Materials Reliability Program Generic Guidance for Alloy 600 Management (MRP-126)

Technical Report

Materials Reliability Program: Generic Guidance for Alloy 600 Management (MRP-126)

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REPORT SUMMARY

This report provides guidance for plants to use in developing their individual Alloy 600 management plans. It defines the key elements of an Alloy 600 management plan and directs readers to useful resources for developing and implementing a plant-specific plan.

Background

The EPRI Materials Reliability Program (MRP) Alloy 600 Issue Task Group (ITG) determined that every plant should have an overall plan for managing Alloy 600 primary water stress corrosion cracking (PWSCC) degradation. This decision was based on the need for the industry to stop reacting to each finding of Alloy 600 PWSCC degradation as an isolated event and start pro-actively managing the issue. A committee of Alloy 600 ITG members volunteered to produce a guidance document for plants to use in developing their Alloy 600 management plans. The committee worked with a contractor (EPRIsolutions) to prepare this document.

Objective

To document a standard guideline for plants to use in developing their Alloy 600 management plans that provides short- and long-term guidance for managing inspection, evaluation, mitigation, and repair/replacement of all Alloy 600 base material and Alloy 82/182 weld metal locations (with the exception of steam generator tubing—which is addressed in separate industry programs, including EPRI's Steam Generator Management Program—and reactor internals, which also are addressed in separate industry programs such as the EPRI MRP Reactor Internals program) in pressurized water reactor (PWR) primary systems.

Approach

The committee defined the objectives of an Alloy 600 management plan: 1) maintain plant safety; 2) minimize the impact of PWSCC on plant availability; and 3) develop and execute long-term strategies for Alloy 600 management. The committee outlined key elements of an Alloy 600 management plan in the introduction with more detail in later sections. The appendices of this document direct readers to existing resources that can be used in developing a plant-specific Alloy 600 management plan. The committee's scope was limited to Alloy 600 and its associated weld metals Alloy 82/182. MRP is still investigating properties of the replacement metals Alloy 690/52/152 and is not issuing guidance on managing Alloy 690/52/152 components at this time.

Results

This document establishes a mandatory requirement that "*Each plant shall develop and document an Alloy 600 management plan, defining the processes it intends to use to maintain the integrity and operability of each Alloy 600/82/182 component for the remaining life of the plant.*" All U.S. PWRs must implement this requirement within eighteen months of the

document's issuance. Implementing the key elements listed in Table 1-1 of this document is considered good practice. The remainder of the document consists of background material and general information. Complete guidelines are provided for plants to use in developing their Alloy 600 management plans. The document offers comprehensive reference lists that newer staff can use to become more familiar with Alloy 600 PWSCC degradation. More experienced staff can use the document as an outline for preparing their Alloy 600 management plans.

EPRI Perspective

All plants need to develop and implement an Alloy 600 management plan defining the processes they intend to use to maintain the integrity and operability of each Alloy 600/82/182 component for the remaining life of the plant. This document outlines the key elements of a plant specific plan and includes comprehensive lists of available resources that plants should use in developing their plans.

Keywords

Alloy 600 management
Alloy 600 management plan
Primary water stress corrosion cracking (PWSCC)
PWSCC leakage
Stress corrosion
Boric acid corrosion
Alloy 600
Alloy 690
Alloy 82/182
Alloy 52/152
CRDM nozzle
CEDM nozzle
In-core instrument (ICI)
Bottom mounted nozzle (BMN)
Bottom mounted instrument (BMI)
J-groove weld
Reactor vessel head
Reactor vessel closure head
Reactor vessel upper head
Safety assessment
Circumferential cracking
Inspection
Probabilistic fracture mechanics

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1 INTRODUCTION

Throughout the nuclear industry, many reactor coolant system nozzles, welds and welded attachments such as instrument nozzles, nozzle safe ends, heater sleeves in pressurizer vessels, and control rod drive nozzles in the reactor vessel closure heads were manufactured of Alloy 600 materials. Alloy 600 and its associated weld materials, Alloys 82 and 182, are susceptible to primary water stress corrosion cracking (PWSCC). PWSCC has been observed in control rod drive mechanism nozzles, control element drive nozzles, pressurizer nozzles, hot leg nozzles, and bottom mounted instrument nozzles, and in J-groove welds and full penetration butt-welds. Pro-active identification of degradation areas is particularly important due to the impact on outage time, radiation exposure, and cost associated with inspections and repairs.

Each plant shall develop and document an Alloy 600 management plan, defining the processes it intends to use to maintain the integrity and operability of each Alloy 600/82/182 component for the remaining life of the plant. This plan should include consideration of mitigation (zinc, MSIP, etc.), inspection (type and frequency), repair (weld repair, overlay, or mechanical clamp), and replacement (substitute with stainless steel or Alloy 690/52/152) options.

The scope of this document is limited to Alloy 600 and its associated weld metals Alloy 82/182. The MRP is still investigating the properties of the replacement metals Alloy 690/52/152 and is not issuing guidance on managing Alloy 690/52/152 components at this time.

This document provides a recommended structure for plant specific Alloy 600 management plans and provides guidance to available resources to assist individual plants in developing their plans.

PWSCC Experience

Past industry experience with PWSCC is a series of unwelcome surprises. Control Rod Drive Mechanism (CRDM) nozzle outside diameter (OD) initiated circumferential cracking was considered implausible by utilities and the NRC until it appeared in multiple penetrations on one reactor head. It has since been found at other reactors. A repaired penetration in another plant cracked in a weld that did not match the construction drawings. Utilities contended that cracks would be discovered and repaired before boric acid wastage could challenge safety, but one plant, its regulators, and the industry oversight organization all failed to properly analyze and resolve evidence of leakage for a substantial time. Reactor bottom head penetrations were not expected to crack due to low temperature, however two penetrations at one plant have cracked. Cracks at various locations with “unique” geometries or fabrication circumstances were treated as isolated events, but similar conditions would unexpectedly be found later at other Alloy 600 locations. Every surprise causes the staffs of the utility and the regulator to be taken away from important day to day activities in order to manage the event in crisis-mode. A comprehensive inspection and mitigation plan will help plants to control events instead of vice versa.

Guidance Document Objective

Document a standard guideline for plants to use in developing their Alloy 600 management plan that provides short and long term guidance for management of inspection, evaluation, mitigation, and repair/replacement of all Alloy 600 base material and Alloy 82/182 weld metal locations (with the exception of steam generator tubing which is addressed in separate industry programs including EPRI's Steam Generator Management Program and reactor internals which are also addressed in separate industry programs such as the EPRI MRP Reactor Internals program area) in PWR primary systems.

Materials Guidelines Implementation Protocol

This guidance document includes a mandatory requirement on page 1-1, that *Each plant shall develop and document an Alloy 600 management plan, defining the processes it intends to use to maintain the integrity and operability of each Alloy 600/82/182 component for the remaining life of the plant.* This requirement is to be implemented at all U.S. PWRs within eighteen months of issuance of this guidance document. Implementation of the key elements listed in Table 1-1 of this document is considered good practice. The remainder of this document consists of background material and general information.

Objectives of a Plant Specific Alloy 600 Management Plan

The main objectives for each plant specific Alloy 600 management plan are listed below.

- Maintain plant safety
- Minimize the impact of PWSCC on plant availability
- Develop and execute long-term strategies for Alloy 600 management

The plan should use decision analysis expertise with engineering, operational, and financial inputs to determine the optimal strategy for Alloy 600 management. The plan shall comply with specific industry and regulatory guidance for inspections and repairs.

Key Elements of a Plant Specific Alloy 600 Management Plan

The purpose of a plant specific plan is to provide guidance for administering Alloy 600/82/182 inspections, implementing preventative actions (replacement or mitigation), and developing contingent repair plans. A plant specific Alloy 600 management plan cannot rely solely on generic assessments. Detailed plant specific information is required in order to identify and rank/prioritize locations/components to be inspected, and to detect, repair, and mitigate PWSCC cracking of Alloy 600/82/182.

Most plants have addressed PWSCC of Alloy 600/82/182 in some way as part of aging management and/or license renewal activities. Important resources for these activities include NUREG-1800, Standard Review Plan for Review of License Renewal Applications for Nuclear Power Plants, July, 2001 and NUREG-1801, Generic Aging Lessons Learned (GALL) Report (Vol 1 and Vol 2), July, 2001.

The NRC outlined ten attributes for evaluation of generic aging management programs in NUREG-1801. These attributes are also suited to managing Alloy 600/82/182, and have been incorporated here. Table 1-1 lists the NRC attributes along with the associated key elements to be included in a plant specific Alloy 600 management plan document[1].

Table 1-1
Key Elements of a Plant Specific Alloy 600 Management Plan Document

	NRC Evaluation Attribute	Alloy 600 Management Plan Document Elements
1	Scope of Program	• Alloy 600/82/182 locations and inspection programs • Assigned responsibilities for Alloy 600 management (including individuals from multiple disciplines and departments) • Implementation plans (modification packages, budget, scheduling, etc.) with contingency planning
2	Preventative Actions	• Plan for implementation of Alloy 600/82/182 mitigation strategies • Plan for possible replacement of components as preventative action
3	Parameters Monitored/Inspected	• Detailed data (including location, component function, service history, temperature, operating environment, fabrication records, etc.) about components containing Alloy 600/82/182 to be used in inspection ranking
4	Detection of Aging Effects	• Plant specific inspection plan for detection of PWSCC cracking designed to detect any PWSCC cracking before it impacts plant safety and operability • Plant specific inspection matrix listing applicable inspection techniques for each type of Alloy 600/82/182 component/weld
5	Monitoring and Trending	• Inspection schedule that meets Code and regulatory requirements for Alloy 600/82/182 locations {In-Service Inspection (ISI), Pre-Service Inspection(PSI)} and incorporates results from previous inspections
6	Acceptance Criteria	• Reference to applicable Code and regulatory requirements for Alloy 600/82/182 locations (ASME and NRC requirements) for evaluation of inspection results
7	Corrective Actions	• Procedures for disposition of inspection findings • Plant specific repair matrix listing acceptable repair techniques for each type of Alloy 600/82/182 component/weld
8	Confirmation Process	• Reference to site quality assurance procedures and associated regulations
9	Administrative Controls	• Reference to site quality assurance procedures and associated regulations
10	Operating Experience	• References to Industry Alloy 600/82/182 experience • Schedule for periodic review of industry data on available inspection, repair, and mitigation technologies and lessons learned from industry experience

It is recommended that each plant draw upon industry and plant specific knowledge, operational, engineering, and field service experiences when drafting a plant specific Alloy 600 management plan.[2]

[1] Items may be included via reference to another plant or industry document.
[2] See Appendix A for specific examples of PWSCC of Alloy 600/82/182.

