Exelon Generation.

4300 Winfield Road
Warrenville, IL 60555

630 657 2000 Office

10 CFR 50.55a

RS-14-251

September 8, 2014

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

Braidwood Station, Units 1 and 2
Facility Operating License Nos. NPF-72 and NPF-77
NRC Docket Nos. STN 50-456 and STN 50-457

Byron Station, Units 1 and 2
Facility Operating License Nos. NPF-37 and NPF-66
NRC Docket Nos. STN 50-454 and STN 50-455

Subject: Revision to the Third 10-Year Inservice Inspection Interval Requests for Relief for Alternative Requirements for the Repair of Reactor Vessel Head Penetrations

References:

(1) Letter from J. L. Hansen (EGC) to U.S. NRC, "Third 10-Year Inservice Inspection Interval Requests for Relief for Alternative Requirements for the Repair of Reactor Vessel Head Penetrations," dated April19, 2011, ADAMS Accession No. ML111100620

(2) Letter from N. DiFrancesco, (U. S. NRC) to M. J. Pacilio, (EGC), "Unacceptable with Opportunity to Supplement RE: Alternatives to the ASME Code Requirements for Repairs to the Reactor Vessel Head Penetrations (TAC Nos. ME6071, ME6072, ME6073, and ME6074)," dated June 6, 2011, ADAMS Accession No. ML111330653

(3) Letter from J. L. Hansen (EGC) to U.S. NRC, "Supplement to Third 10-Year Inservice Inspection Interval Requests for Relief for Alternative Requirements for the Repair of Reactor Vessel Head Penetrations", Dated June 14, 2011, ADAMS Accession No. ML111650286

(4) Letter from Jacob Zimmerman, (U. S. NRC) to M. J. Pacilio, (EGC), "Braidwood Station, Units 1 and 2 and Byron Station, Unit Nos. 1 and 2 – Relief Requests I3R-09 and I3R-20 Regarding Alternative Requirements for Repair of Reactor Vessel Head Penetrations (TAC Nos. ME6071, ME6073, and ME6074)", Dated March 29, 2012, ADAMS Accession No. ML120790647

In accordance with 10 CFR 50.55a, "Codes and standards," paragraph (a)(3)(i), Exelon Generation Company, LLC (EGC), submitted relief requests (RRs) I3R-20 for Byron Station, Units 1 and 2, and I3R-09 for Braidwood Station, Units 1 and 2, (Reference 1). The RRs proposed an alternative repair technique using weld overlays on the reactor vessel head penetration housing and J-groove welds, using a Westinghouse embedded flaw repair method. EGC proposed the alternative for indications that may be encountered in the future and that are the result of primary water stress corrosion cracking (PWSCC). Embedding a flaw within PWSCC resistant materials (i.e., Alloy 52 weld metal) will assure structural integrity of the nozzles.

In Reference 2, the NRC provided results of the acceptance review of the relief requests. The NRC concluded that information was needed to enable the NRC to begin its detailed technical review. In Reference 3, EGC provided a response to the NRC request for additional information that included Revision 1 of the subject relief requests. In Reference 4, the NRC provided their authorization to implement Relief Requests I3R-09 and I3R-20, Revision 1 as a repair method for degradation identified in Reactor Vessel Head Penetrations.

In Reference 4, the NRC approved Reactor Vessel Head Penetrations repair weld examinations methods including surface examinations (i.e., dye penetrant (PT)) in accordance with NB-2545 or NB-2546. EGC has reviewed the technical basis and previous examination results for requiring PT examinations of applied weld material each outage and determined that it is appropriate to relax the required inservice PT examination frequency. It has been determined that personnel radiation exposure associated with examinations would be reduced. Attachment 1 provides Revision 2 of Relief Requests I3R-09 and I3R-20 which proposes relaxation of PT examination frequency for installed repairs that have demonstrated continued satisfactory PT examination results. The proposed changes are shown with revision bars in Attachment 1 for ease of identification and review. Attachment 2 provides Revision 2 of the relief requests with changes incorporated. Attachment 3 provides the technical basis for relaxation of the PT examination frequency.

While Revision 2 of Relief Request I3R-09 and I3R-20 continue to credit ultrasonic examination (UT) every cycle, the PWR Owners Group and EGC are currently evaluating the safety aspects of performing UT of Alloy 600 reactor vessel head penetrations at a frequency less than that defined by the requirements of Code Case N-729-1 and the conditions of 10 CFR 50.55a(g)(6)(ii)(D)*(5)*. EGC intends to submit a relief request in the near-term to apply the ultrasonic examination frequency of Code Case N-729-1 without application of the condition identified in 10 CFR 50.55a(g)(6)(ii)(D)*(5)*. This near-term relief request would allow implementation of alternative examination scheduling should the NRC approve this or other applicable alternatives. The planned reduced frequency of UT examinations is not expected to impact the reduced frequency of PT examinations for repair welds as proposed here. Technical justification of the impact of reduced frequency of UT examination along with reduced PT examination frequency will be included in the planned near-term relief request.

EGC requests approval of this proposed relief request by September 4, 2015, prior to beginning of the Byron Station refueling outage in Fall 2015 (B1R20).

There are no regulatory commitments contained in this submittal.

If you have any questions regarding this matter, please contact Jessica Krejcie at (630) 657-2816.

Respectfully,

David M. Gullott
Manager - Licensing
Exelon Generation Company, LLC

Attachment 1: 10 CFR 50.55a Relief Requests I3R-09 and I3R-20, Revision 2 (Markup)
Attachment 2: 10 CFR 50.55a Relief Requests I3R-09 and I3R-20, Revision 2 (Clean)
Attachment 3: Westinghouse Report LTR-PSDR-TAM-14-005, Revision 0, March 2014

Attachment 1

10 CFR 50.55a RELIEF REQUESTS I3R-09 and I3R-20, Revision 2
(Markup)

Alternative Requirements for the Repair of Reactor Vessel Head Penetrations
In Accordance with 10 CFR 50.55a(a)(3)(i)

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Request for Relief
Alternative Requirements for the Repair of Reactor Vessel Head Penetrations
In Accordance with 10 CFR 50.55a(a)(3)(i)

1.0 ASME CODE COMPONENT(S) AFFECTED

Component Numbers	Braidwood and Byron Station, Units 1 and 2, Reactor Vessels 1RC01R (Unit 1) and 2RC01R (Unit 2)
Description:	Alternative Requirements for the Repair of Reactor Vessel Head Penetrations (VHPs) and J-groove Welds
Code Class:	Class 1
Examination Category:	ASME Code Case N-729-1
Code Item:	B4.20
Identification:	Byron Units 1 and 2, VHP Numbers 1 through 78, (P-1 through P-78) Previous repairs (I3R-14): Unit 2, P-68 (I3R-19): Unit 1, P-31, P-43, P-64, and P-76[1] Braidwood Units 1 and 2, VHP Numbers 1 through 78, (P-1 through P-78) Previous repairs (I3R-09): Unit 1, P-69[1]
Drawing Numbers:	Various

2.0 APPLICABLE CODE EDITION AND ADDENDA

Inservice Inspection and Repair/Replacement Programs: American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code), Section XI, 2001 Edition, through 2003 Addenda. Examinations of the VHPs are performed in accordance with 10 CFR 50.55a(g)(6)(ii)(D), which specifies the use of Code Case N-729-1, with conditions.

Code of Construction [Reactor Pressure Vessel (RPV)]: ASME Section III, 1971 Edition through summer 1973 Addenda.

3.0 APPLICABLE CODE REQUIREMENT

[1] This relief request includes Inservice Inspection (ISI) examination requirements for repairs previously completed in accordance with I3R-14, I3R-19 and I3R-09.

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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).

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

> *Welding, brazing, 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.

<u>Base Material Defect Repairs:</u>

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 to satisfy the design thickness requirement of NB-3000, repair welding in accordance with NB-2539.

