APS

David Mauldin
Vice President
Nuclear Engineering
and Support

Palo Verde Nuclear
Generating Station

TEL (623) 393-5553
FAX (623) 393-6077

Mail Station 7605
P.O. Box 52034
Phoenix, AZ 85072-2034

10 CFR 50.55a

102-05112-CDM/SAB/RJR
June 15, 2004

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

Reference:
1. Letter 102-04941-CDM/SAB/RJR, "10 CFR 50.55a Alternative Repair Request for the Second 10-Year Interval of the Inservice Inspection Program: Relief Request 23, Pressurizer Heater Sleeves," dated May 15, 2003.
2. NRC letter to APS, "Palo Verde Nuclear Generating Station, Units 1, 2, and 3 – Relief Request No. 23 RE: Alternative to Temper Bead Welding Requirements for Inservice Inspection Program (TAC No.s MB8973, MB8974, and MB8975)," dated July 30, 2003.

Dear Sirs:

Subject: Palo Verde Nuclear Generating Station (PVNGS)
Units 1, 2 and 3
Docket No. STN 50-528, 50-529 and 50-530
10 CFR 50.55a Alternative Repair Requests for the PVNGS Pressurizers: Relief Requests 28 and 29

Pursuant to 10 CFR 50.55a(a)(3)(i), Arizona Public Service Company (APS) is proposing alternatives to the requirements of American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, 1992 Edition, 1992 Addenda, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components." These requests pertain to the Palo Verde Nuclear Generating Station (PVNGS) alloy 600 small-bore sleeves of the Unit 1, 2 and 3 pressurizers during the second 10-Year interval of the Inservice Inspection Program.

APS has made a proactive decision to move the Unit 3 pressurizer heater sleeve replacements from the steam generator replacement outage planed for the fall of 2007 to the fall 2004 refueling outage. This decision is, based on the inspection results of the Unit 2 pressurizer in the previous outage. Therefore, APS will require approval of these relief requests to support this schedule change.

A047

APS has taken the lead for developing two relief requests in a cooperative agreement between Arizona Public Service Company (APS), Entergy Nuclear Incorporated (Entergy), and Southern California Edison Company (SCE). The aforementioned utilities are supporting the licensing activities required for the approval of these requests.

Specifically, APS' Relief Request 28, "Ambient Temperature Temper Bead Welding for Pressurizer Half-Sleeve Replacement," requests authorization to use an ambient temperature automatic or machine Gas Tungsten Arc Welding (GTAW) temper bead process during modification of the pressurizer heater sleeves similar to the request made by APS in Reference 1 and approved by the NRC in Reference 2. APS is currently in the process of developing the half-sleeve, mid-wall weld repair proposed in this relief request and would use this process for the remaining sleeves in Units 1 and 3. The schedule for completing the welding procedure and procedure qualification records is July 28, 2004.

Relief Request 29, "Remnant Sleeve(s) Flaw Evaluation," requests relief from certain flaw evaluation requirements and from the successive examination of the remnant sleeves left in-place after performing a half-sleeve mid-wall weld repair In Units 1 and 3. The flaw evaluation supporting this request utilizes both Linear Elastic Fracture Mechanics (LEFM) and Elastic Plastic Fracture Mechanics (EPFM), and demonstrates compliance with ASME Section XI criteria for the 40-year plant life as well as a potential 20-year life extension. This relief also applies to Unit 2 pressurizer heater sleeve replacements performed during the steam generator replacement outage in the fall of 2003. The flaw evaluation is completed and attached to Enclosure 2.

APS will schedule a meeting with the NRC in the near future to discuss the details and timing of the proposed requests. In order for APS to mobilize equipment in support of the pressurizer heater sleeve replacements we request the NRC inform us that the relief has been found acceptable for approval by September 1, 2004. APS will require Relief Requests 28 and 29 to be approved by October 15, 2004. This letter contains no new commitments; should you have any questions, please contact Thomas N. Weber at (623) 393-5764.

Sincerely,

David Mauldin

CDM/SAB/RJR/

Enclosures 1. Relief Request 28, "Ambient Temperature Temper Bead Welding for Pressurizer Half-Sleeve Replacement"
Attachment 1, "Dissimilar Metal Welding Using Ambient Temperature Machine GTAW Temper Bead Technique"

2. Relief Request 29, "Remnant Sleeve(s) Flaw Evaluation"
   Attachment 1, "Report SIR-04-045, Technical Report Supporting the Palo Verde Pressurizer Heater Sleeve Mid-Wall Repair"

cc:	B. S. Mallett, NRC Region IV Regional Administrator	(w/Enclosure)
	M. B. Fields, NRC NRR Project Manager	(w/Enclosure)
	N. L. Salgado, NRC Senior Resident Inspector for PVNGS	(w/Enclosure)

Enclosure 1

Relief Request 28, "Ambient Temperature Temper Bead Welding For Pressurizer Half-Sleeve replacement"

Relief Request 28, Ambient Temperature Temper Bead Welding For Pressurizer Half-Sleeve replacement

Background Information

The existing Palo Verde Nuclear Generating Station (PVNGS) pressurizer heater sleeves are made from Inconel 600 material and are susceptible to primary water stress corrosion cracking (PWSCC). The pressurizer head is manufactured from P-Number 3, Group 3 low alloy steel. Each pressurizer has 36 heater sleeves (nominal dimensions: 1.66" outside diameter (OD) and .192" wall thickness) which are attached to the lower pressurizer head by partial penetration welds made at the pressurizer inside diameter (ID) surface.

The PVNGS Unit 2 pressurizer heater sleeves were repaired using a half-sleeve, pad repair in which the new sleeves were attached to an Inconel 52 temper bead weld pad that was deposited over the pressurizer SA-508 Class 1 (P3) material on the outside surface of the pressurizer shell. This pad was installed using the process described in PVNGS Relief Request 23 approved on July 30, 2003 (Reference 1 of this Enclosure).

The half-sleeve, mid-wall weld repair being proposed for the heater sleeves in Units 1 and 3 relocates the reactor coolant pressure boundary from a partial penetration weld on the inside surface of the pressurizer to a partial penetration weld at the mid-wall of the pressurizer (see Figure 1). This requires the removal of a portion of the old Alloy 600 sleeve below the attachment weld, the vessel bore cleaned, and a new Alloy 690 sleeve inserted. The mid-wall weld attaches a new Alloy 690 material (the replacement sleeve) directly to the cleaned vessel bore, thereby achieving significant enhancements in the welding environment. A partial penetration weld is made at the pressurizer mid-wall with a 0.40" throat. This repair design satisfies the design requirements of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, for Class 1 components. APS has used Code Case N-638 as a guide in preparation of this relief request which eliminates the need for elevated temperature preheat and elevated temperature post weld soak.

Mid-wall Repair Versus Pad Repair

The proposed mid-wall repair has three significant advantages over the previous pad repair. The first advantage is the mid-wall repair permits a significant decrease in the number of machining steps required. The second advantage is the weld volume required for the mid-wall repair is significantly less. Finally, the welding configuration is considerably less complex than that of the pad repair. These inherent advantages reduce welding time and welding complexity, which reduces radiation exposure while producing a weld of acceptable quality and safety.

Relief Request 28, Ambient Temperature Temper Bead Welding For Pressurizer Half-Sleeve replacement

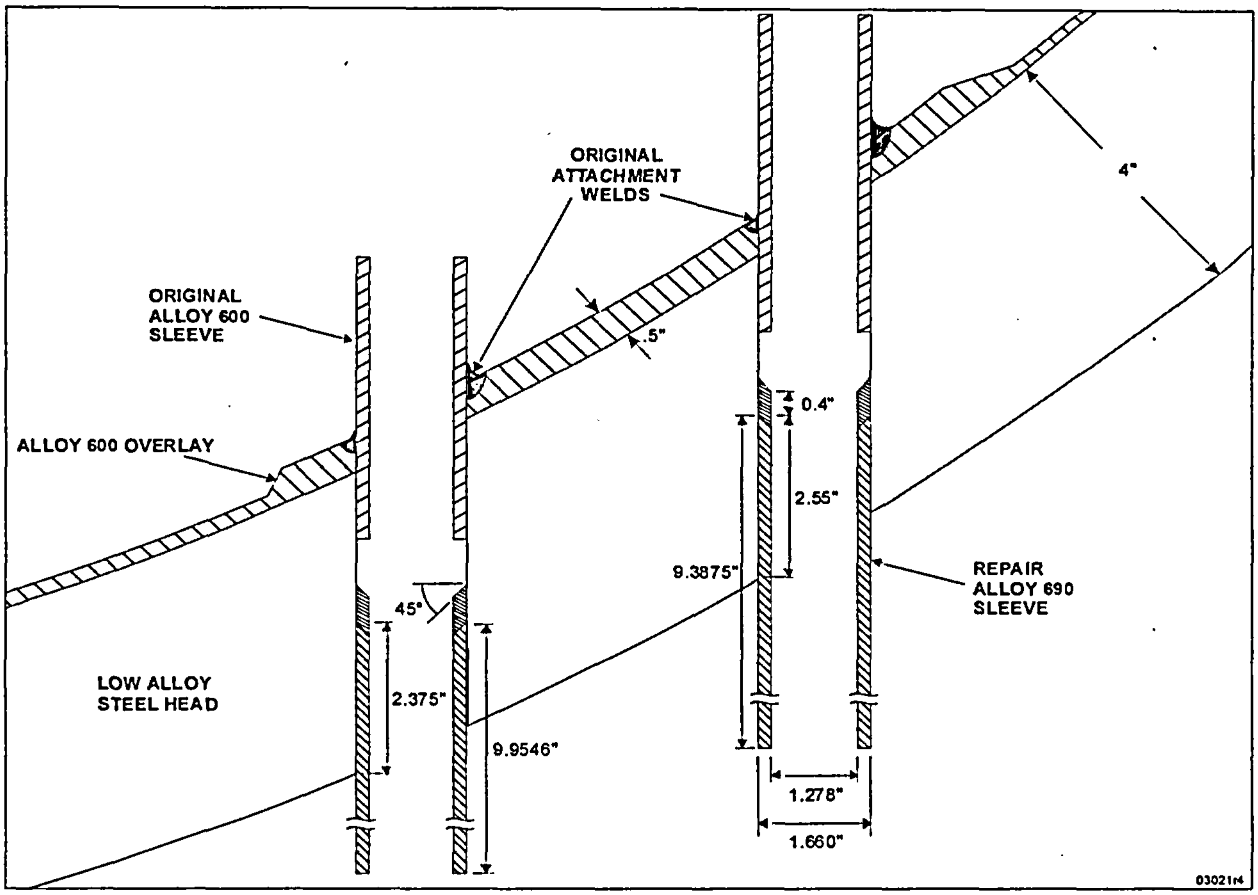


Figure 1: Conceptual Drawing of Pressurizer Heater Sleeve Mid-Wall Repair

Radiation Exposure Reduction

APS estimates that a significant dose savings can be achieved by using an ambient temperature temper bead welding process and changing from an external pad repair to a mid-wall repair . APS has previously estimated the dose associated with the set-up and disassembly of the elevated preheat and post weld soak the pressurizer to be at least 60 REM. APS estimates that the dose associated with a manual Shielded Metal Arc Welding (SMAW) temper bead repair to be 35 to 45 REM more per unit than the proposed ambient temperature temper bead Gas Tungsten Arc Welding (GTAW) method of repair. Reviewing the radiological tracking during the Unit 2 pressurizer repair, the pad repair (Fall 2003) resulted in a total dose of 32 REM. APS has projected the dose for the proposed mid-wall repair to be 23.5 REM. The projected savings in radiological exposure (8.5 Rem) between the pad repair and the mid-wall repair is primarily due to fewer machining operations and significantly less weld metal deposited in the mid-wall repair in comparison to the pad repair. In addition, the mid-wall repair can be implemented in approximately two-thirds the time required for the pad repair. Using the half-sleeve mid-wall weld repair with the ambient temperature temper bead weld, a total dose savings of 103.5 – 113.5 REM per unit is projected.

This table summarizes the differences in dose discussed above and shows the dose savings expected.

Subject	Dose (REM)	Dose Savings (REM)
Heating Method • Pre-heat/Post-heat Set-up/Disassembly • Ambient Temperature Temper Bead	 60 0	 60
Welding Options (for Pad Repair) • SMAW (manual) • GTAW (machine)	 60 - 70 25	 35 - 45
Total dose savings using ambient temperature temper bead and GTAW for pad repair		95 - 105
Repair Methods • Pad Repair performed in Unit 2 (actual) • Proposed mid-wall repair (estimated)	 32 23.5	Additional Dose Savings 8.5
		Total = 103.5 – 113.5

I. ASME Code Component(s) Affected

Component number B4.20
Description: Pressurizer Heater Sleeve, 36 per Unit.
Code Class: 1

II. Applicable Code Addition and Addenda

Second 10-year inservice inspection interval code for Palo Verde Nuclear Generating Station (PVNGS) Units 1, 2, and 3: The American Society of Mechanical Engineers (ASME) Code, Section XI, 1992 Edition, 1992 Addenda.

Construction code for PVNGS Units 1, 2, and 3: ASME Section III, 1971 Edition, and 1973 Winter Addenda.

Installation code for PVNGS Units 1, 2, and 3: ASME Section III, 1974 Edition, and 1975 Winter Addenda.

III. Applicable Code Requirements for Welding Alloy 690 Half Sleeve to Pressurizer Mid-wall

Sub-article IWA-4170(b) of ASME Section XI, 1992 Edition, 1992 Addenda states: "Repairs and installation of replacement items shall be performed in accordance with the Owner's Design Specification and the original Construction Code of the component or system. ...If repair welding cannot be performed in accordance with these requirements, the applicable requirements of IWA-4200, IWA-4400, or IWA-4500 may be used."

IWA-4500 of ASME Section XI establishes alternative repair welding methods for performing temper bead welding. According to IWA-4500(a), "Repairs to base materials and welds identified in IWA-4510, IWA-4520, and IWA-4530 may be made by welding without the specified postweld heat treatment requirements of the Construction Code or Section III, provided the requirements of IWA-4500(a) through (e) and IWA-4510, IWA-4520, or IWA-4530, as applicable, are met."

IWA-4530 applies to dissimilar materials such as welds that join P-Number 43-nickel alloy to P-Number 3 low alloy steels. According to IWA-4530, "Repairs to welds that join P-No. 8 or P-No. 43 material to P-Nos. 1, 3, 12A, 12B, and 12C material may be made without the specified postweld heat treatment, provided the requirements of IWA-4530 through IWA-4533 are met."

When the GTAW process is used in accordance with IWA-4500 and IWA-4530, then temper bead welding is performed as follows:

- Only the automatic or machine GTAW process using cold wire feed can be used. Manual GTAW cannot be used.
- A minimum preheat temperature of 300°F is established and maintained throughout the welding process. Interpass temperature cannot exceed 450°F.
- The weld cavity is buttered with at least six (6) layers of weld metal.

- Heat input of the initial six layers is controlled to within +/-10% of that used for the first six layers during procedure qualification testing.
- After the first six weld layers, repair welding is completed with a heat input that is equal to or less than that used in the procedure qualification for weld layers seven and beyond.
- Upon completion of welding, a postweld soak or hydrogen bake-out at 300°F (minimum) for a minimum of 4 hours is required.
- Preheat, interpass, and postweld soak temperatures are monitored using thermocouples and recording instruments.
- The repair weld and preheated band are examined in accordance with IWA-4533 after the completed weld has been at ambient temperature for 48 hours.

IV. Proposed Alternative

Pursuant to 10CFR50.55a(a)(3)(i), APS proposes alternatives to the GTAW-machine temper bead welding requirements of IWA-4500 and IWA-4530 of ASME Section XI. Specifically, APS proposes to perform ambient temperature temper bead welding in accordance with Attachment 1, "Dissimilar Metal Welding Using Ambient Temperature Machine GTAW Temper Bead Technique," as an alternative to IWA-4500 and IWA 4530.

APS has reviewed the proposed ambient temperature temper bead welding techniques of Attachment 1 against the GTAW-machine temper bead welding requirements of IWA-4500 and IWA-4530. This review was performed to identify differences between Attachment 1 and IWA-4500 and IWA-4530. Based upon this review, APS proposes alternatives to the following ASME Section XI requirements of IWA-4500 and IWA-4530:

1. **IWA-4500(a)** specifies that repairs to base materials and welds identified in IWA-4530 may be performed without the specified postweld heat treatment of the construction code or ASME Section III provided the requirements of IWA-4500 and IWA-4530 are met. IWA-4530 includes temper bead requirements applicable to the SMAW and the machine or automatic GTAW processes. As an alternative, APS proposes to perform temper bead weld repairs using the ambient temperature temper bead technique described in Attachment 1. Only the machine or automatic GTAW process can be used

when performing ambient temperature temper bead welding in accordance with Attachment 1.

2. **IWA-4500(d)(2)** specifies that if repair welding is to be performed where physical obstructions impair the welder's ability to perform, the welder shall also demonstrate the ability to deposit sound weld metal in the positions, using the same parameters and simulated physical obstructions as are involved in the repair. This limited accessibility demonstration applies when manual temper bead welding is performed using the SMAW process. It does not apply to "welding operators" who perform machine or automatic GTAW welding from a remote location. This distinction is clearly made in IWA-4500 and IWA-4530. Because the proposed ambient temperature temper bead technique described in Attachment 1 utilizes a machine GTAW welding process, limited access demonstrations of "welding operators" are not required. Therefore, the requirement of IWA-4500(d)(2) does not apply.

3. **IWA-4500(e)(2)** specifies that the weld area plus a band around the repair area of at least 1½ times the component thickness or 5 inches, whichever is less, shall be preheated and maintained at a minimum temperature of 300°F for the GTAW process during welding; maximum interpass temperature shall be 450°F. As an alternative, APS proposes that the weld area plus a band around the repair area of at least 1½ times the component thickness or 5 inches, whichever is less, shall be preheated and maintained at a minimum temperature of 50°F for the GTAW process during welding; maximum interpass temperature shall be 350°F regardless of the interpass temperature during qualification.

4. **IWA-4500(e)(2)** specifies that thermocouples and recording instruments shall be used to monitor process temperatures, and that thermocouple attachment and removal shall be performed in accordance with ASME Section III. APS will not use any thermocouples or recording instrument since there is no elevated preheat; because of the large heat sink interpass temperature does not approach anywhere near 350°F.

5. **IWA-4532.1** establishes procedure technique requirements that apply when using the SMAW process. Because the proposed ambient temperature temper bead technique of Attachment 1 utilizes the machine or automatic GTAW welding process, the SMAW temper bead technique requirements of paragraph IWA-4532.1 do not apply.

