
Temporary Instruction 2515/150

REACTOR PRESSURE VESSEL HEAD AND VESSEL HEAD PENETRATION NOZZLES
(NRC BULLETIN 2002-02)

CORNERSTONE: BARRIER INTEGRITY
INITIATING EVENTS

APPLICABILITY: This temporary instruction (TI) applies to all holders of operating licenses for pressurized-water reactors (PWRs).

2515/150-01 OBJECTIVE

The objective of this TI is to support the review of licensees' activities in response to NRC Bulletin 2002-02, "Reactor Pressure Vessel (RPV) Head and Vessel Head Penetration (VHP) Nozzle Inspection Programs." This TI validates that a plant conforms to its inspection commitments using procedures, equipment, and personnel that have been demonstrated to be effective in the detection and sizing of primary water stress corrosion cracks (PWSCC) in VHP nozzles. As an ancillary benefit, this TI promotes information gathering to help the NRC staff identify and shape possible future regulatory positions and generic communications.

2515/150-02 BACKGROUND

Bulletin 2002-02 is the third bulletin issued in a two year span to address RPV head material wasteage and VHP nozzle PWSCC. The intent of the first bulletin, Bulletin 2001-01, was to ascertain the extent of CRDM cracking in pressurized water reactors (PWRs). One of the intents of the second bulletin, Bulletin 2002-01, was to ascertain the extent of material wastage similar to Davis-Besse in other PWRs. During the review of the responses to the first two bulletins, the staff identified a weakness in the ASME Code requirements applicable to RPV head and VHP nozzle inspections. Specifically, the staff is questioning the adequacy of current RPV head and VHP inspection requirements and programs that rely on visual examinations as the primary inspection method. Visual examinations, as a primary inspection method for the RPV head and VHPs, may need to be supplemented with additional non-visual examinations to demonstrate compliance with applicable regulations. The intent of Bulletin 2002-02 is to learn what, if any, changes PWR licensees have made to their RPV head and

VHP nozzle inspection programs to account for the identified weakness in the ASME Code requirements.

On August 9, 2002, NRC Bulletin 2002-02 was issued in response to continuing investigation into circumferential cracking in control rod drive mechanism (CRDM) nozzles and material wastage of RPV heads. Circumferential cracking has been identified at Crystal River 3, Davis-Besse, Oconee 2, and Oconee 3. Cracking has been identified in the J-groove welds of CRDM nozzles at ANO 1, Crystal River 3, Davis-Besse, Millstone 2, North Anna 1, North Anna 2, Oconee 1, Oconee 2, Oconee 3, Surry 1, and TMI 1. Material wastage has been identified at Davis-Besse.

The discovery of PWSCC in PWR control rod drive mechanism (CRDM) nozzles and other VHP nozzles fabricated from Alloy 600 is not a new issue. Axial cracking in the CRDM nozzles has been identified since the late 1980s. In addition, numerous small-bore Alloy 600 nozzles and pressurizer heater sleeves have experienced leaks attributable to PWSCC. The area of interest for potential cracking of RPV head penetrations is the pressure-retaining boundary, which includes the J-groove weld between the nozzle and reactor vessel head and the portion of the nozzle at and above the J-groove weld. Circumferential cracking above the J-groove weld is considered a safety concern because of the possibility of nozzle ejection should the circumferential cracking progress without being detected and corrected.

For additional background on the technical and safety concerns and descriptions of selected plant events, please read the Discussion and Background Sections in Bulletins 2001-01 (accession number ML012080284), 2002-01 (accession number ML020770497]), and 2002-02 (accession number ML022200494).

NRC Bulletin 2002-02 states that visual examinations, as a primary inspection method for the RPV head and VHP nozzles, may need to be supplemented with additional measures (e.g., volumetric and surface examinations). If a plant's 30-day response to Bulletin 2002-02 does not contain a justification for continued reliance on visual examinations, it is expected that the plant will explain which combination of volumetric, surface, and visual examinations of their RPV head and VHP nozzles that they intend to use and provide a technical justification for their selected combination of examinations.

Bulletin 2002-02 provides an example of a combination of volumetric, surface, and visual examinations that the staff would find acceptable. In the Bulletin example, plants with a RPV head with high susceptibility to cracking are expected to perform 100% volumetric examination of the VHP nozzles, 100% surface examination of the J-groove welds, and 100% bare metal visual examination of the RPV head, including 360^{O} around each VHP nozzle (see Appendices A and B). In the Bulletin example, plants with a RPV head with moderate susceptibility to cracking are expected to perform either 100% volumetric examination of the VHP nozzles and 100% surface examination of the J-groove welds or 100% bare metal visual examination of the RPV head, including 360^{O} around each VHP (see Appendices A and B). In the Bulletin example, plants with a RPV head with low susceptibility to cracking are expected to perform 100% volumetric examination of the VHP nozzles and 100% surface examination of the J-groove welds within 5 years of the issuance of Bulletin 2002-02 and 100% bare metal visual examination of the RPV head, including 360^{O} around each VHP within 3 years of the issuance of Bulletin 2002-02 (see Appendices A and B). It should be noted that the combination of examinations stated in the example is not the only acceptable combination for verifying the integrity of RPV head and VHP nozzles.

