November 5, 2004

Mr. Gregg R. Overbeck
Senior Vice President, Nuclear
Arizona Public Service Company
P. O. Box 52034
Phoenix, AZ 85072-2034

SUBJECT: PALO VERDE NUCLEAR GENERATING STATION, UNITS 1, 2, AND 3 - RELIEF REQUEST NO. 29 RE: REMNANT SLEEVE(S) FLAW EVALUATION (TAC NOS. MC3606, MC3607, AND MC3608)

Dear Mr. Overbeck:

By letter dated June 15, 2004, as supplemented by letter dated August 24, 2004, Arizona Public Service Company submitted Relief Request No. 29, requesting relief from certain American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (Code) requirements at Palo Verde Nuclear Generating Station (Palo Verde), Units 1, 2, and 3. The request for relief is from certain flaw evaluation requirements and from the successive examination of the remnant sleeves left in-place after performing half-sleeve mid-wall weld repairs at all three units. These repairs were completed for Unit 2 during the fall 2003 refueling outage, and these repairs are scheduled during the fall 2004 refueling outage for Unit 3 and during the fall 2005 refueling outage for Unit 1. The relief is requested for the second 10-year inservice inspection (ISI) interval at the three units.

Based on the enclosed Safety Evaluation, the NRC staff concludes that the proposed alternatives provide an acceptable level of quality and safety. The NRC staff concludes that granting relief pursuant to 50.55a(g)(6)(i) of Title 10 of the *Code of Federal Regulations* is authorized by law and will not endanger life or property or the common defense and security, and is otherwise in the public interest giving due consideration to the burden upon the licensee that could result if the requirements were imposed on the facility. Therefore, the NRC staff authorizes the proposed alternatives at the Palo Verde, Units 1, 2, and 3 for the second 10-year ISI interval. All other requirements of the ASME Code, Section III and XI for which relief has not been specifically requested and approved remain applicable, including third party review by the Authorized Nuclear Inservice Inspector.

Sincerely,

/RA/

Robert A. Gramm, Chief, Section 2
Project Directorate IV
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Docket Nos. STN 50-528, STN 50-529
and STN 50-530

Enclosure: Safety Evaluation

cc w/encl: See next page

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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

INSERVICE INSPECTION PROGRAM RELIEF REQUEST NO. 29

ARIZONA PUBLIC SERVICE COMPANY, ET AL.

PALO VERDE NUCLEAR GENERATING STATION, UNITS 1, 2, AND 3

DOCKET NOS. STN 50-528, STN 50-529, AND STN 50-530

1.0 INTRODUCTION

By letter dated June 15, 2004, as supplemented by letter dated August 24, 2004, Arizona Public Service Company (APS or the licensee) submitted for NRC staff review and approval proposed alternatives to the requirements of Section XI of American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (Code), 1992 Edition, 1992 Addenda. The request for relief (Relief Request 29) pertains to certain flaw evaluation and successive examination requirements of the remnant heater sleeves and associated welds after performing the proposed half-sleeve replacement in the pressurizer. The relief request is related to the inservice inspection (ISI) program of the second 10-year interval of the pressurizer heater sleeves for the Palo Verde Nuclear Generating Station (Palo Verde), Units 1, 2, and 3.

2.0 BACKGROUND

The pressurizer lower head, to which the heater sleeves are attached, is manufactured from SA-533, Grade B, Class 1 low alloy steel. The pressurizer in each unit has 36 heater sleeves. Each sleeve is a tube having nominal 1.66 inch outside diameter and 0.192 inch wall thickness and is attached to the lower pressurizer head by a partial penetration weld (J-groove weld) made at the pressurizer inside surface. The original sleeves are made from Alloy 600 material, a nickel-based alloy, which has been found to be susceptible to primary water stress corrosion cracking (PWSCC). The attachment weld is made with Alloy 82/182 material which is a nickel-based alloy and is susceptible to PWSCC also. There is an overlay on the inside surface of the pressurizer at the intersection of the sleeve and penetration to reinforce the pressurizer wall. The heater is inserted into the sleeve and is welded (fillet weld) to the sleeve.

