,000	7,000				
50	RBCCW	Spray	53	53	53	53	53	53	53	53	53	53			
		Flood	53	211	476	846	846	846	846	846	846	846			
		Major	53	211	476	846	1,903	2,500	2,500	2,500	2,500	2,500			
15	CW	Spray	29	29	29	29	29	29	29	29	29	29	29	29	29
		Flood	29	116	261	463	463	463	463	463	463	463	463	463	463
		Major	29	116	261	463	1,042	1,853	4,169	7,411	11,580	16,676	22,697	29,645	66,702
1,100	FW	Spray	248	248	248	248	248	248	248	248	248	248	248	248	248
		Flood	248	992	2,231	3,967	3,967	3,967	3,967	3,967	3,967	3,967	3,967	3,967	3,967
		Major	248	992	2,231	3,967	8,925	15,867	22,000	22,000	22,000	22,000	22,000	22,000	22,000

All green cells are binned as ***small*** leaks ("spray"), yellow cells are ***medium*** leaks ("floods"), and orange cells are ***large*** leaks ("major floods"). Flow is assessed as the largest value in the group, and frequencies are calculated by summing the frequency of all applicable cells. This procedure condenses down to the following:

Table C-3
Maximum Leak Flow Rates and Frequency Determination for Various Systems

		flow (gpm)	freq (per year)
SW	Small	63	= (F-spray x all SW pipes) + (F-flood x 0.5" SW pipes) + (F-Major x 0.5" SW pipes)
	Medium	1,001	= (F-flood x all SW pipes >=1") + (F-Major x (1" + 1.5" + 2" SW pipes))
	Large	18,000	= F-Major x (SW pipes >= 3")
FPS	Small	75	
	Medium	1,196	
	Large	7,000	
RBCCW	Small	29	
	Medium	846	
	Large	2,500	
CW	Small	29	
	Medium	463	
	Large	66,702	
FW	Small	248	
	Medium	3,967	
	Large	22,000	

In this example of a summary, the maximum flow rate for each of the leak types is selected from Table C-3. Since ***sprays*** are defined as the upper flow rate limit for spray flow, 100 gpm, any piping failure that can produce this flow should be included in the determination of ***spray*** frequency. By definition, spray failure in all SW piping will contribute to the frequency of the ***spray*** rate. In addition, the flooding and major failure modes will also contribute to the frequency of the ***spray*** rate when it occurs in SW piping of 0.5" or smaller. Therefore, the total frequency of the ***spray*** rate will be the sum of the spray failures of all SW system piping plus the flooding and major failures for all piping of 0.5" or smaller.

The ***Flood*** rate of greater than 100 gpm and less than or equal to 2,000 gpm cannot, by definition, be produced by any spray failure. Similarly, in this example the medium leak rate cannot be generated by leaks in 0.5" piping. Therefore, the total frequency of the medium leak rate can be determined by applying the flooding frequency to all SW piping greater than or equal to 1” and the major frequency to the piping that will produce flow less than or equal to 1,500 gpm, which in this example is the 1”, 1.5”, and 2” SW pipes.

The ***Major flood*** rate of greater than 2,000 gpm is determined by applying the frequency of the major failure to piping sizes that can produce flows of greater than 2,000 gpm. In this example, only piping larger than 3” is capable of generating this flow rate.

A similar approach can be applied to the other piping systems to determine the frequency of small, medium, and large leak rates for the site as a whole or for any flooding area, based on the systems that pass through the flooding area and the size of the piping.

D

EXAMPLE FLOOD DOOR CAPACITY EVALUATION

D.1 Purpose

This is an example extracted from a recent plant PRA to show how the structural capability of doors to retain their integrity during a flood can be evaluated.

In order to support plant PRA efforts, the doors listed in Table D-1 below are to be structurally verified to determine what level of water build-up against the doors will cause the doors to fail.