Since May 2001, the staff has had an ongoing effort to assess the capabilities of the nondestructive examination techniques. This has been accomplished both through witnessing equipment performance demonstrations and assessing results during outages at North Anna, D.C. Cook and Three Mile Island. Demonstrations have been accomplished to detect service-induced PWSCC. Recently, demonstrations supervised by the Electric Power Research Institute and the Materials Reliability Program (EPRI/MRP) have been conducted using Cold Isostatic Process (CIP) flaws to more accurately determine the limitations of the NDE systems to detect and size cracking.

2515/150-03 INSPECTION REQUIREMENTS

03.01 <u>General</u>

If a licensee has chosen a course of action other than the example contained in Bulletin 2002-02, the inspectors will coordinate with their respective region and the NRC's Office of Nuclear Reactor Regulation (NRR), Division of Engineering (DE), Materials and Chemical Engineering Branch (EMCB) to determine which section(s) of this TI to use in performing an inspection that will verify whether the licensee's course of action meets the intent of NRC Bulletin 2002-02.

03.02 <u>Susceptibility Ranking</u>

The susceptibility ranking for a plant is based on the plant's RPV head operating time and temperature. The susceptibility calculation should take into account the time-at-temperature for operation until the current outage.

a. The inspector will review the susceptibility ranking calculation.

03.03 <u>Volumetric Examination</u>

If volumetric examinations are performed, the inspection will consist of the following activities:

a. Inservice Inspection (ISI) specialist inspectors will perform Inspection Procedure (IP) 57080,"Ultrasonic Testing Examination." Inspection requirement and guidance associated with inspection objective 01.01 in IP 57080 will be excluded from the inspection scope. The inspection of the licensee's reactor VHP nozzle examinations may be considered part of the sample required by IP 71111.08, "Inservice Inspection Activities," Sections 02.01 and 02.03. The inspection sample should consist of:

    1. Review 10% of VHP nozzle volumetric examinations.

    2. If an inspection opportunity is available, observe one or two VHP nozzle volumetric examinations.

3. If applicable, review one or two of examinations from the previous outage with recordable indications that have been accepted by the licensee for continued service.

4. If applicable, review one examination of a repaired nozzle. This review may be included in the 10% mentioned in 03.03 a 1.

5. If applicable, review one or two ASME Section XI Code repairs or replacements.

b. The inspector will observe the licensee's implementation of the chosen method to detect PWSCC within and on the surface of the VHP nozzle. In particular verify that the implementation of the chosen method is consistent with the qualification or demonstration of that method.

c. The inspector will interview personnel, and observe a sample of the volumetric examination of the VHP nozzles.

d. The inspector will report anomalies, deficiencies, and discrepancies identified with the reactor coolant system (RCS) structures or the examination process, when such problems are judged to be significant enough to potentially impede the examination process.

03.04 Surface Examination

If a surface examination (i.e., liquid penetrant or eddy current) is to be performed, the inspection will consist of the following activities:

a. Inservice Inspection (ISI) specialist inspectors will follow Inspection Procedure (IP) 57060, "Liquid Penetrant Testing Examination," using a sample of VHP nozzles to assess the licensee's qualified surface examination. The inspection of the licensee's VHP nozzle and/or J-groove weld surface examinations may be considered part of the sample required by IP 71111.08," Sections 02.01 and 02.03. The inspection sample should consist of:

1. Review 5% - 10% of VHP nozzle and/or J-groove weld surface examinations.

2. If an inspection opportunity is available, observe one or two VHP nozzle and/or J-groove weld surface examinations.

3. If applicable, review one or two of examinations from the previous outage with recordable indications that have been accepted by the licensee for continued service.

4. If applicable, review one examination of a J-groove weld that was repaired during a previous inspection. This review may be included in the 5% - 10% mentioned in 03.04 a 1.

