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March 12, 2018
L-18-055

10 CFR 50.55a

ATTN: Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT:
Beaver Valley Power Station, Unit No. 2
Docket No. 50-412, License No. NPF-73
<u>10 CFR 50.55a Request to Use Alternative Repair Methods for Reactor Vessel Head Penetrations and J-Groove Welds (Request 2-TYP-4-RV-04, Revision 0)</u>

In accordance with the provisions of 10 CFR 50.55a(z)(1), FirstEnergy Nuclear Operating Company (FENOC) hereby requests Nuclear Regulatory Commission (NRC) approval of a proposed alternative to certain requirements associated with reactor vessel head repairs for the Beaver Valley Power Station, Unit No. 2. Enclosure A identifies the affected components, the applicable code requirements, and the description and basis of the proposed alternative.

FENOC requests approval of the proposed alternative by August 28, 2018, which is the end of the current 10-year inservice inspection interval.

WCAP-16158-P, Revision 1, "Technical Basis for Repair Options for Reactor Head Penetration Nozzles and Attachment Welds: Beaver Valley Unit 2," which was used as a basis for this request, is provided as Enclosure B. WCAP-16158-P is considered proprietary and should be withheld from public disclosure under 10 CFR 2.390. Enclosure C provides the Westinghouse proprietary information affidavit. Enclosure D provides a non-proprietary version of WCAP-16158.

There are no regulatory commitments contained in this submittal. If there are any questions or if additional information is required, please contact Mr. Thomas A. Lentz, Manager – Fleet Licensing, at (330) 315-6810.

Sincerely,

Richard D. Bologna

Enclosures:

A. Beaver Valley Power Station, Unit No. 2, 10 CFR 50.55a Request 2-TYP-4-RV-04, Revision 0
B. WCAP-16158-P, Revision 1, "Technical Basis for Repair Options for Reactor Head Penetration Nozzles and Attachment Welds: Beaver Valley Unit 2"
C. Westinghouse Affidavit
D. WCAP-16158-NP, Revision 1, "Technical Basis for Repair Options for Reactor Head Penetration Nozzles and Attachment Welds: Beaver Valley Unit 2"

cc: NRC Region I Administrator
NRC Resident Inspector
NRC Project Manager
Director BRP/DEP
Site BRP/DEP Representative

ENCLOSURE A
L-18-055

10 CFR 50.55a Request 2-TYP-4-RV-04, Revision 0

[10 Pages Follow]

Proposed Alternative
In Accordance with 10 CFR 50.55a(z)(1)

--Alternative Provides Acceptable Level of Quality and Safety--

1. ASME Code Components Affected

Component Numbers:	2RCS-REV21 (Reactor Vessel) Reactor Vessel Head Penetrations (VHP) 1 through 65
Code Class:	Class 1
Examination Category:	Class 1 PWR Reactor Vessel Upper Head (ASME Code Case N-729-4, Table 1)
Item Number:	B4.20
Description:	Alternative Repair Methods for Reactor Vessel Head Penetrations and J-groove Welds

2. Applicable Code Edition and Addenda

American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (ASME Code), Section XI, 2013 Edition with no Addenda.

The reactor vessel Construction Code is ASME Section III, 1971 Edition through Summer 1972 Addenda.

3. Applicable Code Requirements

IWA-4000 of ASME Section XI contains requirements for the removal of defects from and welded repairs performed on ASME components. The specific Code requirements for which use of the proposed alternative is being requested are as follows:

ASME Section XI, IWA-4421 states, that:

> Defects shall be removed or mitigated in accordance with the following requirements:
>
> (a) Defect removal by mechanical processing shall be in accordance with IWA-4462.
>
> (b) Defect removal by thermal methods shall be in accordance with IWA-4461.

(c) Defect removal or mitigation by welding or brazing shall be in accordance with IWA-4411.

(d) Defect removal or mitigation by modification shall be in accordance with IWA-4340.

Use of the "Mitigation of Defects by Modification" provisions of IWA-4340 is prohibited per 10 CFR 50.55a(b)(2)(xxv).

For the removal or mitigation of defects by welding, ASME Section XI, IWA-4411 states, in part:

> Welding, brazing, fabrication, and installation shall be performed in accordance with the Owner's Requirements and...in accordance with the Construction Code of the item...

The applicable requirements of the Construction Code required by IWA-4411 for the removal or mitigation of defects by welding from which relief is requested are as follows.

For defects in base material, ASME Section III, NB-4131 requires that the defects are removed, repaired, and examined in accordance with the requirements of NB-2500. These requirements include the removal of defects via grinding or machining per NB-2538 and, if necessary to satisfy the design thickness requirement of NB-3000, repair welding in accordance with NB-2539.

For defects in weld material, ASME Section III, NB-4451 requires that unacceptable defects in weld metal be eliminated and, when necessary, repaired in accordance with NB-4452 and NB-4453.

4. Reason for Request

FirstEnergy Nuclear Operating Company (FENOC) conducts inspections of the Beaver Valley Power Station Unit No. 2 (BVPS-2) reactor vessel head in accordance with ASME Code Case N-729-4, with conditions as specified in 10 CFR 50.55a(g)(6)(ii)(D). During the reactor vessel head inspections, unacceptable flaw indications may be discovered in the penetration tube material or in the J-groove attachment welds that require repair. Relief is requested from the requirements of ASME Code Section XI, IWA-4421, IWA-4411, and the applicable sections of the Construction Code.

Specifically, relief is requested from the requirements of ASME Code Section III, NB-4131, NB-2538, and NB-2539 for the removal of base material defects prior to repair by welding. Relief is also requested from the requirements of ASME Code Section III, NB-4451, NB-4452, and NB-4453 for the removal of weld material defects prior to repair by welding.

5. Proposed Alternative and Basis for Use

The Nuclear Regulatory Commission (NRC) Safety Evaluation for WCAP-15987 specified the use of "Flaw Evaluation Guidelines," which was sent to the Nuclear Energy Institute (NEI) by letter dated April 11, 2003 (Reference 2). In lieu of these guidelines, FENOC proposes to follow the criteria for flaw evaluation established in 10 CFR 50.55a(g)(6)(ii)(D), which specifies the use of Code Case N-729-4, with conditions.

As an alternative to the defect removal requirements of ASME Section XI and Section III, FENOC proposes the use of the embedded flaw repair process described in WCAP-15987, Revision 2-A (Reference 3), for the repair of unacceptable indications in reactor vessel head penetrations and J-groove welds, as approved by the NRC (Reference 1). Design and implementation of the repairs will be consistent with WCAP-15987 and WCAP-16158-P, Revision 1 (Reference 4). Preservice inspections and inservice inspections of repairs will be consistent with ASME Code Case N-729-4. Pursuant to 10 CFR 50.55a(z)(1), the alternative is proposed on the basis that it will provide an acceptable level of quality and safety while minimizing cumulative occupational radiation exposure [dose].

5.1 Reactor Vessel Head Penetration Inside Diameter (ID) Repair Methodology for Axial Flaws

Consistent with WCAP-15987 methodology, the following repair requirements are proposed for a reactor vessel head penetration ID axial flaw repair.

An unacceptable axial flaw will be first excavated (or partially excavated) from the ID surface of the penetration tube to a depth no greater than 0.125 inches. Although this depth differs from that specified in WCAP-15987, Revision 2-A, Section 2.2.1, the cavity depth is not a critical parameter in the implementation of a repair on the ID surface. The goal of the inlay is to isolate the susceptible material from the primary water environment. The purpose of the excavation is to accommodate the application of primary water stress corrosion cracking (PWSCC) resistant Alloy 52 or 52M weld layers to isolate the susceptible material from the primary water environment. The excavation depth specified in WCAP-15987 is a nominal dimension and represents the depth needed to accommodate three weld layers while still maintaining the tube ID dimension. Since only two weld layers will be applied, less excavation is necessary and an excavation depth of 0.125 inches is all that is required. The smaller thickness of the cavity excavated for two layers of weld material results in a slightly thinner weld, and produces less residual stress.

The excavation will be performed using an electrical discharge machining process to minimize penetration tube distortion. After the excavation is complete, either an ultrasonic test (UT) or eddy current test (ECT) will be performed to ensure the entire flaw length is captured. Then, a minimum of two layers of Alloy 52 or 52M weld material will be applied to fill the excavation. The expected chemistry of the weld surface is that typical of Alloy 52 weldment with no significant dilution. Finally, the finished weld will be machined to restore the inside diameter of the penetration tube, and then a UT and surface examination will be performed to ensure acceptability.

5.2 Reactor Vessel Head Penetration Inside Diameter (ID) Repair Methodology for Circumferential Flaws

Consistent with WCAP-15987 methodology, the following repair requirements are proposed for a reactor vessel head penetration ID circumferential flaw repair.

If repair of an ID circumferential flaw is required, it will be either repaired in accordance with existing code requirements; or it will be partially excavated to reduce the flaw to an acceptable size, examined by UT or surface examination, inlaid with Alloy 52 or 52M, and examined by UT and surface examination as described in Section 5.1 of this request.

5.3 Reactor Vessel Head Penetration Outside Diameter (OD) and J-groove Weld Repair Methodology

Consistent with WCAP-15987 methodology, the following repair requirements are proposed for reactor vessel head penetration OD and J-groove weld repairs.

1. An unacceptable axial or circumferential flaw in a tube below a J-groove attachment weld will be sealed off with Alloy 52 or 52M weldment. Excavation or partial excavation of such flaws is not necessary, since clearance is not a concern on the outside of a tube. The embedded flaw repair technique may be applied to OD axial or circumferential cracks below the J-groove weld because they are located away from the pressure boundary, and the proposed repair of sealing the crack with Alloy 690 weld material would isolate the crack from the environment as stated in Section 3.6.1 of the NRC staff safety evaluation for WCAP-15987.

2. Unacceptable radial flaws in the J-groove attachment weld will be sealed off with a 360 degree overlay of Alloy 52 or 52M covering the entire weld. No excavation will be required. The overlay will extend onto and encompass the outside diameter of the penetration tube. The seal weld will extend beyond the Alloy 600 weld material by at least one half inch, as stated in the NRC safety evaluation for WCAP-15987.

3. Unacceptable axial penetration tube flaws extending into the J-groove attachment weld will be sealed with Alloy 52 or 52M as discussed in Item 1 above. In addition, the entire J-groove attachment weld will be overlaid with Alloy 52 or 52M to embed the axial flaw. The overlay will extend onto and encompass the outside diameter of the penetration tube. The seal weld will extend beyond the Alloy 600 weld material by at least one half inch, as stated in the NRC safety evaluation for WCAP-15987.

4. For weld overlays performed on the J-groove attachment weld, the interface boundary between the J-groove weld and stainless steel cladding will be located

with a hand-held ferrite meter instrument that identifies this interface boundary. This technique has been successfully used at BVPS-2 for the positive identification of the weld clad interface to ensure that all of the Alloy 82 material of the J-groove weld is overlaid during the repair. Markings are made to locate the interface as well as a boundary of at least 1/2-inch outboard of the stainless steel clad 182 interface.

5. Prior to application of three Alloy 52M repair weld layers on the clad surface, a minimum of three passes (one layer) of Alloy ER309L shall be installed at the periphery of the weld overlay (at the repair-to-clad interface).

   The Alloy ER309L weld passes ensure that the outer pass of the Alloy 52M embedded flaw weld overlay repair only contacts the Alloy ER309L weld deposit, and does not contact the original clad material. The Alloy ER309L weld passes are not permitted to come into contact with the Alloy 600 weld. Alloy 52M weld passes do not extend beyond the outermost edge of the Alloy ER309L weld passes. This ensures that the entirety of the outer-most edge of the Alloy 52M weld will rest on the surface of the barrier layer of the Alloy ER309L filler and does not contact the stainless steel cladding. However, if unacceptable indications are identified at the periphery of the embedded flaw weld overlay repair during final examination, and repair welding is required, Alloy 52M material may extend beyond the Alloy ER309L weld beads to accommodate the repair.

6. The embedded flaw repair weld will be three layers thick for applications to the J-groove attachment welds and at least two layers thick for application to base metal locations.

7. For all of the above flaw configurations, the finished repair will be examined in accordance with ASME Code Case N-729-4, with conditions as specified in 10 CFR 50.55a(g)(6)(ii)(D).

8. For all embedded flaw repairs, inservice inspections of the overlay and original penetration during subsequent outages will be performed in accordance with the requirements of Code Case N-729-4, with conditions as specified in 10 CFR 50.55a(g)(6)(ii)(D).

9. Whenever an embedded flaw repair is planned for an axial or circumferential flaw in a tube above the J-groove attachment weld, the NRC will be notified.

10. In lieu of the examination requirements identified for J-groove welds in the table on page 9 of the NRC staff safety evaluation of WCAP-15987-P, Revision 2, FENOC proposes to perform non-destructive examination (NDE) of the completed repair and inservice inspection (ISI) of the repair as provided in the table below:

Repair Location	**Flaw Orientation**	**Repair Weld**	**Repair NDE**	**ISI NDE of the Repair, Note 2**
VHP Nozzle Tube ID	Axial or Circumferential	Seal	UT and Surface	UT or Surface
VHP Nozzle Tube OD above J-groove weld	Axial or Circumferential	Note 1	Note 1	Note 1
VHP Nozzle Tube OD below J-groove weld	Axial or Circumferential	Seal	UT or Surface	UT or Surface
J-groove weld	Axial	Seal	UT and Surface, Note 3	UT and Surface, Notes 3 and 4
J-groove weld	Circumferential	Seal	UT and Surface, Note 3	UT and Surface, Notes 3 and 4

Notes:

1) Repair method to be approved separately by the NRC.
2) Preservice and inservice inspection to be consistent with 10 CFR 50.55a(g)(6)(ii)(D), which requires the implementation of Code Case N-729-4 with conditions; or NRC approved alternatives to these specified conditions.
3) UT personnel and procedures qualified in accordance with 10 CFR 50.55a(g)(6)(ii)(D), which requires the implementation of Code Case N-729-4 with conditions. Examine the accessible portion of the J-groove repaired region. The UT plus surface examination coverage must equal 100 percent.
4) Surface examination of the embedded flaw repair shall be performed to ensure the repair satisfies ASME Code Section III, NB-5350, acceptance standards. The frequency of examination shall be as follows:
    a. Perform surface examination during the first and second refueling outage after installation or repair of the embedded flaw repair.
    b. When the examination results of 4.a verify acceptable results, then reinspection of the embedded flaw repair will be continued at a frequency of every other refueling outage. If these examinations identify unacceptable results that require flaw removal, flaw reduction to acceptable dimensions, or welded repair, the requirements of 4.a above shall be applied during the next refueling outage.