6. **IWA-4532.2(c)** specifies that the repair cavity shall be buttered with the first six layers of weld metal in which the heat input of each layer is controlled to within +/-10% of that used in the procedure qualification test, and heat input control

for subsequent layers shall be deposited with a heat input equal to or less than that used for layers beyond the sixth in the procedure qualification. As an alternative, APS proposes to deposit the weld area with a minimum of three layers of weld metal to obtain a minimum thickness of 1/8-inch. The heat input of each weld layer in the 1/8-inch thick weld section shall be controlled to within +/-10% of that used in the procedure qualification test. The heat input for subsequent weld layers shall not exceed the heat input used for layers beyond the 1/8-inch thick section (first three weld layers) in the procedure qualification.

7. **IWA-4532.2(c)** specifies that the completed weld shall have at least one layer of weld reinforcement deposited and then this reinforcement shall be removed by mechanical means. As an alternative, APS' proposed ambient temperature temper bead technique does not include a reinforcement layer.

8. **IWA-4532.2(d)** specifies that, after at least 3/16-inch of weld metal has been deposited, the weld area shall be maintained at a temperature of 300°F (minimum) for a minimum of four (4) hours (for P-No. 3 materials). As an alternative, APS' proposed ambient temperature temper bead technique does not include a postweld soak.

9. **IWA-4532.2(e)** specifies that after depositing at least 3/16-inch of weld metal and performing a postweld soak at a minimum temperature of 300°F, the balance of welding may be performed at an interpass temperature of 350°F. As an alternative, APS proposes that an interpass temperature of 350°F may be used after depositing at least 1/8-inch of weld metal without a postweld soak.

10. **IWA-4533** specifies the following examinations shall be performed after the completed repair weld has been at ambient temperature for at least 48 hours: (a) the repair weld and preheated band shall be examined by the liquid penetrant method; (b) the repaired region shall be examined by the radiographic method, and if practical, (c) by the ultrasonic method. APS will perform the liquid penetrant examination of the completed repair weld. As an alternative to the radiographic examination of IWA-4533, APS proposes ultrasonic examination of the repair weld.

V. Basis of Alternative for Providing Acceptable Level of Quality and Safety

The pressurizer head is manufactured from P-Number 3, Group 3 low alloy steel. If repairs are performed in accordance with ASME Section III, APS would have two options: (1) perform a weld repair that includes a postweld heat treatment at 1100°F – 1250°F in accordance with NB-4622.1; or (2) perform a temper bead repair using the SMAW process in accordance with NB-4622.11. Each option is discussed below.

1. Postweld heat treatment (PWHT) of the pressurizer head is an impractical option that could cause ovalization and misalignment of heater sleeves, permanently damaging the pressurizer lower head including the heater support assembly. ASME Section III NB-4600 requires PWHT to be performed at 1100°F to 1250°F.

2. NB-4622.11 provides temper bead rules for repair welding of dissimilar materials using the SMAW process. Because NB-4622.11 does not include temper bead rules for the machine or automatic GTAW process, a manual SMAW temper bead process must be used. However, a manual SMAW temper bead repair is not a desirable option due to radiological considerations. First, resistant heating blankets, thermocouples, and insulation must be installed. Secondly, the manual SMAW temper bead welding process is a time and dose intensive process. Each weld layer is manually deposited in a high dose and high temperature (350°F) environment. The manual SMAW temper bead process of NB-4622.11 also requires that the weld crown of the first weld layer be mechanically removed by grinding. Upon completing repair welding, resistant heating blankets, thermocouples, and insulation must be removed. Thermocouples and heating blanket-mounting pins must be removed by grinding. The ground areas must be subsequently examined by the magnetic particle or liquid penetrant examination.

APS is not requesting an alternative to NB-4622.11; rather, this request proposes an alternative to IWA-4500 and IWA-4530. Owners are allowed by ASME Section XI IWA-4170(b) and IWA-4500(a) to perform temper bead repairs of dissimilar materials. IWA-4170(b) and IWA-4500(a) provide requirements and controls for performing such repairs.

IWA-4500 and IWA-4530 of ASME Section XI establish requirements for performing temper bead welding of "dissimilar materials". According to IWA-4530, either the automatic or machine GTAW process or SMAW process may be used. When using the machine GTAW process, a minimum preheat temperature of 300°F must be established and maintained throughout the welding process while the interpass temperature is limited to 450°F. Upon completion of welding, a postweld soak is performed at 300°F (minimum) for a minimum of 4 hours.

The IWA-4500 and IWA-4530 temper bead welding process is a time and dose intensive process. Resistant heating blankets are typically attached to the pressurizer head using a capacitor discharge stud welding process. Thermocouples must also be attached to the pressurizer head using a capacitor discharge welding process to monitor pre-heat, interpass, and postweld soak temperatures. Prior to heat-up, thermal insulation is also installed. Upon completion of repair welding (including the postweld soak), the insulation, heating blankets, studs, and thermocouples must be removed from the pressurizer head. Thermocouples and stud welds are removed by grinding. Ground removal areas are subsequently examined by the liquid penetrant or magnetic particle method. A significant reduction in dose could be realized by utilizing an ambient temperature temper bead process, as explained in the background information under "Radiation Exposure Reduction." Therefore, APS proposes an alternative welding technique based on methodology of code case N-638.

A. Evaluation of the Ambient Temperature Temper Bead Technique

Research by the Electric Power Research Institute (EPRI) and other organizations on the use of an ambient temperature temper bead technique using the machine GTAW process is documented in EPRI Report GC-111050. According to the EPRI report, repair welds performed with an ambient temperature temper bead procedure utilizing the machine GTAW welding process exhibit mechanical properties that are equivalent or better than those of the surrounding base material. Laboratory testing, analysis, successful procedure qualifications, and successful repairs have all demonstrated the effectiveness of this process.

The effects of the ambient temperature temper bead welding process of Attachment 1 on mechanical properties of repair welds, hydrogen cracking, and restraint cracking are addressed below.

1. Mechanical Properties

The principal reason to preheat a component prior to repair welding is to minimize the potential for cold cracking. The two cold cracking mechanisms are hydrogen cracking and restraint cracking. Both of these mechanisms occur at ambient temperature. Preheating slows down the cooling rate resulting in a ductile, less brittle microstructure thereby lowering susceptibility to cold cracking. Preheat also increases the diffusion rate of monatomic hydrogen that may have been trapped in the weld during solidification. As an alternative to preheat, the ambient temperature temper bead welding process utilizes the tempering action of the welding procedure to produce tough and ductile microstructures. Because precision bead placement and heat input control is characteristic of the machine GTAW process, effective tempering of the weld heat affected zones is possible without the application of preheat. The ambient temperature temper bead procedure is carefully designed and controlled such that successive weld beads supply the appropriate quantity of heat to the untempered heat affected zone such that the desired degree of carbide precipitation (tempering) is achieved. The resulting microstructure is very tough and ductile.

The IWA-4530 temper bead process also includes a postweld soak requirement. Performed at 300°F for 4 hours for P-Number 3 base materials, this postweld soak assists diffusion of any remaining hydrogen from the repair weld. As such, the postweld soak is a hydrogen bake-out and not a postweld heat treatment as defined by the ASME Code. At 300°F, the post weld soak does not stress relieve, temper, or alter the mechanical properties of the weldment in any manner.

Section 2.1 of Attachment 1 establishes detailed welding procedure qualification requirements for base materials, filler metals, restraint, impact properties, and other procedure variables. The qualification requirements of Section 2.1 provide assurance that the mechanical properties of repaired welds will be equivalent or superior to those of the surrounding base material.

2. Hydrogen Cracking

Hydrogen cracking is a form of cold cracking. It is produced by the action of internal tensile stresses acting on low toughness heat affected zones. The internal stresses are produced from localized build-up of monatomic hydrogen. Monatomic hydrogen forms when moisture or hydrocarbons interact with the welding arc and molten weld pool. The monatomic hydrogen can be entrapped during weld solidification and tends to migrate to transformation boundaries or other microstructure defect locations. As concentrations build, the monatomic hydrogen will recombine to form molecular hydrogen – thus generating localized internal stresses at these internal defect locations. If these stresses exceed the fracture toughness of the material, hydrogen induced cracking will occur. This form of cracking requires the presence of hydrogen and low toughness materials. It is manifested by intergranular cracking of susceptible materials and normally occurs within 48 hours of welding.

IWA-4500 establishes elevated preheat and postweld soak requirements. The elevated pre-heat temperature of 300°F increases the diffusion rate of hydrogen from the weld. The postweld soak at 300°F was also established to bake-out or facilitate diffusion of any remaining hydrogen from the weldment. However, while hydrogen cracking is a concern for SMAW, which uses flux covered electrodes, the potential for hydrogen cracking is significantly reduced when using the machine GTAW welding process.

The machine GTAW welding process is inherently free of hydrogen. Unlike the SMAW process, GTAW welding filler metals do not rely on flux coverings that are susceptible to moisture absorption from the environment. The GTAW process utilizes dry inert shielding gases that cover the molten weld pool from oxidizing atmospheres. Any moisture on the surface of the component being welded will be vaporized ahead of the welding torch. The vapor is prevented from being mixed with the molten weld pool by the inert shielding gas that blows the vapor away before it can be mixed. Furthermore, modern filler metal manufacturers produce weld wires that have very low residual hydrogen. This is important because filler metals and base materials are the most realistic sources of hydrogen for automatic or machine GTAW temper bead welding. Therefore, the potential for hydrogen induced cracking is greatly reduced by using machine GTAW process.

3. Restraint Cracking

Restraint cracking generally occurs during cooling at temperatures approaching ambient temperature. As stresses build under a high degree of restraint, cracking may occur at defect locations. Brittle microstructures with low ductility are subject to cold restraint cracking. However, the ambient temperature temper bead process is designed to provide a sufficient heat inventory to produce the desired tempering for high toughness. Because the machine GTAW temper bead process provides precision bead placement and control of heat, the toughness and ductility of the heat-affected zone is typically superior to the base material. Therefore, the resulting structure is tempered to produce toughness that is resistant to cold cracking.

In conclusion, no elevated preheat or postweld soak above ambient temperature is required to achieve sound and tough repair welds when performing ambient temperature temper bead welding using the machine GTAW process. This conclusion is based upon strong evidence that hydrogen cracking will not occur with the machine GTAW process (Reference 6). In addition, automatic or machine temper bead welding procedures without preheat will produce satisfactory toughness and ductility properties both in the weld and weld heat affected zones. The results of previous industry qualifications and repairs further support this conclusion. The use of an ambient temperature temper bead welding procedure will improve the feasibility of performing localized weld repairs with a significant reduction in radiological exposure.

B. Evaluation of Proposed Alternatives to ASME Section XI, IWA-4500 and IWA-4530

1. According to **IWA-4500(a)**, repairs may be performed to dissimilar base materials and welds without the specified postweld heat treatment of ASME Section III provided the requirements of IWA-4500 and IWA-4530 are met. The temper bead rules of IWA-4500 and IWA-4530 apply to dissimilar materials such as P-No. 43 to P-No. 3 base materials welded with F-No. 43-filler metals. When using the machine GTAW process, the IWA-4500 and IWA-4530 temper bead process is based fundamentally on an elevated preheat temperature of 300°F, a maximum interpass temperature of 450°F, and a postweld soak of 300°F. The proposed alternative of Attachment 1 also establishes requirements to perform temper bead welding on dissimilar material welds that join P-No. 43 to P-No. 3 base materials using F-No. 43-filler metals. However, the temper bead process of Attachment 1 is an ambient temperature technique, which only utilizes the machine GTAW, or automatic GTAW process. The suitability of the proposed ambient temperature temper bead technique is evaluated in this section. The results of this evaluation demonstrate that the proposed ambient temperature temper bead technique provides an acceptable level of quality and safety.

2. According to **IWA-4500(e)(2)**, the weld area plus a band around the repair area of at least 1½ times the component thickness or 5 inches, whichever is less, shall be preheated and maintained at a minimum temperature of 300°F for the GTAW process during welding while the maximum interpass temperature is limited to 450°F. The ambient temperature temper bead technique of Attachment 1 also establishes a preheat band of at least 1½ times the component thickness or 5 inches, whichever is less. However, the ambient temperature temper bead technique requires a minimum preheat temperature of 50°F, a maximum interpass temperature of 150°F for the first three layers, and a maximum interpass temperature of 350°F for the balance of welding. The suitability of an ambient temperature temper bead technique with reduced preheat and interpass temperatures was previously addressed in Section V.A.

3. According to **IWA-4500(e)(2)**, thermocouples and recording instruments shall be used to monitor process temperatures.

   The use of thermocouples and recording instruments is only required by ASME Sections III and XI when performing either postweld heat treatment operations or traditional temper bead welding operations with elevated preheat and postweld soak temperatures. The use of thermocouples and recording instruments is not required by ASME Section XI Code Case N-638 for monitoring welding process temperatures. Code Case N-638 is the basis for APS' proposed alternative.

Per paragraph 1(d) of Attachment 1 of this request, the minimum welding temperature is 50°F. The containment temperatures are not expected to be less than the required 50°F during the welding operations, which would be conducted in the spring or fall. However, to ensure compliance with the minimum requirement of the Welding Procedure Specification, APS will verify the temperature prior to welding.

4. According to **IWA-4532.2(c)**, the repair cavity shall be buttered with six layers of weld metal in which the heat input of each layer is controlled to within +/-10% of that used in the procedure qualification test, and heat input control for subsequent layers shall be deposited with a heat input equal to or less than that used for layers beyond the sixth in the procedure qualification. As an alternative to IWA-4532.2(c), APS proposes to weld with at least three layers of weld metal to obtain a minimum weld thickness of 1/8-inch. The heat input of each layer in the 1/8-inch thick weld section shall be controlled to within +/-10% of that used in the procedure qualification test. The heat input for subsequent weld layers shall not exceed the heat input used for layers beyond the 1/8-inch thick section (first three weld layers) in the procedure qualification. When using the ambient temperature temper bead technique of Attachment 1, the machine GTAW process is used. Machine GTAW is a low heat input process that produces consistent small volume heat affected zones. Subsequent GTAW weld layers introduce heat into the heat-affected zone produced by the initial weld layer. The heat penetration of subsequent weld layers is carefully applied to produce overlapping thermal profiles that develop a correct degree of tempering in the underlying heat affected zone. When welding dissimilar materials with nonferritic weld metal, the area requiring tempering is limited to the weld heat affected zone of the ferritic base material along the ferritic fusion line.

   After welding the ferritic base material to Alloy 690 with at least 1/8-inch of weld metal (first 3 weld layers), subsequent weld layers should not provide any additional tempering to the weld heat affected zone in the ferritic base material. Therefore, less restrictive heat input controls are adequate after depositing the 1/8-inch thick weld section.

5. According to **IWA-4532.2(c)**, at least one layer of weld reinforcement shall be deposited on the completed weld and this reinforcement is subsequently removed by mechanical means. In the proposed alternative of Attachment 1, the deposition and removal of a reinforcement layer is not required. A reinforcement layer is required when a weld repair is performed to a ferritic base material or ferritic weld using a ferritic weld metal. On ferritic materials, the weld reinforcement layer is deposited to temper the last layer of untempered weld metal of the completed repair weld. Because the weld reinforcement layer is untempered (and unnecessary), it is removed.

   However, when repairs are performed to dissimilar materials using nonferritic weld metal, a weld reinforcement layer is not required because nonferritic weld metal does not require tempering. When performing a dissimilar material weld with a nonferritic filler metal, the only location requiring tempering is the weld heat affected zone in the ferritic base material along the weld fusion line. The three weld layers of the 1/8-inch thick weld section are designed to provide the required tempering to the weld heat affected zone in the ferritic base material. Therefore, a weld reinforcement layer is not required.

   While APS recognizes that IWA-4532.2(c) does require the deposition and removal of a reinforcement layer on repair welds in dissimilar materials, APS does not believe that this reinforcement layer is necessary. This position is further supported by the fact that ASME Code Case N-638 only requires the deposition and removal of a reinforcement layer when performing repair welds on similar (ferritic) materials. Repair welds on dissimilar materials are exempt from this requirement in the Code Case.

6. According to **IWA-4532.2(d)**, the weld area shall be maintained at a minimum temperature of 300°F for a minimum of 4 hours (for P-No. 3 materials) after at least 3/16-inch of weld metal has been deposited. In the proposed alternative of Attachment 1, a postweld soak is not required. The suitability of an ambient temperature temper bead technique without a postweld soak was previously addressed in Section A.

7. According to **IWA-4532.2(e)**, after depositing at least 3/16-inch of weld metal and performing a postweld soak at a minimum temperature of 300°F, the balance of welding may be performed at an interpass temperature of 350°F. As an alternative, APS proposes that an interpass temperature of 350°F may be used after depositing at least 1/8 inch of weld metal without a postweld soak. The proposed ambient temperature temper bead process of Attachment 1 is carefully designed and controlled such that successive weld

beads supply the appropriate quantity of heat to the untempered heat affected zone such that the desired degree of carbide precipitation (tempering) is achieved. The resulting microstructure is very tough and ductile. This point is validated during weld procedure qualification. Based on the Charpy V-notch testing requirement of the procedure qualification test coupon, impact properties in weld heat affected zone will be demonstrated to be equal to or better than those of the unaffected base material. The suitability of an ambient temperature temper bead technique without a postweld soak was previously addressed in Section A.

8. **IWA-4533** specifies that the repair weld and preheated band shall be examined by liquid penetrant. Since there is no elevated preheated band, APS will be performing a penetrant examination of the final weld surface and the adjacent heat affected zone only. **IWA-4533** also states that the repair weld shall be volumetrically examined by the radiographic method, and if practical, by the ultrasonic method after the completed repair weld has been at ambient temperature for at least 48 hours. As an alternative to the radiographic examination of IWA-4533, APS proposes using the ultrasonic examination method.

   Radiographic examination is impractical since the pressurizer vessel ID surface is inaccessible for positioning the gamma source. Ultrasonic examination is another acceptable volumetric NDE method to assure weld quality and the 1996 Addenda of ASME Section XI (approved by the NRC) provides such an option. The ultrasonic examination will be performed in accordance with NB-5000 and acceptance criteria will be in accordance with NB-5330.