Replacement of these sleeves by excavating the original attachment weld and then re-welding new full-length sleeves is not practical due to inaccessibility of the pressurizer vessel internal surface and high radiation field associated with the pressurizer. Therefore, APS proposes the half-sleeve replacement method. The lower half of the original sleeve is removed in two independent steps. First, the original sleeve is cut approximately 1 inch below the bottom surface of the pressurizer using a grinder. Second, the sleeve is severed within the penetration, approximately mid-wall, using a circular cutting disk, and is then removed. APS will clean and perform a liquid penetrant test (PT) on the penetration bore surface. The half-length replacement Alloy 690 sleeve is then inserted into the penetration by slip fit. The new weld is made at the top of the replacement half-sleeve. The top half of the original sleeve and associated attachment weld will remain in service. There will be a gap between the original half-sleeve and the new half-sleeve in the penetration.

The proposed sleeve replacement relocates the reactor coolant pressure boundary (RCPB) from the original partial penetration weld on the inside surface of the pressurizer to the new partial penetration weld at the mid-wall of the pressurizer penetration. The remaining original sleeve and the original attachment weld may contain pre-existing cracks or may develop crack(s) in the future. Leaving a potentially degraded remnant sleeve and weld without performing successive examinations requires relief from the flaw characterization methods and successive examination requirements described in the ASME Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components."

APS stated that the Palo Verde, Unit 1 pressurizer sleeves have not had any repairs; however, as a preventive measure, APS will perform half-sleeve replacement on all 36 heater sleeves in Palo Verde, Unit 1 in the fall of 2005. The Palo Verde, Unit 2 pressurizer sleeves have been repaired using the half-sleeve replacement method and no additional repairs are necessary. APS will perform half-sleeve replacement on all 36 heater sleeves in Palo Verde, Unit 3 in the fall of 2004.

3.0 REGULATORY REQUIREMENTS

The ISI of the ASME Code Class 1, 2, and 3 components in nuclear plants is to be performed in accordance with the ASME Code Section XI and applicable edition and addenda as required by 50.55a(g) of Title 10 of the *Code of Federal Regulations* (10 CFR), except where specific relief has been granted by the Commission pursuant to 10 CFR 50.55a(g)(6)(i). The regulation at 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."

The regulation at 10 CFR 50.55a(b)(1) states requirements that the RCPB components must meet. This section states that components which are part of the RCPB must meet the requirements for Class 1 components in Section III of the ASME Code. This requirement applies to the new repair weld attaching the replacement half-sleeve to the pressurizer penetration.

Pursuant to 10 CFR 50.55a(g)(4), ASME Code Class 1, 2, and 3 components (including supports) will meet the requirements, except the design and access provisions and the preservice examination requirements, set forth in the ASME Code, Section XI, “Rules for Inservice Inspection of Nuclear Power Plant Components,” to the extent practical within the limitations of design, geometry, and materials of construction of the components. The regulations require that inservice examination of components and system pressure tests conducted during the first 10-year interval and subsequent intervals comply with the requirements in the latest edition and addenda of Section XI of the ASME Code incorporated by reference in 10 CFR 50.55a(b) 12 months prior to the start of the 120-month interval, subject to the limitations and modifications listed therein.

4.0 RELIEF REQUEST NO. 29, REMNANT SLEEVE(S) FLAW EVALUATION

4.1 Component for which Relief is Requested

The proposed Relief Request No. 29 applies to all 36 heater sleeves in each of the three units' pressurizer.

4.2 Applicable ASME Code Edition and Addenda

The second 10-year ISI interval for Palo Verde Units 1, 2, and 3 follows the ASME Code Section XI, 1992 Edition, 1992 Addenda. The construction code for the Palo Verde Units 1, 2, and 3 is ASME Code Section III, 1971 Edition, and 1973 Winter Addenda. The installation code for Palo Verde Units 1, 2, and 3 is ASME Code Section III, 1974 Edition, and 1975 Winter Addenda.

