From: <rainsbjl@songs.sce.com>
To: "N. Kaly Kalyanam" <NXK@nrc.gov>
Date: 3/16/06 3:43PM
Subject: Re: Fwd: SONGS Unit 2: Relief Request ISI-3-17 Pressurizer instrument line repair TAC MC9434 and 9488

They are being boxed now. You may wish to try to intercept them in your mail room (or whereever Fed Ex delivers). We usually hear from Fed Ex that the delivers are made to your offices around 9 or 10 in the morning your time.

CALCULATION M-DSC-360.
SONGS 2&3
EVALUATION OF HALF-NOZZLE
REPAIR ~~of~~ FOR PZR AND
SG INST. NOZZLE
UNDER LONG-TERM
SERVICE

DOCKET 50-361, 362
DATE: 03-20-06

"N. Kaly Kalyanam" <NXK@nrc.gov>
03/16/2006 08:32 AM

To <rainsbjl@songs.sce.com>
cc
Subject Fwd: SONGS Unit 2: Relief Request ISI-3-17 Pressurizer instrument line repair TAC MC9434 and 9488

Jack,

Can you provide the documents John Tsao has identified in the attached email?

Thanks

Kaly

----- Message from "John Tsao" <JCT@nrc.gov> on Thu, 16 Mar 2006 09:55:01 -0500 -----

To: "N. Kaly Kalyanam" <NXK.OWGWPO02.HQGWDO01@nrc.gov>

cc: "Kimberly Gruss" <KAG1.twf4_po.TWFN_DO@nrc.gov>

Subject: SONGS Unit 2: Relief Request ISI-3-17 Pressurizer instrument line repair TAC MC9434 and 9488

Kaly,

RE: SONGS Unit 2: Relief Request ISI-3-17 Pressurizer instrument line repair TAC MC9434 and MC9488

I would like the licensee to mail us a copy of the following reports:

1). M-DSC-414, Rev. 0, "SONGS Unit 2 & 3 Pressurizer Lower Level and Thermowell Nozzles J-Weld Fracture Mechanics Evaluation."

2). M-DSC-411, Revision 0, "SONGS Unit 2 and 3 Pressurizer Lower Level Nozzle Welding and Transient Analysis."

3). M-DSC-360, Revision 0, "Evaluation of Half Nozzle Repair for PZR and SG INST. Nozzles under Long-Term Service Conditions -SONGS 2 and 3."

I am wondering if the licensee can simply forward a copy of the reports without formal submittal. I will take a look at the reports. If I think the reports need to be on the docket (i.e., if I use the information in my SE) we can put the reports on the docket later. This is to expedite the review process due to the short fuse of the SE.

Also I would like SONGS to fedex the reports to us due to the short fuse of the SE.

The purpose of reviewing the reports is to confirm what SONGS said in its relief request is acceptable. Also, SONGS relief request contains no numerical values and is sketchy in flaw evaluations.

CALCULATION TITLE PAGE

ICCN NO./ PRELIM. CCN NO.	PAGE ___ OF ___
	CCN CONVERSION: CCN NO. CCN-

Calc. No. M-DSC-360 DCP/FIDCN/FCN No. & Rev. ________

Subject Evaluation of Half-Nozzle Repair for PZR and SG Inst. Nozzles Under Long-Term Service Sheet 1 of 101

System Number/Primary Station System Designator 1201 / BBB SONGS Unit 2 & 3 Q-Class 1

Tech. Spec. Affecting? ◉ NO ○ YES, Section No. N/A Equipment Tag No. ________

Site Programs/Procedure Impact? ◉ NO ○ YES, AR No. ________

CONTROLLED COMPUTER PROGRAM/ DATABASE	☐ PROGRAM ☐ DATABASE ACCORDING TO SO123-XXIV-5.1	PROGRAM/DATABASE NAME(S) ☒ ALSO, LISTED BELOW BIGIF	VERSION/RELEASE NO.(S) 1.0

RECORDS OF ISSUES

REV. / DISC.	DESCRIPTION	TOTAL SHTS. / LAST SHT.	PREPARED (Print name/sign/date)	APPROVED (Signature/date)	
0	Initial Issue	101	ORIG. Russell Cipolla [signature] 5/27/98	FLS [signature] 9/9/98	Other
	-	101	IRE Michael J. Crowford [signature] 7/27/98	Other	Other
			ORIG. Nabil M. El-Akily N.M. El-Akily / 7/27/1998	FLS	Other
			IRE Jun Gaot J-Gao 7/27/98	Other	Other
			ORIG.	FLS	Other
			IRE	Other	Other
			ORIG.	FLS	Other
			IRE	Other	Other

Space for RPE Stamp, identify use of an alternate calc., and notes as applicable.

Note: This calculation provides the long-term Justification/Evaluation report on the modified PZR and SG Instrument Nozzle performed by Aptech Engineering Services for Songs 2&3.

This calc. was prepared for the identified DCP/FCN. DCP/FCN completion and turnover acceptance to be verified by receipt of a memorandum directing DCN Conversion. Upon receipt, this calc. represents the as-built condition. Memo date ________ by ________

CALCULATION CROSS-INDEX

ICCN NO./ PRELIM. CCN NO.	PAGE ____ OF ____
CCN CONVERSION: CCN NO. CCN-	

Calculation No. M-DSC-360 Sheet No. 2 of ____

Calc. rev. number and responsible FLS initials and date	INPUTS These interfacing calculations and/or documents provide input to the subject calculation and if revised may require revision of the subject calculation.		OUTPUTS Results and conclusions of the subject calculation are used in these interfacing calculations and/or documents.		Does the output interface calc/ document require revision?	Identify output interface calc/document CCN, DCN, TCN/Rev., FIDCN, or tracking number.
	Calc / Document No.	Rev. No.	Calc / Document No.	Rev. No.	YES / NO	
0 RCL 9/8/98	M-DSC-279 M-DSC-351 M-DSC-354	0 1 0	M-DSC-279	0	Yes	ICCN # C-11

M-DSC-360 SH. 3

CALCULATION COVER SHEET

CONTROLLED

Calculation No.: AES-C-3247-1

Client: Southern California Edison Company

Title: Evaluation of Half-Nozzle Repair for Pressurizer and Steam Generator Instrumentation Nozzles Under Long-Term Service Conditions — SONGS 2 and 3

Project No.: AES 97123247-1Q

APTECH Office: Sunnyvale

Sheet No. 1 of 69

☐ **Uncontrolled** ■ **Controlled**

Document Control No.: I-2

Purpose: This calculation documents the evaluation performed to assess the long-term service of the Alloy 690 half-nozzle repair, as designed for use in the pressurizer and steam generator. The evaluation is based on a fracture mechanics analysis of the repair geometry conservatively postulating flaws to exist in the low alloy steel base metal. Both fatigue crack growth and borated water corrosion are evaluated in this calculation.

Assumptions: The analysis assumptions are described in Section 3.

Results: The results of this calculation are summarized in Section 2. The evaluation period covered by this calculation is a 40-year service life, considering all loads from the original design. The postulated degradation for corrosion and fatigue for the evaluation period will be acceptable to the safety margins of ASME Section XI under IWB-3600.

Revision No.	Prepared By / Date	Checked By / Date	Verified By / Date	Approved By / Date	Revision Description
0	RCC 5/8/98	MTC 8 MAY 98	MTC 8 MAY 98	RCC 5/11/98	Initial Release

APTECH® ENGINEERING SERVICES, INC.

CIAN45
REV. 8/96

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EC&FS DEPARTMENT

CALCULATION SHEET

ICCN NO./ PRELIM. CCN NO.	PAGE ___ OF ___
	CCN CONVERSION: CCN NO. CCN -

Project or DCP/FCN SONGS 2&3 Calc No. M-DSC-360

Subject See Title Sheet Sheet 6 of ___

REV	ORIGINATOR	DATE	IRE	DATE	REV	ORIGINATOR	DATE	IRE	DATE
	Nabil M. El-Akily	07/24/98	Jun Gaor	07/24/98					

REV INDICATOR

APPENDIX D - EVALUATION OF THE EFFECT OF THE MNSA HOLES ON THE NOZZLE STRESSES

D-1 OF D-5

1.0 INTRODUCTION

The pressurizer and steam generators at San Onofre Nuclear Generating Station, Units 2 and 3 (SONGS 2 and 3) are provided with small diameter instrumentation nozzles. The original nozzles are 3/4 inch and 1 inch nominal pipe size (NPS) fabricated from Inconel 600. These nozzles penetrate the head/shell and are attached at the inside surface by a J-groove weld.

A replacement nozzle design, called a half-nozzle design and fabricated from Inconel 690, has been developed by Southern California Edison Company (SCE). The replacement nozzle is of similar configuration to the original design except that the attachment weld is located on the outside diameter (OD) of the head/shell, rather than on the inside diameter (ID).

The compliance of the half-nozzle repair design to American Society of Mechanical Engineers (ASME) Section III (Ref. 1) has been satisfied by explicit code calculations (Refs. 2 through 4). The stress allowable limits were satisfied for all design requirements of the original design specification, including normal operating, upset, faulted, and test conditions. The nozzle fatigue exemption requirements of NB-3222.4(d) were also satisfied.

The new half-nozzle design will replace the existing Inconel 600 nozzles in the event that repairs to the original nozzles become necessary. The original nozzle configurations are shown in Figures 1-1 and 1-2 (Refs. 3 and 4). As previously mentioned, the original nozzle is attached to the head/shell by a J-groove weld at the ID. The replacement design for the pressurizer bottom head is illustrated in Figure 1-3 (Ref. 4). Similarly, the replacement designs for the pressurizer shell and the steam generator primary head nozzles are shown in Figures 1-4 and 1-5 (Refs. 2 and 3). The new design is installed by first cutting and removing an outer segment of the existing nozzle, laying down a base pad of Inconel 690 on the OD by welding, and installing the new Inconel 690 nozzle by a J-groove attachment weld with a reinforcing fillet to the base pad. The inner segment or stub and J-groove weld of the original nozzle is left in place.

The purpose of this calculation is to evaluate the long-term acceptance of the half-nozzle configuration, specifically the possibility of flaws remaining in the inner nozzle stub and the possible corrosion of the low allow steel head/shell material, which is now exposed to primary (borated) water. The overall objectives are to evaluate postulated flaws in the nozzle stub to assess the potential of flaw propagation during plant operation and to determine the extent of borated water corrosion (BWC) within the annulus between the nozzle and head/shell penetration. In performing this evaluation, the postulated flaws and corrosion degradation are conservatively assessed as cracks oriented in the worst possible manner, as discussed herein.

The evaluated conditions addressed in this evaluation are pressure, mechanical loads, and design basis transients. The design cycles for a 40 year design life are imposed to justify long-term acceptance. The flaw evaluation procedures and acceptance criteria of ASME Section XI, Appendices A and H, are used as guidance in completing the calculations (Ref. 5).

Mechanical Nozzle Seal Assemblies (MNSA) were installed on SONGS Unit 2 pressurizer and steam generator E089 during Cycle 9 mid-cycle outage. Each MNSA installation requires drilling four bolt holes in the vessel wall to attach the MNSA. An evaluation of the effect of the MNSA holes on the stresses in the nozzle is included in Appendix D of this calculation.

nme 07/20/98 JFC. 7/23/98

Calculation No.: AES-C-3247-1	Made by: RLC	Date: 5/8/98	Client: SCE
Title: Evaluation of Half-Nozzle Repair for Pressurizer and Steam Generator Instrumentation Nozzles Under Long-Term Service Conditions — SONGS 2 and 3	Checked by: MTC	Date: 8 MAY 98	Project No.: AES 97123247-1Q
	Revision No.: 0	Document Control No.: I-2	Sheet No.: 6 of 69

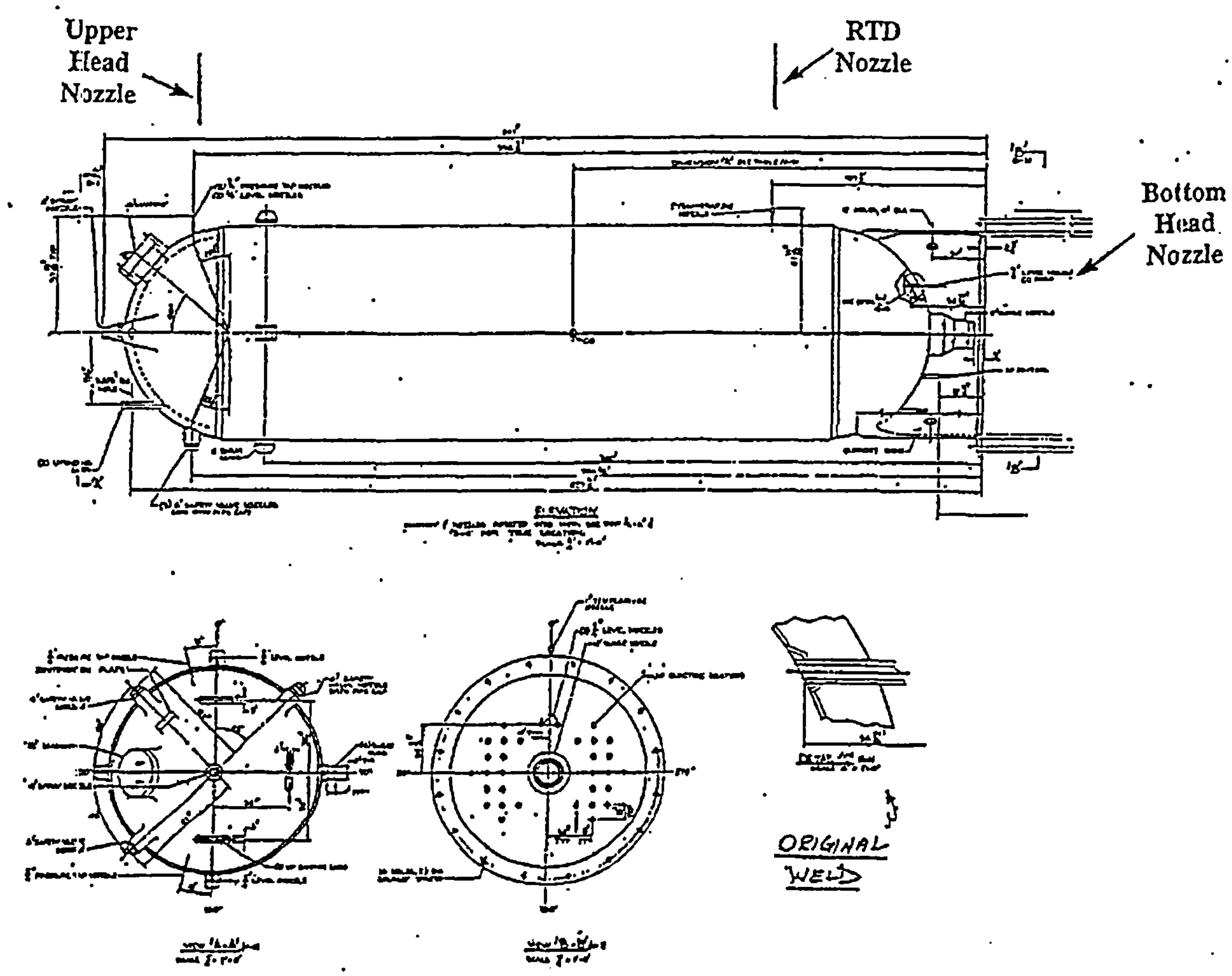

Figure 1-1 — Illustration Showing the Original Nozzle Configurations for the Pressurizer.