2
ASSIGNED RESPONSIBILITIES AND INTERFACES

A key element of the Alloy 600 management plan is assignment of responsibilities to the various organizations involved in managing Alloy 600. These assignments should be clearly documented and should include all organizations that have specific responsibilities in the management of Alloy 600/82/182.

Senior Management

Senior management is ultimately responsible for the successful implementation of an Alloy 600 management plan at any site.[3]

Management Plan Ownership

The ownership of the plan should be clearly delineated; explaining which department and position is responsible for the overall implementation of the plan. For multi-site organizations, the overall plan owner may be from the corporate organization, but in this case there should be clear assignment of site ownership as well to ensure all site functions are appropriately managed and interfaced with the overall plan. There should be clear ownership for tracking and trending of inspection results with an assigned individual or group. The plan should identify a clear chain of responsibility and lines of communication.

Other Disciplines

The Alloy 600 management plan should document responsibilities of all plant and corporate organizations that are important to the success of the plan where those responsibilities are beyond their normal everyday activities. Plant and corporate organizations that may be involved include business planning, project management, plant maintenance, design engineering, systems engineering, program engineering, procurement, ALARA/radiation protection, operations, and the Non-Destructive Evaluation (NDE) team.

[3] Reactor Pressure Vessel Head Degradation at Davis Besse, LER 2002-002-00 Principles for Effective Operational Decision Making, INPO, December 2001.

Interfaces

The Alloy 600 management plan will also interface with or be a part of several existing plant and corporate programs. The Alloy 600 management plan should not duplicate processes or procedures located within Equipment Reliability, Corrosion Control, or In-service Inspection programs, but should interface with these programs where appropriate. Finally, as long as Alloy 600/82/182 is present in the plant there is some potential for cracking, leakage, and failure. The consequences of this must be understood in order to prioritize inspection, mitigation, and replacement efforts. Most component failures due to PWSCC of Alloy 600/82/182 are bounded by existing FSAR analysis in the licensing basis for operating reactors and generic safety assessments have been performed for many locations. The Alloy 600 management plan should interface with the plant analysis group (i.e. the group that understands LOCA analysis) to verify that failure at a specific location is bounded by existing analysis.[4]

[4] Any potential failure that is not bounded by existing analysis should be entered in the plant corrective action program and reported to the MRP and the associated OG for determination of the generic implications.

3
INDUSTRY EXPERIENCE

It is extremely important that personnel responsible for the Alloy 600 management plan be very familiar with the experience of the industry with respect to Alloy 600/82/182 degradation. Responsible personnel need to keep up with industry operating events and incorporate changes to their plan based on the new knowledge gained by experience. Personnel responsible for the Alloy 600 management program should participate in industry meetings and initiatives. Other resources of information on industry events include:

- Nuclear Regulatory Commission (NRC), Licensee Event Reports (LERs), Notices, etc., www.nrc.gov
- Owners Groups – Babcock & Wilcox (BWOG), Westinghouse (WOG), Combustion Engineering (CEOG, now merged with WOG)
- Institute of Nuclear Power Operators (INPO)
- World Association of Nuclear Operators, www.wano.org
- Electric Power Research Institute (EPRI), www.epri.com
- EPRI Materials Reliability Program (MRP) Alloy 600 Issue Task Group (ITG)

Appendix A of this document includes a table of key industry events. The remaining appendices of this document (with the exception of Appendix F) list reports and program initiatives that have been completed by EPRI, the NRC, and the owners groups. There are separate appendices for resources related to Alloy 600/82/182 locations, inspections, mitigation, component ranking and susceptibility, and repair/replacement. Appendix H lists assorted EPRI and NRC resources that do not fall into these specific categories, and Appendix I does the same for owners group resources.

4
DETERMINE ALL ALLOY 600/82/182 LOCATIONS

Another key element of an Alloy 600 management plan is a comprehensive list of all PWR Reactor Coolant System (RCS) components utilizing Alloy 600 base metal and Alloy 82/182 weld metal. Generic and plant specific locations have been identified in various documents prepared by the NSSS Owners Groups and EPRI. These documents should be reviewed and included or referenced in each plant's Alloy 600 management plan Alloy 600 location list.

Generic Locations

Information on generic locations is available from several sources. The data provided in this document and the reports referenced here should be reviewed in order to develop a list of generic locations applicable to each plant's design. The scope of components that are known to contain Alloy 600/82/182 in at least some plant designs[5] includes:

- Reactor Vessel Heads
- Reactor Vessel Hot Leg Nozzles
- Reactor Vessel Cold Leg Nozzles
- Reactor Vessel Bottom Mounted Nozzles
- Steam Generator Primary Nozzles
- Pressurizer
- Heat Exchangers
- Piping
- Reactor Coolant Loop Pipe Branch Connections
- Attachments and internal sub-components of any of the above noted components

The following table lists some typical locations of Alloy 600/82/182 for each NSSS type. These are generic locations; each individual plant will need to verify whether these locations are applicable. Additional references for NSSS generic and plant specific locations are included in Appendix B.

[5] This document is not intended to address Alloy 600 in steam generator tubing, the industry has a separate program for this issue, EPRI's Steam Generator Management Program.

Table 4-1
Typical Locations of Alloy 600/82/182 Type Materials in PWR Plants Designed by Westinghouse, Combustion Engineering, and Babcock & Wilcox

Location	Westinghouse Design Plants	Combustion Engineering Design Plants	Babcock & Wilcox Design Plants
Large Diameter (>4") Reactor Vessel Head Nozzles			
- Top Head CRDM/CEDM	Yes	Yes	Yes
- Top Head ICI	No	Yes	No
Small Diameter Nozzles (<4.0")			
- Pressurizer Steam Space Instrument	No	Yes	Yes
- Pressurizer Liquid Space Instrument	No	Yes	Yes
- Reactor Vessel Top Head Vent	Yes	Yes	No
- Reactor Vessel Top Head Thermocouple	No	No	Yes (Note 3)
- Reactor Vessel Head Leak Monitor Tubes	Yes	Yes	Yes
- Hot Leg Instrument	No (Note 6)	Yes	Yes
- Cold Leg Instrument	No	Yes	Yes
- Reactor Vessel Bottom Head Instrument	Yes	Yes(Note 5)	Yes
- Steam Generator Bowl Drain	Yes	Yes	Yes
Pressurizer Heater Sleeves	No	Yes	Yes (Note 2)
Reactor Vessels			
- Inlet & Outlet Nozzle	Yes	No (Note 1)	No
- CRDM Motor Housing	No	Yes	Yes (Note 7)
- Core Flood Nozzle	NA		Yes
Pressurizers			
- Surge Line Nozzles	Yes	Yes	Yes
- Spray Nozzles	Yes	Yes	Yes
- Safety & Relief Valve Nozzles	Yes	Yes	Yes
Main Coolant Piping Loop			
- SG Inlet & Outlet Nozzles	Yes	No	No
- RCP Suction & Discharge Nozzles	No	Yes	Yes
Branch Line Connections			
- Pipe-to-Surge Nozzle Connection	No	Yes	Yes
- Charging Inlet Nozzles	No	Yes	Yes
- Safety Injection and SDC Inlet (Note 4)	No	Yes	Yes
- Shutdown Cooling Outlet Nozzle	No	Yes	Yes
- Spray Nozzles	No	Yes	Yes
- Let-Down and Drain Nozzles	No	Yes	Yes
- Core Flood Tank Nozzle	NA		Yes
Steam Generator Divider Plate/Weld	Yes	Yes	No
Steam Generator Tube Sheet Cladding	Yes	Yes	Yes
Core Support Blocks/Alignment Lugs	Yes	Yes	Yes
Flow Element	N/A	N/A	Yes
Steam Generator Nozzle Dams	No	Yes (Note 8)	Yes
Flow Meter	N/A	N/A	Yes

1. One CE design plant has Alloy 82/182 welds and is therefore similar to the Westinghouse design plants.
2. Oconee 1 and TMI 1 only.
3. Applies only to TMI 1 since the Oconee 1 replacement head has no thermocouples.
4. B&W terminology for “safety injection” nozzle is “high pressure injection (HPI)” nozzle.
5. Palo Verde Only.
6. Some plants may have used Alloy 600 in plant modifications for RTD bypass elimination.
7. Type A and B plants have Alloy 600, type C plants do not.
8. May be removed for replacement steam generators.

