Southern Nuclear

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Enclosure 3 to this letter contains Proprietary Information to be withheld from public disclosure per 10 CFR 2.390. When separated from Enclosure 3, this transmittal document is decontrolled.

September 10, 2021

Docket Nos.: 50-424
50-425

NL-21-0767

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

Vogtle Electric Generating Plant, Units 1 & 2
Proposed Alternative Requirements for the Repair of Reactor Vessel Head Penetrations
for the 4th 10-Year Inservice Inspection Interval (VEGP-ISI-ALT-04-05, Version 1.0)

Ladies and Gentlemen:

In accordance with 10 CFR 50.55a(z)(1), Southern Nuclear Operating Company (SNC) hereby requests Nuclear Regulatory Commission (NRC) approval of a proposed inservice inspection (ISI) alternative to certain requirements associated with reactor vessel head repairs for the Vogtle Electric Generating Plant (VEGP) Units 1 and 2. Enclosure 1 provides the affected components, the applicable code requirements, and the description and basis of the proposed alternative.

Enclosure 2 provides an Affidavit supporting proprietary information provided in Enclosure 3, signed by Westinghouse Electric Company LLC (“Westinghouse”), the owner of the information. The Affidavit sets forth the basis on which the information may be withheld from public disclosure by the Nuclear Regulatory Commission (“Commission”) and addresses with specificity the considerations listed in paragraph (b)(4) of Section 2.390 of the Commission’s regulations. Accordingly, it is respectfully requested that the information which is proprietary to Westinghouse be withheld from public disclosure in accordance with 10 CFR Section 2.390 of the Commission’s regulations.

Enclosure 3 provides Westinghouse WCAP-18647-P, Revision 0, “Technical Basis for Westinghouse Embedded Flaw Repair of Vogtle Units 1 and 2 Reactor Vessel Head Penetrations,” which is used as a basis for this request, and contains information proprietary to Westinghouse. Enclosure 4 provides a non-proprietary version of WCAP-18647.

Correspondence with respect to the copyright or proprietary aspects of the items listed above or the supporting Westinghouse Affidavit should reference CAW-21-5215 and should be addressed to Anthony J. Schoedel, Manager, eVinci Licensing & Configuration Management, Westinghouse Electric Company, 1000 Westinghouse Drive, Cranberry Township, Pennsylvania 16066.

NRC review and approval of the proposed alternative is respectfully requested by October 30, 2022.

This letter contains no NRC commitments. If you have any questions, please contact Ryan Joyce at 205.992.6468.

Respectfully submitted,

Cheryl A. Gayheart
Regulatory Affairs Director

CAG/DSP/cbg

Enclosure 1: Proposed Alternative VEGP-ISI-ALT-04-05, Version 1.0, in Accordance with 10 CFR 50.55a(z)(1)

Enclosure 2: CAW-21-5215, Westinghouse Affidavit Requesting Withholding of Proprietary Information

Enclosure 3: Westinghouse WCAP-18647-P, Revision 0, "Technical Basis for Westinghouse Embedded Flaw Repair of Vogtle Units 1 and 2 Reactor Vessel Head Penetrations" (Proprietary)

Enclosure 4: Westinghouse WCAP-18647-NP, Revision 0, "Technical Basis for Westinghouse Embedded Flaw Repair of Vogtle Units 1 and 2 Reactor Vessel Head Penetrations" (Non-Proprietary)

cc: Regional Administrator
NRR Project Manager – Vogtle 1 & 2
Senior Resident Inspector – Vogtle 1 & 2
RType: CVC7000

Vogtle Electric Generating Plant, Units 1 & 2
Proposed Alternative Requirements for the Repair of Reactor Vessel Head Penetrations
for the 4th 10-Year Inservice Inspection Interval (VEGP-ISI-ALT-04-05, Version 1.0)

Enclosure 1

Proposed Alternative VEGP-ISI-ALT-04-05, Version 1.0,
in Accordance with 10 CFR 50.55a(z)(1)

10 CFR 50.55a Request No. VEGP-ISI-ALT-04-05,
Alternative Requirements for the Repair of Reactor Vessel Head Penetrations
Vogtle Electric Generating Plant Units 1 & 2
Proposed Alternative in Accordance with 10 CFR 50.55a(z)(1)
Alternative Provides Acceptable Level of Quality and Safety

1. ASME Code Component(s) Affected

Code Class:	Class 1
Exam Category:	ASME Code Case N-729-6, Table 1
Item number:	B4.10 and B4.20
Description:	Alternative Requirements for the Repair of Reactor Vessel Head Penetrations (VHPs) and J-groove Welds

Component Numbers: Vogtle-1 and 2 Reactor Vessels
Vogtle-1, VHP Numbers 1 through 78
Vogtle-2, VHP Numbers 1 through 78

2. Applicable Code Edition and Addenda

PLANT	RPV CONSTRUCTION CODE	ISI INTERVAL	ASME B&PV CODE SECTION XI EDITION	INTERVAL START	INTERVAL SCHEDULED END
Vogtle Electric Generating Plant, Unit 1 and 2	ASME B&PV Code, Section III, 1971 Edition through Summer 72 Addenda	4	2007 Edition, through 2008 Addenda	05/31/2017	5/30/2027

Examinations of the VHPs are performed in accordance with 10 CFR 50.55a(g)(6)(ii)(D), which specifies the use of ASME Code Case N-729-6, (Reference 4) with conditions.

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:

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.*

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

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

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

> *(a) Later editions and addenda of the Construction Code, or a later different Construction Code, either in its entirety or portions thereof, and Code Cases may be used provided the substitution is as listed in IWA-4221(c).*

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.

Base Material Defect Repairs:

For defects in base material, ASME Section III, NB-4131 requires that the defects are eliminated, 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. Defect removal must be verified by a Magnetic Particle (MT) or Liquid Penetrant (PT) examination in accordance with NB-2545 or NB-2546, and if necessary, repaired by welding in accordance with NB-2539 to satisfy the design thickness requirement of NB-3000.

ASME Section III, NB-2539.1 addresses removal of defects and requires defects to be removed or reduced to an acceptable size by suitable mechanical or thermal methods.

ASME Section III, NB-2539.4 provides the rules for examination of the base material repair welds and specifies they shall be examined by the MT or PT methods in accordance with NB-2545 or NB-2546. Additionally, if the depth of the repair cavity exceeds the lesser of 3/8-inch or 10% of the section thickness, the repair weld shall be examined by the radiographic method in accordance with NB-5110 using the acceptance standards of NB-5320.

Weld Metal Defect Repairs (This applies to the CRDM penetration J-Groove weld.)

ASME Section III, NB-4450 addresses repair of weld metal defects.

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

ASME Section III, NB-4452 addresses requirements for elimination of weld metal surface defects without subsequent welding and specifies defects may be removed by grinding or machining.

ASME Section III, NB-4453.1 addresses requirements for removal of defects in welds by mechanical means or thermal gouging processes and requires the defect removal to be verified with MT or PT examinations in accordance with NB-5340 or NB-5350 and weld repairing the excavated cavity. In the case of partial penetration welds where the entire thickness of the weld is removed, only a visual examination is required to determine suitability for re-welding.

As an alternative to the requirements above, repairs will be conducted in accordance with the appropriate edition/addenda of ASME Section III and the alternative requirements, based on WCAP-15987-P, Revision 2-P-A, "Technical Basis for the Embedded Flaw Process for Repair of Reactor Vessel Head Penetrations," December 2003, (Refer to Reference 1, hereafter known as WCAP-15987-P).

4. Reason for Request

Southern Nuclear Operating Company, (SNC) will conduct examinations of the reactor Vessel Head Penetrations (VHPs) in accordance with Code Case N-729-6, as amended by 10 CFR 50.55a. Flaw indications that require repair may be found on the VHP tube material and/or the J-groove attachment weld(s) on the underside of the reactor vessel head. Relief is requested from the requirements of ASME Section XI, IWA-4411, IWA-4421, 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 to eliminate and repair defects in materials. Relief is also requested from the requirements of ASME Code Section III, NB-4450 to repair defects in weld metal.

5. Proposed Alternative and Basis for Use

5.1 Proposed Alternative

SNC proposes to use the less intrusive embedded flaw process (Reference 1) for the repair of VHP(s) as approved by the NRC (Reference 2) as an alternative to the defect removal requirements of ASME Section XI and Section III.

5.1.1 The criteria for flaw evaluation established in 10 CFR 50.55a(g)(6)(ii)(D), which specifies the use of Code Case N-729-6, will be used in lieu of the "Flaw Evaluation Guidelines" (Reference 3) specified by the NRC Safety Evaluation (Reference 2) for WCAP-15987-P.

5.1.2 Consistent with WCAP-15987-P, Revision 2-P-A methodology, the following repair requirements will be performed.

1. Inside Diameter (ID) VHP Repair Methodology

    a. An unacceptable axial flaw will be first excavated (or partially excavated) to a maximum depth of 0.125 inches. Although this depth differs from that specified in WCAP-15987-P, the cavity depth is not a critical parameter in the implementation of a repair on the ID surface of the VHP. The goal of the inlay is to isolate the susceptible material from the primary water (PW) 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 depth specified in WCAP-15987-P is a nominal dimension and the depth needed to accommodate three weld layers while still maintaining the tube ID dimension. Since two weld layers will be applied, less excavation is necessary, thus an excavation depth of 0.125 inches is all that is required. The shallower excavated cavity for 2 weld layers result in a slightly thinner weld, which would produce less residual stress.

       The excavation will be performed using an Electrical Discharge Machining (EDM) process to minimize VHP tube distortion. After the excavation is complete, either an ultrasonic test (UT) or surface examination will be performed to ensure that 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 of typical Alloy 52 or 52M weldment with no significant dilution. The finished weld will be conditioned to restore the inside diameter and then examined by UT and surface examination to ensure acceptability.

    b. If required, the unacceptable ID circumferential flaw will be either repaired in accordance with existing code requirements; or 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 or surface examination as described above.