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.

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

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 elimination of weld metal surface defects without subsequent welding and specifies defects are to be removed by grinding or machining.

ASME Section III, NB-4453.1 addresses 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).

4.0 REASON FOR THE REQUEST

Exelon Generation Company, LLC (EGC) will conduct examinations of the reactor Vessel Head Penetrations (VHPs) in accordance with Code Case N-729-1, 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 to perform permanent repair of future defects that may be identified on the VHP's and/or J-groove attachment weld(s) in accordance with the rules of the ASME Section III Construction Code as described in this relief request.

Specifically, relief is requested from:

- The requirements of ASME Section III, NB-4131, NB-2538, and NB-2539 to eliminate and repair defects in materials.
- The requirements of ASME Section III, NB-4450 to repair defects in weld metal.

5.0 PROPOSED ALTERNATIVE AND BASIS FOR USE

5.1 Proposed Alternative

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EGC 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-729-1, will be used in lieu of the "Flaw Evaluation Guidelines" specified by the NRC Safety Evaluation for WCAP-15987-P (Refer to Reference 5).

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 is to isolate the susceptible material from the primary water (PW) environment. The purpose of the excavation is to accommodate the application of at least two (2) weld layers of Alloy 52 or 52M, which is resistant to Primary Water Stress Corrosion Cracking (PWSCC), to meet that requirement. 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 (2) weld layers will be applied, less excavation is required and only 0.125 inches of excavation is necessary. The shallower excavated cavity for 2 weld layers would mean a slightly thinner weld, which would produce less residual stress.

      The excavation will be performed using an ~~Electronic~~ 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 2 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, 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 and 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

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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 EGC 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 seal weld will extend onto and encompass the portion of the flaw on the outside diameter of the VHP tube.

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 (3) 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.

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- The VHP tube will have at least two (2) 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).

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 in Original Component	Flaw Orientation in Original Component	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 to 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-729-1 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-729-1 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 entire embedded flaw repair (EFR) shall be performed during each refueling outage. Surface examinations may be discontinued after the EFR or any localized welded repairs to the EFR subsequent to initial installation have been in service for two fuel cycles and the most recent examination satisfies ASME Section III, NB-5350 acceptance standards.

5.1.3 J-Groove Weld ISI NDE Requirements~~Deleted~~

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Note 4 permits discontinuing surface examinations provided the EFR has been in service for at least two fuel cycles and the most recent PT examination results are acceptable. Below are examples regarding application of Note 4.

- Surface examinations (i.e., dye penetrant (PT)) may be discontinued if the EFR has been in service for two fuel cycles without subsequent welded repair and the most recent examination satisfies ASME Section III, NB-5350 acceptance standards.

- If unacceptable indications are observed during the first inspection after initial EFR and removed with minor surface grinding not requiring welded repair; surface examinations may be discontinued provided the most recent examination conducted after the EFR has been in service for two fuel cycles satisfies ASME Section III, NB-5350 acceptance standards.

- If acceptable indications are observed during the first inspection after initial EFR; and, if during the second inspection after initial EFR unacceptable indications during surface examinations are observed and removed with minor surface grinding not requiring welded repair, surface examinations are required during the next refueling outage and may be discontinued thereafter provided the examination satisfies ASME Section III, NB-5350 acceptance standards.

- If a surface examination of a previously installed EFR during any outage identifies conditions requiring localized welded repair, the surface examinations may be discontinued if the localized EFR welded repair has been in service for two fuel cycles without subsequent welded repair,; and the most recent examination satisfies ASME Section III, NB-5350 acceptance standards.

Westinghouse Report LTR-PSDR-TAM-14-005, Revision 0 (Reference 13; provided in Attachment 3) 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.

A surface examination of EFR weld material after the repair has been in service for at least two fuel cycles assures that there are no EFR installation conditions that could provide a path for primary water to contact the original Alloy 600/82/182 nozzle and weld material. After two cycles of operation, the nozzles are adequately monitored for degradation by ultrasonic examination methods similar to the nozzles without EFR repairs.

EGC projects that the elimination of the PT examination of nozzles would result in a dose savings of approximately 0.4 to 0.7 REM per nozzle examination. The radiation dose associated with these examinations is presented in Reference 13, Table 1. In addition, subsequent to issuance of Reference 13, PT examinations of two Byron

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Station, Unit 1 previously repaired nozzles resulted in a total personnel radiation exposure of approximately 1.4 Rem. Both nozzle repairs met the ASME Section III acceptance standards.

The proposed changes to the inservice examination requirements assure that the EFR repaired nozzles are adequately monitored through a combination of frequent early volumetric and surface examinations and continued volumetric examination 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

EGC will notify NRC of the Division of Component Integrity or its successor 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

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 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 ~~head~~ 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 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.

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WCAP-16401-P, Revision 0 (Reference 3) provides the plant-specific analysis performed for Byron and Braidwood Stations using the same methodology as 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.

The above proposed embedded flaw repair process is supported by applicable generic and plant specific 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(a)(3)(i).

6.0 DURATION OF THE PROPOSED ALTERNATIVE

The duration of the proposed alternative is for the remainder of the Byron Station Units 1 and 2, Third Inservice Inspection Interval currently scheduled to end in July 15, 2016.

The duration of the proposed alternative is for the remainder of the Braidwood Units 1 and 2, Third Inservice Inspection Interval currently scheduled to end in July 28, 2018, and October 16, 2018, respectively.

7.0 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 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. The NRC approved a similar repair for Byron Station Unit 2 in Reference 9. On March 28, 2011, Byron Station Unit 1 received verbal authorization for use of the seal weld repairs methodology on P-64 and P-76, and again on April 10, 2011, for P-31 and P-43 (References 10 and 11).

This alternative incorporates lessons that are learned regarding the significant radiation dose incurred for seal weld repair surface examinations at Beaver Valley, Unit 2, during the fall 2009 outage repair activities, which were discussed in the previously approved 10 CFR 50.55a request for Beaver Valley, Unit 2 (Reference 8). As such, this alternative requests provisions that permit original construction code acceptance criteria for the post weld overlay surface examination, and a barrier layer of ER309L filler material, prior to the application of three Alloy 52M repair weld layers on the clad surface, at the periphery of the weld overlay (at the repair-to-clad interface).

8.0 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

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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. Westinghouse WCAP-16401-P, Revision 0, "Technical Basis for Repair Options for Reactor Vessel Head Penetration Nozzles and Attachment Welds: Byron and Braidwood Units 1 and 2," March 2005

4. Letter LTR-NRC-03-61 from J. S. Galembush (Westinghouse Electric Company) to Terence Chan (U. S. NRC) and Bryan Benney (U.S. NRC), "Inspection of Embedded Flaw Repair of a J-groove Weld," dated October 1, 2003

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

6. Byron Station, Unit No. 2 – Relief Request I3R-14 for the Evaluation of Proposed Alternatives for Inservice Inspection Examination Requirements (TAC NO. MD5230)

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

8. Letter from N. L. Salgado (U. S. NRC) to P. A. Harden (FirstEnergy), "Beaver Valley Power Station, Unit No. 2 – Relief Request Regarding an Alternative Weld Repair Method for Reactor Vessel head Penetrations J-Groove Welds (TAC No. ME4176)," Request 2-TYP-3-RV-03, February 25, 2011 (ADAMS Accession No. ML110470557)

9. Letter from R. Gibbs (U. S. NRC) to C. M. Crane (EGC), "Byron Station, Unit No. 2 – Relief Request I3R-14 for the Evaluation of Proposed Alternatives for Inservice Inspection Examination Requirements (TAC No. MD5230)," dated May 23, 2007

10. NRC Memorandum, "Byron Station, Unit No. 1 – Verbal Authorization of Relief Request I3R-19 – Alternative Requirements for Repair of Reactor Vessel Head Penetrations 64 and 76 (TAC No. ME5877)," dated March 29, 2011