In addition to the work on doors, the following plant areas are to be verified for water build-up within the specified area:

A. Auxiliary Building Standby Gas Treatment Room flooding (Elevation 141, south of Column line # 4)

B. Auxiliary Building Main Steam Tunnel flooding with 600,000 gallons of water

C. Control Building North-West, South-West, and Aux. Bldg West wall stair case walls

D. Flooding In RHR Cubicles, Aux . Bldg EL 70'-00"

D.2 Assumptions

a) The hardware for doors with similar size, material, and configuration is assumed to be identical.

b) All doors without an identified design calculation in Table D-1 shall be analyzed using the methodology outlined in a specific referenced calculation. See section D.3 for the justification of this assumption.

c) Total maximum normal load on a door during failure is assumed to be due to water pressure only, including the case where the height of water at failure is less than the height of the door.

D.3 Approach

Based on a detailed review of the plant's door specifications, door schedules, calculations, drawings and equipment database, Table D-1 was generated. This table classifies the doors in question into three main groups. Group 1 and 2 contain 12 doors with similar sizes, materials, and overall configuration. The maximum capacity of these doors will be verified by reverse engineering the methodology used in a referenced calculation. The reverse engineering process will be used to determine the stress at which the weak link (when door is loaded towards or away from the door frame) of the door fails, to determine the maximum normal load on the doors surface—normal load on door is wind loading in the current door calculation. This load will be converted into water pressure and finally into water height behind the door using algebraic representation of the average water pressure of linearly increasing water pressure from top to bottom due to increase in water height.

Although the current content of the calculation addresses only door CB098-25, it is acceptable to use this calculation for all doors listed in Groups 1 and 2 because the doors in these groups have similar configuration (flush doors) and size. Further review of the calculation shows that doors qualified under this calculation are of a hollow construction consisting of a formed structural channel frame covered with double steel sheets (see door description on page 6 of the referenced calculation) that is, hollow steel (HS), which is the same material designation used for all the doors in Group 1. Therefore, the difference in material designation of HS and SII shown in Table D-1 is due to the door's application. Doors purchased under specification 210.461 are special doors while doors purchased under specification 210.440 are generic doors. Hence, analyzing the special door CB098-25, as shown in the calculation, envelops all doors listed in Groups 1 and 2 of Table D-1.

The remaining six doors listed in Group 3 are special doors (i.e., each door is unique).

This analysis evaluates Group 1 and 2 doors, which are considered the weaker doors.

Table D-1
Classification of Doors

Spec	Calc	Door ID per sch	Dwg	Door ID in EDB	Size	Material (Per Door Sch and Spec)	Type (Configuration Per Door sch. DWG. AE-006A&B)	Grp
210.440		C98-23		CB098-23	3’ x 7’	HS	Flush DR (F)	1
		C98-26		CB098-26		HS	Flush DR (F)	
		C98-22		CB098-22		HS	Flush DR (F)	
		C116-25		CB116-25		HS	Flush DR (F)	
		D98-5		DG098-05		HS	Flush DR (F)	
		D98-6		DG098-06		HS	Flush DR (F)	
		C70-22		CB070-22		HS	Flush DR (F)	
		A95-4		AB095-04	3’ x 6’ – 10” (Approx 3’ x 7’)	HS	Louver Dr (L) Can be assumed as flush)	
210.461	4210.461-304-002I	C98-25	0210.461-304-051	CB098-25	3’ x 7’	SII	Flush DR (F)	2
	4210.461-304-004D	C70-23	0210.461-304-073	CB070-23	Special	SII	See Spec. and calc. for configuration	3
		A70-4	0210.461-304-082	AB070-04	Special	SII		
		T67-10	0210.461-304-005	TB067-10	3’ x 7’	SII	Flush DR (F)	2
		T67-9	0210.461-304-004	TB067-09	3’ x 5’ – 6” (approx 3’ x 7’)		Flush DR (F)	
		T67-6	0210.461-304-003	TB067-06			Flush DR (F)	
210.462	4210.462-346-001D	A95-5		AB095-05	2.8’ x 7.2’ (Per calc.)	SII	See Spec. and calc. for configuration	3
		A95-6		AB095-06		SII		
		A95-2	0210.462-346-004	AB095-02	7.5’ x 7’ (Per calc.)	SII		
		A141-3		AB141-03	3.5’ x 8’ (Per calc.)			