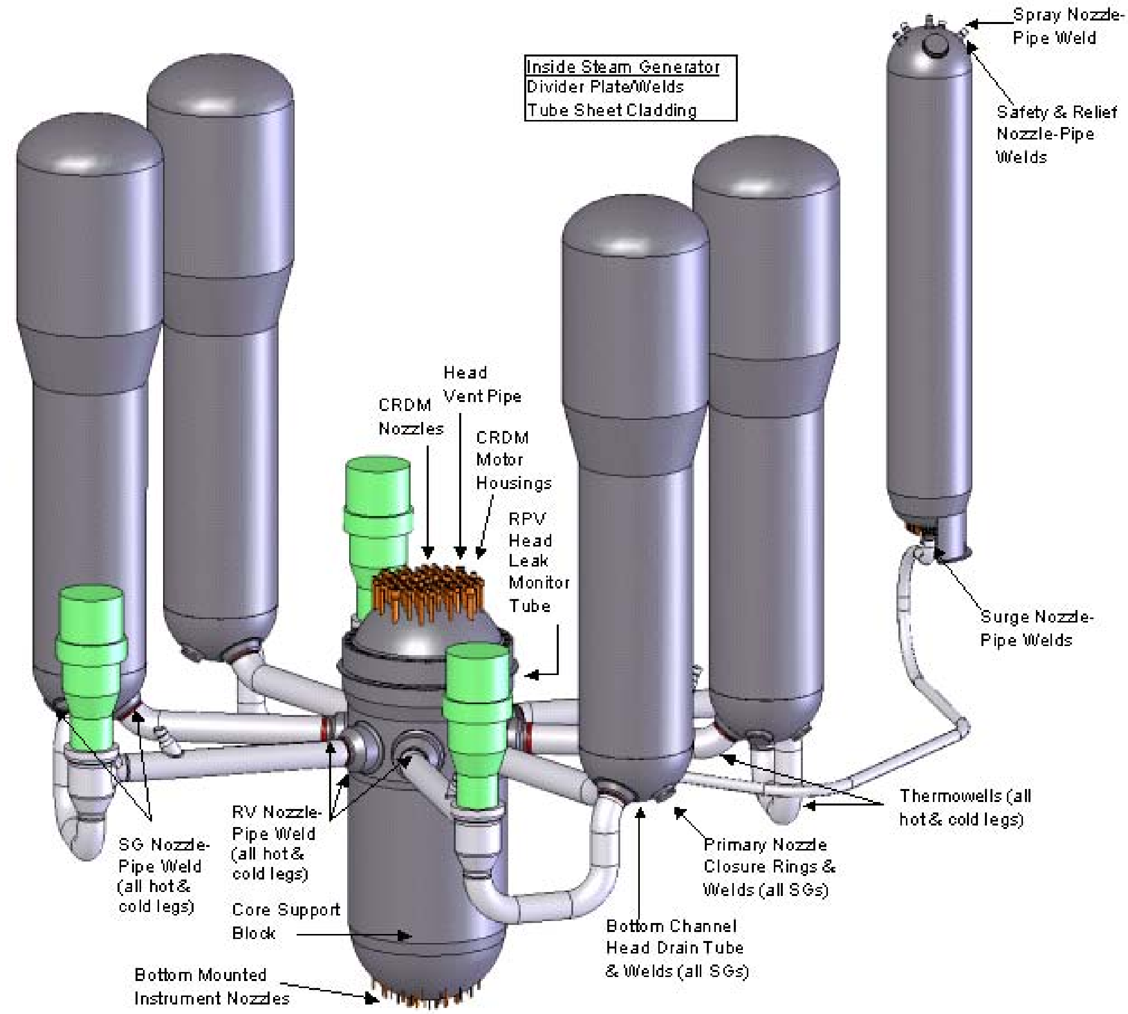

Figure 4-1
Typical Alloy 600 Locations in Westinghouse Plants

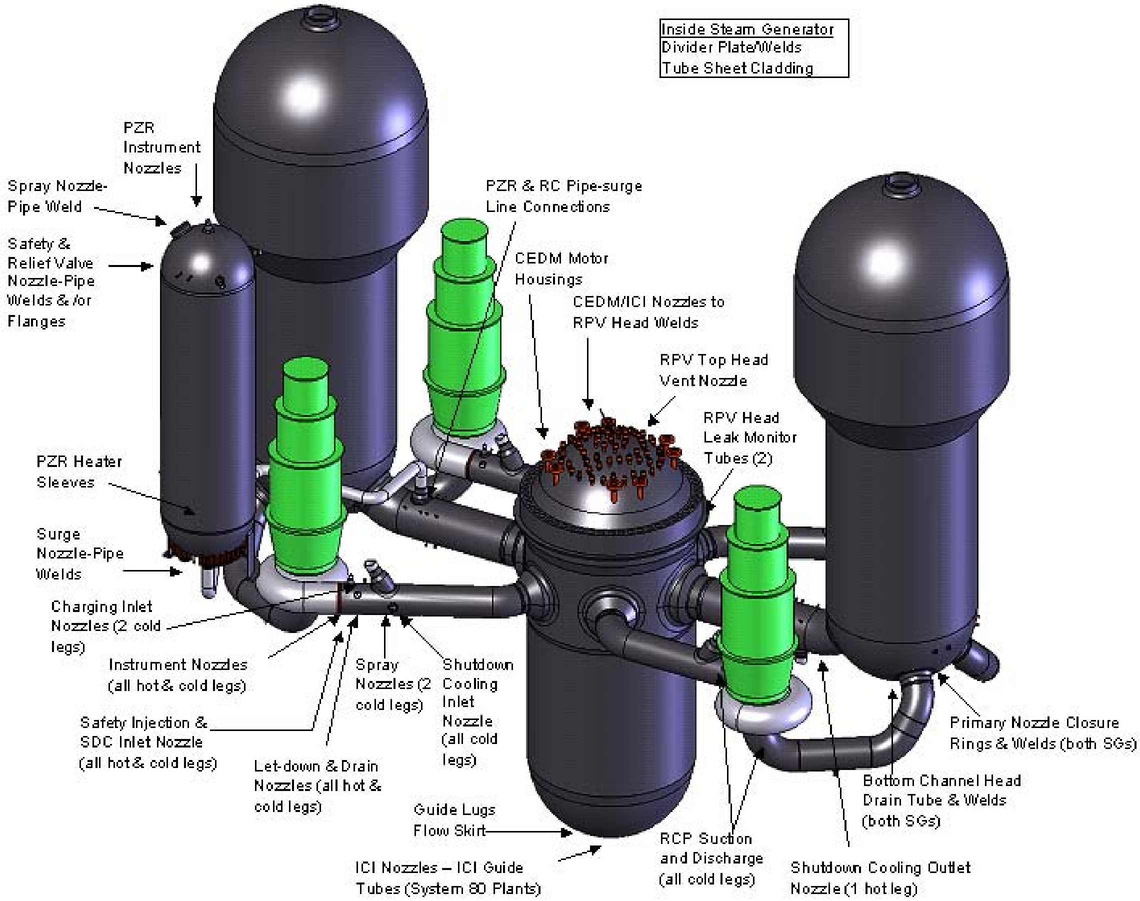

Figure 4-2
Typical Alloy 600 Locations in CE Plants

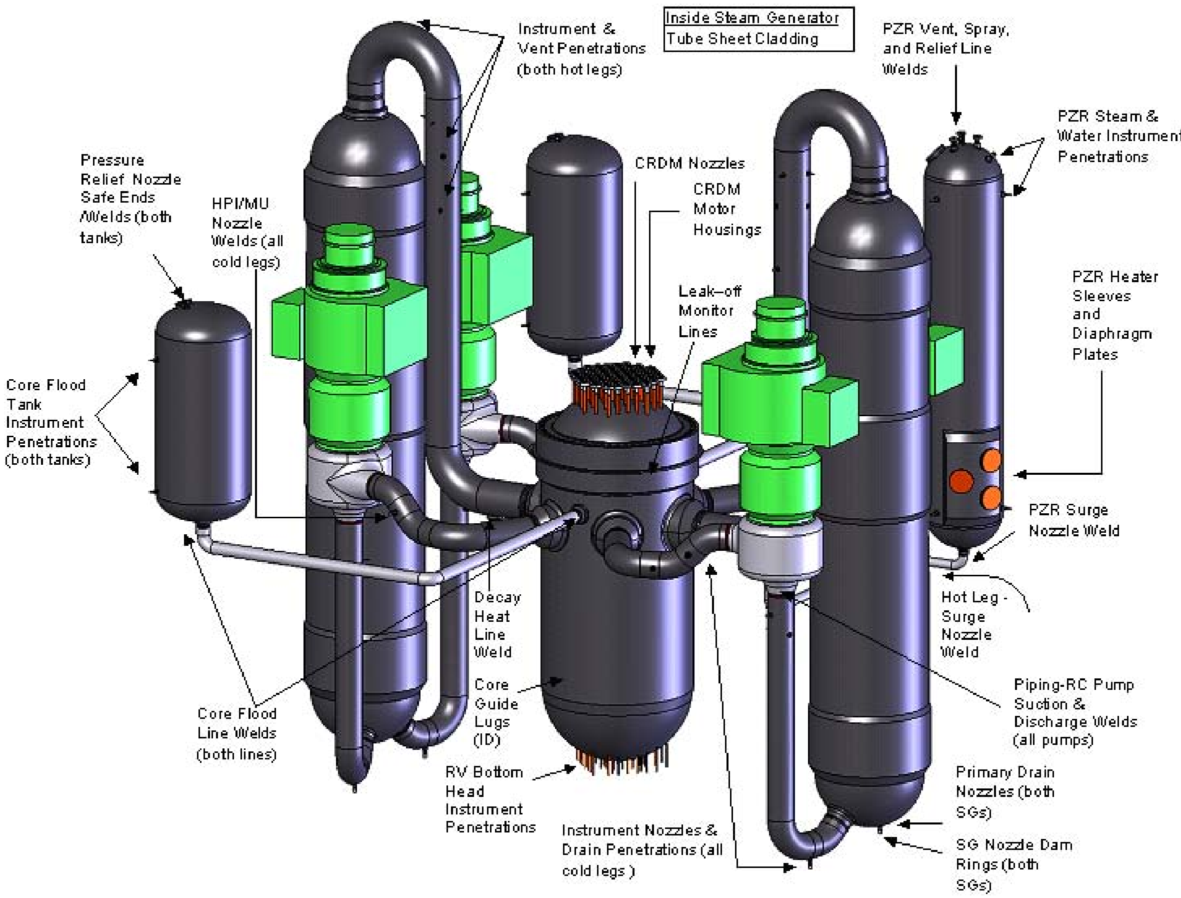

Figure 4-3
Typical Alloy 600 Locations in B&W Plants

Specific Plant Identification

Each plant's documented response to the Request for Additional Information on 60-Day Responses to NRC Bulletin 2002-01, "Reactor Pressure Vessel Head Degradation and Reactor Coolant Pressure Boundary Integrity" contains a complete list of Alloy 600/82/182 locations in their plant. This document should be reviewed and referenced by utilities for their plant specific location list in the Alloy 600 management plan. Each plant should verify and document if Alloy 600/82/182 is present at the generic locations and include other locations that may not be generic (e.g., plant specific modifications). Useful information should be available in the plant specific ISI plan. Documentation in support of license renewal activities (if applicable) also identifies all Alloy 600/82/182 locations. Other sources of information include design drawings and specifications, Certified Material Test Reports (CMTRs), weld documentation, and plant specific inquiries to NSSS vendors. Materials codes should be available from Westinghouse, CE, and B&W. The B&WOG Materials Committee has developed a comprehensive list of Alloy 600/82/182 locations for each of its members. Responsible personnel should consider that actual as built data may vary from design.