11. NRC Memorandum, "Byron Station Unit No. 1 – Verbal Authorization of Relief Request I3R-19 – Alternative Requirements for Repair of Reactor Vessel Head Penetrations Nos. 31 and 43 (TAC No. ME5948)," dated April 13, 2011

12. Letter from Jacob Zimmerman, (U. S. NRC) to M. J. Pacilio, (EGC), "Braidwood Station, Units 1 and 2 and Byron Station, Unit Nos. 1 and 2 – Relief Requests I3R09 and I3R-20 Regarding Alternative Requirements for Repair of Reactor Vessel Head Penetrations (TAC Nos. ME6071, ME6073, and ME6074)," dated March 29, 2012, ADAMS Accession No. ML120790647

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13. Westinghouse Report LTR-PSDR-TAM-14-005, Revision 0, "Technical Basis for Optimization or Elimination of Liquid Penetrant Exams for the Embedded Flaw Repair," dated March 2014

14. Letter from J. Zimmerman (U.S. NRC) to M. Pacilio (EGC), "Byron Station, Unit No. 1 – Inservice Inspection Relief Request I3R-19: Alternative Requirements for the Repair of Reactor Vessel Head Penetrations (TAC Nos. ME5877 and ME5948)," dated February 1, 2012

Attachment 2

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(Clean)

Alternative Requirements for the Repair of Reactor Vessel Head Penetrations
In Accordance with 10 CFR 50.55a(a)(3)(i)

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Request for Relief
Alternative Requirements for the Repair of Reactor Vessel Head Penetrations
In Accordance with 10 CFR 50.55a(a)(3)(i)

1.0 ASME CODE COMPONENT(S) AFFECTED

Component Numbers	Braidwood and Byron Station, Units 1 and 2, Reactor Vessels 1RC01R (Unit 1) and 2RC01R (Unit 2)
Description:	Alternative Requirements for the Repair of Reactor Vessel Head Penetrations (VHPs) and J-groove Welds
Code Class:	Class 1
Examination Category:	ASME Code Case N-729-1
Code Item:	B4.20
Identification:	Byron Units 1 and 2, VHP Numbers 1 through 78, (P-1 through P-78) Previous repairs (I3R-14): Unit 2, P-68 (I3R-19): Unit 1, P-31, P-43, P-64, and P-76[1] Braidwood Units 1 and 2, VHP Numbers 1 through 78, (P-1 through P-78) Previous repairs (I3R-09): Unit 1, P-69[1]
Drawing Numbers:	Various

2.0 APPLICABLE CODE EDITION AND ADDENDA

Inservice Inspection and Repair/Replacement Programs: American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code), Section XI, 2001 Edition, through 2003 Addenda. Examinations of the VHPs are performed in accordance with 10 CFR 50.55a(g)(6)(ii)(D), which specifies the use of Code Case N-729-1, with conditions.

Code of Construction [Reactor Pressure Vessel (RPV)]: ASME Section III, 1971 Edition through summer 1973 Addenda.

3.0 APPLICABLE CODE REQUIREMENT

[1] This relief request includes Inservice Inspection (ISI) examination requirements for repairs previously completed in accordance with I3R-14, I3R-19 and I3R-09.

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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).

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

> *Welding, brazing, 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.

<u>Base Material Defect Repairs:</u>

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 to satisfy the design thickness requirement of NB-3000, repair welding in accordance with NB-2539.

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.

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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 elimination of weld metal surface defects without subsequent welding and specifies defects are to be removed by grinding or machining.

ASME Section III, NB-4453.1 addresses 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).

4.0 REASON FOR THE REQUEST

Exelon Generation Company, LLC (EGC) will conduct examinations of the reactor Vessel Head Penetrations (VHPs) in accordance with Code Case N-729-1, 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 to perform permanent repair of future defects that may be identified on the VHP's and/or J-groove attachment weld(s) in accordance with the rules of the ASME Section III Construction Code as described in this relief request.

Specifically, relief is requested from:

- The requirements of ASME Section III, NB-4131, NB-2538, and NB-2539 to eliminate and repair defects in materials.
- The requirements of ASME Section III, NB-4450 to repair defects in weld metal.

5.0 PROPOSED ALTERNATIVE AND BASIS FOR USE

5.1 Proposed Alternative

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EGC 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-729-1, will be used in lieu of the "Flaw Evaluation Guidelines" specified by the NRC Safety Evaluation for WCAP-15987-P (Refer to Reference 5).

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 is to isolate the susceptible material from the primary water (PW) environment. The purpose of the excavation is to accommodate the application of at least two (2) weld layers of Alloy 52 or 52M, which is resistant to Primary Water Stress Corrosion Cracking (PWSCC), to meet that requirement. 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 (2) weld layers will be applied, less excavation is required and only 0.125 inches of excavation is necessary. The shallower excavated cavity for 2 weld layers would mean 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 2 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, 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 and 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

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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 EGC 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 seal weld will extend onto and encompass the portion of the flaw on the outside diameter of the VHP tube.

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 (3) 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.

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- The VHP tube will have at least two (2) 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).

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 in Original Component	Flaw Orientation in Original Component	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 to 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-729-1 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-729-1 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 entire embedded flaw repair (EFR) shall be performed during each refueling outage. Surface examinations may be discontinued after the EFR or any localized welded repairs to the EFR subsequent to initial installation have been in service for two fuel cycles and the most recent examination satisfies ASME Section III, NB-5350 acceptance standards.

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5.1.3 J-Groove Weld ISI NDE Requirements

Note 4 permits discontinuing surface examinations provided the EFR has been in service for at least two fuel cycles and the most recent PT examination results are acceptable. Below are examples regarding application of Note 4.

- Surface examinations (i.e., dye penetrant (PT)) may be discontinued if the EFR has been in service for two fuel cycles without subsequent welded repair and the most recent examination satisfies ASME Section III, NB-5350 acceptance standards.

- If unacceptable indications are observed during the first inspection after initial EFR and removed with minor surface grinding not requiring welded repair; surface examinations may be discontinued provided the most recent examination conducted after the EFR has been in service for two fuel cycles satisfies ASME Section III, NB-5350 acceptance standards.

- If acceptable indications are observed during the first inspection after initial EFR; and, if during the second inspection after initial EFR unacceptable indications during surface examinations are observed and removed with minor surface grinding not requiring welded repair, surface examinations are required during the next refueling outage and may be discontinued thereafter provided the examination satisfies ASME Section III, NB-5350 acceptance standards.

- If a surface examination of a previously installed EFR during any outage identifies conditions requiring localized welded repair, the surface examinations may be discontinued if the localized EFR welded repair has been in service for two fuel cycles without subsequent welded repair; and the most recent examination satisfies ASME Section III, NB-5350 acceptance standards.

Westinghouse Report LTR-PSDR-TAM-14-005, Revision 0 (Reference 13; provided in Attachment 3) 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.

A surface examination of EFR weld material after the repair has been in service for at least two fuel cycles assures that there are no EFR installation conditions that could provide a path for primary water to contact the original Alloy 600/82/182 nozzle and weld material. After two cycles of operation, the nozzles are adequately monitored for degradation by ultrasonic examination methods similar to the nozzles without EFR repairs.

EGC projects that the elimination of the PT examination of nozzles would result in a dose savings of approximately 0.4 to 0.7 REM per nozzle examination. The radiation

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dose associated with these examinations is presented in Reference 13, Table 1. In addition, subsequent to issuance of Reference 13, PT examinations of two Byron Station, Unit 1 previously repaired nozzles resulted in a total personnel radiation exposure of approximately 1.4 Rem. Both nozzle repairs met the ASME Section III acceptance standards.

The proposed changes to the inservice examination requirements assure that the EFR repaired nozzles are adequately monitored through a combination of frequent early volumetric and surface examinations and continued volumetric examination 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

EGC will notify NRC of the Division of Component Integrity or its successor 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

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 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 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

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accounted for in the residual stress measurements reported in the technical basis for the embedded flaw repair, as noted in the WCAP-15987-P.