VI. Conclusion

10 CFR 50.55a(a)(3) states:

"Proposed alternatives to the requirements of paragraphs (c), (d), (e), (f), (g), and (h) of this section or portions thereof may be used when authorized by the Director of the Office of Nuclear Reactor Regulation. The applicant shall demonstrate that:

(i) The proposed alternatives would provide an acceptable level of quality and safety, or
(ii) Compliance with the specified requirements of this section would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety."

APS believes that compliance with the repair rules as stated in Reference 2 and as described in Section III of this request would result in unwarranted damage to the pressurizer head assembly. The proposed alternative discussed in Section IV would provide an acceptable level of quality and safety without exposing the pressurizer head to potential distortion of the sleeves and heater support structure. Additionally, the work required meeting the current Code repair method, automatic or machine GTAW temper bead with 300°F minimum preheat and 300°F post weld hydrogen bake-out, would be extremely difficult and the personnel radiation exposures resulting from the set-up, monitoring, and removal of the required equipment is unjustified. It is estimated that a savings of 95-105 Rem per unit could be realized if this alternative is implemented during the mid-wall repair weld. An additional 8.5 Rem per unit could be realized by implementing the mid-wall repair in lieu of the pad repair. Therefore, APS requests that the proposed alternative be authorized pursuant to 10 CFR 50.55a(a)(3)(i).

APS requests approval of this relief through the end of the 2nd inservice inspection interval for PVNGS Units 1 and 3.

VII. References

1. APS Letter 102-04941-CDM/SAB/RJR, "10 CFR 50.55a Alternative Repair Request for the Second 10-Year Interval of the Inservice Inspection Program: Relief Request 23, Pressurizer Heater Sleeves," dated May 15, 2003.

2. NRC letter to APS, "Palo Verde Nuclear Generating Station, Units 1 2, an d3 – Relief Request No. 23 RE: Alternative to Temper Bead Welding Requirements for Inservice Inspection Program (TAC No.s MB8973, MB8974, and MB8975)," dated July 30, 2003.

3. ASME Section XI, 1992 Edition, 1992 Addenda

4. ASME Section III, Subsection NB, 1971 Edition, Winter 1973 Addenda

5. ASME Section III, Subsection NB, 1974 Edition, Winter 1975 Addenda

6. ASME Section XI Code Case N-638, "Similar and Dissimilar Metal Welding Using Ambient Temperature Machine GTAW Temper Bead Technique"

7. EPRI Report GC-111050, "Ambient Temperature Preheat for Machine GTAW Temper Bead Applications"

Attachment 1 to Relief Request 28

Dissimilar Metal Welding Using Ambient Temperature Machine GTAW Temper Bead Technique

1.0 General Requirements

(a) The maximum area of an individual weld based on the finished surface shall be less than 100 square inches, and the depth of the weld shall not be greater than one-half of the ferritic base metal thickness.

(b) Repair/replacement activities on a dissimilar-metal weld are limited to those along the fusion line of a nonferritic weld to ferritic base material on which 1/8-inch or less of nonferritic weld deposit exists above the original fusion line. Repair/replacement activities on nonferritic base materials where the repair cavity is within 1/8-inch of a ferritic base material may also be performed.

(c) If a defect penetrates into the ferritic base material, repair of the base material, using a nonferritic weld filler material, may be performed provided the depth of repair in the base material does not exceed 3/8-inch.

(d) Prior to welding, the temperature of the area to be welded and a band around the area of at least 1½ times the component thickness (or 5 inches, whichever is less) shall be at least 50°F.

(e) Welding materials shall meet the Owner's Requirements and the Construction Code and Cases specified in the repair/replacement plan. Welding materials shall be controlled so that they are identified as acceptable until consumed.

(f) The area prepared for welding shall be suitably prepared for welding in accordance with a written procedure.

2.0 Welding Qualifications

The welding procedures and the welding operators shall be qualified in accordance with ASME Section IX and the requirements of paragraphs 2.1 and 2.2.

2.1 Procedure Qualification:

(a) The base materials for the welding procedure qualification shall be the same P-Number and Group Number as the materials to be welded. The materials shall be post weld heat treated to at least the time and temperature that was applied to the material being welded.

(b) Consideration shall be given to the effects of irradiation on the properties of material, including weld material for applications in the core belt line region of the reactor vessel. Special material requirements in the Design Specification shall also apply to the test assembly materials for these applications.

(c) The root width and included angle of the cavity in the test assembly shall be no greater than the minimum specified for the repair.

(d) The maximum interpass temperature for the first three layers or as required to achieve the 1/8-inch butter thickness in the test assembly shall be 150°F. For the balance of the welding, the maximum interpass temperature shall be 350°F.

(e) The test assembly cavity depth shall be at least one-half the depth of the weld to be installed during the repair/replacement activity, and at least 1-inch. The test assembly thickness shall be at least twice the test assembly cavity depth. The test assembly shall be large enough to permit removal of the required test specimens. The test assembly dimensions surrounding the cavity shall be at least the test assembly thickness, and at least 6 inches. The qualification test plate shall be prepared in accordance with Figure 1.

(f) Ferritic base material for the procedure qualification test shall meet the impact test requirements of the Construction Code and Owner's Requirements. If such requirements are not in the Construction Code and Owner's Requirements, the impact properties shall be determined by Charpy V-notch impact tests of the procedure qualification base material at or below the lowest service temperature of the item to be repaired. The location and orientation of the test specimens shall be similar to those required in subparagraph (h) below, but shall be in the base metal.

(g) Charpy V-notch tests of the ferritic weld metal of the procedure qualification shall meet the requirements as determined in subparagraph (f) above.

(h) Charpy V-notch tests of the ferritic heat-affected zone (HAZ) shall be performed at the same temperature as the base metal test of subparagraph (f) above. Number, location, and orientation of test specimens shall be as follows:

1. The specimens shall be removed from a location as near as practical to a depth of one-half the thickness of the deposited weld metal. The test coupons for HAZ impact specimens shall be taken transverse to the axis of the weld and etched to define the HAZ. The notch of the Charpy V-notch specimens shall be cut approximately normal to the material surface in such a

manner as to include as much HAZ as possible in the resulting fracture. When the material thickness permits, the axis of a specimen shall be inclined to allow the root of the notch to be aligned parallel to the fusion line.

2. If the test material is in the form of a plate or a forging, the axis of the weld shall be oriented parallel to the principal direction of rolling or forging.

3. The Charpy V-notch test shall be performed in accordance with SA-370. Specimens shall be in accordance with SA-370, Figure 11, Type A. The test shall consist of a set of three full-size 10-mm x 10-mm specimens. The lateral expansion, percent shear, absorbed energy, test temperature, orientation and location of all test specimens shall be reported in the Procedure Qualification Record.

(i) The average values of the three HAZ impact tests shall be equal to or greater than the average values of the three unaffected base metal tests.

2.2 Performance Qualification:

Welding operators shall be qualified in accordance with ASME Section IX.

3.0 Welding Procedure Requirements

The welding procedure shall include the following requirements:

(a) The weld metal shall be deposited by the automatic or machine GTAW process using cold wire feed.

(b) Dissimilar metal welds shall be made using F-No. 43-weld metal (QW-432) for P-No. 43 to P-No. 3 weld joints.

(c) The area to be welded shall be buttered with a deposit of at least three layers to achieve at least 1/8-inch butter thickness as shown in Figure 2, steps 1 through 3, with the heat input for each layer controlled to within ± 10% of that used in the procedure qualification test. Particular care shall be taken in placement of the weld layers at the weld toe area of the ferritic base material to ensure that the HAZ is tempered. Subsequent layers shall be deposited with a heat input not exceeding that used for layers beyond the third layer (or as required to achieve the 1/8-inch butter thickness) in the procedure qualification.

(d) The maximum interpass temperature field applications shall be 350°F regardless of the interpass temperature during qualification.

(e) Particular care shall be given to ensure that the weld region is free of all potential sources of hydrogen. The surfaces to be welded, filler metal, and shielding gas shall be suitably controlled.

4.0 Examination:

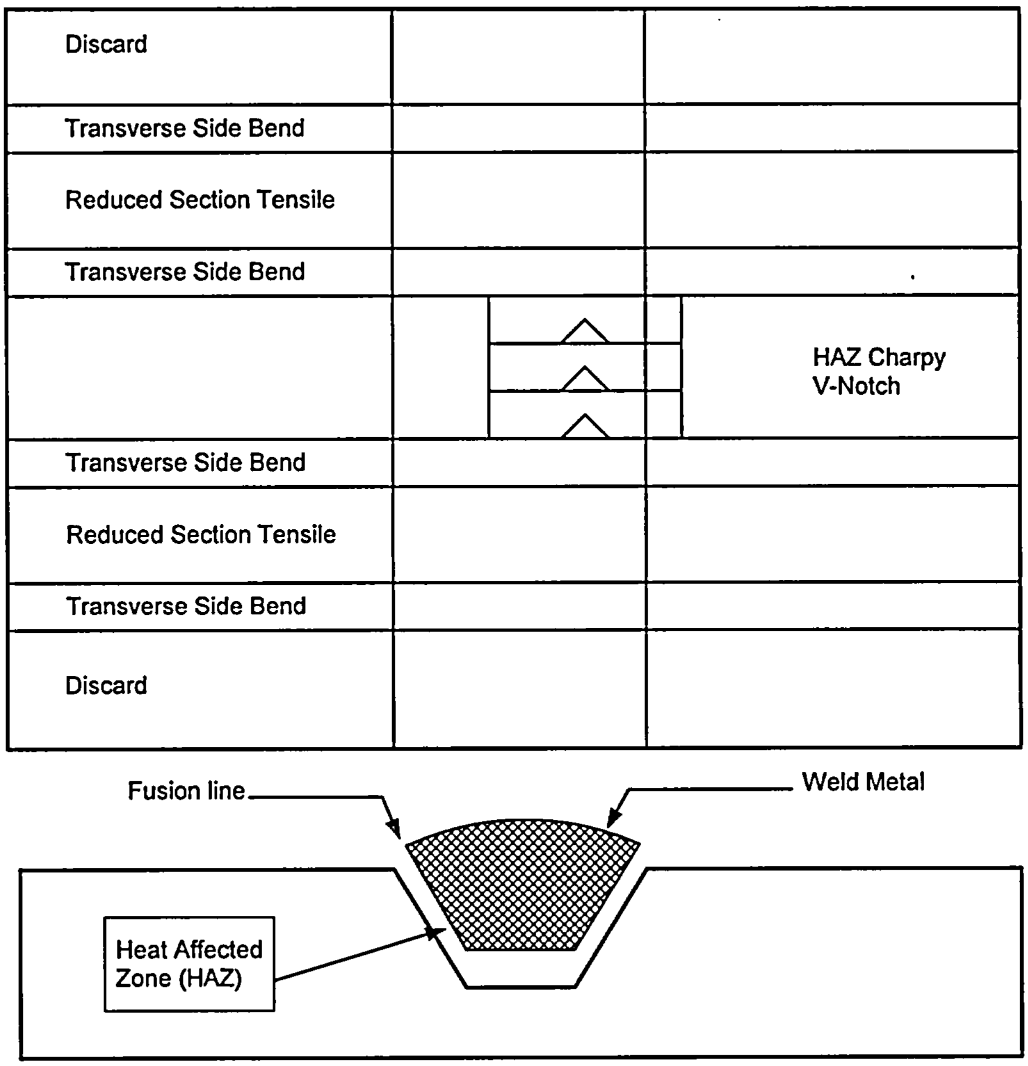
(a) Prior to welding, a surface examination shall be performed on the area to be welded.

(b) Alloy 690 half sleeve to pressurizer mid-wall weld shall be examined by liquid penetrant and ultrasonic methods in accordance with NB-5000.

(c) NDE personnel performing liquid penetrant and ultrasonic examination shall be qualified and certified in accordance with NB-5500.

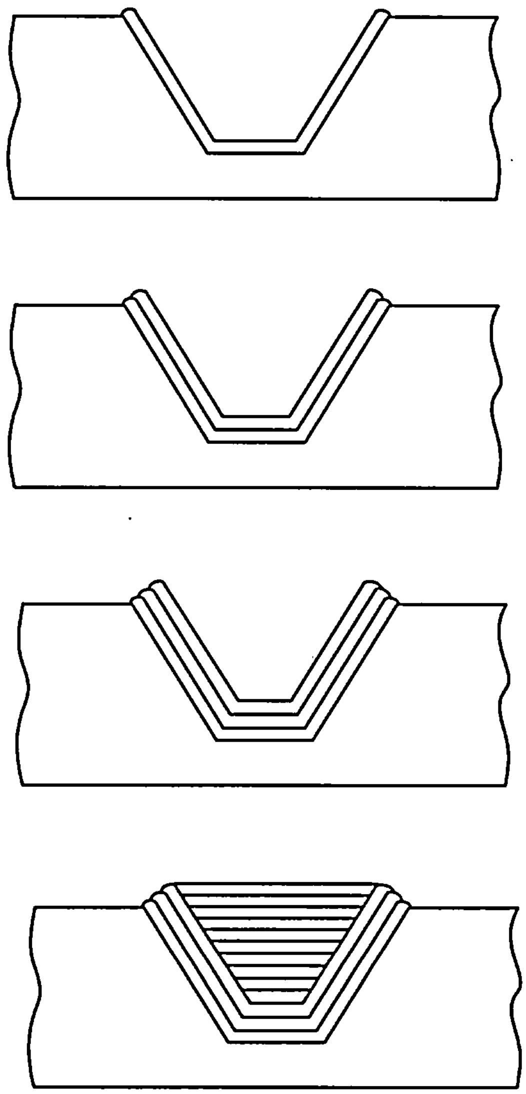
5.0 Documentation

Use of this request shall be documented on NIS-2.



GENERAL NOTE: Base Metal Charpy impact specimens are not shown.

Figure 1 - QUALIFICATION TEST PLATE



Step 1: Deposit layer one with first layer weld parameters used in qualification.

Step 2: Deposit layer two with second layer weld parameters used in qualification. NOTE: Particular care shall be taken in application of the second layer at the weld toe to ensure that the weld metal and HAZ of the base metal are tempered.

Step 3: Deposit layer three with third layer weld parameters used in qualification. NOTE: Particular care shall be taken in application of the third layer at the weld toe to ensure that the weld metal and HAZ of the base metal are tempered.

Step 4: Subsequent layers to be deposited as qualified, with heat input less than or equal to that qualified in the test assembly. NOTE: Particular care shall be taken in application of the fill layers to preserve the temper of the weld metal and HAZ.

GENERAL NOTE: For dissimilar-metal welding, only the ferritic base metal is required to be welded using Steps 1 through 3 of the temper bead welding technique.

Figure 2 - AUTOMATIC OR MACHINE GTAW TEMPER BEAD WELDING

Enclosure 2

Relief Request 29, "Remnant Sleeve(s) Flaw Evaluation"

Background Information

The remaining original Palo Verde Nuclear Generating Station (PVNGS) Units 1 and 3 pressurizer heater sleeves are made from Inconel 600 material and are susceptible to primary water stress corrosion cracking (PWSCC). The pressurizer head is manufactured from P-Number 3, Group 3 low alloy steel. Each pressurizer has 36 heater sleeves (nominal dimensions: 1.66" outside diameter (OD) and .192" wall thickness) which are attached to the lower pressurizer head by partial penetration welds made at the pressurizer inside diameter (ID) surface.

Replacement of these sleeves by excavating the original weld and then re-welding new Alloy 690 is not practical due to 1) inaccessibility of the pressurizer vessel internal surface and 2) high radiation field associated with the pressurizer. Therefore, new sleeves are attached to the exterior surface of the pressurizer. This replacement method is known as half-nozzle replacement, or in this application half-sleeve replacement. The half-sleeve, mid-wall weld repair being proposed for the remaining heater sleeves in Units 1 and 3 relocates the reactor coolant pressure boundary from a partial penetration weld on the inside surface of the pressurizer to a partial penetration weld at the mid-wall of the pressurizer. The remaining sleeve (above the new sleeve) and the weld may contain cracks or may crack in the future due to PWSCC.

Leaving a remnant sleeve with a flaw attached to the inside wall of the pressurizer without performing successive examinations of the flaw requires relief from the flaw characterization methods and successive examination requirements described in the American Society of Mechanical Engineers (ASME) Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components."

I. ASME Code Component(s) Affected

Component number:	B4.20
Description:	Pressurizer Heater Sleeve, 36 per Unit.
Code Class:	1

II. Applicable Code Addition and Addenda

Second 10-year inservice inspection interval code for Palo Verde Nuclear Generating Station (PVNGS) Units 1, 2, and 3: The American Society of Mechanical Engineers (ASME) Code, Section XI, 1992 Edition, 1992 Addenda.

Construction code for PVNGS Units 1, 2, and 3: ASME Section III, 1971 Edition, and 1973 Winter Addenda.

Installation code for PVNGS Units 1, 2, and 3: ASME Section III, 1974 Edition, and 1975 Winter Addenda.

III. Applicable Code Requirements of Half Sleeve Replacement

Sub-article **IWA-4310** of ASME Section XI, 1992 Edition, 1992 Addenda states in part that the "defects shall be removed or reduced in size in accordance with this Paragraph." Furthermore, IWA-4310 allows, "...the defect removal and any remaining portion of the flaw may be evaluated and the component may be accepted in accordance with the appropriate flaw evaluation rules of Section XI or the design rules of either the Construction Code, or Section III, when the Construction Code was not Section III."

The evaluation of the remaining portion of the flaw further requires successive examination as stated in **IWB-2420**, "Successive Inspections".

IWA-3300 states that flaws detected by inservice examinations shall be sized by the bounding rectangle or square for the purpose of description and dimensioning.

IWB-3610 specifies acceptance criteria for flaw evaluation based on Linear Elastic Fracture Mechanics (LEFM).

IV. Proposed Alternative

Pursuant to 10 CFR 50.55a(a)(3)(i), APS is proposing alternatives to the required flaw characterization (IWA-3300) and successive inspections (IWB-2420). APS will not be removing the remnant sleeve or its attachment weld and has assumed that cracks in alloy 600 sleeves or attachment welds will not be removed. In lieu of fully characterizing/sizing the existing cracks, APS proposes to assume worst case cracks in alloy 600 base and weld material. APS has evaluated this assumption using appropriate flaw evaluation rules of Section XI.

As part of this evaluation, APS is also requesting relief from IWB-3610 and proposes an alternative evaluation procedure based on Elastic Plastic Fracture Mechanics (EPFM) for portions of the evaluation. EPFM will be used for loading conditions that are at plant operating temperature and therefore in the Charpy V-Notch upper shelf regime for the low alloy steel pressurizer material. APS has provided this evaluation in Attachment 1 to this enclosure.