4.3 Applicable ASME Code Requirements

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."

IWB-2420 specifies successive examinations of remaining portions of the flaw that will remain in service.

IWA-3300 specifies 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.

4.4 Licensee's Proposed Alternative

Pursuant to 10 CFR 50.55a(a)(3)(i), APS proposed alternatives to the required flaw characterization of the ASME Code Section XI, IWA-3300, and successive inspections of IWB-2420. As a result of the proposed half-sleeve replacement method, APS will not be removing the remnant Alloy 600 sleeve or its attachment weld and has assumed that cracks in the remnant sleeves or attachment welds will not be removed. In lieu of fully characterizing the existing cracks, APS proposes to assume worst-case cracks in the remnant Alloy 600 sleeve and weld material.

APS also requested relief from IWB-3610 and proposed an alternative evaluation procedure based on elastic plastic fracture mechanics for portions of the flaw evaluation. IWB-3610 uses linear elastic fracture mechanics. Elastic-plastic fracture mechanics 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 requested relief from the successive inspections required by IWB-2420 and proposed no successive inspections for the remnant Alloy 600 sleeves and associated attachment weld. This request is based on the flaw evaluation of worst case cracks in the Alloy 600 base and weld material, which demonstrated compliance with ASME Code Section XI criteria for the 40-year plant life and a 20-year life extension.

APS proposed Relief Request No. 29 to be effective through the end of the 2nd ISI interval for all three units.

4.5 Licensee's Basis For The Proposed Alternative

The proposed alternative of leaving potential flaws in place in lieu of flaw characterization is based on the design of the half-sleeve repair/replacement method and analyses of postulated flaws in the remnant sleeve and associated attachment weld. APS performed linear elastic fracture mechanics and elastic-plastic fracture mechanics analysis of a postulated flaw in the remnant sleeve and associated remnant J-groove weld to demonstrate that the flaw would not affect the integrity of the pressurizer lower head. The analyses showed that the worst-case flaw in the Alloy 600 remnant sleeve and weld material will remain acceptable in accordance with ASME Section XI for the 40-year plant life and a 20-year life extension.

APS has designed the pressurizer replacement nozzle and attachment weld in accordance with the requirements of ASME Code Section III and has not requested relief from any of these requirements. As a result, the structural and leakage integrity of the primary system pressure boundary will be maintained by the repaired heater sleeve design. The ASME Code also requires the use of qualified installation (welding) and testing (PT, ultrasonic testing (UT), and pressure testing) procedures. APS, in conjunction with its vendors and associated utilities, is in the process of developing these qualified processes.

In the proposed half-sleeve repair method, there will be a gapped space in the pressurizer penetration between the remnant sleeve and the replacement half-sleeve. In that gapped space, the low alloy steel of the pressurizer base metal will be exposed to the primary coolant. The base metal may be corroded when in contact with the borated primary coolant. APS performed a corrosion analysis to demonstrate that any wastage of carbon or low alloy steel in a borated primary water environment will remain within acceptable ASME Code Section XI limits.

APS has estimated that a savings of 1.5 to 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 and corrosion analysis demonstrate compliance with ASME Code Section XI criteria for the life of the plant, including a 20-year life extension, APS requested that the proposed alternative be authorized pursuant to 10 CFR 50.55a(a)(3)(i).

5.0 <u>NRC STAFF EVALUATION</u>

5.1 Staff Evaluation of the New Repair Weld

The new repair weld serves as the primary system pressure boundary. Therefore, it must satisfy the stress criteria in ASME Code Section III as required by 10 CFR 50.55a. APS performed a stress analysis of the new sleeve weld to demonstrate that the stress criteria of

ASME Code Section III are met. Sub-article NB-3200 of Section III provides limits on primary stress, primary plus secondary stresses, and cumulative fatigue usage (CFU). APS used a three-dimensional finite element model to obtain the various stresses as specified in sub-article NB-3200.