WCAP-16401-P, Revision 0 (Reference 3) provides the plant-specific analysis performed for Byron and Braidwood Stations using the same methodology as 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.

The above proposed embedded flaw repair process is supported by applicable generic and plant specific 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(a)(3)(i).

6.0 DURATION OF THE PROPOSED ALTERNATIVE

The duration of the proposed alternative is for the remainder of the Byron Station Units 1 and 2, Third Inservice Inspection Interval currently scheduled to end in July 15, 2016.

The duration of the proposed alternative is for the remainder of the Braidwood Units 1 and 2, Third Inservice Inspection Interval currently scheduled to end in July 28, 2018, and October 16, 2018, respectively.

7.0 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 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. The NRC approved a similar repair for Byron Station Unit 2 in Reference 9. On March 28, 2011, Byron Station Unit 1 received verbal authorization for use of the seal weld repairs methodology on P-64 and P-76, and again on April 10, 2011, for P-31 and P-43 (References 10 and 11).

This alternative incorporates lessons that are learned regarding the significant radiation dose incurred for seal weld repair surface examinations at Beaver Valley, Unit 2, during the fall 2009 outage repair activities, which were discussed in the previously approved 10 CFR 50.55a request for Beaver Valley, Unit 2 (Reference 8). As such, this alternative requests provisions that permit original construction code acceptance criteria for the post weld overlay surface examination, and a barrier layer of ER309L filler material, prior to the application of three Alloy 52M repair weld layers on the clad surface, at the periphery of the weld overlay (at the repair-to-clad interface).

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8.0 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. Westinghouse WCAP-16401-P, Revision 0, "Technical Basis for Repair Options for Reactor Vessel Head Penetration Nozzles and Attachment Welds: Byron and Braidwood Units 1 and 2," March 2005

4. Letter LTR-NRC-03-61 from J. S. Galembush (Westinghouse Electric Company) to Terence Chan (U. S. NRC) and Bryan Benney (U.S. NRC), "Inspection of Embedded Flaw Repair of a J-groove Weld," dated October 1, 2003

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

6. Byron Station, Unit No. 2 – Relief Request I3R-14 for the Evaluation of Proposed Alternatives for Inservice Inspection Examination Requirements (TAC NO. MD5230)

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

8. Letter from N. L. Salgado (U. S. NRC) to P. A. Harden (FirstEnergy), "Beaver Valley Power Station, Unit No. 2 – Relief Request Regarding an Alternative Weld Repair Method for Reactor Vessel head Penetrations J-Groove Welds (TAC No. ME4176)," Request 2-TYP-3-RV-03, February 25, 2011 (ADAMS Accession No. ML110470557)

9. Letter from R. Gibbs (U. S. NRC) to C. M. Crane (EGC), "Byron Station, Unit No. 2 – Relief Request I3R-14 for the Evaluation of Proposed Alternatives for Inservice Inspection Examination Requirements (TAC No. MD5230)," dated May 23, 2007

10. NRC Memorandum, "Byron Station, Unit No. 1 – Verbal Authorization of Relief Request I3R-19 – Alternative Requirements for Repair of Reactor Vessel Head Penetrations 64 and 76 (TAC No. ME5877)," dated March 29, 2011

11. NRC Memorandum, "Byron Station Unit No. 1 – Verbal Authorization of Relief Request I3R-19 – Alternative Requirements for Repair of Reactor Vessel Head Penetrations Nos. 31 and 43 (TAC No. ME5948)," dated April 13, 2011

12. Letter from Jacob Zimmerman, (U. S. NRC) to M. J. Pacilio, (EGC), "Braidwood Station, Units 1 and 2 and Byron Station, Unit Nos. 1 and 2 – Relief Requests I3R09 and I3R-20 Regarding Alternative Requirements for Repair of Reactor

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Vessel Head Penetrations (TAC Nos. ME6071, ME6073, and ME6074)," dated March 29, 2012, ADAMS Accession No. ML120790647

13. Westinghouse Report LTR-PSDR-TAM-14-005, Revision 0, "Technical Basis for Optimization or Elimination of Liquid Penetrant Exams for the Embedded Flaw Repair," dated March 2014

14. Letter from J. Zimmerman (U.S. NRC) to M. Pacilio (EGC), "Byron Station, Unit No. 1 – Inservice Inspection Relief Request I3R-19: Alternative Requirements for the Repair of Reactor Vessel Head Penetrations (TAC Nos. ME5877 and ME5948)," dated February 1, 2012

Attachment 3

Westinghouse Report LTR-PSDR-TAM-14-005, Revision 0
March 2014

Technical Basis for Optimization or Elimination of Liquid Penetrant Exams for the Embedded Flaw Repair

Westinghouse Non-Proprietary Class 3

LTR-PSDR-TAM-14-005
Revision 0

TECHNICAL BASIS FOR OPTIMIZATION OR ELIMINATION OF LIQUID PENETRANT EXAMS FOR THE EMBEDDED FLAW REPAIR

March 2014

Author: W. H. Bamford*, Consulting Engineer, Primary Systems Design & Repair

Verifier: A. Udyawar*, Piping Analysis and Fracture Mechanics

Approved: J. R. Stukus*, Manager, Structural Design and Analysis Engineering

Electronically approved records are authenticated in the Electronic Document Management System.

Westinghouse

Technical Basis for Optimization or Elimination of Liquid Penetrant Exams for the Embedded Flaw Repair

ABSTRACT

The embedded flaw repair for reactor vessel head penetrations was first applied at the DC Cook plant in 1996, and since that time it has been implemented on over 45 reactor vessel head penetrations world-wide. The technical basis for the approach has been accepted by the Nuclear Regulatory Commission (NRC) through their published Safety Evaluation of WCAP-15987-P Rev 2-P-A [1], December 2003. As an additional requirement of the safety evaluation, a liquid penetrant examination was imposed on the embedded flaw repair weld each refueling outage after its implementation. While this requirement may have been a reasonable one when the process was new, the dose required for implementation of this examination is no longer justified.

This report provides technical justification for eliminating the liquid penetrant examination. Some of the key points to be covered in this report are listed below:

- The original technical basis for these repairs has stood the test of time. Multiple layers have resulted in an impervious barrier of highly resistant material, which continues to fulfill its intended purpose.
- The service history of these repairs has been excellent, with no failures of the repair to protect the head penetrations from Primary Water Stress Corrosion Cracking (PWSCC).
- Alloy 52/Alloy 152 applied weld material is highly resistant to PWSCC, with no crack initiations in over 18 years. (Reference 5)
- The initial and post installation PT's performed on the embedded flaw repair weld established the integrity of the repair. Degradation with service leading to PWSCC is highly unlikely. No PWSCC of these repairs has been experienced to date.
- Follow-up PT exams have not revealed any service-induced cracking or structural degradation. A boat sample removed and examined at San Onofre proved that the penetrant indication found in the Embedded Flaw Repair (EFR) weld during service was not PWSCC. (Reference 3)
- Continued UT examination of the repaired nozzle is sufficient to find degradation of the EFR and nozzle material.
- The UT leak-path examination technique is demonstrated per 10CFR50 and is the current standard for inspection of nozzles which have not been repaired. This approach has become accepted since the embedded flaw repair was first licensed and will provide the same level of confidence/safety for the embedded flaw repaired nozzles. Therefore, additional examination of these welds by PT adds little to any value.
- There is significant radiation dose associated with the penetrant examinations.
- The zinc addition implemented at Byron and Braidwood adds further benefit towards mitigating PWSCC of the already resistant Alloy 52 weld material.

1. BACKGROUND

The embedded flaw repair technique was developed by Westinghouse in 1994, and involves the deposition of at least two layers of Alloy 52 weld metal to isolate existing flaws and susceptible material from the primary water environment (three layers on welds, to avoid chromium dilution).