If a plant intends to use a plant specific susceptibility ranking to prioritize locations as part of their overall management plan, they will need additional information beyond simple identification of the specific locations. Material properties, fabrication history, and operating conditions can affect the susceptibility of various components. Various susceptibility models may need the following types of input:

- Service temperatures and times at temperatures
- Ranges of stress states
  - Operating and thermal stress
  - Fabrication history (stress relief, hot work, cold work, repair)
- Metallurgical characteristics
- Fatigue history of the component
- Industry experience

This information may also be found in resources such as:

- System or component drawings with dimensions, materials, weld preps, and weld process
- ASME material designations for base material and weld material
- Construction and fabrication records, CMTRs, and post weld treatment records
- Original manufacturing details such as sequence of manufacturing steps, PWHT time and temperature, pre-service NDE performed, any deviation reports or repairs
- NDE, PSI, and ISI schedules and results
- ISI identification number if in plan, ISI planned inspections, ISI past inspections
- Installed location information regarding ease of access, type of insulation, dose rate, a picture of the component, etc.

Once the plant specific Alloy 600/82/182 locations and associated parameters have been established, this data should be maintained in an easily retrievable form for future use.

5 INSPECTION PLAN

Inspection is a key component of Alloy 600 management. Alloy 600/82/182 inspection requirements from regulations, ASME Section XI, and recommendations and guidelines issued by industry groups, such as EPRI MRP or Owners Groups, shall be incorporated into each plant's overall Alloy 600 Inspection Plan. Plants may choose to perform inspections beyond those required or recommended by industry organizations in order to better assess the condition of the plant or to assist in future planning for mitigation or repair and replacement activities. For many plants, the most convenient place to document the Alloy 600/82/182 Inspection Plan will be as either "required " or "augmented' inspections in their normal Section XI ISI plan. Periodic review of such plans should be conducted to ensure continued alignment with the overall Alloy 600 management plan and to capture industry experience. A sampling of reports and other documents containing industry recommendations is provided in Appendix C. Inspection results should be made available to the industry through the EPRI MRP.

A plan for monitoring each Alloy 600/82/182 location should account for susceptibility and safety and economic consequences of degradation/failure. An inspection plan should optimize inspection intervals and techniques to maximize the likelihood of detecting a flaw prior to any impact on plant safety and reliability and to properly delegate resources.

Technique and Frequency of Inspection

The techniques and frequency of inspection should be determined with the following in mind:

- Nuclear safety
- Regulatory compliance
- Economic impact
- Component ranking
- Integration with outage and ISI schedules
  - Extended outage should be recognized as an opportunity for inspection.
  - Determine optimum outage
    - Activities required in outages prior to inspection outage
    - Other planned outage activities
- Define windows within an outage
- Anticipate scope expansion

- Configuration required for one inspection versus another
- Method capabilities
- Availability of qualified inspectors and equipment
- Radiation exposure As Low As Reasonably Achievable (ALARA)

A plant specific matrix with inspection techniques applicable to specific plant locations should be included in the Alloy 600 management plan document. Appendix F includes an example of a plant specific inspection and repair matrix.

Disposition

Defects found during inspection shall be dispositioned in accordance with applicable regulatory requirements. It may be possible to apply a mitigation technique in order to prevent further growth of a flaw.

A decision tree or matrix may be helpful to guide plant staff in determining whether analysis, mitigation of defect growth, defect repair, or replacement of the degraded component is appropriate. The factors used in this decision should include the type of component, the location of the component in the plant, the size and orientation of the defect.

Any corrective actions should be reviewed and approved in accordance with site quality assurance procedures and associated regulations to ensure that these actions have been completed and are effective.

6
COMPONENT RANKING

A ranking system may be used to prioritize the expenditure of resources for mitigation, replacement, and additional inspection beyond requirements. The ranking system should account for susceptibility and safety and economic consequences of degradation/failure.

Generic work may be available to evaluate susceptibility, analyze safety and economic consequences, and devise a ranking system that considers both safety and economic risk. Individual utilities will be ultimately responsible for any plant specific ranking used in their Alloy 600 management plan.

If a ranking system is used, the model should be documented in the plant's Alloy 600 management plan.

Susceptibility

Susceptibility models can be used to evaluate the likelihood of PWSCC initiation at various Alloy 600/82/182 locations in a plant. The susceptibility of a specific component or weld is dependent on multiple factors such as:

- Materials Factors
  - Material properties
  - Metallurgical characteristics
  - Material processing history (cold work, heat treat, etc.)
  - Welding method/process
  - Repair history
- Temperature Factors
  - Time-temperature history
- Applied Stresses
  - Fabrication residual stress
  - Operational stress
  - Operational environment
  - Industry and plant experience with a particular component type

Plant staff should be aware that written records may not include all repair/in-process information and the uncertainty this introduces into any susceptibility models should be recognized and accounted for when using susceptibility as part of a ranking system.

More than one susceptibility model exists. It is important to consider whether or not the model is appropriate for the Alloy 600/82/182 location being evaluated. Reports on susceptibility are listed in Appendix D.

Consequences

Component ranking should be based not just on susceptibility to cracking, but also on the consequences associated with a crack or leak at each location. Failure could impact plant safety, personnel safety, and operations. Inspections required for regulatory compliance are designed to prevent any safety consequence.

The economic consequences of flaws should be evaluated as appropriate. A crack or leak may lead to a forced outage or an outage extension. Some plants have a risk informed in-service inspection program that identifies the consequences of failure for many locations in the plant.

7 MITIGATION

Mitigation activities are important to assure the long term operability of certain components containing Alloy 600/82/182. Without appropriate mitigative actions, it is possible that a significant number of components, especially those with high susceptibility, will develop cracks from PWSCC during the remaining life of the plants. Stress Corrosion Cracking (SCC) requires the confluence of a susceptible material, a chemical environment conducive to cracking, and sufficiently high tensile stresses on the material in contact with the coolant. Mitigation is intended to extend the life of components by altering one or more of the conditions necessary for SCC to occur in PWRs. Removing the susceptible material would appropriately be called a replacement activity, such as replacement of the reactor vessel top heads with new heads containing no Alloy 600/82/182. However cladding over the susceptible material with a material less susceptible would also remove the material from contact with reactor coolant and therefore be a mitigative action. There are a number of mitigative actions that address the stresses on the material in contact with reactor coolant, some already developed and implemented in the field, such as Mechanical Stress Improvement Process (MSIP), and some still under development, such as cavitation peening. In addition, approaches to modify the environment to reduce the likelihood of PWSCC are under investigation. Laboratory results and limited field experience indicate that Zinc injection can play a role in reducing the probability of crack initiation and may help reduce crack growth, although results on growth are mixed to date. Other mitigation processes are under investigation in the industry and their development should be followed to ensure the latest available information is utilized.

Mitigation techniques that are currently available or under evaluation include the following:

- Zinc Addition
- Mechanical Stress Improvement Process (MSIP)
- Waterjet Peening
- Outer Diameter (OD) Weld Overlay to put Inner Diameter (ID) in compression
- Clad with Alloy 690/52/152 material

Additional information on some of these technologies can be found in the reports listed in Appendix E.

8 REPAIR/REPLACEMENT

Prior to each inspection outage the plant should evaluate the level of contingency for repairs. Some considerations and suggested pre-outage actions include:

- Gather design information (i.e., code stress report)
- Review prior inspection records
- Material, personnel, and equipment availability
- NDE support, personnel, and procedures
- Vendor selection
- Code review/possible relief requests
- Personnel/Vendor readiness
- In-house repair capabilities (small bore hot and cold leg nozzles)
- Relief requests
  - MNSA2 currently requires ASME Code relief per the NRC
  - Ambient temper bead is an option for weld repairs attaching nozzles to vessel material without preheat requirements

Repair techniques that are currently in use include:

- Mechanical Nozzle Seal Assembly (MNSA)
- Embedded Flaw Repair
- Excavate crack & weld repair
- Half nozzle repair
- ID Weld Inlay
- Replace with Alloy 690/52/152 material
- Sleeving
- Weld overlay on OD/Structural weld overlay
- Mechanical Stress Improvement Process (MSIP) (where applicable in accordance with flaw acceptance criteria)
- Relocate attachment weld to the OD or mid-wall of the vessel or pipe

In some cases, component replacement may be the best option. Example of components that have been replaced at some U.S. plants include:

- Reactor Vessel Head
- Steam Generator
- Alloy 600 pipe sections with stainless steel

Some other considerations that may impact repair and mitigation techniques include:

- Containment hatch size
- Outage length
- Synergies with other actions (10 year ISI, MSIP at multiple locations, head assembly upgrades)
- Contingencies when performing inspections
- Regulatory drivers (mandated inspections)

Plant Specific Repair Matrix

Plants should identify repair options for each location in order to effectively respond to inspection findings. Appendix F includes an example of a plant specific inspection and repair matrix.

The plant specific matrix may be organized by location and flaw type. Fields could include the primary inspection technique for detecting the flaw, the probability that a repair is required, the recommended repair method(s), and the specific actions to be taken by plant staff. The plant specific matrix may indicate the status of any on-going analysis related to the flaw, any known limitations in repair technique, and references to procedures related to repair and testing.

Several reports that are available to assist plant staff in selecting Alloy 600/82/182 repair techniques are listed in Appendix G.

9
MAINTAINING THE ALLOY 600 MANAGEMENT PLAN

The Alloy 600 Management plan should be reviewed and updated on a periodic basis to address:

- Industry events
  - Inspection history/results both plant specific and industry wide
  - Operating Experience
- Developing technologies
  - Inspection
  - Mitigation
  - Repair
  - Replacement
- Plant changes
  - Operational
  - Hardware
- Implementation issues
  - Lessons learned

This periodic plan review should be documented to capture the results of the review.