Since APS proposes to assume worst case cracks in the alloy 600 base and weld material and the results demonstrate compliance with ASME Section XI criteria for the 40 year plant life and a 20 year life extension, APS is also requesting relief from the successive inspections required by IWB-2420 and proposes no successive inspections.

APS has determined that the proposed alternatives will provide an acceptable level of quality and safety.

V. Basis of Alternative for Providing Acceptable Level of Quality and Safety

When using a half-sleeve replacement as proposed in Relief Request 28 APS has assumed a flaw in the Alloy 600 remnant sleeve or weld material exists. As a result, a flaw evaluation using the worst case flaw has been completed that demonstrates that the flaw will remain within acceptable Section XI limits for the 40-year plant life and a 20-year life extension (see Attachment 1). For materials such as the Palo Verde pressurizer shell material operating at temperatures above approximately 150°F, the material is on the upper shelf of the Charpy V-Notch impact energy curve and therefore possesses significant ductility. Application of LEFM techniques, such as Section XI Appendix A to materials in this regime is overly conservative. ASME Section XI contains several alternative procedures for flaw evaluation of ductile materials, such as

- Appendix C for Flaws in Austenitic Piping
- Appendix H for Flaws in Ferritic Piping
- Appendix K for Assessment of RPVs with Low Upper Shelf Toughness

These procedures utilize EPFM techniques, and provide for different safety factors for primary (load controlled) versus secondary (strain controlled) loading conditions. They also permit EPFM-based crack stability analysis to allow for the higher ductility of these materials.

An EPFM technique has been used in lieu of the Section XI, Appendix A, LEFM technique to evaluate assumed cracks in the existing Alloy 600 heater sleeves and weldments that potentially propagate into the low alloy pressurizer base material when it is at upper shelf temperatures. EPFM material properties applicable to the Palo Verde pressurizer and appropriate safety factors have been applied. Use of the EPFM technique demonstrates that the assumed flaw will not exceed applicable Section XI criteria for the 40-year plant life and a 20-year life extension.

In addition, general corrosion (wastage) of carbon or low alloy steel may occur since this material is exposed to borated primary water. A corrosion analysis demonstrates that any wastage will remain within acceptable Section XI limits (Reference 1).

VI. Conclusion

10 CFR 50.55a(a)(3) states:

"Proposed alternatives to the requirements of paragraphs (c), (d), (e), (f), (g), and (h) of this section or portions thereof may be used when authorized by the Director of the Office of Nuclear Reactor Regulation. The applicant shall demonstrate that:

(i) The proposed alternatives would provide an acceptable level of quality and safety, or
(ii) Compliance with the specified requirements of this section would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety."

APS believes that the proposed alternative discussed in Section IV would provide an acceptable level of quality and safety. APS has estimated that a savings of 1.5-2.0 Rem per sleeve inspection could be realized if successive inspections of the remnant sleeve and attachment weld are eliminated. Since the completed flaw evaluation (utilizing EPFM) and corrosion analysis demonstrate compliance with Section XI criteria for the life of the plant, including a 20 year life extension, APS requests that the proposed alternative be authorized pursuant to 10 CFR 50.55a(a)(3)(i).

APS requests approval of this relief through the end of the 2nd inservice inspection interval for each unit.

VII. References

1. WCAP-15973-P Rev. 1, "Low Alloy Steel Component Corrosion Analysis Supporting Small Diameter Alloy 600/690 Nozzle Repair/Replacement Programs".

Attachment 1 to Relief Request 29

"Report SIR-04-045, Technical Report Supporting the Palo Verde Pressurizer Heater Sleeve Mid-Wall Repair"

Report No.: SIR-04-045
Revision No.: 0
June 2004

Technical Report Supporting the Palo Verde Pressurizer Heater Sleeve Mid-Wall Repair

Prepared for:

Arizona Public Service Company

Prepared by:

Structural Integrity Associates, Inc.

Table of Contents

Section	Page
1.0 Background	1
2.0 Introduction	3
2.1 Objective	3
2.2 Licensing Change Summary	3
2.3 Repair Concept	3
3.0 ASME Code EvaluationS	5
3.1 ASME Code, Section III Stress/Fatigue Evaluations	5
3.1.1Load Definition	5
3.1.2 Stress Analyses	5
3.1.3 Load Combinations and Design Limitations	6
3.1.4 Fatigue Evaluations	7
3.2 ASME Code, Section XI Linear Elastic Fracture Mechanics Evaluations	8
3.2.1 Stress Analyses	8
3.2.2 Stress Intensity Factor Calculation Methodology	8
3.2.3 Calculated and Allowable Stress Intensity Factors	9
3.3 Elastic-Plastic Fracture Mechanics and Fatigue Crack Growth Evaluations	10
3.3.1 Material J-Resistance Curve	11
3.3.2 Calculation of Applied J-T	12
3.3.3 Fatigue Crack Growth Evaluations	13
3.4 Corrosion Evaluation of Pressurizer Base Material	14
4.0 Conclusions	33
5.0 References	33

List of Tables

Table		Page
Table 3-1	Load Combinations	16
Table 3-2	Stress Criteria for ASME Code, Class 1 Components	16
Table 3-3	Transients	17
Table 3-4	Linearized Stress Intensity Results for Controlling Sleeve	17
Table 3-5	Primary Stress Intensity Evaluation	18
Table 3-6	Service Level A/B Load Combination Primary-Plus-Secondary Stress Intensity Evaluation	18
Table 3-7	Total Fatigue Usage for Option 1	19
Table 3-8	Total Fatigue Usage for Option 2	19
Table 3-9	Stress Intensity Factor Results	20
Table 3-10	J-T Instability Computations for Palo Verde Pressurizer Remnant Crack using ASME Code, Section XI, Appendix K Approximate Method, Initial Flaw Size of 0.6"	20
Table 3-11	J-T Instability Computations for Palo Verde Pressurizer Remnant Crack using ASME Code, Section XI, Appendix K Approximate Method, Extended Flaw Size of 1.2"	21
Table 3-12	Crack Growth Evaluation Cyclic Loads	21
Table 3-13	Stress Intensity Factor vs. Crack Size	22

List of Figures

Figure	Page
Figure 1-1. Sketch of Palo Verde Pressurizer	2
Figure 2-1. Conceptual Drawing of Pressurizer Heater Sleeve Mid-Wall Repair	4
Figure 3-1. Finite Element Model	23
Figure 3-2. Row and Sleeve Numbering	24
Figure 3-3. Linearized Stress Paths for Sleeve Repairs	25
Figure 3-4. Crack Tip Element Location Definition	26
Figure 3-5. Schematic of EPFM Stability Analysis from ASME Code, Section XI, Appendix K	27
Figure 3-6. J-T Diagram for Several Reactor Vessel Steels and Welds Showing Rough Correlation with Charpy V-notch Upper Shelf Energy	28
Figure 3-7. Correlation of Coefficient C of Power Law J-R Curve Representation with Charpy V-notch Upper Shelf Energy	29
Figure 3-8. Correlation of Exponent m of Power Law J-R Curve Representation with Coefficient C and Flow Stress σ_o	30
Figure 3-9. J-T Diagram for EPFM Stability Analysis for Palo Verde Pressurizer Remnant Cracking Concern at a Flaw Size of 0.6"	31
Figure 3-10. J-T Diagram for EPFM Stability Analysis for Palo Verde Pressurizer Remnant Cracking Concern at a Flaw Size of 1.2"	32
Figure 3-11. Fatigue Crack Growth Results	32

EXECUTIVE SUMMARY

The pressurizer heater sleeves in the Combustion Engineering (CE) designed pressurized water reactors are made of Alloy 600 material which is welded to Alloy 82/182 weld metal, which is in turn welded to the low alloy steel pressurizer base material. These materials have been found to be susceptible to primary water stress corrosion cracking (PWSCC). Owners have taken one of two approaches in dealing with the adverse consequences of PWSCC in these materials, other than a complete pressurizer replacement. The first is to repair as problems arise, and the second is to take preemptive action. Arizona Public Service (APS) has chosen the latter approach.

An extensive pressurizer heater sleeve management study has been completed by APS. The study concluded that the appropriate technical and economical long term solution for Palo Verde is a repair method versus pressurizer replacement, particularly considering thirty-six (36) heater sleeves per unit. Palo Verde is, therefore, executing a pressurizer heater sleeve replacement program. The heater sleeves in Unit 2 were recently replaced (Fall 2003) during a steam generator replacement outage. A half-sleeve pad repair was implemented in Unit 2. A mechanical nozzle seal assembly has been utilized as an interim repair in the past until a permanent repair is prepared, planned and available for implementation on a wholesale and efficient basis.

This report describes a mid-wall repair technique that is a permanent solution to PWSCC in pressurizer heater sleeves. Stress analyses have been completed for the mid-wall repair and are summarized in this report. The analyses demonstrate that the repair satisfies all applicable construction code and licensing requirements. Fracture mechanics analyses have also been completed for leaving a flaw within the pressurizer vessel, and these analyses are also summarized in this report. A postulated flaw resides in a section of the original Alloy 600 heater sleeve and weld metal. The fracture mechanics analyses demonstrate that an assumed flaw left in place is acceptable for the life of the Palo Verde units, including a 20 year life extension. Similarly, a corrosion analysis has been performed for the crevice region between the sleeve and pressurizer base material. The analysis concludes that anticipated corrosion in the crevice region will be within code allowables, and is acceptable for the life of the plant, including a 20 year life extension.

Background

The pressurizer is a vessel that is used to maintain and regulate system pressure in pressurized water reactors (PWRs). It contains water in the bottom and steam in the top of the vessel, and the fluid inside is heated to approximately 650°F, corresponding to a saturation pressure of approximately 2250 psia. To maintain the 650°F temperature, which is higher than the reactor vessel outlet (hot leg) temperature, there are thirty-six (36) pressurizer heaters in sleeves that penetrate the bottom head of the pressurizer. Figure 1-1 shows the Palo Verde pressurizer.

The heaters in CE designed plants are contained within sleeves made of Alloy 600 material and welded to Alloy 82/182 weld metal, which in turn was welded to the low alloy steel pressurizer base material. However, Alloy 600 material and associated weld metals (Alloy 82/182) have been found to be susceptible to PWSCC. These susceptible materials are present in all PWRs to some extent, and PWSCC has been observed previously in a number of locations, including reactor vessel top head control element drive mechanism nozzles and hot leg nozzles.

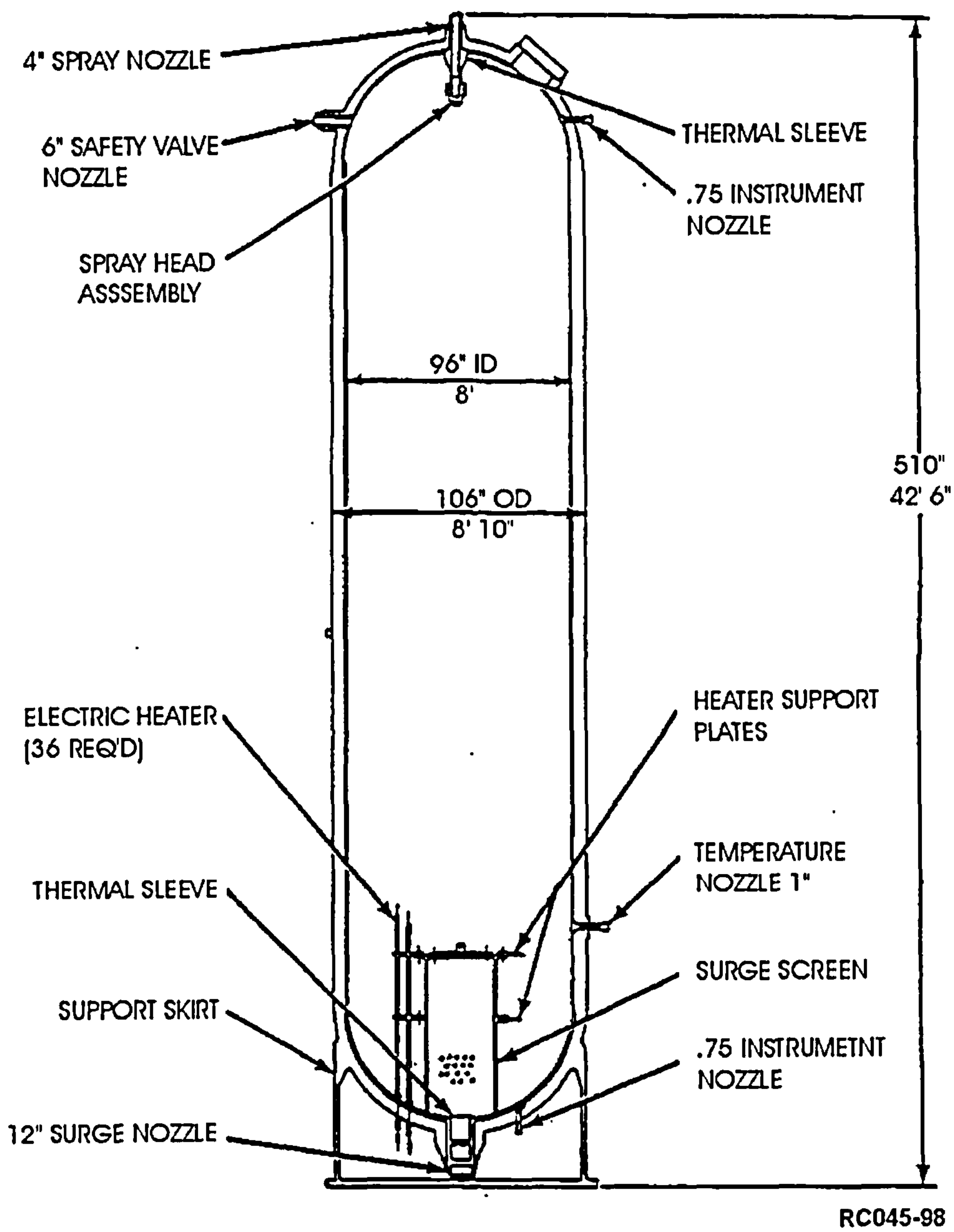


Figure 1-1. Sketch of Palo Verde Pressurizer

Introduction

D. Objective

The proposed mid-wall repair described in this document is a repair that can be implemented on a preemptive or emergent basis. The objective of this repair is to provide a permanent solution to PWSCC in pressurizer heater sleeves, incurring less radiation exposure and less expense than other repair methods. This report describes licensing issues and ASME Code evaluations associated with the mid-wall repair.

E. Licensing Change Summary

The mid-wall repair described in this report relocates the reactor coolant pressure boundary from a partial penetration weld on the inside surface of the pressurizer to a partial penetration weld at the mid-wall of the pressurizer. Figure 2-1 presents the concept. The repair design has been reviewed to ensure that it satisfies the design requirements of the ASME Code, Section III, for Class 1 components. Code Case N-638 was used as a guide in preparation of this document. Therefore, elevated temperature pre-heat, elevated temperature post-soak, and postweld heat treatment (PWHT) are not required.

The half sleeve mid-wall repair also leaves a postulated flaw within the pressurizer vessel. The flaw resides in a section of the original Alloy 600 heater sleeve and weld metal. This report contains fracture mechanics analyses that demonstrate that an assumed flaw left in place is acceptable for the life of the Palo Verde units, including a 20 year life extension. Similarly, a corrosion analysis has been performed for the crevice region between the sleeve and pressurizer base material. The analysis concludes that anticipated corrosion in the crevice region will be within code allowables, and is acceptable for the life of the plant, including a 20 year life extension. Since the fracture mechanics analyses utilize elastic-plastic fracture mechanics techniques, relief from some requirements of ASME Code, Section XI is required.

F. Repair Concept

The proposed mid-wall repair removes the lower section of the existing Alloy 600 heater sleeve. The new replacement heater sleeve is welded at about the mid-wall location to the inside of the vessel bore using the machine GTAW process and ambient temperature temperbead methodology. The reactor coolant system (RCS) pressure boundary is moved from the existing J-groove weld inside the vessel to the new mid-wall weld. A portion of the existing Alloy 600 sleeve (including the J-groove weld) is left in place. Figure 2-1 presents the concept.

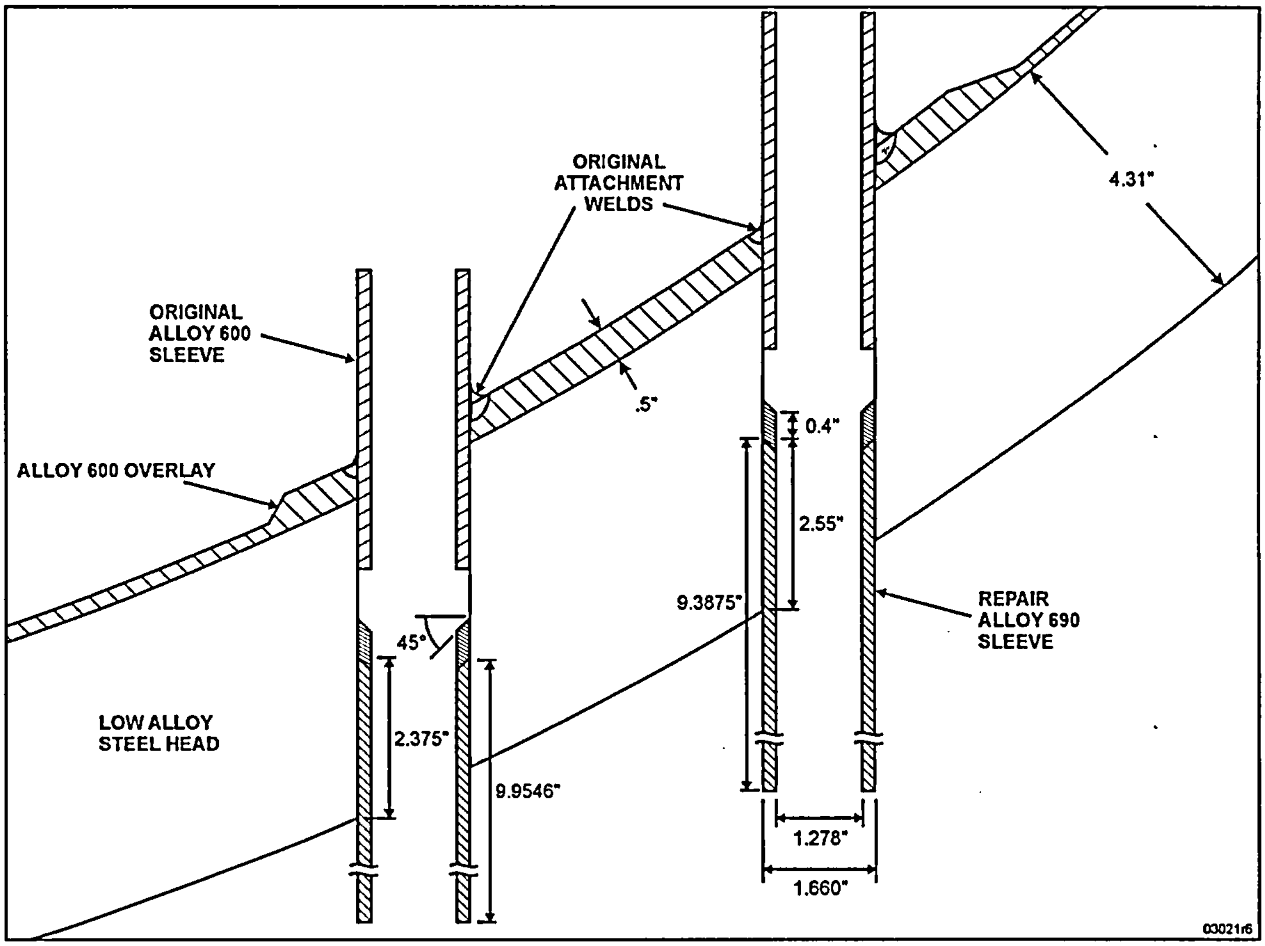


Figure 2-1. Conceptual Drawing of Pressurizer Heater Sleeve Mid-Wall Repair

ASME Code Evaluations

G. ASME Code, Section III Stress/Fatigue Evaluations

The requirements of Section III of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code must be met for the repair. Subarticle NB-3200 of Section III has limits on primary stress, primary-plus-secondary stress, and cumulative fatigue usage. Three-dimensional finite element analyses of the pressurizer bottom head region have been performed for application at Palo Verde. This section contains details of the analyses.