The embedded flaw repair technique is considered a permanent repair because as long as the degraded region remains isolated from the primary water (PW) environment, flaws cannot initiate or propagate due to PWSCC. Since Alloy 52 weld metal is highly resistant to PWSCC, a new PWSCC crack will not initiate and grow through the Alloy 52 overlay permitting the PWR environment to contact the susceptible material. The resistance of Alloy 690 and its associated weld metals, Alloys 52 and 152, has been demonstrated by laboratory testing in which no cracking has been observed in simulated PWR environments, and by approximately 24 years of operational service in steam generator tubes, where no PWSCC has occurred. The crack growth resistance of this material has been documented in reference [2], as well as numerous other papers.

2. EMBEDDED FLAW REPAIR: OVERVIEW

J-weld flaws have a complex, three dimensional geometry, which does not lend itself to conventional repairs. Since conventional repair is considered impractical and ineffective, Westinghouse has developed a unique repair alternative called the embedded flaw repair method. This method enables the installation of a non-structural Alloy 52/52M weld barrier that effectively isolates the Control Rod Drive Mechanism (CRDM) tube and J-weld from Reactor Coolant System (RCS) water. This Westinghouse design has been developed by over 10 years of direct interface with nuclear Owners (both US and international) and regulatory authorities, culminating in a formal Westinghouse report [1] recognized and accepted by the US NRC. Regulatory endorsement of this Westinghouse methodology has become routinely accepted by plant owners and the NRC as an acceptable method to prevent further PWSCC degradation to reactor vessel head penetrations. This repair method has also been licensed and implemented in both Japan and Korea.

Several factors make J-weld repair welding difficult to address. The J-welds themselves are located on the inside of the RPV head. The result is that each nozzle is unique, in that its location relative to the outer edges of the head results in a constantly varying degree of curvature in the J-weld itself. Welding challenges associated with this curvature are further complicated by the fact that the CRDM tubes are all vertically oriented. This means that each J-weld, as it extends around the circumference of the CRDM tube, has significant variations in height. Also, the J-weld itself, due to the fact that it welds a vertical CRDM tube to a sloped vessel ID surface, is oval in shape. In light of the high radiation levels (typically 2 to 3 REM) underneath the reactor vessel head, any attempt at manual repair of the J-welds will result in unacceptably high radiation exposure levels; levels that are undesirable, costly, and contrary to Utility ALARA objectives. These exposure levels make remote, machine welding a necessity. They also make liquid penetrant examinations of the completed welds a costly endeavor.

To address these and other concerns, PCI designed and manufactured a welding system specifically tailored for installation of a J-weld overlay. This four-axis, custom manufactured weld head is unique in the industry, in that it can deposit a high quality weld in this challenging

environment (Reference 1). PCI began this equipment development effort in 2000. Over the following years, PCI has made major upgrades, enhancements, and improvements in this welding equipment. The result is a proven, robust, and reliable equipment set capable of consistent, schedule-effective delivery of quality welds. Specifically, the repair involves at least two (offset) layers of weld metal over the head penetration base metal, and at least three layers over the J-groove weld. The multiple layers are to ensure that no path exists to allow the PWR water to contact the susceptible materials. The additional layer over the weld region is to minimize dilution of the chromium.

3. EMBEDDED FLAW REPAIR EXPERIENCE

Embedded flaw repairs serve to mitigate RVHP flaws in the following locations: Tube-to-vessel J-groove weld, Tube OD, and Tube ID. For purposes of this document, the review of EFR performance history will focus only on OD repairs, i.e., repairs that deposit weld metal on the surface of the Tube-to-vessel J-groove weld and the OD surface of the tube.

Forty five EFR OD repairs have been installed at 13 separate nuclear power plants. Thirty one are currently in service; others have been removed from service by head replacement or other reasons not related to EFR. Nuclear plants where EFR's have been removed from service include North Anna 2, Arkansas 1, Beaver Valley 1, Ohi 3 (Japan), San Onofre 3 and DC Cook 2. Nuclear plants with in-service EFR's include Beaver Valley 2, Byron 1, Byron 2, Beznau, VC Summer, Braidwood 1, and Hanbit 3 and 4 (Korea). Service exposure duration for individual EFR varies among units, with 8 years constituting the longest period of service exposure to date for an OD repair. (An ID embedded flaw repair implemented at the DC Cook plant was in service for ten years, without any evidence of further degradation, before the head was replaced.)

4. PT EXAMINATION DETAILED HISTORY

Every EFR is presently required to be PT examined every outage. To date, no PT examination has shown evidence of PWSCC in EFR deposits; however, PT examinations have periodically identified fabrication flaws and/or discontinuities in installed EFR deposits. The following paragraphs summarize PT examination results for in-service EFR welds.

Of the 45 EFR's of the OD that were placed in service, 10 were installed in 2012 (4 at VC Summer, 6 at Hanbit 3), and six more in 2014, at Hanbit 4. These newly installed EFRs have not yet completed their first cycle of operating service, and therefore have not been PT examined subsequent to being placed in service. PT examinations have been performed on each of the remaining 29 EFRs during each refueling outage, and these PT examinations have been repeated each outage for the entirety of the service life of each EFR. This means that, for these 29 installed EFR's, a total of 74 outage-related PT examinations have been performed. Of these 74 PT examinations, 68 have been acceptable and 6 have identified rejectable PT indications.

The six PT examinations identifying rejectable indications are summarized below:

Songs 3 – October 2008 PT Results:

- Penetration 64:
  - Number of Defects: One
  - Location: On pad, above J-weld to vessel interface

  - Repair: Boat sample was used to extract the flaw intact. Subsequent metallurgical analysis showed no PWSCC. Boat sample excavation was manually re-welded. More details of this event appear in a later section of this report.

Beaver Valley 2 – Fall 2009 PT Results:

- Penetration 16:
  - Number of Defects: One
  - Location: At tube-to-pad intersection.
  - Repair: Minor grinding followed by manual welding.
- Penetration 57:
  - Number of Defects: One
  - Location: Toe of pad.
  - Repair: Buffing/grinding; no welding required.

Byron 1 – Fall 2012 PT Results:

- Penetration 31:
  - One PT Indication
  - Location: Intersection of tube and pad.
  - Repair: Buffing/grinding; no welding required.
- Penetration 43:
  - Two PT indications
  - Location: Tube (between beads), intersection of tube and pad.
  - Repair: Buffing/grinding; no welding required.

Braidwood 1 – Fall 2013 PT Results:

- Penetration 69:
  - 27 PT indications; 5 were non-relevant (i.e., <1/16" diameter), 9 were acceptable, 13 rejectable.
  - Location: Tube, intersection of tube and pad, pad
  - Repair: Buffing/grinding, followed by manual welding.

This summary indicates overall acceptable service performance of Westinghouse Embedded Flaw Repairs. The six penetrations with rejectable PT indications represent a relatively small portion of installed EFR welds, and all of the embedded flaw repairs continued to perform their function, which is to protect the susceptible Alloy 600 tubes from the water environment. Each of these six penetrations has subsequently been repaired and PT-accepted. The nature of each of these repairs confirmed no PT indications compromised the integrity or performance of the associated EFR. In each case, each EFR was restored to a fully acceptable condition by minor buffing/grinding and, where needed, limited manual repair welding. In no case was PWSCC identified in these welds. Furthermore, the absence of PT indications for the remaining 68 PT examinations demonstrates that PT indications are not typical in these repair welds. As can be seen in these results, the quantity of PT indications detected on the Braidwood P69 EFR differs significantly from all prior PT examination results, making P69 results atypical.