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M-DSC-360 SH. 10

Calculation No.: AES-C-3247-1	Made by: RLL	Date: 5/8/98	Client: SCE
Title: Evaluation of Half-Nozzle Repair for Pressurizer and Steam Generator Instrumentation Nozzles Under Long-Term Service Conditions — SONGS 2 and 3	Checked by: MTC	Date: 8 MAY 98	Project No.: AES 97123247-1Q
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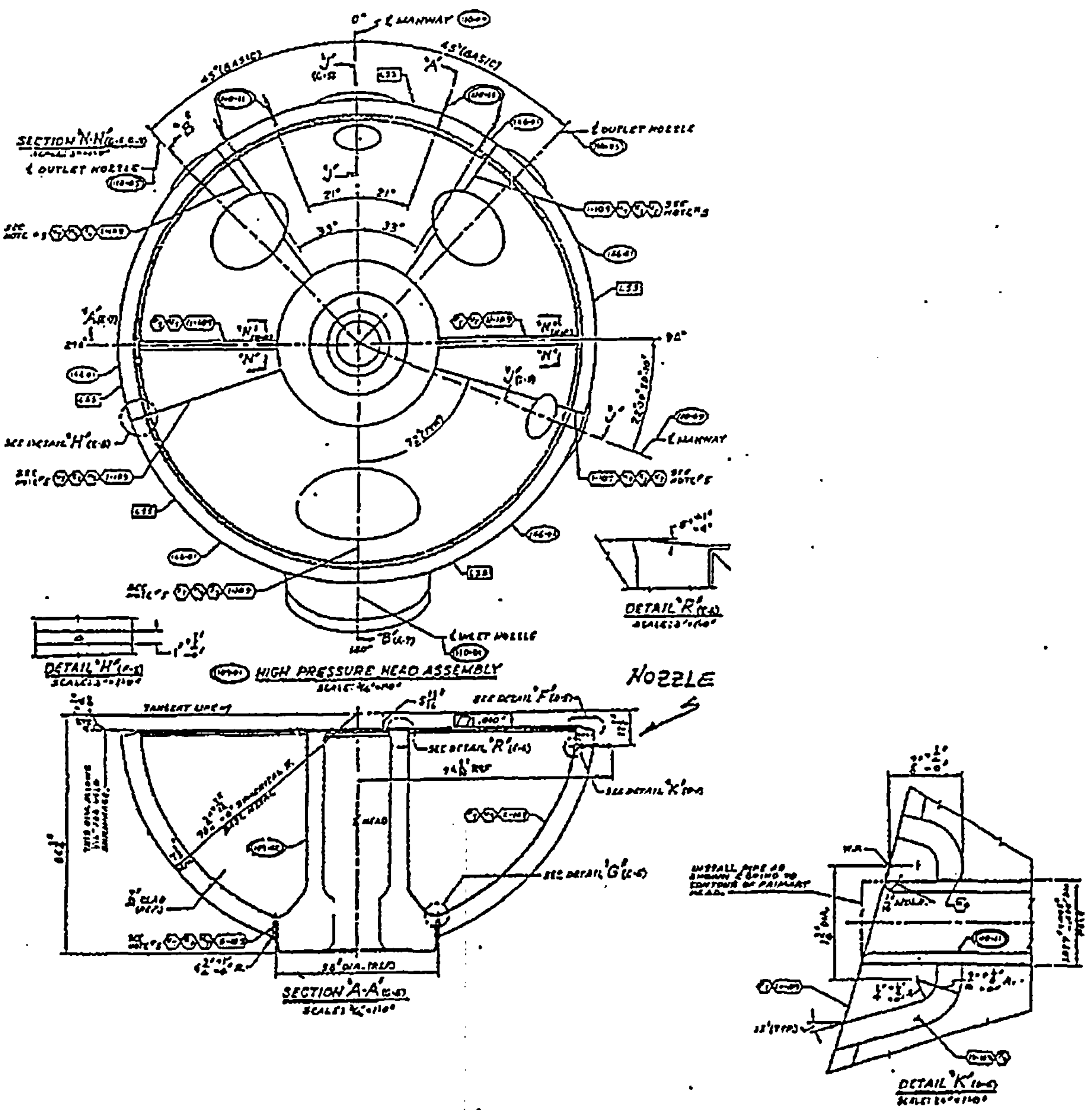

Figure 1-2 — Illustration Showing the Original Nozzle Configuration for the Steam Generator Primary Head.

Calculation No.: AES-C-3247-1	Made by: RCC	Date: 5/8/98	Client: SCE
Title: Evaluation of Half-Nozzle Repair for Pressurizer and Steam Generator Instrumentation Nozzles Under Long-Term Service Conditions — SONGS 2 and 3	Checked by: MTC	Date: 8 MAY 98	Project No.: AES 97123247-1Q
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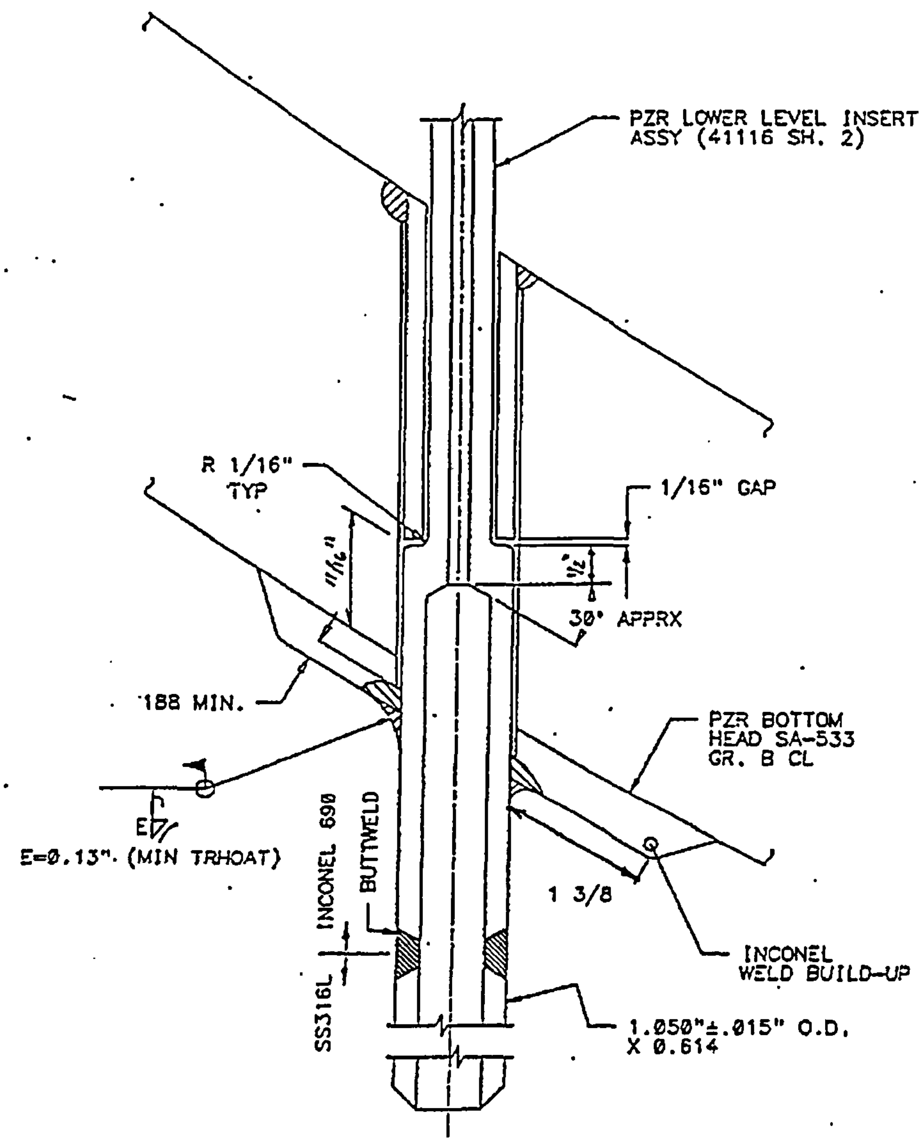

Figure 1-3 — Illustration Showing the Replacement Nozzle Design for the Pressurizer Bottom Head.

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Calculation No.: AES-C-3247-1	Made by: RCC	Date: 5/8/98	Client: SCE
Title: Evaluation of Half-Nozzle Repair for Pressurizer and Steam Generator Instrumentation Nozzles Under Long-Term Service Conditions — SONGS 2 and 3	Checked by: MTC	Date: 8 May 98	Project No.: AES 97123247-1Q
	Revision No.: 0	Document Control No.: I-2	Sheet No.: 9 of 69

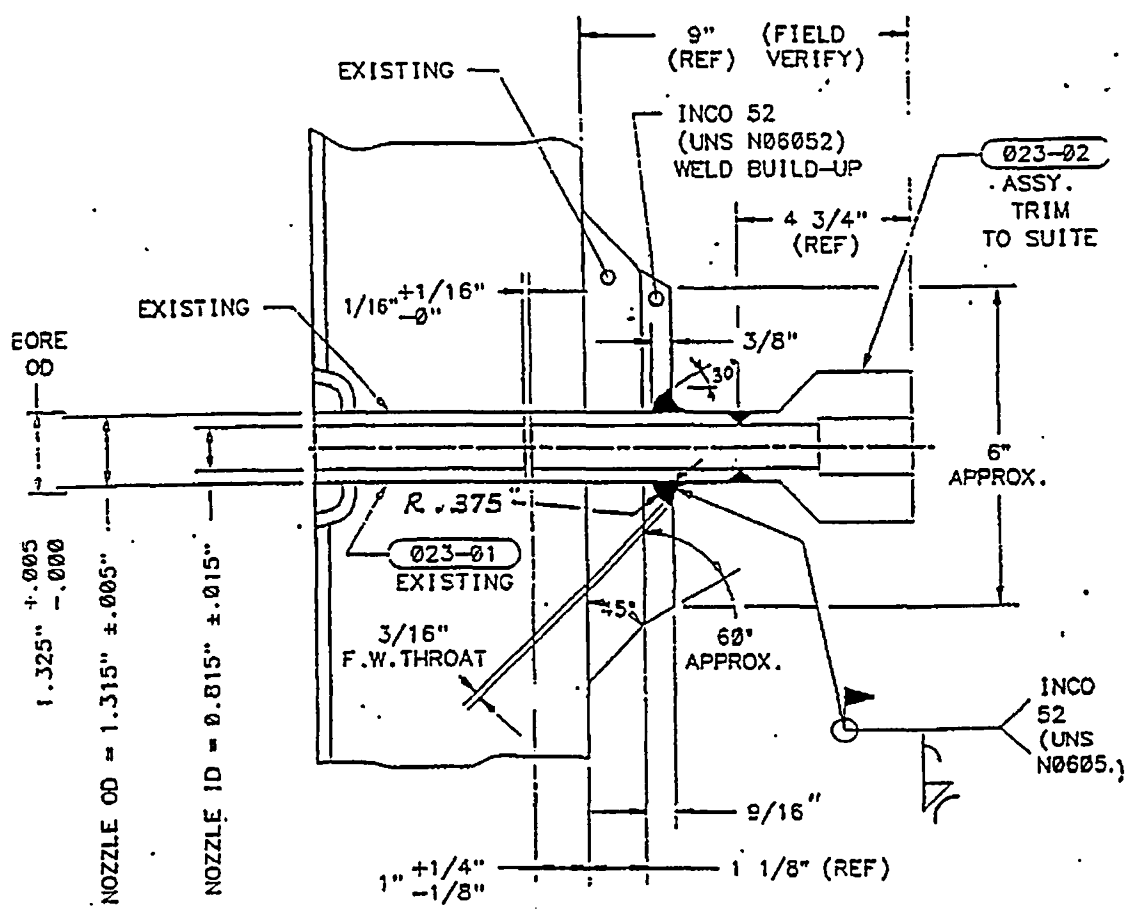

Figure 1-4 — Illustration Showing the Replacement Nozzle Design for the 1-Inch RTD Nozzle in the Pressurizer.

Calculation No.: AES-C-3247-1	Made by: RCC	Date: 5/8/98	Client: SCE
Title: Evaluation of Half-Nozzle Repair for Pressurizer and Steam Generator Instrumentation Nozzles Under Long-Term Service Conditions — SONGS 2 and 3	Checked by: MTC	Date: 8 MAY 98	Project No.: AES 97123247-1Q
	Revision No.: 0	Document Control No.: I-2	Sheet No.: 10 of 69

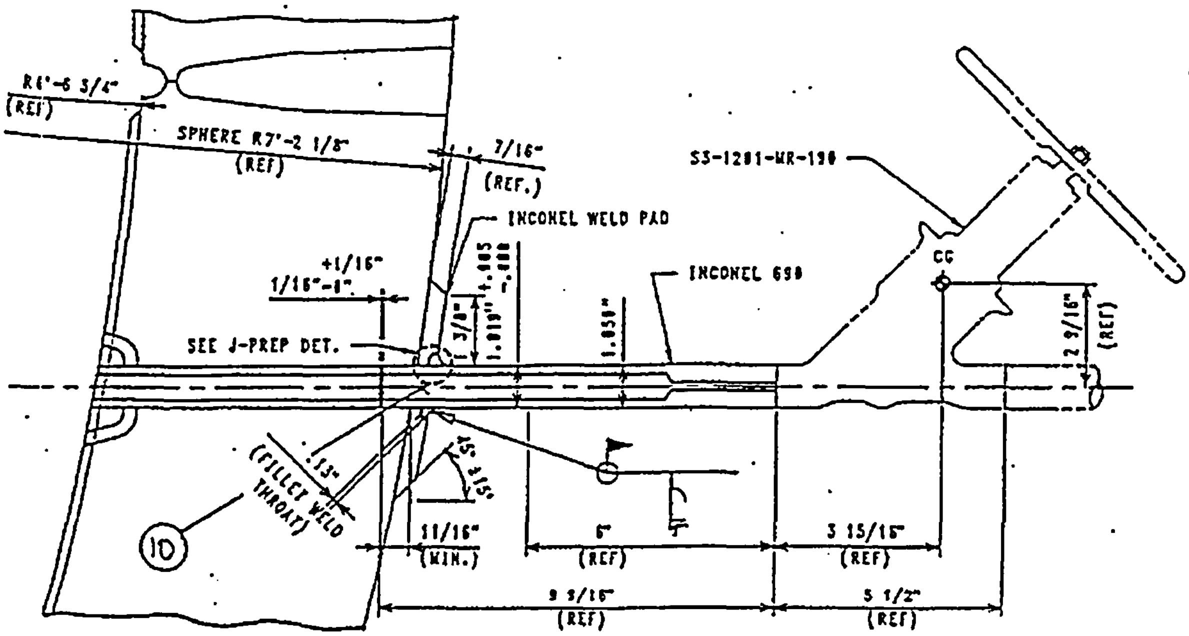

Figure 1-5 — Illustration Showing the Replacement Nozzle Design for the Steam Generator Primary Head.

2.0 SUMMARY

2.1 Scope and Objectives

A fracture mechanics-based evaluation has been performed to justify the long-term acceptance of the half-nozzle design for repair of existing Inconel 600 instrumentation nozzles in the pressurizer and steam generator. The long-term service of the half-nozzle design is subject to two postulated degradation mechanisms: (1) the existence of axial cracks in the remaining nozzle stub at the original J-groove attachment weld and (2) BWC of the low alloy steel head, which is now in contact with primary water. The flaw evaluation rules and acceptance criteria of ASME Section XI were employed to establish the allowable service life for the replacement design.

2.2 Nozzle Stub Flaw Evaluation

The cracks postulated to remain in the original nozzle stub were conservatively evaluated. The highest computed stresses for the nozzles were used to envelop the service conditions for all instrumentation nozzles subject to repair. A large 1-inch depth corner crack, penetrating into the low alloy steel head/shell was conservatively assumed to bound the size of any remaining in the Inconel 600 material. The postulated flaw is illustrated in Figures 4-1 and 8-1. Fracture mechanics and fatigue crack growth analyses following the procedures of ASME Section XI, Appendix A, were completed to determine the allowable flaw depths and service life. The calculations for this evaluation are given in Section 8.1.

The allowable flaw depth is computed to be 2.59 inches. The acceptance criterion is based on maintaining a minimum safety factor of $\sqrt{10}$ on load for normal and upset loading conditions and $\sqrt{2}$ on load for emergency and faulted conditions, whichever is limiting. For the completed evaluation, the limiting service condition is the hydrotest for which the smallest allowable flaw depth is calculated (i.e., a_{allow} = 2.59 inches). The maximum flaw growth for the postulated initial flaw (a_o = 1 inch) for a 40-year design life is computed to be 0.37 inch. Therefore, the final crack depth is calculated to be 1.37 inches < a_{allow} = 2.59 inches and is therefore acceptable for a 40 year design life. Based on this evaluation, any flaws remaining in the nozzle stub will be acceptable to the safety margin requirements of ASME Section XI under IWB-3600.

2.3 Borated Water Corrosion Evaluation

The potential BWC of the low alloy steel head/shell material was conservatively evaluated. Local corrosion was modeled as a circumferential planar groove within the hole penetration. The postulated corrosion damage is shown in Figure 4-2. The integrity of the nozzle attachment was determined as a function of location of BWC within the hole, and depth and length of the corrosion groove. A limit load-based evaluation (including fatigue crack growth) was completed following the general approach of ASME Section XI, Appendix H, for flaws in ferritic piping. The allowable corrosion depths and lengths were established based on maintaining a minimum safety factor of 2.77 for normal and upset service conditions and 1.39 for accident conditions.

The allowable corrosion depths were computed at two hole penetration locations: (1) at the gap region between the new nozzle and the remaining nozzle stub and (2) in the crevice region at the nozzle-to-pad weld. The allowable corrosion depths for a 360° circumferential groove are summarized below:

Location	Allowable Corrosion Size	
	Depth	Length
Gap Region	> 0.50 inch	360°
Crevice Region	0.42 inch	360°

The computed corrosion growth rates and maximum flaw growth by fatigue (FCG) for a 40-year design life are as follows:

Location	Flaw Depths (inches)		
	BWC	FCG	Total
Gap Region	0.144	0.0007	0.15
Crevice Region	0.064	0.002	0.07

The total corrosion depths (including fatigue), after 40 years of service, are computed to be less than the allowable corrosion depths. Therefore, the safety margin requirements of ASME Section XI will be satisfied for the half-nozzle attachment weld design.

2.4 Allowable Flaw Depths

The allowable flaw depths for nozzle stub flaws and BWC degradations for use as inspection standards are developed in Section 8.3. The computed results are given in Figures 8-3 and 8-4.

3.0 ANALYSIS ASSUMPTIONS

The following general assumptions regarding methods and analysis parameters are made in this evaluation:

1. Flaw evaluation procedure given under IWB-3610 and Appendix A of ASME Section XI are generally applicable.

2. Weld residual stresses and the effects of vessel cladding are neglected. (SEE REVIEWER'S COMMENT NEXT PAGE).

3. The hoop stresses at the inside surface of the shell due to external pipe loads applied at the modified pad-weld attachment (outside surface of the head) are assumed to be negligible.