A

SUMMARY OF KEY INDUSTRY EVENTS INVOLVING PWSCC OF ALLOY 600/82/182

Year	Event
1959	Coriou reported on the cracking of high nickel alloys in “high purity” water at 662°F.
1971 and beyond	There have been several discoveries of PWSCC of Alloy 600 in steam generator tubes, this phenomena is managed as an independent issue in the industry and thus the details of these events are not included here.
1986	A leak occurred from a pressurizer instrument nozzle at San Onofre Unit 3. This instrument nozzle was welded into the pressure vessel by a J-groove weld.
1987	A leak was discovered from a pressurizer heater sleeve at Arkansas Nuclear One Unit 2 (a second cracked sleeve was subsequently identified). Swelling of a failed electric heater element inside the sleeve was identified as a contributing cause of the PWSCC.
1988	A leak was discovered from two steam generator drain nozzles at Shearon Harris. The drain nozzles had been roll expanded into the steam generator head and then seal welded on the inside surface of the head.
1989	Leaks were discovered from 20 pressurizer heater sleeves at Calvert Cliffs Unit 2. Cold working of the inside surface of these sleeves produced by reaming the inside surface before welding into the pressure vessel head was identified as a contributing cause of the PWSCC. The repair was completed about a year after the course of action was established.
1989	A steam generator tube plug failed at North Anna 1 leading to the top of the plug being propelled upward through the tube and rupturing the tube at the U-bend region.
1989	Leaks were discovered in pressurizer instrument nozzles in two EDF plants (Nogent 1 and Cattenom 2). These instrument nozzles were roll expanded into the pressure vessel shell and then welded to the inside of the vessel shell by a J-groove weld. Subsequent examinations at other plants showed shallow circumferential cracks in pressurizer instrument nozzles in two other plants (Belleville 1 and Flamanville 2).
1990	One upper level tap nozzle found leaking during heatup at ANO Unit 1. This was the first B&W stress relieved nozzle to fail. This was the first half nozzle repair used and later justified as a permanent repair.
1991	A leak was discovered from a control rod drive mechanism nozzle in Bugey 3.
1992	Cracks were discovered in CRDM nozzles at an EDF plant with a “cold head” reported to operate at about 290°C (554°F).
1992	A leak was discovered from a pressurizer instrument nozzle that had been replaced at San Onofre 3 in 1986 as a result of PWSCC of the original nozzle.

Year	Event
1992	Cracks were discovered in two of eight hot leg piping instrument nozzles which were preventively removed from Palo Verde 2.
1992	Several indications were found on the outside surface of the leaking Bugey 3 nozzle which had been removed for destructive examination. These indications were located near the top of the J-groove weld and included a circumferentially oriented crack on the outside of the nozzle and cracks in the J-groove weld.
1993	A leak occurred from a circumferential crack in an Alloy 600 pressurizer relief valve nozzle safe end at Palisades.
1993	A crack from a leaking pressurizer instrument nozzle at St. Lucie 2 was chased for a considerable depth into the J-groove weld. A temper bead repair was required before installing a new nozzle.
1994	A 7 mm (0.276 inch) deep crack was discovered in a CRDM nozzle at DC Cook 2.
2000	Shallow ID cracks were found in hot leg nozzle butt welds at Ringhals 3 & 4.
2000	A leak was discovered at a reactor vessel hot leg nozzle pipe butt weld at V. C. Summer.
2000	Leaks were discovered from a CRDM nozzle and five thermocouple nozzles located on the Oconee 1 reactor vessel head.
2001	A through-wall circumferential crack was discovered above the J-groove weld in an Oconee 3 CRDM nozzle.
2001	Eddy Current inspection of four nozzles suspected to be leaking at Oconee Unit 2 found clusters of axial cracking on the ID both above and below the J-groove weld. One nozzle had a circumferential OD crack.
2001	Eight axial indications were found on CRDM penetrations at North Anna Unit 1, all on the ID and above the weld. NDE evaluation found that the nozzles were safe for one cycle of operation without repair.
2001	Three circumferential flaws were found in CRDM penetration welds of the North Anna Unit 2 reactor pressure vessel head and repairs were made.
2001	Visual inspections noted boric acid deposits on one CRDM nozzle at ANO Unit 1, follow up NDE showed a circumferential flaw on the OD surface of the nozzle. The circumferential crack was found to be linked with an axial crack.
2001	Crystal River Unit 3 had one CRDM with boric acid deposits, UT testing found two axial-oriented through wall cracks.
2001	Visual examination of the RPV Head at TMI Unit 1 found boric acid deposits, 12 nozzles were suspected to be leaking. UT and PT tests were performed on these nozzles six of them were found to be in need of repair, four were found to be acceptable, and two were found to be acceptable for one cycle only. Eight suspect thermocouple nozzles were also repaired.
2001	Indications of cracks were detected in 10 CRDM penetrations at Surry Unit 1. Six of these CRDM nozzles required repairs for circumferential cracks in the J-groove weld, the other four nozzles did not require repairs.

Year	Event
2002	Davis Besse identified axial indications in three CRDM nozzles, further investigation and repair activities led to the discovery of significant wastage of the RPV Head. This discovery prompted a great deal of NRC and Industry attention to Alloy 600 issues.
2002	Millstone Unit 2 NDE inspection identified 3 CEDM nozzles with cracks on the OD below the J-groove weld. Bare metal visual inspection found 2 pressurizer heater sleeve leaks.
2002	ET inspection of 59 welds in North Anna Unit 2 RPV head found tube OD circumferential “crack like” indications in 20% of the penetrations. This RPV head was replaced.
2002	ANO 1 visual inspection found one leaking CRDM Nozzle (previously repaired in 2001) requiring repair and UT inspections found six other nozzles with OD axial indications below and protruding into the weld area but not breaking through the toe of the weld. One nozzle had a rounded indication in the weld.
2002	Visual inspection found evidence of leakage on seven CRDM penetrations at Oconee Unit 2. None of these nozzles had been previously repaired.
2002	Axial flaw detected close to fabrication repair in pressurizer surge nozzle to safe-end weld at Tihange 2.
2003	Visual evidence of leakage on two CRDM nozzle penetrations and one thermocouple penetration in the Oconee 1 RPV head. The thermocouple penetration had been plugged in December 2000.
2003	South Texas Project Unit 1 performed visual inspection of RPV bottom head, residue was found on two BMI penetrations, analysis showed that this residue had come from the reactor coolant system. UT and eddy current testing found axial cracks in the two leaking penetration tubes.
2003	Axial flaws were detected in two penetrations during inspection of the RPV head at St. Lucie Unit 2.
2003	Axial indications in the tube material of 4 CRDM penetrations extending up to the toe of the weld discovered at Beaver Valley 1, no leakage.
2003	Tsuruga Unit 2 Pressurizer Safety Relief Nozzle A experienced axial cracking in the 132 weld metal of the dissimilar metal joint between connecting the nozzle and pipe.
2003	Circumferential through-wall cracks were detected in some of the Alloy 600 pressurizer heater sleeves at Palo Verde Unit 2. all the cracks were located above the J-groove weld, inside the pressure boundary.
2003	Millstone Unit 2 NDE inspection identified 11 CEDM nozzles with cracks on the OD below the J-groove weld. Bare metal visual inspection found 2 pressurizer heater sleeve leaks.
2003	Crystal River Unit 3, three pressurizer instrument nozzle leaks found after shutdown, this was the second B&W unit to have stress relieved nozzles leak.
2003	Inspection of the pressurizer heater bundle at TMI unit 1 identified a primary system leak at the lower pressurizer heater bundle diaphragm plate due to Alloy 600 degradation.

B
RESOURCES – LOCATIONS OF ALLOY 600/82/182

Description	Date	Product Classification
Alloy 600 Primary Pressure Boundary Penetrations in CEOG Plants (access database of detailed information on each Alloy 600 penetration)	June 2001	CEOG Task 1142
Available fabrication and construction data summary of Alloy 182 and Alloy 82 weld locations	1996	B&WOG Alloy 600 Program
Westinghouse Letter Report, "Alloy 600 Primary Loop Locations in Domestic WOG Plant Reactor Vessels, Steam Generators, Pressurizers, and Reactor Vessel Internals"	1994	WOG-94-140
Westinghouse Letter Report, Alloy 600 Primary Loop Locations in Domestic WOG Plants, W Proprietary Class 3, Report number MSE-MNA-389 (94)	1995	WOG-95-22
Westinghouse Letter Report, Alloy 600 Primary Loop Locations in Domestic WOG Plants, Report number MSE-MNA-368 (94) Revision 1	1995	WOG-95-010

C
RESOURCES – INSPECTION PLANNING

Description	Date	Product Classification
An Evaluation of Available Leak Detection and Monitoring Systems for Identifying CRDM Nozzle Leakage on the RV Head	1993	B&WOG CRDM Nozzle Program
Automated Ultrasonic Inside Surface Examinations of Reactor Coolant System Alloy 82/182 Nozzle Welds Performed in Spring 2001 (MRP-59)	July 2001	EPRI 1006225
BMI Integrated Industry Inspection Plan	May 14, 2004	MRP Letter 2004-04
Demonstration of Inspection Technology for Alloy 600 CRDM Head Penetrations	October 1996	EPRI TR-106260
Demonstrations of Vendor Equipment and Procedures for the Inspection of Control Rod Drive Mechanism Head (MRP-89)	September 2003	EPRI 1007831
Examination of Dissimilar Metal Welds in BWR and PWR Piping Systems	November 1993	EPRI TR-102148
Flow Chart for CRDM Nozzle Inspections Developed for Utility use in Preparing an Inspection Plan	1994	B&WOG CRDM Nozzle Inspection Guidelines
Generic Evaluation of Examination Coverage Requirements for Reactor Pressure Vessel Head Penetration Nozzles, Revision 1 (MRP-95R1)	2004	EPRI 1011225
Inspection Plan for Reactor Vessel Closure Head Penetrations in U.S. PWR Plants (MRP-117)	2004	EPRI 1007830
Inspection of Alloy 82/182/600 Materials Used in the Fabrication of Pressurizer Penetrations and Steam Space Piping Connections at Pressurized-Water Reactors	May 28, 2004	NRC Bulletin 2004-01
Needed Action for Visual Inspection of Alloy 82/182 Butt Welds and Good Practice Recommendations for Weld Joint Configurations	April 2, 2004	MRP Letter 2004-05
NRC Bulletin 2002-02: Reactor Pressure Vessel Head and Vessel head Penetration Nozzle Inspection Programs	August 22, 2002	MRP Letter 2002-92A
Pre-Service Inspection Requirements for New RPV Heads	October 17, 2002	MRP Letter-2002-106