5. POTENTIAL CAUSES OF PT INDICATIONS IN EFR WELD REPAIRS

Several factors can affect PT examination accuracy and results. These factors can contribute to differing PT results on a given weld from one examination to the next, even when the examination is performed under ideal conditions. These factors include:

Minor Changes in Weld Surface: EFR weld surfaces are PT examined upon initial installation, and rejectable (ASME Section III criteria) indications are removed. Therefore, upon initial introduction to service conditions, the EFR weld surfaces are ASME Section III compliant. Thermal expansion, vessel head dilation due to pressurization, and water flow can have an effect on the EFR surface. For example, a small welding flaw in an EFR surface may be present, but the flaw face (i.e., the portion of the flaw exposed to the EFR weld surface) may be compressed too tightly to permit penetrant absorption. The face of this small welding flaw, when exposed to service conditions, may be slightly changed, widening the gap at the weld surface. Upon subsequent PT examination, this indication surface may now have sufficient width to enable penetrant entry, causing it to appear as rejectable during subsequent examinations. Such indications do not indicate failure of the EFR; rather, they are indicative of minor change in surface configuration resulting from service exposure.

A similar situation may occur in areas where separate weld passes/beads join together. These areas often constitute geometric discontinuities, and (as explained previously) can cause penetrant to become entrapped. Operating conditions may cause minor additional changes in the surface geometry in these locations, and these slight changes can increase the risk of penetrant entrapment. An example is shown in Figures 1 and 2. These changes may then preclude effective cleaning during subsequent PT examinations. When these situations occur, metal removal is typically required to smooth the area, and restore a configuration suitable for PT acceptance. Again, these minor configuration changes do not constitute weld failure of the EFR; they constitute only a condition warranting surface conditioning to facilitate the PT process, thus confirming the integrity of the weld. This situation is the most common source of indications which are found in subsequent PT inspections. Since the OD of the head penetrations near the J-groove weld is located in a very high dose region, subsequent surface preparation by grinding has a significant impact on personnel radiation exposure, and is only performed when absolutely necessary to facilitate the PT process.

It is also possible that EFR welds contain welding flaws that, at the time of introduction to service, are not open to the weld surface, and are not, therefore, detectable by PT. Service conditions can cause welding flaws of this nature to become surface exposed, and any such exposed flaws would likely appear as PT indications during subsequent PT examinations. Indications of this type may be rounded (i.e., porosity) or linear (i.e., lack of fusion between beads, such as localized flaws at tie-in areas). When flaws of this nature are detected, they are repaired by excavation and, where necessary, localized weld repair (typically manual GTAW). Indications of this nature have occurred in limited situations, and repairs have been successfully performed, as confirmed by subsequent PT inspections. The EFR specifically employs multiple weld layers to ensure weld integrity, and flaws of this nature are typically limited in size and depth to less than one weld layer. As demonstrated by ongoing EFR inservice experience, these types of welding flaws do not compromise the integrity or acceptability of the EFR weld to perform its intended purpose.

As-Welded Surfaces: Embedded flaw repair welds require that the final PT be performed on an

as-welded surface, which requires careful and thorough cleaning to adequately remove penetrant prior to developer application. Due to inherent differences in cleaning from one examination to the next, some variation in indication size is an unavoidable aspect of the PT examination process. It is possible, therefore, that the original surface (with or without a preexisting welding flaw) has not changed, but that the more recent PT examination produced different results due to this variability between PT examinations. This is not indicative of an unacceptable examination technique; rather, it is a degree of examination variability inherent in the PT process. The ASME Code recognizes the liquid penetrant test method to be inherently susceptible to indications of this nature, and cites 'surface conditions' (Ref. NB-5351(a)) as a common contributing factor. ASME Section III, NB-5351 (2010 Edition) states:

> **NB-5350 LIQUID PENETRANT ACCEPTANCE STANDARDS**
>
> **NB-5351 Evaluation of Indications**
>
> *(a)* Mechanical discontinuities at the surface are revealed by bleeding out of the penetrant; however, localized surface discontinuities, such as may occur from machining marks, surface conditions, or an incomplete bond between base metal and cladding, may produce similar indications which are nonrelevant.
>
> *(b)* Any indication which is believed to be nonrelevant shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation which would mask defects are unacceptable.
>
> *(c)* Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

As confirmed by ASME, 'surface conditions' can produce PT indications which may initially appear rejectable. ASME addresses this issue by specifically permitting minor metal removal to address indications of this nature.

<u>Accessibility for Examination:</u> As described in the preceding paragraphs, as-welded surfaces pose unique challenges to the PT process. Careful removal of penetrant from valleys between weld beads is essential for accurate EFR PT, and this process can be challenging. EFR repair welds are located in the high radiation environment within the Reactor Pressure Vessel head, and radiation controls require strict limitations on entry times. Work near the surface of the RPV head, which is an inherent aspect of EFR PT's, increases radiation exposure levels. The welds themselves are located overhead, requiring the PT examiner to reach upward and apply considerable pressure to the surface of the weld, in order to achieve effective penetrant cleaning. Accessibility to these welds may be limited by thermal sleeves, guide funnels, and other obstructions, any of which increase the difficulty of the examination. These factors combine to increase the difficulty of precise implementation of the PT process, and introduce an inherent level of variability in the examination process. This inherent variability may result in differences in examination results from one examination to the next, even when no changes have occurred in the weld surface. Variability in the PT examination process is unavoidable, and may lead to differences in PT examination results. It is well known that, although these differences exist, they do not affect the functional integrity of the embedded flaw repair, or any other pressure boundary structure. If they did, the ASME code would not allow this flexibility.

6. BRAIDWOOD PENETRATION 69 RESULTS:

In 2012, Westinghouse implemented an Embedded Flaw Repair (EFR) to mitigate flaws in RPV Head Penetration P69 at Braidwood Unit 1. This repair weld was successfully installed, accepted by liquid penetrant (PT) testing, and the unit was returned to service. After one cycle, PT examination was re-performed on the P69 EFR as required. This examination identified 27 PT indications.

All indications were rounded; none were linear. Of the 27 indications, 5 were non-relevant (i.e., <1/16" diameter), and 9 were acceptable (i.e., not rejectable in accordance with ASME Section III PT acceptance criteria). The remaining 13 rounded indications were deemed rejectable and required remediation. Minor grinding completely removed two of these welding defects, leaving 11 that required additional remediation. Continued grinding removed the remaining welding defects, and localized manual welding was performed where it was necessary to restore EFR thickness. Final PT accepted these localized weld repairs.

As explained earlier in this report, a number of factors can contribute to PT detection of indications in previously accepted EFR weld surfaces, and any of these factors may have played a role in this application. An exact explanation regarding the nature/cause of these PT indications is not possible. Lacking other exculpatory evidence, it must be acknowledged that there were 11 EFR weld defects in Penetration 69 requiring remediation. The nature and extent of these welding defects is evidenced by the extent of the repair effort required to mitigate each. This repair effort was localized and limited in extent, demonstrating that none of these 11 welding defects adversely affected the EFR's continued suitability for service. Each flaw has subsequently been removed (with removal verified by PT examination) and repaired, confirming that all flaws were confined to the region at or near the weld outer surface.

7. BOAT SAMPLE REMOVAL AND TESTING FROM SAN ONOFRE UNIT 3 (REFERENCE 3)

The first example of PT indications observed on an embedded flaw repair surface was at San Onofre Unit 3 in October of 2008. As a result of this finding, the NRC was concerned that the observed cracking in the repair weld might be PWSCC, and so a boat sample was removed and examined further. The repair had been in service since the EFR was completed in 2004, and had undergone an acceptable PT examination in 2006, after one cycle of operation. The boat sample contained a rejectable rounded indication, in the EFR for penetration #64.

The examinations included visual inspections, stereo-visual inspections, X-ray radiography, high resolution replication, extended dwell fluorescent PT, scanning electron microscopy (SEM), energy dispersive spectroscopy, and optical metallography. The primary purpose was to identify the most likely cause of the delayed appearance of the PT indication.