Design basis loading conditions per the original construction documentation were considered, including pressure and thermal transient conditions. These include all normal and upset conditions, as well as any postulated accident conditions. APS' analysis results showed that stresses in all locations satisfy the allowable value and the CFU factor is less than 1.0 as required by ASME Code Section III.

The NRC staff asked APS whether sleeve ejection is possible. APS stated that since ASME Code criteria have been satisfied, including appropriate factors-of-safety, ejection of the half-sleeve is not a concern. The NRC staff finds that ejection of the new sleeve would not be likely because the attachment weld satisfies the design and analysis requirements of ASME Code Section III.

The NRC staff noted that the new pressure boundary repair weld that connects the new half-sleeve and the low alloy pressurizer base metal may contain a material triple point anomaly. The triple point is at the root of the repair weld where the half-sleeve is welded to the pressurizer base metal. Experience has shown that because of the joint geometry of the welded components, a lack of fusion may occur during solidification of the weld filler material. This is otherwise described as a welding solidification anomaly. The NRC staff raised the issue that such a flaw should be assumed at this triple point, and its stability and growth should be evaluated.

APS responded that its vendors have conducted an extensive welding development and metallurgical examination program to address the potential triple point/welding solidification anomaly. This program includes the production of approximately fifteen weldments to date, which simulate the weld geometry and triple point by welding Alloy 690 sleeves into large blocks of low alloy steel material that have been bored to simulate the pressurizer bottom head. The initial seven welding samples were slightly over-sized (2.1" inside diameter (ID) sleeves) to accommodate a larger welding head that was immediately available for testing. The last eight welding samples were field size (1.3" ID sleeves), and used the field welding head specifically developed for this repair. Welding parameters were continuously adjusted and optimized during this program, and each sample was sectioned and metallurgically examined at high magnification after welding. Although initial attempts resulted in small triple point cracks due to welding solidification problems, a production welding process was subsequently developed that consistently produces welds that contain no welding triple point defects or solidification anomalies. This is typical of over seven weldments produced using the prototype geometry and production welding head.

APS stated that by virtue of the optimized welding parameters obtained in the welding development effort, mid-wall repair welds in the field will not contain any triple point solidification anomalies. Nonetheless, since the actual installation welds on the pressurizer cannot be sectioned for metallurgical examination, APS performed a fracture mechanics evaluation to establish inspection criteria and acceptance standards for the field welds. The evaluation was conducted for two crack paths emanating from the triple point.

APS used the requirements in ASME Code Section XI, IWB-3514.3 and IWB-3514.4, to establish limits on nondestructive examination detectability for the mid-wall repair weld. If no indications are detected that exceed these limits, the welds are considered acceptable in accordance with ASME Code Section XI, IWB-3112, and no successive examinations, in accordance with ASME Code Section XI, IWB- 2420, are required.

The fracture mechanics evaluations of potential triple point indications using the flaw evaluation methods of ASME Code Section XI, IWB-3640, including fatigue crack growth evaluations for the remainder of the 60-year extended life of the plant, demonstrate that the allowable flaw sizes permitted by the standards would not grow to an unacceptable size in service. The allowable end-of-evaluation period flaw sizes were determined in accordance with Table IWB-3641-1. Stresses for the flaw evaluation were obtained from prior finite element analyses performed for the Palo Verde pressurizer mid-wall repair. Fracture mechanics fatigue crack growth calculations were then performed for both crack paths. Since the assumed triple point flaws are not exposed to the reactor water environment, PWSCC is not a factor, and APS used the fatigue crack growth law for austenitic material in air environments in ASME Code Section XI, Appendix C, Figure C-3210-1. A conservative operating temperature of 650 degrees F was assumed in the crack growth law.

APS assumed residual stresses of 50 ksi uniform through the thickness perpendicular to flaw paths. This results in a high sustained stress level, about which cycling between the various operational stress levels was superimposed. The effect of residual stresses in fatigue crack growth is to produce a high R-ratio of minimum and maximum stress intensity factor (Kmin / Kmax) which increases the crack growth rate for a given cycling amplitude.