Description	Date	Product Classification
Pressurizer Inspection Recommendations	January 1992	CEOG Task 700
Pressurizer Inspection Recommendations: Evaluation of pressurizer penetrations and evaluation of corrosion after unidentified leakage develops	January 1992	CEOG Task 700
PWR Reactor Pressure Vessel (RPV) Upper Head Penetrations Inspection Plan, Revision 1 (MRP-75)	August 2002	EPRI 1007337
PWR RPV Upper Head Penetration Inspection Plan, Revision 1	August 15, 2002	MRP Letter 2002-086
Qualification of Eddy Current Examination Technique Develop standards, procedures, and qualification of techniques to more accurately detect heater sleeve cracks in units with 0.905 sleeves.	November 1990	CEOG Task 635
Reactor Pressure Vessel Head and Vessel Head Penetration Nozzle Inspection Programs	August 9, 2002	NRC Bulletin 2002-02
Recommendation for Inspection of Alloy 600/82/182 Components Via Insulation Removal	November 20, 2003	MRP Letter 2003-39
Recommendation for PWR Owners with Alloy 600 Bottom Mounted Reactor Vessel Instrument Nozzles	June 23, 2003	MRP Letter 2003-017
Revised RVHP Inspection Guidance Regarding Fall 2002 Inspections	November 11, 2002	MRP Letter 2002-109
Revised RVHP Inspection Guidance Regarding Recent North Anna Unit 2 Findings	October 1, 2002	MRP Letter 2002-104
Update on MRP RVHP Inspection Performance Demonstration Activities	August 22, 2002	MRP Letter 2002-091
Visual Examination for Leakage of PWR Reactor Head Penetrations (MRP-60)	August 2001	EPRI 1006296
Visual Examination for Leakage of PWR Reactor Head Penetrations: Revision 1 of 1006296, Includes Fall 2001 Inspection Results	March 2002	EPRI 1006899
Visual Examination for Leakage of PWR Reactor Head Penetrations: Revision 2 of 1006296, Includes 2002 Inspection Results and MRP Inspection Guidance	March 2003	EPRI 1007842
Westinghouse Generic Guidance for an Effective Boric Acid Inspection Program for Pressurized Water Reactors		WCAP-15988-NP
Westinghouse Inspection Plan Guideline's for Industry/Plant Inspection of RV Closure Head Penetration Tubes (Proprietary Class 2C)		WCAP-14024
WOG CE Fleet Pressurizer Heater Sleeve Inspection Program (WOG-04-057 Letter)	January 30, 2004	WCAP-16180-NP, Rev 0 Project # 694

D
RESOURCES – COMPONENT RANKING AND SUSCEPTIBILITY

Description	Date	Product Classification
A Model for Ranking the PWSCC Risks of all Alloy 600 Component Items and Weld Locations	1998	B&WOG Alloy 600 Program
A Revised Model for Ranking the PWSCC Susceptibility of all Alloy 600 Component Items and Weld Locations	1998	B&WOG Alloy 600 Program
Database of all Alloy 600 Component Items and Welds (Excluding Steam Generator Tubing, Plugs, Stabilizers, etc.) and Original PWSCC Susceptibility Ranking Model	1992-1993	B&WOG Alloy 600 Database and Original Ranking Model
Original CIRSE Model (Developed by DEI for Duke Energy) Revised for all B&WOG Plants Use	1995	B&WOG Long Range CRDM Nozzle PWSCC Planning Model
Westinghouse Susceptibility/Screening Methodology (Inspection Guidelines)		MED-PCE-12738

E
RESOURCES – MITIGATION

Description	Date	Product Classification
A Model of the Effects of Li, B, and H2 on Primary Water Stress Corrosion Cracking Initiation in Alloy 600 (MRP-68)	April 2002	EPRI 1006888
Evaluation of the Capabilities and Limitations of Existing Technologies for Mitigation of PWSCC (MRP-122)	June 2004	EPRI 1009504
Effect of Zinc Addition on Mitigation of PWSCC of Alloy 600 (MRP-78)	October 2002	EPRI 1003522
Evaluation of Zinc Addition During Cycle 9 at Diablo Canyon (MRP-17)	November 1999	EPRI TR-113540
Evaluation of Zinc Addition in Cycle 12 at Farley Unit 2 (MRP-15)	December 1998	EPRI TR-111349
Evaluation of Zinc Addition in Cycle 13 at Farley Unit 2 (MRP-22)	August 2000	EPRI 1000251
Laser Peening – A Technology to Improve Lifetime, Reliability, and Safety of PWRS While Reducing Maintenance Costs	January 2003	EPRI White Paper
Mechanical Stress Improvement Process (MSIP) Implementation and Performance for PWR Applications (MRP-121)	June 2004	EPRI 1009503
Overview Report on Zinc Addition in PWRs (MRP-63)	February 2001	EPRI 1001020
Recommendations for Testing of Emerging Mitigation Techniques for PWSCC (MRP-119)	June 2004	EPRI 1009501
Report on Alloy 600 Nozzle Repair and Mitigation Historical Application (MRP-76)	September 2002	EPRI 1007293
Suitability of Emerging Technologies for Mitigation of PWSCC (MRP-118)	June 2004	EPRI 1009500

F
EXAMPLE INSPECTION AND REPAIR MATRIX

Location	Primary Inspection Technique	Repair Method (If a flaw is detected)
	Reactor Pressure Vessel Head	
CRDM/CEDM J-Groove Weld	Manual PT	Weld overlay – Design/Analysis will determine required weld depth and number of layers. Framatome mid-wall repair.
CRDM/CEDM Nozzle -OD	UT of Nozzle Bare Metal Visual Required per Order	Weld overlay – Design/Analysis will determine required weld depth and number of layers. Framatome mid-wall repair.
CRDM/CEDM Nozzle - ID	UT of Nozzle Bare Metal Visual Required per Order	ID-Weld inlay – May require mechanical boring of the nozzle prior to welding. Design/Analysis will determine required weld depth and number of layers. Framatome mid-wall repair.
ICI Nozzles J-Groove Weld	Manual PT	Weld overlay – Design/Analysis will determine required weld depth and number of layers.
ICI Nozzles - OD	UT of Nozzle Bare Metal Visual Required per Order	Weld overlay - Design/Analysis will determine required weld depth and number of layers.
ICI Nozzles - ID	UT of Nozzle Bare Metal Visual Required per Order	ID-Weld inlay – May require mechanical boring of the nozzle prior to welding. Design/Analysis will determine required weld depth and number of layers.
Vent Line Nozzle	UT of Nozzle Bare Metal Visual Required per Order	Repair method developed for SONGS (Westinghouse) relocates the attachment weld in the head bore.
	Reactor Vessel Bottom Head	
ICI Nozzles	Limited Bare Metal Visual	FTI developed repair method (Davis Besse). Westinghouse developed MNSA2 (for some B&W and Westinghouse plants).

Location	Primary Inspection Technique	Repair Method (If a flaw is detected)
	Pressurizer	
PZR Heater Nozzles/PZR Heater Sleeves	Bare Metal Visual	MNSA2 available for repair – No drain down required – Analysis required at some locations due to cooldown curve. Half nozzle repair with weld pad – Drain down required. Mid-wall repair being developed for Entergy and Palo Verde.
PZR Instrument Nozzles	Bare Metal Visual	MNSA2 available for repair – No drain down required. Half nozzle repair with weld pad – Drain down required. Replacement
PZR Safety and Relief Valve Nozzles	Bare Metal Visual UT from outside surface	Structural Weld Overlay. Replacement/Partial Replacement.
PZR Surge Line Nozzles	Bare Metal Visual UT from outside surface	Structural Weld Overlay. Replacement/Partial Replacement.
PZR Spray Nozzles	Bare Metal Visual UT from outside surface	Structural Weld Overlay. Replacement/Partial Replacement.
	Steam Generator (Outside)	
SG Instrument Nozzles	Visual with insulation on	MNSA2 available for repair. – No drain down required. Half nozzle repair with weld pad. – Drain down required.
SG Inlet and Outlet Nozzles	Bare Metal Visual UT from outside surface	Structural Weld Overlay. Replacement/Partial Replacement.
	Reactor Coolant System Piping	
Piping Butt Welds	Bare Metal Visual UT of OD	Weld Overlay. Permanent Weld Repair. Replacement/Partial Replacement.
Piping Butt Welds to RV Nozzles	Bare Metal Visual UT of ID	Weld Overlay. Permanent Weld Repair. Replacement/Partial Replacement.

Location	Primary Inspection Technique	Repair Method (If a flaw is detected)
Hot Leg Nozzle Partial Penetration Welds	Bare Metal Visual UT of Nozzle	Permanent Weld Repair available – Drain down required. MNSA2 available for repair(final approval as permanent method expected in 2004) – No drain down required. Half nozzle repair – Drain down required. Interim Repair that adds a structural weld to OD of piping at nozzle intersection could be used – No drain down required. Replacement.
Cold Leg Nozzle Partial Penetration Welds	Bare Metal Visual UT of Nozzle	MNSA2 available for repair (final approval as permanent method expected in 2004) – No drain down required. Half nozzle repair – Drain down required. Interim Repair that adds a structural weld to OD of piping at nozzle intersection could be used – No drain down required
Reactor Coolant Pump Suction and Discharge Nozzles	Bare Metal Visual UT from outside surface	Structural Weld overlay. Cut out and replace with spool piece.