    5. If applicable, review one or two ASME Section XI Code repairs or replacements.

b. The inspector will observe the licensee's implementation of the chosen method to detect relevant surface conditions. In particular verify that the implementation of the chosen method is consistent with the qualification or demonstration of that method.

c. The inspector will interview personnel, and observe a sample of the surface examination of the VHP nozzles and/or J-groove welds.

d. The inspector will report anomalies, deficiencies, and discrepancies identified with the reactor coolant system (RCS) structures or the examination process, when such problems are judged to be significant enough to potentially impede the examination process.

03.05 Bare Metal Visual Examination

The identification of boron crystals may be evidence of a leak in the pressure boundary. If a bare metal visual examination is to be performed, the inspection will consist of the following activities:

a. Inservice Inspection (ISI) specialist inspectors will follow Inspection Procedure (IP) 57050,"Visual Testing Examination." Inspection requirement and guidance associated with inspection objective 01.01 in IP 57050 will be excluded from the inspection scope. The inspection of the licensee's reactor VHP nozzle examinations may be considered part of the sample required by IP 71111.08, "Inservice Inspection Activities," Sections 02.01 and 02.03. The inspection sample should consist of:

    1. Review 5% - 10% of RPV head bare metal visual examination.

    2. If an inspection opportunity is available, observe three to five VHP nozzle examinations (i.e., 360^{O} around penetration).

b. The inspector will interview personnel, and observe and assess the effectiveness of a sample of the visual examination of the VHP nozzles.

c. If an inspection opportunity is available, inspectors will observe and report the condition of the reactor vessel head, and also report on the licensee's capability to detect small amounts of boron.

d. Inspectors will report areas of the RPV head or VHP nozzles obscured by boron deposits from preexisting leaks (i.e., masked, masking) or debris.

e. Inspectors will report anomalies, deficiencies, and discrepancies identified with the associated structures or the examination process when such problems are judged to be significant enough to potentially impede the examination process in accordance with the reporting instructions of this TI.

2515/150-04 GUIDANCE

04.01 General. The inspectors should be cognizant of extenuating circumstances at their respective plant(s), such as the operational history, physical layout and material condition of the reactor vessel head, and any identified VHP nozzle leakage or other Alloy-600 PWSCC indications that would suggest a need for more aggressive licensee inspection practices. In addition, since inspection and repair activities can potentially result in large collective occupational doses, licensees should ensure that all activities related to the inspection of VHP nozzles and the repair of identified degradation are planned and implemented to keep personnel exposures as low as reasonably achievable (ALARA), consistent with the NRC Part 20, ALARA requirements.

04.02 Susceptibility Ranking. The initial susceptibility ranking is based on time and head temperature. However, if a part through-wall flaw was identified in a previous inspection for a plant with less than 8 effective degradation years (EDY), then the plant should be categorized as moderately susceptible. Regardless of EDY, if through-wall or through-weld cracking was identified during a previous inspection or is identified during the current inspection, then the plant should be categorized as a high susceptibility plant. Other factors that affect crack initiation and growth such as material heat, microstructure, and residual stresses are not included in the susceptibility ranking established by the industry.

a. Review the plant's RPV head susceptibility calculation to verify that appropriate plant-specific information was used as input. The time-at-temperature model developed by Electric Power Research Institute for this purpose is described in Appendix C.

b. Review the basis for the head temperature(s) used by the licensee to determine the RPV head susceptibility ranking.

c. Review previous inspection results to determine if there were any part-through wall, through wall, or circumferential cracks identified and whether that information was used in determining RPV head susceptibility ranking.

d. Document the manufacturer and material heat(s) for the RPV head and the VHP nozzles.

04.03 Volumetric Examination

a. Verify whether the examination procedures and equipment used in the examinations are consistent with those used during the qualification or demonstration.

b. Verify whether the essential variables such as type and frequency of transducer used in the examination are consistent with the those used during qualification or demonstration.

c. Interview examination personnel and/or analysts to verify that they are knowledgeable of the licensee's activities and procedural requirements.

d. Review the qualifications and certification of the inspection personnel to ascertain the basis used for certification (e.g., successful participation in the qualification or demonstration of the equipment and methods).

e. Review the examination procedure to verify that it requires documentation of work, such that the examination scope, process, criteria, and results are complete and clearly described.

f. Review the examination procedure to verify that it provides inspection standards and acceptance criteria that are clear and on which personnel have been trained.

g. Review the licensee’s documentation to verify that it provides flaw evaluation guidelines that are clear and on which personnel have been trained. An example of an acceptable flaw evaluation guideline is provided in Appendix D.

h. Identify any anomalies, deficiencies, and discrepancies associated with the RCS structures or the examination process including those identified by the licensee and then verify they are placed in the licensee’s corrective action process. In accordance with the bulletin, the licensee will provide information concerning any identified VHP nozzle leakage and for cracking detected in the plant. The inspectors will report lower-level issues concerning data collection and analysis, as well as any issues that are deemed to be significant to the phenomenon described in the bulletin. The inspector will report whether the demonstrated exam procedures were implemented properly. These items should be reported in accordance with the reporting instructions of this TI.