5.4 Technical Basis for Proposed Alternative

The purpose of the repair overlay welds is to embed and isolate identified flaws in the Alloy 600 reactor vessel head penetration tube and its Alloy 600 (Inconel 182) J-groove attachment weld. The repair overlay welds are not credited for providing structural strength to the original pressure boundary materials.

As discussed in WCAP-15987, the embedded flaw repair technique is considered a permanent repair for a number of reasons. As long as a primary water stress corrosion cracking (PWSCC) flaw remains isolated from the primary water (PW) environment, it cannot propagate. Alloy 690 and Alloy 52 are highly-resistant to stress corrosion cracking, as demonstrated by multiple laboratory tests, as well as over 15 years of service experience in replacement steam generators. Since Alloy 52 weldment is considered highly-resistant to PWSCC, a new PWSCC flaw cannot initiate and grow through the Alloy 52 repair weld layers to reconnect the PW environment with the embedded flaw.

The residual stresses produced by the embedded flaw technique have been measured and found to be relatively low, indicating that no new flaws will initiate and grow in the area adjacent to the repair weld. As described in WCAP-13998, Revision 1 (Reference 5), Section 7, the hole drilling method of residual stress measurement was used to determine the buildup of residual stresses from welding on the reactor vessel closure head and penetration tube. This technique involves mounting a three strain gage rosette at the location where the measurement is required. A small hole is drilled at the center of the rosette and the relieved strain is measured by the three gages of the rosette. The relieved strain and elastic constants of the material and the constants for the rosette are used to calculate the residual stress. There are no other known mechanisms for significant flaw propagation in this region since cyclic fatigue loading is negligible. Therefore, fatigue driven crack growth is not a mechanism for further crack growth after the embedded flaw repair process is implemented.

The thermal expansion properties of Alloy 52 weld metal are not specified in the ASME Code, as is the case for other weld metals. In this case, the properties of the equivalent base metal (Alloy 690) should be used. For that material, the thermal expansion coefficient at 600 degrees Fahrenheit (F) is 8.2 E-6 inch/inch/degree F, as found in Section II part D of the Code. The Alloy 600 base metal has a coefficient of thermal expansion of 7.8 E-6 inch/inch/degree F, a difference of about 5 percent.

The effect of this small difference in thermal expansion is that the weld metal will contract more than the base metal when it cools, thus producing a compressive stress on the Alloy 600 tube or attachment weld. This beneficial effect has already been accounted for in the residual stress measurements reported in the technical basis for the embedded flaw repair, as noted in WCAP-15987.

The small residual stresses produced by the embedded flaw weld will act constantly, and, therefore, will have no impact on the fatigue effects in this region. Since the stress would be additive to the maximum and minimum stress, the stress range will not change, and the already negligible usage factor for the region will not change.

Use of the Alloy ER309L weld barrier for weld overlay repairs will reduce the contaminant level present during installation of the critical Alloy 52M outer pass. Specifically, only the first Alloy ER309L pass will be in full contact with the cladding. This first pass, due to its exposure to maximum substrate-related dilution, has the highest susceptibility to cracking. The second Alloy ER309L pass will be exposed to substantially lower substrate-related contaminant levels, by virtue of its overlap with the initial Alloy ER309L pass. The third Alloy ER309L weld pass will also benefit from reduced substrate-related contaminant exposure in the same manner. This Alloy ER309L weld sequence will reduce contaminant exposure and crack susceptibility at the outer edge of this weld region.

WCAP-16158-P provides the plant-specific analysis performed for BVPS-2 using the same methodology as WCAP-15987. This analysis provides the means to evaluate a broad range of postulated repair scenarios to the reactor vessel head penetrations and J-groove welds relative to ASME Code requirements for allowable size and service life. Based on WCAP-16158-P, Revision 1, embedded flaw repairs of the reactor vessel head penetration tubes have a service life of at least 40 years, and embedded flaw repairs of J-groove attachment welds have a service life of 22 years. Since the first BVPS-2 EFR was installed in 2006, the 22-year service life bounds the duration of the upcoming fourth BVPS-2 ISI interval, which is scheduled to end on August 28, 2028. Additionally, non-destructive preservice and inservice inspections discussed below ensure that any initial embedded flaw growth due to a postulated fatigue mechanism remains bounded by the WCAP-16158-P analysis, thus ensuring the continued structural integrity of each embedded flaw repair until the reactor vessel head is replaced or the end of the fourth ISI interval (August 28, 2028), whichever occurs first.

Prior to return to service, preservice inspections will be performed in accordance with ASME Code Case N-729-4, with conditions as required by 10 CFR 50.55a(g)(6)(ii)(D).

Inservice inspections of reactor vessel head penetrations and J-groove welds repaired utilizing the embedded flaw repair process, along with submission of any necessary reports, will be in accordance with 10 CFR 50.55a(g)(6)(ii)(D), which requires implementation of Code Case N-729-4, with certain conditions.

When monitored with the proposed periodic ISI examinations, the embedded flaw repair is considered to be a robust permanent repair technique. The embedded flaw repair is designed to have a minimum of two layers of Alloy 52/152 weld metal, which is highly-resistant to PWSCC. In over 22 years of service history, there have been no PWSCC crack initiations in this material. Over 50 embedded flaw repairs have been installed in 12 separate nuclear power plants, with the longest period of service exposure being at least 10 years. Of the many dye penetrant surface examinations that have been performed on embedded flaw repairs to date, none have provided evidence of service-induced cracking or structural degradation. The indications found in embedded flaw repairs have been attributable to fabrication defects and not PWSCC. Westinghouse letter LTR-PSDR-16-008-P (Reference 6) provides the technical basis for extending the surface examination frequency to every other outage after two successful surface examinations of the embedded flaw repair have been performed in the first and second cycles after installation or repair of the embedded flaw repair.

In order to provide reasonable assurance that the embedded flaw repairs at BVPS-2 will continue to perform their design function, a combination of volumetric and surface examinations will continue to be performed in accordance with 10 CFR 50.55a and ASME Code Case N-729-4. The volumetric (UT) examination that is performed each outage will continue to monitor the embedded flaw repair for flaw growth or potential leak paths. The surface (dye penetrant) examination will continue to supplement the UT examination when the surface examination is performed every other outage as proposed. The proposed alternative examinations continue to provide reasonable assurance of the structural integrity of the embedded flaw repair while minimizing radiation exposure to plant personnel.

The above proposed alternative, as supported by the referenced generic and plant-specific technical bases, is considered to be an alternative to Code requirements that provides an acceptable level of quality and safety.

6. Duration of Proposed Alternative

The duration of the proposed alternative is until the reactor vessel head is replaced or the end of the fourth ISI interval (August 28, 2028), whichever occurs first.

7. Precedent

The NRC approved a request to implement the embedded flaw repair at the Byron station, as discussed in a March 6, 2017 NRC staff letter (Reference 7). FENOC's Request 2-TYP-4-RV-04, Revision 0, proposes the same repair method for BVPS-2. Byron and BVPS-2 utilize the embedded flaw repair methodology identified in Westinghouse WCAP-15987-P, Revision 2.

8. References

1. Letter from H. N. Berkow (U.S. NRC) to H. A. Sepp (Westinghouse Electric Company), "Acceptance for Referencing - Topical Report WCAP-15987-P, Revision 2, 'Technical Basis for the Embedded Flaw Process for Repair of Reactor Vessel Head Penetrations,' (TAC No. MB8997)," dated July 3, 2003. [Accession Number ML031840237]
2. Letter from R. Barrett (U.S. NRC) to A. Marion (Nuclear Energy Institute), "Flaw Evaluation Guidelines," dated April 11, 2003. [Accession Number ML030980322]

3. Westinghouse WCAP-15987-P, Revision 2-P-A, "Technical Basis for the Embedded Flaw Process for Repair of Reactor Vessel Head Penetrations," December 2003. [Accession Number ML040290246]

4. Westinghouse WCAP-16158-P, Revision 1, "Technical Basis for Repair Options for Reactor Vessel Head Penetration Nozzles and Attachment Welds: Beaver Valley Unit 2," January 2018.

5. WCAP-13998, Revision 1, "RV Closure Head Penetration Tube ID Weld Overlay Repair," November 1995.

6. Westinghouse Letter LTR-PSDR-16-008-P, Revision 0, "Technical Basis for Optimization Or Elimination Of Liquid Penetrant Exams For The Embedded Flaw Repair, Beaver Valley Unit 2," September 2016.

7. Letter from K. Green (U.S. NRC) to B. Hanson (Exelon Generation Company, LLC), "Byron Station, Unit Nos. 1 and 2 – Request for Relief from the Requirements of the ASME Code (CAC Nos. MF8282 and MF8283)," March 6, 2017. [Accession Number ML17062A428]

ENCLOSURE C
L-18-055

Westinghouse Affidavit
"Application for Withholding Proprietary Information from Public Disclosure"

[7 Pages Follow]

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CAW-18-4703

January 24, 2018

APPLICATION FOR WITHHOLDING PROPRIETARY INFORMATION FROM PUBLIC DISCLOSURE

Subject: WCAP-16158-P, Revision 1, "Technical Basis for Repair Options for Reactor Vessel Head Penetration Nozzles and Attachment Welds: Beaver Valley Unit 2" (Proprietary)

The Application for Withholding Proprietary Information from Public Disclosure is submitted by Westinghouse Electric Company LLC ("Westinghouse"), pursuant to the provisions of paragraph (b)(1) of Section 2.390 of the Nuclear Regulatory Commission's ("Commission's") regulations. It contains commercial strategic information proprietary to Westinghouse and customarily held in confidence.

The proprietary information for which withholding is being requested in the above-referenced report is further identified in Affidavit CAW-18-4703 signed by the owner of the proprietary information, Westinghouse. The Affidavit, which accompanies this letter, sets forth the basis on which the information may be withheld from public disclosure by the Commission and addresses with specificity the considerations listed in paragraph (b)(4) of 10 CFR Section 2.390 of the Commission's regulations.

Accordingly, this letter authorizes the utilization of the accompanying Affidavit by FirstEnergy Corporation.

Correspondence with respect to the proprietary aspects of the Application for Withholding or the Westinghouse Affidavit should reference CAW-18-4703, and should be addressed to James A. Gresham, Manager, Regulatory Compliance, Westinghouse Electric Company, 1000 Westinghouse Drive, Building 2 Suite 259, Cranberry Township, Pennsylvania 16066.

J A Gresham

James A. Gresham, Manager
Regulatory Compliance

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF BUTLER:

I, James A. Gresham, am authorized to execute this Affidavit on behalf of Westinghouse Electric Company LLC ("Westinghouse") and declare that the averments of fact set forth in this Affidavit are true and correct to the best of my knowledge, information, and belief.

Executed on: 1/24/18

James A. Gresham, Manager
Regulatory Compliance

(1) I am Manager, Regulatory Compliance, Westinghouse Electric Company LLC ("Westinghouse"), and as such, I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing and rule making proceedings, and am authorized to apply for its withholding on behalf of Westinghouse.

(2) I am making this Affidavit in conformance with the provisions of 10 CFR Section 2.390 of the Nuclear Regulatory Commission's ("Commission's") regulations and in conjunction with the Westinghouse Application for Withholding Proprietary Information from Public Disclosure accompanying this Affidavit.

(3) I have personal knowledge of the criteria and procedures utilized by Westinghouse in designating information as a trade secret, privileged or as confidential commercial or financial information.

(4) Pursuant to the provisions of paragraph (b)(4) of Section 2.390 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse.

(ii) The information is of a type customarily held in confidence by Westinghouse and not customarily disclosed to the public. Westinghouse has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application of that system and the substance of that system constitute Westinghouse policy and provide the rational basis required.

Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of

Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage (e.g., by optimization or improved marketability).

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

(iii) There are sound policy reasons behind the Westinghouse system which include the following:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

(b) It is information that is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

(c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

(d) Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Westinghouse of a competitive advantage.

(e) Unrestricted disclosure would jeopardize the position of prominence of Westinghouse in the world market, and thereby give a market advantage to the competition of those countries.

(f) The Westinghouse capacity to invest corporate assets in research and development depends upon the success in obtaining and maintaining a competitive advantage.

(iv) The information is being transmitted to the Commission in confidence and, under the provisions of 10 CFR Section 2.390, is to be received in confidence by the Commission.

(v) The information sought to be protected is not available in public sources or available information has not been previously employed in the same original manner or method to the best of our knowledge and belief.

(vi) The proprietary information sought to be withheld in this submittal is that which is appropriately marked in WCAP-16158-P, Revision 1, "Technical Basis for Repair Options for Reactor Vessel Head Penetration Nozzles and Attachment Welds: Beaver Valley Unit 2" (Proprietary), dated January 2018, for submittal to the Commission, being transmitted by FirstEnergy Corporation letter. The proprietary information as submitted by Westinghouse is that associated with the technical justification to support the flaw repair options for Beaver Valley Unit 2 reactor vessel head penetration nozzles and attachment welds, and may be used only for that purpose.

(a) This information is part of that which will enable Westinghouse to provide technical justification to support flaw repair options for Beaver Valley Unit 2 reactor vessel head penetration nozzles and attachment welds.

(b) Further, this information has substantial commercial value as follows:

   (i) Westinghouse plans to sell the use of similar information to its customers for the purpose of providing technical justification to support the flaw repair options for reactor vessel head penetration nozzles and attachment welds.

   (ii) Westinghouse can sell support and defense of industry guidelines and acceptance criteria for plant-specific applications.

   (iii) The information requested to be withheld reveals the distinguishing aspects of a methodology which was developed by Westinghouse.

Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar technical evaluation justifications and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

The development of the technology described in part by the information is the result of applying the results of many years of experience in an intensive Westinghouse effort and the expenditure of a considerable sum of money.

In order for competitors of Westinghouse to duplicate this information, similar technical programs would have to be performed and a significant manpower effort, having the requisite talent and experience, would have to be expended.

Further the deponent sayeth not.

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ENCLOSURE D
L-18-055

WCAP-16158-NP, Revision 1, “Technical Basis for Repair Options for Reactor Head Penetration Nozzles and Attachment Welds: Beaver Valley Unit 2”

[52 Pages Follow]

Westinghouse Non-Proprietary Class 3

WCAP-16158-NP
Revision 1

January 2018

Technical Basis for Repair Options for Reactor Vessel Head Penetration Nozzles and Attachment Welds: Beaver Valley Unit 2

Westinghouse

WCAP-16158-NP
Revision 1

Technical Basis for Repair Options for Reactor Vessel Head Penetration Nozzles and Attachment Welds: Beaver Valley Unit 2

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Record of Revisions

Rev.	Date	Revision Description
0	November 2003	Original Issue
1	January 2018	Revision 1 of this WCAP was revised to extend the service life for the embedded flaw repair for Beaver Valley Unit 2 from 5 years to 22 years. Changes are marked by revision bars in the left margin.