4. Acceptance criteria for normal/upset and accident conditions are considered in the evaluation.

5. Maximum stress conditions for the pressurizer bottom head are assumed, which bounds all instrumentation nozzles covered by this calculation.

6. Maximum envelop of applied mechanical nozzle loads is assumed to bound external loads for all nozzles covered by this calculation.

7. Weld indications are assumed to be crack-like. The crack model is assumed to completely penetrate the J-groove weld and enter the low alloy steel shell.

8. Minimum strength properties for Inconel 690 material are assumed. Since these properties bound the strength properties for the low alloy steel material, they are conservatively used in the limit load evaluation.

9. Crack growth rate for reactor water for an $R > 0.65$ is conservatively assumed.

10. Conservative estimates of BWC rates from Ref. 7 are considered in the evaluation of general corrosion.

11. Irradiation embrittlement of the pressurizer and steam generator is negligible since these components are remote from the reactor pressure vessel (RPV) beltline.

12. The design specification for the pressurizer specifies 200 cycles for the operating basis earthquake event (OBE). For the fatigue evaluation, one OBE cycle is conservatively assumed to cause 40 stress cycles at the nozzle attachment. This assumption is consistent with nozzle design calculations (Ref. 2).

In general, use of the above assumptions will result in a conservative analysis of the flaw for normal operating conditions. Conservative means any condition that will result in a smaller calculated critical flaw size or in accelerated crack growth rates under normal operation.

The flaw evaluation was completed using the 1992 Edition of ASME Section XI as guidance. The current approved Code for SONGS is the 1989 Edition of ASME Section XI. However, the flaw evaluation methods and criteria are very similar in both the 1989 and 1992 codes. The 1992 Edition is used herein because the equations and information are more complete and direct in application to the problem being evaluated. For these reasons, the 1992 Edition is technically equivalent to the 1989 Edition and can be used as guidance in the assessment of half-nozzle repair.

REVIEWER'S COMMENT FOR ASSUMPTION # 2 – RESIDUAL STRESS WILL BE HIGHLY LOCALIZED AND WILL NOT SIGNIFICANTLY ADD TO THE OPERATING STRESS IN THE SHELL/HEAD AWAY FROM THE WELD. J.L.G. 7/23/98.

4.0 METHODOLOGY

4.1 Evaluation of the Nozzle Stub Flaw

4.1.1 Technical Approach

The evaluation procedures of ASME Section XI, Appendix A, are used to analyze the postulated flaw geometries. The flaw is evaluated as a sharp crack and normal to the maximum principal stress direction (hoop direction) of the head/shell. The flaws are postulated as axially oriented cracks originating in the nozzle stub, as shown in Figure 4-1. It is conservatively assumed that the flaws will grow radially through the J-groove and into the low alloy steel head/shell material. The initial flaw assumed in the evaluation is a large quarter circular crack that resides in the low alloy steel. This assumption conservatively ignores any crack growth life through the J-groove material.

The evaluation procedure is described in Article A-5000 of Section XI, Appendix A. Both theoretical solutions and numerical methods are used to evaluate the flaw, given the flaw size and geometry data, material properties, and the transient stresses and temperatures at the penetration location. These methods are used to calculate the following Section XI flaw parameters:

a_f — The maximum size to which the detected flaw is calculated to grow in a specified time period

a_c — The minimum critical size of the flaw under normal/upset operating conditions

a_i — The minimum critical size of the flaw under emergency/faulted accident conditions

Stress results from design calculations are used to define boundary stress distributions at the ID corner of the shell penetrations. The BIGIF (Ref. 6) computer program is used in the stress intensity factor and FCG analyses. The accuracy of the BIGIF program has been verified for both fracture and FCG analyses.

4.1.2 Flaw Acceptance Criteria

Flaws are acceptable if the critical flaw parameters satisfy the criteria of IWB-3611. These flaw size acceptance criteria are:

$$a_f < 0.1\,a_c \qquad (4\text{-}1)$$

$$a_f < 0.5\,a_i \qquad (4\text{-}2)$$

where a_f, a_c, and a_i are defined in Section 4.1. Equation 4-1 is the requirement for normal conditions and Eq. 4-2 governs the emergency/faulted conditions.

Alternatively, if the applied stress intensity factor and the flaw size, a_f, satisfy the following IWB-3612 criteria

$$a_f < a_{allow} \qquad (4\text{-}3)$$

where a_{allow} is the minimum value of "a" determined from the following equations:

$$K_I(a) < K_{Ia}/\sqrt{10}, \quad \text{(normal/upset)} \qquad (4\text{-}4a)$$

$$K_I(a) < K_{Ic}/\sqrt{2}, \quad \text{(emergency/faulted)} \qquad (4\text{-}4b)$$

then the flaw is acceptable based on load. For Eq. 4-4a, K_I is the maximum applied stress intensity factor under normal conditions, and K_{Ia} is the available fracture toughness based on crack arrest for the corresponding crack tip temperature. For Eq. 4-4b, K_I is the maximum stress intensity factor under emergency and faulted conditions, and K_{Ic} is the available fracture toughness based on fracture initiation for the corresponding crack tip temperature.

Satisfying either the flaw size criteria or the applied load criteria and checking that the appropriate primary stress limits are satisfied will demonstrate acceptance of the flaw to ASME Section XI for the design conditions. It is expected that the acceptance criteria for normal conditions will govern the allowable flaw size because of the higher required safety margins imposed by ASME Section XI.

4.1.3 Calculation of End-of-Life Flaw Size (a_f)

The expected end-of-life flaw size (a_f) is computed by a cumulative FCG analysis for normal operating conditions for the remainder of the expected service life of the component, according to Article A-5200 of Section XI, Appendix A. Normal conditions include all transients expected to occur during testing and normal operation. Included in normal operation are upset conditions that are anticipated to occur frequently enough as to warrant their consideration during design.

The FCG rate (da/dN) of the shell material is characterized by the following relation:

$$da/dN = C_o \Delta K_I^n \qquad (4\text{-}5)$$

where da/dN is the crack growth rate (i.e., inches per cycle of loading), C_o and n are material constants, and ΔK_I is the range in stress intensity factor for the load cycle ($\Delta K_I = K_{max} - K_{min}$). The BIGIF computer program performs the FCG analysis by integrating Eq. 4-5. The number of applied load cycles, N, for the design transients is calculated from

$$N = \int_{a_o}^{a_f} \frac{da}{da/dN} \qquad (4\text{-}6)$$

where a_o is the starting crack depth and a_f is the final crack depth.

4.1.4 Calculation of Minimum Critical Flaw Size (a_c) for Normal/Upset Conditions

The procedure to compute the minimum critical flaw size for normal operation (a_c) as specified by Article A-5200 of Section XI, Appendix A is outlined below:

1. Determine the maximum end-of-life irradiation level at the flaw location (embrittlement of the pressurizer or steam generator shell due to neutron radiation is assumed to be negligible, i.e., $\Delta RT_{NDT} = 0$).

2. Using fracture toughness data, determine the crack-arrest fracture toughness (K_{Ia}) as a function of temperature.

3. Calculate stress intensity factors, K_I, for various geometrically similar crack depths of the assumed flaw.

4. Compare the calculated stress intensity factors to the material fracture toughness (K_{Ia}) for the appropriate temperature to determine a_c for the transient.

5. Proceed to the next transient.

The calculated values for the stress intensity factor as a function of crack depth, $K_I(a)$, are utilized in the determination of a_c from

$$K_I(a_c) = K_{Ia}(T, RT_{NDT}) \quad (4\text{-}7)$$

where T is temperature at the crack tip and RT_{NDT} is the nil ductility temperature for the shell material. Equation 4-7, therefore, represents the intersection of the toughness distribution and the applied K_I field. The smallest value of a_c determined by the above procedure after all transients have been considered is the minimum critical flaw size for normal operation. This minimum value of a_c is checked against the flaw acceptability criteria of IWB-3600 (see Section 4.1.2).

4.1.5 Calculation of Minimum Initiating Flaw Size (a_i) for Accident Conditions

The procedure to compute the minimum initiating flaw size (a_i) for emergency/faulted conditions as specified by Article A-5200 of Section XI, Appendix A, is outlined below:

1. Determine the maximum end-of-life irradiation level at the flaw location (embrittlement of the pressurizer or steam generator shell due to neutron radiation is assumed to be negligible, i.e., $\Delta RT_{NDT} = 0$).
2. Using fracture toughness data, determine the initiation fracture toughness (K_{Ic}) as a function of temperature.
3. Calculate stress intensity factors, K_I, for various geometrically similar crack depths of the assumed flaw.
4. Compare the calculated stress intensity factors to the material fracture toughness (K_{Ic}) for the appropriate temperature to determine a_i for the transient.
5. Proceed to the next transient.

The calculated values for the stress intensity factor as a function of crack depth, $K_I(a)$, are utilized in the determination of a_i from

$$K_I(a_i) = K_{Ic}(T, RT_{NDT}) \qquad (4\text{-}8)$$

where T is the temperature at the crack tip and RT_{NDT} is the nil ductility temperature for the shell material. Equation 4-8, therefore, represents the intersection of the toughness distribution and the applied K_I field. The smallest value of a_i determined by the above procedure after all accident conditions have been considered is the minimum initiating flaw size for emergency/faulted conditions. This minimum value of a_i is checked against the flaw acceptability criteria of IWB-3600 (see Section 4.1.2).

4.1.6 Calculation of Stress Intensity Factor

The stress intensity factor is defined as

$$K_I = \sigma F \sqrt{\pi a / Q} \qquad (4\text{-}9)$$

where σ is the applied stress, F is a function which accounts for flaw geometry and loading mode, "a" is the crack depth, and Q is the flaw shape parameter. Details of the calculation of K_I are provided later.

4.2 Evaluation of Borated Water Corrosion

4.2.1 Technical Approach

The evaluation procedures of Section XI, Appendix H are used to analyze the postulated corrosion damage. The postulated damage from BWC is illustrated in Figure 4-2. The degradation is postulated as the loss of metal in the annulus between the nozzle and shell penetration. The integrity of the weld attachment would be challenged if significant metal loss occurred to cause the nozzle to pull out under pressure plus mechanical nozzle loads.

The BWC rate increases with increasing flow velocity (Ref. 7). It is expected that water in the annulus will be stagnant except at the 1/16-inch gap between the half-nozzle and the original nozzle stub. At this location, circumferential flow (swirling) is postulated. The resulting corrosion is assumed to be localized, as illustrated in Figure 4-2. In addition, BWC just under the pad is postulated. This corrosion degradation, although at a slower rate, would be acting at a location where the metal reinforcement for the fillet weld is the smallest.

The integrity of the nozzle-to-pad weld is assessed by modeling the axial load-carrying section by an equivalent cylinder, as illustrated in Figure 4-3. The inner radius is defined as r_1, outer radius as r_2, and the thickness as "w." The thickness, "w", is defined as the distance from the corrosion region to the toe of the fillet weld and, therefore, represents the minimum structural connection distance. From the geometry of Figure 4-3,

$$\alpha = \tan^{-1}\left[\frac{\ell}{t_p + e}\right]$$

$$r_1 = (d_h/2)/\sin\alpha$$

$$w = [(t_p + e)^2 + \ell^2]^{1/2}$$

$$r_2 = r_1 + w$$

The flaw penetration in the equivalent cylinder is the projected length (a) of the corrosion along the minimum section (w), as illustrated in Figure 4-3. The corrosion depth is defined as "d." To characterize a skewed flaw per ASME Section XI, the evaluated flaw depth is the perpendicular projection of the skewed flaw to the plane of interest. In this evaluation, the projected length is conservatively doubled to account for the irregularities and roughness of the corrosion groove, as shown in Figure 4-3. This projected length assumes that the triangular area between the area of corrosion and the minimum section does not carry any load. This triangular area is an isosceles triangle with an apex angle equal to 2α (factor of two on projected length). Therefore, the projected depth, a, is conservatively defined as:

$$a = 2d\sin\alpha \qquad \textbf{(4-10)}$$

The cross-sectional area of the equivalent cylinder is the conical surface area given by:

$$A = \pi[d_h + \ell]w \qquad \textbf{(4-11)}$$

The section modulus of the equivalent cylinder is conservatively defined as the normal cross-section across the fillet weld leg:

$$Z = \frac{\pi}{4}[(d_h/2+\ell)^4 - (d_h/2)^4]/(d_h/2+\ell) \qquad (4\text{-}12)$$

The values of area and section modulus define the magnitude of applied stress to be carried by the equivalent cylinder.

4.2.2 Corrosion Acceptance Criteria

The BWC of the low alloy steel shell is acceptable provided that the safety margins of Appendix H are satisfied. These safety margins of factors (SF) are 2.77 on load for normal/upset loading conditions and 1.39 on load for emergency and faulted conditions. For the applied bending (σ_b) and membrane (σ_m) stresses acting on the nozzle, the acceptance of BWC is established from the following relationship consistent with Article H-5320 (Ref. 5):

$$\frac{\sigma_b^c + \sigma_m}{\sigma_m + \sigma_b} \geq SF \qquad (4\text{-}13)$$

where σ_b^c is the critical bending stress at incipient failure, σ_m is the applied membrane stress, σ_b is the applied bending stress, and SF is the appropriate safety factor.

4.2.3 Definition of Nozzle Stresses

The membrane and bending stresses acting on the nozzle attachment are determined from the pressure and mechanical loads. The membrane stress is conservatively estimated from the absolute summation of forces

$$\sigma_m = F_A/A \qquad (4\text{-}14)$$

$$F_A = \pi(d_h/2)^2 P_D + F_a + F_b + F_c$$

The bending stress is computed from applied moments according to

$$\sigma_b = M_B/Z \qquad (4\text{-}15)$$

$$M_B = [M_a^2 + M_b^2 + M_c^2]^{1/2}$$

4.2.4 Determination of Critical Bending Stress

The allowable flaw depth due to corrosion is determined from the limit load criteria of Article H-5000. It is assumed that the low alloy steel head/shell material will be ductile under all service conditions, as supported by the upper shelf toughness material behavior determined in Section 5.4.2. For the pipe flaw geometry of Figure 4-4, the relationship between plastic failure, applied stresses, and flaw geometry is given by (Ref. 5):

$$\sigma_b^c = \frac{2\sigma_f}{\pi}[2\sin\beta - (a/w)\sin\theta] \qquad (4\text{-}16)$$

$$\beta = (\pi/2)[1-(a/w)(\theta/\pi)-(\sigma_m/\sigma_f)] \qquad (4\text{-}17)$$

For $(\beta + \theta) \le \pi$. When $(\beta + \theta) \ge \pi$, the above equations become:

$$\sigma_b^c = \frac{2\sigma_f}{\pi}[2-(a/w)]\sin\beta \qquad (4\text{-}18)$$

$$\beta = \frac{\pi}{2-(a/w)}[1-(a/w)-(\sigma_m/\sigma_f)] \qquad (4\text{-}19)$$

In the above equations, "a" is the depth of the corrosion flaw, θ is the half-flaw angle around the penetration, and σ_f is the flow stress equal to $(S_y + S_u)/2$. The angle, β, is the angle position of the neutral axis, as shown in Figure 4-4.

4.2.5 Corrosion/Fatigue Growth Analysis

The depth of the corrosion is established from the estimated growth rate for a 40 year service life. Estimated growth rates for stagnant and high flow rate conditions are discussed later in Section 5.4.4. Flaw growth due to FCG is also included and combined by the simple linear cumulative damage rule. An initial crack depth equal to the corrosion flaw depth is assumed in a FCG analysis. Forty years of cyclic service loads, including seismic, is applied in the fatigue evaluation. The calculation of final flaw size from FCG follows the approach discussed in Section 4.1.3.