2. Outside Diameter (OD) VHP and J-groove Weld Repair Methodology

   a. An unacceptable axial or circumferential flaw in a tube below a J-groove attachment weld will be sealed off with an Alloy 52 or 52M weldment. Excavation or partial excavation of such flaws is not necessary. 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 Safety Evaluation for WCAP-15987-P.

   b. Unacceptable radial flaws in the J-groove attachment weld will be sealed off with a 360-degree seal weld of Alloy 52 or 52M covering the entire weld. Excavation or partial excavation of such flaws is not necessary.

   c. If SNC determines an excavation is desired (e.g., boat sample), then:
      - The excavation will be filled with Alloy 52 or 52M material.
      - It is expected that a portion of the indication may remain after the boat sample excavation; however, a surface examination will be performed on the excavation to assess the pre-repair condition.
      - Depending on the extent and/or location of the excavation, the repair procedure requires the Alloy 52 or 52M weld material to extend at least one-half inch outboard of the Alloy 82/182 to stainless steel clad interface.

   d. Unacceptable axial flaws in the VHP tube extending into the J-groove weld will be sealed with Alloy 52 or 52M as discussed in Item 5.1.2.2.a above. In addition, the entire J-groove weld will be sealed 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-P.

   e. For seal welds performed on the J-groove weld, the interface boundary between the J-groove weld and stainless steel cladding will be located to positively identify the weld clad interface to ensure that all of the Alloy 82/182 material of the J-groove weld is seal welded during the repair.

f. The seal weld that will be used to repair an OD flaw in the nozzles and the J-groove weld will conform to the following.
   - Prior to the application of the Alloy 52 or 52M seal weld repair on the RPV clad surface, at least three beads (one layer) of ER309L stainless steel buffer will be installed 360° around the interface of the clad and the J-groove weld metal.
   - The J-groove weld will be completely covered by at least three layers of Alloy 52 or 52M deposited 360° around the nozzle and over the ER309L stainless steel buffer. Additionally, the seal weld will extend onto and encompass the outside diameter of the penetration tube Alloy-600 material by at least one-half inch.
   - The VHP tube will have at least two layers of Alloy 52 or 52M deposited over the flaw on the VHP tube, extending out at least one-half inch beyond the flaw, or to the maximum extent allowed by the nozzle geometry (e.g., limited length of the VHP tube).
   - The seal weld process and procedures provide controls which produce a weld layer thickness of approximately 0.070”. The three layers of weld deposit produce a nominal 0.190” to 0.210” thickness. Each layer is surface conditioned to remove the nickel oxide to promote better weld quality. Controls are in place to ensure the valleys, which are formed at the overlap region of the weld beads, remain. The peaks of the weld may be reduced during the surface conditioning; however, the material removed is not accounted for in the nominal layer thickness estimate. The final surface is conditioned to provide a surface suitable for examination. All surface conditioning is procedurally controlled to remove minimal material. Any surface examination indications determined to exceed the acceptance criteria in the final configuration will be removed or reduced to an acceptable value. If during the removal of material, the depth of the excavation removes the valleys between the weld beads, weld metal restoration would be performed to assure that adequate layer thickness is maintained.

g. Nondestructive examinations of the finished seal weld repair (i.e., Repair NDE) and during subsequent outages (i.e., ISI NDE) are summarized in the table below.

Repair Location	Flaw Orientation	Repair Method	Repair NDE Note (2)	ISI NDE Note (2)
VHP Nozzle/Tube ID	Axial or Circumferential	Seal Weld	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 Weld	UT or Surface	UT or Surface
J-groove Weld	Axial	Seal Weld	UT and Surface Note (3)	UT and Surface Notes (3) and (4)
J-groove Weld	Circumferential	Seal Weld	UT and Surface Note (3)	UT and Surface Notes (3) and (4)

Notes:

(1) Repair method, if required, must be approved separately by NRC.

(2) Preservice and Inservice Inspection to be consistent with 10 CFR 50.55a(g)(6)(ii)(D), which requires implementation of Code Case N-729-6 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 implementation of Code Case N-729-6 with conditions. Examine the accessible portion of the J-groove repaired region. The UT plus surface examination coverage equals to 100%.

(4) Surface examination of the embedded flaw repair (EFR) shall be performed to ensure the repair satisfies ASME 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 EFR.

   b. When the examination results in Note 4.a above verify acceptable results then re-inspection of the EFR 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 Note 4.a above shall be applied during the next refueling outage.

5.1.3. J-Groove Weld ISI NDE Requirements

Note 4 permits a reinspection frequency of every other cycle when the surface examination results of the EFR are verified to be acceptable for two consecutive cycles after the original installation or repair of the EFR. Westinghouse Report LTR-PSDR-TAM-14-005, Revision 3 (Reference 5) provides the technical bases for reducing surface examination requirements for J-groove weld repairs. This technical justification includes a detailed review of PT examination history, review of potential causes of PT indications in EFRs, and the use of crack resistant alloys in the EFR. The EFR is a robust design that is resistant to PWSCC. EFR installation, examination, and operational history indicate that the EFR performs acceptably. Examination and removed sample history indicate that the flaws identified shortly after installation of EFR weld material were due to embedded weld discontinuities and not due to service induced degradation. With inspection of the EFR every other cycle of operation, the nozzles are adequately monitored for degradation by ultrasonic examination methods similar to the nozzles without EFR repairs.

The proposed changes to the inservice examination requirements assure that the EFR repaired nozzles are adequately monitored through a combination of volumetric and surface examinations throughout the life of the installation at a frequency approved by the NRC, thus ensuring the EFR repaired nozzles will continue to perform their required function.

5.1.4. Reporting Requirements and Conditions on Use

SNC will notify the NRC of changes in indication(s) or findings of new indication(s) in the penetration nozzle or J-groove weld beneath a seal weld repair, or new linear indications in the seal weld repair, prior to commencing repair activities in subsequent outages.

5.2 Technical Basis for Proposed Alternative

The purpose of the repair weld overlay 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 weld overlays are not credited for providing structural strength to the original pressure boundary materials.

As discussed in WCAP-15987-P, the embedded flaw repair technique is considered a permanent repair. As long as a PWSCC flaw remains isolated from the Primary Water (PW) environment, it cannot propagate. Since an Alloy 52 or 52M weldment is considered highly resistant to PWSCC, a new PWSCC flaw should not initiate and grow through the Alloy 52 or 52M seal weld to reconnect the PW environment with the embedded flaw. Structural integrity of the affected J-groove weld and/or nozzle will be maintained by the remaining unflawed portion of the weld and/or the VHP. Alloy 690 and Alloy 52/52M are highly resistant to stress corrosion cracking, as demonstrated by multiple laboratory tests, as well as over ten years of service experience in replacement T_{hot} VHPs and service experience in replacement steam generators.

The residual stresses produced by the embedded flaw technique have been measured and found to be relatively low because of the small seal weld thickness. This implies that no new flaws will initiate and grow in the area adjacent to the repair weld. There are no other known mechanisms for significant flaw propagation in the reactor vessel closure head and penetration tube region since cyclic loading is negligible, as described in WCAP-15987-P. Therefore, fatigue driven crack growth should not be a mechanism for further crack growth after the embedded flaw repair process is implemented.

The thermal expansion properties of Alloy 52 or 52M weld metal are not specified in the ASME Code. In this case the properties of the equivalent base metal (Alloy 690) should be used. For Alloy 690, the thermal expansion coefficient at 600 degrees F is 8.2E-6 in/in/degree F as found in ASME B&PV Code, Section II part D. The Alloy 600 base metal has a coefficient of thermal expansion of 7.8E-6 in/in/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 J-groove 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 the WCAP-15987-P.

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.

Prior to return to service, preservice inspections will be performed in accordance with ASME Code Case N-729-6, 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-729-6, 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 over 10 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-TAM-14-005 (Reference 5) 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 VEGP 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-729-6.

WCAP-18647-P (Reference 6) provides the plant-specific analysis performed for VEGP 1 & 2 using the staff-approved methodology from WCAP-15987-P. 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. Embedded flaw repairs will continue to be inspected per the Table in section 5.1.2.2 of this alternative and if a measurable change in the embedded flaw is detected, additional analysis or repairs will be performed at that time.

The above proposed embedded flaw repair process is supported by applicable generic technical bases and is therefore considered to be an alternative to Code requirements that provides an acceptable level of quality and safety, as required by 10 CFR 50.55a(z)(1).

10 CFR 50.55a Request No. VEGP-ISI-ALT-04-05,
Alternative Requirements for the Repair of Reactor Vessel Head Penetrations
Vogtle Electric Generating Plant Units 1 & 2
Proposed Alternative in Accordance with 10 CFR 50.55a(z)(1)
Alternative Provides Acceptable Level of Quality and Safety

6. Duration of Proposed Alternative

The duration of the proposed alternative is through the end of the Inservice Inspection Interval ending May 30, 2027.

7. Precedents

In Reference 2, the NRC generically approved the embedded flaw repair process described in Reference 1. Requests to use the embedded flaw technique to repair cracks on the ID and OD of VHPs as well as to repair flaws in the J-groove attachment welds of VHPs have been previously approved by the NRC on a plant specific basis.

- Beaver Valley Power Station, Unit 2 (ML18072A288 / ML18227A733)
- Braidwood, Units 1 and 2 (ML18284A445 / ML19141A020)
- Byron, Units 1 and 2 (ML16229A250 / ML17062A428)
- Catawba Nuclear Station No. 2 (ML21114A000 / ML21117A129)

8. References

1. Westinghouse WCAP-15987-P, Revision 2-P-A, "Technical Basis for the Embedded Flaw Process for Repair of Reactor Vessel Head Penetrations," December 2003

2. 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

3. Letter from R. J. Barrett (U. S. NRC) letter to A. Marion (Nuclear Energy Institute), "Flaw Evaluation Guidelines," dated April 11, 2003

4. American Society of Mechanical Engineers Boiler and Pressure Vessel Case N-729-6, "Alternative Examination Requirements for PWR Reactor Vessel Upper Heads With Nozzles Having Pressure-Retaining Partial-Penetration Welds Section XI, Division 1"

5. Westinghouse Report LTR-PSDR-TAM-14-005, Revision 3, "Technical Basis for Optimization or Elimination of Liquid Penetrant Exams for the Embedded Flaw Repair," dated May 2015.

6. Westinghouse WCAP-18647-P, Technical Basis for Westinghouse Embedded Flaw Repair of Vogtle Units 1 and 2 Reactor Vessel Head Penetrations

Vogtle Electric Generating Plant, Units 1 & 2
Proposed Alternative Requirements for the Repair of Reactor Vessel Head Penetrations
for the 4th 10-Year Inservice Inspection Interval (VEGP-ISI-ALT-04-05, Version 1.0)

Enclosure 2

CAW-21-5215, Westinghouse Affidavit Requesting Withholding of Proprietary Information

COMMONWEALTH OF PENNSYLVANIA:
COUNTY OF BUTLER:

(1) I, Anthony J. Schoedel, have been specifically delegated and authorized to apply for withholding and execute this Affidavit on behalf of Westinghouse Electric Company LLC (Westinghouse).

(2) I am requesting the proprietary portions of WCAP-18647-P, Revision 0 be withheld from public disclosure under 10 CFR 2.390.

(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 10 CFR 2.390, 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 and is not customarily disclosed to the public.

(ii) The information sought to be withheld is being transmitted to the Commission in confidence and, to Westinghouse's knowledge, is not available in public sources.

(iii) Westinghouse notes that a showing of substantial harm is no longer an applicable criterion for analyzing whether a document should be withheld from public disclosure. Nevertheless, 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.