G
RESOURCES – REPAIR/REPLACEMENT

Description	Date	Product Classification
CEDM Deep Crack Repair - Investigation of repair approach for repair of deep cracks in CEDM penetrations	July 1996	CEOG Task 822
Conceptual Ideas for Repair or Replacement of IMI Nozzles	1994	B&WOG IMI Nozzle Repair/Replacement
Development of Advanced Testing Techniques to Quantify the Improved PWSCC Resistance of Alloy 690 and its Weld Metals (MRP-123)	June 2004	EPRI 1010269
EPRI Alloy 600 Repairs with PTAW Process	June 2003	EPRI 1006798
EPRI: Qualification of Welding Alloy IN-52M for Alloy 600 and 690 Repairs: Welding Procedures and Process Development	December 2002	EPRI 1006804
Qualification Report for CRDM Nozzle Repairs using an ID Temper Bead Process	2001	B&WOG CRDM Nozzle Program
Summary Document Containing Each of the Generic Pressurizer Nozzle Repair Deliverables	1994	B&WOG Alloy 600 Program
Summary Report of the Process Qualification Activities of the Abrasive Water-Jet Machining System for Use in the Repair and Remediation of CRDM Nozzles	1998	B&WOG
Westinghouse Study of Proposed RV Closure Head Penetration Repair Configurations (Proprietary Class 2)		WCAP-13663

H
ASSORTED EPRI AND NRC ALLOY 600/82/182 RESOURCES

Assorted EPRI Reports on Alloy 600/82/182

Title	Date	EPRI Product Number
Alloy 82/182 Pipe Butt Weld Safety Assessment for U.S. PWR Plant Designs: Babcock & Wilcox Design Plants (MRP-112)	2004	1009805
Alloy 82/182 Pipe Butt Weld Safety Assessment for U.S. PWR Plant Designs: Westinghouse and CE Design Plants (MRP-109)	2004	1009804
Alloy 82/182 Pipe Butt Weld Safety Assessment for U.S. PWR Plant Designs (MRP-113)	2004	1007029
An Assessment of the Control Rod Drive Mechanism (CRDM) Alloy 600 Reactor Vessel Head Penetration PWSCC Remedial Techniques (MRP-61)	June 2003	1008901
An Improved Approach for Performing Simplified Elastic-Plastic Fatigue Analysis	October 1998	TR-107533
Analysis of Stress Corrosion Cracks in Alloy 182 Weld Metal after Exposure to PWR Primary Water (MRP-107)	February 2004	1009399
BWOG Activities to Support Industry BMI Management Plan	September 19, 2003	MRP Letter 2003-33
Comparison of the EPRI Stress Algorithm with ANSYS Calculation for Alloy 600 CRDM Penetrations in KEPCO Reactors	September 1997	TR-108986
Control Rod Drive Mechanism Destructive Examinations and Related Frequently Asked Questions at Electricite de France (MRP-91)	April 2004	1009013
Crack Growth and Microstructural Characterization of Alloy 600 PWR Vessel Head Penetration Materials	December 1997	TR-109136
Crack Growth of Alloy 182 Weld Metal in PWR Environments (MRP-13)	January 1999	TR-111993

Assorted EPRI and NRC Alloy 600/82/182 Resources

Title	Date	EPRI Product Number
Crack Growth of Alloy 182 Weld Metal in PWR Environments, June 2000 (MRP-21)	June 2000	1000037
Crack Growth Rates for Evaluating Primary Water Stress Corrosion Cracking (PWSCC) of Alloy 82, 182, and 132 Welds (MRP-115)	2004	1006696
Crack Growth Rates for Evaluating Primary Water Stress Corrosion Cracking (PWSCC) of Thick-Wall Alloy 600 Materials (MRP-55) Revision 1	November 2002	1006695
Cracking In Vessel Head Adapters: Analysis of Crack Growth Rate Reports (MRP-12)	April 2000	TR-114757
Davis-Besse Root Cause Review Letter Report	July 26, 2002	MRP Letter 2002-077
Elastic-Plastic Finite Analysis: Single- and Double-J Hot Leg Nozzle-to-Pipe Welds (MRP-33): Welding Residual and Operating Stresses	March 2002	1001501
EPRI MRP Alloy 600 Industry Workshop Proceedings (MRP-64)	June 2001	1006278
EPRI: In Situ Characterization of Surface Films on Alloy 600 High-Temperature PWR Water	December 2002	1002871
Evaluation of the Effect of Weld Repairs on Dissimilar Metal Butt Welds (MRP-114)	2004	1009559
GE Experience Report on Cracking in Alloy 182 (MRP-57)	November 2001	1006603
Industry Material for Use in Responding to NRC Bulletin 2002-02	August 22, 2002	MRP Letter 2002-090
Letter Minutes of the PWSCC Expert Panel Meeting from 10/03/03	October 7, 2003	MRP Letter 2003-38
Letter report on the Generic Implications of Davis-Besse RPV Head Corrosion	April 5, 2002	MRP Letter 2002-037
Low-Temperature Cracking of Nickel-Based Alloys and Weld Metals (MRP-108)	February 2004	1009400
Materials Handbook for Nuclear Plant Pressure Boundary Applications	December 2002	1002792
Materials Reliability Program PWSCC of Alloy 600 Type Materials in Non-Steam Generator Tubing Applications – Survey Report Through June 2002 part 1 PWSCC in Components Other than CRDM/CEDM Penetrations (MRP-87)	July 2003	1007832

Title	Date	EPRI Product Number
Modeling Assessment of SCC Initiation Time in Alloy 600	December 1997	TR-109137
Non-Destructive Measurement of Residual Stresses by Photothermal Technique: Application to Alloy 600	November 2002	1006894
Photographic Results of EPRI Annulus Boric Acid Corrosion	June 19, 2002	MRP Letter 2002-071
Photographic Results of EPRI Boric Acid Corrosion Tests Involving Leakage into Annular Gaps (MRP-72)	June 2002	N/A
Probabilistic Fracture Mechanics Analysis of PWR Reactor Pressure Vessel Top Head Nozzle Cracking (MRP-105)	2004	1007834
Probabilistic Risk Assessment of Alloy 82/182 Piping Butt Welds (MRP-116)	2004	1009806
Proceedings: 1992 EPRI Workshop on PWSCC of Alloy 600 in PWRs	December 1993	TR-103345
Proceedings: 1994 EPRI Workshop on PWSCC of Alloy 600 in PWRs Parts 1 and 2 (MRP-70)	August 1995	TR-105406
Proceedings: 1997 EPRI Workshop on PWSCC of Alloy 600 in PWRs: Parts 1 and 2	November 1997	TR-109138-P1 and TR-109138-P2
Proceedings: 2000 EPRI Workshop on PWSCC of Alloy 600 in PWRs (MRP-27)	November 2000	1000873
PWR Materials Reliability Program Response to NRC Bulletin 2001-01 (MRP-48)	August 2001	1006284
PWR Materials Reliability Project Interim Alloy 600 Safety Assessments for U.S. PWR Plants Part 1: Alloy 82/182 Pipe Butt Welds (MRP-44 Part 1)	April 2001	TP-1001491 (Part 1)
PWR Materials Reliability Project Interim Alloy 600 Safety Assessments for U.S. PWR Plants Part 2: Reactor Vessel Top Head Penetrations (MRP-44 Part 2)	May 2001	TP-1001491(Part 2)
PWR Vessel and Internals Application, Version 1.1	December 1999	SW-103198 P8R1 DK
Reactor Vessel Closure Head Penetration Safety Assessment for U.S. PWR Plants (MRP-110), Evaluations Supporting the MRP Inspection Plan	2004	1009807
Residual Stress Measurements on Alloy 600 Pressurizer Nozzle and Heater Sleeve Weld Mockups	December 1993	TR-103104

Title	Date	EPRI Product Number
Resistance to Primary Water Stress Corrosion Cracking of Alloys 690, 52, and 152 in Pressurized Water Reactors (MRP-111)	March 2004	1009801
Revised MRP-75 Reactor Vessel Closure Head Penetration Wastage Evaluations - Boric Acid Corrosion Testing for RPV Head Wastage Prediction	December 2003	1007843
Reactor Vessel Head Nozzle and Weld Safety Assessment for B&W Plants (MRP-103)	2004	1009402
RV Head Nozzle and Weld Safety Assessment for Westinghouse and Combustion Engineering Plants (MRP-104)	2004	1009403
South Texas Project Unit 1 Bottom Mounted Instrumentation Nozzles (#1 and #46) Analysis Reports and Related Documentation (MRP-102)	December 2003	1009309
Welding Residual and Operating Stresses in PWR Alloy 182 Butt Welds (MRP-106)	February 2004	1009378

Assorted NRC Resources Related to PWSCC of Alloy 600/82/182

Title	Date	Document Description
Changes to Chapter VI of “Generic Aging Lessons Learned (GALL) Report” (NUREG-1801)	March 10, 2003	ML030690518
Degradation of Control Rod Drive Mechanism Nozzle and Other Vessel Closure Head Penetration	April 1, 1997	Generic Letter 1997-001
Degradation of the Davis-Besse Nuclear Power Station Reactor Pressure Vessel Head Lessons-Learned Report	September 30, 2002	ML022760172
Generic Aging Lessons Learned (GALL) Report (Vol 1 and Vol 2)	July 2001	NUREG-1801
Leakage Found on Bottom-Mounted Instrumentation Nozzles	August 13, 2003	NRC Information Notice 2003-11
Leakage from Reactor Pressure Vessel Lower Head Penetrations and Reactor Coolant Pressure Boundary Integrity	August 21, 2003	NRC Bulletin 2003-02
NRC Inspection Manual Temporary Instruction 2515/150 Reactor Pressure Vessel Head and Vessel Head Penetration Nozzles	October 2002	NRC Inspection Manual
NRC Review of Responses to Bulletin 2002-01, “Reactor Pressure Vessel Head Degradation and Reactor Coolant Pressure Boundary Integrity”	July 29, 2003	NRC Regulatory Issue Summary 2003-13

Title	Date	Document Description
Possible Indicators of Ongoing Reactor Pressure Vessel Head Degradation	April 4, 2002	NRC Information Notice 2002-13
Primary Water Stress Corrosion Cracking (PWSCC) of Inconel 600	February 23, 1990	NRC Information Notice 90-10
Reactor Pressure Vessel Head Degradation and Reactor Coolant Pressure Boundary Integrity	March 18, 2002	NRC Bulletin 2002-01
Recent Experience with Degradation of Reactor Pressure Vessel Head	March 12, 2002	NRC Information Notice 2002-11
South Texas Project Electric Generating Station; Units 1 and 2 ; Special Inspection Team Report	September 8, 2003	ML032510978
Standard Review Plan for Review of License Renewal Applications for Nuclear Power Plants	July 2001	NUREG-1800
Through-Wall Circumferential Cracking of Reactor Pressure Vessel Head Control Rod Drive Mechanism Penetration Nozzles at Oconee Nuclear Station, Unit 3	April 30, 2001	NRC Information Notice 2001-05

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ASSORTED OWNERS GROUP ALLOY 600/82/182 RESOURCES