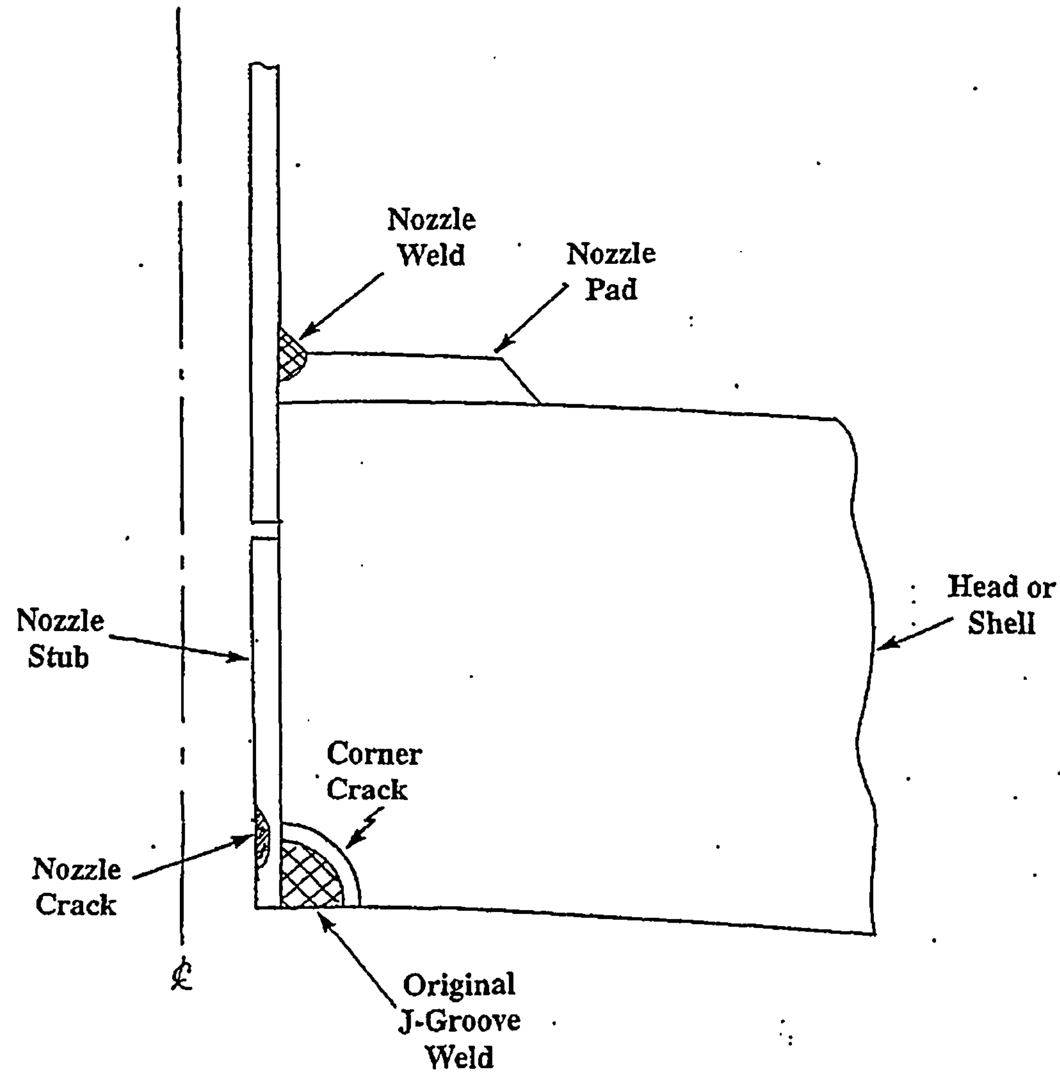

Figure 4-1 — Postulated Flaw in Nozzle Stub Weld Region.

Calculation No.: AES-C-3247-1	Made by: [signature]	Date: 5/8/98	Client: SCE
Title: Evaluation of Half-Nozzle Repair for Pressurizer and Steam Generator Instrumentation Nozzles Under Long-Term Service Conditions — SONGS 2 and 3	Checked by: [signature]	Date: 8 MAY 98	Project No.: AES 97123247-1Q
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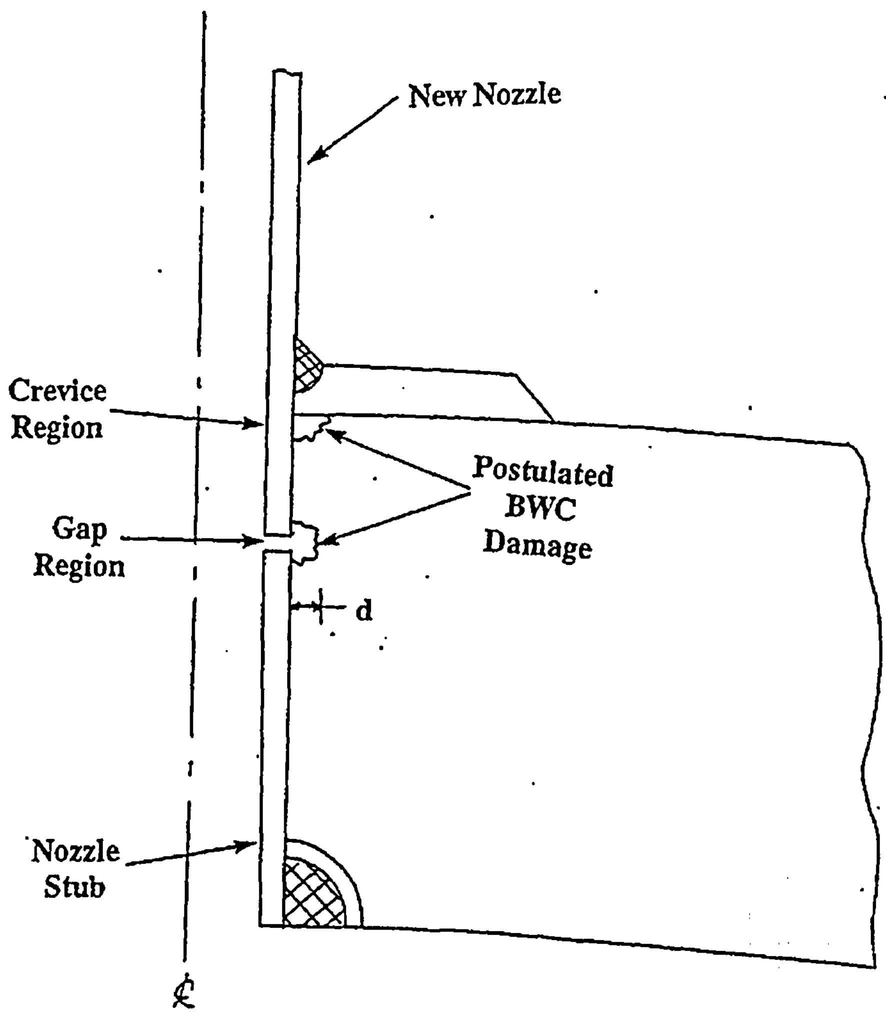

Figure 4-2 — Postulated BWC in Nozzle Repair Region.

Calculation No.: AES-C-3247-1	Made by: lcc	Date: 5/8/98	Client: SCE
Title: Evaluation of Half-Nozzle Repair for Pressurizer and Steam Generator Instrumentation Nozzles Under Long-Term Service Conditions — SONGS 2 and 3	Checked by: MTC	Date: 8 MAY 98	Project No.: AES 97123247-1Q
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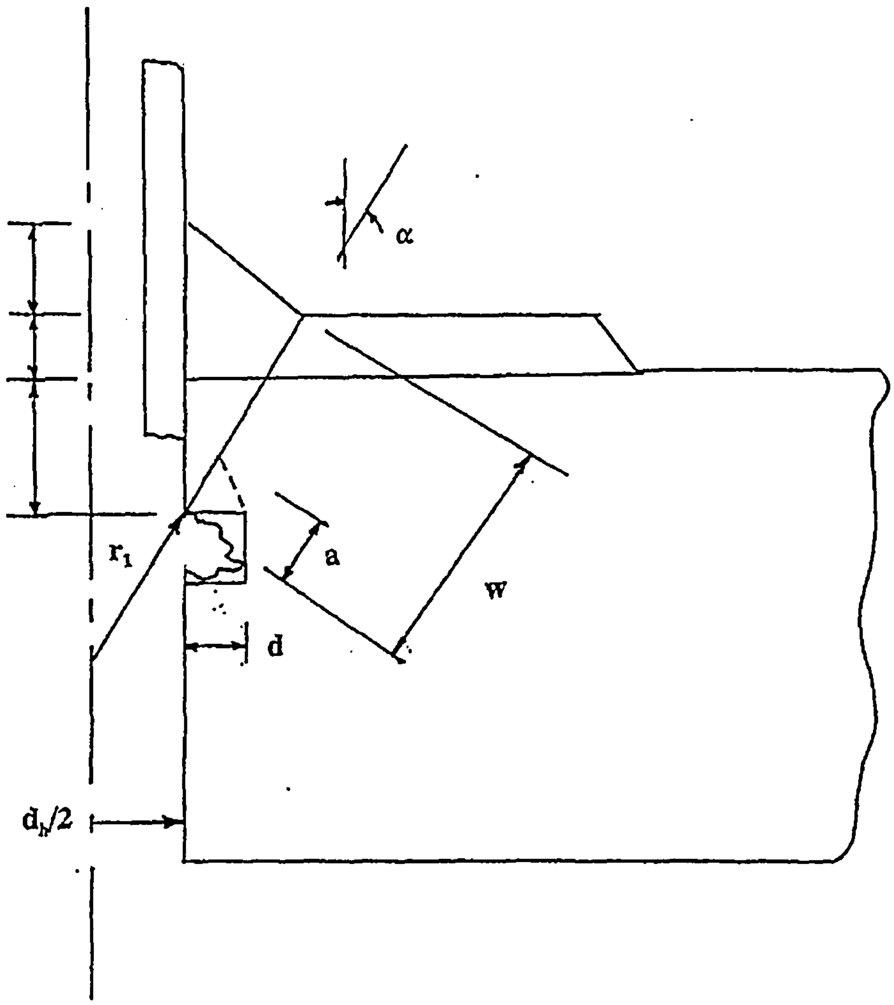

Figure 4-3 — Equivalent Cylinder Model for Nozzle Loading.

Calculation No.: AES-C-3247-1	Made by: RCC	Date: 5/8/98	Client: SCE
Title: Evaluation of Half-Nozzle Repair for Pressurizer and Steam Generator Instrumentation Nozzles Under Long-Term Service Conditions — SONGS 2 and 3	Checked by: MTC	Date: 8 MAY 98	Project No.: AES 97123247-1Q
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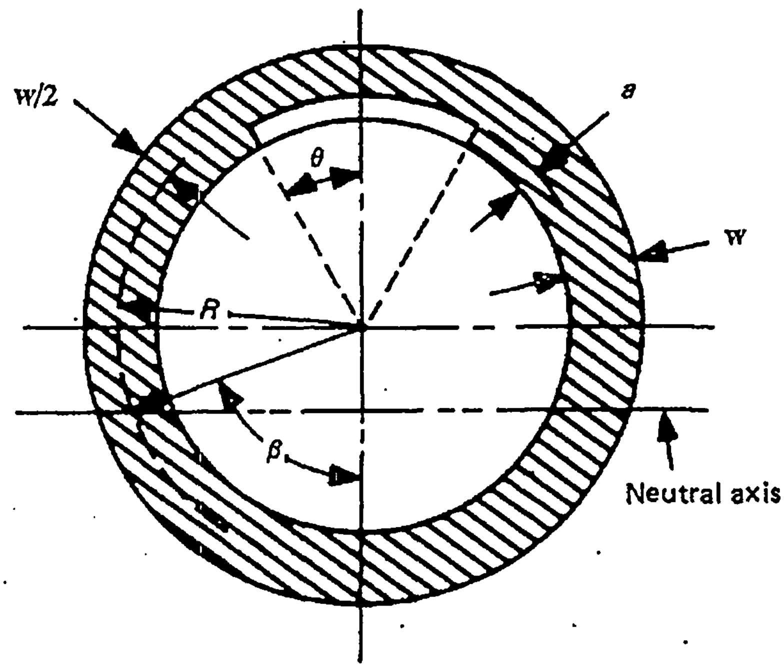

Figure 4-4 — Net Section Plastic Failure Model.

5.0 DESIGN INPUT

5.1 Nozzle and Shell Geometry

The instrumentation nozzles used in the pressurizer and steam generators for pressure and level sensors are 3/4-inch Schedule 160 pipe size. There is one temperature instrumentation nozzle in the pressurizer that is 1-inch Schedule 160. The nozzles penetrate either the spherical head or cylindrical shell portions of the components. A schematic illustration of the nozzle geometry is given in Figure 5-1. A summary of the important dimensions for the different nozzles is given in Table 5-1.

The geometry information in Table 5-1 was used to select a repair nozzle configuration that is conservative/bounding of all nozzles. The nozzle geometry that was selected was the pressurizer bottom head for the following reasons:

1. Largest local R_i /t value for the hole penetration
2. Smallest pad thickness
3. Small pad diameter

The above attributes would cause the pressurizer bottom head nozzle to produce the highest stress of all the 3/4-inch nozzles. The 1-inch nozzle has a much thicker and larger pad and a smaller local R_i /t value for the penetration. However, the 1-inch nozzle penetrates the cylindrical shell and would have a higher nominal hoop stress in the circumferential direction. The elevated hoop stress is estimated below:

$$\frac{\sigma_\theta\ (1-\text{inch})}{\sigma_\theta\ (3/4-\text{inch})} = \frac{p\,R_i/t}{p\,R_i/2t} = \frac{7.33}{(12.50)/2} = 1.17$$

Therefore, the nominal hoop stress in the shell at the 1-inch nozzle location is approximately 20% higher than at the pressurizer bottom head nozzle. This hoop stress increase will be taken into account in this evaluation, with a multiplication factor on pressure loading.

5.2 Design and Operating Conditions

5.2.1 Pressurizer

The design data for the pressurizer from Ref. 4 are as follows:

Design pressure	=	2500 psia
Design temperature	=	700°F
Operating pressure	=	2250 psia
Operating temperature	=	653°F
Hydrotest pressure	=	1.25 P_D = 3125 psia (3110 psig)

Thermal transients are given in Table 5-2 (Ref. 4). Five thermal cases were conservatively assumed in Ref. 4 that envelop the thermal transients. These cases are:

1. Isothermal steady-state load of 653°F
2. Heatup/cooldown at a rate of 200°F per hour
3. Cooldown with flow stratification (Figure 5-2)
4. Temperature step change of ±20°F for plant load changes
5. Temperature change of −40°F and −20°F then +60°F for loss of flow conditions (Figure 5-3)

All normal/upset transients are less severe than loss of flow condition or cooldown transient with flow stratification.

5.2.2 Steam Generator

The design data for the primary side of steam generators from Ref. 3 are as follows:

Design pressure	=	2500 psia
Design temperature	=	650°F
Operating pressure	=	2250 psia
Operating temperature	=	553°F (cold leg), 611°F (hot leg)
Hydrotest pressure	=	1.25 P_D = 3125 psia (3110 psig)

Thermal transients are given in Table 5-3 (Ref. 3). Four thermal cases were conservatively assumed in Ref. 3 that envelop the thermal transients. These are:

1. Isothermal steady-state load of 553°F
2. Heatup/cooldown at a rate of 100°F per hour
3. Temperature step change of ±10°F for plant load changes
4. Temperature change of +10°F and –30°F for loss of flow conditions (Figure 5-4)

All normal/upset transients are less severe than loss of flow condition.

5.2.3 Bounding Transient Conditions

From a comparison of the transient conditions in Tables 5-2 and 5-3, and the temperature transient responses (Figures 5-2 through 5-4), the pressurizer bottom head nozzle has the most limiting operating and upset conditions. Therefore, the stress results from the pressurizer bottom head nozzle will be used to evaluate all component instrumentation nozzles.

5.3 Mechanical Loads

The mechanical loads due to dead weight (DW), operating basis earthquake (OBE), and design basis earthquake (DBE) are different. A maximum envelop of the reported mechanical loads is conservatively used to bound all nozzle locations. These maximum values are summarized below:

MAXIMUM NOZZLE EXTERNAL LOADS FOR 3/4-INCH PIPING

Loading	F_a (lb)	F_b (lb)	F_c (lb)	M_a (in-lbs)	M_b (in-lbs)	M_c (in-lbs)
Dead weight (DW)	25	19	0	0	0	240
Thermal (THERM)	0	104	0	0	0	1176
Seismic (OBE)	76	55	35	816	420	360
Seismic (DBE)	152	110	70	1632	840	720

Notes:

F_a = Axial to the nozzle (outward positive)
F_b = Lateral to the nozzle
F_c = Lateral to the nozzle
M_a, M_b, M_c = Moments associated with a, b, and c axes

The above loads were extracted from Table 8.1 (Sheets 33 and 116) of Ref. 2, Table 5-2 of Ref. 3, and Table 5-2 of Ref. 4.

5.4 Material Properties

5.4.1 Mechanical Strength

The materials that comprise the heads, shell, and replacement instrument nozzle (Refs. 2 through 4) are as follows:

Head and Shell:	SA-533, Grade B, Class 1
Cladding:	Stainless steel
Instrumentation Nozzle:	Inconel SB-166, Grade 690
Pad:	Inconel 690

In the analysis, the cladding is conservatively ignored. The mechanical strength properties at the highest design temperature are summarized below (Ref. 4):

MECHANICAL STRENGTH AT 700°F		
	Inconel 690	SA-533B-1
S_m (ksi)	23.3	26.7
S_y (ksi)	27.6	40.6
S_u (ksi)	85.0	80.0

Also, S_y for Inconel 690 at 100°F is 35 ksi.

5.4.2 Fracture Toughness

Definition of fracture toughness at the flaw location as a function of temperature was obtained from Article A-4000 of Appendix A to Section XI (Ref. 5). Section XI defines lower-bound behavior for K_{Ia} and K_{Ic} for SA-533B-1, SA-503-2, and SA-508-3 steels and associated welds, as shown in Figure 5-5. The equational formats of these reference curves are given below:

$$K_{Ia} = 26.8 + 12.445 \exp[0.0145(T - RT_{NDT})] \quad (5\text{-}1)$$

$$K_{Ic} = 33.2 + 20.734 \exp[0.02(T - RT_{NDT})] \quad (5\text{-}2)$$

where T is the metal temperature in °F, RT_{NDT} is the reference nil ductility temperature in °F, and K_{Ia} and K_{Ic} are fracture toughness in ksi in$^{1/2}$. The toughness parameter, K_{Ic}, is based on the lower bound of static initiation critical K_I values measured from specimens tested at several temperatures. Similarly, K_{Ia} is based on the lower bound of crack-arrest toughness data. It is assumed that the transition behavior of SA-533B-1 will be such that the normal operation of the pressurizer will be on the upper shelf during times when maximum pressure stresses are imposed. The pressure-temperature (P-T) operation of the reactor coolant system (RCS) will be controlled by the P-T limit curves for the RPV and, therefore, maximum operating stresses will not be experienced by the pressurizer or steam generator at low temperatures. This assumption is justified on the fact that RT_{NDT} of SA-533B-1 will be less than +20°F, which is the mean plus two standard deviations bound reported in Ref. 8. An RT_{NDT} = +20°F will cause the onset of upper shelf conditions at T ≈ 120°F for initiation toughness. For this condition, the upper shelf toughness is 200 ksi in$^{1/2}$, as reflected in Figure 5-5, and is based on data evaluations in Ref. 9.