FOREWARD

This document contains Westinghouse Electric Company LLC proprietary information and data which has been identified by brackets. Coding $^{(a,c,e)}$ associated with the brackets sets forth based on which the information is considered proprietary.

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The proprietary information in the brackets is provided in the proprietary version (WCAP-16158-P Rev. 1) of this report.

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1 INTRODUCTION

Leakage has been reported from the reactor vessel closure head penetration nozzles in a number of plants. This has led to requests for inspection of these regions. Inspections of the leaking penetrations indicate the presence of axial cracks that extend above and below the head penetration attachment welds. The cause of these axially oriented cracks has been determined to result from primary water stress corrosion cracking (PWSCC) that are driven by both steady state operating and residual stress. [

]a,c,e

As a part of the inspection and repair efforts associated with the head penetration inspection program for Beaver Valley Unit 2, engineering evaluations were performed to support the repair efforts. The purpose of this report is to provide the technical basis for the use of the embedded flaw repair method if indications or flaws are found in a head penetration nozzle and attachment weld during the Beaver Valley Unit 2 vessel head inspections. [

]a,c,e The methodology used is based on extensive analytical work completed to-date for the Westinghouse Owners Group (WOG), and a large collection of test data obtained under the sponsorship of Westinghouse, Babcock & Wilcox (B&W) and Combustion Engineering Owners groups (CEOG), as well as the Electric Power Research Institute (EPRI).

[

]a,c,e Engineering evaluations were performed to determine the maximum flaw sizes that would satisfy the requirements in Section XI of the ASME Code [1] and be suitable to support the weld repair process. The results presented in this report would enable the weld repair team to effectively determine the appropriate repair method.

Section XI repair rules allow the use of grinding to remove flaws, regardless of the edition of the Code. The only requirement is to ensure that the excavated region still meets the stress limits of the original construction code, which was Section III. Evaluations were performed to address the potential local structural discontinuities that would result from grinding operations performed to excavate flaws in the head penetration nozzles.

In this report, the technical basis to support the use of the embedded flaw repair method for a flawed Control Rod Drive Mechanism (CRDM) penetration is provided in Section 2. The technical basis that supports a similar application for a flawed head penetration attachment weld is provided in Section 3. The results of the evaluation to provide a basis for grinding operations to excavate flaws are discussed in Section 4.

Note that there are several locations in this report where proprietary information has been identified and bracketed. For each of the bracketed locations, the reason for the proprietary classification is given, using a standardized system. The proprietary brackets are labeled with three different letters to provide this information and the explanation for each letter is given below:

a. The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.), where the prevention of its use by any Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

c. The information, if used by a competitor, would reduce the competitor's expenditure of resources or improve the competitor's advantage in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product.

e. The information reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

Revision 1 of this WCAP report is to revise the technical basis to support the flaw repair method of the attachment weld and embedded flaws in the penetration tube. The projected life of the repair has been increased from 5 years to 22 years.

In Revision 0 of this WCAP, the evaluation procedures and acceptance criteria were based on the 2001 Edition with the 2002 Addenda of ASME Section XI [1]. The current ASME Section XI code of record for Beaver Valley Unit 2 is the 2001 Edition with 2003 Addenda; furthermore, Beaver Valley Unit 2 will enter the 4th ISI (inservice inspection) interval in August 2018, and the code of record at that time will be updated to the 2013 Edition of ASME Section XI Code. However, it should be noted that there are no significant changes in the fracture mechanics criteria or methodology between the 2002 Addenda up to the 2013 Edition of Section XI Code that would affect the overall conclusions of the analysis provided in this WCAP report.

2 TECHNICAL BASIS FOR APPLICATION OF EMBEDDED FLAW REPAIR TECHNIQUE TO CRDM PENETRATION NOZZLES

This section provides a discussion on the technical basis for the use of embedded flaw repair method for a flawed head penetration nozzle. [

]^{a,c,e} Flaw evaluations for postulating planar flaws with various flaw sizes in the head penetration nozzles were performed. [

]^{a,c,e}

2.1 Acceptance Criteria

The evaluation procedures and acceptance criteria for indications in austenitic piping are contained in paragraph IWB-3640 of ASME Section XI [1]. These criteria are directly taken from the 2002 Addenda for Revision 0 of this WCAP report. The current ASME Section XI code of record is the 2001 Edition with 2003 Addenda; furthermore, Beaver Valley Unit 2 will enter its 4th ISI (inservice inspection) interval in August 2018, and the code of record at that time will be updated to the 2013 Edition of ASME Section XI. However, it should be noted that there is no significant change in criteria or methodology between the 2002 Addenda and the 2013 Edition of Section XI. [

]^{a,c,e}

The applicability of the [ ]^{a,c,e} used in Section XI was investigated based on a study of all the piping fracture experiments to date (about 3000) by the Working Group on Pipe Flaw Evaluation. It was determined that the [ ]^{a,c,e} become progressively more conservative as the pipe radius to thickness ratio gets smaller. Conversely, for pipes with thin walls, the [ ]^{a,c,e} can become non-conservative. Therefore, a limitation has been imposed by Appendix C of Section XI to limit its applicability to those pipes whose radius to thickness ratio is less than 15. Since the nozzle mean radius to thickness ratio for the CRDM penetration nozzles is about 2.7, the [ ]^{a,c,e} in Section XI is applicable to Beaver Valley Unit 2 CRDM penetration nozzles.

2.1.1 Acceptance Criteria for Axial Flaws

[

]^{a,c,e}

2.1.2 Acceptance Criteria for Circumferential Flaws

[

]a,c,e

2.2 METHODOLOGY

The evaluation assumed that a flaw has been detected in a penetration nozzle and that the embedded flaw repair method is used to seal the flaw from further exposure to the primary water environment. The evaluation began with the determination of an allowable flaw size based on the acceptance criteria described in Section 2.1 for a flaw postulated in the penetration nozzle. [

]a,c,e The modified allowable flaw size was used to determine the maximum allowable flaw size that is acceptable using the embedded flaw repair method.

2.2.1 Geometry and Source of Data

There are many head penetration nozzles in the reactor vessel upper head. The outermost CRDM penetration nozzles (penetrations 58-65) were selected for analysis because [

]a,c,e A schematic of a closure head penetration nozzle for a typical Westinghouse design plant is shown in Figure 2-1. Table 4-1 shows the head penetration nozzle dimensions for Beaver Valley Unit 2. The distributions of residual, transient thermal, and pressure stresses in the vessel head penetration nozzle were obtained from detailed three-dimensional elastic-plastic finite element analysis [14]. The through-wall stress distributions from the finite element analysis were used to determine the maximum allowable flaw sizes and the fatigue crack growth for the CRDM penetration nozzles. [

]a,c,e The finite element model with the selected stress cuts is shown in Figure 2-2. A "stress cut" means an imaginary line or plane over which stress distribution is evaluated.

The regions of the head penetration that have the highest stresses are the ones closest to the attachment weld (Stress Cuts 1 and 2 in Figure 2-2). [

]a,c,e

2.2.2 Loading Conditions

Thermal Transient Selection for Maximum Allowable Flaw Size Determination

The requirement for evaluation of a flaw using the rules of Section XI is that the governing transients be chosen from the normal/upset conditions as well as from the emergency/faulted conditions. This is necessary because, as discussed in Section 2.1, different safety margins are used for the normal/upset conditions and the emergency/faulted conditions. A lower safety factor is used to reflect the lower probability of occurrence for the emergency/faulted conditions.

[

]a,c,e

Thermal Transient Selection for Fatigue Crack Growth Prediction

[

]a,c,e The thermal transients that occur in the upper head region are relatively mild, because most of the water in the head region has already passed through the core region. The flow in the upper head region is low compared to other regions of the reactor vessel, which mutes the effects of the operating thermal transients. The thermal transients that occur in Beaver Valley Unit 2 are shown in Table 2-1. [

]a,c,e

Since Beaver Valley Unit 2 is operated as a base-load plant, it does not change power to respond to the demands of the grid. The cycles for the unit loading and unloading transient were reduced from 18300 to 5700, based on conservative operating plant experience for base-load plants. The 5700 cycle count conservatively bounds historical records and projected cycles to the end of the 60 year design life for Beaver Valley Unit 2. The value of 5700 cycles is also conservative based on operating plant experience for other base-load plants.

2.2.3 Stress Intensity Factors

One of the key elements in a fracture mechanics evaluation is the determination of the crack driving force or stress intensity factor (K_I). This is based on the equations available in the literature.

Stress Intensity Factor for Surface Flaw

For a part-through wall flaw, the stress profile is approximated by a cubic polynomial as follows:

$$\sigma(x) = A_0 + A_1 x + A_2 x^2 + A_3 x^3$$

where:

x	=	The distance into the wall (inch)
σ	=	Stress perpendicular to the plane of the crack (ksi)
A_i	=	Coefficients of the cubic polynomial Fit, i = 0, 1, 2, 3

[

]^{a,c,e}

2.2.4 Allowable Flaw Size Determination

Allowable flaw sizes for axial and circumferential flaws with various aspect ratios (flaw length/flaw depth) in a CRDM penetration nozzle are calculated in accordance with the acceptance criteria discussed in Section 2.1. The thermal transients that have the [ ]^{a,c,e} were considered in determining the allowable flaw sizes. It should be noted that these allowable flaw sizes must be adjusted to account for fatigue crack growth. Since the repaired flaws are embedded and sealed, they are not subjected to PWSCC. Adjustments to the allowable flaw sizes are based on the results from the fatigue crack growth evaluation described in Section 2.2.5.

2.2.5 Fatigue Crack Growth Prediction

The analysis procedure involves postulating various types of flaws in the penetration nozzle subjected a series of design loads. The applied loads include pressure, thermal transient and residual stresses. The governing thermal transients used for this evaluation are shown in Section 2.2.2. The cycles are distributed evenly over the entire plant design life. The stress intensity factor range, ΔK_I, that controls fatigue crack growth, depends on the geometry of the crack, its surrounding structure and the range of applied stresses in the region of the postulated crack. Once ΔK_I is calculated, the fatigue crack growth due to a particular stress cycle can be determined using a crack growth rate reference curve applicable to the material of the head penetration nozzle.

The crack growth rate (CGR) reference curves for these nickel base alloys are [

]a,c,e

The crack growth rate reference curve in air for the repair weld Alloy 52 is not available. There are 4 tests on Alloy 52 in PWR water environment. The available data in Reference 9 showed Alloy 52 and Alloy 600 have the same CGR in PWR water environment. Therefore, Alloy 600 CGR in air could be used as Alloy 52 CGR in air.

Once the incremental crack growth corresponding to a specific transient, for a small time period, is calculated, it is added to the original crack size, and the analysis continues to the next time period and/or thermal transient. The procedure is repeated in this manner until all the significant analytical thermal transients and cycles known to occur in a given period of operation have been analyzed.

2.3 FRACTURE MECHANICS ANALYSIS RESULTS

Axial and circumferential flaws found on the inside surface of a CRDM head penetration nozzle can be repaired using the embedded flaw repair method. A range of potential flaw sizes and shapes was investigated to thoroughly evaluate the embedded flaw repair method.

2.3.1 Results for Allowable Flaw Sizes (Without Fatigue Crack Growth Adjustment)

Allowable Flaw Sizes for Axial Flaws

[

]a,c,e

The allowable flaw sizes for a maximum design pressure of 2.5 ksi can then be determined as shown in

Figure 2-3 for a postulated inside surface axial flaw with a given aspect ratio (flaw length/flaw depth). It should be noted that the allowable flaw sizes determined this way for the inside surface axial flaws can be [ ]^{a,c,e} Allowable flaw sizes determined from Figure 2-3 must be adjusted to account for the fatigue crack growth of the repaired flaws, which are embedded and free from stress corrosion cracking. The amount of adjustments is described in Section 2.3.2.

Allowable Flaw Sizes for Circumferential Flaws

[

]^{a,c,e} The allowable flaw sizes for a maximum design pressure of 2.5 ksi can then be determined as shown in Figure 2-4 for a postulated inside surface circumferential flaw with a given aspect ratio (flaw length/flaw depth). It should be noted that the allowable flaw sizes determined this way for the surface flaws can be [ ]^{a,c,e} Allowable flaw sizes determined from Figure 2-4 must be adjusted to account for the fatigue crack growth of the repaired flaws, which are embedded and free from stress corrosion cracking. The amount of adjustments is described in Section 2.3.2.

2.3.2 Results for Allowable Flaw Sizes (With Fatigue Crack Growth Adjustment)

Fatigue crack growth evaluation was performed to determine the potential crack growth for the outside surface flaws. The FCG results for the outside surface flaws envelop those for the embedded flaws of comparable sizes. Therefore, the FCG results can be applied to both outside surface flaws and embedded flaws.

Allowable Axial Flaw Sizes

Figures 2-5 and 2-6 show the fatigue crack growth prediction of the CRDM penetration nozzles for a range of flaw depths at uphill side and downhill side, respectively. It should be noted that the total flaw depth is limited to 75% of the wall thickness in all cases except for the flaws with aspect ratio (flaw length/flaw depth) of 10. The allowable flaw depth for longer flaw with aspect ratio of 10 is 74% of the wall thickness. The allowable flaw sizes could be determined from these figures, by subtracting the fatigue crack growth increments from the ASME Code allowable flaw sizes shown on Figure 2-3, for the desired period of service life. For example, Figure 2-7 shows the allowable flaw sizes for 40 years of service life.

Allowable Circumferential Flaw Sizes

Figures 2-8 and 2-9 show the fatigue crack growth prediction of the CRDM penetration nozzles for a range of flaw depths at uphill side and downhill side, respectively. It should be noted that the total flaw depth is limited to 75% of the wall thickness in all cases. The initial allowable flaw sizes could be determined from these figures, by subtracting the fatigue crack growth increments from the ASME Code allowable flaw sizes shown on Figure 2-4, for the desired period of service life. For example, Figure 2-10 shows the allowable flaw sizes for 40 years of service life.

2.4 SUMMARY

Axial and circumferential flaws found on the inside surface or outside surface of a CRDM head penetration nozzle can be repaired using the embedded flaw repair method to seal it from the primary water environment. The maximum allowable axial and circumferential flaw sizes in the repaired penetration nozzles are shown in Figures 2-7 and 2-10 with the effects of fatigue crack growth included for 40 years of plant operation. For other periods of service life, the maximum allowable flaw sizes can be determined from Figures 2-3 and 2-4 with the aid of 2-5, 2-6, 2-8, and 2-9.