04.04 Surface Examination

a. Verify whether the examination procedures and equipment used in the examination are consistent with the those used during qualification or demonstration.

b. Interview examination personnel and/or analysts to verify that they are knowledgeable of the licensee’s activities and procedural requirements.

c. Review the qualifications and certification of the inspection personnel to ascertain the basis used for certification (e.g., successful participation in the qualification or demonstration of the equipment and methods).

d. Review the examination procedure to verify that it requires adequate documentation of work, such that the examination scope, process, criteria, and results are complete and clearly described.

e. Review the examination procedure to verify that it provides inspection standards and acceptance criteria that are clear and on which personnel have been trained.

f. Review the licensee’s documentation to verify that it provides flaw evaluation guidelines that are clear and on which personnel have been trained. An example of an acceptable flaw evaluation guidelines are provided in Appendix D.

g. Identify any anomalies, deficiencies, and discrepancies associated with the RCS structures or the examination process including those identified by the licensee and then verify they are placed in the licensee's corrective action process. In accordance with the bulletin, the licensee will provide information concerning any identified VHP nozzle leakage and for cracking detected in the plant. The inspectors will report lower-level issues concerning data collection and analysis, as well as any issues that are deemed to be significant to the phenomenon described in the bulletin. The inspector will report whether the demonstrated exam procedures were implemented properly. These items should be reported in accordance with the reporting instructions of this TI.

04.05 Bare Metal Visual Examination

a. Observe a sample of the visual examination of the VHP nozzles. The sample should consist of VHP nozzles at different points distributed around the reactor vessel head curvature. The sample should also allow for assessment of the physical difficulties in conducting the examination. Assess the effectiveness of the visual examination and ensure that it can reliably detect and accurately characterize any leakage from cracking in VHP nozzles, and that it is not compromised by the presence of insulation, pre-existing deposits on the reactor vessel head, or other factors that could interfere with the detection of leakage.

   1. Interview examination personnel and/or analysts to verify that they are knowledgeable of the licensee's activities and procedural requirements.

   2. Review the qualifications and certification of the inspection personnel to ascertain the basis used for certification (e.g., successful participation in the qualification or demonstration of the equipment and methods).

   3. Review examination procedure to determine whether it provides adequate guidance and examination criteria to implement the licensee's examination plan. The procedures should meet the following minimum criteria:

      (a) Ensure that a complete reactor vessel head examination is planned and successfully implemented. A complete examination means that all penetration nozzles are examined 360^o around the circumference of the nozzle. A VHP nozzle location indexing plan may be established to ensure that the examination accounts for all nozzles. If so, it should be reviewed for completeness.

      (b) Require adequate documentation of work, such that the examination scope, process, criteria, and results are complete and clearly described.

      (c) Provide inspection standards and acceptance criteria that are clear and on which personnel have been trained.

   4. Conduct a performance-based inspection to verify that the licensee properly performed the procedure. Pay particular attention to ensure that the visual

clarity of the examination process was adequate; the method used to track identification of the penetrations being inspected is effective; and that prior (pre-existing) boron deposits, debris, and insulation were effectively identified and categorized.

b. If an inspection opportunity is available, inspectors will assess the condition of the reactor vessel head through either direct observations or video inspections. In particular, inspectors should look for and document items on the reactor vessel head, such as debris, insulation, dirt, boron from other sources, physical layout, and viewing obstructions. Additionally, inspectors should assess the licensee's ability to distinguish small boron deposits on the head. If an opportunity to observe the reactor vessel head does not become available, inspectors will briefly describe the circumstances (i.e., is this a routine outage condition that does not permit viewing the reactor vessel head) and what they could observe.

c. If boron deposits are attributed to a source other than leakage through the pressure boundary and if supplemental non-visual NDE is not performed of the obscure area (i.e., masked), inspectors will review the criteria used by licensee to assure boron deposit may not be the result of leakage from a through wall or through weld crack in the VHP assembly.

d. Inspectors will identify any anomalies, deficiencies, and discrepancies associated with the RCS structures or the examination process including those identified by the licensee and then verify they are placed in the licensee's corrective action process. In accordance with the bulletin, the licensee will provide information concerning any identified VHP nozzle leakage and cracking detected. The inspectors will report lower-level issues concerning data collection and analysis, as well as any issues that are deemed to be significant to the phenomenon described in the bulletin. These items should be reported in accordance with the reporting instructions of this TI.