Load Definition

The analyses address original design basis conditions, as defined in the original Design Specifications. The Design Pressure for the pressurizer is 2500 psia, with a corresponding Design Temperature equal to 700°F. The normal operating pressure is 2250 psia, with a corresponding temperature of 653°F.

The following events were used in the analysis:

- Plant Leak Test at 2250 psia and 400°F
- Heatup and Cooldown at 200°F per hour
- Reactor Trip

The Reactor Trip transient also bounds the Loss of Reactor Coolant Flow and Loss of Load transients.

Table 3-1 defines the combinations of the basic loads that were examined, and Table 3-2 presents the allowable stress intensities for these load combinations. Table 3-3 summarizes the number of cycles associated with all transients considered in the design of the repair.

Stress Analyses

All stresses for this evaluation (aside from general closed-form solutions) were determined using a detailed three-dimensional finite element model, which was developed using the ANSYS computer program [1]. The model consists of the pressurizer lower head, a portion of the pressurizer cylinder, the support skirt, the surge nozzle and thermal sleeve, the instrument nozzle, the remaining portion of the original heater sleeves and the attachment J-groove/cover fillet welds, the new heater sleeves, and the new heater sleeve welds.

The dimensions of the repair were obtained from the sketch presented in Figure 2-1. Because of symmetry, a 90° model was used, with appropriate boundary conditions at the planes of symmetry. The model is shown in Figure 3-1. All components were modeled with three-dimensional isoparametric solid elements, which allows for refinement of the critical regions of the model.

A unit internal pressure load of 1,000 psi was evaluated. Stress results were then scaled to appropriate values by the ratio of the unit pressure load evaluated and the actual load occurring. Thermal transient analyses were performed for the Heatup, Cooldown, and Reactor Trip, as described below. For these analyses, thermal boundary conditions were taken from the original pressurizer Stress Reports.

The Heatup transient begins at an initial uniform temperature of 70°F, followed by a ramp to 653°F at 200°F/hour. The maximum peak stress intensity occurred at 10,494 seconds into the transient.

The Cooldown transient starts at a steady state temperature of 653°F, then the internal fluid temperature drops to 70°F at a rate of 200°F/hour. The maximum peak stress intensity occurred at 4,408 seconds into the transient.

The Reactor Trip transient was modeled as two separate downward ramps followed by one upward ramp. The first downward ramp was from 653°F to 613°F over a total of 50 seconds. The second downward ramp was from 613°F to 593°F over a total of 550 seconds, followed by 400 seconds of an upward ramp to a temperature of 610°F. As maximum stresses were expected to occur near the steep portion of the transient, a total transient time of 1,000 seconds was used in the analysis. The maximum peak stress intensity occurred at 600 seconds into the transient.

The maximum membrane and membrane-plus-bending stress intensity results and their time of occurrence during the transients are shown in Table 3-4 for the controlling heater sleeve (see Figures 3-2 and 3-3 for sleeve and stress locations, respectively).

Load Combinations and Design Limitations

Subsubarticle NB-3220 of the ASME Code defines the stress limits that must be met for Class 1 components for all specified load combinations, as summarized in Table 3-2. To satisfy these limits, the maximum stress intensities for pressure and thermal effects at the various stress paths shown in Figure 3-3 were conservatively combined to determine the total stress intensities. The paths shown in Figure 3-3 represent a number of locations around the sleeves from 0° to 180° (for sleeves at the symmetric plane) or 0° to 360°.

For the Design, Service Level C/D, and Test Load Combinations, only primary stresses need to be evaluated. Hence, only pressure needs to be considered, as there are no other mechanical loads acting on the repair. The only material of consideration in the load combination is the Alloy 690 repair weld and sleeve. The allowable stress intensity (S_m) at 700°F for this material is 23.3 ksi. Note that since the original Code of Construction (the 1971 Edition of the ASME Code, through Winter 1973 Addenda [2]) does not have data on Alloy 690 material, the material data was provided by the 1989 Edition of the ASME Code [3].

Table 3-5 presents a summary of the stress intensities, and a comparison of the resulting stress intensities with the allowable values for the controlling sleeve. As can be seen from this table, all calculated stress intensities are less than their corresponding allowable values.

For the Service Level A/B Load Combination, only primary-plus-secondary stress intensities need to be evaluated. Table 3-6 summarizes the evaluation for the controlling sleeve. A very conservative load combination was used; the stress intensities of the operating pressure, cooldown thermal transient, and reactor trip thermal transient were summed to determine the range of stress intensity. As can be seen from Table 3-6, all locations have calculated stress intensities that are less than the allowable value for this load combination.

Fatigue Evaluations

Subsubparagraph NB-3222.4(e) of the ASME Code, as supplemented by Subparagraph NB-3228.5, requires the determination of the ability of components to withstand cyclic service. A fatigue evaluation was performed to assure that the repair satisfied the requirements of the ASME Code with respect to cyclic loads during service. The fatigue evaluation was performed for the path locations shown in Figure 3-3.

Table 3-3 presents the total number of cycles for the design life, including a 20 year life extension. To provide maximum confidence in the fatigue calculation, two methods of cyclic combination were investigated. The cyclic combinations for Option 1 and Option 2 are as follows:

Option 1:

- Cooldown+Trip+P_{Trip} (for a total of 720 cycles)
- Cooldown+Heatup+$P_{Operate}$ (for a total of 30 cycles)
- P_{leak} (for a total of 300 cycles)

Option 2

- Trip+$P_{Delta\ Trip}$ (for a total of 720 cycles)
- Heatup+Cooldown+$P_{Operate}$ (for a total of 750 cycles)
- P_{leak} (for a total of 300 cycles)

The total fatigue usage was obtained by summing the contributions from each of the three load combinations described above for the two options. Table 3-7 tabulates the fatigue usage for Option 1, while Table 3-8 tabulates the fatigue usage for Option 2. As can be seen in these tables, the cumulative fatigue usage factor is less than unity for all locations.

Based on the analysis results above, the requirements of Section III of the ASME Code have been satisfied.

H. ASME Code, Section XI Linear Elastic Fracture Mechanics Evaluations

Section XI of the ASME Code requires that any flaws that are not removed be analyzed for acceptability on fracture toughness and potential crack growth. Section XI provides acceptance criteria, and any flaw must be shown not to grow beyond an allowable flaw size within the remaining life of the plant. For purposes of this analysis, flaws were conservatively postulated on both the uphill and downhill sides in the remnant portion of the original sleeve, the original attachment welds, and the overlay material (see Figure 2-1).

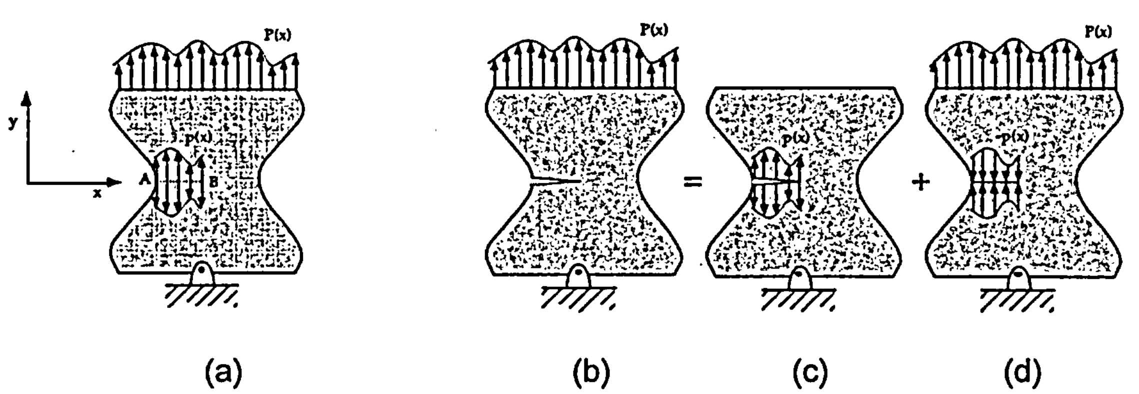
Stress Analyses

As with the Section III analyses described in Section 3.1, three-dimensional finite element techniques were used in the fracture mechanics analyses, with crack face pressures input from the Section III analyses. In addition to the Heatup, Cooldown, and Reactor Trip transients analyzed for the ASME Code, Section III analyses, the Loss of Secondary Pressure transient was analyzed as well for allowable flaw size. However, it was not used for the fatigue crack growth analysis since it is a Service Level C/D event.

Stress Intensity Factor Calculation Methodology

A finite element model, more detailed than that used in the stress analyses, was used to calculate stress intensity factors during the transients. The postulated cracks are located at both the uphill and downhill sides of the penetration, as shown in Figure 3-4. The model includes a crack in the entire cross-section of the J-groove weld, extending through the overlay material to the overlay/vessel interface, and a through-wall axial crack in the sleeve body. The postulated axial crack in the original sleeve body begins at the top of the sleeve and extends all the way to the bottom of the sleeve remnant.

Stresses from the stress analyses described above, in which the crack is not modeled, are input as pressures on the crack face, using a standard fracture mechanics superposition technique. This technique is based on the principle that in the linear elastic regime, stress intensity factors of the same mode, which are due to different loads, are additive, similarly to stress components in the same direction [4].



A load P(x) on an uncracked body (Sketch (a)) produces a normal stress distribution p(x) on Plane A-B. Sketches (b), (c) and (d) show the same body with a crack at Plane A-B, and the stress intensity factors resulting from these loading cases are such that:

$$K_{I(b)} = K_{I(c)} + K_{I(d)}$$

Thus, since $K_{I(d)} = 0$ because the crack is closed,

$$K_{I(b)} = K_{I(c)}$$

This means that the stress intensity factor obtained from subjecting the cracked body to a nominal load P(x) equals the stress intensity factor resulting from loading the crack faces with the resulting stress distribution p(x) at the crack location in the uncracked body.

Since each of the postulated cracks to be analyzed is an axial crack (with respect to the heater sleeve penetration axis), the hoop stresses on the elements representing the crack face are extracted from the stress results and applied in the form of pressure loading.

Calculated and Allowable Stress Intensity Factors

The allowable stress intensity factor was determined for the postulated initial flaw described above. Since the fracture toughness criteria are temperature dependent, evaluations were made for both hot and cold conditions.

The flaw evaluation criteria of Section XI of the ASME Code [5] define the allowable stress intensity factor under normal operating and upset conditions as the material toughness divided by the safety factor of $\sqrt{10}$. Similarly, the safety factor of $\sqrt{2}$ is prescribed for emergency and faulted plant conditions. The pressurizer bottom head is fabricated from low alloy steel SA-533, Grade B, Class 1 material. Therefore, the lower bound fracture toughness curves provided in Appendix A of Section XI can be used to obtain the critical fracture toughness.

The computed maximum stress intensity factor at the overlay-low alloy steel interface under normal/upset conditions was determined, and the transient event during which it occurs was identified, as well as the corresponding temperature. Using that temperature, the critical fracture toughness was calculated and compared to the maximum stress intensity factor. The same procedure was used for the Loss of Secondary Pressure transient, which is the only emergency/faulted condition considered. Table 3-9 shows the maximum stress intensity factors and allowable values for the heater sleeve penetrations.

An ASME Code, Section XI interpretation has been issued regarding the safety factor to be considered at the end of the cooldown transient. If the applied pressure is less than 20% of the Design Pressure (2,500 psia) and the temperature is greater than RT_{NDT} +60°F, then a factor-of-safety of $\sqrt{2}$ may be used instead of $\sqrt{10}$. This results in an allowable stress intensity factor of 47 ksi$\sqrt{in}$ [5] at 70°F at the end of the cooldown transient for an RT_{NDT} of (-)10°F for the Palo Verde low alloy steel base material.

As Table 3-9 shows, all ASME Code allowable stress intensity factor criteria have been satisfied for all loading conditions.

I. Elastic-Plastic Fracture Mechanics and Fatigue Crack Growth Evaluations

The controlling loading condition in the foregoing linear elastic fracture mechanics (LEFM) analyses is the Trip at Maximum Pressure Stress event, for which the applied stress intensity factor is 59.2 ksi$\sqrt{in}$ versus an allowable of 63.2 ksi$\sqrt{in}$, as shown in Table 3-9. However, this condition occurs at normal plant operating temperatures, for which the low alloy steel pressurizer base material is on the upper shelf of its Charpy V-notch impact energy curve, and therefore possesses considerable ductility. For low alloy steel components in this temperature regime, elastic-plastic fracture mechanics (EPFM) techniques are more appropriate fracture mechanics technologies than LEFM techniques. The LEFM methodology used above [5] treats all loadings on the vessel equivalently, applying equal safety factors (~3 for normal and upset loads, and ~1.4 for emergency and faulted loads) to both primary stresses, due to internal pressure and mechanical loads, as well as to secondary and peak stresses, such as those caused by differential thermal expansion. These loadings are equivalent in their potential to produce fracture only in the most brittle of materials, such as glass, RPV beltline materials at low temperatures after significant irradiation embrittlement, and thick, ferritic materials at very low temperatures.

Ample precedent exists in the ASME Code, Section XI for the use of EPFM methodologies in materials that exhibit some ductility. Such precedent may be seen in Appendix C for Evaluation of Flaws in Austenitic Piping [5], Appendix H for Evaluation of Flaws in Ferritic Piping [5], and Appendix K for Assessment of Reactor Vessels with Low Upper Shelf Charpy Impact Energy Levels [5]. Appendix H includes a screening criteria to determine into which regime a ferritic piping flaw evaluation falls (LEFM, EPFM or Limit Load), and for problems that fall into the EPFM regime, specifies different safety factors for primary stresses (~3) than for secondary loadings (1). An even more appropriate approach for the pressurizer heater sleeve penetrations is presented in Appendix K [5]. In addition to different safety factors for primary versus secondary loadings, this appendix also provides a procedure for performing flaw instability analysis of reactor vessel materials on the upper shelf, as illustrated schematically in Figure 3-5. The left hand plot in this figure illustrates a typical material J-Resistance (J-R) curve. As loading is applied to the top of a fracture specimen of a ductile material, the J value for that material increases until it exceeds the material fracture toughness, J_{1c} (similar to K_{1c} in LEFM evaluations). At this point, if the material is ductile, the crack in the specimen will begin to extend in a slow stable fashion until it reaches the instability point indicated by the upper extent of the J-R curve. For analytical convenience, the material J-R curve may be converted to J versus Tearing Modulus (T), as illustrated in the right hand plot in Figure 3-5. Application of this Tearing Modulus to an engineering component, such as the Palo Verde pressurizer, is then performed by computing J versus T applied for the component, illustrated by the dashed line on the right hand plot. The J-value at which the J-applied line crosses J_{1c} corresponds to the initiation of slow stable crack propagation. Unstable crack propagation or failure, however, is not predicted until the instability point in the diagram is reached. The difference between $J = J_{1c}$ versus J at the instability point is a measure of the additional ability to sustain loading afforded by the ductility of the material. In a brittle material, failure occurs at $J = J_{1c}$ (equivalent to $K = K_{1c}$ in an LEFM analysis).

In this section, the technical approach and approximate methodology of Appendix K [5] is applied to the Palo Verde pressurizer heater sleeve postulated remnant crack under the Trip at Maximum Pressure Stress event. Safety factors of 3 for primary loads and 1.5 for secondary loads are applied, which are more conservative than those required by Appendices C, H or K. The results indicate considerably more margin to failure, and thus larger allowable crack sizes than the foregoing LEFM analyses.

Material J-Resistance Curve

Appendix K [5] specifies three methods for selection of the material J-integral resistance curve. A J-R curve may be generated by actual testing of the material following accepted test procedures, it may be generated from a J-integral database obtained from the same class of material with the same orientation, or an indirect method of estimating the J-R curve may be used, provided the method is justified for the material. For this analysis, an indirect method is used, based on Charpy V-notch correlations contained in Reference 7.

Figure 3-6, obtained from Reference 7, presents J-T materials curves for irradiated and unirradiated nuclear vessel steels at various upper shelf Charpy V-notch energy levels (in joules). The results show a rough correlation, in that higher J-T curves are generally obtained for higher Charpy V-notch energy levels. An actual correlation curve has been developed (Figure 3-7 and Figure 3-8) between Charpy V-notch energy and the parameters of a J-R curve power law fit of the following form:

$$J = C (\Delta a)^m$$

In general, a power law fit of this type is only valid for small crack extension (Δa). However, Loss and coworkers [8] have observed good fit for the power law for larger Δa for materials with high upper shelf Charpy energy levels, such as those addressed herein.