Table 2-1 Summary of Reactor Vessel Transients for Beaver Valley Unit 2 [2, 3]

Normal Conditions	**Number of Occurrences**
Plant Heatup And Cooldown	200
Load Follow Cycles (Unit Loading And Unloading At 5% /Minute)	18300*
Step Load Increase And Decrease (10% Of Full Power)	2,000
Large Step Load Decrease With Steam Dump	200
Refueling	80
Steady State Fluctuations	Infinite
Upset Conditions	
Loss of load w/o Immediate Turbine or Reactor Trip	80
Loss of Power	40
Loss of Flow	80
Reactor Trip From Full Power	400
Inadvertent Auxiliary Spray	10
Inadvertent Safety Injection	60
RCS Cold Depressurization	10
Operating Basis Earthquake (OBE)	400
Test Conditions	
Turbine Roll Test	10
Primary Side Hydrostatic Test	5
Secondary Side Hydrostatic Test	5
Primary Side Leak Test	50
Emergency Faulted Conditions	
Main Reactor Coolant Pipe Break	1
Steam Pipe Break	1
Steam Generator Tube Rupture	1
Design Basis Earthquake	1

*5700 cycles were used since Beaver Valley Unit 2 is a base-load plant. Use of load follow cycles of 5700 bound historical records and projected cycles to the end of the 60 year design life.

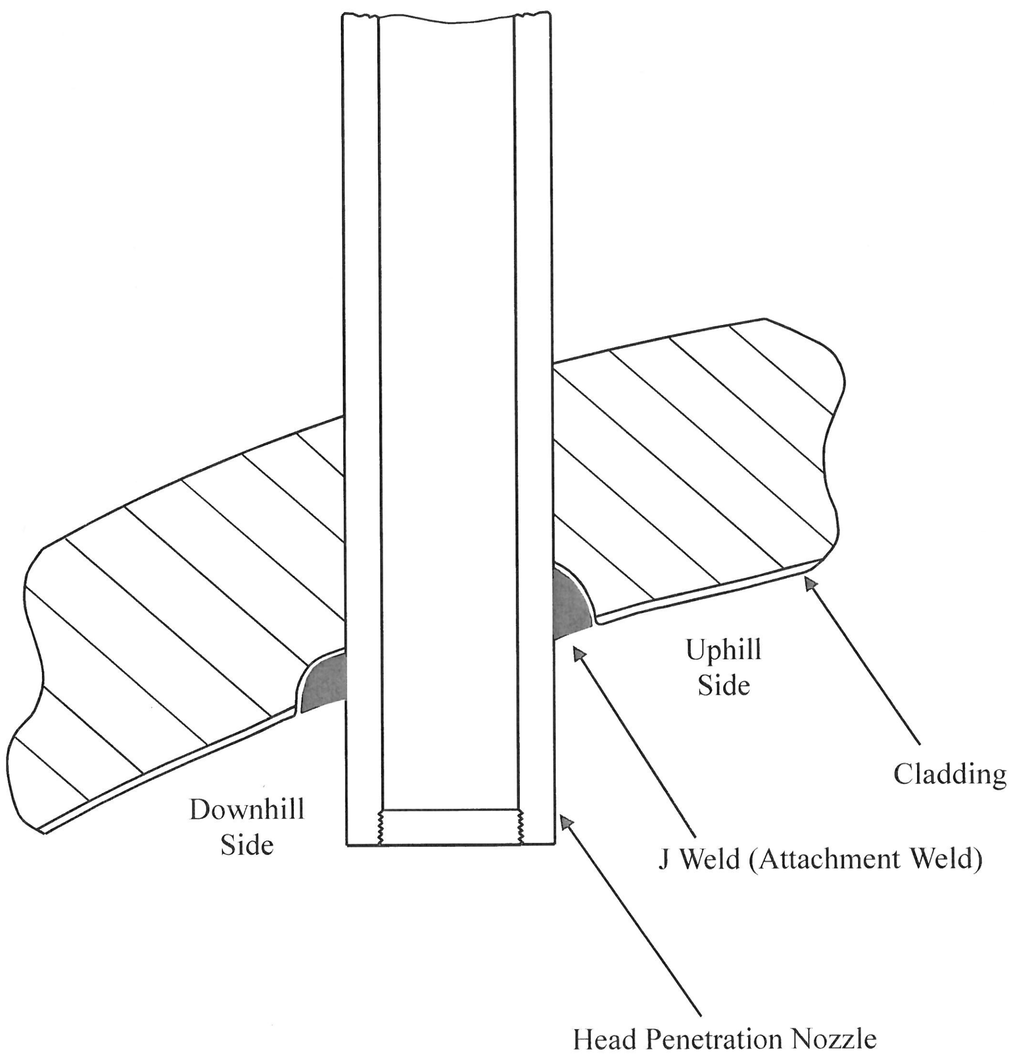


Figure 2-1 Geometry of Closure Head Penetration for a Typical Westinghouse Design

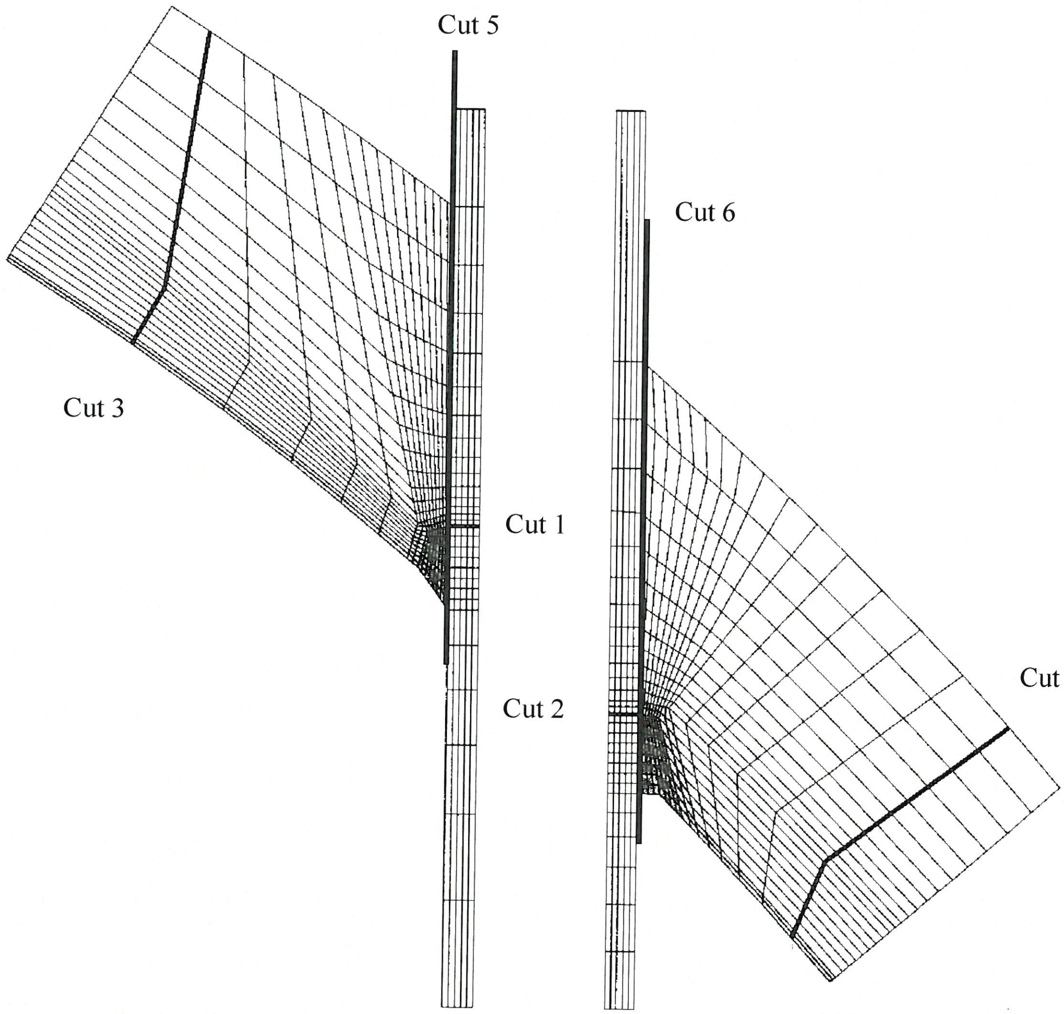


Figure 2-2 Finite Element Model with Analytical Stress Cuts Identified

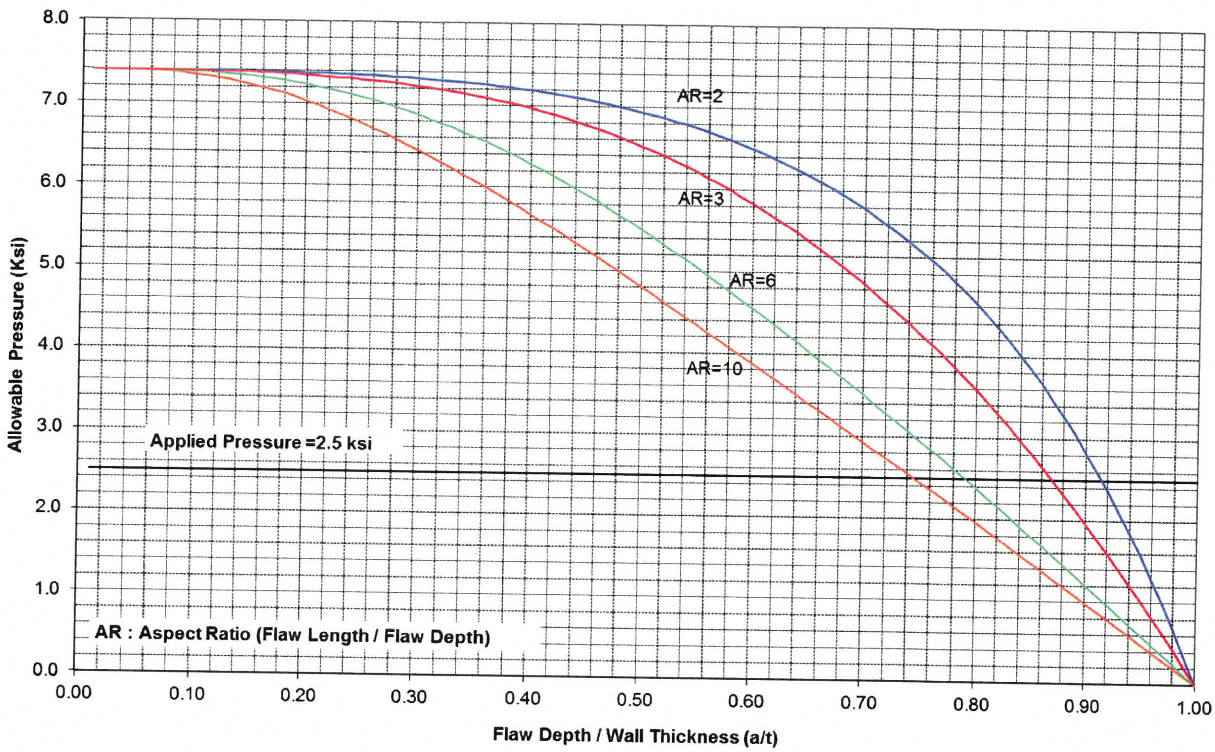


Figure 2-3 Allowable Embedded Axial Flaw Sizes In CRDM Penetration Nozzle (Without Fatigue Crack Growth) [ ]^{a,c,e}