2515/150-05 REPORTING REQUIREMENTS

Document inspection results in a resident inspectors' routine inspection report, and send a copy of the applicable sections to NRR/DE/EMCB, Attention: Allen Hiser and Michael Marshall, or e-mail to ALH1@NRC.GOV and MXM2@NRC.GOV. Mr. Hiser can also be reached by telephone at (301) 415-1034. Mr. Marshall can be reached by telephone at (301) 415-2734. One purpose of this TI is to support NRR/DE/EMCB by inspecting and reporting on the licensees' performance of reactor VHP nozzle examinations. Specifically, the inspectors should provide a qualitative description of the effectiveness of the licensees' examinations. At a minimum, the inspectors should be able to briefly answer the following questions (with a description of inspection scope and results) in IMC 0612, Section 4OA5, "Other," of the next integrated inspection report.

a. Was the examination:

   1. Performed by qualified and knowledgeable personnel? (Briefly describe the personnel training/qualification process used by the licensee for this activity.)

2. Performed in accordance with approved procedures?

3. Able to identify, disposition, and resolve deficiencies?

4. Capable of identifying the PWSCC phenomenon described in the bulletin?

b. What was the condition of the reactor vessel head (debris, insulation, dirt, boron from other sources, physical layout, viewing obstructions)?

c. Could small boron deposits, as described in the bulletin 01-01, be identified and characterized?

d. What material deficiencies (associated with the concerns identified in the bulletin) were identified that required repair?

e. What, if any, significant items that could impede effective examinations?

2515/150-06 COMPLETION SCHEDULE

This TI should be completed by the end of next scheduled unit refueling outage.

2515/150-07 EXPIRATION

This TI will expire 30 days after restart for the plant with the last scheduled refueling outage after issuance of Bulletin 2002-02, such that each plant is required to provide a response to this Temporary Instruction once. This time frame is consistent with response time for 30-day post-outage responses to Bulletin 2002-02.

2515/150-08 CONTACT

For questions regarding the performance of this TI and emergent issues, contact Allen Hiser at (301) 415-1034. or ALH1@NRC.GOV, or Michael Marshall at (301) 415-2734 or MXM2@NRC.GOV.

2515/150-09 STATISTICAL DATA REPORTING

All direct inspection effort expended on this TI is to be charged to 2515/150 for reporting by the Regulatory Information Tracking System (RITS) reporting with an IPE code of SI.

2515/150-10 ORIGINATING ORGANIZATION INFORMATION

10.01 Organizational Responsibility

This TI was initiated by the Materials and Chemical Engineering Branch (NRR/DE/EMCB).

10.02 Resource Estimate

The estimated direct inspection effort to perform this TI is estimated to be 15 to 50 hours per PWR unit.

10.03 Training

No formal training is proposed for the performance of this TI.

END

Appendix A:	Combination of Volumetric, Surface, and Visual Examinations Acceptable to the Staff
Appendix B:	Plants' RPV Head Susceptibility Rankings
Appendix C:	Calculation of Susceptibility Ranking
Appendix D:	Flaw Evaluation Guidelines Acceptable to the Staff

Appendix A

Combination of Volumetric, Surface, and Visual Examinations Acceptable to the Staff

(Excerpt from Bulletin 2002-02)

Source: Bulletin 2002-02, "Reactor Pressure Vessel Head And Vessel Head Penetrations Inspection Programs," August 9, 2002.

Table 1: Example of Reasonable Supplemental Inspections

Inspections	Frequency/Time (Notes 1 and 2)		
	< 8 EDY	≥8 EDY and ≤12 EDY	> 12 EDY
100% Ultrasonic Testing of CRDM Nozzle Base Material (Note 3) and	within 5 years, then at least once every 60 full power months	every other refueling outage (not to exceed 48 full power months), beginning with the refueling outage after the next refueling outage	every refueling outage (not to exceed 24 full power months), beginning with the next refueling outage
100% Eddy Current Testing or Dye Penetrant Testing of all J-Groove Weld and CRDM Penetration Material Wetted Surfaces (Note 4) and	within 5 years, then at least once every 60 full power months	every other refueling outage (not to exceed 48 full power months), beginning with the refueling outage after the next refueling outage	every refueling outage (not to exceed 24 full power months), beginning with the next refueling outage
100% Bare Metal Visuals Examination of CRDM to RPV Junction at Top of RPV Head (Note 5)	within 3 years, then at least once every 60 full power months	every other refueling outage (not to exceed 48 full power months), beginning with the next refueling outage	every refueling outage (not to exceed 24 full power months), beginning with the next refueling outage

Note 1: An effective degradation year (EDY) is a means for assessing the potential for cracking at a plant. It accounts for the amount of time a plant has operated and the temperatures at which it has operated.