Thin fragments of material (0.0005" or less) were identified surrounding the entrance to the rejected void. These ligaments were found to likely explain the delayed presentation of the void, because the underlying cavity had been protected from the surface by a very thin layer of Alloy 52. The exact cause of the failure of this layer is not known, but it is likely that the protective ligaments failed due to operational stresses or cleaning efforts following the 2006 penetrant examination. The evidence obtained did not support PWSCC, thus demonstrating that the Alloy

52 weld material continued to protect the Alloy 600/82/182 from the PWR water.

8. SERVICE HISTORY OF EMBEDDED FLAW REPAIRS AT BYRON AND BRAIDWOOD PLANTS

Table 1 provides a summary of the repair history of the head penetrations at the Byron and Braidwood units. No indications have been found in Braidwood 2, but the other three have had indications, and therefore repairs.

In reviewing Table 1, it becomes very clear that there is a cost to the PTs that have been carried out as an additional requirement of the repair methodology. Also, when indications are discovered and grinding or welding is required, the man-rem dose goes up by an order of magnitude. This dose needs to be compared with the benefits obtained by the process.

Since no PWSCC flaws have been found, the cost, once welding flaws have been eliminated, is not justified. In light of the service experience of Alloy 52 welds, which will be discussed below, PWSCC is not likely to occur in the remaining operating life of the plant.

9. RESISTANCE TO CRACKING OF ALLOY 690 AND ITS ASSOCIATED WELDS

Alloy 690 is known to be much more highly resistant to PWSCC than Alloy 600. This conclusion is also true for its associated welds, Alloy 52 and 152, and results from increased resistance to crack initiation, as well as crack growth.

From the standpoint of crack initiation, there are no known incidents of PWSCC for Alloy 690 materials in service. While this does not prove that the material will not initiate cracks, it does argue strongly that the material is much more resistant than Alloy 600. One of the most challenging locations for either Alloy 600 or Alloy 690 is the steam generator, where the use of Alloy 600 has been prevalent since the earliest steam generators. Leaks were observed in Alloy 600 steam generator tubing in the first few fuel cycles. The leakage and detected SCC cracks led utilities to replace steam generators when the percentage of plugged and degraded tubes rose to levels that caused operational and economic difficulties. As a result, some Alloy 600 steam generators were replaced within 7 years of service and as little as 3.6 EFPY of operation. Conversely, Alloy 690 steam generator tubes have been in service since 1989, a period now exceeding 24 years, with no observed stress corrosion cracking.

Looking at this susceptibility another way, one could compile the ‘effective degradation years’ (EDY) when cracking occurred for the two materials. An effective degradation year has been defined as one effective full power year at 600°F (316°C) (reference 1). Looking at the service experience from this point of view, we see that the earliest steam generator replacement occurred in mill annealed Alloy 600 after 4 EDY due to extensive SCC problems, while the longest service for an Alloy 690 steam generator has been over 30 EDY, with no cracking.

In the US fleet of PWRs, 59 PWRs started operation with mill annealed Alloy 600 steam generator tubes. As of the end of 2009, 52 of those 59 PWRs have replaced their steam generators, principally due to stress corrosion cracking issues. Forty-one of those utilities have

replaced their steam generators with new steam generators tubes with thermally treated Alloy 690 tubes. Considering that there are typically 8000 to 20000 steam generator tubes in a PWR and multiple high stress locations in a single tube, the Alloy 690 operating experience is impressive. The remaining replacement steam generators and some 10 original steam generators were tubed with thermally treated Alloy 600 that had improved microstructural features and lower residual stresses. The lead plants with this tubing had operated about 35 EDY when the first SCC related plugging operations occurred. The operation of thermally treated Alloy 690 tubing would be expected to be significantly improved over the Alloy 600 TT.

From either point of view, we can see that there is at least a 24 calendar year lead time which would provide advanced warning of any potential trouble for Alloy 690. Similar service experience has been recorded for Alloy 152/52 welds, except that the first weld went into service in contact with a water environment in 1994, about five years later. Therefore, operating history provides evidence of at least 20 years of crack-free service for Alloy 152/52 welds.

From the standpoint of crack growth, it is clear that PWSCC has been observed in laboratory tests for Alloy 690 in the standard PWR environment. Experimentally, it is difficult to get a crack to initiate, and also very difficult to keep the crack growth going long enough to obtain a measurement. The only successful attempts have employed a fatigue pre-sharpened crack, and the growth rates that have been obtained are about two orders of magnitude slower than that of Alloy 600 [2].

Therefore, we can conclude that these materials are very highly resistant to PWSCC. Although cracking can be measured, crack initiation has not been seen in service or in the lab, and if a flaw does not initiate, it will certainly not propagate.

10. DISTORTION EFFECTS OF THE EMBEDDED FLAW REPAIR PROCESS

One factor which can enhance the PWSCC growth rate of both Alloy 690 and Alloy 52/152 welds is cold work [2]. Although cold work has not been purposely applied, analytical work was recently completed to quantify the amount of distortion introduced by the EFR process.

The embedded flaw repair was developed, and continues to function as an effective SCC-resistant barrier between the RCS water and the SCC-susceptible J-weld and CRDM tube. The repair is not intended to be structural, and therefore does not need to meet ASME Section III requirements. It is also important to mention that there are no Section III requirements for residual stresses, since they do not affect potential failure.

That said, however, great care was taken in the design of the repair technique, and especially the weld thickness of the EFR, to minimize any distortion of the tube as a result of the welding process, and the repair has been effectively applied to many head penetrations over the past 20 years. Since it is well known that cold work can degrade the SCC resistance of Alloy 52/152 welds, it is important to examine the amount of distortion imposed by the embedded flaw repair. To investigate this issue, a detailed analysis was recently completed for the repair method, as applied to an operating plant [4]. The maximum distortion of the tube ID was estimated to be 0.01 inch from this analysis. Measurements were made of the actual distortion of the tube after the embedded flaw repair was actually completed, and the maximum distortion of the tube was determined to be less than 0.1 mm, or 0.0039 inch (Reference 4).

Therefore it can be concluded that the entire repair causes little or no distortion or cold work of the tube. A small area of welding to refill the area removed by grinding would cause even less distortion, and would therefore be of no concern.

11. SUMMARY AND CONCLUSIONS

The embedded flaw repair (EFR) process has been described in detail, and it was pointed out that the requirement for PT of the OD of the repair surface was not part of the original proposed inspections, but was added as part of the Safety Evaluation Report for the process. At the time of the original implementation of the generic relief request, the UT leak path examination was not accepted, but now it has replaced the need to examine even the J-groove welds.

Significant radiation dosage is incurred as the result of each liquid penetrant exam, and this dosage is increased by an order of magnitude if grinding or welding is needed to clear the PT indications. This dosage is not justified in light of the advantage gained with respect to the integrity of the head penetration.

The EFR is a complex repair developed for implementation using entirely remote techniques, so as to minimize man-rem dosage. This is counteracted by the requirement for PT every outage. UT inspection of the entire volume of the head penetrations is already required, but this can be accomplished with minimal exposure. Any evidence of further growth on indications in the susceptible tube material can be obtained from this remote examination.

The resistance to PWSCC of Alloy 52/152 and Alloy 690 continues to be confirmed by testing and operating experience. Currently, at least 20 years of experience exists in the welds with no initiation, regardless of application. Contrast that with only a few years of experience before PWSCC with Alloy 600 and its welds, and the EFR has proven to be a robust process. Efforts are continuing to further improve its reliability.

The first embedded flaw repair to have PT indications has been sampled, and carefully examined, and two key findings emerged. First, it is likely that the protective ligaments failed due to operational stresses or cleaning efforts following the 2006 penetrant examination. The protective boundary provided by the EFR was still intact. Secondly, the evidence obtained did not support PWSCC.

Since no PWSCC flaws have been found, the cost of PT exams every outage does not seem to be justified. In light of the service experience of Alloy 52 welds, it does not seem likely that any PWSCC is going to occur in the future, at least for the next 20+ years. Future performance of the EFR can be monitored using the same UT examinations currently performed for the other reactor vessel head penetrations.

