SCE&G®
A SCANA COMPANY

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RC-12-0165

Document Control Desk
U. S. Nuclear Regulatory Commission
Washington, DC 20555

Dear Sir / Madam:

Subject: VIRGIL C. SUMMER NUCLEAR STATION (VCSNS) UNIT 1
DOCKET NO. 50-395
OPERATING LICENSE NO. NPF-12
RELIEF REQUEST RR-III-09 ALTERNATIVE WELD REPAIR FOR REACTOR VESSEL HEAD PENETRATION

Reference:
1. WCAP-15987-P-A Revision 2, "Technical Basis for the Embedded Flaw Process for Repair of Reactor Vessel Head Penetrations" [ML040290246]
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 [ML031840237]
3. Letter from T. D. Gatlin (VCSNS) to Document Control Desk (NRC), "Reactor Vessel Head Penetration Weld Repair Under WCAP-15987," dated October 22, 2012.

Pursuant to 10CFR50.55a(g)(6)(ii)(D), South Carolina Electric & Gas Company (SCE&G), acting for itself and as an agent for South Carolina Public Service Authority (Santee Cooper), hereby submits a request for relief. In accordance with 10CFR50.55a(a)(3)(i), SCE&G is requesting relief from the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components" in that proposed alternatives would provide an acceptable level of quality and safety. Specifically, this relief request proposes to perform an alternative repair technique using the embedded flaw process of Reference 1 on the reactor Vessel Head Penetration (VHP) nozzles. The proposed repair process has been generically approved by the NRC in Reference 2.

The technical basis supporting the embedded flaw process to the VHPs has been provided by the Westinghouse letter supplied within Attachment 1. This letter provides the technical basis for the applicability of an embedded flaw repair for the VHP nozzles.

A047
NRR

SCE&G requests that this repair alternative be approved by November 2, 2012 in support of the ongoing Fall 2012 refueling outage (RF20).

This letter contains no commitments. Should you have any questions, please call Bruce L. Thompson at 803-931-5042.

Very truly yours,

Thomas D. Gatlin

JG/TDG/bj

Enclosure 1: VCSNS Relief Request RR-III-09
  Attachment 1: LTR-PAFM-12-137-NP Revision 0

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South Carolina Electric & Gas Co. (SCE&G)
Virgil C. Summer Nuclear Station Unit 1 (VCSNS)
VCSNS Relief Request RR-III-09

1. ASME Code Component(s) Affected

The affected VCSNS component is the reactor vessel head. The vessel head is required to be inspected under the augmented inspection plan conforming to 10CFR50.55a(g)(6)(ii)(D) and ASME Code Case N-729-1. The reactor vessel head is the original installed head and was constructed under ASME section III 1971 edition with no addenda. There have been no previous repairs to the reactor vessel head penetrations or J-Groove welds. VCSNS is in the third 10-year inservice inspection (ISI) interval which ends December 31, 2013.

2. Applicable Code Edition and Addenda

ASME Code Section XI, “Rules for Inservice Inspection of Nuclear Power Plant Components,” 1998 Edition through 2000 Addenda.

3. Applicable Code Requirement

Code 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."

ASME Section XI, Article IWA-4000 of contains requirements for the repair/replacement activity regardless of the reason or method of identifying the need for the activity performed on ASME components. The specific Code requirements for which use of the proposed alternative are as follows:

ASME Section XI 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-4400.
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 10CFR50.55a(b)(2)(xxv).

The applicable requirements of the Construction Code required by IWA-4420 for the removal or mitigation of defects by welding from which relief is requested are as follows:

Base Material Defect Repairs:
For defects in base material, ASME Section III, NB-4131 requires that the defects are eliminated, repaired, and examined in accordance with the requirements of NB-2500. These requirements include the removal of defects via grinding or machining per NB-2538. Defect removal must be verified by a Magnetic Particle (MT) or Liquid Penetrant (PT) examination in accordance with NB-2545 or NB-2546, and if necessary 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 percent of the section thickness, the repair weld shall be examined by the radiographic method in accordance with NB-5110 using the acceptance standards of NB-5320.

Weld Metal Defect Repairs (RVH Penetration J-Groove Weld):
ASME Section III, NB-4450 addresses repair of weld metal defects.

ASME Section III, NB-4451 requires 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 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.

4. Reason for Request

VCSNS has conducted examinations of the reactor vessel head penetrations (VHPs) in accordance with Code Case N-729-1, as amended by 10CFR50.55a. Based on the prescribed examinations VCSNS has identified four VHP nozzles (as reflected in Table 1) that need to be repaired to meet the requirements of 10CFR50.55a prior to returning the vessel head to service.