(5) Westinghouse has policies in place to identify proprietary information. 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.

(6) The attached documents are bracketed and marked to indicate the bases for withholding. The justification for withholding is indicated in both versions by means of lower-case letters (a) through (f) located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower-case letters refer to the types of information Westinghouse customarily holds in confidence identified in Sections (5)(a) through (f) of this Affidavit.

I declare that the averments of fact set forth in this Affidavit are true and correct to the best of my knowledge, information, and belief.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on: 8/27/2021

Anthony J. Schoedel, Manager,
eVinci Licensing & Configuration Management

Utility Customer Instructions

Include the following information in the TRANSMITTAL LETTER to NRC. This is not part of the affidavit.

Enclosed is:

CAW-21-5215

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Accordingly, it is respectfully requested that the information which is proprietary to Westinghouse be withheld from public disclosure in accordance with 10 CFR Section 2.390 of the Commission's regulations.

Correspondence with respect to the copyright or proprietary aspects of the items listed above or the supporting Westinghouse Affidavit should reference CAW-21-5215 and should be addressed to Anthony J. Schoedel, Manager, eVinci Licensing & Configuration Management, Westinghouse Electric Company, 1000 Westinghouse Drive, Cranberry Township, Pennsylvania 16066.

Vogtle Electric Generating Plant, Units 1 & 2
Proposed Alternative Requirements for the Repair of Reactor Vessel Head Penetrations
for the 4th 10-Year Inservice Inspection Interval (VEGP-ISI-ALT-04-05, Version 1.0)

Enclosure 3

Westinghouse WCAP-18647-P, Revision 0, "Technical Basis for Westinghouse Embedded Flaw Repair of Vogtle Units 1 and 2 Reactor Vessel Head Penetrations" (Proprietary)

Vogtle Electric Generating Plant, Units 1 & 2
Proposed Alternative Requirements for the Repair of Reactor Vessel Head Penetrations
for the 4th 10-Year Inservice Inspection Interval (VEGP-ISI-ALT-04-05, Version 1.0)

Enclosure 4

Westinghouse WCAP-18647-NP, Revision 0, “Technical Basis for Westinghouse Embedded Flaw Repair of Vogtle Units 1 and 2 Reactor Vessel Head Penetrations” (Non-Proprietary)

WCAP-18647-NP
Revision 0

August 2021

Technical Basis for Westinghouse Embedded Flaw Repair of Vogtle Units 1 and 2 Reactor Vessel Head Penetrations

WCAP-18647-NP
Revision 0

Technical Basis for Westinghouse Embedded Flaw Repair of Vogtle Units 1 and 2 Reactor Vessel Head Penetrations

August 2021

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RECORD OF REVISIONS

Revision	Date	Revision Description
0	August 2021	Original Issue

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1 INTRODUCTION

Leakage and cracks have been reported from the reactor vessel closure head penetration nozzles in a number of plants that resulted in repairs or prompted the replacement of the reactor vessel closure head. The degradation of the reactor vessel closure head penetration nozzles increases the probability of a more significant loss of reactor coolant pressure boundary. This has led to the issuance of various regulatory requirements and guidelines in the United States imposing additional volumetric and surface examinations to supplement the existing visual inspections of the reactor vessel closure head as well as the penetration nozzles. The presence of axial cracks extending above and below the head penetration nozzle attachment J-groove welds was discovered in some of the leaking penetration nozzles. The cause of these axially oriented cracks has been determined to result from primary water stress corrosion cracking (PWSCC) that is driven by both the steady state operating stress and the residual stress resulting from the weld fabrication process. [

]a,c,e

As a part of the inspection and repair efforts associated with the reactor vessel closure head inspection program at Vogtle Unit 1 and Unit 2, engineering evaluations have been performed in this report to support plant-specific use of the Westinghouse embedded flaw repair process in the repair of unacceptable flaws. [

]a,c,e

[

]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 in [2] to provide repair guidelines that may be used for removal of defects found on the surfaces of J-groove attachment welds and associated nozzles for the Vogtle Units 1 and 2 control rod drive mechanism (CRDM) and instrumentation port penetrations.

The technical basis of the embedded flaw repair process is documented in WCAP-15987-P [3], which has been reviewed and accepted by the NRC. The staff also concluded that WCAP-15987-P [3] is acceptable for referencing in licensing applications. As discussed in Appendix C of WCAP-15987-P [3], Westinghouse has developed the following three repair scenarios/method to address the most common types of flaws during the vessel head inspection:

Scenario 1: Axial or circumferential crack in the penetration nozzle inner surface

Scenario 2: Axial crack in the penetration J-groove weld

Scenario 3: Axial or circumferential crack in the penetration nozzle outer surface

Figure 1-1 shows the repair for Scenario 1, and Figure 1-2 shows the repair for Scenario 2 and 3.

The purpose of this report is to provide plant-specific technical basis for the use of the embedded flaw repair process and to confirm that Vogtle Unit 1 and Unit 2 meet the criteria for application of the embedded flaw repair process stated in Appendix C of WCAP-15987-P [3]. Engineering evaluations were performed and the results are presented in this report to provide the maximum allowable initial embedded flaw sizes that could be repaired using the Westinghouse embedded flaw repair process and would satisfy the requirements in Section XI of the ASME Code [1]. The ASME Section XI Code of record for Vogtle Unit 1 and Unit 2 is 2007 Edition with 2008 Addenda [1]. Note that the methodology used in this report from the 2007 Edition with 2008 Addenda is the same up to the 2017 Edition of ASME Section XI Code, which is the most recent ASME Code edition approved by the NRC. The results presented in this report would support the use of the Westinghouse embedded flaw repair process as the repair option for the Vogtle Units 1 and 2 reactor vessel head penetration nozzles.

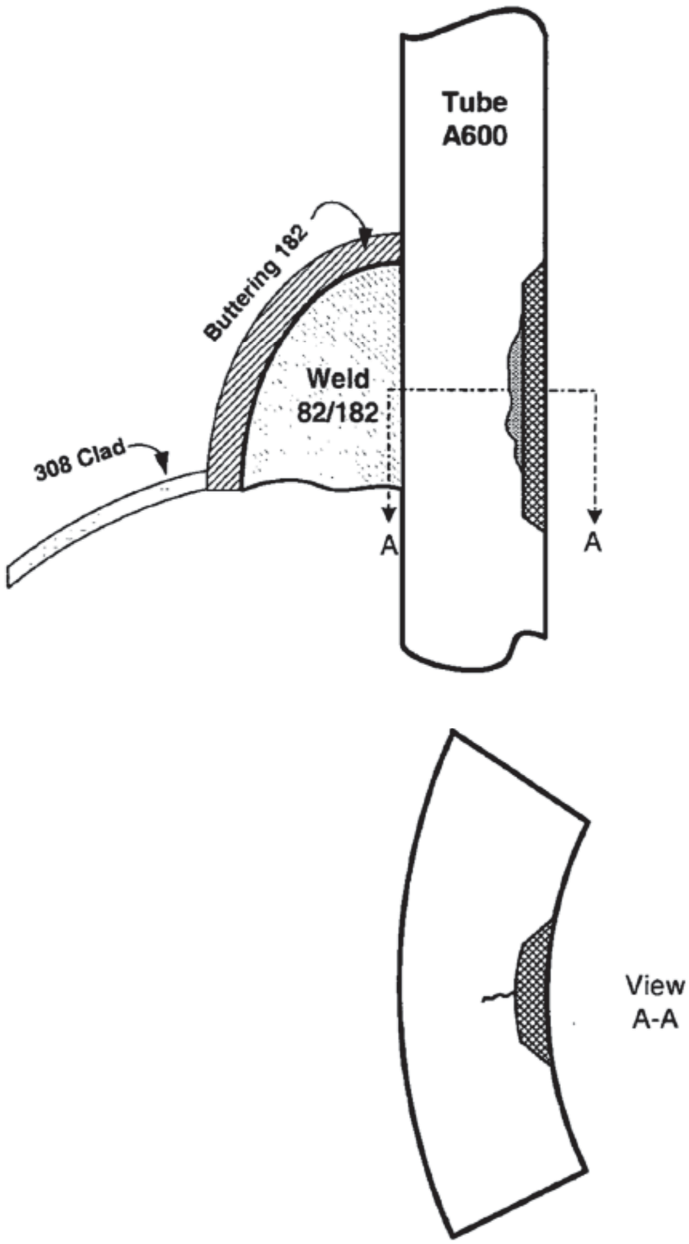

Figure 1-1 General Schematic of the Embedded Flaw Repair to a Flaw in the Head Penetration Tube Inside Surface

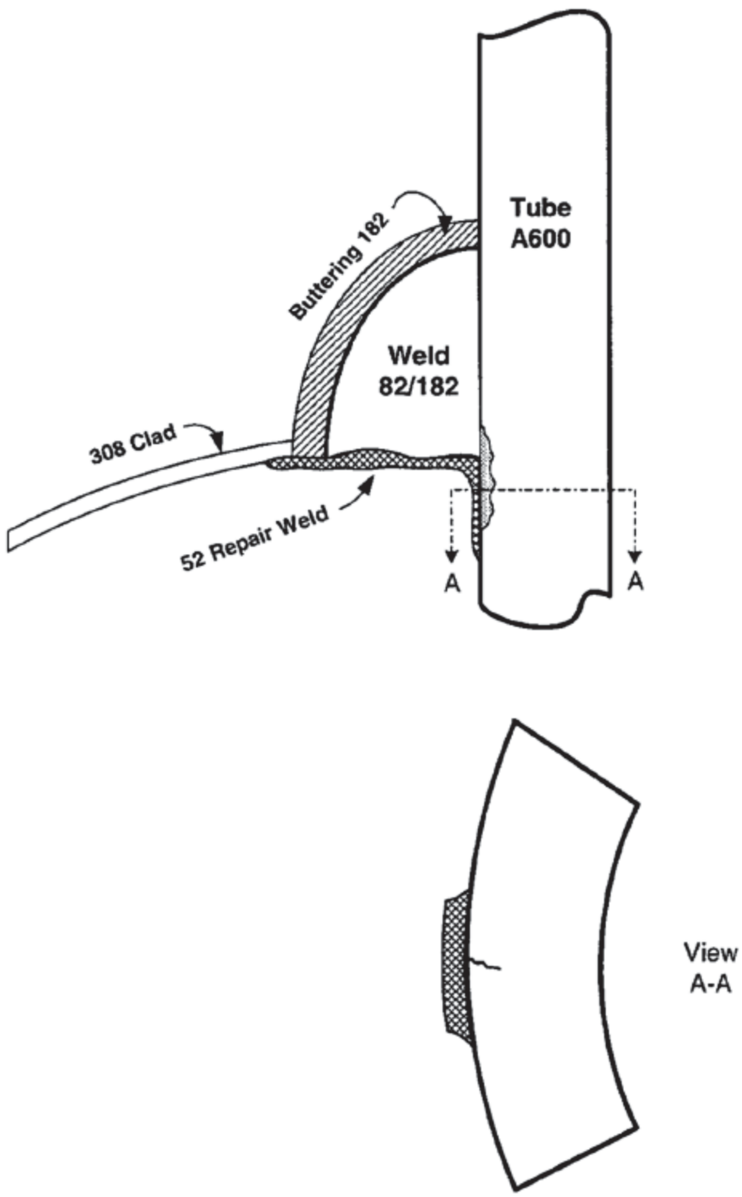

Figure 1-2 General Schematic of the Embedded Flaw Repair to a Flaw in the Head Penetration Tube Outside Surface, or to a Flaw in the Attachment Weld (J-Groove Weld)

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

This section provides a discussion on the technical basis for the use of the embedded flaw repair method for a flawed head penetration nozzle (i.e., flaws on the ID or OD of the head penetration nozzles (Scenario 1 and Scenario 3)). The technical basis for the use of the embedded flaw repair method for the flawed head attachment weld (Scenario 2) is provided in Section 3.