Note 2: If a part through-wall flaw is identified in a plant with less than 8 EDY, then the guidance in the middle column becomes applicable. Regardless of EDY, if through-wall or through-weld cracking is identified during the inspection, then the guidance in the last column becomes immediately applicable.

Note 3: Testing should include as a minimum, the portion of the nozzle inside the RPV head to the bottom of the nozzle.

Note 4: If ultrasonic testing has been demonstrated as reliable and effective in detecting and characterizing flaws in the J-groove weld, it may be used for inspections of J-groove welds.

Note 5: If boron deposits or other indications of leakage are identified, then non-visual examination needs to be used to make a determine whether the leakage is from a through-wall or through-weld crack.

Plants' RPV Head Susceptibility Rankings

The initial susceptibility ranking is based on time and head temperature. However, if a part through-wall flaw was identified in a previous inspection for a plant with less than 8 EDY, then the plant should be categorized as moderate susceptible. Regardless of EDY, if through-wall or through-weld cracking was identified during a previous inspection or is identified during the current inspection, then the plant should be categorized as high susceptible.

These calculated rankings reflect what the NRC has calculated during the development of Bulletin 2002-02. As time passes, these numbers increase, thus potentially moving plants between categories. Attachment 3 contains a description on how to calculate EDY. Should a plant replace its RPV head, the value of EDY is reset to zero.

High Susceptibility includes the sub-population of the following plants that have an estimated effective degradation years (EDY) value of greater than 12.

Plant	EDY	Plant	EDY	Plant	EDY
ANO 1	19.5	North Anna 1	19.4	San Onofre 3	14.4
Beaver Valley 1	12.4	North Anna 2	18.3	St. Lucie 1	14.7
Calvert Cliffs 1	14.2	Oconee 1	22.1	St. Lucie 2	12.3
Calvert Cliffs 2	13.8	Oconee 2	22.0	Surry 1	18.6
Crystal River 3	15.6	Oconee 3	21.7	Surry 2	18.6
D.C. Cook 2	13.0	Palisades	12.3	TMI 1	17.5
Davis-Besse	17.9	Point Beach 1	13.5	Turkey Point 4	16.6
Farley 1	15.8	Point Beach 2	14.9	Turkey Point 3	16.7
Farley 2	14.5	Robinson	19.0	Waterford 3	14.1
Ginna	15.1	San Onofre 2	14.5		

Moderate Susceptibility includes the sub-population of the following plants that have an estimated EDY between 8 to 12.

Plant	EDY	Plant	EDY	Plant	EDY
ANO 2	10.5	Indian Point 3	10.6	Prairie Island 2	9.9
Beaver Valley 2	8.3	Kewaunee	10.8	Salem 1	10.6
D.C. Cook 1	9.5	Millstone 2	10.5	Salem 2	8.3
Diablo Canyon 1	8.4	Palo Verde 1	9.4	South Texas 1	10.7
Diablo Canyon 2	9.6	Palo Verde 2	9.1	South Texas 2	11.1
Fort Calhoun	10.8	Palo Verde 3	9.1		

Low Susceptibility includes the sub-population of plants that have an estimated EDY of less than 8.

Plant	EDY	Plant	EDY	Plant	EDY
Braidwood 1	1.5	Comanche Peak 2	1.3	Shearon Harris 1	2.0
Braidwood 2	1.4	Indian Point 2	7.1	V.C. Summer	2.3
Byron 1	1.6	McGuire 1	2.2	Vogtle 1	2.2
Byron 2	1.4	McGuire 2	2.2	Vogtle 2	1.9
Callaway	2.3	Millstone 3	1.6	Watts Bar 1	0.7
Catawba 1	2.1	Seabrook	1.6	Wolf Creek	2.2
Catawba 2	1.9	Sequoyah 1	1.3		
Comanche Peak 1	1.7	Sequoyah 2	1.3		

Appendix C

Calculation of Susceptibility Ranking

(Excerpt from EPRI MRP's report MRP-48NP)

Source: PWR Materials Reliability Program Response to NRC Bulletin 2001-01 (MRP-48NP), EPRI, Palo Alto, CA: 2001. 1006284-NP.

2.1 PWSCC Rankings

Plants have been ranked for the potential for RPV top head nozzle PWSCC using a time-at-temperature model. The methodology is the same as was described previously in MRP-44, Part 2. However, the plant rankings presented here are based on the best available inputs as of August 21, 2001.