Table 1

Nozzle Number	Examination Category	Inspection Item	Description
19	N-729-1	B4.20	Part-Length Penetration
31	N-729-1	B4.20	CRDM Thermal Sleeve Penetration
37	N-729-1	B4.20	CRDM Thermal Sleeve Penetration
52	N-729-1	B4.20	Spare CRDM Thermal Sleeve Penetration

Relief is required because the use of the "Mitigation of Defects by Modification" provisions of IWA-4340 is prohibited per 10CFR50.55a(b)(2)(xxv). VCSNS will be conducting the repair as directed within WCAP-15987-P-A Revision 2, (Reference 1). VCSNS intends to follow this industry practice and use the embedded flaw technique to repair flaws on the outside diameter of the RVH penetration tubes. This repair methodology has been generically approved by the NRC in a letter from H. N. Berkow (U. S. NRC) to H. A. Sepp (Westinghouse Electric Company), (Reference 2).

Relief is needed from the requirements of ASME Section XI, IWA-4420 to perform permanent repair of the identified flaws 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. Proposed Alternative and Basis for Use

5.1 Proposed Alternative

SCE&G proposes to use the less intrusive embedded flaw process (Reference 1) for the repair of reactor vessel head penetrations as approved by the NRC (Reference 2). This methodology is an alternative to the defect removal requirements of ASME Section XI and Section III. The reactor vessel head is the original installed head. There have been no previous in-service repairs to the reactor vessel head penetrations or J-Groove welds. Embedding a flaw within PWSCC resistant materials (i.e., Alloy 52 or 52M type weld metal) will assure structural integrity of the VHP nozzles as bounded within WCAP-15987 and the NRC Safety Evaluation Report. Further reference to the seal weld or weldment will be reflected as Alloy 52 indicating PWSCC resistant materials as approved by the NRC as reflected in WCAP-15987 and existing precedence.

5.1.1 Flaw Repair

For the repair of the unacceptable outside surface flaws in head penetration nozzles 19, 31, 37 and 52, at least three layers of Alloy 52 material will be deposited (360 degrees full circumference) covering the entire wetted surface of the attachment J-Groove weld. The repair weld of Alloy 52 will extend at least 0.5 inches past the interface between the J-Groove weld and stainless steel cladding as well as covering the outside surface (360 degrees full circumference) of the head penetration nozzle tube. The interface boundary between the J-Groove weld and stainless steel cladding will be located to positively identify the weld clad interface thus ensuring that all of the Alloy 82/182 material of the J-Groove weld is seal welded during the repair. Prior to the application of the Alloy 52 repair on the weld clad surface, a stainless steel buffer of 309L will be installed 360 degrees around at the interface of the clad and the J-Groove weld metal. The J-Groove weld will then be completely covered with least three (3) layers of Alloy 52 deposited 360 degrees around the nozzle and extending over the 309L stainless steel buffer. The outside surface of the Alloy 600 penetration tube will be covered with at least two (2) layers of Alloy 52 material and extend at least 0.5 inches beyond the flaw indication.

5.1.2 Reporting Requirements and Conditions on Use

VCSNS 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 inspections.

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 weldment is considered highly resistant to PWSCC, a new PWSCC flaw should not initiate and grow through the Alloy 52 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 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 provides the basis 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 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 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/degrees F as found in ASME Section II, part D "Properties." The Alloy 600 base metal has a coefficient of thermal expansion of 7.8E-6 in/in/degrees 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.

Attachment 1 provides the plant-specific analysis performed for VCSNS Unit 1 using the same methodology as WCAP-15987-P. 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 10CFR50.55a(a)(3)(i).

5.3 Safety Evaluation Compliance

VCSNS intends to follow WCAP-15987-NP-Revision 2-P-A, "Technical Basis for the Embedded Flaw Process for Repair of Reactor Vessel Head Penetrations." Below VCSNS has provided the applicability and compliance with each item of the NRC Safety Evaluation.

<table>
<tr><th>Item</th><th>Description</th></tr>
<tr><td>1</td><td><i>Licensees must follow the NRC flaw evaluation guidelines.</i></td></tr>
<tr><td colspan="2">[VCSNS Response]
VCSNS will follow 10CFR50.55a(g)(6)(ii)(D) and Code Case N-729-1. The inspection plan consists of performing volumetric and/or surface examination of essentially 100 percent of the required volume or equivalent surfaces of the nozzle housings. As stated within 10CFR50.55a(g)(6)(ii)(D)(1), once a licensee has implemented the requirements of ASME Code Case N-729-1 "the First Revised NRC Order EA-03-009 no longer applies to that licensee and shall be deemed to be withdrawn." VCSNS has implemented the first inspection under ASME Code Case N-729-1 during Fall 2009 (RF18).</td></tr>
<tr><td>2</td><td><i>The crack growth rate is not applicable to Alloy 600 or Alloy 690 weld material, i.e., Alloy 52, 82, 152, and 182 filler material.</i></td></tr>
<tr><td colspan="2">[VCSNS Response]
Any cracks identified during subsequent inspections will be evaluated as directed by 10CFR50.55a(g)(6)(ii)(D) and Code Case N-729-1.</td></tr>
</table>