[

]a,c,e

[

]a,c,e

The evaluation of the embedded flaw repair for the axial or circumferential crack on the penetration inner surface (Scenario 1) or outer surface (Scenario 3) began with the determination of an allowable end-of-evaluation period flaw size based on the acceptance criteria described in Section 2.1 for a flaw postulated to remain in the repaired penetration nozzle. [

]a,c,e

2.1 ACCEPTANCE CRITERIA

Rapid, non-ductile failure is possible for ferritic materials at low temperatures, but is not applicable to the nickel-base alloy head penetration nozzle material, Alloy 600. Nickel-base alloy material is a high toughness material and plastic collapse would be the dominant mode of failure. [

]^{a,c,e}

2.1.1 Axial Flaws

For axial flaws the allowable flaw depth is given by [

]^{a,c,e}

2.1.2 Circumferential Flaws

For circumferential flaws [

]^{a,c,e}

2.2 METHODOLOGY

The evaluation assumed that an unacceptable flaw has been detected on the surface of a penetration nozzle and that the embedded flaw repair process is used to seal the flaw from further exposure to the primary water environment. The evaluation began with the determination of an allowable end-of-evaluation period flaw size based on the acceptance criteria described in Section 2.1 for a flaw postulated to remain in the repaired penetration nozzle. [ ]^{a,c,e} The maximum initial flaw size in a penetration nozzle that can be repaired using the embedded flaw repair process can then be determined [ ]a,c,e The following provides a discussion of the geometry, loading conditions, thermal transient stress analysis, and [ ]a,c,e used in the development of the plant specific technical basis for the embedded flaw repair process.

2.2.1 Geometry and Material

There are seventy eight CRDM head penetration nozzles in the reactor vessel upper closure head with the same nozzle geometry but at different locations in the closure head [4.a and 5.a]. The outside radius and thickness for all Alloy 600 tubes are [ ]a,c,e. The CRDM nozzle material is [ ]a,c,e.

2.2.2 Finite Element Analysis

The distributions of transient thermal and pressure stresses [ ]a,c,e Reference [6] considers the welding residual stresses associated with original nozzle installation. Subsequent to the welding residual stress analysis, the stresses that result from the [ ]a,c,e in the presence of welding residual conditions are calculated. [ ]a,c,e, including the welding residual stresses associated with original nozzle installation. [ ]a,c,e Figure 2-2 shows the location of the stress cuts. [ ]a,c,e of the circumferential and axial cracks postulated on the inside or outside of the nozzles.

[ ]a,c,e

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

2.2.3 Loading Conditions

The requirement for determining the maximum allowable end-of-evaluation period flaw size using the rules of Section XI is that the governing loadings from the normal, upset, emergency, and faulted conditions be considered. 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

[

]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 normal, upset and test transients considered for Vogtle Unit 1 and Unit 2 reactor vessel analyses [8 and 9] and the design cycles of the transients from Table 3.9.N.1-1 of Vogtle plants final safety analysis report (FSAR) [10] are summarized in Table 2-1. [

]a,c,e The operating licenses for both Vogtle units have been renewed and the original licensed operating terms have been extended by 20 years. The effect of the extended operating term on the number of transient cycles was evaluated as a Time-Limited Aging Analyses (TLAA) for license renewal in accordance with 10 CFR Part 54 and it was concluded in Section 19.4.2.1 of the FSAR [10] that the design cycles in Table 3.9.N.1-1 are conservative and bound 60 years of operation. Note that the fatigue crack growth evaluation performed herein will be applicable to 80 years of operation, given that the 80-year projected transients and cycles are also bounded by the design cycles.

Table 2-1 Vogtle Unit 1 and Unit 2 Normal, Upset and Test Transients for FCG Analyses

Transient	**Cycles(1)**
Plant Heatup and Cooldown (100°F/hour)	200
Unit Loading, 0-15% of Full Power	500
Plant Loading @ 5% Full Power/min	11,200
Step Load Decrease of 10% Full Power	2,000
Step Load Increase of 10% Full Power	2,000
Plant Unloading @ 5% Full Power/min.	13,200
Unit Unloading (15% to 0%)	500
Reactor Trip with no Cooldown	230
Reactor Trip with Cooldown, No Safety Injection	160
Reactor Trip with Cooldown, Safety Injection	10
Large Step Load Decrease	200
Reduce Temp. Return to Power	2,000
Excessive Feedwater Flow	30
Control Rod Drop	80
Inadvertent Startup, Inactive Loop	10
Feedwater Cycling	2,000
Partial Loss of Flow	80
Inadvertent Depression	20
Inadvertent Safety Injection	60
Loss of Power	40
Loss of Load	80
Loop out of Service, Startup	70
Loop out of Service, Shutdown	80
Turbine Roll Test	20
Steady State Fluctuation – Initial Fluctuations, ±3°F, ±25 psi	176,400(2)
Steady State Fluctuation – Random Fluctuations, ±0.5°F, ±6 psi	3,000,000

Notes:

1. Cycles are from Table 3.9.N.1-1 of Vogtle plants final safety analysis report (FSAR) [10].
2. [

]^{a,c,e}

2.2.4 Allowable Flaw Size Determination

Allowable end-of-evaluation 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 allowable initial flaw sizes are subsequently determined by adjusting the allowable end-of-evaluation flaw sizes based on the results from the fatigue crack growth evaluation described in Section 2.2.6. Since the repaired flaws are embedded and sealed, they are not subjected to PWSCC.

2.2.5 Stress Intensity Factors

One of the key elements in a crack growth analysis is the crack driving force or crack tip stress intensity factor, K_I. This is based on the equations available in public literature. Both embedded and surface flaws are analyzed for repaired inside and outside surface flaws.

Outside and Inside Surface Flaws

The stress intensity factors (SIF), K_I, for the part through-wall surface cracks are calculated based on [ ]a,c,e. The stress distribution profile is represented by a 3rd order polynomial as shown below.

$$\sigma = \sigma_0 + \sigma_1 \left(\frac{a}{t}\right) + \sigma_2 \left(\frac{a}{t}\right)^2 + \sigma_3 \left(\frac{a}{t}\right)^3$$

where:

σ_0, σ_1, σ_2, and σ_3 are the stress profile curve fitting coefficients to be determined;

a is the distance from the wall surface where the crack initiates;

t is the wall thickness; and

σ is the stress perpendicular to the plane of the crack.

The SIFs can be expressed in the general form as follows:

[

]a,c,e

Embedded Flaws

The stress intensity factor calculation for an embedded flaw was based on [

]^{a,c,e}

This stress intensity factor expression for subsurface (embedded) flaws can be expressed [

]^{a,c,e}

2.2.6 Fatigue Crack Growth Prediction

With the application of the embedded flaw repair process, any postulated flaws in the reactor vessel head penetration tubes are sealed from the PWR environment; therefore, the only mechanism for crack growth would be due to fatigue crack growth.

The FCG analysis procedure involves postulating an initial flaw at the region of concern and predicting the growth of that flaw due to an imposed series of loading transients. The applied loads include pressure, thermal transients, and residual stresses. The normal and upset thermal transients as well as the associated design cycles considered in the fatigue crack growth analysis are shown in Table 2-1. The cycles are distributed evenly over 60 years of 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. Once the incremental crack growth corresponding to a specific transient is calculated for a small time period, 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.

[

'

]a,c,e

2.3 FRACTURE MECHANICS ANALYSIS RESULTS

2.3.1 Maximum End-of-Evaluation Period Flaw Sizes

The maximum allowable end-of-evaluation period flaw sizes are determined for axial and circumferential surface flaws for postulated flaw aspect ratios (flaw length/flaw depth) of 2, 3, 6, and 10. The allowable flaw sizes are considered for all normal, upset, test, emergency, and faulted conditions and the most limiting allowable flaw sizes from these conditions are summarized in Table 2-2 and will be used in the generation of flaw evaluation charts.

Table 2-2 Maximum Allowable End-of-Evaluation Period Flaw Size Based on Section XI

Location	Aspect Ratio (l/a)	Axial Allowable Flaw Size		Circumferential Allowable Flaw Size	
		a/t	a (in.)	a/t	a (in.)
CRDM Nozzle (t = 0.625”)	2	0.75	0.469	0.75	0.469
	3	0.75	0.469	0.75	0.469
	6	0.75	0.469	0.61	0.381
	10	0.75	0.469	0.48	0.300

2.3.2 Allowable Initial Flaw Sizes for Penetration Nozzles

After the maximum allowable end-of-evaluation period flaw sizes are determined, [ ]a,c,e First, the outside and inside surface flaws with aspect ratios of 2, 3, 6, and 10 are postulated. [ ]a,c,e The results are also plotted in Figure 2-3 and Figure 2-4.