APS' analysis results showed (1) no significant growth for assumed flaws at the triple point in 60 years; (2) there are large margins between the ASME Code Section XI standards and the flaw sizes that can be justified by fracture mechanics evaluations; and (3) the inspection detectability targets are set consistent with the ASME Code Section XI standards to eliminate successive inspections of the triple point. The NRC staff finds APS' analysis acceptable because it follows ASME Code Section XI.

Another issue APS considered was the potential corrosion of the pressurizer base metal after the repair. The final configuration of the mid-wall repair results in a crevice between the original sleeve, the new sleeve, and the pressurizer base metal inside the penetration. The pressurizer base material is made of low alloy steel which is subject to corrosion in borated water. APS' corrosion analysis of the pressurizer base metal is based on the Westinghouse report, WCAP-15973-P, Revision 1, "Low Alloy Steel Component Corrosion Analysis Supporting Small Diameter Alloy 600/690 Nozzle Repair/Replacement Program." Westinghouse evaluated worst-case corrosion conditions in the primary water environment for the nozzle repairs in its report.

The Westinghouse report showed that the bounding case for small diameter Alloy 600 nozzles such as heater sleeve nozzles has a corrosion rate of 0.00153 inch per year. Westinghouse concluded that the minimal amount of corrosion that may occur, due to the low oxygenated environment, is well within the acceptable limits identified in ASME Code Section XI. The report also considered the effects of corrosion product buildup in the crevices such that the crevice will eventually become packed with dense corrosion product which will insulate the pressurizer base metal from primary water environment. This will cause the corrosion process of the pressurizer base metal to be reduced over a period of time.

APS also considered the inspection of the new repair weld. For the pre-service inspection, APS will examine the new sleeve attachment weld by UT and PT in accordance with the ASME Code Section III. The weld will be pressure tested in accordance with the ASME Section XI and no leakage is allowed during the pressure test. The installation will meet acceptance criteria of sub-article NB-5330 for UT and sub-article NB-5350 for PT. A system leakage test will be performed at normal operating pressure after sleeve installation in accordance with ASME Code Section XI IWA-4700 and Code Case N-416-1.

For the ISI, APS will perform: (1) ISI in accordance with the ASME Code Section XI requirements, including a VT-2 visual examination for leakage through the partial penetration weld that joins the sleeve to the pressurizer vessel wall under Section XI Category B-E examination. The Category B-E examination is required to be performed each 10-year interval; (2) a supplemental VT-2 on all heater sleeves each refueling outage; and (3) a VT-2 visual examination for leakage through the partial penetration weld under Category B-P examination. The Category B-P examination is required to be performed after each refueling outage under normal operating pressure and temperature.

In addition, by letter dated July 22, 2004, APS provided its response to the information requested by NRC Bulletin 2004-01, "Inspection of Alloy 82/182/600 Materials Used in the Fabrication of Pressurizer Penetrations and Steam Space Piping Connections at Pressurized-Water Reactors." In its response, APS committed to adopt the three inspection elements proposed by the Westinghouse Owners Group dated January 30, 2004, (ADAMS ML040480309). The three inspection elements are stated below:

1. Perform a bare metal visual inspection of 100% of all pressurizer heater sleeve locations in such a way that visual access to the bare metal 360 degrees around each sleeve can be attained.

2. Perform non-destructive examination (NDE) capable of characterizing crack orientation of all sleeves for which visual inspection shows evidence of leakage. The NDE of each leaking sleeve will be performed prior to repair of the sleeve.

3. If the NDE defines the flaw as potential circumferential cracking below the sleeve attachment weld, the NRC will be notified immediately and an appropriate inspection plan will be developed. The plan will define additional sleeves to be inspected by NDE sufficient to determine the extent of condition commensurate with the characterization of the flaw.

The NRC staff is reviewing the APS response to Bulletin 2004-01 in an effort separate from this relief request review. The NRC staff's decision on the APS response to Bulletin 2004-01 will not affect the staff's evaluation of this relief request because the response is not the primary basis upon which the NRC staff evaluated this relief request. However, APS' commitment to perform additional inspections will provide additional assurance of the integrity of the half-sleeve replacement.