Item	Description
3	***The NDE requirements listed in the Table below must be implemented for examinations of repairs made using the embedded flaw process.***

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

Notes:

1. ***Repairs must be reviewed and approved separately by the NRC.***
2. ***Inspection consistent with the NRC Order EA-03-009 dated February 11, 2003 and any subsequent changes.***
3. ***Inspect with personnel and procedures qualified with UT performance-based criteria. Examine the accessible portion of the repaired region. The UT coverage plus surface coverage must equal 100 percent.***

[VCSNS Response]

VCSNS will follow 10CFR50.55a(g)(6)(ii)(D) and Code Case N-729-1. There have been no previous repairs to the reactor vessel head penetrations nozzles and J-Groove welds. Inservice volumetric and surface examinations will comply with the acceptance criteria of ASME Code Case N-729-1 paragraph -3130 or -3140. Specifically, any volumetric or surface examination that reveals a leak or flaw not acceptable for continued service in accordance with the provisions of -3132.3 is unacceptable for continued service. Additional exams of -2430 are required to be satisfied and the component corrected by a repair or replacement activity to the extent necessary to meet the acceptance standards of -3000.

6. Duration of Proposed Alternative:

VCSNS is in the last period of its third 10 year inservice inspection (ISI) interval that will end December 31, 2013. The duration of the proposed alternative is for the remainder of the period.

7. Precedents:

The NRC generically approved the embedded flaw repair process described in Reference 1. Requests to use the embedded flaw technique to repair cracks have been previously approved by the NRC on a plant specific basis. The NRC approved a similar repair for Byron Station Unit 2. 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. (Reference 5 and 6)

8. References:

1. WCAP-15987-NP-A Revision 2, "Technical Bases for the Embedded Flaw Process for Repair of Reactor Vessel Head Penetrations" [ML040290246]
2. Letter 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 Penetration,’ (TAC NO. MB8997),” dated July 3, 2003 [ML031840237]
3. Letter from T. D. Gatlin (VCSNS) to Document Control Desk (NRC), "Reactor Vessel Head Penetration Weld Repair Under WCAP-15987," dated October 22, 2012.
4. Code 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."
5. NRC Memorandum, "Byron Station, Unit No. 1 - Verbal Authorization of Relief Request 13R-19 - Alternative Requirements for Repair of Reactor Vessel Head Penetrations 64 and 76 (TAC No. ME5877)," dated March 29, 2011
6. NRC Memorandum, "Byron Station Unit No. 1 - Verbal Authorization of Relief Request 13R-19 - Alternative Requirements for Repair of Reactor Vessel Head Penetrations Nos. 31 and 43 (TAC No. ME5948)," dated April 13, 2011

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Westinghouse Non-Proprietary Class 3

LTR-PAFM-12-137-NP

Revision 0

Technical Basis for Westinghouse Embedded Flaw Repair for V. C. Summer Unit 1 Reactor Vessel Head Penetration Nozzles

October 2012

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Westinghouse

1 INTRODUCTION

As a part of the inspection and contingence repair efforts associated with the reactor vessel closure head inspection program at V. C. Summer Unit 1, engineering evaluations were performed to support plant specific use of the Westinghouse embedded flaw repair process to repair unacceptable flaws detected in the head penetration nozzles during the Fall 2012 outage. The embedded flaw repair process involves depositing a weld material, which is Primary Water Stress Corrosion Cracking (PWSCC) resistant, over the detected flaw on the outside surface of the penetration nozzle of interest as well as over the wetted surface of the attachment J-groove weld. As a result, the surface flaw becomes a sub-surface flaw and is no longer exposed to the primary water environment. The methodology used is based on extensive analytical work completed by the Westinghouse Owners Group, currently the Pressurized Water Reactor Owners Group (PWROG), and a large collection of test data obtained under the sponsorship of Westinghouse, Babcock & Wilcox (B&W) and the former Combustion Engineering Owners groups (CEOG), as well as the Electric Power Research Institute (EPRI). The technical basis of the embedded flaw repair process is documented in WCAP-15987-P Revision 2-P-A [1] and has been reviewed and accepted by the Nuclear Regulatory Commission (NRC) in the United States. In the NRC Safety Evaluation Report that was incorporated in WCAP-15987-P Revision 2-P-A, the NRC staff concluded that, subject to the specified conditions and limitations, the embedded flaw repair process described in WCAP-15987-P provides an acceptable level of quality and safety. The staff also concluded that WCAP-15987-P is acceptable for referencing in licensing applications.