Table 2-3 Maximum Allowable Initial Flaw Size on CRDM Nozzle for Repair

Location	Years of Operation	Aspect Ratio (l/a)	Inside Surface				Outside Surface			
			Circumferential Flaw		Axial Flaw		Circumferential Flaw		Axial Flaw	
			a/t	a (in.)	a/t	a (in.)	a/t	a (in.)	a/t	a (in.)
Downhill Side	20	2	0.74	0.4625	0.74	0.4625	0.74	0.4625	0.73	0.4563
		3	0.74	0.4625	0.71	0.4438	0.73	0.45625	0.68	0.4250
		6	0.60	0.3750	0.62	0.3875	0.54	0.3375	0.51	0.3188
		10	0.47	0.2938	0.52	0.3250	0.41	0.25625	0.43	0.2688
	40	2	0.74	0.4625	0.73	0.4563	0.74	0.4625	0.72	0.4500
		3	0.74	0.4625	0.68	0.4250	0.71	0.44375	0.63	0.3938
		6	0.60	0.3750	0.56	0.3500	0.49	0.30625	0.45	0.2813
		10	0.47	0.2938	0.46	0.2875	0.37	0.23125	0.37	0.2313
	60	2	0.74	0.4625	0.69	0.4313	0.74	0.4625	0.71	0.4438
		3	0.74	0.4625	0.65	0.4063	0.69	0.43125	0.59	0.3688
		6	0.60	0.3750	0.51	0.3188	0.46	0.2875	0.41	0.2563
		10	0.47	0.2938	0.42	0.2625	0.34	0.2125	0.34	0.2125
Uphill Side	20	2	0.74	0.4625	0.70	0.4375	0.74	0.4625	0.72	0.4500
		3	0.73	0.4563	0.66	0.4125	0.73	0.4563	0.63	0.3938
		6	0.60	0.3750	0.52	0.3250	0.55	0.3438	0.45	0.2813
		10	0.47	0.2938	0.41	0.2563	0.43	0.2688	0.37	0.2313
	40	2	0.74	0.4625	0.63	0.3938	0.74	0.4625	0.69	0.4313
		3	0.73	0.4563	0.58	0.3625	0.71	0.4438	0.57	0.3563
		6	0.60	0.3750	0.43	0.2688	0.52	0.3250	0.39	0.2438
		10	0.47	0.2938	0.34	0.2125	0.4	0.2500	0.32	0.2000
	60	2	0.74	0.4625	0.58	0.3625	0.74	0.4625	0.67	0.4188
		3	0.73	0.4563	0.55	0.3438	0.7	0.4375	0.53	0.3313
		6	0.60	0.3750	0.38	0.2375	0.48	0.3000	0.36	0.2250
		10	0.47	0.2938	0.29	0.1813	0.37	0.2313	0.29	0.1813

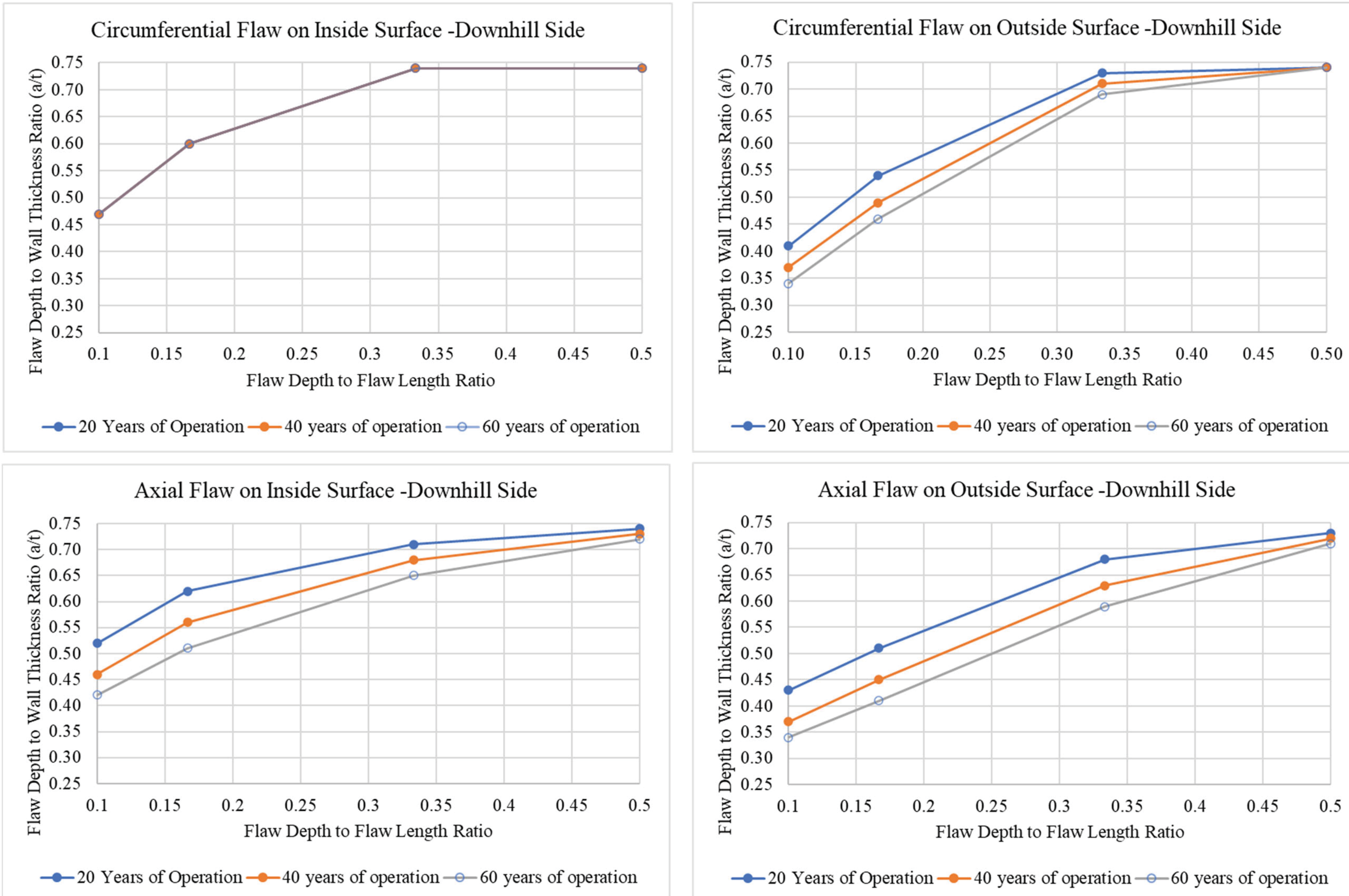

Figure 2-3 Maximum Allowable Initial Flaw Size on CRDM Nozzle for Repair – Downhill Side

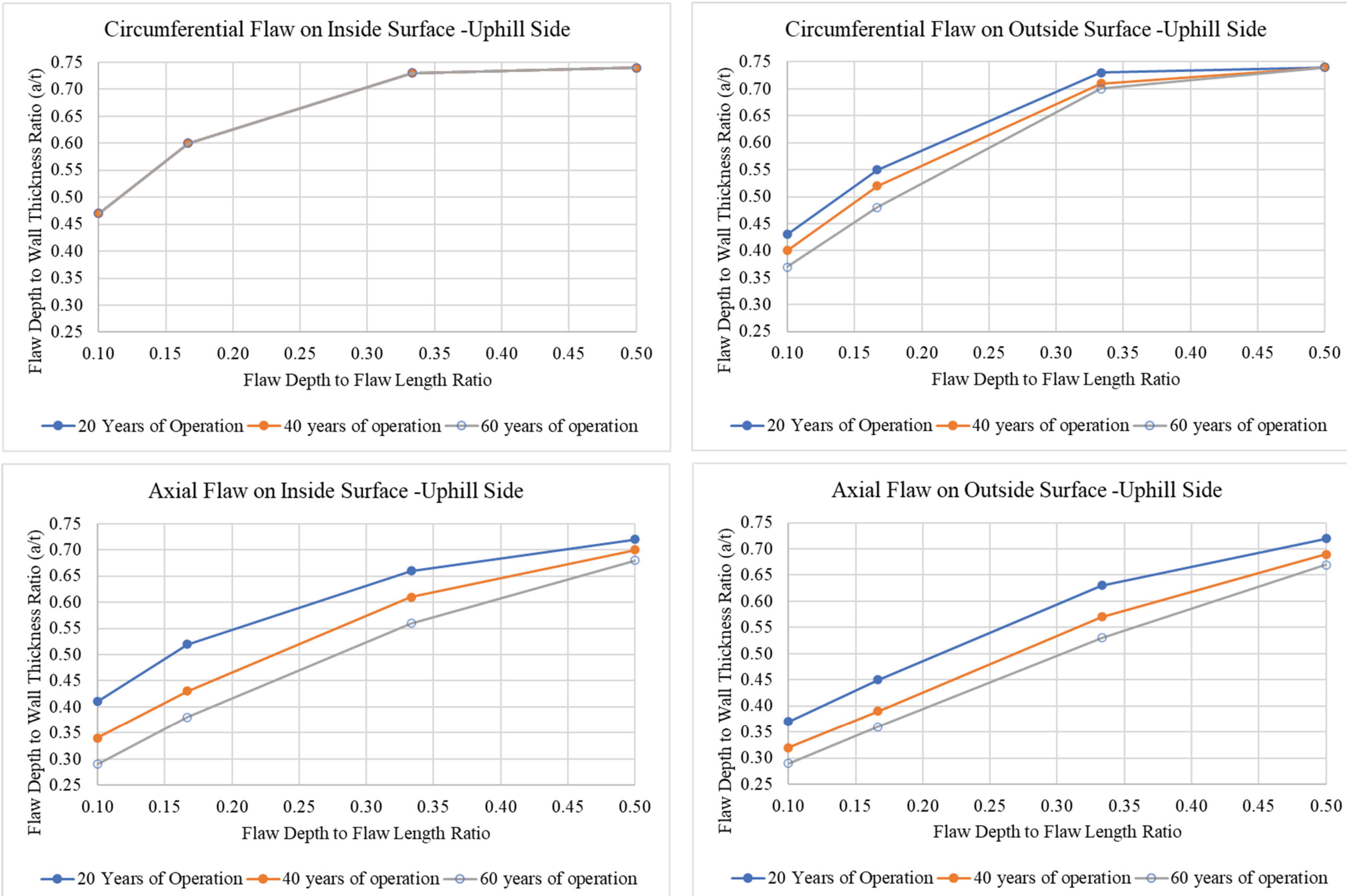

Figure 2-4 Maximum Allowable Initial Flaw Size on CRDM Nozzle for Repair – Uphill Side

3 TECHNICAL BASIS FOR APPLICATION OF EMBEDDED FLAW REPAIR TECHNIQUE TO ATTACHMENT J-GROOVE WELD

This section provides a discussion on the technical basis for the use of the embedded flaw repair method for the flawed head attachment weld (Scenario 2). [

]a,c,e A flaw evaluation was carried out by analyzing a planar flaw in the reactor vessel head the size of the J-groove weld size.

3.1 ACCEPTANCE CRITERIA

3.1.1 Section XI Appendix K

The evaluation procedure and acceptance criteria used to demonstrate structural integrity of the reactor vessel closure head is contained in Appendix K of ASME Section XI Code [1] as well as Regulatory Guide 1.161 [13]. Although the original purpose of Appendix K was to evaluate reactor vessels with low upper shelf fracture toughness, the general approach in paragraph K-4220 is equally applicable to any region of the reactor vessel where the fracture toughness can be described with elastic plastic parameters. This approach to evaluate the integrity of a nuclear vessel has been developed over several years, and has been illustrated with a number of example problems [14] 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) promote ductile behavior. The closure head region of the reactor vessel has the operating temperature of about 558 ºF. This would result in ductile behavior and therefore the use of elastic-plastic fracture mechanics method is appropriate.