The NRC staff finds that the new repair weld to attach the half-sleeve to the pressurizer penetration is acceptable because APS has demonstrated that (1) the weld satisfies the structural integrity of the ASME Code Section III by analysis; (2) its analysis shows that a postulated flaw at the weld triple point will not exceed the allowable flaw size in 60 years; and (3) APS will perform preservice and ISI to assure the structural and leakage integrity of the sleeves.

5.2 Staff Evaluation of the Remnant Sleeve Weld

As discussed above, APS proposed not to examine the remnant attachment weld and remnant original half-sleeve after sleeve replacement because performing flaw characterization and successive examinations would be impractical. It is impractical because of the following factors: (1) the current technology is not available for ultrasonic examinations of the remnant weld due to the weld configuration; (2) the examination of the remnant welds may damage the heaters because they have to be removed from the sleeves; and (3) the inspection of remnant welds would incur high radioactive doses. In accordance with ASME Code Section XI, APS needs to show by analysis that any potential flaw(s) in the remnant weld and sleeve will be stable. If it does grow, it will not grow to beyond an allowable flaw size for the remaining life of the plant. APS used linear elastic fracture mechanics and elastic-plastic fracture mechanics in its flaw evaluation.

Linear Elastic Fracture Mechanics Calculations

APS assumed a worst-case flaw geometry based upon PWSCC initiation and growth through the entire remnant sleeve, original J-groove weld, and overlay material. All locations in the weld are assumed to be cracked. In addition, APS conservatively postulated that the same flaw configuration is on both the uphill side and downhill side of the heater sleeve centerline. An initial flaw length of 0.6 inch is assumed. The thickness of the overlay material is 0.5 inch, which results in a 0.6-inch overlay thickness in a direction parallel to the heater sleeve axis. The 0.6-inch dimension includes the length from the crack tip to the interface with the pressurizer base metal. The NRC staff finds that this flaw length is acceptable because the entire weld in the axial direction is conservatively assumed to be cracked.

APS used three-dimensional finite element techniques in the linear elastic fracture mechanics analyses to analyze the postulated flaw. The stresses from the finite element analyses were used as input to the linear elastic fracture mechanics calculations.

The NRC staff raised an issue of how the weld residual stresses are modeled in the flaw evaluation. APS responded that the effect of weld residual stresses was evaluated as follows: A three-dimensional finite element model of a heater sleeve with axisymmetric geometry was developed. The model was subjected to the process used during original construction. Weld overlay material was applied to the base material, and then post-weld heat treated. The model then incorporated the bore hole and machining of the J-groove weld. The J-groove weld and cover fillet were then applied to the model. The model was subjected to a hydrostatic test pressure, where the pressure was increased to account for the increased pressure stresses in the heater sleeve located furthest away from the pressurizer centerline. The resulting stresses were applied to a fracture mechanics finite element model, and the resulting applied stress intensity factors at the interface between the overlay material and pressurizer bottom head base material were found to be insignificant.

The largest applied stress intensity factor in the base material is at the interface with the bore hole. Therefore, APS postulated that the flaw grows along the bore hole. As to crack arrest, APS assumed the PWSCC growth to arrest at the intersection of the overlay material and the pressurizer base material. Further growth into the base material is postulated to be through a fatigue crack growth mechanism. Crack growth due to fatigue is analyzed based on the methodology in Appendix A to the ASME Code Section XI. The fatigue crack growth analyses show that after 60 years of operation, the postulated initial flaw of 0.6 inch grew to a depth of 1.16 inches, which is less than the allowable flaw size of 1.2 inches, and therefore, the fatigue crack growth is acceptable.

APS calculated the stress intensity factor for the following five loading events: cooldown, end of cooldown, trip maximum thermal stress, trip maximum pressure stress, and loss of secondary pressure. The linear elastic fracture mechanics calculation results show that for four of the five events, the safety factors associated with the stress intensity factors exceed / 10 as required by ASME Code Section XI, IWB-3612(a) and therefore are acceptable. However, for the end-of-cooldown transient, the safety factor was calculated to be less than / 10.