In this report, the technical basis and the flaw evaluation results to support the use of the Westinghouse embedded flaw repair process for head penetration nozzle number 19, 31, 37 and 52 with unacceptable outside surface flaws in the vicinity of the J-groove weld toes are provided. Engineering evaluations were performed to determine the maximum acceptable initial flaw sizes that can be left behind in a repaired penetration nozzle which would satisfy the ASME Section XI requirements [2]. The purpose of this report is to provide plant-specific technical basis for the use of the embedded flaw repair process and to confirm that V. C. Summer Unit 1 meets the criteria for application of the embedded flaw repair process stated in Appendix C of WCAP-15987-P [1].

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

This section provides a discussion on the technical basis for the use of embedded flaw repair process for head penetration nozzle number 19, 31, 37 and 52 with unacceptable outside surface flaws. Such a repair involves depositing several layers of Alloy 52/52M weld material over the flaw on the outside surface of the penetration nozzle of interest below the J-groove weld as well as the wetted surface of the attachment J-groove weld. Since the Alloy 52/52M repair weld material is PWSCC resistant, the detected surface flaw in the head penetration nozzle of interest is then shielded from the primary water environment and is no longer susceptible to primary water stress corrosion cracking.

For the repair of the unacceptable outside surface flaws in head penetration nozzle number 19, 31, 37 and 52, at least three layers of Alloy 52/52M material are deposited (360° full circumference) covering the entire wetted surface of the attachment J-groove weld. The repair weld extends at least 0.5 inch past the interface between the J-groove weld buttering and stainless steel cladding as well as covering the entire outside surface of the head penetration nozzle with at least two layers of Alloy 52/52M material. A schematic of the repair configuration for the repaired outside surface flaw is illustrated in Figure 2-1.

Flaw evaluations were performed based on the flaw sizes and shapes remaining in the repaired head penetration nozzles of interest to demonstrate that the left behind flaws are acceptable for continued operation. The as-found flaw parameters for penetration nozzle number 19, 31, 37 and 52 are shown below in Table 2-1. Since all the indications located on the outside surface of the penetration nozzles in the vicinity of the attachment J-groove weld toes are skewed with respect to the axis of the penetration nozzles, both axial and circumferential flaws are assumed.

Table 2-1
As-Found Flaw Parameters in V. C. Summer Unit 1 Head Penetration Nozzles

Indications	**Flaw Orientation**	**Flaw Length (in)**	**Flaw Depth (in)**	**Flaw Location**
Penetration No. 19 (Indications #1 & #2)	Circumferential	1.36	0.283	Outside Surface/Downhill Side
	Axial	0.72		
Penetration No. 31 (Indication #1)	Circumferential	0.16	0.122	Outside Surface/Downhill Side
	Axial	0.52		
Penetration No. 31 (Indication #2)	Circumferential	0.16	0.177	Outside Surface/Downhill Side
	Axial	0.36		
Penetration No. 31 (Indication #3)	Circumferential	0.26	0.256	Outside Surface/Downhill Side
	Axial	0.61		
Penetration No. 37 (Indication #1)	Circumferential	0.31	0.249	Outside Surface/Downhill Side
	Axial	0.76		
Penetration No. 37 (Indication #2)	Circumferential	0.10	0.214	Outside Surface/Downhill Side
	Axial	0.56		
Penetration No. 37 (Indication #3)	Circumferential	0.61	0.294	Outside Surface/Downhill Side
	Axial	0.52		
Penetration No. 52 (Indication #1)	Circumferential	0.47	0.279	Outside Surface/Downhill Side
	Axial	0.32		
Penetration No. 52 (Indication #2)	Circumferential	0.21	0.132	Outside Surface/Downhill Side
	Axial	0.12		

2.1 EVALUATION PROCEDURE AND ACCEPTANCE CRITERIA

Rapid, non-ductile failure is possible for ferritic materials at low temperatures, but is not applicable to the nickel-base alloy head penetration nozzle material such as Alloy 600. Nickel-base alloy material is a high toughness material and plastic collapse would be the dominant mode of failure. Therefore the evaluation procedures and acceptance criteria for indications in austenitic piping contained in paragraph IWB-3640 of ASME Section XI Code [2] are applicable for evaluation of flaws in the head penetration nozzles. The evaluation procedure used is consistent with those in Appendix C of WCAP-15987-P [1] and summarized below:

2.1.1 Acceptance Criteria for Axial Flaws

For axial flaws, the allowable flaw depth for a given flaw length can be determined from the following expression:

$$\sigma_h = \frac{\sigma_f}{SF_m}\left[\frac{1-\frac{a}{t}}{1-\left(\frac{a}{t}\right)/M_2}\right]$$

where

$$M_2 = \left[1+\left(\frac{1.61}{4R_m t}\right)\ell^2\right]^{1/2}$$

and

σ_f = Flow stress = $\frac{S_u + S_y}{2}$ (Average of Ultimate and Yield Strengths)
σ_h = PR_m/t
ℓ = Total Flaw Length
a = Flaw Depth
R_m = Mean Radius of Penetration Nozzle
t = Wall Thickness of Penetration Nozzle
P = Internal Pressure
SF_m = Safety Factor for membrane stress:
2.7 for Level A Service Loading
2.4 for Level B Service Loading
1.8 for Level C Service Loading
1.3 for Level D Service Loading

The limits of applicability of this equation are $a/t \leq 0.75$ and $\ell < \ell_{allow}$, where

$$\ell_{allow} = 1.58(R_m t)^{0.5}[(\sigma_f/\sigma_h)^2 - 1]^{0.5}$$

This limit is chosen such that surface flaws would remain below the critical size based on the plastic collapse condition if they should grow through the wall.