The acceptance criteria are to be satisfied for each category of transients, namely, Service Load Level A (normal), Level B (upset, including test), Level C (emergency) and Level D (faulted) conditions and two criteria discussed below must be satisfied.

The first criterion is that the crack driving force must be shown to be less than the material toughness as follows:

$$J_{applied} < J_{material}$$

where $J_{applied}$ is the J-integral value calculated for the postulated flaw under the applicable Service Level condition and $J_{material}$ is the J-integral characteristic of the material resistance to ductile tearing at a crack extension of 0.1 inch. For Level A and B conditions, a safety factor of 1.15 is conservatively applied to the $J_{applied}$ per Reg Guide 1.161 [13] and ASME Section XI Appendix K Article K-4220 of ASME Section XI Code [1]. The factor of 1.15 needs only to be applied on pressure, however, in this evaluation it is applied to the J-integral calculated from the transient and residual stresses in addition to the normal operating pressure. For Level C and D conditions, the safety factor on $J_{applied}$ is 1.0.

The second criterion is that the flaw must also be stable under ductile crack growth as follows:

$$\frac{\partial J_{applied}}{\partial a} < \frac{dJ_{material}}{da}$$

$$\text{at } J_{applied} = J_{material}$$

where,

$J_{material}$ = J-integral resistance to ductile tearing for the material.

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

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

For Level A and B conditions, a safety factor of 1.25 is conservatively applied to the $J_{applied}$ per Reg Guide 1.161 [13] and ASME Section XI Appendix K Article K-4220 of ASME Section XI Code [1]. The factor of 1.25 needs only to be applied on pressure, however, in this evaluation it is conservatively applied to the transient and residual stresses in addition to the normal operating pressure. For Level C and D conditions, the safety factor on $J_{applied}$ is 1.0. Flaw stability is verified when the slope of the applied J-integral curve is less than the material J-integral curve at the point on J-R curve where the two curves intersect.

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 [15] 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 the maximum pressure of [ ][a,c,e] for all service conditions. The results show the allowable flaw depth is 1.933 inches.

3.2 METHODOLOGY

Since the depth of a flaw in the attachment weld cannot be detected using current technology, the engineering evaluation for the embedded flaw repair process was performed to demonstrate the stability of an assumed hypothetical flaw that encompasses the entire attachment J-groove weld region in the reactor vessel head near the penetration nozzle. The criteria used to demonstrate the stability and structural integrity of the reactor vessel closure head is described in Section 3.1.1 as per the ASME Code [1] and Regulatory Guide 1.161 [13].

After the implementation of the embedded flaw repair process, [

][a,c,e] That is, the flaw depth at the end of evaluation period should be below the 1.933 inches as determined in Section 3.1.2 such that primary stress limit of the ASME Code Section III, paragraph NB-3000 [15] is satisfied. In addition, it needs to be shown that the postulated flaw will not grow through the repair layer.

3.2.1 Geometry and Material

The reactor vessel head is made of [ ]a,c,e, with the following geometry:

[

]a,c,e

The reactor vessel upper head nozzle attachment weld geometry for the nozzles used in this calculation is tabulated in Table 3-1 for the case without the weld fillet as shown in Figure 3-1. The weld dimensions in Table 3-1 are used for the fatigue crack growth and J-integral analyses for postulated flaws in the reactor vessel head. The height and width of the J-groove weld configurations are the built-up dimensions.

The weld depths for all penetration nozzles on the uphill and downhill sides are also provided based on the UT scanning of the Alloy 600 tubes [16]. The weld depth dimension 'a', as shown in Figure 3-1 and Table 3-2, includes the weld fillet and butter thickness. The weld dimensions in Table 3-2 are used in the fatigue crack growth analysis for the growth of postulated flaws through the weld repair layer. [

]a,c,e these flaw depths bound all penetration row weld depths 'a' for Vogtle Unit 1 and Unit 2.

a,c,e

a,c,e

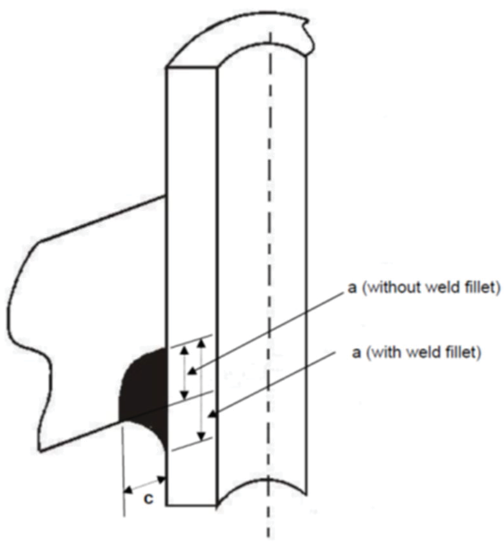

Figure 3-1 Definition of J-Groove Weld Dimensions

3.2.2 Loading Conditions

For the normal/upset condition, the reactor vessel closure head structural integrity evaluation is performed for all the transients in Table 2-1, and [ ]^{a,c,e} For the emergency and faulted condition evaluation, [ ]^{a,c,e}

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 [6]. [ ]^{a,c,e}

3.2.3 Stress Intensity Factors

J-Groove Weld Double Corner Crack in the Reactor Vessel Head

Since the depth of a flaw in the attachment weld cannot be detected using current technology, it is conservatively assumed that the flaw in the attachment weld extends radially over the entire attachment weld. [ ]^{a,c,e}

The stress intensity factor expression shown above is applicable for a range of flaw shapes, with the depth of the flaw defined as "a", and the width of the flaw defined as "c", as shown in Figure 3-2. This flexibility is necessary because this expression can be applied to different attachment J-groove weld shapes for Vogtle Units 1 and 2 closure head penetrations as shown in Table 3-1. The attachment J-groove weld shapes were based on the J-groove geometry shown in the head penetration nozzle drawings for Vogtle Units 1 and 2 [4 and 5]. [ ]^{a,c,e}

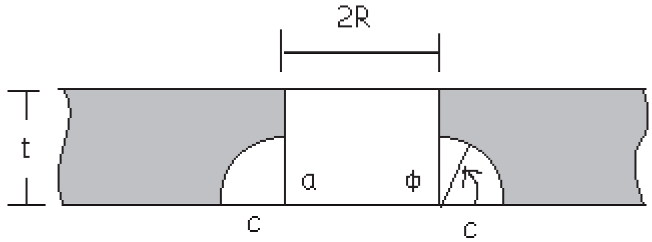

Figure 3-2 Corner Crack Geometry

Embedded Flaw in the Reactor Vessel Head

[

]a,c,e The details of the method is discussed in Section 2.2.5 and thus not repeated here.

3.2.4 J-R curve for Reactor Vessel Closure Head Material

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

[

]a,c,e

Neutron irradiation has been shown to produce embrittlement that reduces the toughness properties of the reactor vessel ferritic steel material. The irradiation levels are very low in the reactor vessel closure 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 based on the crack tip stress intensity factor, K_I, calculated as per Section 3.2.3. However, a plastic zone correction must be performed to account for the plastic deformation at the crack tip similar to the approach in Regulatory Guide 1.161 [13]. 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:

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

where K_{ep} is the plastic zone corrected K-value, and $E'=E/(1-\nu^2)$ for plane strain, E = Young's Modulus, and ν = Poisson's Ratio.

K_{ep} is equal to the elastically calculated K_I-value based on the plastic zone adjusted crack depth or size. 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, this can be simplified as

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

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

Once the J-applied is calculated, stability for the postulated flaw in the attachment J-groove weld can be determined using the methodology described in Section 3.1.1.

3.2.6 Fatigue Crack Growth Prediction

With the application of the embedded flaw repair process, any postulated flaws in the reactor vessel head penetration tubes or the attachment weld are sealed from the PWR environment; therefore, the only mechanism for crack growth would be due to fatigue.

The FCG analysis procedure involves postulating an initial flaw at the region of concern and predicting the growth of that flaw due to an imposed series of loading transients, using the same approach described in Section 2.2.6. The FCG curves used for [
]^{a,c,e} and the embedded flaw beneath the repair weld are discussed below.

FCG Curve for the Reactor Vessel Closure Head: Carbon and Low Alloy Ferritic Steel

The crack growth rate curves used in the analyses for [
]^{a,c,e} are taken directly from Appendix A in the ASME Section XI Code [1] for ferritic steel material. With the repair weld any potential flaws in the J-groove weld (Alloy 182) are sealed from the primary water environment and the only applicable growth mechanism is fatigue crack growth in air environment; therefore, the analysis is performed for a surface flaw based on the limiting crack growth rate reference curve of the air environment. 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. The crack growth equation is given below:

$$\frac{da}{dN} = C_0(\Delta K_I)^n$$

where n is the slope of the log (da/dN) versus log (ΔK_I) curve and is equal to 3.07 for subsurface flaws.

Parameter C_o is a scaling constant:

$$\begin{aligned} C_0 &= 0 && for\ \Delta K_I < \Delta K_{th} \\ &= 1.99 \times 10^{-10} S && for\ \Delta K_I \geq \Delta K_{th} \end{aligned}$$

where ΔK_{th} is the threshold ΔK_I value below which the fatigue crack growth rate is negligible and S is a scaling parameter. Both ΔK_{th} and S are a function of the R ratio (K_{min}/K_{max}). The calculation of crack tip stress intensity factor range (ΔK_I) also changes with R ratio when $\Delta K_I \geq \Delta K_{th}$.

$$\begin{aligned} \Delta K_{th} &= 5.0 && for\ R < 0 \\ &= 5.0(1 - 0.8R) && for\ 0 \leq R < 1.0 \end{aligned}$$

The calculation of crack tip stress intensity factor range (ΔK_I) also changes with R ratio when $\Delta K_I \geq \Delta K_{th}$. The calculation of S and ΔK_I for different R ratio ranges is summarized below:

- For $0 \leq R \leq 1$

  $S = 25.72(2.88-R)^{-3.07}$ and $\Delta K_I = K_{max} - K_{min}$

- For $R < 0$ and $K_{max} - K_{min} > 1.12\sigma_f\sqrt{\pi a}$

  $S=1$ and $\Delta K_I = K_{max} - K_{min}$

- For $-2 \leq R \leq 0$ and $K_{max} - K_{min} \leq 1.12\sigma_f\sqrt{\pi a}$

  $S=1$ and $\Delta K_I = K_{max}$

- For $R<-2$ and $K_{max} - K_{min} \leq 1.12\sigma_f\sqrt{\pi a}$

  $S=1$ and $\Delta K_I = (1-R)K_{max}/3$

[

]a,c,e

Note that a condition is imposed on A-4300(b)(1) of ASME Code Section XI in 10CFR 50.55a Codes and Standards and a factor of 0.8 is applied to the limit in $K_{max} - K_{min}$ defined in A-4300 of the ASME Code Section XI [1].