12. REFERENCES

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4. Ng, Chris K., "Finite element Residual Stress Analysis Results for the Yonggwang Unit 3 Outermost Reactor Vessel Control element Drive Mechanism Penetration Nozzle Before and After the Embedded Flaw Repair Process", Westinghouse Letter report LTR-PAFM-13-43, Rev. 0, April 2013.

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Table 1: Summary of Inspection and Repair History of Embedded Flaw Repairs at Byron and Braidwood Plants

	New Repair	PT Results	Buffing Required	Welding Required	PT and Repair Exposure
Byron					
B1R17	4 Repairs P31/43/64/76	Acceptable after Repairs completed	N/A	N/A	N/A
B1R18		P31 - 1 indication rejectable P43 - 1 indication rejectable	Yes	No	5.701 Rem
B2R13	1 Repair Pen 68				
B2R14		P68 Acceptable	No	No	697 mrem
B2R15		P68 Acceptable	No	No	345 mrem
B2R16		P68 Acceptable	No	No	422 mrem
B2R17		P68 Acceptable	No	No	428 mrem
Braidwood					
A1R16	1 Repair Pen 69	Acceptable after Repairs completed	N/A	N/A	N/A
A1R17		P69 - 13 indications rejectable	Yes	YES 10 indications required welding	10.333 Rem

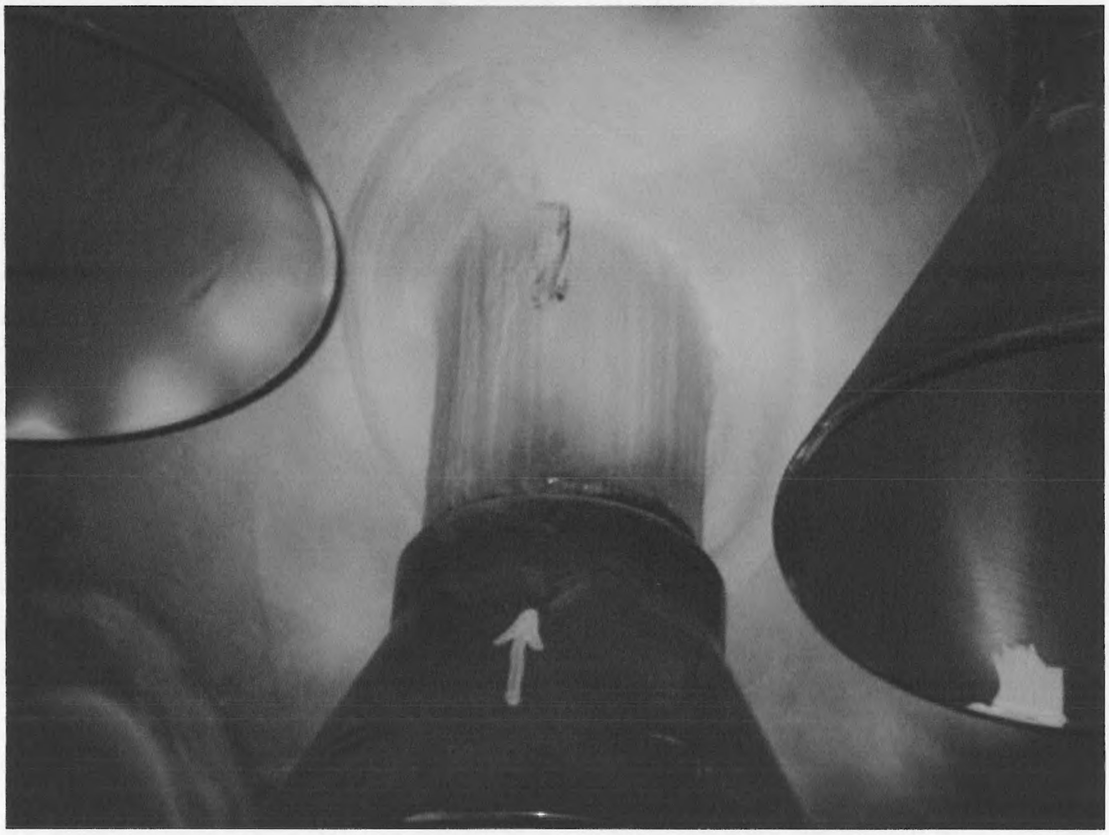

Figure 1: Example of an indication at the boundary of the vertical weld passes on the penetration tube, and the elliptical weld passes on the head

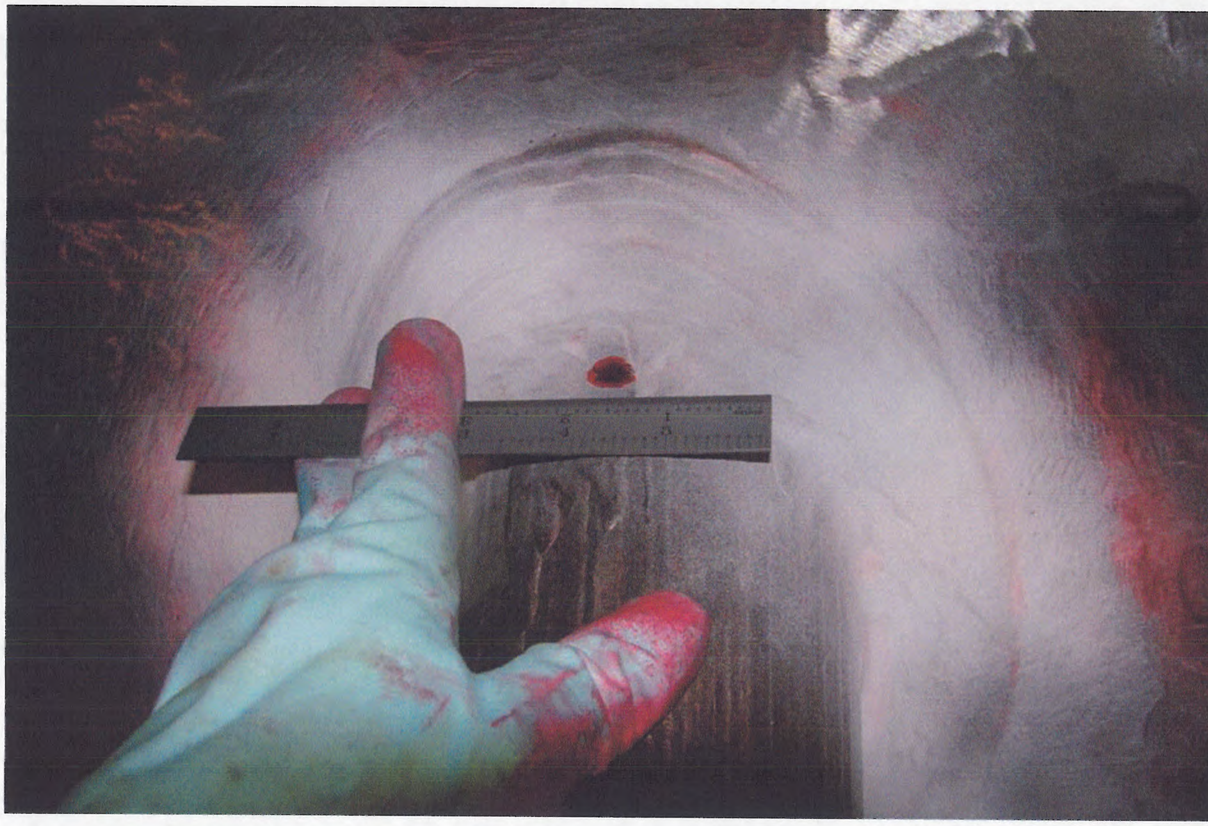

Figure 2: Closer View of the indication of Figure 1