2.1.1 Acceptance Criteria for Circumferential Flaws

For circumferential flaws, the following relationship between the applied loads and flaw depth at incipient collapse given by equations in ASME Section XI Article C-5000 [2] is used:

$$\sigma_b^c = \frac{2\sigma_f}{\pi}\left[2\sin\beta - \frac{a}{t}\sin\theta\right]$$

$$\beta = \frac{1}{2}\left(\pi - \frac{a}{t}\theta - \pi\frac{\sigma_m}{\sigma_f}\right)$$

where:

σ_b^c = Bending stress at incipient plastic collapse
θ = One-half of the final flaw angle
β = Angle to neutral axis of penetration nozzle
a/t = Flaw depth to wall thickness ratio
σ_f = Flow stress = $\frac{S_u + S_y}{2}$ (Average of Ultimate and Yield Strengths)
σ_m = Applied membrane stress

The allowable bending stress, S_c, is as follows, which is used to calculate the maximum allowable end-of-evaluation period flaw sizes and the limit of applicability of this equation is a/t ≤ 0.75.

$$S_c = \frac{\sigma_b^c}{SF_b} - \sigma_m\left[1 - \frac{1}{SF_m}\right]$$

where

S_c = Allowable bending stress for penetration nozzle
σ_m = Applied membrane stress
SF_m = Safety factor for membrane stress
= 2.7, 2.4, 1.8 and 1.3 for Service Level A, B, C, and D respectively
SF_b = Safety factor for bending stress
= 2.3, 2.0, 1.6, and 1.4 for Service Level A, B, C, and D respectively

2.2 Methodology

The flaw evaluation considered that the embedded flaw repair process is used to seal the unacceptable flaws from further exposure to the primary water environment. The evaluation began with the determination of the maximum allowable end-of-evaluation period flaw sizes based on the acceptance criteria described in Section 2.1 for the repaired penetration nozzles. With the embedded flaw repair process, the only mechanism for future sub-critical crack growth is fatigue. The maximum initial embedded flaw size that can remain in a repaired penetration nozzle using the embedded flaw repair process can then be determined by subtracting the predicted fatigue crack growth for future plant operation from the maximum allowable end-of-evaluation period flaw size. This maximum initial allowable embedded flaw size is then compared with the left-behind flaw in the repaired head penetration nozzle of interest to demonstrate acceptability. The following provides a discussion of the loading conditions, geometry, thermal transient stress and fatigue crack growth analysis used in the development of the plant specific technical basis for the embedded flaw repair process.

2.2.1 Geometry and Source of Data

There are many penetration nozzles in the reactor vessel upper head. The outermost penetration nozzles (46.0° intersection angle) were selected for thermal transient and residual stress analysis because the stresses in the outermost penetration nozzles are more limiting and can be used to conservatively represent those at penetration nozzle number 19, 31 and 37 and 52.

The dimensions of all the V. C. Summer Unit 1 penetration nozzles are identical, with a 4.00 inch nominal outside diameter and a nominal wall thickness of 0.625 inch [3]. The distributions of residual, thermal transient and pressure stresses in the upper head penetration nozzle were obtained from the detailed three-dimensional plant specific elastic-plastic finite element analyses [4]. The through-wall stress distributions from the finite element analyses were used to determine the fatigue crack growth. The resulting crack growth is then used to determine the maximum allowable initial flaw sizes for the left-behind flaws in the repaired penetration nozzles of interest.

2.2.2 Maximum Allowable End-of-Evaluation Period Flaw Size Determination

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

Plastic collapse is the governing mode of failure for the head penetration nozzles because the high fracture toughness of the nickel base alloy (Alloy 600) material would prevent brittle fracture from occurring. Therefore, it is not necessary to consider the effects of secondary stresses resulting from thermal transient stresses and residual stresses. The governing loading for determining the maximum allowable end-of-evaluation period flaw sizes is therefore those due to internal pressure and other applicable external mechanical loads for the normal, upset, emergency and faulted conditions.

2.2.3 Thermal Transients Used in Fatigue Crack Growth Analysis

For the fatigue crack growth prediction, the effects of secondary stresses resulting from thermal transient and residual stresses must also be considered. The thermal transients that occur in the upper reactor vessel head region are relatively mild. The normal and upset thermal transients considered in the fatigue crack growth calculation are shown in Table 2-2 [5].