FCG Curve for the Repair Weld, Alloy 52/52M, Below the J-Groove Attachment Weld

[

]a,c,e

3.3 FRACTURE MECHANICS ANALYSIS RESULTS

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

For the J-integral calculation, the key aspects of the analysis are to demonstrate that the magnitude of J-applied is less than J-material at 0.1 inch crack extension, and the slope of the J-material curve is greater than the slope of the J-applied curve at the intersection of the J_{mat} and $J_{applied}$ curves. This evaluation is performed for the postulated flaws encompassing the J-groove welds at all the nozzle locations. The weld dimensions are shown in Table 3-1. The results shows that for all the nozzle locations, the applied J-integral is less than material J-integral at 0.1 inch crack extension, as shown in Table 3-3 and Table 3-4. The slope of the J-material curve is also greater than the slope of the J-applied curve at the intersection of the J-applied and J-material curves for all the locations. Figures 3-3 and 3-4 show the plots for the penetration nozzle locations with the highest J-applied at 0.1 inch crack extension for Level A/B and Level C/D conditions, respectively.

Table 3-3 J-Integral Results for 0.1 inch Crack Extension on Downhill and Uphill Sides – Level A/B

Unit	Pen. No.	Penetration Angle	Downhill		Uphill	
			$J_{applied}^{(1)}$ (kip-in/in^2)	$J_{material}^{(1)}$ (kip-in/in^2)	$J_{applied}^{(1)}$ (kip-in/in^2)	$J_{material}^{(1)}$ (kip-in/in^2)
1	1	0	0.573	1.156	0.809	1.156
	2-5	11.4	0.420	1.156	0.771	1.156
	6-9	16.2	0.577	1.156	0.790	1.156
	10-13	18.2	0.581	1.156	0.798	1.156
	14-17	23.3	0.610	1.156	0.814	1.156
	18-21	24.8	0.611	1.156	0.841	1.156
	22-29	26.2	0.617	1.156	0.849	1.156
	30-37	30.2	0.637	1.156	0.877	1.156
	38-41	33.9	0.671	1.156	0.924	1.156
	42-49	35.1	0.679	1.156	0.938	1.156
	50-53	36.3	0.688	1.156	0.953	1.156
	54-61	38.6	0.701	1.156	0.982	1.156
	62-65	44.3	0.739	1.156	1.083	1.156
	66-73	45.4	0.752	1.156	1.104	1.156
	74-78	48.7	0.779	1.156	1.113	1.156
					1.194	1.265(2)
2	1	0	0.582	1.511	0.824	1.511
	2-5	11.4	0.609	1.511	0.727	1.511
	6-9	16.2	0.639	1.511	0.713	1.511
	10-13	18.2	0.645	1.511	0.708	1.511
	14-17	23.3	0.674	1.511	0.696	1.511
	18-21	24.8	0.693	1.511	0.706	1.511
	22-29	26.2	0.699	1.511	0.704	1.511
	30-37	30.2	0.729	1.511	0.701	1.511
	38-41	33.9	0.775	1.511	0.716	1.511
	42-49	35.1	0.785	1.511	0.718	1.511
	50-53	36.3	0.802	1.511	0.721	1.511
	54-61	38.6	0.830	1.511	0.728	1.511
	62-65	44.3	0.921	1.511	0.762	1.511
	66-73	45.4	0.949	1.511	0.771	1.511
	74-78	48.7	1.018	1.511	0.795	1.511

Notes:

1. The applied and material J-integrals are conservatively calculated at maximum Level A/B temperature of [ ]^{a,c,e} unless otherwise noted.
2. The material J-integrals calculated at the temperature of [ ]^{a,c,e}, which is closer to the actual temperature when the corresponding maximum applied J-integrals occur.

Table 3-4 J-Integral Results for 0.1 inch Crack Extension on Downhill and Uphill Sides – Level C/D

Unit	Pen. No.	Penetration Angle	Downhill		Uphill	
			$J_{applied}$(1) (kip-in/in^2)	$J_{material}$(1) (kip-in/in^2)	$J_{applied}$(1) (kip-in/in^2)	$J_{material}$(1) (kip-in/in^2)
1	1	0	0.561	1.111	0.699	1.111
	2-5	11.4	0.412	1.111	0.644	1.111
	6-9	16.2	0.566	1.111	0.656	1.111
	10-13	18.2	0.570	1.111	0.661	1.111
	14-17	23.3	0.606	1.111	0.668	1.111
	18-21	24.8	0.608	1.111	0.693	1.111
	22-29	26.2	0.614	1.111	0.698	1.111
	30-37	30.2	0.637	1.111	0.717	1.111
	38-41	33.9	0.679	1.111	0.757	1.111
	42-49	35.1	0.689	1.111	0.767	1.111
	50-53	36.3	0.699	1.111	0.779	1.111
	54-61	38.6	0.718	1.111	0.807	1.111
	62-65	44.3	0.769	1.111	0.912	1.111
	66-73	45.4	0.793	1.111	0.934	1.111
	74-78	48.7	0.830	1.111	1.024	1.111
2	1	0	0.572	1.453	0.714	1.453
	2-5	11.4	0.591	1.453	0.607	1.453
	6-9	16.2	0.626	1.453	0.592	1.453
	10-13	18.2	0.633	1.453	0.587	1.453
	14-17	23.3	0.674	1.453	0.572	1.453
	18-21	24.8	0.707	1.453	0.583	1.453
	22-29	26.2	0.712	1.453	0.580	1.453
	30-37	30.2	0.748	1.453	0.574	1.453
	38-41	33.9	0.818	1.453	0.587	1.453
	42-49	35.1	0.828	1.453	0.588	1.453
	50-53	36.3	0.851	1.453	0.589	1.453
	54-61	38.6	0.885	1.453	0.594	1.453
	62-65	44.3	0.999	1.453	0.623	1.453
	66-73	45.4	1.043	1.453	0.631	1.453
	74-78	48.7	1.127	1.453	0.650	1.453

Note:

1. The applied and material J-integrals are conservatively calculated at maximum Level C/D temperature of [ ]a,c,e unless otherwise noted.

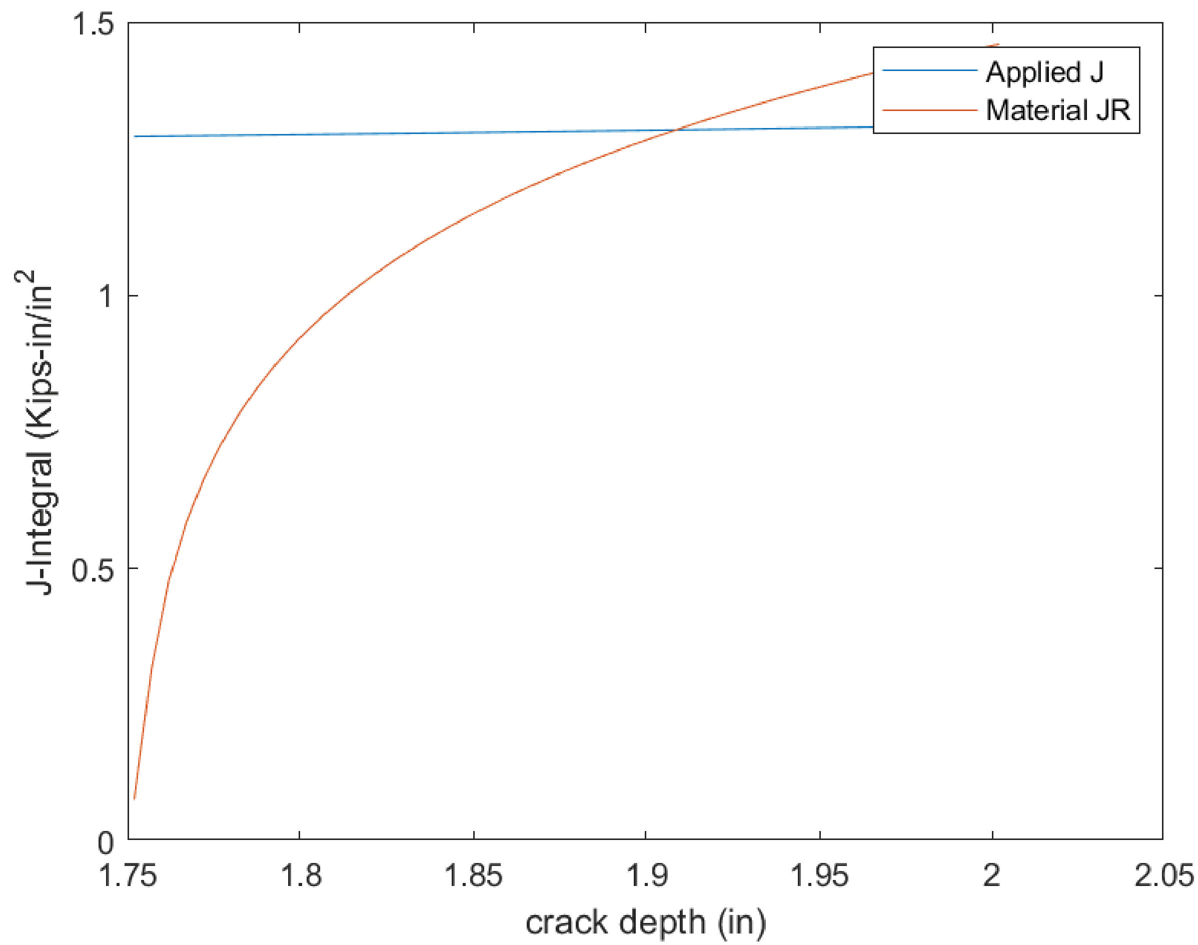

Figure 3-3 Comparison of the Slopes for Applied and Material J-Integral versus Crack Depth Curves for the Case with the Highest $J_{applied}$ at 0.1 inch Crack Extension – Level A/B Conditions