For the end-of-cooldown transient, APS calculated an applied stress intensity factor of 22.9 ksi / in. The allowable stress intensity factor of 47 ksi / in was calculated based upon a safety factor of / 2. If the safety factor of / 10 was used, the allowable stress intensity factor would have been 21 ksi / in. This would result in the applied stress intensity factor of 22.9 ksi / in, exceeding the allowable stress intensity factor 21 ksi / in.

APS obtained the safety factor of / 2 based on an ASME Code interpretation, File Number IN 03-013, issued by the ASME International on September 8, 2003 (as shown in the August 24, 2004 submittal). In addition, APS stated that IWB-3613 allows a safety factor of / 2 to be applied to the allowable stress intensity factor for structural discontinuity around flanges and shell regions. APS stated that the shell region near a heater sleeve is also a structural discontinuity, and the criteria of IWB-3613 should apply to this structural discontinuity. This would allow the use of a factor of safety of / 2.

The NRC staff does not routinely recognize ASME Interpretations. The NRC staff also does not agree with APS' interpretation of IWB-3613 in the application of / 2. The NRC staff believes that the safety factor of / 10 should be considered in accordance with IWB-3613. However, although the safety factor for the end-of-cooldown transient is less than / 10, the NRC staff does not believe that a postulated flaw in the remnant weld will affect the structural integrity of the pressurizer lower head significantly because (1) the safety factor of the end-of-cooldown transient is 2.9 which is not much lower than / 10 (=3.16); and (2) the postulated flaw is shown to be stable in the elastic-plastic fracture mechanics calculations as discussed below.

Elastic-Plastic Fracture Mechanics Calculations

Before elastic-plastic fracture mechanics can be used in a flaw evaluation, certain analytical criteria need to be satisfied. APS used the screening criteria in Appendix H to the ASME Code Section XI to determine whether elastic-plastic fracture mechanics is applicable to evaluate the postulated flaw in the pressurizer remnant sleeve and remnant weld. APS showed that the postulated flaw in the sleeve and weld satisfies the screening criteria of Appendix H; therefore, elastic-plastic fracture mechanics is applicable to the flaw evaluation. The NRC staff finds that elastic-plastic fracture mechanics is acceptable to be used in the flaw evaluation because APS has followed the procedures in Appendix H to show that the flaw geometry in question satisfies the screening criteria in Appendix H.

APS also used the methodology in Appendix K to the ASME Code Section XI as a guide in the elastic-plastic fracture mechanics calculations. The intent of Appendix K is to provide guidance on using elastic-plastic fracture mechanics for the evaluation of flaws in the reactor vessel beltline region. The Appendix K methodology considers the ductility of the low alloy steel of the reactor vessel in resisting sudden propagation and catastrophic failure of a postulated flaw in the reactor vessel. The fracture mechanics approach in Appendix K is based on the concept of the J-integral in which fracture toughness of a material, represented by the J-Resistance curve, is the allowable limit. The applied J-integral value derived from the postulated flaw is then compared to the allowable limit (J-Resistance value). If the applied J-integral value is less than the allowable limit, the flaw would be stable and acceptable. If the applied J-integral value exceeds the allowable limit, the flaw would be unstable and unacceptable.

The NRC staff notes that the stress intensity factor methodology in Appendix K is not applicable to the flaw geometry in the J-groove weld and heater sleeve in the pressurizer lower head because the stress intensity factor calculation in Appendix K is primarily used to evaluate the flaw in the reactor vessel beltline region. The reactor vessel beltline region and the pressurizer lower head are two different structural components. However, the J-integral methodology in Appendix K may be used because it is generic and can be applied to different flaw geometries in different structural components. APS did not use the Appendix K method to calculate the stress intensity factors. Instead, the stress intensity factors associated with the flaw were calculated based on linear elastic fracture mechanics and finite element analysis of the Palo Verde pressurizer lower head as discussed above.