5.4.3 Fatigue Crack Growth Rate

The reference curve for crack growth rate (da/dN) in a reactor water environment is given in Figure A-4300-2 of ASME Section XI, Appendix A, and is shown in Figure 5-6 for two R-ratio regimes. The crack growth behavior for the highest R-ratio range ($0.65 \le R \le 1.0$) is conservatively used in this evaluation. The equation for crack growth is:

$$da/dN = 1.20 \times 10^{-11} \Delta K^{5.95} \qquad \Delta K \le 12.04 \text{ ksi in}^{1/2} \quad (5\text{-}3)$$

$$da/dN = 2.53 \times 10^{-7}\ \Delta K^{1.95} \qquad \Delta K \gtrsim 12.04 \text{ ksi in}^{1/2} \qquad (5\text{-}4)$$

These crack growth rates are used as input to the FCG analysis.

5.4.4 Corrosion Rates

It is postulated that BWC will occur within the penetrations of repaired nozzles. The nozzle penetrations will be under deaerated conditions at high temperatures during normal operation. In shutdown conditions, the water is conservatively taken to be under aerated conditions at low temperatures, as assumed in Ref. 7. Corrosion rates are also greater for high flow rates than for stagnant conditions. It is assumed that the pressurizer nozzles in the water space will experience stagnant conditions, whereas the pressurizer nozzles in the steam space and the steam generator nozzles will experience nonstagnant conditions. For these conditions, the following metal losses were conservatively estimated (Ref. 7):

Pressurizer upper head:	0.0036 in/yr
Pressurizer shell and bottom:	0.0017 in/yr
Steam Generator bottom head:	0.0036 in/yr

The highest estimated corrosion rate of 0.0036 inches/year (nonstagnant) will be used in the evaluation for the gap region between the new nozzle and the original nozzle stub. This corrosion rate corresponds to a 0.144 inch increase in the penetration hole radius in 40 years of service. In the crevice region at the nozzle-to-pad attachment, the stagnant corrosion rate (0.0017 inches/year) will be used. This corrosion rate corresponds to a 0.068 inch increase in penetration hole radius in 40 years of service.

Table 5-1

SUMMARY OF INSTRUMENTATION NOZZLES/GEOMETRIES
(Refs. 2 through 4, and 15)

	INSTRUMENTATION NOZZLES			
	Pressurizer Nozzles			Steam Generator Nozzles
Description	Tap/Level	Level	Tap	Tap
Location	Upper head	Bottom head	Shell	Bottom head
Number	4	2	1	4
Size (NPS)	3/4-inch	3/4-inch	1-inch	3/4-inch
Schedule	160	160	160	160
Nozzle, r_o (in)	0.525	0.525	0.6575	0.5095
r_i (in)	0.307	0.307	0.4075	0.3125
t_n (in)	0.218	0.218	0.250	0.197
Shell, R_o (in)	52.375	52.313	53.000	86.125
R_i (in)	48.500	48.438	48.125	78.750
t_s (in)	3.875	3.875	4.875	7.375
d_h (in)	1.072	1.072	1.325	1.029
Weld pad, d_p (in)	4.55	3.80	6.00	3.77
t_p (in)	0.50	0.4375	1.6875	0.4375
Nozzle insert depth, x_d min (in)	11/16	11/16	7/8	11/16
Ratio, r_i / t_n	1.408	1.408	1.630	1.586
Ratio, R_i / t_s	12.52	12.50	9.87*	10.68

Note: * The local R_i /t values at the 1-inch nozzle, taking into account the larger pad reinforcement thickness is 7.33.

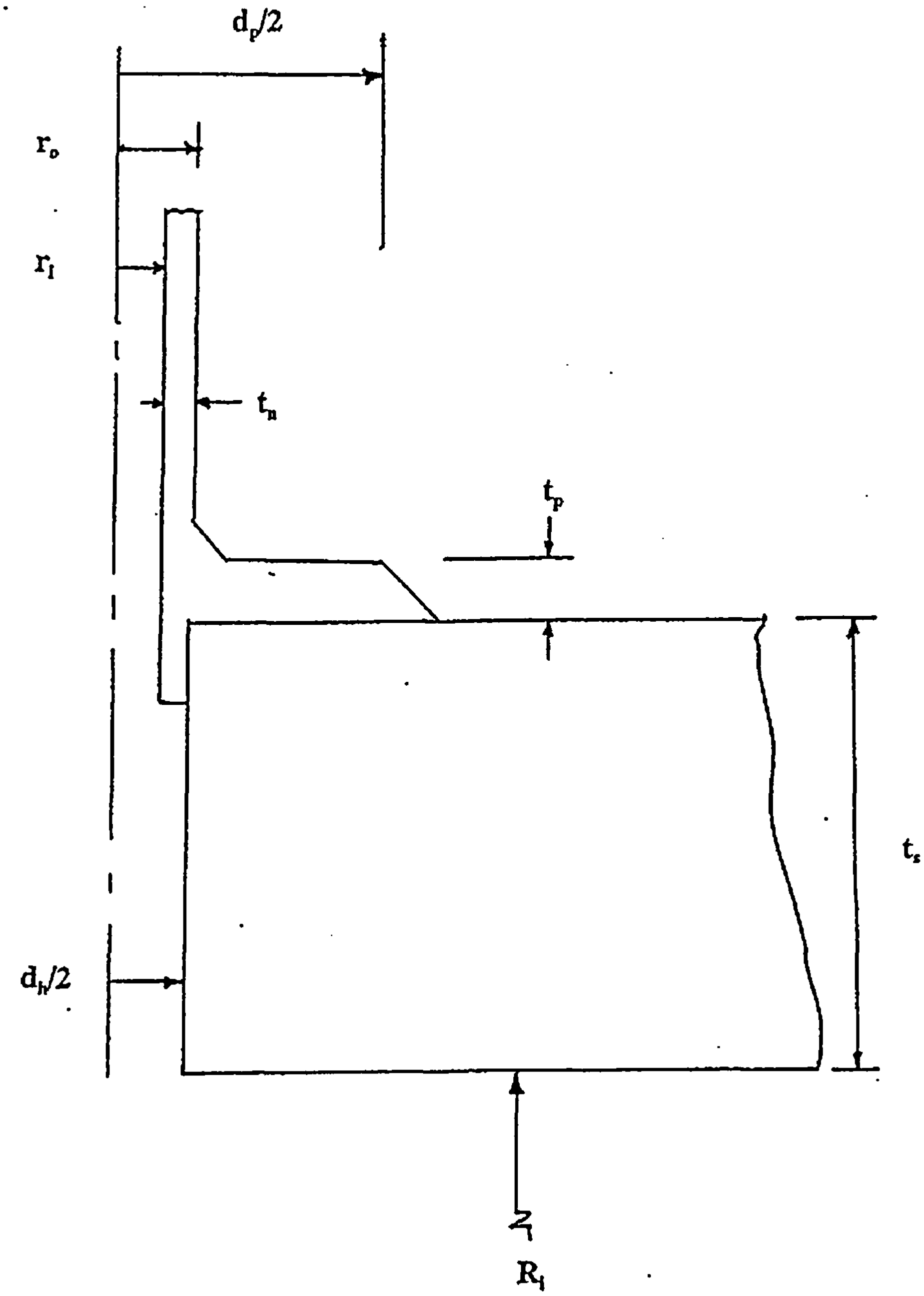

Figure 5-1 — Illustration of the Repair Nozzle Geometry.

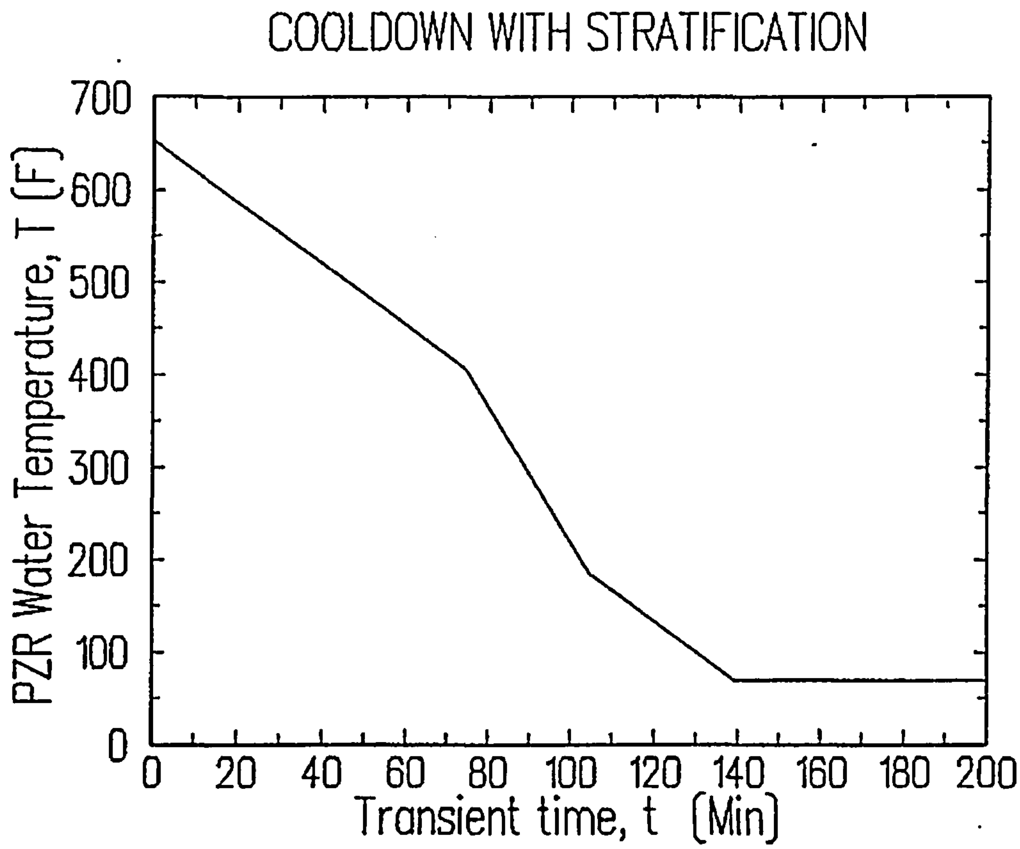

Figure 5-2 — Transient Condition — Cooldown Stratification Transient (Ref. 4).

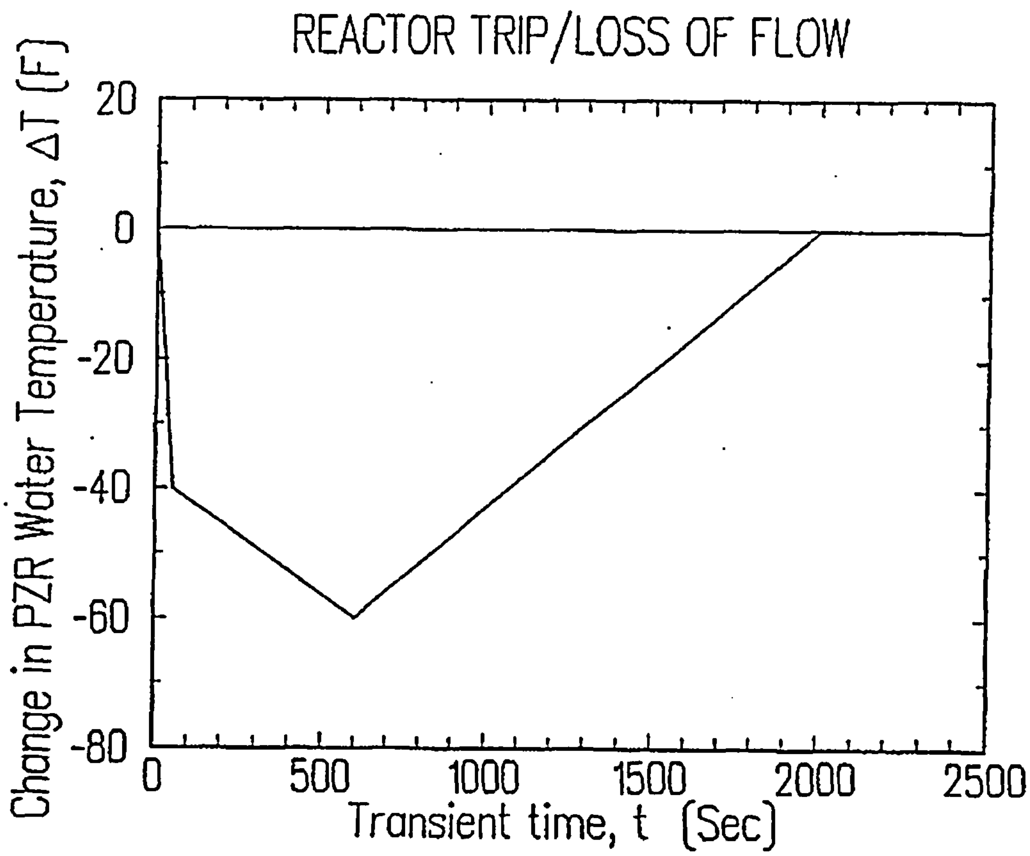

Figure 5-3 — Temperature Change in Pressurizer Bottom Head During Loss of Flow Transient (Ref. 4).

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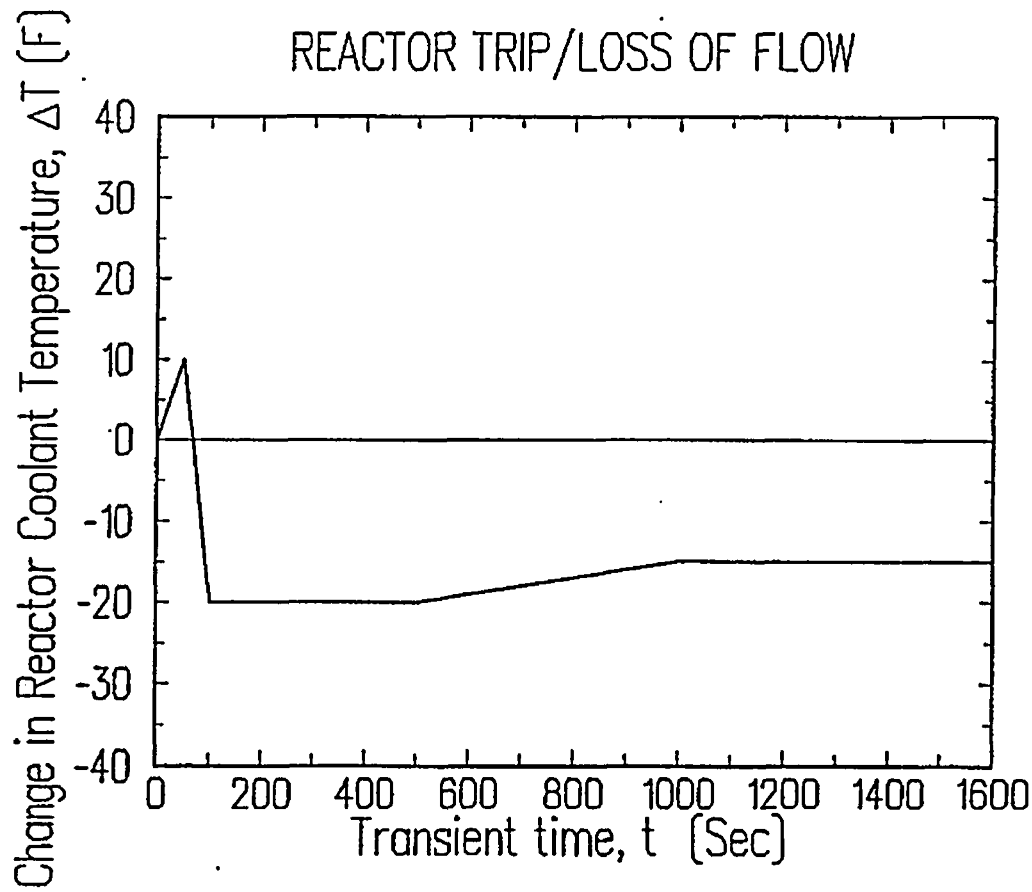

Figure 5-4 — Temperature Change in the Steam Generator Primary Head During Loss of Flow Transient (Ref. 3).