2.1.1 Time-at-Temperature Model

Since stress corrosion cracking (SCC) of Alloy 600 nozzle material and Alloy 182 weld metal is sensitive to temperature, the current MRP model adjusts the operating time for each plant using its head temperature history and an activation energy appropriate to SCC initiation. Initiation is a more important factor than crack growth for assessing plants since the time for crack initiation is longer than the time for crack growth.

The ranking for a particular plant is based on the number of effective full power years (EFPYs) of operation required for that plant to reach the same number of EFPYs as Oconee 3, normalized for any differences in head temperature. For example, a plant with a predicted value of 10 EFPYs would reach an equivalent degradation time as Oconee 3 after 10 EFPYs of additional operation at the current vessel head temperature.

2.1.2 Total Effective Full Power Years

The first step in the simplified plant ranking methodology was to assign an operating time to each plant. Effective full power years (EFPYs) was selected as the measure of operating time because it reflects the effect of lower head temperatures during startups, shutdowns and periods of reduced power operation. The model is based on the EFPYs for each plant through February 2001.

2.1.3 Head Temperature History

The second step in the time-at-temperature ranking methodology was to identify the current reactor closure head temperature at 100% power and any periods of past operation at significantly different temperatures. The three NSSS vendors previously determined the head temperatures as part of their work for the PWR NSSS Owners Groups, and the head temperature histories for all plants were compiled as part of the response to NRC Generic Letter 97-01.

Because of thermal-hydraulic differences between reactor designs, some plants operate with a head temperature close to the hot leg temperature, while some plants have a small amount of internals bypass flow and operate with a head temperature closer to the cold leg temperature. Most, but not all, plants listed their head temperature history in the initial responses to GL 97-01. For plants that have had prior head temperature changes, the operating time accumulated at the current head temperature through the end of February 2001 was calculated using the expression:

$$\Delta EFPY_n = EFPY_{total} - \sum_{j=1}^{n-1}\left(\Delta EFPY_j\right)$$

where:

$EFPY_n$ = effective full power years through February 2001 accumulated during time with the current head temperature Thead,n
$EFPY_{total}$= total effective full power years through February 2001
$EFPY_j$ = effective full power years accumulated during time period j
n = number of time periods with distinct 100% power head temperatures

2.1.4 Temperature-Adjusted Degradation Time

The third step in the time-at-temperature calculation was to calculate the plant operating time normalized to a reference temperature of 600°F. The standard Arrhenius activation energy dependence on temperature is applied to each time period with a distinct head temperature:

$$\mathrm{EDY}_{600^\circ\mathrm{F}} = \sum_{j=1}^{n}\left\{\Delta EFPY_j \exp\left[-\frac{Q_i}{R}\left(\frac{1}{T_{head,j}} - \frac{1}{T_{ref}}\right)\right]\right\}$$

where:

$EDY_{600^\circ F}$ = total effective degradation years through February 2001, normalized to a reference temperature of 600°F
Q_i = activation energy for crack initiation (50 kcal/mole)
R = universal gas constant (1.10310 -3 kcal/mol-°R)
Thead,j = 100% power head temp. during time period j (°R = °F + 459.67)
T_{ref} = arbitrary reference temperature (600°F = 1059.67°R)

An activation energy of 50 kcal/mole is an accepted industry best estimate activation energy for SCC initiation in primary water environments. A sensitivity study included in MRP 2001-050 shows that a change in the activation energy for crack initiation from 50 kcal/mole to a lower bound of 40 kcal/mole has little effect on the ranking of plants relative to Oconee 3.

2.1.5 Remaining Time to Reach Oconee 3 Degradation Time

The fourth step was to calculate the remaining time until the plant reaches the equivalent normalized operating time as Oconee 3 using the remaining margin in degradation time and the current head temperature to translate the margin back to EFPYs at the actual head temperature:

$$\Delta EFPY_{histogram} = \left(EDY_{600^\circ\mathrm{F}}^{Oconee3} - EDY_{600^\circ\mathrm{F}}\right)\exp\left[\frac{Q_i}{R}\left(\frac{1}{T_{head,n}} - \frac{1}{T_{ref}}\right)\right]$$

where:

$?EFPY_{histogram}$ = EFPYs from March 1, 2001, until reaching Oconee 3 EFPYs at time of its spring 2001 outage, normalized for differences in reactor vessel head temperature 3 Oconee

$EDY^{Oconee\,3}_{600^\circ F}$ = effective degradation time for Oconee 3 at time of spring 2001 outage (down Febraury 16) (= 21.7 years)

$T_{head,n}$ = current 100% power head temperature (°R)

In addition, the effect of any reported significant planned future head temperature changes (e.g., future conversion of head temperature to cold leg temperature) were also considered by breaking future operation into two time periods similar to the calculation approach of equation 2.2.