Tests of the actual Palo Verde pressurizer base material were conducted in the transverse orientation. These exhibited Charpy V-notch energy levels ranging from a minimum of 98 ft-lbs up to a maximum of 117 ft-lbs at or near the upper shelf temperature (measured at +50°F; the upper shelf temperature is most probably higher than this, and actual upper shelf energies applicable at plant operating temperature are thus expected to be much higher). Thus, the 98 ft-lbs value is used as a conservatively low estimate of the Charpy V-notch upper shelf energy (CVN) level for the Palo Verde pressurizer base material. The CMTR data also provides an average value of the room temperature yield strength of the Palo Verde pressurizer base material of 75.1 ksi, compared to a 50 ksi minimum value from the ASME Code. At 500°F, the yield strength of SA-533, Grade B, Class 1 material is listed at 43.2 ksi in the ASME Code [3]. Therefore, a factored value of 60 ksi is conservatively used in this evaluation.

Based on this CVN of 98 ft-lbs and a flow stress of 80.1 ksi (3.0 Sm), Figure 3-7 and Figure 3-8 are used to determine values of the coefficient "C" and the exponent "m" for the power law J-R curve fit of 5.10 and 0.45, respectively. These have been converted to a J-T diagram, and are illustrated by the "98 ft-lb" J-T curve in Figure 3-9 and Figure 3-10. Additional J-T curves are also presented for an estimated upper shelf Charpy V-notch energy level of 140 ft-lbs [9] and the average CVN upper shelf energy level of 107 ft-lbs for the Palo Verde pressurizer material.

Calculation of Applied J-T

Analyses for J-T applied are performed in accordance with the approximate technique of ASME Code, Section XI, Appendix K. This allows EPFM J-integral estimates to be developed from the foregoing LEFM stress intensity factor calculations. For the Trip at Maximum Pressure Stress event, the resulting stress intensity factors listed in Table 3-9 are:

$$K_{1t} \text{ (Thermal)} = 13.8 \text{ ksi}\sqrt{\text{in}}$$
$$K_{1p} \text{ (Pressure)} = 45.4 \text{ ksi}\sqrt{\text{in}}$$
$$K_{1total} = 59.2 \text{ ksi}\sqrt{\text{in}}$$

Before proceeding with the EPFM analyses, the screening criteria of Appendix H [5] are applied to demonstrate that the evaluation is in the EPFM regime:

$$K_r' = K_{total} / K_{1c} = 59.2/ 200 = 0.296$$
$$S_r' = \text{Peak Stress in Penetration / Flow Stress} = 69.7 / 80.1 = 0.87$$

where the peak stress in the penetration was taken as the maximum stress applied on the crack face.

Thus:

$$SC = K_r' / S_r' = 0.34$$

The Appendix H screening criteria limits are $SC \geq 1.8$ for LEFM, $1.8 > SC \geq 0.2$ for EPFM, and $SC < 0.2$ for Limit Load. Thus, the analysis is clearly in the EPFM regime.

The Appendix K [5] approximate procedure for J-integral involves the calculation of a plastic zone corrected crack size for small scale yielding from elastically calculated K values, in accordance with the following:

$$a_e = a + [1/(6\pi)] \left[(K_{1p} + K_{1t})/YS \right]^2$$

The J-integral is then calculated from revised stress intensity factors (K'_{1p} and K'_{1r}) computed at the plastic zone corrected crack size as follows:

$$J = (K'_{1p} + K'_{1r})^2/E'$$

In the above LEFM analyses, stress intensity factors were only calculated for one crack size (0.6"). Therefore, the following approximation was used to determine K's for the plastic zone corrected crack sizes:

$$K' = K\sqrt{(a_e / a)}$$

This approximation, which is based on the assumption that the stress intensity factor (K) is proportional to the square root of the flaw size (a), is conservative since the dominant stresses decrease rather than increase when the crack size becomes larger.

A list of plastic zone size adjusted K' and associated J-applied values, computed in accordance with the above described method, is provided in Table 3-10 and Table 3-11 for the flaw sizes of 0.6" and 1.2", respectively. Results are reported for various combinations of safety factors, as indicated in the first column of the tables, and are plotted as the J-T applied lines in Figure 3-9 and Figure 3-10. Data points are indicated on the J-applied lines with the corresponding values of safety factor (SF) denoted. The instability points in these diagrams correspond to the J-values at which the J-T applied lines intersect the 98 ft-lbs J-T material curves. These occur at 3 in-kips/in^2 for the 0.6" crack size, and at 4 in-kips/in^2 for the 1.2" crack size, which are listed in the last column of Tables 3-10 and 3-11 for comparison with the applied J values.

As discussed above, the appropriate safety factors for normal/upset operating conditions for ductile materials are SF=3 on primary and SF=1.5 on secondary (indicated by the shaded cells in the tables). It is seen that the applied J for both the 0.6" and 1.2" flaw sizes are below the instability limit by a large margin. Therefore, it can be stated that the ASME Code, Section XI allowable flaw size for the Trip at Maximum Pressure Stress event is greater than 1.2".

Fatigue Crack Growth Evaluations

The LEFM methodology of Section XI, Appendix A of the ASME Code [5] was used to perform the fatigue crack growth evaluation.

The fatigue crack growth evaluation used the 40 year number of cycles from Table 3-3. The Loss of Secondary Pressure transient, an emergency/faulted condition transient, was not included in this evaluation. The design transient cycles were assumed to be evenly distributed over the plant lifetime of 40 years. The Cooldown and Reactor Trip transients were each combined with the Heatup transient to form maximum stress intensity factor ranges. Table 3-12 presents the defined cyclic load ranges based on the stress intensity factor values, and corresponding number of cycles for a postulated 60 year life.

To perform the crack growth analysis, the stress intensity factor (K_1) was assumed to be proportional to the square root of the flaw size (a). The K versus "a" distribution was then determined for each transient based on the calculated initial stress intensity factors (K_{1i}) at the initial flaw size (a_i) using the following equation:

$$K_I = K_{Ii}\sqrt{\frac{a}{a_i}}$$

Table 3-13 presents the K versus "a" distributions for all the transients considered. The initial flaw size, a_i, was taken at the overlay/low alloy steel interface. Using the downhill side of the heater sleeve penetration where the stress intensity factors are the largest, a_i is 0.60 inches.

For the flaw growth through the pressurizer base material, it was assumed that fatigue is the primary propagation mechanism. The ASME Code fatigue crack growth law for carbon and low alloy steels in water environments was used [5]. The crack growth analyses were performed with the **pc-CRACK for Windows** [6] fracture mechanics analysis program.

The fatigue crack growth results are presented in Figure 3-11. The postulated 0.60 inch initial flaw was predicted to grow to a depth of 1.16 inches after 60 years. This end-of-evaluation period flaw is less than the allowable flaw size calculated in Section 3.3.2.

J. Corrosion Evaluation of Pressurizer Base Material

The final configuration of the mid-wall repair results in a crevice between the sleeve and the pressurizer base material. This crevice exists for any type of half sleeve repair in the industry (i.e., this condition is not specific to the mid-wall repair). The pressurizer base material consists of SA-533, Grade B, Class 1 low alloy steel, and is therefore subject to corrosion in borated water.

Reference 10, "Low Alloy Steel Component Corrosion Analysis Supporting Small Diameter Alloy 600/690 Nozzle Repair/Replacement Programs", WCAP-15973-P, Rev. 1, has evaluated worst case corrosion conditions and concluded that the minimal amount of corrosion that may occur is well within the acceptable limits identified in Section XI of the ASME Code.

Specifically, WCAP-15973-P, Rev. 1 states that the corrosion rate of the carbon or low alloy steel in the crevice of replaced or repaired nozzles/sleeves that are bounding cases for small diameter Alloy 600 nozzles in Combustion Engineering plants will be approximately 1.53 mils per year (0.00153 inches per year). The bounding case pressurizer heater sleeves have an estimated life of 194 years.

A second evaluation considered the effects of corrosion product buildup in the crevices of bounding case nozzles/sleeves. Corrosion will occupy a greater volume than the material from which they originate. As a result, the crevices will eventually become packed with dense corrosion products that will isolate the steel from the primary water environment. This will cause the corrosion process to be greatly reduced over a period of time.. This evaluation estimated that approximately a 0.025 inch increase in hole diameter as a result of corrosion will significantly reduce the corrosion process.

Table 3-1

Load Combinations

Loads	Load Combinations					
	Design	Level A	Level B	Level C	Level D	Test
Pressure (psia)	2500	2550(3)	2550(3)	2250	2250	2250
Temperature (°F)	700	(1)	(1)	(1)	(1)	(2)
Thermal Transients						
Heatup		X	X			
Cooldown		X	X			
Reactor Trip		X	X			

Notes:
1) Varies between 70°F and 653°F.
2) Varies from 120°F to 400°F.
3) Based on the maximum pressure occurring for the Reactor Trip transient.

Table 3-2

Stress Criteria for ASME Code, Class 1 Components

Load Combination	P_m	P_L	$P_L + P_b$	$P_L + P_b + Q$	Notes
Design	1.0 S_m	1.5 S_m	1.5 S_m	-	1
Level A/B	-	-	-	3.0 S_m	1, 2
Level C	Greater of 1.0 S_y or 1.2 S_m	Greater of 1.5 S_y or 1.8 S_m	Greater of 1.5 S_y or 1.8 S_m	-	1, 3
Level D	Greater of 1.0 S_y or 1.2 S_m	Greater of 1.5 S_y or 1.8 S_m	Greater of 1.5 S_y or 1.8 S_m	-	1, 3
Test	0.9 S_y	-	1.35 S_y	-	1, 4

Notes:
1) Alloy 690 material evaluated.
2) The requirements of ASME Code, Section III, Subparagraph NB-3222.4 for peak stresses and cyclic operation must be met.
3) The two service levels were combined in Level C/D, and the allowable of Level C was used.
4) All statically determined membrane stresses resulting from pressure loading were classified as general primary membrane.

Table 3-3

Transients

Event	Cycles[1]
Pressurizer Heatup	500 (750)
Pressurizer Cooldown	500 (750)
Reactor Trip[2]	480 (720)
Plant Leak Test	200 (300)

Notes:
1) Base number is for 40 years of plant operation. Value in parentheses is for 60 years.
2) Includes Loss of Reactor Coolant Flow and Loss of Load.

Table 3-4

Linearized Stress Intensity Results for Controlling Sleeve

Event	Maximum Membrane Stress Intensity (ksi)		Time @ Max Membrane Stress Intensity (sec)		Maximum Mem. + Bending Stress Intensity (ksi)		Time @ Max Mem. + Bending Stress Intensity (sec)	
	Path 1	Path 2	Path 1	Path 2	Path 1	Path 2	Path 1	Path 2
Cooldown	13.2	7.9	4408	4408	15.6	9.7	4408	4408
Heatup	6.5	9.2	10494	10494	11.7	11.6	10494	10494
Trip	9.8	5.5	600	600	11.9	7.1	600	600
Pressure(1)	12.4	10.5	N/A	N/A	16.5	12.0	N/A	N/A

Note:
1) Pressure stress intensities as reported are based on a 1,000 psi internal pressure.

Table 3-5

Primary Stress Intensity Evaluation

Load Comb.	Path[1]	Membrane Stress Intensity (ksi)			Membrane + Bending Stress Intensity (ksi)		
		Pressure P_m	Allowable $1.0S_m$[5]	Accept.	Pressure[3] $P_L + P_b$	Allowable $1.5S_m$[5]	Accept.
Design	1	10.5[2]	23.3	Yes	31.1	34.9	Yes
	2	4.0[4]	23.3	Yes	26.3	34.9	Yes
Level C/D	1	10.5[2]	30.6	Yes	31.1	45.9	Yes
	2	4.0[4]	30.6	Yes	26.3	45.9	Yes
Test	1	10.5[2]	29.7	Yes	28.0	44.5	Yes
	2	4.0[4]	29.7	Yes	23.6	44.5	Yes

Notes:
1) Stress paths are shown in Figure 3-3.
2) General primary membrane stress intensity due to pressure was determined by closed form solution. Note that 2,500 psia pressure was conservatively used for Service Level C/D and Test, as well as for Design.
3) Membrane stress intensity from a 1,000 psi unit pressure analysis was scaled to obtain P_L at the Design Pressure of 2,500 psia and Test Pressure of 2,250 psi. P_b = 0 for pressure.
4) General primary membrane stress intensity due to pressure was determined via closed form solution for shear in the repair weld along Path 2.
5) Design stress intensity and yield strength for Alloy 690 material per Reference 3 at 700°F.

Table 3-6

Service Level A/B Load Combination

Primary-Plus-Secondary Stress Intensity Evaluation

Path[1]	Membrane + Bending Stress Intensity (ksi)					
	Pressure[2] $P_L + Q$	Cooldown[3] $P_L + Q$	Trip[3] $P_L + Q$	Combined $P_L + Q$	Allowable $3.0S_m$[4]	Accept.
1	42.1	15.6	11.9	69.6	69.9	Yes
2	30.5	9.7	7.1	47.3	69.9	Yes

Notes:
1) Stress paths are shown in Figure 3-3.
2) Membrane-plus-bending stress intensity from a 1,000 psi unit pressure analysis was scaled to obtain $P_L + Q$ at a pressure of 2,550 psia, as this was the maximum pressure experienced under any Service Level A/B load combination (pressure occurs during a Reactor Trip transient).

3) From analysis and post-processing of the Cooldown and Reactor Trip transients. The Heatup stress intensities do not govern and were excluded.
4) Design stress intensity for Alloy 690 material per Reference 3 at 700°F.

Table 3-7

Total Fatigue Usage for Option 1

Path	Location (1)	Region	Fatigue Usage			
			Cooldown+ Trip+ P_{Trip}	Cooldown+ Heatup+ $P_{Operate}$	P_{leak}	Total
1	(I)	Sleeve	0.006	0.000	0.000	0.006
1	(O)	Crevice	0.596	0.023	0.015	0.634
2	(I)	Weld	0.482	0.018	0.022	0.522
2	(O)	Weld	0.262	0.014	0.010	0.286

Note:

1) See Figure 3-3 for illustration of indicated locations.

Table 3-8

Total Fatigue Usage for Option 2

Path	Location (1)	Region	Fatigue Usage			
			Trip+ $P_{Delta\ Trip}$	Cooldown+ Heatup+ $P_{Operate}$	P_{leak}	Total
1	(I)	Sleeve	0.000	0.002	0.000	0.002
1	(O)	Crevice	0.009	0.574	0.015	0.598
2	(I)	Weld	0.005	0.445	0.022	0.472
2	(O)	Weld	0.002	0.347	0.010	0.359

Note:

2) See Figure 3-3 for illustration of indicated locations.

Table 3-9

Stress Intensity Factor Results

Event	Applied Stress Intensity Factor ($ksi\sqrt{in}$)				Allowable Stress Intensity Factor ($ksi\sqrt{in}$)[1]
	Thermal	Internal Pressure	Crack Face Pressure	Total	
Cooldown	25.2	2.9	0.8	28.9	63.2 [3]
End of Cooldown	21.4	1.2	0.3	22.9	47.0 [2]
Trip Max. Thermal Stress	16.5	24.2	7.0	47.7	63.2 [3]
Trip Max. Pressure Stress	13.8	35.2	10.2	59.2	63.2 [3]
Loss of Secondary Pressure	96.9	2.1	0.6	99.6	141.4 [4]

Notes:

1) ASME Code, Section XI acceptance criteria are contained in Paragraph IWB-3612.
2) The allowable stress intensity factor for normal/upset conditions at 70°F is 47.0 $ksi\sqrt{in}$, using a factor-of-safety of $\sqrt{2}$ per the recent ASME Code interpretation with an RT_{NDT} of (-)10°F.
3) The allowable stress intensity factor for normal/upset "hot" conditions is 63.2 $ksi\sqrt{in}$.
4) The allowable stress intensity factor for emergency/faulted "hot" conditions is 141.4 $ksi\sqrt{in}$.