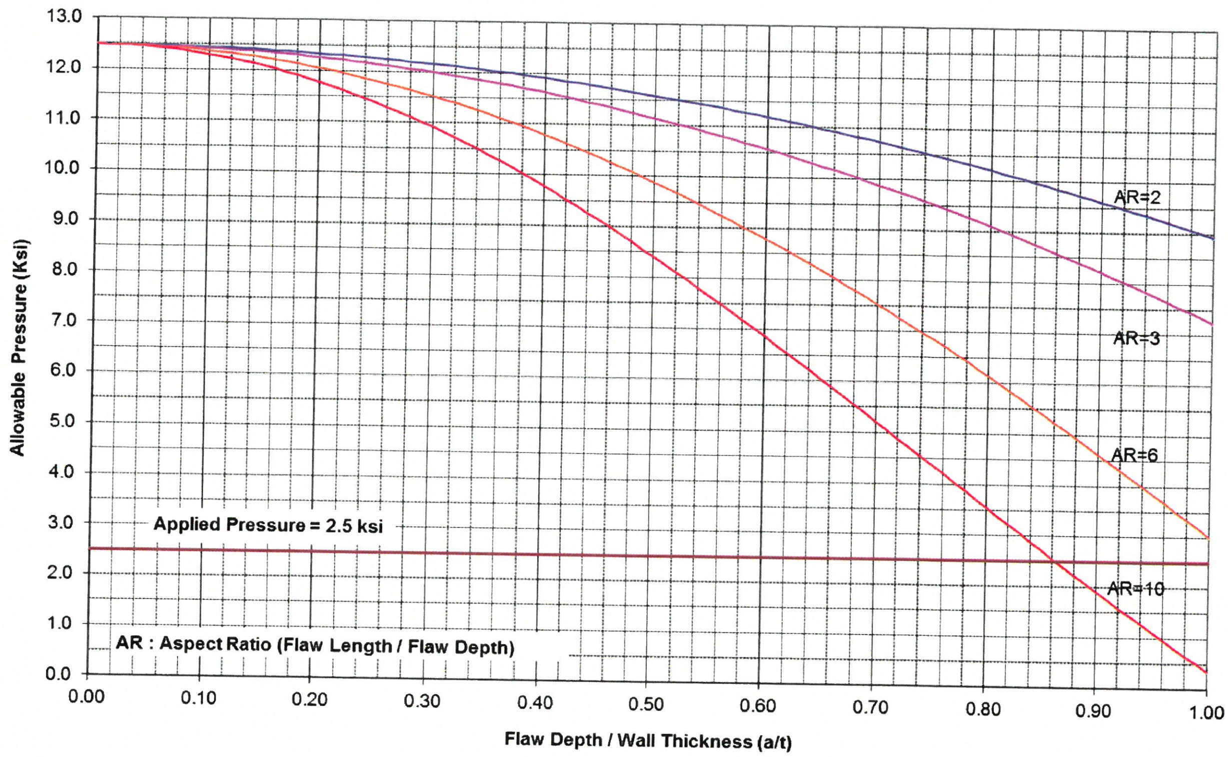
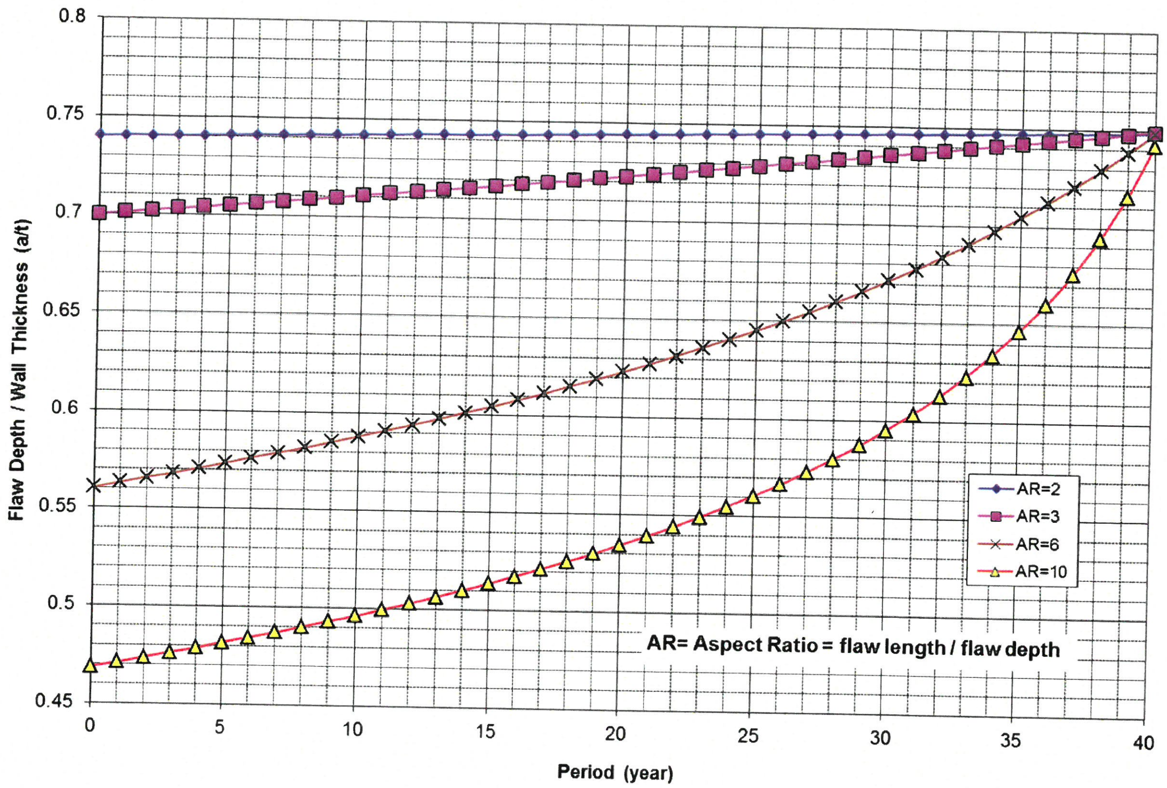
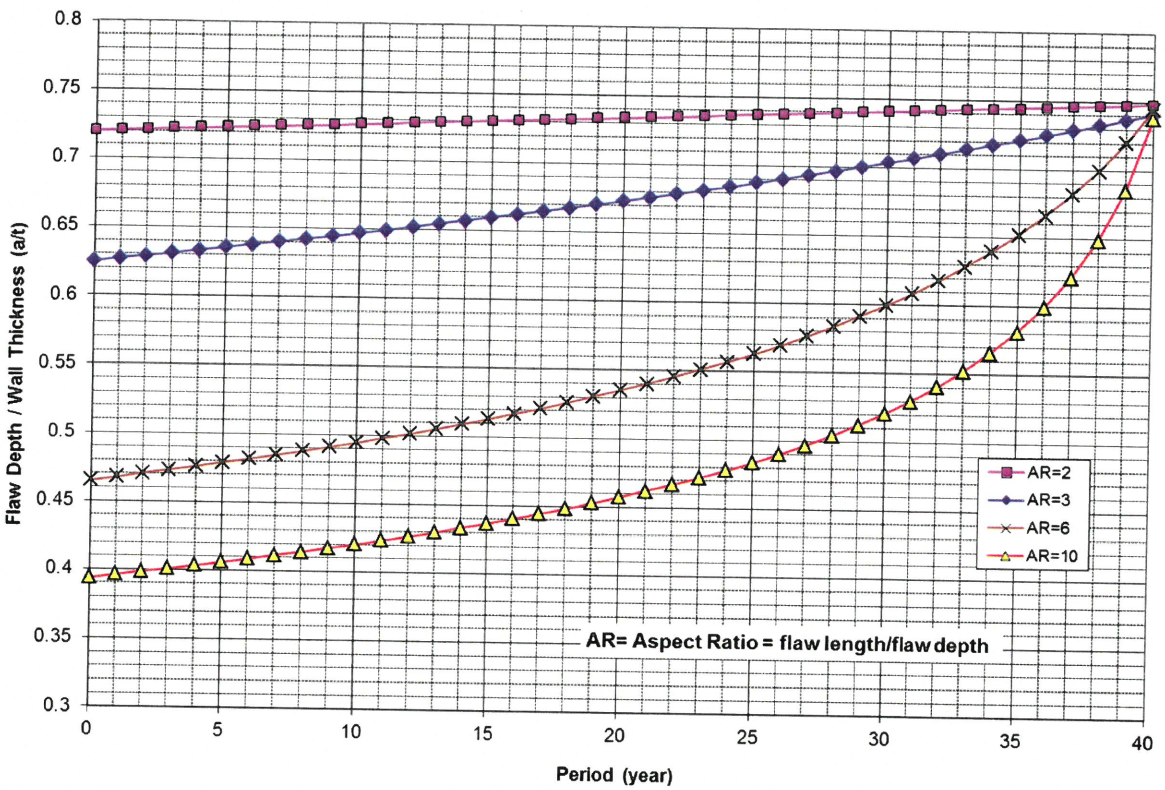


Figure 2-4 Allowable Embedded Circumferential Flaw Sizes In CRDM Penetration Nozzle (Without Fatigue Crack Growth) [ ]^{a,c,e}



Note: For Revision 1, a minor update to the crack growth calculations is made in this figure to improve accuracy of the results. The changes in this figure do not impact the overall conclusions for the head penetration nozzle repair.

Figure 2-5 Fatigue Crack Growth Prediction for Repaired Axial Flaws in the CRDM Penetration Nozzles (Uphill side)



Note: For Revision 1, a minor update to the crack growth calculations is made in this figure to improve accuracy of the results. The changes in this figure do not impact the overall conclusions for the head penetration nozzle repair.

Figure 2-6 Fatigue Crack Growth Prediction for Repaired Axial Flaws in the CRDM Penetration Nozzles (Downhill side)

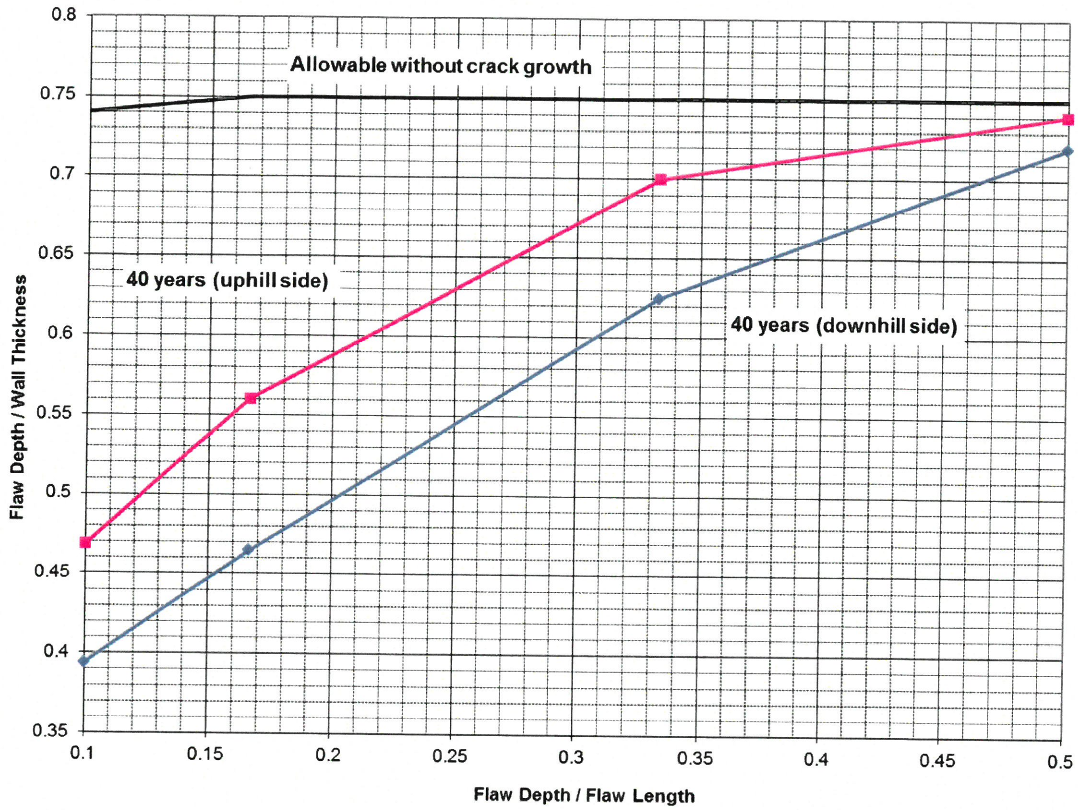


Figure 2-7 Maximum Allowable Axial Flaw Sizes in the CRDM Penetration Nozzles for 40 years Service Life

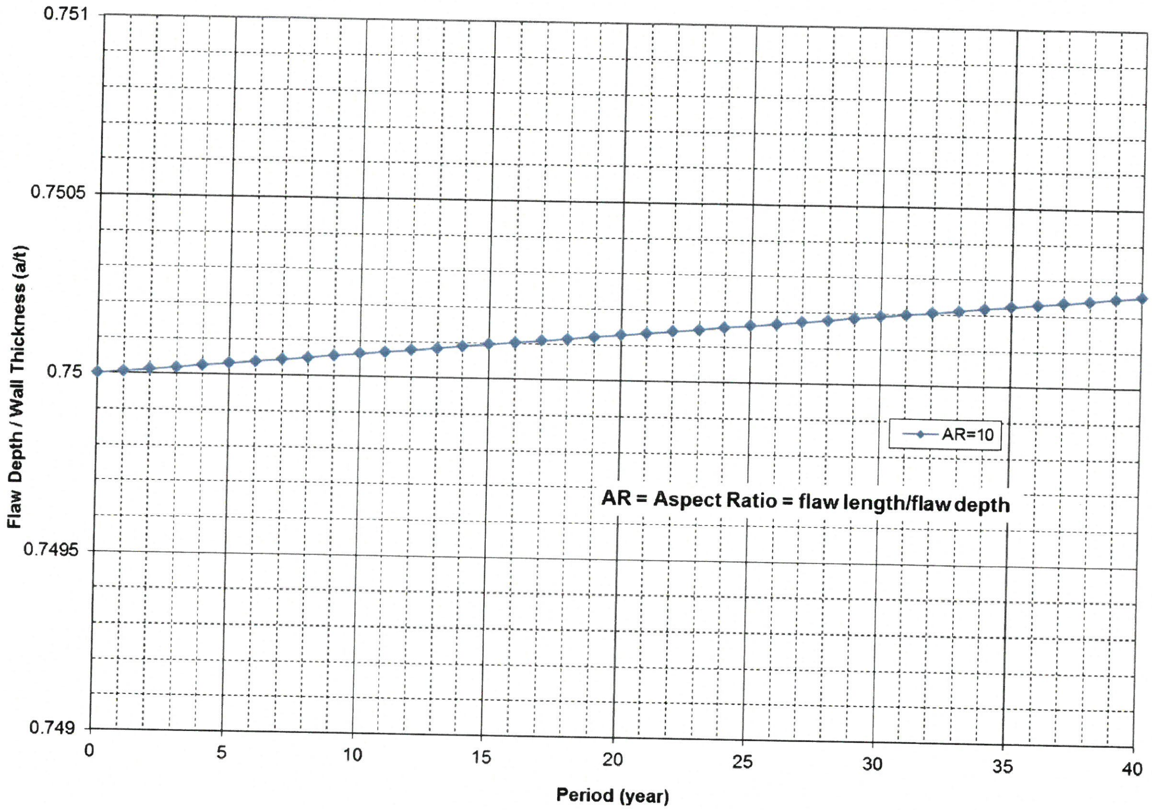
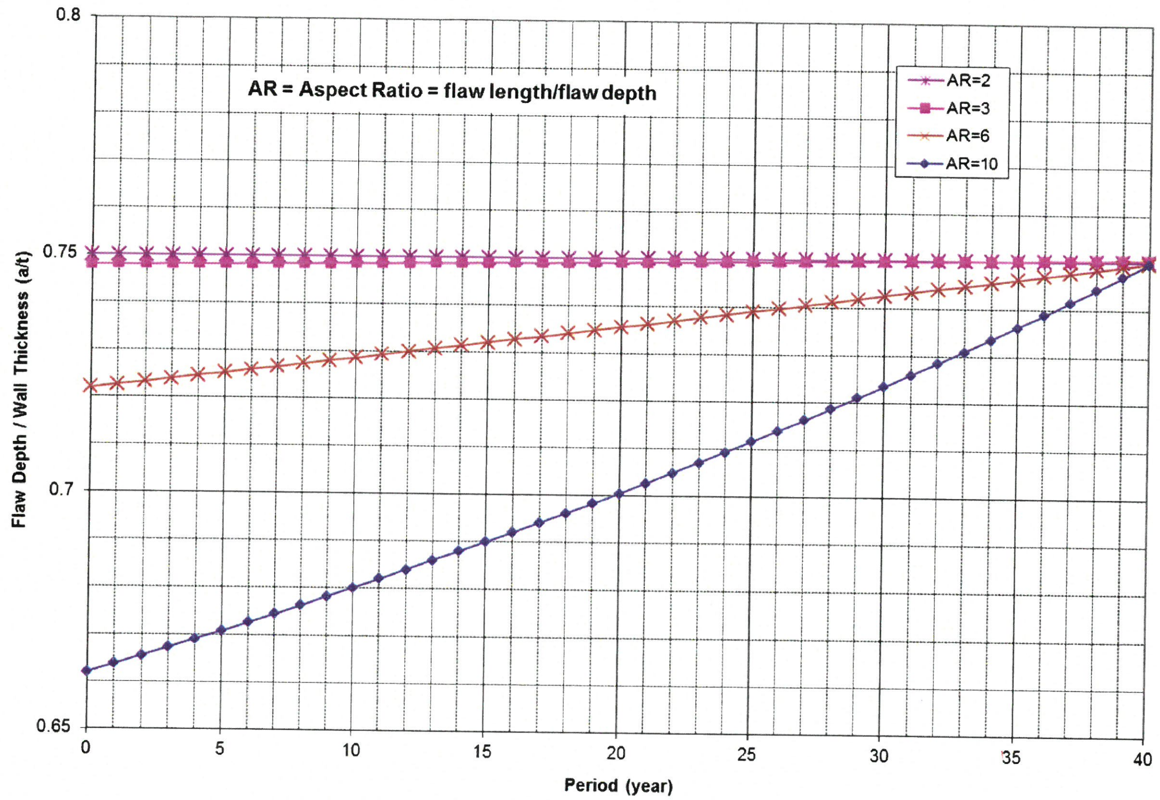


Figure 2-8 Fatigue Crack Growth Prediction for Circumferential Flaws in the CRDM Penetration Nozzles (Uphill side)



Note: For Revision 1, a minor update to the crack growth calculations is made in this figure to improve accuracy of the results. The changes in this figure do not impact the overall conclusions for the head penetration nozzle repair.