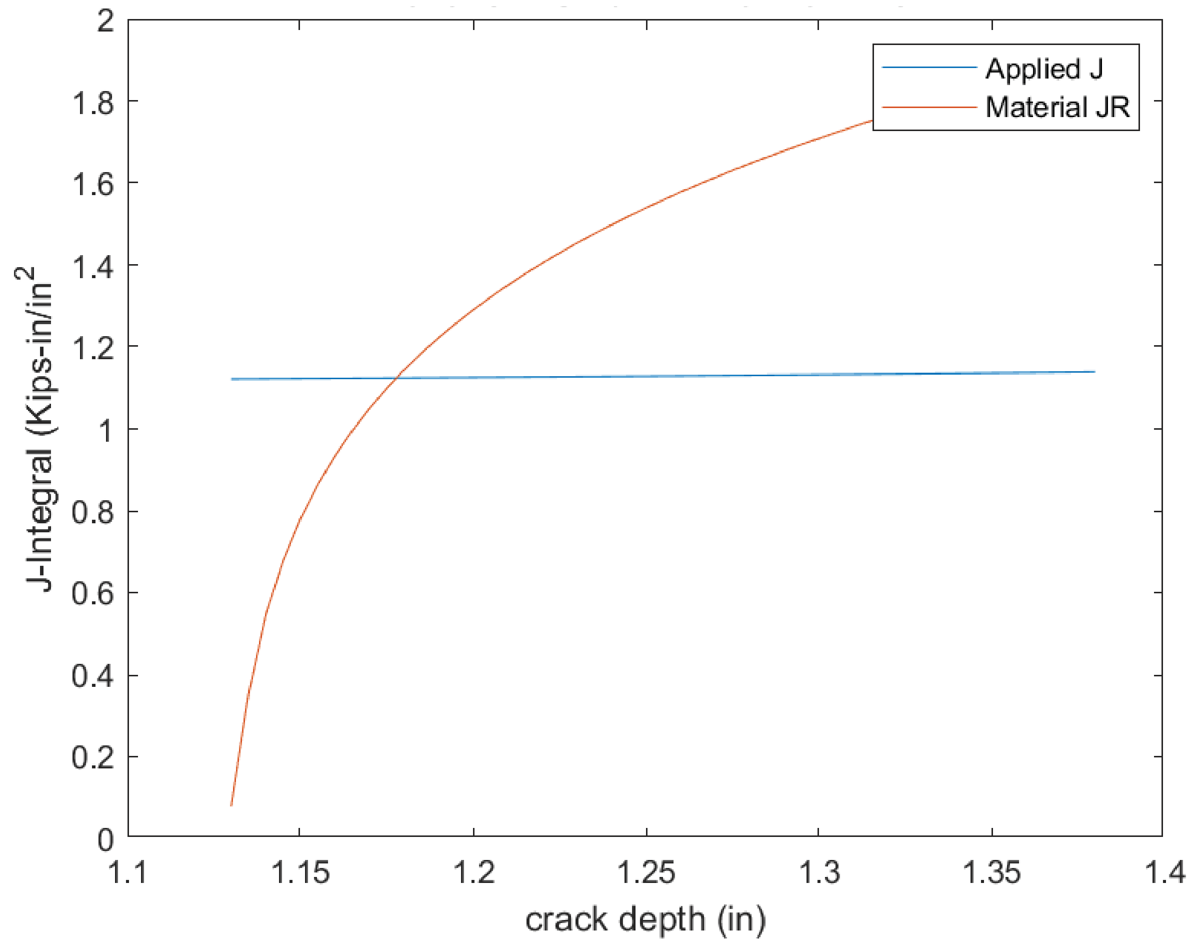

Figure 3-4 Comparison of the Slopes for Applied and Material J-Integral versus Crack Depth Curves for the Case with the Highest $J_{applied}$ at 0.1 inch Crack Extension – Level C/D Conditions

3.3.2 Results for Fatigue Crack Growth into the Reactor Vessel Head

The FCG into the reactor vessel head is considered for the postulated cracks with the initial flaw size based on the J-groove weld depth from Table 3-1. The weld dimensions in Table 3-1 show the following:

1. For downhill side, [ ]a,c,e

2. For uphill side, [ ]a,c,e

Therefore, the fatigue crack growth is performed for these two locations (i.e., the outermost nozzles), which bound all the other penetration nozzles. It is assumed that the initial aspect ratio is held constant as the flaw grows through the reactor head wall thickness.

The stress intensity factor is conservatively calculated based on [ ]a,c,e and the fatigue crack growth law for the reactor vessel head carbon steel material described in Section 3.2.6 is used. The FCG results are shown in Figure 3-5, which shows that the postulated flaw will not reach the reactor vessel head primary stress limit (1.933 inches) after 60 years of growth.

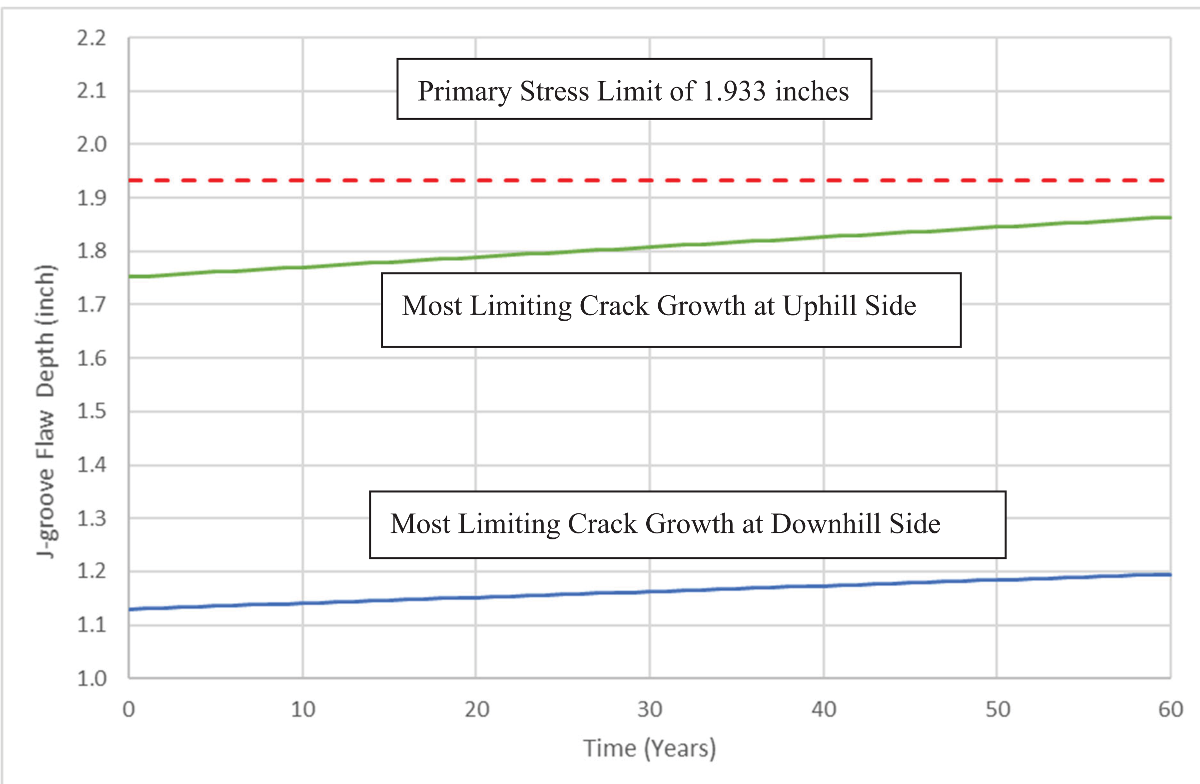

Figure 3-5 Fatigue Crack Growth Prediction into the Reactor Vessel Shell for Postulated Flaws in the J-Groove Welds for the Bounding Penetration Angles of 48.7° on the Downhill and Uphill Sides

3.3.3 Results for Fatigue Crack Growth into the Repair Weld

The attachment weld (J-groove) repair is performed by [ ]a,c,e The attachment weld is thus sealed, and the thickness of the reactor vessel shell is locally increased by [ ]a,c,e In order to determine the durability of the repair weld, an embedded flaw based on the J-Groove weld geometry is postulated, which starts from [ ]a,c,e beneath the free surface. The postulated flaw is an axial flaw with the aspect ratio (flaw length/flaw depth) of 2. This aspect ratio of 2 bounds all the aspect ratios for the uphill and downhill side attachment weld dimensions shown in Table 3-1. For the FCG analysis, the initial total flaw depth (2a) is assumed equal to the maximum uphill and downhill weld depths [ ]a,c,e in Table 3-2. The crack growth results are summarized in Table 3-5 and it shows that the structural integrity of the repaired weld layer is expected to be maintained for at least 20 years of service life.

Table 3-5 Growth of Embedded Axial Flaw in J-Groove Weld

Location	Year	Half Crack Depth (inch)	Remaining Repair Weld Thickness (inch)
Uphill Side	0	[ ]a,c,e	[ ]a,c,e
	10	[ ]a,c,e	[ ]a,c,e
	20	[ ]a,c,e	[ ]a,c,e
Downhill Side	0	[ ]a,c,e	[ ]a,c,e
	10	[ ]a,c,e	[ ]a,c,e
	20	[ ]a,c,e	[ ]a,c,e
	30	[ ]a,c,e	[ ]a,c,e

4 SUMMARY AND CONCLUSIONS

Engineering evaluations were performed to provide plant specific technical basis for the Westinghouse embedded flaw repair process that is associated with the reactor vessel head penetration nozzle inspection and contingency repair program for Vogtle Units 1 and 2.

The technical basis for the use of the embedded flaw repair process if unacceptable flaws are detected in the head penetration nozzles is provided in Section 2. Based on the results in Section 2.3, it is determined that unacceptable axial and circumferential flaws detected on the inside surface or outside surface of a head penetration nozzle can be repaired using the embedded flaw repair process by shielding them from the primary water environment. The maximum allowable initial axial and circumferential flaw sizes that can be repaired using the Westinghouse embedded flaw repair process are shown in Table 2-3 and Figures 2-3 and 2-4 for a plant service life up to 60 years.

The technical basis for the use of the embedded flaw repair process if indications or flaws are found in the head penetration attachment J-groove welds is provided in Section 3. Based on the results shown in Section 3.3, the evaluation documented herein has demonstrated that the embedded flaw repair process is a viable method for repairing flaws found in the attachment J-groove weld. The fracture mechanics evaluation demonstrated that a flaw postulated in the J-groove weld which encompasses the entire attachment J-groove weld shape is stable under the J-integral analysis. Furthermore, the reduced wall thickness considering the 60-year fatigue crack growth of the postulated flaw will meet the reactor vessel head primary stress limit minimum thickness requirement. The fatigue crack growth through the weld overlay repair layer demonstrates that a postulated flaw in the J-groove weld will not grow through the repair layer in less than 20 years. Therefore, it is technically justified to use the embedded flaw repair process as the repair option for the reactor vessel head penetration nozzle attachment J-groove welds since the criteria for application of such a process as stated in Appendix C of WCAP-15987-P Revision 2-P-A is met.

5 REFERENCES

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6. [ ]a,c,e
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