Table 3-10

J-T Instability Computations for Palo Verde Pressurizer Remnant Crack using ASME Code, Section XI, Appendix K Approximate Method, Initial Flaw Size of 0.6"

Safety Factors	K_{total}	K'_{total}	J'_{total}	T'	J @ Instability
	$ksi\sqrt{in}$		in-kips/in^2		in-kips/in^2
SF=1	59.2	61.7	0.119	0.900	3.00
SF=3, 1.5	156.9	198.8	1.231	9.338	3.00

SF=√10	187.2	255.4	2.032	15.416	3.00
SF=4	236.8	365.1	4.154	31.511	3.00
SF=5	296.0	525.5	8.606	65.281	3.00

Table 3-11

J-T Instability Computations for Palo Verde Pressurizer Remnant Crack using ASME Code, Section XI, Appendix K Approximate Method, Extended Flaw Size of 1.2"

Safety Factors	K_{total}	K'_{total}	J'_{total}	T'	J @ Instability
	ksi$\sqrt{in}$		in-kips/in^2		in-kips/in^2
SF=1	83.7	87.3	0.237	0.900	4.0
SF=3, 1.5	221.9	281.1	2.462	9.338	4.0
SF=√10	264.8	361.1	4.065	15.41 6	4.0
SF=4	334.9	516.3	8.309	31.51 1	4.0
SF=5	418.6	743.2	17.213	65.28 1	4.0

Table 3-12

Crack Growth Evaluation Cyclic Loads

Load Range	Cycles
Reactor Trip – Heatup	720
Cooldown – Heatup	30
Leak Test	300

Table 3-13

Stress Intensity Factor vs. Crack Size

a, in.	K (ksi-in$^{1/2}$)			
	Heatup	Cooldown	Trip	Leak Test
0.600	-18.8	28.9	59.2	40.1
0.615	-19.0	29.2	59.9	40.5
0.630	-19.3	29.6	60.7	41.0
0.645	-19.5	29.9	61.4	41.5
0.660	-19.7	30.3	62.1	42.0
0.675	-19.9	30.6	62.8	42.5
0.690	-20.2	31.0	63.5	42.9
0.705	-20.4	31.3	64.2	43.4
0.720	-20.6	31.6	64.8	43.9
0.735	-20.8	32.0	65.5	44.3
0.750	-21.0	32.3	66.2	44.8
0.765	-21.2	32.6	66.8	45.2
0.780	-21.4	32.9	67.5	45.7
0.795	-21.6	33.2	68.1	46.1
0.810	-21.8	33.6	68.8	46.5
0.825	-22.0	33.9	69.4	47.0
0.840	-22.2	34.2	70.0	47.4
0.855	-22.4	34.5	70.7	47.8
0.870	-22.6	34.8	71.3	48.2
0.885	-22.8	35.1	71.9	48.6
0.900	-23.0	35.4	72.5	49.1
0.915	-23.2	35.7	73.1	49.5
0.930	-23.4	36.0	73.7	49.9
0.945	-23.6	36.2	74.3	50.3
0.960	-23.8	36.5	74.9	50.7
0.975	-24.0	36.8	75.5	51.1
0.990	-24.1	37.1	76.0	51.4
1.005	-24.3	37.4	76.6	51.8
1.020	-24.5	37.7	77.2	52.2
1.035	-24.7	37.9	77.7	52.6
1.050	-24.9	38.2	78.3	53.0
1.065	-25.0	38.5	78.9	53.4
1.080	-25.2	38.7	79.4	53.7
1.095	-25.4	39.0	80.0	54.1
1.110	-25.6	39.3	80.5	54.5
1.125	-25.7	39.5	81.0	54.8
1.140	-25.9	39.8	81.6	55.2
1.155	-26.1	40.1	82.1	55.6
1.170	-26.3	40.3	82.7	55.9
1.185	-26.4	40.6	83.2	56.3
1.200	-26.6	40.8	83.7	56.6

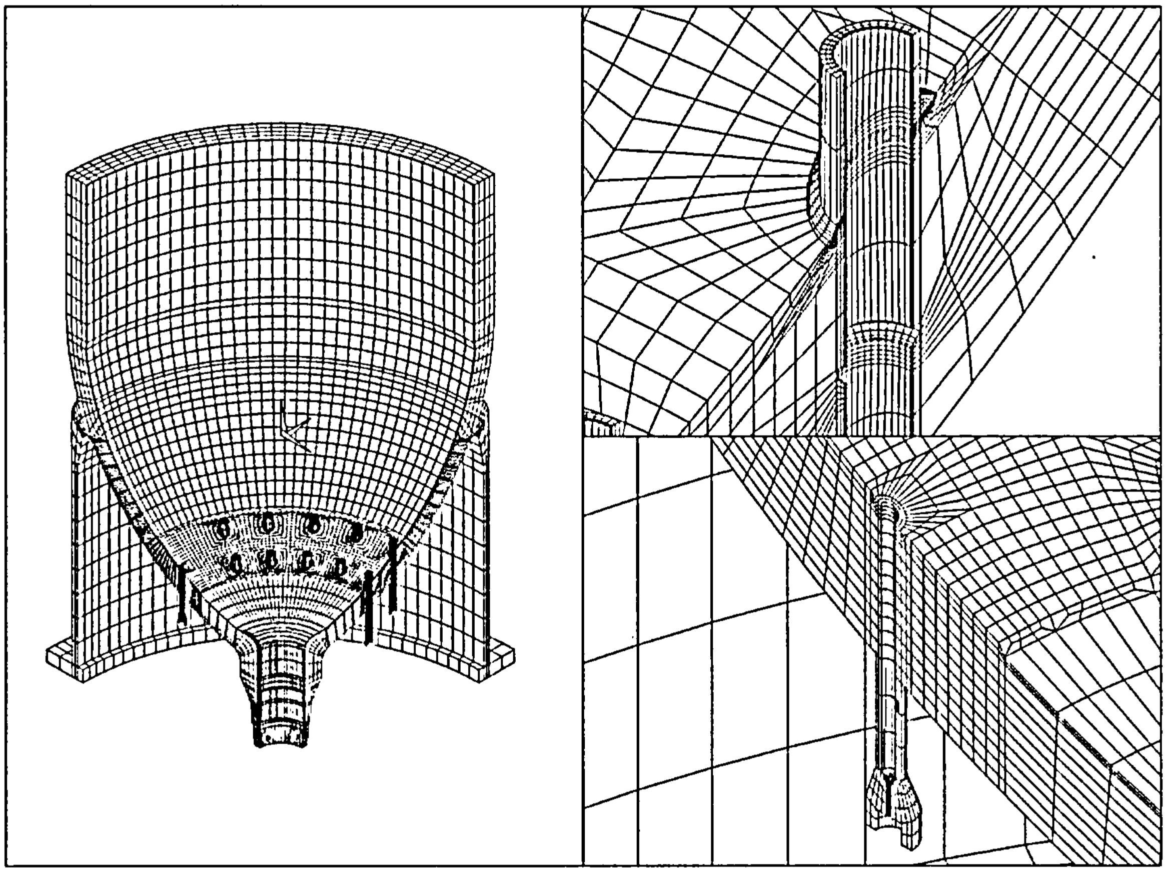


Figure 3-1. Finite Element Model

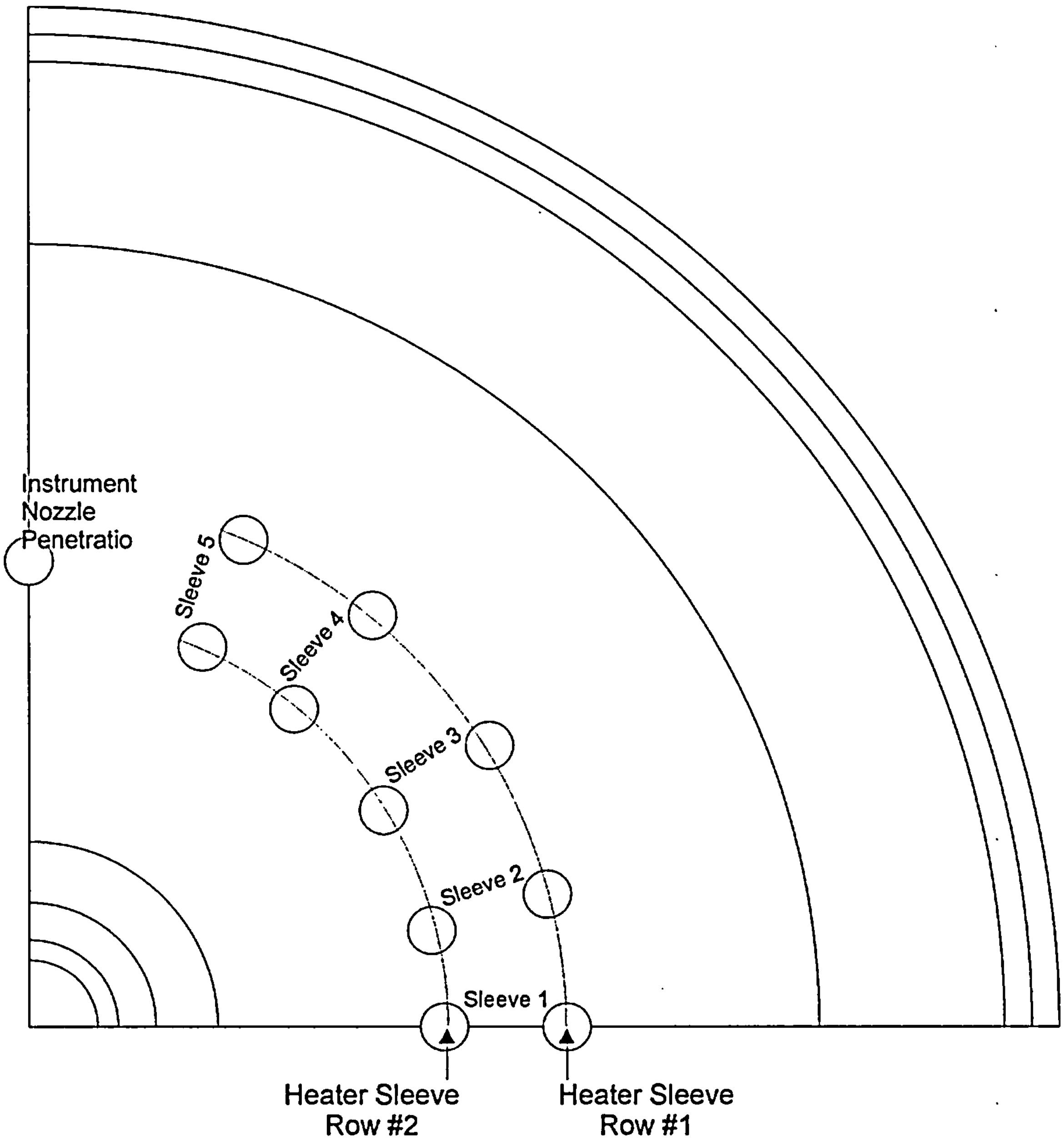


Figure 3-2. Row and Sleeve Numbering

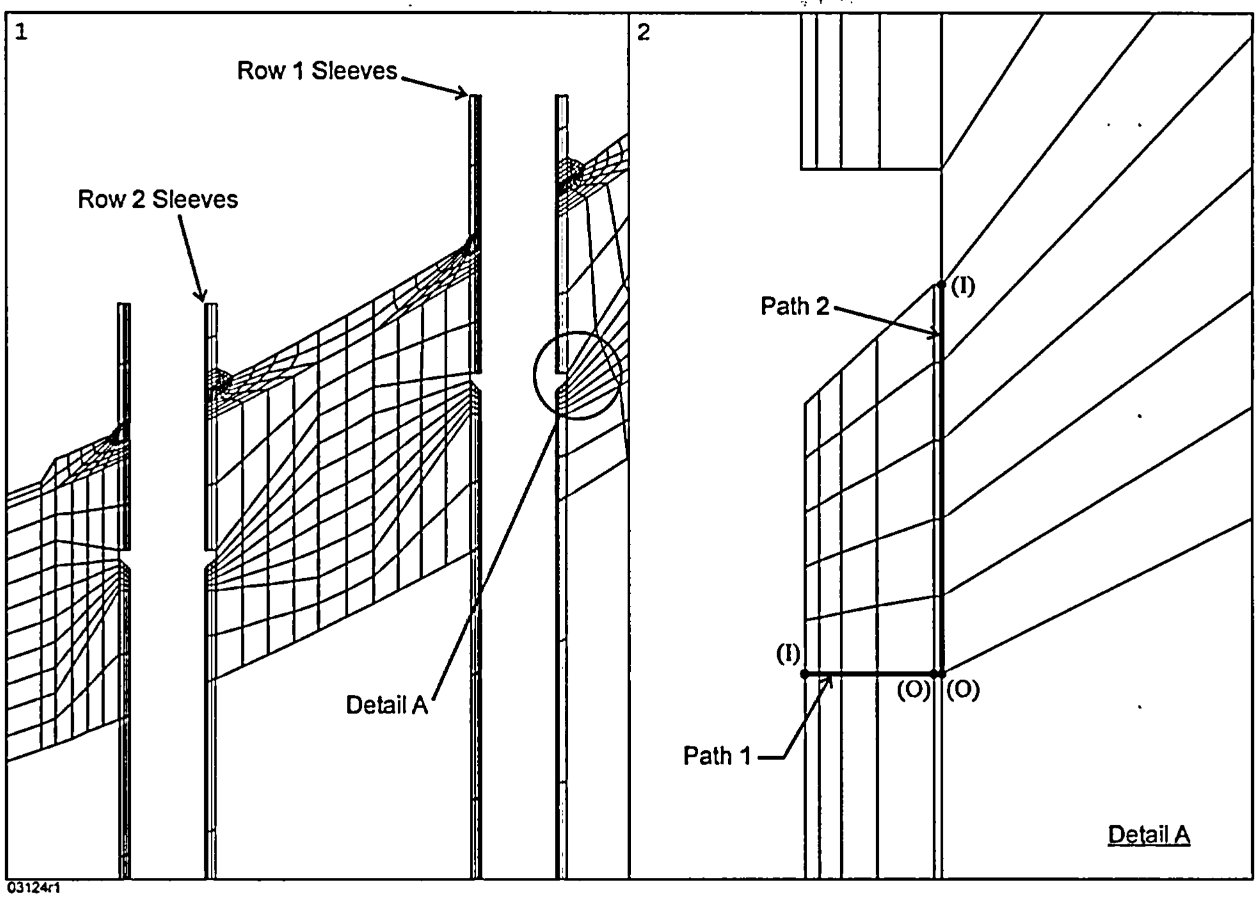


Figure 3-3. Linearized Stress Paths for Sleeve Repairs

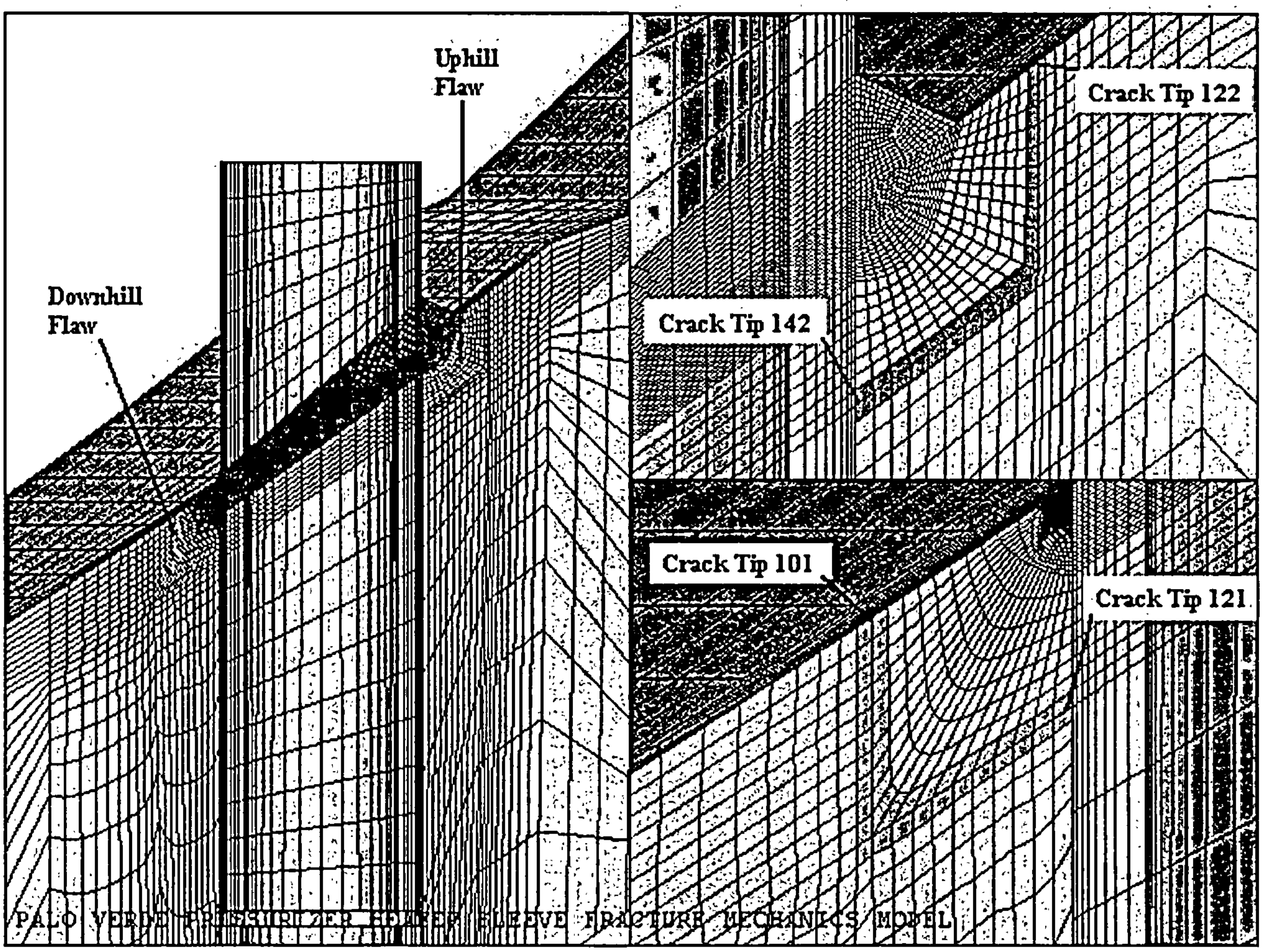


Figure 3-4. Crack Tip Element Location Definition

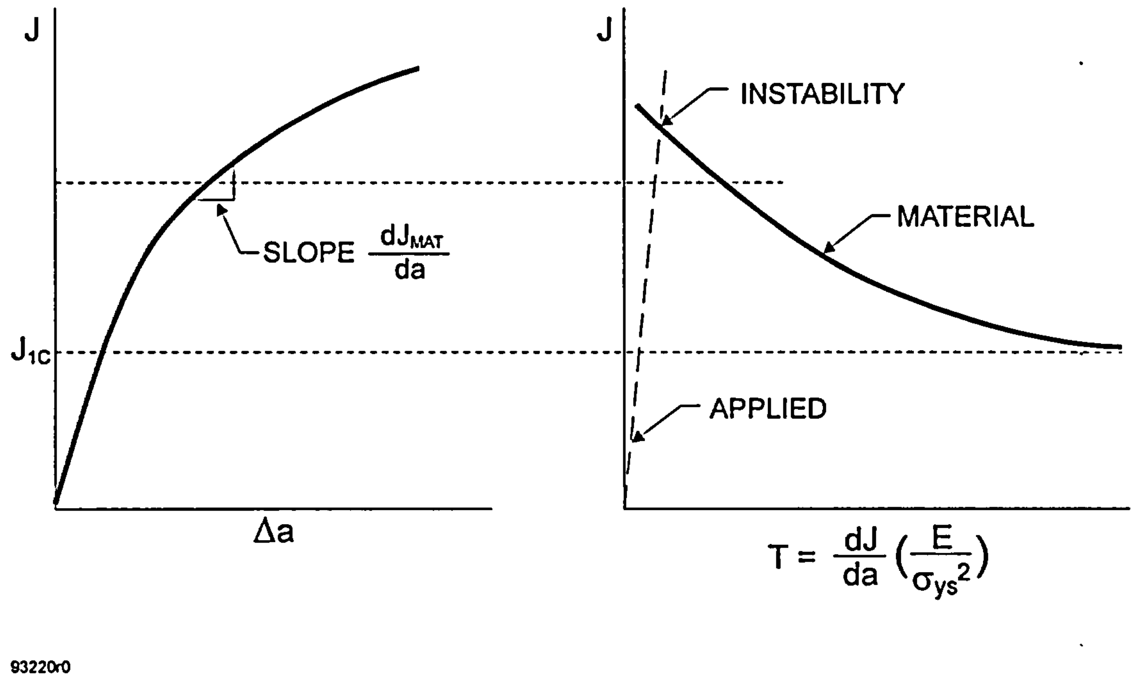


Figure 3-5. Schematic of EPFM Stability Analysis from ASME Code, Section XI, Appendix K [5]