D.4 Analysis

Analysis Number 1: Verification of water level Behind Door CB098- 25. As stated in Section D.3 above, the water level on either side of door CB098-25 envelops all doors listed in Groups 1 and 2 of Table D-1 above. Based on the Equipment Data Base (EDB), this door is qualified per referenced calculation as a Type A door and purchased under RBS specification 210.461.

The steps of analysis are as follows:

I. Determination of weak links (when door is loaded towards and away from the door frame).

II. Reverse engineering of weak link analysis to determine maximum height of water behind door.

I. Determination of Weak Links (when door is loaded towards and away from the door frame).

Based on a detailed review of the existing qualification of door CB098- 25 per RBS calculation 4210.461-304-002I, the most stressed components were identified and their interaction ratio determined. The component with highest interaction ratio is the weak link.

Table D-2
Weak Link Determination “Type A Door per Referenced Calculation

	Design	**Allowable**	**Interaction Ratio**		**Ref. calculation 4210.461-304-002I**
Most stressed components for door loaded with normal load away from door frame					
Hinge					
Bending stress	11000	18000	0.611		Pg 19
Shear stress	449	12000	0.037		Pg 19
Latch Bolt					
Bending stress	13915	18000	0.773	**Weak link**	Pg 27
Shear stress	3859	12000	0.321		Pg 27
Most stressed components for door loaded with normal load towards door frame					
Door Frame’s anchor Bolt	3188	46500	0.069	**Weak link**	
Door Structure Frame Work					
Crossmember Analysis					
Shear stress	0.154	14.4	0.011		pg 14
Door Free Edge/interface Analysis					
Shear stress	0.13	14.4	0.009		pg 17

<u>II. Reversed Engineering of weak link analysis to determine max height of water behind door.</u>

Latch Bolt Reverse Analysis (Bending), Page 27 of Referenced Calculation
Failure at allowable:
Height of door = 7ft
Width of Door = 3ft
Allowable = 18ksi
Length of latch bolt (L) = 0.375 in
Section Modulus (S) = 0.065 in^3
Max bending stress at failure (S_b) = M/S = allowable =18ksi
Max moment M = S x S_b = 0.065 x 18 =1.17kip-in
Applied load to Latch bolt (F) = M / L = 1 .17 / 0.375 =3.12kips
From ref. calc. page 27, F = (H_1 / 2) + (H_1 / 4)
With H_1 being horizontal load on door (H_1) = 4F/3 =(4x3. 12)/3 =4.16kips
Average Pressure on door surface due to H_1 is (ΔP) = H_1 / A_{door} =4.16/ (21) =0.1981 ksf
Height of water above door = h,
Specific weight of water = γ = 62.42 lbs/ft^3
Average pressure on door due to water is (ΔP) = (P_T + P_B) / 2
Where:
P_T = Pressure at top of door = γ (h - 7)
P_B = Pressure at bottom of door = γ h
ΔP =[γ (h - 7) + h] / 2
From the above expression, height of water behind door (h) = $\Delta P/\gamma$ + 3.5 = 198 / 62.42 + 3.5 = 6.67 ft

Failure at Yield:.
F_y = 30 ksi
M = 0.065 x 30 = 1.95 kips-in
F = 1.95 / 0.375 = 5.2 kips
H_1 = (4 x 5.2) / 3 = 6.93 kips
ΔP = 6.93 / 21 = 0.33 ksf
H = 330 / 62.42 + 3.5 = 8.79 ft

Door frames Anchor Bolt reverse analysis (Shear), Page 29 of Referenced Calculation:

Per RBS calculation G13.18.2.5*007 “Development of Concrete Expansion Wedge Anchor Standard,” Hilti’s published ultimate shear load for 3/8” dia. anchors is 4400 lbs; and its allowable load is 880 lbs (Ref Page 6).