Assorted B&WOG Developed Alloy 600 PWSCC Resources

Description	Date	Product Classification
A Tool for Development of a Program Plan for Life Cycle Management of Alloy 600 PWSCC Issues	1999	Life Cycle Management Alternatives
Allowable Axial Flaw Sizes for CRDM Nozzles Evaluated Based on the NEI Acceptance Criteria	1994	CRDM Nozzle Flaw Acceptability Evaluation
An Engineering Evaluation of Sulfur Intrusions at B&WOG Plants Relative to the Zorita Event	1996	Investigation of Sulfur Intrusions
An Evaluation of Available Leak Detection and Monitoring Systems for Identifying CRDM Nozzle Leakage on the RV Head	1993	Leak Detection/Monitoring System Evaluation
An integrated B&WOG response to NRC Generic Letter 97-01	1997	B&WOG Response to Generic Letter 97-01
Available Heats of Archive Alloy 600 Material (CRDM nozzles) were Procured from B&W for Testing	1993	Archive Alloy 600 Material Procurement
B&WOG Funding Provided for CRDM Nozzle Re-Inspection Activities at ONS-2 as Continued Justification of CRDM Nozzle Acceptability (part of GL 97-01 B&WOG integrated inspection program)	1999	CRDM Nozzle Inspection
B&WOG Position Concerning the Safety Significance of SCC of Partial Penetration Welded Pressurizer Nozzles	1991	Position Statement
Evaluation of CRDM Nozzle Inspection Results - Update to the 1995 Report, Evaluating the Latest Inspection Results	1997	Evaluation of CRDM Nozzle Inspection Results
Evaluation of the RTD Bosses on the Reactor Coolant Piping		B&WOG
Leakage Assessment for Potential Leakage through a CRDM Nozzle and the Closure Head Due to PWSCC	1993	CRDM Nozzle Leakage Assessment

Description	Date	Product Classification
Leakage Assessment for Potential Leakage through a CRDM Nozzle and the Closure Head due to PWSCC	1993	B&WOG CRDM Nozzle Program
Original CRDM Nozzle Safety Evaluation for B&WOG Plants	1993	CRDM Nozzle Safety Evaluation
Original CRDM Nozzle Safety Evaluation for B&WOG Plants	1993	B&WOG CRDM Nozzle Program
Replication of Several Heats of CRDM Nozzles Performed In-Situ to Identify Heat-to-Heat and Lot-to-Lot Differences in Microstructure	1997-1998	CRDM Nozzle Replication
Responses to NRC Generic Letter 97-01 Requests for Additional Information	1998	B&WOG Response to GL 97-01 RAIs
Safety Assessment for Identified Flaws in CRDM Nozzles	1999	CRDM Nozzle Flaw Assessment
Safety Assessment for Identified Flaws in CRDM Nozzles	1999	B&WOG Alloy 600 Program
Safety Assessment for Identified Flaws in IMI Nozzles	1999	IMI Nozzle Flaw Assessment
Safety Assessment for Identified Flaws in IMI Nozzles	1999	B&WOG Alloy 600 Program
Safety Assessment for Identified Flaws in RTE Nozzles	1999	RTE Nozzle Flaw Assessment
Safety Assessment for Identified Flaws in RTE Nozzles	1999	B&WOG Alloy 600 Program
Summary and Evaluation of CRDM Nozzle Inspection Results Obtained in 1994 as they Pertain to the B&WOG	1995	Evaluation of CRDM Nozzle Inspection Results
Summary Documentation of CRDM Nozzle Fabrication and Manufacturing for all B&W-design 177-FA RV Heads	2001	CRDM Nozzle Fabrication and Manufacturing History
Summary of all B&WOG Efforts on Alloy 600 PWSCC and Suggestions for Future Utility Actions	1999	Guidelines for Alloy 600 PWSCC Aging Management
Summary of the Manufacturing and Fabrication of Thermocouple Nozzles at ONS-1 and TMI-1	1999	Thermocouple Nozzle Fabrication and Manufacturing History

Assorted CEOG Tasks and Products Related to Alloy 600

Task Description	Date	Product Description
Alloy 600 Penetration Information Package (Task 634)	March 1991	Review of fabrication and material identification drawings to compare forging/anneal conditions of all penetrations to heater sleeve applications
CEDM Penetration Cracking – Response to GL 97-01	July 1997	Provided CEOG plant response to GL 97-01 questions on material, resin events etc.
CEDM Penetration Cracking (Task 1053)	April 1998	Documented locations and inspections performed on bi-metallic weld CEDM locations in CEOG plants in response to Prairie Island part length CEDM housing crack
CEDM Penetration Cracking Program (Tasks 744, 769)	November 1994	Safety evaluations of CEDM penetration cracking, addressing ID-initiated axial cracking and OD-initiated circumferential cracking
CEDM Penetration Cracking Program CEOG Tasks 744 and 769	November 1994	Safety evaluations of CEDM penetration cracking, addressing ID-initiated axial cracking and OD-initiated circumferential cracking
CEOG Alloy 600 Working Group Program Plan (Task 692)	October 1991	Summarized work accomplished through 1991 and established mitigation goals for future work
Cooling of Upper Head to Mitigate PWSCC of Alloy 600 CEDM Nozzles (Tasks 953, 1050)	May 1999	Investigated magnitude of bypass cooling in CE plant RV heads to provide estimate of CEDM nozzle temperatures
EPRI/Dominion Engineering Timing Model	February 1999	Provided input on materials, nozzle configuration to the DEI timing model used by NEI in responding to NRC on GL 97-01 CEDM nozzle susceptibility assessment
Information Package on Pressurizer Heater Sleeves (Task 631)	November 1989	Documented response to specific NRC concerns on susceptibility to other CEOG plants to Alloy 600 penetration PWSCC
Low Alloy Steel Corrosion/Fatigue Analysis Supporting Small Diameter Nozzle Repairs (Tasks 1131, 1170)	January 2001	Generic analysis of LAS corrosion and fatigue crack growth to support non-Code repairs to small bore penetration nozzles
Pressurizer and Piping Surge Nozzle Stress Analyses (Task 639, 697)	October 1993	Stress analyses to address surge line thermal stratification
Pressurizer Heater Sleeve Examinations (Task 636)	September 1991	Failure examinations of Calvert Cliffs-2 heater sleeves looked at microstructure, residual stress and surface cold work contribution to failures.

Task Description	Date	Product Description
Pressurizer Instrument Nozzle Evaluation (Task 633)	February 1991	Failure examination of Calvert Cliffs-2 pressure tap nozzle looked at welding/re-work issues contributing to failure
Pressurizer Shell Corrosion Testing (Task 637)	April 1991	Assess safety significance of Alloy 600 heater sleeve penetration leaks on pressurizer shell material
Pressurizer Shell Corrosion Testing (Task 637)	April 1991	
Response to Prairie Island Part Length CEDM Housing Crack (Task 1053)	April 1998	Documented locations and inspections performed on bi-metallic weld CEDM locations in CE OG plants
VC Summer Weld Crack Comparison to CEOG Plants	March 2001	Identified location of bi-metallic RCS pipe welds, performed design comparison and evaluated susceptibility to weld crack found at VC Summer

Assorted Westinghouse Owners Group Alloy 600 Issue Program Deliverables

Title	Number
50.59 Safety Evaluation (Proprietary Class 3)	Westinghouse WCAP-13565 R1
Additional Microstructure Assessments (Proprietary Class 2)	WCAP-13856
American Society of Mechanical Engineers (ASME) Letter Providing Comments on Draft PWSCC Generic Letter	ESBU/WOG-96-349
Configuration Controlled Program RVHPPROF Version 1.0 for probability with time and spreadsheet files in Lotus 123, Excel and Quattro-Pro formats for the failure cost range calculation	WOG-96-024.
Crack Growth and Microstructural Characterization of Alloy 600 Head Penetration Materials (Proprietary Class 2 & 2C),	WCAP-13929, R1 & R2
Crack Growth Data for Representative Penetration Material	ME-SAT-108(93)
Environmental Effects on Crack Growth	WOG-95-157
Establish Relationship Between French Parameters and Parameters Utilized on Westinghouse Vessels (Proprietary Class 2)	MED-PCE-13493
Final Report Documenting the Development and Use of Simple Decision Risk Tools for Managing PWSCC in Reactor Vessel Head Penetrations - Phase 1," (Westinghouse Proprietary Class 2C)	WCAP-14588
Finite Element Analysis (Elastic/Plastic), Crack Propagation Analysis/Acceptable Flaw Size, Penetration Leakage Assessment, Plant Categorization, Material Condition and Microstructure Characterization, Wastage Rates Under Tight Annulus Conditions (Proprietary Class 2)	WCAP-13525

Title	Number
Finite Element Analysis (Elastic/Plastic), Crack Propagation Analysis/Acceptable Flaw Size, Penetration Leakage Assessment, Plant Categorization, Wastage Rates Under Tight Annulus Conditions (Propriety Class 2)	Westinghouse WCAP-13525
NEI Fax on Alloy 600 Reactor Pressure Vessel (RPV) Head Penetration Cracking Task Force Draft Comment Letter on Proposed Generic Letter	ESBU/WOG-96-322
NEI Letter on Proposed Generic Communication, "PWSCC of Control Rod Drive Mechanism and Other Vessel Head Penetrations"	ESBU/WOG-96-331
OD Crack Assessment (Proprietary Class 2)	WCAP-13525 A1
Outer Diameter (OD) Crack Assessment (Proprietary Class 2)	Westinghouse WCAP-13525 A1
Reactor Vessel (RV) Closure Head Penetrations Finite Element Stress Analysis (Proprietary Class 2)	WCAP-13426
Root Cause of Cracking	MED-PCE-1224
RV Closure Head Penetration - Supplemental Assessment of NRC SER Issues" (Westinghouse Proprietary Class 2C)	WCAP-14219 Rev. 1
RV Closure Head Penetration - Supplemental Assessment of NRC SER Issues" (Westinghouse Non-Proprietary Class 3	WCAP-14432
RV Closure Head Penetration Alloy 600 PWSCC - Phase 2 (Proprietary Class 3)	WCAP-13603
Summary of 5/5/97 NEI Task Force Meeting on Alloy 600 Head Penetrations	ESBU/WOG-97-130
Survey of WOG Member Utilities' Plans to Address Alloy 600 Reactor Vessel Head Penetration (RVHP) Cracking	OG-97-029
Transmittal Babcock and Wilcox Owners Group (B&WOG) Report "Midland CRDM J-Groove Weld UT Inspection Results"	ESBU/WOG-96-428
Transmittal of Draft WCAP-14712 "An Assessment of the Potential for IGA/Stress Corrosion Cracking (SCC) in the Primary System Components of WOG Units Due to Resin Ingress into the RCS, a White Paper"	ESBU/WOG-96-352
Transmittal of Final Resin Intrusion Guidelines and Suggested Response for Item 2 of GL 97-01	WOG-97-116

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