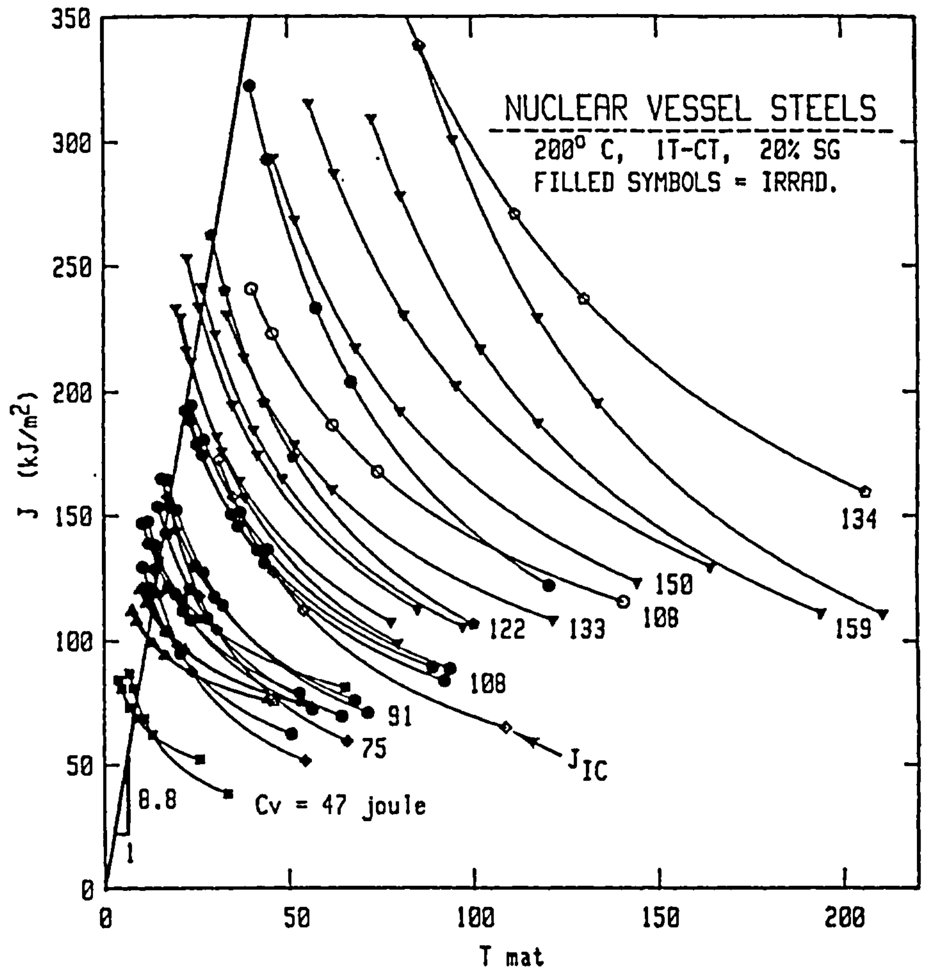


Figure 3-6. J-T Diagram for Several Reactor Vessel Steels and Welds Showing Rough Correlation with Charpy V-notch Upper Shelf Energy [7]

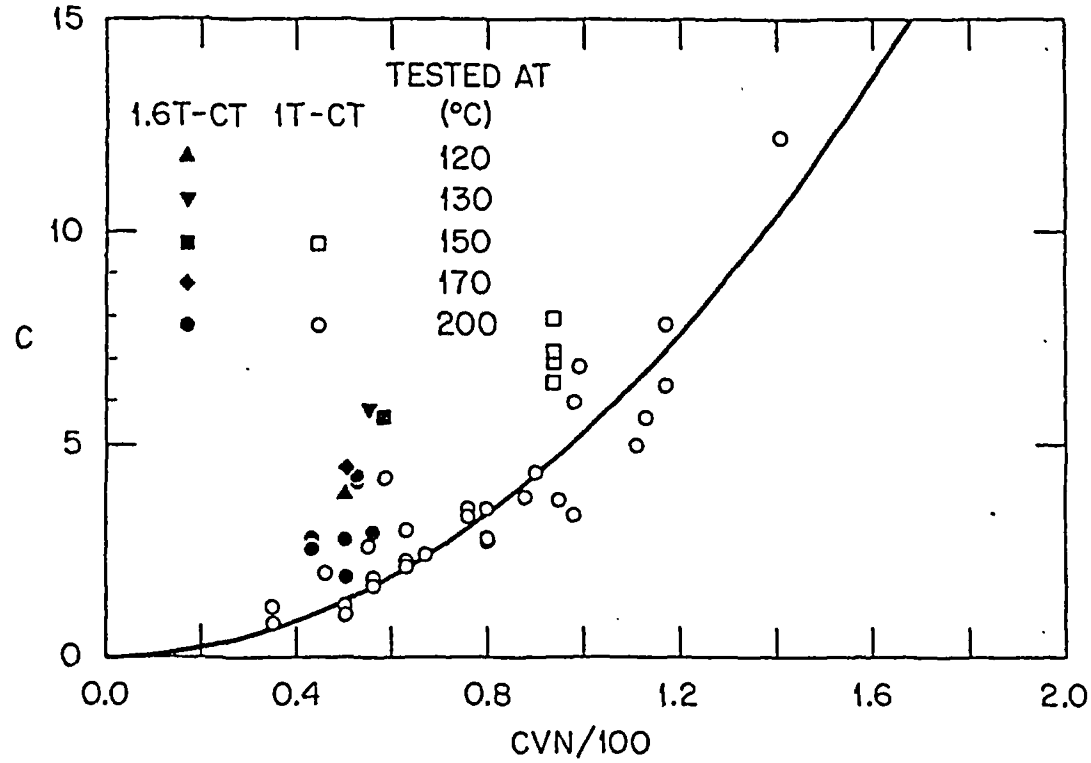


Figure 3-7. Correlation of Coefficient C of Power Law J-R Curve Representation with Charpy V-notch Upper Shelf Energy [7]

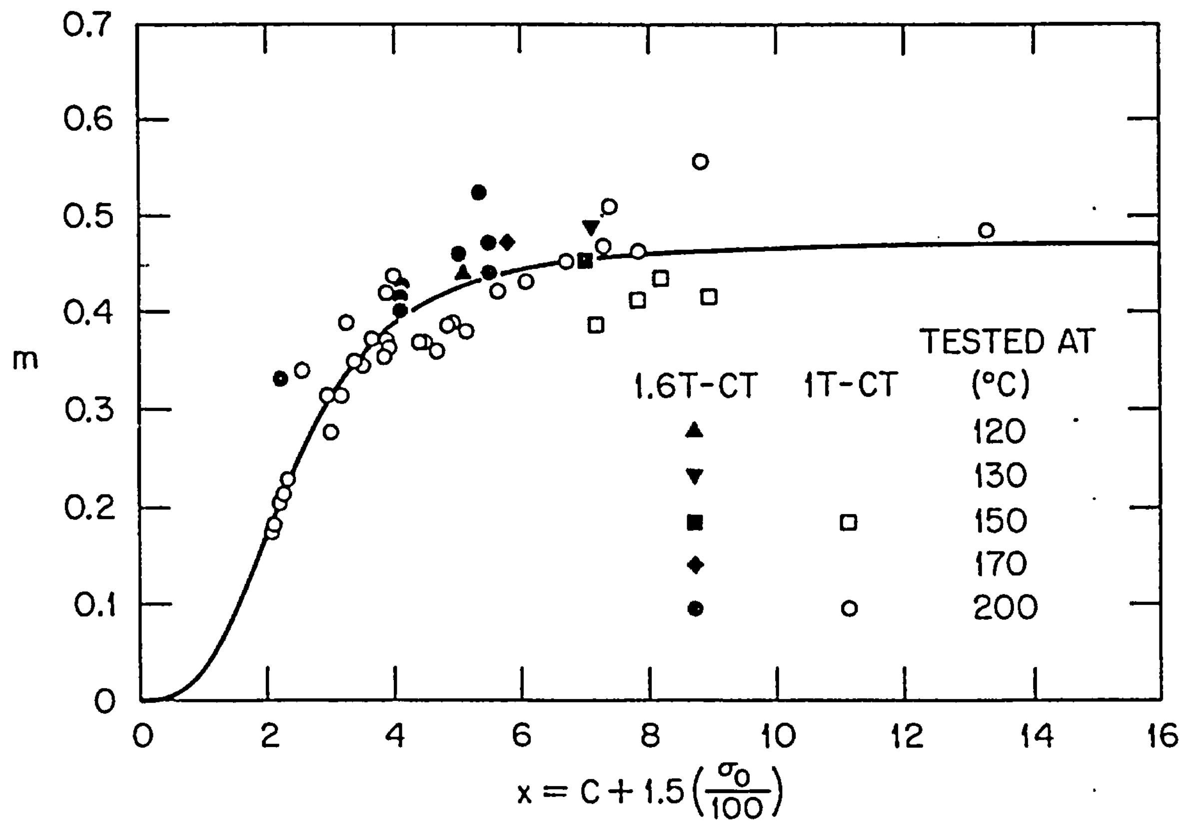


Figure 3-8. Correlation of Exponent m of Power Law J-R Curve Representation with Coefficient C and Flow Stress σ_o [7]

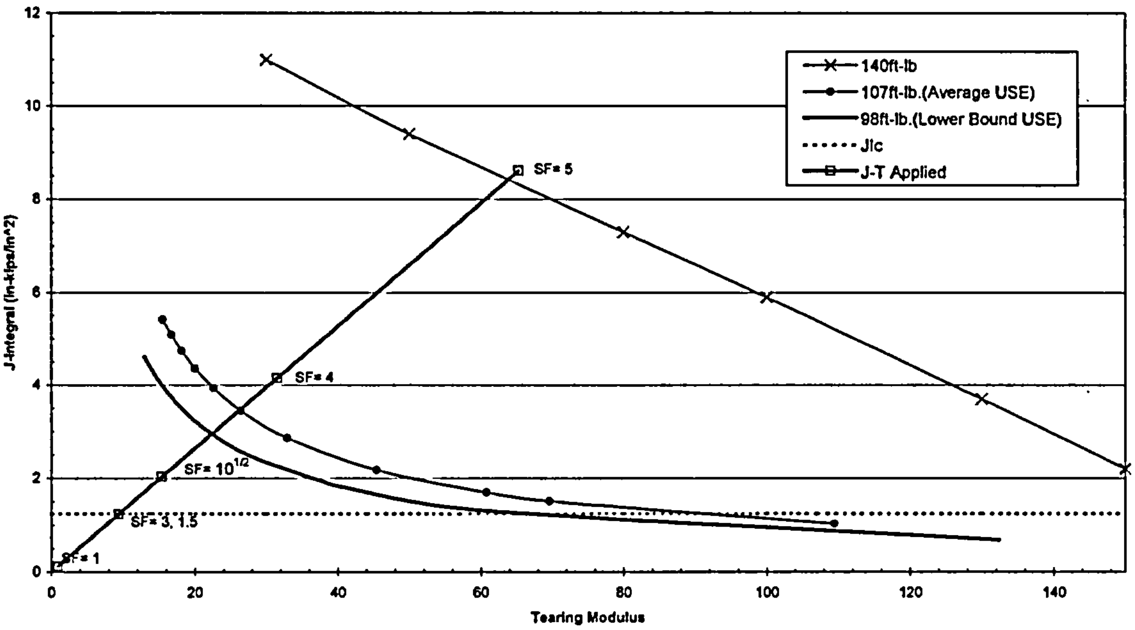


Figure 3-9. J-T Diagram for EPFM Stability Analysis for Palo Verde Pressurizer Remnant Cracking Concern at a Flaw Size of 0.6"

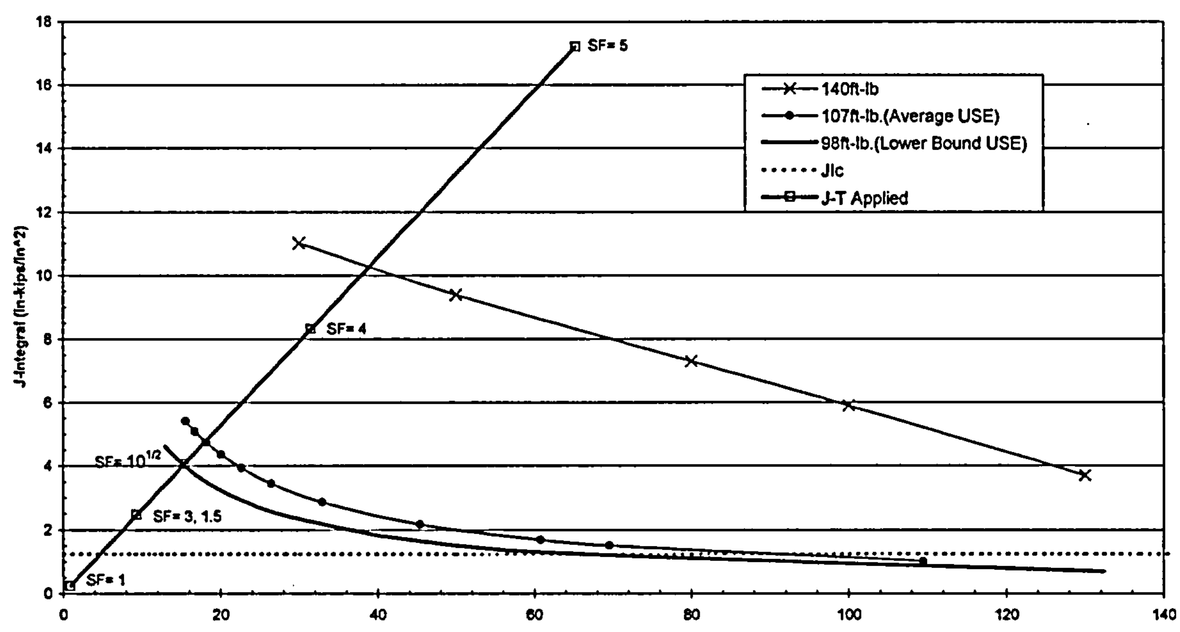


Figure 3-10. J-T Diagram for EPFM Stability Analysis for Palo Verde Pressurizer Remnant Cracking Concern at a Flaw Size of 1.2"

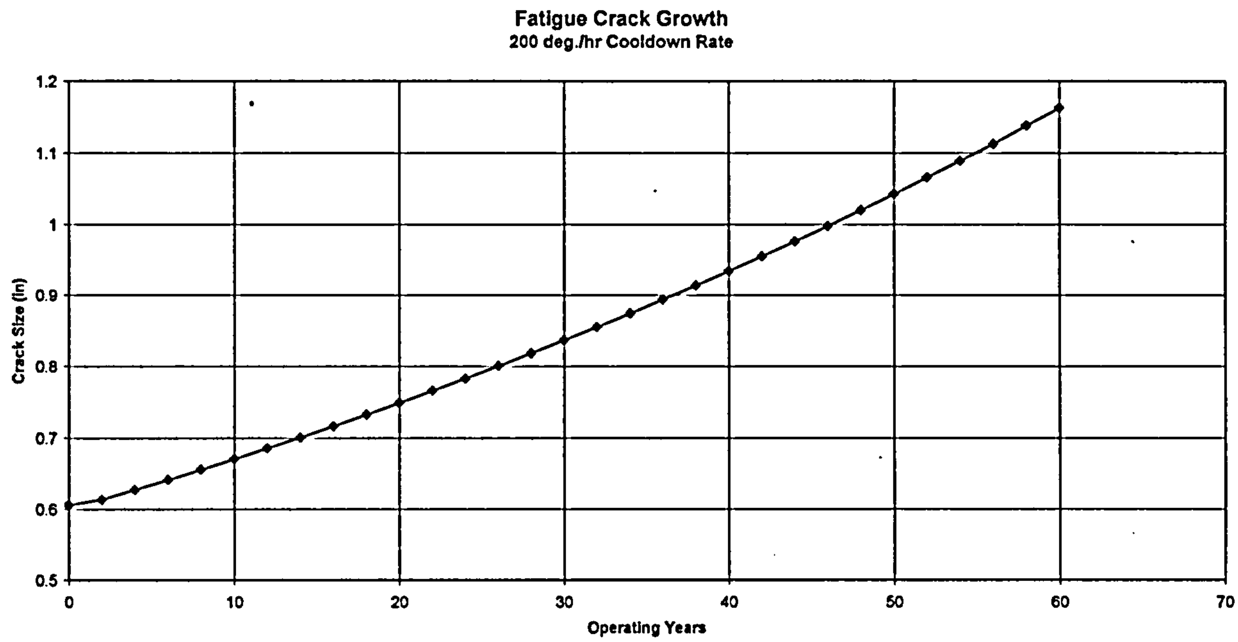


Figure 3-11. Fatigue Crack Growth Results

Conclusions

The proposed pressurizer heater sleeve mid-wall repair concept is acceptable because:

- The design of the heater sleeve repair meets the requirements of ASME Code, Section III.
- The remaining postulated defect in the Alloy 600 material has been evaluated and found acceptable for the life of the plant plus life extension.
- Postulated wall loss due to corrosion of base material is minimal.

References

1. ANSYS Mechanical, Revision 5.7, ANSYS Inc., December 2000.

2. ASME Boiler and Pressure Vessel Code, 1971 Edition through Winter 1973 Addenda.

3. ASME Boiler and Pressure Vessel Code, Section III, Appendices, 1989 Edition.

4. T. L. Anderson, "Fracture Mechanics Fundamentals and Applications", Second Edition, CRC Press, 1995.

5. ASME Boiler and Pressure Vessel Code, Section XI, 1992 Edition, including the 1992 Addenda. For references to Appendix K, see the 1993 Addenda.

6. **pc-CRACK** for Windows, Version 3.1-98348, Structural Integrity Associates, 1998.

7. NUREG-0744, Vol. 2, Rev. 1, "Resolution of the Task A-11 Reactor Vessel Materials Toughness Safety Issue," Appendices C-K, Division of Safety Technology, Office of Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, October 1982.

8. F. Loss, ed., "Structural Integrity of Water Reactor Pressure Boundary Components," USNRC Report NUREG/CR-1128, 1979.

9. S.S. Tang, P.C. Riccardella, and R. Huet, "Verification of Tearing Modulus Methodology for Application of Pressure Vessels with Low Upper Shelf Fracture Toughness," presented at ASTM 2nd International Symposium on Elastic-Plastic Fracture Mechanics, October 6-9, 1981, Philadelphia, PA.

10. WCAP-15973-P, Rev. 1, "Low Alloy Steel Component Corrosion Analysis Supporting Small Diameter Alloy 600/690 Nozzle Repair/Replacement Programs."