Figure 2-9 Fatigue Crack Growth Prediction for Circumferential Flaws in the CRDM Penetration Nozzles (Downhill side)

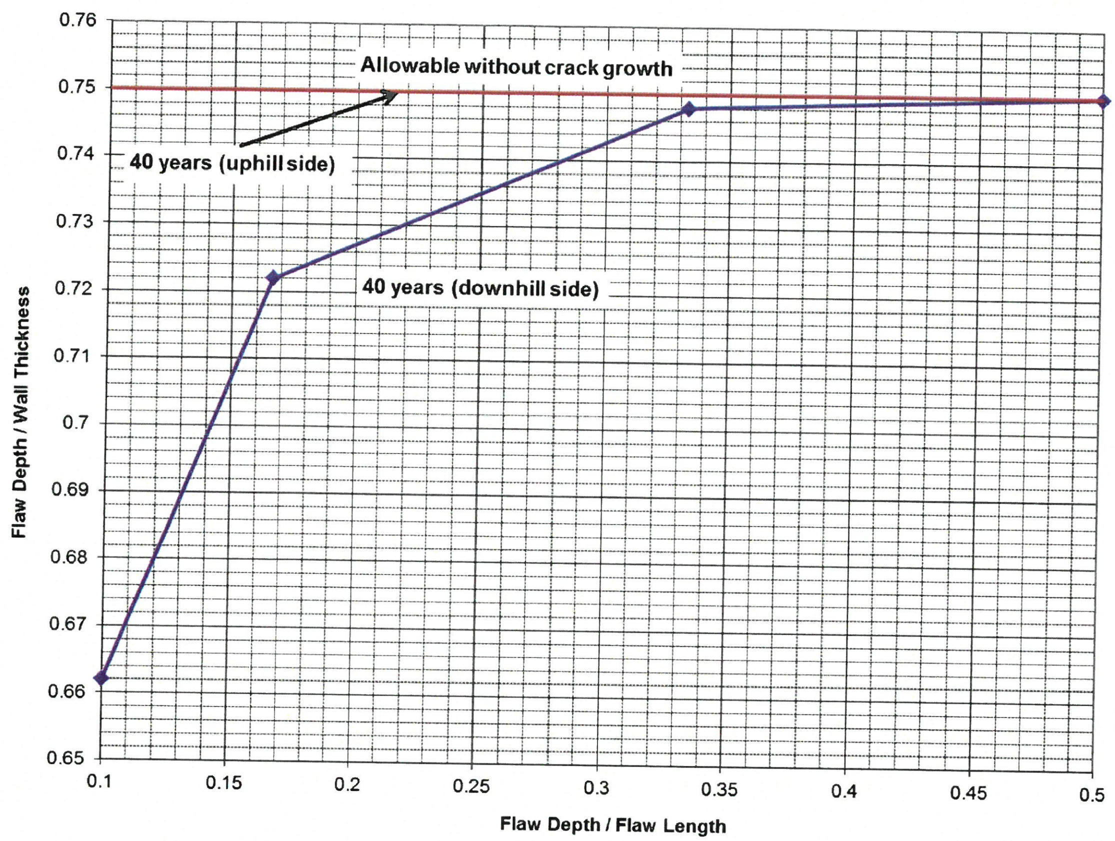


Figure 2-10 Maximum Allowable Circumferential Flaw Sizes in the CRDM Penetration Nozzles for 40 years Service Life

3 TECHNICAL BASIS FOR APPLICATION OF EMBEDDED FLAW REPAIR TECHNIQUE TO PENETRATION NOZZLE ATTACHMENT WELDS

This section provides a discussion on the technical basis for the use of embedded flaw repair method for a flawed head penetration attachment weld. [

]^{a,c,e} A flaw evaluation was carried out by postulating a planar flaw in the reactor vessel head of that size. [

]^{a,c,e}

3.1 Acceptance Criteria

3.1.1 Section XI Appendix K

The acceptance criteria and evaluation procedures used to demonstrate structural integrity of the reactor vessel closure head is Appendix K of ASME Code Section XI [1]. The Appendix K evaluation in Revision 0 of this WCAP report was based on the 2002 Addenda of ASME Section XI. Please note that Beaver Valley Unit 2 will enter the 4th ISI (inservice inspection) interval in August 2018, and the code of record at that time will be updated to the 2013 Edition of ASME Section XI (the current code of record is the 2001 Edition with 2003 Addenda). There are no significant changes in the Section XI Appendix K methodology between the 2002 Addenda up to the 2013 Edition of Section XI that would impact the analysis provided in this WCAP report.

Although the original purpose of Appendix K was evaluation of reactor vessels with low upper shelf fracture toughness, the methods are equally applicable to any region of the reactor vessel where the fracture toughness can be described with elastic plastic parameters. The head region of the reactor vessel is the hottest portion of the reactor vessel where the steady state temperature is approximately 550-620 °F. This ensures ductile behavior, and so the use of elastic-plastic methods is appropriate.

This approach to the integrity of a nuclear vessel has been developed over a ten-year period, and has been illustrated with a number of example problems [15] to demonstrate its use. The extension of this methodology to issues other than the low shelf fracture toughness issue is appropriate when service conditions (temperature) ensure ductile behavior. The extension of the Elastic Plastic Fracture Mechanics (EPFM) method to the reactor vessel head is appropriate, as discussed above.

The acceptance criteria are to be satisfied for each category of transients, namely, Service Load Levels A and B (normal and upset), Level C (emergency) and Level D (faulted) conditions. The criteria are listed below:

$$J < J_{0.1}$$

$$\frac{\partial J}{\partial a} < \frac{dJ_R}{da}$$

J_R = J-integral resistance to ductile tearing for the material

J = Applied J-integral, enlarged by a safety factor of 1.15

$J_{0.1}$ = J-integral resistance at a ductile flaw extension of 0.1 inch

$\frac{\partial J}{\partial a}$ = Partial derivative of the applied J-integral with respect to flaw depth, a

$\frac{dJ_R}{da}$ = Slope of the J-R curve

3.1.2 Primary Stress Limits

In addition to satisfying the Section XI criteria, the primary stress limits of paragraph NB-3000 in Section III of the ASME Code must be satisfied. The effects of a local area reduction that is equivalent to the area of the postulated flaw in the vessel head attachment weld must be considered by increasing the membrane stresses to reflect the reduced cross section. The allowable flaw depth was determined by evaluating the primary stress of the spherical head with reduced wall thickness using design pressure of 2500 psia. The results show the allowable flaw depth is much bigger than the weld size, even with the consideration of fatigue crack growth as discussed in Section 3.3.2.

3.2 METHODOLOGY

The evaluation assumed that a flaw has been detected in a penetration nozzle attachment weld and that the embedded flaw repair method is used to seal the flaw from further exposure to the primary water environment. The evaluation demonstrated the flaw is stable under ductile crack growth based on the acceptance criteria described in Section 3.1, for a postulated flaw in the vessel head near the penetration nozzle that encompassed the entire attachment weld region. [ ]^{a,c,e} Therefore, the fatigue crack growth evaluations for the reactor vessel head and the repair welds were performed to ensure the structural integrity.

3.2.1 Geometry and Source of Data

There are many head penetrations in the reactor vessel upper head, and [ ]^{a,c,e} The distribution of residual, transient thermal, and pressure stresses in the closure head region is obtained from detailed three-dimensional elastic-plastic finite element analyses of the head penetration nozzle region using iso-parametric finite elements [14]. [ ]^{a,c,e} The through-wall stress distributions from the finite element analyses were used to determine the maximum allowable flaw sizes and to predict fatigue crack growth for the postulated flaws in the attachment weld regions. Two stress cuts were selected for the analysis and the finite element model with the selected stress cuts is shown in Figure 2-2. Stress cut 5 is on the uphill side of the outermost penetration nozzle and stress cut 6 is on the downhill side.

3.2.2 Loading Conditions

Thermal Transient Selection for Maximum Allowable Flaw Size Determination

The requirement for an evaluation of a flaw using the rules of Section XI is that the governing transients be chosen for the normal/upset conditions as well as the emergency/faulted conditions. [

]a,c,e

Thermal Transient Selection for Fatigue Crack Growth Prediction

[

]a,c,e The thermal transients that occur in the upper head region are relatively mild because most of the water in the head region has already passed through the core region. The flow in the upper head region is low compared to other regions of the reactor vessel, which mutes the effects of the operating thermal transients. The thermal transients that occur in Beaver Valley Unit 2 are shown in Table 2-1. [

]a,c,e

Since Beaver Valley Unit 2 is operated as a base-load plant, it does not change power to respond to the demands of the grid. The cycles for the unit loading and unloading transient were reduced from 18300 to 5700, based on conservative operating plant experience for base-load plants. The 5700 cycle count conservatively bounds historical records and projected cycles to the end of the 60 year design life for Beaver Valley Unit 2. The value of 5700 cycles is also conservative based on operating plant experience for other base-load plants.

3.2.3 Stress Intensity Factor Calculation

One of the key elements in a fracture mechanics evaluation is the determination of the crack driving force or stress intensity factor (K_I). This is based on the information available in the literature.

The stress intensity factors for two corner flaws emanating from the edge of a hole in a plate was taken from the data by [.]^{a,c,e} Use of this method requires that the stresses remote from the hole be resolved into membrane and bending stress components. The stress intensity factor can be expressed conservatively in terms of the membrane and bending stress components as follows:

[

]^{a,c,e} This flexibility is necessary because this expression will be applied to a range of flaw shapes corresponding to different attachment weld shapes in Beaver Valley Unit 2. The coefficients A and B can be found in [ ]^{a,c,e} for selected values of r/t, a/ℓ and a/t, where "r" is the outside radius of the penetration nozzle and "t" is the wall thickness of the reactor vessel head. For the r/t, a/ℓ and a/t values that are not shown in [

]^{a,c,e}, the coefficients A and B were determined using interpolation. Since the coefficients are provided for various locations around the flaw front, [

]^{a,c,e}

The stress intensity factors for the resulting embedded flaws due to the embedded flaw repair method were calculated based on the method of Appendix A of Section XI. The sub-surface stress intensity factors expression can apply to the crack approaching the surface of the component as stated in the technical basis [11]. The stress intensity factor can be expressed in terms of the equivalent membrane and bending stress components as follows:

$$K_I = (\sigma_m M_m + \sigma_b M_b)\sqrt{\pi a / Q}$$

where

σ_m, σ_b = Equivalent membrane and bending stresses, as defined in A-3200(a) of Code [1]. (See Figure 3-4(a))

M_m, M_b = Correction factors for the membrane and bending stresses. The equations for the correction factors are listed in Reference 11

a = One-half the axis of elliptical flaw

Q = Flaw shape parameter as defined in Reference 11

3.2.4 Material Properties

One of the most important information on the toughness for pressure vessel and piping materials is the J-R curve, or JR-curve, of the material, where JR stands for material resistance to crack extension, as represented by the measured J-integral value versus crack extension. Simply put, J-R curve to cracking resistance is as significant as the stress-strain curve to load-carrying capacity and ductility of a material. Both J-R curve and stress-strain curve are properties of a material.

Unfortunately, directly measured JR-curves are not generally available for a specific material of interest. Fortunately, methods that can generate such information from available data such as material chemistry, radiation exposure, temperature and Charpy V-notch energy, is now available [15]. The method provided in Reference 15 summarizes a large collection of public test data, and fitted into multivariable model based on advanced pattern recognition technology. Separate analysis models and databases were developed for different material groups, including reactor pressure vessel (RPV) welds, RPV base metals, piping welds, piping base metals and a combined materials group.

The material resistance J-values, J_{mat}, are fitted into the following equation [4, 15]:

$$J_{mat} = (MF)C1\,(\Delta a)^{C2} \exp\,[C3(\Delta a)^{C4}]$$

where C1, C2, C3, and C4 are fitting constants, and Δa is crack extension.
MF is the Margin Factor from Reference 4:
MF= 0.749 for Service Levels A, B and C
MF= 1.0 for Service Level D

For the RPV base metal model, the constants C1, C2, C3, and C4 are taken from Table 11 of Reference 15. C1, C2, C3, and C4 are complicated parameters as defined below:

$$\ln C1 = a_1 + a_2 \ln CVNp + a_3 T + a_4 \ln B_n + a_5\,\phi t$$
$$C2 = d_1 + d_2 \ln C1 + d_3 \ln B_n$$
$$C3 = d_4 + d_5 \ln C1 + d_6 \ln B_n$$
$$C4 = d_7$$

where T = Temperature (°F),
B_n = Section thickness (inches).
CVNp = Charpy impact energy (ft-lbs) = 137 ft-lb from Certified Material Test Report [6].
ϕt = Fluence ($x10^{18}$ n/cm^2, E>1Mev).

a_1, a_2, a_3, a_4, a_5, d_1, d_2, d_3, d_4, d_5, d_6, d_7 (briefly, a_i and d_i) are constants given in Table 11 of Reference 15:

a_1 = -2.44

a_2 = 1.13

$a_3 = -0.00277$

$a_4 = 0.0801$

$a_5 = 0.0$

$d_1 = 0.0770$

$d_2 = 0.116$

$d_3 = -0.0412$

$d_4 = -0.0812$

$d_5 = -0.00920$

$d_6 = -0.0295$

$d_7 = -0.409$

Neutron irradiation has been shown to produce embrittlement that reduces the toughness properties of reactor vessel ferritic steel material. The irradiation levels are very low in the reactor vessel head region and therefore the fracture toughness will not be measurably affected.

3.2.5 Applied J-Integral

For small scale yielding, $J_{applied}$ of a crack can be calculated by the Linear Elastic Fracture Mechanics (LEFM) method. A plastic zone correction must be performed to account for the plastic deformation at the crack tip. The plastic deformation ahead of the crack front is then regarded as a failed zone and the crack size is, in effect, increased. The K_I-values can be converted to $J_{applied}$ by the following equation:

$$J_{\text{applied}} = \frac{K_{ep}^2}{E'}$$

where K_{ep} is the elastically calculated K_I-value based on the plastic zone adjusted crack depth or size
$E' = E/(1-\nu^2)$ for plane strain, $E' = E$ for plane stress, E = Young's Modulus,
and ν = Poisson's Ratio.