Table 2-2

Reactor Coolant System Transients for V. C. Summer Unit 1

Design Transients	Design Cycles
Normal Conditions	
Heat Up/Cooldown	200
Plant Loading/Unloading	18300
Step Load Increase/Decrease	2000
Large Step Load Decrease with Steam Dump	200
Turbine Roll Test	80
Feedwater Heaters Out of Service	40
Steady State Fluctuation (Initial)	150000
Steady State Fluctuation (Random)	3000000
Upset Conditions	
Loss of Load	200
Loss of Flow	80
Loss of Power	40
Reactor Trip From Full Power	400
Inadvertent Auxiliary Spray	10
Excessive Feedwater Flow	30
Operating Basis Earthquake	400

2.2.4 Crack Tip Stress Intensity Factor

One of the key elements in a crack growth analysis is the crack driving force or crack tip stress intensity factor, K_I. This is based on the equations available in the public literature. It should be noted that the flaws in the repaired penetration nozzles are conservatively assumed to be surface flaws even though the flaws are embedded after the repair.

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

$$\sigma(x) = A_0 + A_1x + A_2x^2 + A_3x^3 + A_4x^4$$

where:

x = Distance into the wall from the free surface
σ = Stress perpendicular to the plane of the crack
A_i = Coefficients of the 4th order polynomial fit, i = 0, 1, 2, 3, 4

For a surface flaw in the penetration nozzle, the stress intensity factor expression from API-579 [6] is used. The stress intensity factor K_I (ϕ) can be calculated anywhere along the crack front, where ϕ is the elliptical angle of a point on the crack front being evaluated. The following expression is used in calculating K_I (ϕ).

$$K_I = \left[\frac{\pi a}{Q}\right]^{0.5} \sum_{j=0}^{4} G_j\left(a/c,\ a/t,\ t/R,\ \phi\right) A_j\, a^j$$

The magnification factors G_0, G_1, G_2, G_3 and G_4 can be found in [6]. The parameter "a" is the crack depth, "c" is the half crack length, "t" is the wall thickness, "R" is the mean radius, "ϕ" is the parametric angle of the elliptical crack, and "Q" is the shape factor.

2.2.5 Fatigue Crack Growth Analysis

The applied loads used in the fatigue crack growth analysis include pressure, thermal transients and residual stresses. The normal and upset thermal transients considered in the fatigue crack growth analysis are shown in Table 2-2. The transient cycles are distributed evenly over the entire plant design life. The crack tip stress intensity factor range, ΔK, which controls fatigue crack growth, depends on the geometry of the crack, its surrounding structure and the range of applied stresses in the region of the crack. Once ΔK is calculated, the fatigue crack growth due to a particular stress cycle can be determined using a crack growth rate reference curve applicable to the head penetration nozzle material.

The fatigue crack growth rate (CGR) reference curve used in the fatigue crack growth analysis for the Alloy 600 material in air environment is based on that in NUREG/CR-6721 [7] and is shown below.

$$\frac{da}{dN} = CS_R \Delta K^{4.1}$$

$$C = 4.835 \times 10^{-14} + 1.622 \times 10^{-16} T - 1.490 \times 10^{-18} T^2 + 4.355 \times 10^{-21} T^3$$

$$S_R = [1 - 0.82R]^{-2.2}$$

where:

T = Temperature of the Transient (°C)

ΔK = Stress Intensity Factor Range ($\text{MPa}\sqrt{\text{m}}$)

R = Stress Ratio (K_{min}/K_{max})

$\frac{da}{dN}$ = Fatigue crack growth rate (meters/cycle)

Once the incremental crack growth corresponding to a specific transient for a given time period is calculated, it is added to the previous crack size, and the analysis continues to the next time period and/or thermal transient assuming the flaw shape remains constant. The procedure is repeated in this manner until all the significant design thermal transients and cycles known to occur in a given period of operation have been analyzed. For conservatism, R=1 is used in the fatigue crack growth analysis.

2.3 Flaw Evaluation Results

The maximum allowable end-of-evaluation period axial and circumferential flaw depths for the V. C. Summer Unit 1 penetration nozzles of interest are provided for various flaw aspect ratios (flaw depth/flaw length) in Table 2-3. The maximum allowable initial axial and circumferential flaw sizes accounting for fatigue crack growth of 40 years after the repair are shown in Figures 2-2 and 2-3 respectively. The maximum allowable initial flaw sizes are obtained by subtracting the fatigue crack growth for 40 years of service life after the repair from the maximum allowable end-of-evaluation period flaw sizes. As shown in Figures 2-2 and 2-3, the respective maximum allowable initial axial and circumferential flaw sizes are larger than the left-behind flaws in the repaired penetration nozzle number 19, 31, 37 and 52. Therefore, all the repaired flaws are acceptable for continued operation for at least 40 years after the repair. It should be noted in Figures 2-2 and 2-3, the aspect ratios (flaw depth/flaw length) for indications in the penetration nozzles are set to a maximum of 0.5 in accordance with the ASME Section XI Code.