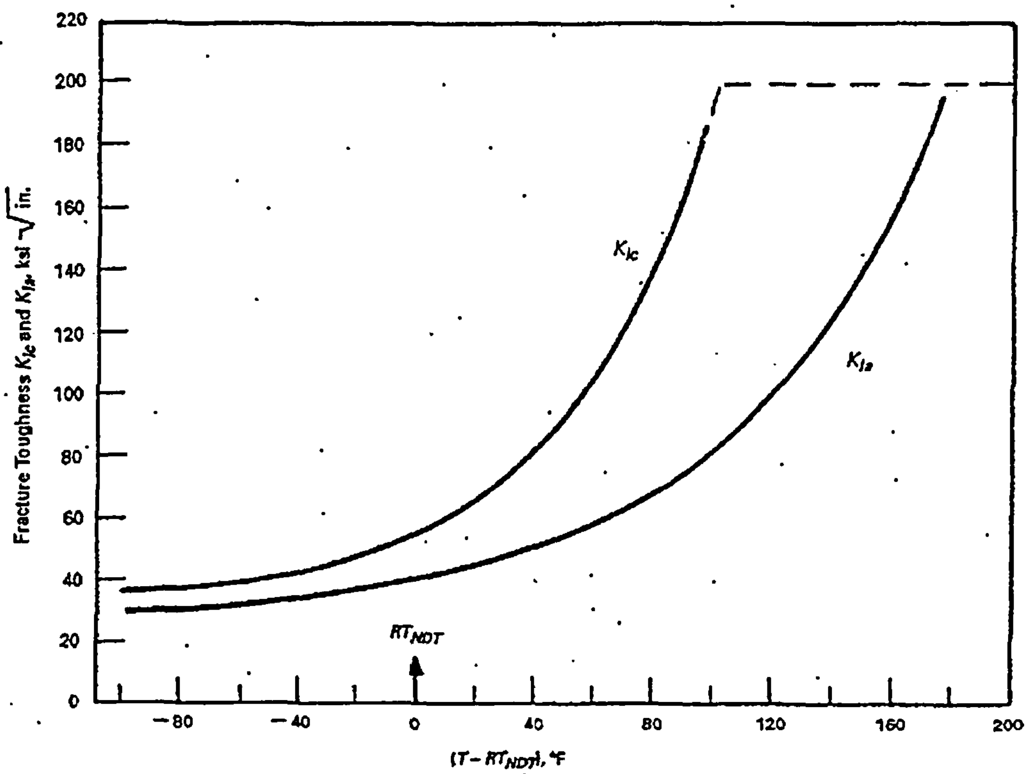

Figure 5-5 — Lower Bound Fracture Toughness from Tests of SA-533B-1, SA-508-2, and SA-508-3 Steel (Figure A-4200-1 from ASME Section XI, Appendix A, in Ref. 5).

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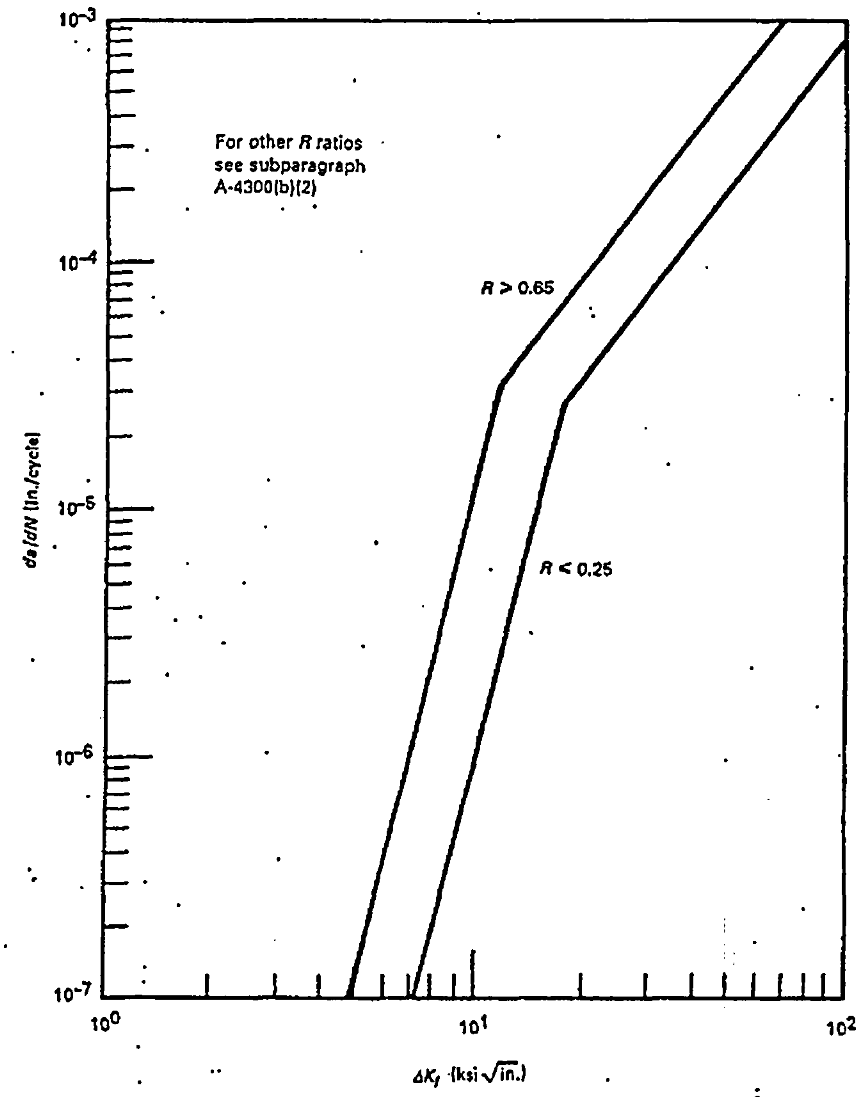

Figure 5-6 — Reference Fatigue Crack Growth Curves for Carbon and Low Alloy Ferritic Steels Exposed to Water Environments (Figure A-4300-2 from ASME Section XI, Appendix A, in Ref. 5).

6.0 REFERENCES

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4. Calculation AES-C-3213-1, Revision 1, "Pressurizer Bottom Head Instrumentation Nozzle Evaluation — SONGS Units 2 and 3," Aptech Engineering Services, Inc., APTECH Project AES 97103213-1Q (March 30, 1998).

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11. Drawing S023-919-2-8, Rev. 6, "Pressurizer Outline for San Onofre 2," (October 15, 1976) (ECD-8 from APTECH Project AES 97103213-1Q).

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13. "Analytical Report for Southern California Edison, San Onofre Unit 3, Pressurizer," CENC-1296 (September 1977) (APTECH Project 97103213-1Q, ECD-5).

14. "Analytical Report for Southern California Edison, San Onofre Unit 3, Steam Generators," CENC-1298 (September 1977) (APTECH Project 97063098-1Q, ECD-6).

15. Drawing S023-919-79-0, "Pressurizer General Arrangement for San Onofre 3," Revision 3, (October 20, 1976) (APTECH Project 97103213-1Q, ECD-11).

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7.0 NOMENCLATURE

a	=	Flaw depth, inch
a_{allow}	=	Allowable flaw depth, inch
a_c	=	Minimum critical crack size for normal/upset conditions, inch
a_f	=	Final flaw depth, inch
a_i	=	Minimum critical crack size for accident conditions, inch
a_o	=	Initial flaw depth, inch
C_o	=	Material constant in the reference fatigue crack growth equation
d	=	Depth of corrosion groove, inch
d_h	=	Diameter of hole penetration, inch
d_p	=	Diameter of pad, inch
D_o	=	Outer diameter, inch
e	=	Distance to the corrosion groove within the hole penetration from the OD surface, inch
F	=	Flaw correction factor
F	=	Force, lb
F_A	=	Axial force, lb
F_L	=	Lateral force, lb
F_a, F_b, F_c	=	Forces in the a, b, c directions, lb
F_x, F_y, F_z	=	Forces in the x, y, z directions, lb
K	=	Stress intensity factor, ksi in$^{1/2}$
K_I	=	Mode I stress intensity factor, ksi in$^{1/2}$
K_{Ia}	=	Fracture toughness for crack arrest, ksi in$^{1/2}$
K_{Ic}	=	Static fracture toughness for initiation, ksi in$^{1/2}$
K_{max}	=	Maximum value of K in stress cycle, ksi in$^{1/2}$
K_{min}	=	Minimum value of K in stress cycle, ksi in$^{1/2}$
ΔK	=	Range in stress intensity factor ($K_{max} - K_{min}$), ksi in$^{1/2}$
ℓ	=	Leg length of the fillet weld, inch

M_B	= Bending moment, in-lb
M_T	= Torsion, in-lb
M_a, M_b, M_c	= Moments in the a, b, c directions, in-lb
M_x, M_y, M_z	= Moments in the x, y, z directions, in-lb
n	= Exponent in the reference fatigue crack growth equation
N	= Number of cycles
P	= Pressure, psi
P_D	= Design pressure, psi
P_{max}	= Maximum pressure in transient, psi
P_{min}	= Minimum pressure in transient, psi
ΔP	= Pressure fluctuation, psi
Q	= Flaw shape parameter
r	= Radial distance, inch
r_o	= Outer radius of nozzle, inch
r_i	= Inner radius of nozzle, inch
R	= Mean radius, inch
R	= R-ratio (K_{min} / K_{max})
R_o	= Outer radius of head or shell, inch
R_i	= Inner radius of head or shell, inch
S_m	= Allowable stress intensity, psi
S_u	= Ultimate strength, psi
S_y	= Yield strength, psi
t	= Wall thickness, inch
T	= Temperature, °F
ΔT	= Temperature difference, °F
t_p	= Pad thickness, inch
t_h	= Head or shell thickness, inch
t_t	= Fillet weld throat thickness, inch

w	= Thickness, inch
α	= Geometric angle, radians
β	= Angle to neutral axis for bending, radians
σ_m	= Applied membrane stress, psi
σ_b	= Applied bending stress, psi
σ^c_b	= Critical bending stress, psi
σ_f	= Material flow stress, psi
θ	= Circumferential half-crack angle, radians
θ	= Angle coordinate, radians

8.0 CALCULATIONS

8.1 Evaluation of Postulated Flaws in the Penetration Hole

8.1.1 Flaw Model

To evaluate the integrity of the half-nozzle repair geometry, it is postulated that an axial flaw(s) remains in the nozzle stub at the original J-groove weld. It is further assumed that the postulated flaw has extended through the nozzle/weldment and penetrated into the low alloy steel base metal. An illustration of the flaw model representing the postulated flaw geometry is shown in Figure 8-1. This represents the worst flaw orientation and size that could develop by stress corrosion cracking.

The initial flaw is conservatively assumed to be located at the corner of the hole and semicircular in shape of depth "a." The initial flaw depth is assumed to be 1-inch (i.e., $a_o = 1.0$ inch). For this depth, the flaw tip will be in low alloy steel since the nominal J-groove prep is approximately 7/8-inch (Ref. 10). A review of drawing details (Refs. 10 through 12) indicates that the size of the J-groove weld could range from 0.5 inch to 1.25 inches, depending on the angle of hole penetration with a curved head. Hence, it will be reasonable and conservative to assume a 1-inch deep flaw as an initial flaw depth for the evaluation.

8.1.2 Penetration Stresses

The hoop stresses for the hole penetration were obtained from the finite element analysis contained in Ref. 4. These stress summaries are given in Appendix A. The loading conditions and corresponding stress results for the pressurizer bottom head nozzle penetration are bounding due to the more severe thermal transients in the pressurizer bottom head region. The following load cases from Ref. 4 were used to bound the maximum stresses and stress ranges at the postulated flaw locations for all nozzles:

1. Internal Pressure (P = 2485 psig)
2. Isothermal (T = 653°F)
3. Heatup Ramp (200°F/hr)

4. Cooldown with Stratification (Figure 5-2)
5. Plant load/unload ($\Delta T = \pm 20°F$)
6. Reactor trip — loss of flow (Figure 5-3)

Appendix A contains the stresses for each individual load case.

The stress combination for the fatigue stress ranges for the five transient conditions were developed from the load cases. The five plant transient conditions (Ref. 17) are listed below:

		Pressure (psig)			
Plant Condition	N	P_{max}	P_{min}	ΔT	N/Month
1. Startup/Shutdown	500	2235	0	200°F/hr	1.042
2. Plant Load Change	10^6	2485	2385	+20°F	2084
3. Reactor Trip	480	2535	1685	−60°F	1.0
4. Leak Test	200	2235	435	100°F/hr	0.417
5. Hydro Test	10	3110	0	0	0.021

The stress summary for σ_{max} and σ_{min} for each transient is given in Appendix A. These stresses are used as input to the BIGIF computer program.

8.1.3 Allowable Flaw Depth Evaluation

The evaluation of allowable flaw depth requires the solution of K_I, and K_{Ia} or K_{Ic} in accordance with Eqs. 4-7 and 4-8. For determining the allowable flaw depth, the fracture toughness acceptance criteria require that

$$K_I < K_{Ia}/\sqrt{10} = 200/\sqrt{10} = 63.2 \text{ ksi in}^{1/2} \quad (8\text{-}1)$$

for normal, upset, and test conditions, and

$$K_I < K_{Ic}/\sqrt{2} = 200/\sqrt{2} = 141 \text{ ksi in}^{1/2} \quad (8\text{-}2)$$

for emergency and faulted conditions. Since seismic loading will have a negligible effect on stress at the flaw location, the limiting criteria for defining allowable flaw depth is Eq. 8-1.

The solution for K_I for the five plant transient conditions defined in Section 8.1.2 was determined with the BIGIF computer program. The semicircular corner crack flaw model (IFI = 303 model in Ref. 6) was used. A listing of the input file for BIGIF is given in Table 8-1 and the solution output is given in Appendix B. The highest K_I is computed for the hydro test condition. The worst normal operating condition is the startup/shutdown transient, assuming that cooldown with fluid stratification occurs with every cycle. A plot of K_I versus flaw depth is given in Figure 8-2. The smallest allowable flaw depth is computed to be 2.59 inches (hydro test) or approximately 67% of the wall thickness.

8.1.4 Fatigue Evaluation

An FCG analysis was performed to determine the final crack depth (a_f) after 40 years of service. The following conservative analysis assumptions were used:

1. Initial flaw depth equal to 1-inch is assumed to exist at the start of service for the repair.

2. The reference FCG curve with the highest R-ratio behavior is assumed.

The 40 year service cycles were divided into one-month block loading, as given in Section 8.1.2. Therefore, 480 blocks equals 40 years of operation. The BIGIF input file is given in Table 8-1 and the fatigue life results are given in Appendix B. The final flaw depth when N = 480 is calculated to be 1.37 inches.

Therefore, $a_f = 1.37$ inches $< a_{allow} = 2.59$ inches. Any flaws remaining in the nozzle stub will be acceptable to the ASME Section XI flaw evaluation rules.

8.2 Evaluation of Postulated Borated Water Corrosion

The degradation due to possible BWC at the penetration bore surface was conservatively evaluated. It is postulated that the corrosion will be localized at the circumferential gap between the new nozzle and the old nozzle stub, and in the crevice under the nozzle-to-pad weld. This degradation is schematically shown in Figure 4-2. The potential failure mode for this damage mechanism will be nozzle blow out due to pressure and applied mechanical loads. The amount of metal loss that can be safely tolerated is determined for both limit load and fatigue failure modes that could initiate from the corrosion groove.

8.2.1 Allowable Corrosion Depth

8.2.1.1 Technical Approach

The allowable corrosion depth in the region of the nozzle-to-pad attachment weld was computed from the equivalent cylinder model shown in Figure 4-4 and the limit load equations of Section 4.2.4. In the evaluation of the attachment weld integrity with BWC, the localized corrosion is projected to the minimum section and is conservatively modeled as a loss in load carrying area. A spreadsheet analysis was performed to solve the equations for allowable depths for a given circumferential length of corrosion damage. In this analysis, the following assumptions were made:

1. The design pressure was used for all transient pressure loads (P = 2485 psig).

2. The flow stress was computed for Alloy 690 material, which is less than the low alloy steel flow stress:

$$\sigma_f = (S_y + S_u)/2$$

$$= (27.6 + 85)/2 = 56.3\,\text{ksi}$$

3. The seismic loads for OBE were used in conjunction with upset conditions. Seismic loads for DBE were used for accident conditions.

4. Safety margins for normal/upset conditions will be limiting.

8.2.1.2 Maximum Limit on Depth

It should be noted that the evaluation of BWC addresses only the integrity of the weld attachment of the nozzle. Loss of metal reinforcement around the hole penetration and the resulting impact to stress requirements for pressure loading are not explicitly evaluated. To limit the depth of grooving based on limits on metal reinforcement, the rules of NB-3330 are applied.

It is initially proposed that an upper limit for corrosion depth be set at 0.5 inch and constant through the thickness. This corresponds to a corroded area equal to the wall thickness "t". This metal loss would be compensated by an excess metal reinforcement area at each penetration. For the 3/4-inch nozzles, the excess reinforcement areas are as follows:

	Reinforcement / Metal Areas (in^2)				
	Furnished Area	Removed Area	Excess Area	Corroded Limit	Ref.
PZR Upper Head	12.16	2.76	9.40	3.875	13, p. A43
PZR Bottom Head	12.09	2.94	9.15	3.875	13, p. A47
SG Bottom Head	51.55	4.04	47.5	7.375	14, p. A33

In all cases, the upper limit on corroded area is less than the excess area available for compensation.

For the 1-inch RTD nozzle, the excess reinforcement area from the original calculations is 2.24 in^2 (Ref. 13, p. A32). This would allow the 0.5 inch depth limit to be valid for a part-thickness length of 2.24 inches or (2.24 / 4.815)t = 0.46t. However, the RTD nozzle is an isolated nozzle away from other penetrations. Applying the exemption rules of NB-3332.1, additional reinforcement is not required for a single penetration, provided that the hole diameter is less than $0.2\,(Rt)^{1/2}$ per NB-3332.1(a). The minimum hole diameter satisfying this limit for the pressurizer shell is

$$0.2\,(Rt)^{1/2} \;=\; 0.2\,[0.5\,(53.0+48.125)(4.875)]^{1/2} \;=\; 3.14 \text{ inches}$$

Therefore, the maximum increase in radius of the existing RTD penetration is (3.14 - 1.325) / 2 = 0.91 inch. This value exceeds the maximum corrosion depth limit set at 0.5 inch.