Based on review of existing anchor bolt qualification, bolts in Type A doors are subject to shear only. Calculation 4210.461-304-002I qualifies the anchor bolt by conservatively using the higher loaded door Type B bolt. The analysis will focus on door Type A bolts. With the ultimate and allowable loads given in pounds, the computation proceeds to determine the total horizontal (H_1) on the door without need for the stresses on the bolt.

Failure at allowable.

Allowable load = 880 lbs

= Total shear load per bolt on Type A door (F_v).

$= (H_1^2 + (V_1 + D)^2)^{0.5}$

Hence H_1/16 bolt $= (F_v^2 - (V_1 + D)^2)^{0.5} = (880^2 - (83)^2)^{0.5}$

= 876.1 lbs/16 bolt

H_1 = 876.1 *16 (bolts) = 14017.23 lbs

$\Delta P = H_1 / A_{door} = 14017.23 / 21$

= 667.4 psf

h $= \Delta P/\gamma + 3.5 = 667.4 / 62.42 + 3.5 = 14.2$ ft

Failure at Ultimate:

<u>Note</u>: The ultimate load is used instead of the yield because the anchor bolt vendor (Hilti North America) does not publish values for the anchor yield loading.

Ultimate load = 4400 lbs

= Total shear load per bolt on Type A door (F_v).

$= (H_1^2 + (V_1 + D)^2)^{0.5}$

Hence H_1/bolt $= (F_v^2 - (V_1 + D)^2)^{0.5} = (4400^2 - (83)^2)^{0.5}$

= 4399.22 lbs/bolt

H_1 = 4399.22 * 16 (bolts) = 70387.47 lbs

$\Delta P = H_1 / A_{door}$

= 70387.47 / (3 x 7) = 3351.8 psf

h $= \Delta P/\gamma + 3.5$

= 3351.8 / 62.42 + 3.5 = 57.2 ft

E

INTERNAL FLOOD WALKDOWN CHECK CHECKLIST

Walkdown Analyst: ________________ Date:

A. GENERAL INFORMATION:

Plant/Unit: ___________________ Building:
Room/Area/Zone: _________________ Floor Elevation:
Room ID/Name:

B. EQUIPMENT LOCATED WITHIN AREA (PROVIDE LIST)

Item	System	Equipment	Height Off Floor
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			

B. FLOOD SOURCES

Tanks (List):

1.	
2.	
3.	

Piping (List):

Item	Maximum Diameter	System
1.		
2.		
3.		

Other (List):

Item	System	Equipment
1.		
2.		
3.		
4.		

Walkdown Analyst: ________________ Date:

C. BARRIERS

CURBS:

Near Doors:

Curb Height	**Curb Length/Size**

Around Equipment:

Curb Height	**Curb Length/Size**	**Equipment Being Protected**

DOORS:

Gap Height <3" Other	**Width (ft)**	**Direction to Open**		**Card Access**	
		Inward	**Outward**	**Yes**	**No**

D. DRAINAGE

Drainage Systems

Drains	**Size <6" Other**	**Condition**		
		Clear	**Degraded**	**Blocked**

Page 3 of 4

Walkdown Analyst: _______________ Date:

Wall Penetrations (i.e., louvers, piping penetrations)

Item	Penetration	Estimated Size of Flow Area	Height From Floor	Sealed? (Y/N)
1.				
2.				
3.				
4.				
5.				
6.				
7.				

Floor Penetrations (i.e., equipment removal hatches, piping penetrations)

Item	Penetration	Estimated Size of Flow Area	Sealed? (Y/N)	Curbing? (Y/N)	Curbing Height
1.					
2.					
3.					
4.					
5.					
6.					
7.					