Appendix D

Flaw Evaluation Guidelines Acceptable to the Staff

The scope of these guidelines is limited at present to PWR control rod drive mechanism (CRDM) penetrations since smaller vessel head penetrations such as vents and thermocouple nozzles are not amenable to volumetric inspection. Flaws are defined in IWA-9000, “Glossary” of Section XI of the ASME Code. As a prerequisite for flaw evaluation, flaws must be reliably detected and sized within specified uncertainty bounds by qualified NDE methods. The other necessary information is the availability of accepted crack growth rates. In the following guidelines, if either of these elements is missing, repair is specified.

FLAW CHARACTERIZATION

Flaws must be characterized by both their length and depth within the specified sizing uncertainties. Currently, there is insufficient data available to assume an aspect ratio if only the flaw length has been determined.

- The proximity rules of ASME Code Section XI for considering flaws as separate may be used.

- When a flaw is detected, its projections in both the axial and circumferential directions shall be determined. Note that the axial direction is always the same for each nozzle head penetration, but that the circumferential direction will vary depending on the angle of intersection of the penetration with the head. The circumferential direction of interest is along the top of the attachment weld as illustrated in Figure 1. It is this angle along which separation of the nozzle penetration from the head could occur.

- Flaws that are equal to or greater than 45-degrees from the vertical centerline of the CRDM nozzle, or those that are within plus or minus 10-degrees of the angle (if less than 45-degrees) that the plane of the partial-penetration attachment weld (J-groove weld) makes with the vertical centerline of the CRDM nozzle, are considered to be circumferential flaws.

- The location of the flaw relative to the top and bottom of the J-groove weld shall be determined since the potential exists for development of a leak path if a flaw progresses up the nozzle past this weld. The flaw acceptance criteria are as specified below depending on whether the flaw is in the pressure boundary or in the portion of the nozzle below the J-groove weld.

FLAW ACCEPTANCE CRITERIA

CRDM Nozzle Pressure Boundary

The CRDM nozzle pressure boundary includes the J-groove weld and the portion of the nozzle projecting above the weld. While the CRDM nozzle is an integral part of the reactor vessel, no flaw evaluation rules exist for non-ferritic vessels or parts thereof in Section XI. Therefore, the following rules shall be applied:

- The allowable flaw standards for austenitic piping in Section XI, IWB-3514.3 may be applied for inside diameter (ID) initiated axial flaws only.

- Crack growth shall be evaluated for the period of service until the next inspection. The maximum flaw depth allowed is 75-percent of the nozzle thickness (refer to crack growth rate below).

- All outside diameter (OD) initiated flaws, regardless of orientation (axial or circumferential), shall be repaired.

- All ID-initiated circumferentially oriented flaws shall be repaired.

- Any flaw detected in the J-groove weld, its heat affected zone (or adjacent base material) must be repaired.

- Alternatives to Code required repairs will be considered for approval if justified.

<u>CRDM Nozzle Below the J-Groove Weld</u>

- Axially oriented flaws (either ID- or OD-initiated) are acceptable regardless of depth as long as their upper extremity does not reach the bottom of the weld during the period of service until the next inspection.

- Circumferential flaws (either ID- or OD-initiated) are acceptable provided that crack growth is evaluated for the period of service until the next inspection. In no case shall the projected end of cycle circumferential flaw length exceed 75-percent of the nozzle circumference.

- Intersecting axial and circumferential flaws shall be removed or repaired because of the greater propensity to develop into loose parts. Note: while flaws below the J-groove weld have no structural significance, loose parts must be avoided.

CRACK GROWTH RATE

<u>CRDM Nozzle Pressure Boundary</u>

- Crack growth to be used for axial ID initiated flaws shall be determined from the following equation as a function of the applied stress intensity:

$$\frac{da}{dT} = 1.8x10^{-11}\left(K-9\right)^{1.16} e^{-\frac{Q}{R}\left(\frac{1}{T+273.16}-\frac{1}{598.16}\right)} \text{ M/sec}$$

where:

K is the applied stress intensity in MPa $\sqrt{m}$
Q is the activation energy [32.4 kcal/mole (135 kJ/mole)]
R is the universal gas constant [1.987 cal/mol- ^{O}K (8.314 J/mol- ^{O}K)]
T is the head operating temperature (^{O}C)

- There is currently no accepted crack growth rate for the Alloy 182 J-groove weld material.

<u>CRDM Nozzle Below the J-Groove Weld</u>

- The crack growth rate to be used for the flaws in this region of the nozzle, shall be the same as that used for ID initiated axial flaws within the CRDM nozzle pressure boundary.