The J-integral method requires data on the resistance of the material (i.e., pressurizer lower head) which can be obtained from Charpy V-notch upper shelf energy. APS stated that the Charpy V-notch energy of the pressurizer lower head ranges from a minimum of 98 ft-lbs up to a maximum of 117 ft-lbs at or near the upper shelf temperature. The upper shelf energy data were taken from tests of the actual Palo Verde pressurizer base material specimens in the transverse orientation. The upper shelf energy data taken from the transverse orientation are required by 10 CFR Part 50, Appendix G(IV)(A)(1) for the reactor vessel beltline base material and therefore is appropriate for the pressurizer base metal. The upper shelf energy values were based on testing conducted at 50 degrees F. Upper shelf energies applicable at plant operating temperatures are expected to be higher. APS used the minimum Charpy upper shelf energy (98 ft-lbs) to construct the J-Resistance curve, which is appropriate. The J-Resistance curve is constructed based on guidance in NUREG-0744, Volume 2, Revision 1, “Resolution of the Task A-11 Reactor Vessel Materials Toughness Safety Issue.”

In the elastic-plastic fracture mechanics calculations, APS assumed two initial flaws with a length of 0.6 inch and 1.2 inches. The technical basis of the 0.6-inch flaw was discussed above. The 1.2-inch dimension is an arbitrary crack length that APS selected for analytical purposes. It is a flaw size that the elastic-plastic fracture mechanics analyses found to be acceptable. The NRC staff finds that a postulated flaw of 1.2-inch long is conservative and, therefore, is acceptable. APS’ results show that the applied J-integral values of both postulated flaws are within the allowable J-resistance value when the safety factors of 3 and 1.5 are applied to the primary stresses and secondary stresses, respectively.

The NRC staff finds that APS' proposed safety factors of 3 on primary stresses and 1.5 on secondary stresses are acceptable when compared to the safety factor of / 10 required by IWB-3613 because the J-Resistance value for the pressurizer lower head material is higher than the applied J-integral value at the crack tip, which indicates that the pressurizer base metal has sufficient resistance to maintain crack stability. The safety factor of / 10 was strictly applicable to the linear elastic fracture mechanics calculations.

The NRC staff concludes that the proposed alternatives to ASME Code, Section XI, IWA-3300, IWA-4310, IWB-2420, IWB-3142.4, and IWB-3610 pertaining to the remnant sleeve welds are acceptable because (1) APS has demonstrated by linear elastic fracture mechanics and elastic-plastic fracture mechanics analyses that a worst-case flaw in the remnant weld and sleeve will not adversely affect the structural and leakage integrity of the pressurizer lower head; and (2) APS has demonstrated that the postulated crack will not grow into the pressurizer lower head base metal significantly. As a result of APS' analysis, the proposed alternative provides reasonable assurance of structural integrity of the pressurizer lower head.

6.0 CONCLUSION

On the basis of information submitted, the NRC staff determines that compliance with the Code requirements regarding flaw characterization and successive examinations of the remnant sleeves and welds is impractical and that the proposed alternatives provide an acceptable level of quality and safety. The NRC staff concludes that granting relief pursuant to 10 CFR 50.55a(g)(6)(i) is authorized by law and will not endanger life or property or the common defense and security, and is otherwise in the public interest giving due consideration to the burden upon the licensee that could result if the requirements were imposed on the facility. Therefore, pursuant to 10 CFR 50.55a(g)(6)(i), relief is granted from the requirements of ASME Code, Section XI, IWA-3300, IWA-4310, IWB-2420, IWB-3142.4, and IWB-3610 pertaining to the remnant heater sleeves and remnant welds in the pressurizer through the end of the second 10-year ISI interval at the Palo Verde, Units 1, 2, and 3.

All other requirements of the ASME Code, Section III and XI for which relief has not been specifically requested and approved remain applicable, including third party review by the Authorized Nuclear Inservice Inspector.

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