The plastic zone size, r_p, is calculated by

$$r_p = \frac{1}{6\pi}\left(\frac{K_I}{S_y}\right)^2$$

where S_y is the yield strength of the material. Assume that the crack depth is a_o, the K_{ep} can now be calculated based on a new crack length, $a_o + r_p$. For small scale yielding, K_{ep} can be simplified as follows:

$$K_{ep} = f\ K_I$$

Where $$f = \sqrt{\frac{(a_0 + r_p)}{a_0}}$$

3.2.6 Fatigue Crack Growth Prediction

The analysis procedure involves postulating planar flaws that extend radially over the entire attachment weld cross-section in the penetration and are subjected to a series of design loads. The loading included pressure, thermal transients, and residual stresses. The transients used for this evaluation are shown in Section 3.2.2 and the cycles are distributed evenly over the plant design life. The stress intensity factor range, ΔK_I, which controls the fatigue crack growth, depends on the geometry of the crack, its surrounding structure and the range of applied stresses in the region of the postulated crack. Once ΔK_I is calculated, the fatigue crack growth due to a particular stress cycle can be determined using a crack growth rate reference curve applicable to the material where the crack is postulated.

The crack growth rate curves used in the analyses for the postulated flaws in the reactor vessel head are taken directly from [ ]a,c,e Since the flaw is sealed from the primary water environment, the crack growth rate reference curve for the air environment is used. This curve is a function of the applied stress intensity factor range (ΔK_I) and the R ratio, which is the ratio of the minimum to maximum stress intensity factor during a thermal transient. [

]a,c,e

Once the incremental crack growth corresponding to a specific transient, for a small time period, is calculated, it is added to the original crack size, and the analysis continues to the next time period and/or thermal transient. The procedure is repeated in this manner until all the significant analytical thermal transients and cycles known to occur in a given period of operation have been analyzed.

3.3 FRACTURE MECHANICS ANALYSIS RESULTS

3.3.1 Results for Applied J-Integral and J-R Curve

The actual geometry or weld shapes of Beaver Valley Unit 2 head penetration attachment welds [7, 13] are shown in Table 3-1, which forms the basis for the geometry of the postulated flaws in the attachment weld region. The stress intensity factors were calculated for the biggest weld sizes (lowest a/ℓ ratio), penetration 58-65 downhill side welds, that were selected to bound all the other penetration nozzle attachment weld shapes in Beaver Valley Unit 2.

The applied J-integral values were evaluated based on the method describe in Section 3.2. The material J-R Curve was obtained by setting the Margin Factor (MF) to 0.749. The applied J-integral values and material J-R Curve were tabulated in Table 3-2 and plotted in Figure 3-2.

The key aspect of the analysis is the slope of the J-material curve and the slope of the J-applied curve. Figure 3-2 demonstrated that the flaw is stable with the slope of the J-material curve far exceeds the slope of the J-applied curve and $J_{applied} < J_{0.1}$. Therefore, all the head penetration welds have been shown to be acceptable to the code requirement.

3.3.2 Results for Fatigue Crack Growth into the Reactor Vessel Head

The fatigue crack growth was determined for postulated flaws in the reactor vessel head with attachment weld shapes on the uphill and downhill sides of the penetration nozzles that envelop all the other attachment weld shapes in Beaver Valley Unit 2. The allowable flaw depth was determined based on the primary stress limit calculation in Section 3.1.2. Based on the design pressure of 2500 psia, the allowable flaw depth is 2.26". As shown in Figure 3-3, the predicted crack growth for the head penetration attachment welds at both the uphill and downhill sides due to fatigue is small, and the final crack growth after 40 years is below the allowable flaw size of 2.26".

In Revision 0 of WCAP-16158, the allowable flaw size was also determined per the primary stress limits but based on a pre-service shop hydrostatic test pressure of 3125 psia, and the allowable flaw size was 1.33" (also shown in Figure 3-3). However, it should be noted that hydrostatic tests at 3125 psia are not performed during in-service operations; thus, the calculated allowable flaw of 1.33" is not applicable. Thus, in Revision 1 of WCAP-16158 herein, the primary stress based on the design pressure of 2500 psia is used to determine the allowable flaw size. The crack growth results as shown in Figure 3-3 demonstrate that there is sufficient margin between the final flaw size after 40 years and the allowable size.

3.3.3 Fatigue Crack Growth into the Repair Weld

J-groove weld or attachment weld repair is done by depositing three layers of Alloy 52 weld material (about 5/32 inch thick) onto the flawed J-groove weld. The flaw is thus sealed, and the thickness of the reactor vessel shell is locally increased by 5/32 inch. In the analysis, an embedded flaw is assumed, which starts from 5/32 inch beneath the free surface. For conservative analysis, it is assumed that the entire depth including the fillet weld (1.36 inch on the downhill side and 1.84 on the uphill side) of the J-weld, which is of Alloy182, is flawed. In other words, the postulated embedded flaw starts 5/32 inch beneath the free surface and ends at 1.516 inch and 2.00 inch from the free surface on the downhill and uphill side respectively. The aspect ratio for the uphill and downhill side embedded flaw is taken to be a representative value of 2.0 (flaw length/flaw depth). This aspect ratio of 2.0 bounds all the aspect ratios for the uphill and downhill side attachment weld dimensions shown in Table 3-1.

The predicted fatigue crack growth for the postulated weld shapes is shown in Table 3-3. The FCG prediction results indicate that the repaired weld can last at least 22 years of service life depending on the initial flaw depth. These weld shapes cover all other weld shapes in the penetration nozzle attachment welds for Beaver Valley Unit 2.

3.4 SUMMARY

The results of the evaluation have demonstrated that the embedded flaw repair method is a viable method for repairing flaws found in the J-weld. The repaired J-weld would last at least 22 years of service life regardless of the size of the flaw in the penetration nozzle attachment weld.

Table 3-1 Geometry of Beaver Valley Unit 2 Head Penetration Attachment Welds (All dimensions in inches)

	Uphill				Downhill		
Pen #	ℓ	a	a/ℓ		ℓ	a	a/ℓ
1	0.88	0.97	1.10		0.88	0.97	1.10
2-5	0.88	1.07	1.22		0.94	0.97	1.03
6-9	0.89	1.12	1.26		0.99	0.99	1.00
10-13	0.91	1.19	1.31		1.04	1.01	0.97
14-17	0.91	1.21	1.33		1.06	0.99	0.93
18-21	0.94	1.29	1.37		1.16	1.01	0.87
22-25	0.95	1.31	1.38		1.20	1.02	0.85
26-33	0.96	1.33	1.39		1.23	1.02	0.83
34-41	1.00	1.41	1.41		1.35	1.02	0.76
42-45	1.04	1.48	1.42		1.49	1.04	0.70
46-53	1.06	1.46	1.38		1.56	1.05	0.67
54-57	1.08	1.53	1.42		1.61	1.06	0.66
58-65	1.12	1.61	1.44		1.77	1.07	0.60

Note: The values a (weld depth) and ℓ (weld length) are dimensions of the J-weld only and do not include the dimensions of the fillet weld

Table 3-2 Results of Applied J-integral and Material J-R Curve

a (inch)	J_{mat} (kip-in/in^2)	$J_{applied}$ (kip-in/in^2)
1.070	0.0000	1.2597
1.074	0.3102	1.2644
1.078	0.5005	1.2691
1.082	0.6349	1.2738
1.086	0.7400	1.2786
1.090	0.8270	1.2833
1.094	0.9015	1.2880
1.098	0.9667	1.2927
1.102	1.0249	1.2974
1.106	1.0775	1.3021
1.110	1.1256	1.3068
1.114	1.1699	1.3115
1.118	1.2110	1.3162
1.122	1.2493	1.3209
1.126	1.2852	1.3256
1.130	1.3191	1.3304
1.134	1.3512	1.3351
1.138	1.3816	1.3398
1.142	1.4105	1.3445
1.146	1.4381	1.3492
1.150	1.4645	1.3539
1.154	1.4898	1.3586
1.158	1.5141	1.3633
1.162	1.5375	1.3680
1.166	1.5601	1.3727
1.170	1.5818	1.3775

Note: Table 3-2 has been updated to revise the J-R calculation to improve accuracy; the requirements of Section 3.1.1 are met.

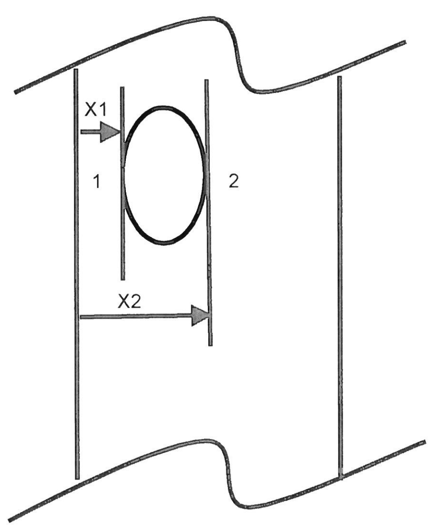
Table 3-3 Results of Fatigue Crack Growth Analysis for the Repaired Attachment Weld

	Downhill Side		Uphill Side	
Year	X1(inch)	X2(inch)	X1(inch)	X2(inch)
0	0.1563	1.5163	0.1563	1.9963
1	0.1557	1.5164	0.1527	1.9966
2	0.1552	1.5165	0.1490	1.9970
3	0.1546	1.5166	0.1452	1.9974
4	0.1541	1.5167	0.1414	1.9978
5	0.1535	1.5168	0.1374	1.9982
6	0.1530	1.5169	0.1332	1.9986
7	0.1524	1.5170	0.1290	1.9990
8	0.1519	1.5171	0.1245	1.9994
9	0.1513	1.5172	0.1199	1.9998
10	0.1508	1.5173	0.1152	2.0002
11	0.1502	1.5174	0.1101	2.0006
12	0.1497	1.5175	0.1049	2.0010
13	0.1491	1.5176	0.0994	2.0015
14	0.1486	1.5177	0.0935	2.0019
15	0.1480	1.5178	0.0872	2.0023
16	0.1474	1.5179	0.0804	2.0027
17	0.1469	1.5180	0.0731	2.0032
18	0.1463	1.5182	0.0649	2.0036
19	0.1457	1.5183	0.0555	2.0040
20	0.1452	1.5184	0.0444	2.0045
21	0.1446	1.5185	0.0299	2.0049
22	0.1440	1.5186	0.0013	2.0054

Note:

X1 = distance from the free surface for point 1.

X2 = distance from the free surface for point 2.



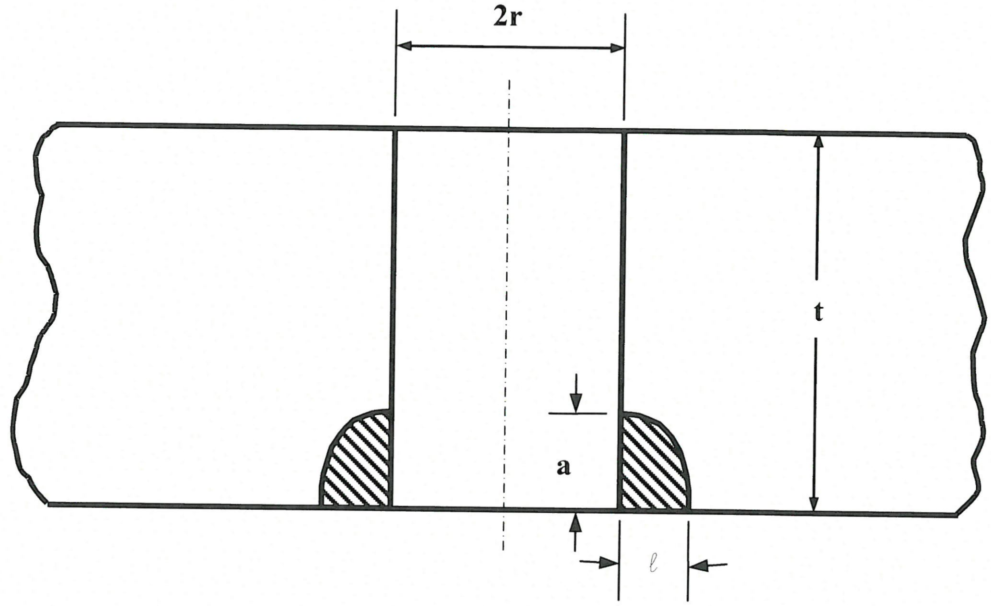
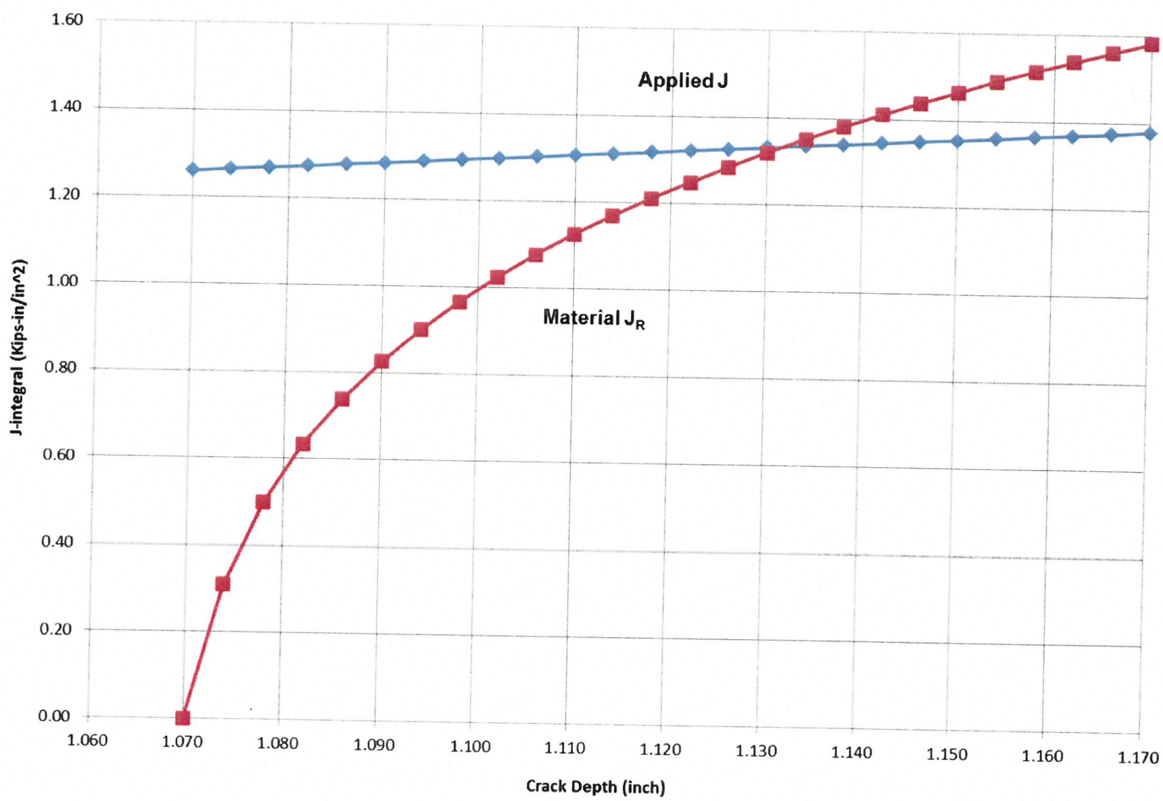


Figure 3-1 Geometry and Terminology as Applied in [ ]a,c,e



Note: Figure 3-2 has been updated to revise the J-R calculation to improve accuracy; the requirements of Section 3.1.1 are met.