The requirements of NB-3332.1(b) and (c) were also confirmed to be satisfied. Since there are no other penetrations near the RTD, NB-3332.1(b) is satisfied. The nearest discontinuity to the RTD is the lower head-to-shell weld. The distance to this region cannot be less than 2.5 $(Rt)^{1/2}$ if P_L at the head-to-shell is greater than 1.1 S_m:

$$2.5\,(Rt)^{1/2} \;=\; 2.5[0.5\,(53.0+48.125)\,(4.875)]^{1/2} \;=\; 39.3 \text{ inches}$$

The distance to the head-to-shell tangent line is 107.31 – 78.06 – 1.325 / 2 = 28.59 inches (Ref. 15). A review of the stress summary results (Ref. 13, p. 10) indicates that the primary membrane stress at this location is 20.3 ksi, which is less than 1.1 S_m = 1.1 (26.7) = 29.4 ksi. Therefore, NB-3332.1(c) at this location is satisfied.

The next closest discontinuity region is the head-to-skirt attachment. The distance to this location is conservatively estimated from Ref. 15 to be 28.59 + $R_i\,\Phi$, where Φ is the angle from the tangent line to the top of the support skirt shoulder. The angle $\Phi \approx 20°$ from Ref. 15; hence,

$$28.59 + 48.4375\,(20/360)\,(2\pi) \;=\; 45.5 \text{ inches}$$

This distance exceeds the NB-3332.1(c) requirement of 2.5 $(Rt)^{1/2}$ = 39.3 inches. Therefore, the RTD penetration satisfies the reinforcement exemption rules.

8.2.1.3 Calculated Results

The spreadsheet evaluation is contained in Appendix C to this calculation. For the weld repair geometry,

t_p = Minimum pad thickness = 0.4375 inch

t_t = Minimum weld throat = 0.13 inch

ℓ = Minimum fillet leg length $= 0.13\sqrt{2} = 0.184$ inch

For the location at the axial gap between the original nozzle stub and the new nozzle, e = 11/16 inch = 0.6875 inch. The predicted corrosion depth at this location is 0.144 inch (Section 5.4.4). For a continuous 360° corrosion groove, the allowable depth exceeds 0.5 inch, from Table C-1. Therefore, the expected corrosion at the gap location will be acceptable with regard to the integrity margins for the nozzle attachment weld.

At the crevice location, the predicted corrosion depth is 0.068 inch (Section 5.4.4). For a continuous 360° corrosion groove, the allowable depth is approximately 0.28 inch, from Table C-2. Therefore, the expected corrosion at the crevice location will be acceptable with regard to the integrity margins for the nozzle attachment weld.

8.2.2 Fatigue Analysis

An FCG evaluation is performed to determine that no significant flaw growth due to cyclic stresses will extend from any corrosion grooving. The FCG equation (Eq. 4-6) is approximated by the following relationship

$$\Delta a \approx (\Delta a/\Delta N)N \qquad (8\text{-}3)$$

where $\Delta a/\Delta N \approx da/dN$ given by Eqs. 5-3 and 5-4, and N is the total number of cycles. The following conservative assumptions are made:

1. Pressure, thermal, dead weight, and mechanical (seismic) loads are assumed to cycle together under OBE conditions. Therefore, N = 200 events times 40 cycles per event equals 8,000 total cycles in a 40-year service life.
2. The membrane and bending stresses are combined to give a uniform stress to be applied across the nozzle section.
3. The stress intensity factor for a continuous 360° flaw will be used to define ΔK in the crack growth rate equation.

4. The ratio of r_1/w is conservatively assumed to be 10 (thin-wall cylinder).

8.2.2.1 Gap Region

For uniform axial stress, the stress intensity factor solution for a continuous 360° circumferential crack is given by (Ref. 16):

$$K = \sigma F (\pi a)^{1/2}$$

where

$$d = 0.144 \text{ inch}$$

$$w = 1.14 \text{ inches (Table C-1)}$$

$$\alpha = 0.16212 \text{ radians (Table C-1)}$$

$$a = 2d \sin\alpha = 2(0.144)\sin(0.16212)$$

$$= 0.0465 \text{ inch}$$

$$a/w = 0.0465/1.14 = 0.041$$

$$A_1 = [0.125(r_1/w) - 0.25]^{0.25}$$

$$= [0.125(10) - 0.25]^{0.25} = 1.0$$

$$F = 1.1 + A_1[1.948(a/w)^{1.5} + 0.3342(a/w)^{4.2}]$$

$$= 1.1 + (1)[1.948(0.041)^{1.5} + 0.3342(0.041)^{4.2}]$$

$$= 1.116$$

$$\Delta\sigma = \sigma_m + \sigma_b = 0.568 + 9.84 = 10.41 \text{ ksi (Table C-1)}$$

Therefore, ΔK is computed as

$$\Delta K = \Delta\sigma F(\pi a)^{1/2}$$

$$= 10.41(1.116)[\pi(0.0465)]^{1/2} = 4.44 \text{ ksi in}^{1/2}$$

The crack growth rate from Eq. 5-3 is computed as

$$da/dN = 1.20 \times 10^{-11} (4.44)^{5.95}$$

$$= 8.53 \times 10^{-8} \text{ inches/cycle}$$

The change in crack size (extension in depth of a corrosion groove) is

$$\Delta a = 8.53 \times 10^{-8} (8000) = 0.00068 \text{ inch}$$

The value of $\Delta a = 0.0007$ inch is not a significant increase in flaw depth due to fatigue and will not cause the predicted corrosion depths to exceed the allowable depths previously computed. Therefore, the final estimated flaw depths due to the combined degradation of BWC and FCG will be acceptable to the safety margins of ASME Section XI.

8.2.2.2 Crevice Region

For the crevice region:

$$d = 0.068 \text{ inch}$$

$$w = 0.4746 \text{ inch (Table C-2)}$$

$$\alpha = 0.39811 \text{ radians (Table C-2)}$$

$$a = 2d \sin\alpha = 2(0.068)\sin(0.39811)$$

$$= 0.0527 \text{ inch}$$

$$a/w = 0.0527/0.4746 = 0.111$$

$$A_1 = 1.0$$

$$F = 1.1 + A_1[1.948(a/w)^{1.5} + 0.3342(a/w)^{4.2}]$$

$$= 1.1 + (1)[1.948(0.111)^{1.5} + 0.3342(0.111)^{4.2}]$$

$$= 1.172$$

$$\Delta\sigma = \sigma_m + \sigma_b \quad \text{(Table C-2)}$$

$$= 1.37 + 9.84 = 11.21 \text{ ksi}$$

Therefore, ΔK is computed as:

$$\Delta K = \Delta\sigma F(\pi a)^{1/2}$$

$$= 11.21(1.172)[\pi(0.0527)]^{1/2}$$

$$= 5.35 \text{ ksi in}^{1/2}$$

The crack growth rate from Eq. 5-3 is computed as:

$$da/dN = 1.20 \times 10^{-11} (5.35)^{5.95}$$

$$= 2.59 \times 10^{-7} \text{ inches/cycle}$$

The change in crack size (extension in depth of a corrosion groove) is

$$\Delta a = 2.59 \times 10^{-7} (8000) = 0.0021 \text{ inch}$$

The value of $\Delta a = 0.002$ inch is not a significant increase in flaw depth due to FCG and will not cause the predicted corrosion depths to exceed the allowable depths previously computed. Therefore, the final estimated flaw depths due to the combined degradation of BWC and FCG will be acceptable to the safety margins of ASME Section XI.

8.3 Allowable Flaw Depth Limits for Inspection

8.3.1 Nozzle Stub Weld Region

The allowable flaw depth for use as an inspection standard for flaw acceptance was computed from the previous results, given in Section 8.1. The allowable flaw depth at end-of-life is $a_{allow} = 2.59$ inches. Conservatively subtracting from a_{allow} the crack growth computed for 40-year service duty will give the allowable flaw depth for continued service to end-of-life. This value is obtained from the fatigue results in Appendix B, as determined below:

$$N = 1850 \text{ cycles} \qquad a = 2.59 \text{ inches}$$

$$N = 1850 - 480 = 1370 \text{ cycles} \qquad a = 2.14 \text{ inches}$$

Therefore, a = 2.14 inches is the maximum allowable flaw depth for acceptance, given a 40-year service life.

The allowable flaw limits for inspection are summarized in Figure 8-3. Two flaw locations are shown. Location A is for an axial flaw contained within the nozzle. For this case, a through-thickness flaw is acceptable because it does not impact the structural integrity of the nozzle repair or the head/shell (flaw at Location B is bounding for all nozzle flaws penetrating into the head/shell). Location B is for a flaw propagating into the original J-groove weld. For this flaw location, the allowable flaw depth is 2.14 inches, as computed above.

8.3.2 Corrosion Degradation of Hole Penetrations

The allowable corrosion sizes (depth and length) for use in in-service inspection for BWC were determined from the calculations given in Section 8.2 and Appendix C. The allowable corrosion depths at end-of-service are summarized in Tables C-1 and C-2. In establishing the allowable inspection standards, FCG was determined to be insignificant. In addition, the upper cut-off limit of 0.50 inch for local corrosion depth was imposed to restrict the maximum size of corrosion, as previously established.

The resulting acceptance values are given in Figure 8-4 as a function of axial position (e) and circumferential angle (θ). Intermediate values for axial position between e = 0 and e = 0.6 inch were conservatively determined by linear interpretation.

Table 8-1

BIGIF INPUT FILE FOR NOZZLE HOLE PENETRATION FLAW

```
PZR INSTRUMENT NOZZLE CORNER FLAW EVALUATION - SONGS UNIT 2 & 3
    1   05  303    1    0    2    1    3    0   20
1.00
3.875
80.0
0.65         3
1.000      1.20  E-11
12.04      3.23  E-05
100.       2.01  E-03
STARTUP/SHUTDOWN                1.042
1.0          0    5    0    0    5    3
0.0        0.0       53.83
0.0        1.478     45.71
0.0        3.875     20.12
0.0576     0.0       47.74
0.0576     1.478     40.16
0.0576     3.875     18.58
0.4983     0.0       33.20
0.4983     1.478     26.44
0.4983     3.875     14.47
1.0407     0.0       29.40
1.0407     1.478     22.29
1.0407     3.875     12.85
4.12       0.0       27.08
4.12       1.478     19.19
4.12       3.875     13.87
0.0          3    0    0    0    0    0
PLANT LOAD/UNLOAD               2084.
1.0          0    5    0    0    5    3
0.0        0.0       38.62
0.0        1.478     38.16
0.0        3.875     29.31
0.0576     0.0       34.29
0.0576     1.478     33.83
0.0576     3.875     27.68
0.4983     0.0       23.93
0.4983     1.478     23.57
0.4983     3.875     23.01
1.0407     0.0       21.06
1.0407     1.478     20.70
1.0407     3.875     21.09
4.12       0.0       19.30
4.12       1.478     18.76
4.12       3.875     18.06
1.0          1    5    0    0    5    3
0.0        0.0       32.62
0.0        1.478     34.18
0.0        3.875     29.65
```

Calculation No.: AES-C-3247-1	Made by: [signature]	Date: 5/8/98	Client: SCE
Title: Evaluation of Half-Nozzle Repair for Pressurizer and Steam Generator Instrumentation Nozzles Under Long-Term Service Conditions — SONGS 2 and 3	Checked by: [signature]	Date: 8 MAY 98	Project No.: AES 97123247-1Q
	Revision No.: 0	Document Control No.: I-2	Sheet No.: 64 of 69

```
0.0576    0.0      28.98
0.0576    1.478    30.45
0.0576    3.875    27.97
0.4983    0.0      20.27
0.4983    1.478    21.85
0.4983    3.875    23.30
1.0407    0.0      17.72
1.0407    1.478    19.57
1.0407    3.875    21.42
4.12      0.0      15.95
4.12      1.478    17.97
4.12      3.875    18.22
REACTOR TRIP               1.0
1.0          0    5    0    0    5    3
0.0       0.0      51.30
0.0       1.478    46.94
0.0       3.875    30.56
0.0576    0.0      45.45
0.0576    1.478    41.22
0.0576    3.875    28.84
0.4983    0.0      31.60
0.4983    1.478    27.20
0.4983    3.875    23.88
1.0407    0.0      28.13
1.0407    1.478    23.22
1.0407    3.875    21.85
4.12      0.0      26.29
4.12      1.478    20.91
4.12      3.875    19.44
1.0          2    5    0    0    5    3
0.0       0.0      24.29
0.0       1.478    26.37
0.0       3.875    24.96
0.0576    0.0      21.59
0.0576    1.478    23.49
0.0576    3.875    23.70
0.4983    0.0      15.10
0.4983    1.478    16.87
0.4983    3.875    20.00
1.0407    0.0      13.23
1.0407    1.478    15.11
1.0407    3.875    18.46
4.12      0.0      12.07
4.12      1.478    14.02
4.12      3.875    14.94
PLANT LEAK TEST            0.417
1.0          0    5    0    0    5    3
0.0       0.0      42.64
0.0       1.478    39.84
0.0       3.875    25.58
0.0576    0.0      37.85
0.0576    1.478    35.23
0.0576    3.875    23.86
```

```
0.4983    0.0      26.38
0.4983    1.478    24.20
0.4983    3.875    19.25
1.0407    0.0      23.22
1.0407    1.478    21.06
1.0407    3.875    17.51
4.12      0.0      21.12
4.12      1.478    18.86
4.12      3.875    17.03
1.0            2    5    0    0    5    3
0.0       0.0      3.410
0.0       1.478    5.759
0.0       3.875    9.638
0.0576    0.0      3.042
0.0576    1.478    5.185
0.0576    3.875    9.426
0.4983    0.0      2.154
0.4983    1.478    3.955
0.4983    3.875    8.476
1.0407    0.0      1.896
1.0407    1.478    3.673
1.0407    3.875    7.910
4.12      0.0      1.939
4.12      1.478    3.559
4.12      3.875    4.553
HYDROTEST                     0.021
1.0            0    5    0    0    5    3
0.0       0.0      57.33
0.0       1.478    52.67
0.0       3.875    31.29
0.0576    0.0      50.90
0.0576    1.478    46.70
0.0576    3.875    28.37
0.4983    0.0      35.49
0.4983    1.478    32.60
0.4983    3.875    21.47
1.0407    0.0      30.99
1.0407    1.478    28.70
1.0407    3.875    19.41
4.12      0.0      27.03
4.12      1.478    26.04
4.12      3.875    24.65
0.0            3    0    0    0    0    0
FINIS
```

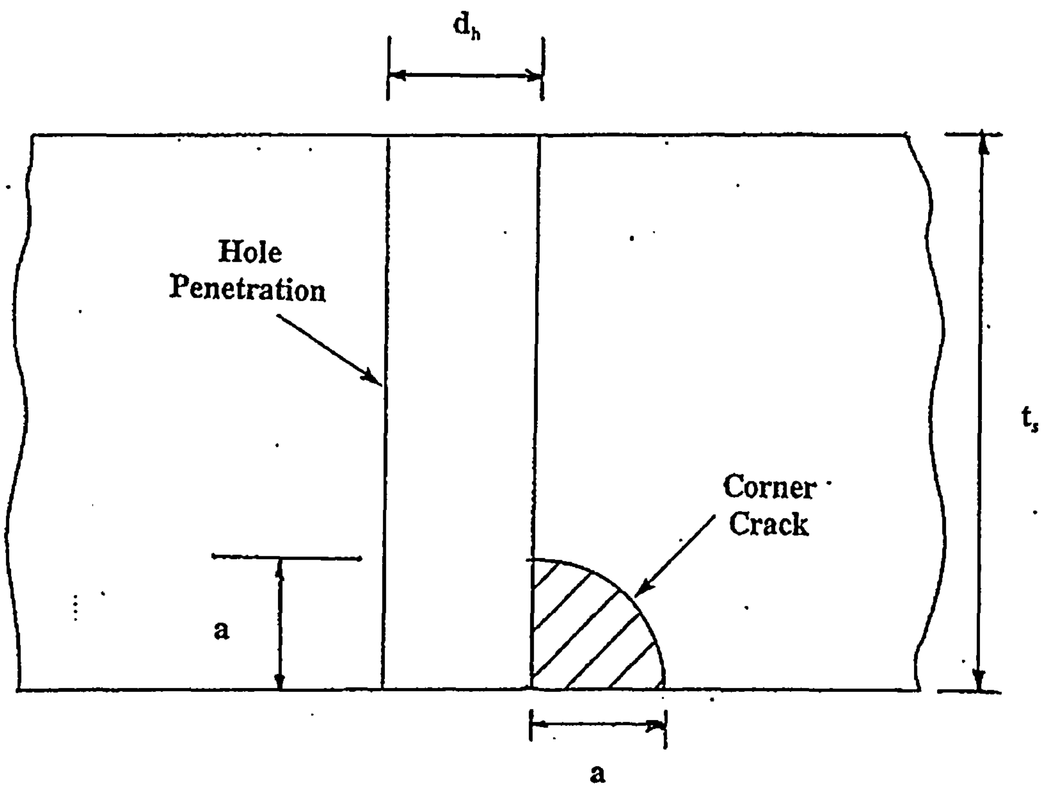

Figure 8-1 — Hole Penetration Flaw Model.