Note the General Cleanliness of the Area (e.g., Waste, Dirt, Tools, Rags, etc.):

Page 4 of 4

Walkdown Analyst: _______________ Date:

Sump Pumps

Are there sump pumps in the area? ☐YES ☐NO

Item	Sump Pump	Location & Height of Initiator/Indicator	Capacity
1.			
2.			
3.			

E. NOTE THE POTENTIAL FOR PROPAGATION

F. FLOODING EFFECTS (Check Appropriate Response)

Are MCCs, Distribution Panels, Instruments, Controls Covered?

☐YES ☐NO ☐Not Applicable

Can water spray onto and fail equipment?:

A. MCCS or Distribution Panels? ☐YES ☐NO ☐Not Applicable

B. Instruments or Controls? ☐YES ☐NO ☐Not Applicable

Table E-1
Example of Worksheet for Documenting Flood Areas, Flood Sources etc.

Pressure Boundary Failure		Detection	Isolation Points	Propagation Pathway	Flood Impact
Location	**Type**				
Define location in plant (Building / Room Number)	Describe type in terms of piping, valve, tank, etc. and provide equipment ID and drawing number. For piping, include pipe line number, size, linear feet of piping, weld count or pipe segment count	If applicable, identify local and remote leak detection and alarms and include corresponding alarm-response procedure(s)	Identify the isolation points upstream and downstream of a postulated pressure boundary failure. The documentation should differentiate between remote and local isolation. For the former, consider access limitations, if any.		Describe

F

APPLICATION MODULE FOR R&R WORKSTATION FRANX SOFTWARE (EPRI 1018189)

For users of the EPRI R&R Workstation technology, Flooding scenario analysis can be performed using the EPRI program FRANX [28]. FRANX is a personal computer based tool originally created for analyzing fire risk at a nuclear power plant, but FRANX can also be used for flooding events.

FRANX performs the following functions:

- Manage a list of scenarios that need risk calculations
- Manage the mapping of the plant components to the elements of the Probabilistic Risk Assessment (PRA) model that are affected by the scenario
- Calculate the risk of each scenario using the PRA model
- Manage the process of screening the scenarios, starting with conservative assumptions and then refining the assumptions as necessary
- Provide analysis and diagnostic information so that you can determine the primary contributors to the risk, so as to further refine the scenario assumptions and identify new scenarios.
- Create a single-top configuration risk model that can be used by tools such as the EPRI EOOS software.

To perform a risk calculation, FRANX starts with the basic PRA model and then adds new flooding initiators and other shaping events. Of course, this task can be accomplished manually by locating the affected events and inserting the required logic at the basic events or at a higher level in the system fault trees. However, this can be very labor-intensive process to assure all occurrences of the basic events are changed.

Using the FRANX tool reduces the amount of work need to perform these tasks. All changes to the fault tree are performed in a structured fashion using inputs created by the user.

Changes that FRANX can model:

- Incorporating the flooding initiators, each of which fail selected equipment

- Replacing human actions with different human actions given the presence of the flood. For example, some actions may need to be done in less time, thereby increasing the human failure probability.
- Adding spurious events caused by the flood
- Incorporating recoveries of the equipment that is failed by the flood
- Blocking existing recoveries from applying, such as when the flood prevents the operator from having access to the location used by the recovery

In the case of Flooding Analysis the “ignition frequency” is used to model the flooding frequency, and the “non-suppression” probability is not normally used.

One feature of FRANX that is often important for flooding is the ability to add recovery actions to the scenarios. These are set by the “Equipment Recoveries” button This input indicates that a component can be initially failed by the flood (e.g. a pump is deluged with water and unable to start), but there is a probability that the operator will be able to subsequently interact with the component to recover it (e.g. secure the water leak and restart the pump).

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