Table 2-3
Maximum Allowable End-of-Evaluation Period Flaw Sizes
(Percentage of Nominal Wall Thickness)

Aspect Ratio (Depth/Length)	Circumferential Flaw	Axial Flaw
0.20	57%	75%
0.33	73%	75%
0.50	75%	75%

3.0 Conclusions

The unacceptable outside surface circumferential flaws are isolated from the primary water environment using the Westinghouse embedded flaw repair process. Primary water stress corrosion is no longer a credible degradation mechanism and fatigue is the only credible crack growth mechanism. The left behind flaws in the repaired head penetration nozzle number 19, 31, 37 and 52 have been shown to be acceptable for continued operation for at least 40 years after the repair. These upper head penetration nozzles will be inspected every refueling outage following the repair. It is therefore technically justified to use the embedded flaw repair process as the repair technique for the reactor vessel head penetration nozzles with the unacceptable outside surface flaws since the criteria for application of such a process as stated in Appendix C of WCAP-15987-P is met.

4.0 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. (Westinghouse Proprietary Class 2)

2. ASME Section XI Code:

    a. ASME Boiler & Pressure Vessel Code, 1998 Edition through 2000 Addenda, Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components.

    b. ASME Boiler & Pressure Vessel Code, 2007 Edition with 2008 Addenda, Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components.

3. Chicago Bridge & Iron Company Drawing No. 40, Contract No. 71-2631, "157" PWR Control Rod Drive Mechanism Housings Details," Revision 6.

4. Dominion Engineering, Inc. Report C-8849-00-01 Rev. 0, "V.C. Summer RPV Head CRDM Nozzle Welding Residual Stress plus Transient Analysis". (Dominion Engineering Inc. Proprietary Document)

5. Design Specification DS-MRCDA-09-10, Revision 0, Equipment: Reactor Vessel – Virgil C. Summer Nuclear Station Addendum to Equipment Specification 679105 Rev. 2. (Westinghouse Proprietary Class 2)

6. American Petroleum Institute, API 579-1/ASME FFS-1 (API 579 Second Edition), "Fitness-For-Service," June 2007.

7. NUREG/CR-6721, ANL-01/07, "Effects of Alloy Chemistry, Cold Work, and Water Chemistry on Corrosion Fatigue and Stress Corrosion Cracking of Nickel Alloys and Welds," April 2001.