Figure 3-2 Comparison of the Slope of the Applied J-integral and J-R Curve

(Governing Transient: Unit Loading and Unloading)

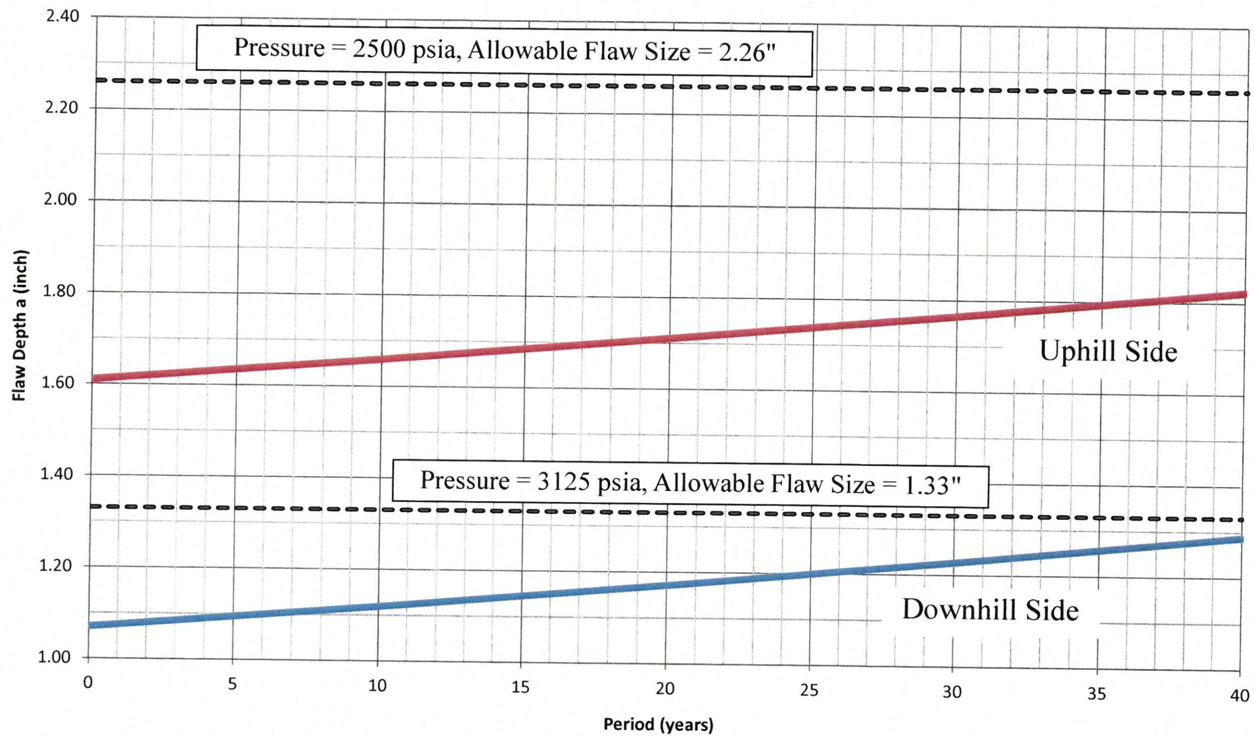


Figure 3-3 Fatigue Crack Growth for the Postulated Flaws in the Head Penetration Nozzle Attachment Welds

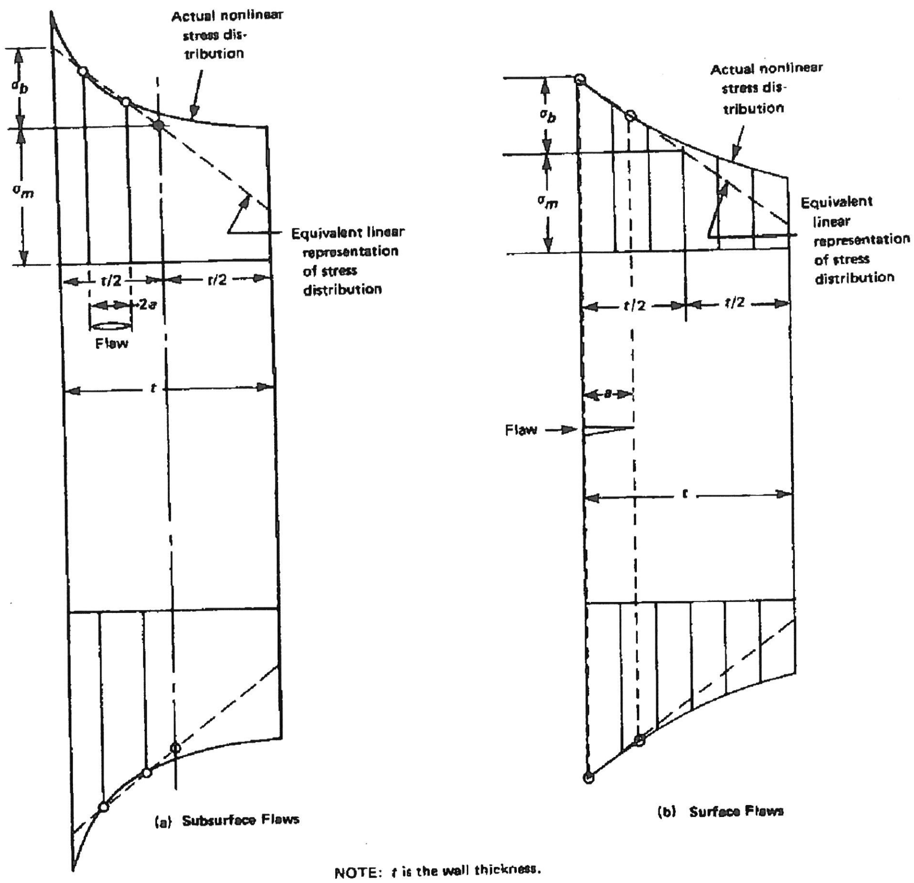


FIG. A-3200-1 LINEARIZED REPRESENTATION OF STRESSES

Figure 3-4 Linearized Representation of Stresses

4 TECHNICAL BASIS FOR "AS-EXCAVATED" REPAIRS

4.1 Introduction

Cracks have been detected on the lower part of the reactor vessel closure head penetration nozzles in some operating plants, both foreign and domestic. Cracks have also been detected in the J-groove attachment welds. The root cause of the problem has been identified as Primary Water Stress Corrosion Cracking (PWSCC) of the Alloy 600 penetration material, or welds.

One of the repair options is to excavate the inside surface of the penetration nozzle on and around each individual crack location. Excavation will serve to remove the material that contains the crack from the penetration nozzle, thus removing the crack.

The purpose of this investigation is to determine the maximum allowable excavation depth and geometry into the penetration nozzle inside surface, which will meet the same ASME Code Section III stress allowables that were used in the reactor vessel stress report for Beaver Valley Unit 2 [12]. In addition, cyclic stresses induced during normal and upset operating conditions are compared against the ASME code fatigue allowable criteria.

4.2 Technical Approach and Acceptance Criteria

A range of excavation sizes in the penetration nozzles was evaluated to determine the maximum depth which meets the ASME Section III stress allowables used in the Beaver Valley Unit 2 reactor vessel stress report [12]. This evaluation was performed for the CRDM penetration nozzles.

The key dimensions of the head penetration nozzles are shown in Table 4-1. The head thickness is 6.188 inches, and the inside radius of the spherical head is 79.03 inches.

The results presented in this section were based on the same evaluation methodology that was used in the Beaver Valley Unit 2 reactor vessel stress report. This report provided the technical basis for the original design compliance with the Section III requirements of the ASME Code. The effects of grind-outs in the regions of interest will be reflected in higher stresses, and the limiting grind-outs will be those which meet the code stress limits.

The design loads include mechanical, thermal, and piping loads. The effect of piping loads in this region is negligible, because the moments are taken out at the location where the penetration exits the vessel head. Thus, the seismic and pipe break loads would be negligible at the location of interest.

The ASME Section III acceptance criteria used in the Beaver Valley Unit 2 reactor vessel stress report are shown in Table 4-2. Calculations were performed for each of the loading conditions. The grind-outs are considered local. The loads and material properties used herein are the same as those used in the original reactor vessel stress report.

Results are provided for the following locations of possible grinding:

1. Penetration nozzles at and above the attachment weld
2. Penetration nozzles below the attachment weld

4.3 Results for the Penetration Nozzles

At and Above the Attachment Welds

For the penetration nozzles, a 360-degree grind out was considered, resulting in a simple thickness reduction in the nozzle. There was no limitation in length. Reducing the nozzle thickness increases the primary stress, and has a small effect on the secondary stress. It was assumed that any grinding performed would have a 3:1 taper or greater, to minimize any stresses from the grinding discontinuity.

For the CRDM penetration nozzle, the required minimum thickness of the nozzle from this evaluation was calculated to be 0.375 inch, so for a nominal thickness of 0.625", the allowable depth of grinding is 0.625" – 0.375" = 0.25 inch. This amounts to a grinding depth of 40 percent of the CRDM penetration nozzle nominal wall thickness.

Below the Attachment Welds

The region of the penetration nozzles below the attachment welds is not part of the pressure boundary, so there are few restrictions on grinding in this region. Also there are no net pressure loads here, so there are no restrictions on the remaining wall thickness. In an extreme case, the entire penetration nozzle below the weld could be removed. If grinding is done in this region, care should be taken to ensure that no sharp corners are created and that the potential for loose part is minimized. The slope of the grinding should be approximately 3:1 to minimize stresses.

4.4 SUMMARY

Allowable grinding depths have been determined for Beaver Valley Unit 2 reactor vessel head penetration nozzles. The approach used is to modify the stresses used in the original stress report to account for various grinding depths, and to determine the maximum depth which would meet the ASME Code Section III requirements.

For the penetration nozzles, grinding can be justified to a depth of 40 percent of the nominal wall thickness for the CRDM penetration nozzles and the minimum required wall thickness is 0.375 inch. For the penetration nozzles below the attachment welds, there are no depth limits on grinding, as this region is within the pressure boundary.

Table 4-1 Key Dimensions of Head Penetration Nozzles		
Penetration Nozzle	**Inside Diameter (in.)**	**Outside Diameter (in.)**
CRDM	2.75	4.00

Table 4-2 Results of Structural Qualification for CRDM housing penetration reduced to 0.375 inch				
Criteria from Ref. [12]	**Category**	**Stress Intensity (ksi)**	**Allowable (ksi)**	**Fatigue Usage Factor**
5.C.1	P_m	12.1	$1.0\ S_m = 16.6$	---
5.C.2	P_L+P_b	24.6	$1.5\ S_m = 24.9$	---
5.C.4	P_L+P_b+Q	55.9[a]	$3.0\ S_m = 49.8$	0.20 [b]
[a] Primary plus secondary membrane plus bending stress intensity, excluding thermal bending stress had been shown to be less than $3S_m$				
[b] Allowable Fatigue Usage Factor is 1.0				

5 SUMMARY AND CONCLUSIONS

As a part of the inspection and repair efforts associated with the reactor vessel head penetration inspection program for Beaver Valley Unit 2, engineering evaluations were performed to support the repair efforts.

The technical basis for the use of the embedded flaw repair method if indications or flaws were found in the head penetration nozzle is provided in Section 2. The fatigue crack growth adjusted allowable flaw sizes for axial and circumferential flaws are provided in Figures 2-7 and 2-10 for the penetration nozzles with repaired flaws.

The technical basis for the use of the embedded flaw repair method if indications or flaws were found in the head penetration attachment welds is provided in Section 3. The results of the evaluation have demonstrated that embedded flaw repair method can be applied to the attachment welds from the inside surface of the vessel head regardless of the sizes of the flaws in the penetration nozzle attachment welds. The repair weld layer would last at least 22 years of service life regardless of the size of the flaw found in the penetration nozzle attachment weld.

The evaluations which address the potential local structural discontinuities resulting from the grinding operations that are performed to excavate flaws in the head penetration nozzle are provided in Section 4. For the penetration nozzles, grinding can be justified to a depth of 40 percent of the nominal wall thickness for the CRDM penetration nozzles and the required minimum wall thickness is 0.375 inch. For the penetration nozzles below the attachment welds, there are no depth limits on grinding, as this region is within the pressure boundary.

6 REFERENCES

1. ASME Code Section XI, "Rules for Inservice Inspection of Nuclear Plant Components," 2001 Edition with 2002 Addenda.

2. [ ]a,c,e

3. [ ]a,c,e

4. Regulatory Guide 1.161, "Evaluation of Reactor Pressure Vessel with Charpy Upper-Shelf Energy Less Than 50 ft-lb.

5. [ ]a,c,e

6. [ ]a,c,e

7. Reference Drawings for the J-Weld Dimensions for Beaver Valley Unit 2:

   a) [

   b)

   c)

   d)

   e)

   f)]a,c,e

8. [ ]a,c,e

9. [ ]a,c,e

10. [ ]a,c,e

11. Marston, T. U. et al., "Flaw Evaluation Procedures: ASME Section XI," Electric Power Research Institute Report EPRI-NP-719-SR, August 1978.

12. [

] a,c,e

13. Reference Drawings for the Control Rod Drive Mechanism for Beaver Valley Unit 2:

a) [

b)

c)

] a,c,e

14. Fleming, M., et al. "CRDM Nozzle Transient Stress Analysis—Beaver Valley Unit 2 Reactor Vessel Head", Dominion Engineering, Inc. Report R-7779-00-1, Revision 0, August 2003.

15. E. D. Eason, J. E. Wright, E. E. Nelson, "Multivariable Modeling of Pressure Vessel and Piping J-R Data, NUREG/CR-5729, MCS 910401, RF, R5, May 1991.