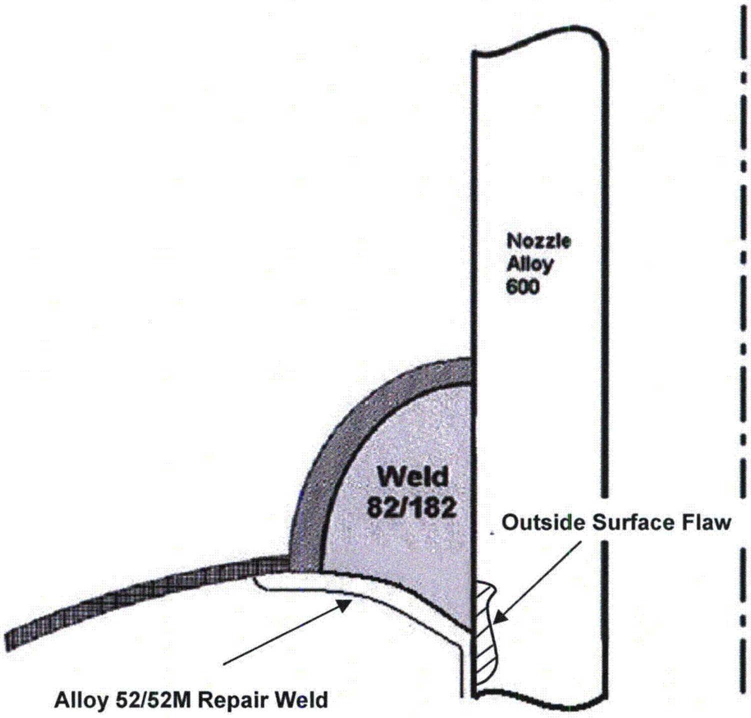

Figure 2-1 A Schematic of the Repair Configuration for the Outside Surface Flaw

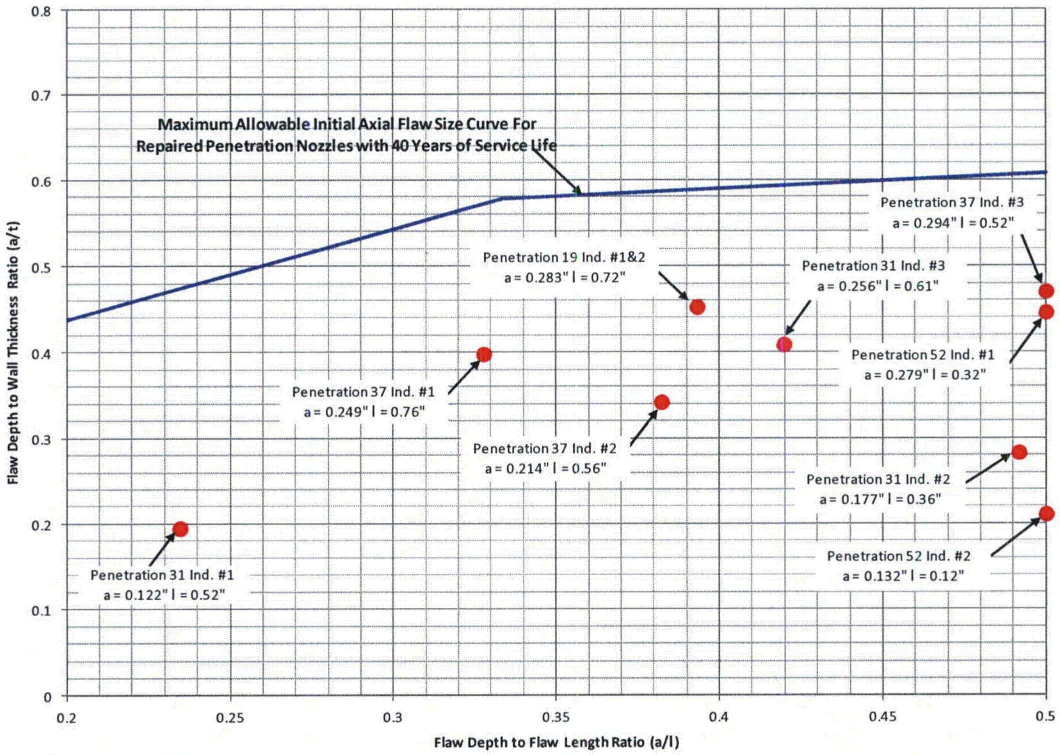

Figure 2-2 Maximum Allowable Initial Axial Flaw Sizes for Repaired Penetration Nozzles

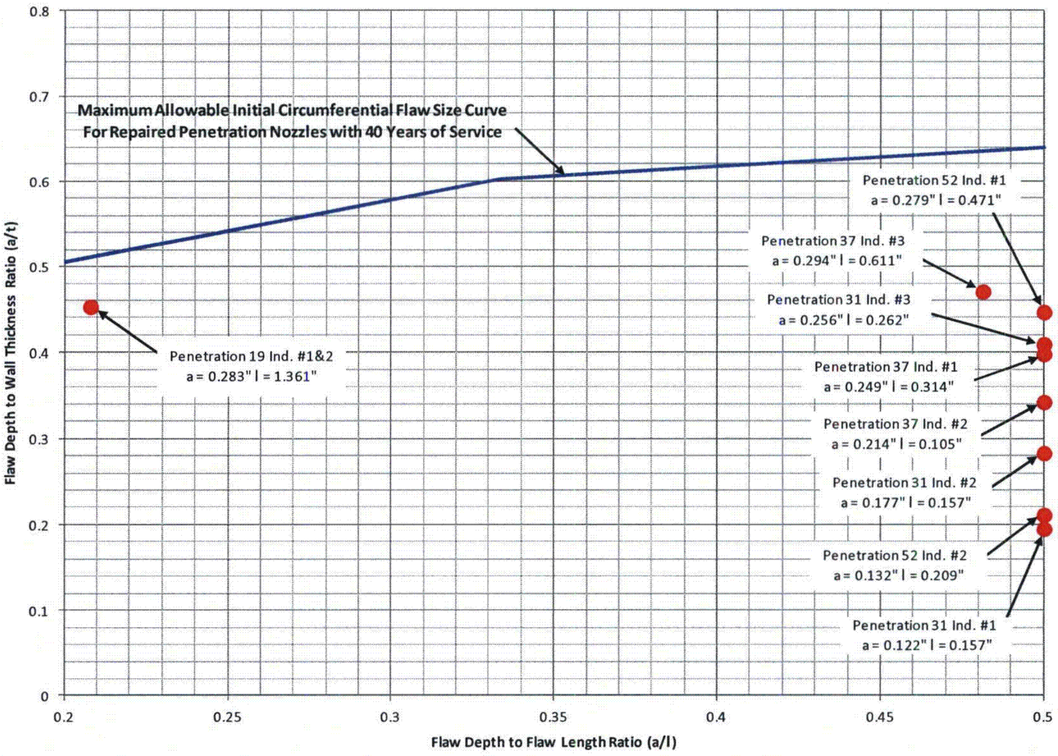

Figure 2-3 Maximum Allowable Initial Circumferential Flaw Sizes for Repaired Penetration Nozzles