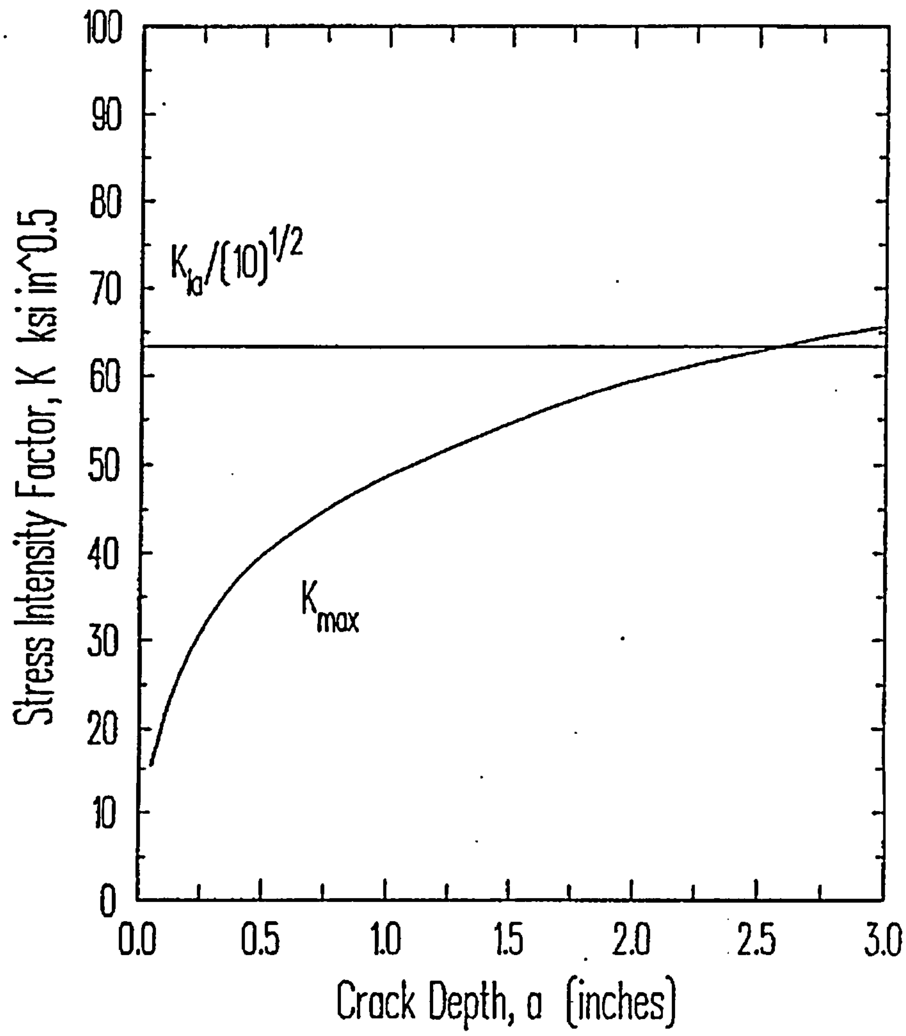

Figure 8-2 — Stress Intensity Factor Versus Flaw Depth for Corner Flaw.

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Calculation No.: AES-C-3247-1	Made by: RCC	Date: 5/8/98	Client: SCE
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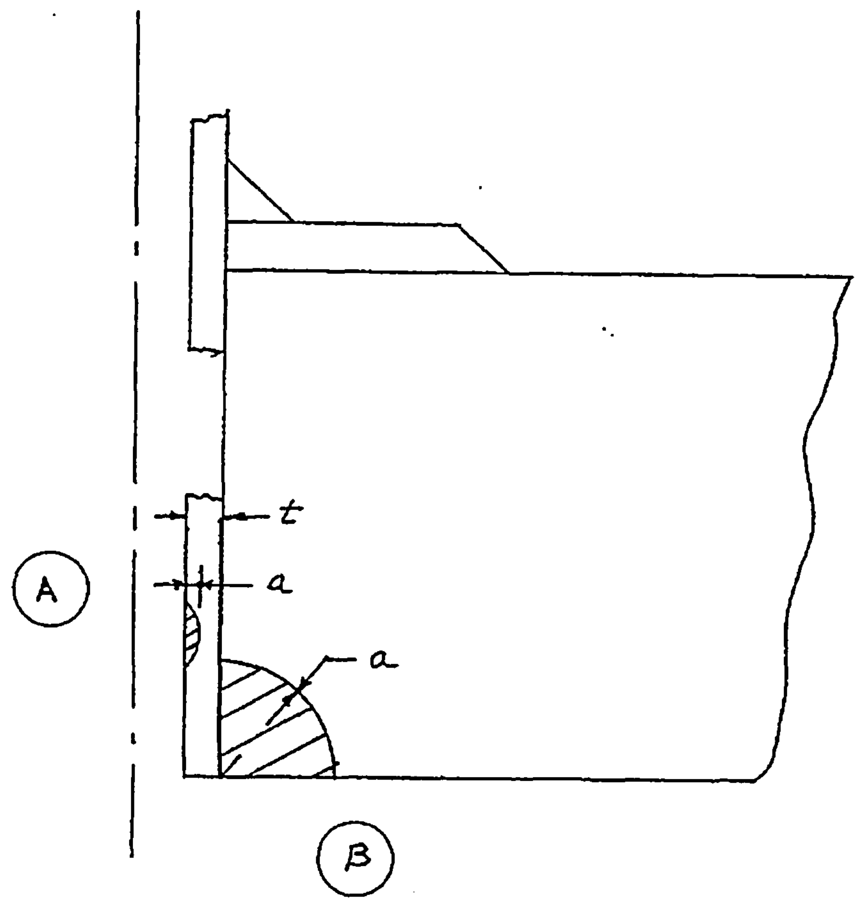
	Revision No.: 0	Document Control No.: 1-2	Sheet No.: 68 of 69



Location	Description	Allowable Size (inch)
A	Axial Nozzle Flaw	a = t
B	Base Metal Flaw (at Corner)	a = 2.14

Figure 8-3 — Inspection Acceptance Standards for Nozzle Flaws in Stub J-Groove Region.

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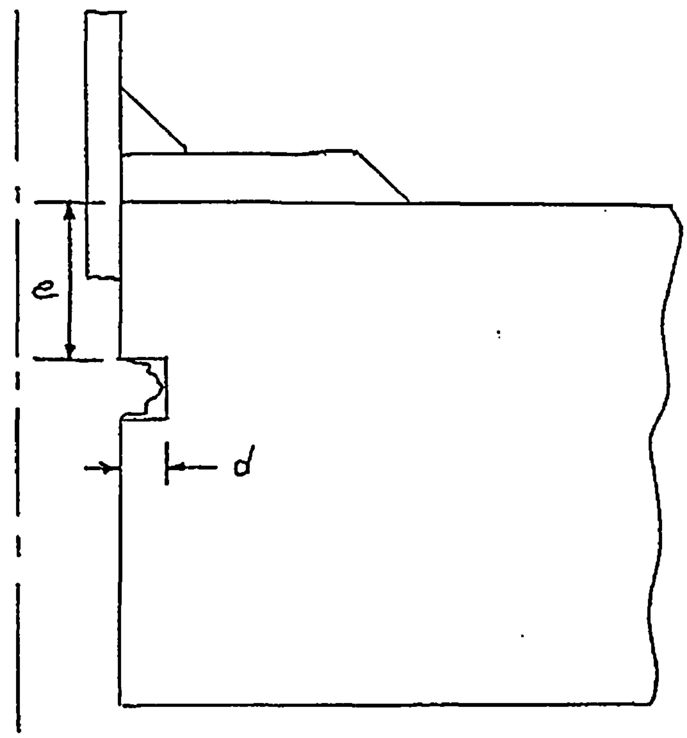

Allowable BWC Depth, d (inch)					
e (inch)	Circumferential Extent				
	20%	40%	60%	80%	100%
0.0	0.50	0.50	0.44	0.42	0.42
0.2	0.50	0.50	0.46	0.44	0.44
0.4	0.50	0.50	0.48	0.47	0.47
≥ 0.6	0.50	0.50	0.50	0.50	0.50

Figure 8-4 — Inspection Acceptance Standards for BWC Flaws.

Appendix A

SUMMARY OF HOLE PENETRATION HOOP STRESSES

Appendix A

SUMMARY OF HOLE PENETRATION HOOP STRESSES

A.1 ANALYSIS GEOMETRY

The stress results from the finite element analysis of the pressurizer bottom head (Ref. 4) were used to define the hoop stresses for the evaluation of a postulated flaw in the hole penetration. The finite element model geometry is shown in Figure A-1. The node numbers shown in Figure A-1 were used to define the stress input points for BIGIF (Ref. 6). The hoop stress values for the selected nodes are summarized in Table A-1.

The r - θ coordinate points for the inside surface nodes were used to define a rectangular grid in x - y coordinates for input to BIGIF. Node 454 is located at the corner and is assigned the x - y coordinate of (0, 0). The three y coordinates for the grid are defined from the radial positions of Nodes 454, 482, and 298 relative to Node 454. The five x coordinates are defined from the arc distances between the nodes along the inside surface where $x = R_i \Delta\theta$:

Node	θ (degrees)	Δθ (radians)	x (inches)
454	89.36597	---	0
453	89.29781	1.1896×10^{-3}	0.0576
560	88.77654	1.0287×10^{-3}	0.4983
555	88.13498	2.1485×10^{-3}	1.0407
951	84.49266	8.5055×10^{-3}	4.1200

A.2 STRESS COMBINATIONS

The stress values for maximum and minimum values for each plant transient were determined from appropriate combinations of stresses from the individual loading cases of Table A-1. The following scaling factors were used:

Plant Transient	Stress	P	Iso-T T=653°F	Ramp 200°F/hr	Cooldown w/strat	Step ΔT=20°F	Trip (t=50s)	Trip (t=2000s)
Startup/Shutdown	σ_{max}	0.90	0.0	0.0	1.0	0.0	0.0	0.0
	σ_{min}	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Load/Unload	σ_{max}	0.90	1.0	0.0	0.0	0.0	0.0	0.0
	σ_{min}	0.859	1.0	0.0	0.0	1.0	0.0	0.0
Reactor Trip	σ_{max}	1.02	0.0	0.0	0.0	0.0	1.0	0.0
	σ_{min}	0.678	0.0	0.0	0.0	0.0	0.0	1.0
Leak Test	σ_{max}	0.90	0.613	-0.5	0.0	0.0	0.0	0.0
	σ_{min}	0.175	0.613	+0.5	0.0	0.0	0.0	0.0
Hydro Test	σ_{max}	1.25	0.0	0.0	0.0	0.0	0.0	0.0
	σ_{min}	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-2 provides the stress values for σ_{max} and σ_{min} and $\Delta\sigma$ for each transient condition. As noted in Table A-1, the pressure stress was increased by 20% over and above the values listed in Column 1 of Table A-1 to account for elevated hoop stress in the cylindrical shell portion of the pressurizer where the 1-inch temperature nozzle is located. Also the pressure acting on the crack face was added to the pressure stress term. As an example, the hoop stress for operating pressure for use in BIGIF is (1.2) (0.9) times the stress values in Column 1 of Table A-1 plus the operating pressure of 2235 psi:

$$\sigma_\theta = (1.2)(0.9)[P_{Load\,Case}] + 2235$$

Calculation No.: AES-C-3247-1	Made by: RCC	Date: 5/8/98	Client: SCE
Title: Evaluation of Half-Nozzle Repair for Pressurizer and Steam Generator Instrumentation Nozzles Under Long-Term Service Conditions — SONGS 2 and 3	Checked by: MTC	Date: 5/14/98	Project No.: AES 97123247-1Q
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This formula was consistently applied to all pressure stress terms contributing to σ_{max} and σ_{min}. Thermal stress cases were combined with pressure to obtain the absolute maximum stress range possible for the transient.

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Calculation No.: AES-C-3247-1	Made by: [signature]	Date: 5/8/98	Client: SCE
Title: Evaluation of Half-Nozzle Repair for Pressurizer and Steam Generator Instrumentation Nozzles Under Long-Term Service Conditions — SONGS 2 and 3	Checked by: [signature]	Date: 8 MAY 98	Project No.: AES 97123247-1Q
	Revision No.: 0	Document Control No.: I-2	Sheet No.: A-5 of A-9

TABLE A-1 STRESS LOAD CASES FOR NOZZLE PENETRATION

NODE	Pressure* 2485 psig (psi)	Isothermal T=653F (psi)	Heatup 200F/Hr t=3600s (psi)	Cooldown w/Strat t=6264s (psi)	Plant Load Change ΔT=20F t=60s (psi)	Reactor Trip t=50s (psi)	Reactor Trip t=2000s (psi)
454	36150	-2636	-6007	12580	-4150	4516	-6806
482	33040	265	-3558	7811	-2285	3962	-2201
289/550**	18790	6790	2194	-2397	1350	5021	7983
453	31860	-2336	-5310	11120	-3663	3914	-6022
481	29060	228	-2988	6560	-1878	3110	-1840
288/549**	16840	7268	2004	-1830	1208	5687	8310
560	21590	-1610	-3660	7663	-2512	2634	-4149
644	19660	113	-1359	2982	-667	594	-815
328/848**	12240	7567	1669	-972	978	6358	8352
555	18590	-1240	-3368	7100	-2338	2841	-3579
639	17060	50	-753	1647	-204	-197	-454
323/843**	10870	7127	1652	-1118	953	6004	7931
951	15950	-147	-3512	7632	-2481	4230	-2593
1231	15290	27	-208	456	41	-342	-107
1851	14360	328	1801	-3860	947	-677	1569

*Pressure stresses will be multiplied by "Factor" to account for increase in hoop stress for cylindrical shell. Factor = 1.2

(Also, crack face pressure was added to pressure stress)

**Next node below outer node was used to define stress when sharp gradient at pad/shell interface affected the value at outer node.

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M-DSC-360 SH. 76

Calculation No.: AES-C-3247-1	Made by: [signature]	Date: 5/8/98	Client: SCE
Title: Evaluation of Half-Nozzle Repair for Pressurizer and Steam Generator Instrumentation Nozzles Under Long-Term Service Conditions — SONGS 2 and 3	Checked by: [signature]	Date: 8 MAY 98	Project No.: AES 97123247-1Q
	Revision No.: 0	Document Control No.: I-2	Sheet No.: A-6 of A-9

TABLE A-2 STRESS SUMMARY (PSI) FOR NOZZLE PENETRATION

1) STARTUP/SHUTDOWN (w STRATIFICATION)

X	Y	SIG_MAX	SIG_MIN	DEL_SIG
0	0	53831	0	53831
0	1.478	45705	0	45705
0	3.875	20118	0	20118
0.0576	0	47741	0	47741
0.0576	1.478	40159	0	40159
0.0576	3.875	18580	0	18580
0.4983	0	33200	0	33200
0.4983	1.478	26436	0	26436
0.4983	3.875	14473	0	14473
1.0407	0	29399	0	29399
1.0407	1.478	22294	0	22294
1.0407	3.875	12849	0	12849
4.12	0	27081	0	27081
4.12	1.478	19193	0	19193
4.12	3.875	13873	0	13873

2) PLANT LOADING/UNLOADING

X	Y	SIG_MAX	SIG_MIN	DEL_SIG
0	0	38615	32619	5996
0	1.478	38159	34179	3980
0	3.875	29305	29647	-343
0.0576	0	34285	28983	5302
0.0576	1.478	33827	30445	3381
0.0576	3.875	27678	27973	-295
0.4983	0	23927	20272	3655
0.4983	1.478	23567	21850	1716
0.4983	3.875	23012	23299	-287
1.0407	0	21059	17723	3336
1.0407	1.478	20697	19570	1128
1.0407	3.875	21094	21422	-328
4.12	0	19302	15951	3351
4.12	1.478	18764	17967	797
4.12	3.875	18061	18215	-154

TABLE A-2 STRESS SUMMARY (PSI) FOR NOZZLE PENETRATION (Contd)

3) REACTOR TRIP

X	Y	SIG_MAX	SIG_MIN	DEL_SIG
0	0	51304	24294	27010
0	1.478	46943	26368	20575
0	3.875	30558	24957	5601
0.0576	0	45450	21587	23863
0.0576	1.478	41219	23491	17728
0.0576	3.875	28837	23697	5139
0.4983	0	31598	15103	16495
0.4983	1.478	27196	16867	10329
0.4983	3.875	23877	19996	3880
1.0407	0	28133	13232	14901
1.0407	1.478	23222	15112	8109
1.0407	3.875	21845	18461	3385
4.12	0	26290	12070	14220
4.12	1.478	20910	14019	6891
4.12	3.875	19437	14938	4498

4) PLANT LEAK TEST

X	Y	SIG_MAX	SIG_MIN	DEL_SIG
0	0	42640	3410	39229
0	1.478	39836	5759	34077
0	3.875	25577	9638	15939
0.0576	0	37845	3042	34803
0.0576	1.478	35232	5185	30047
0.0576	3.875	23860	9426	14434
0.4983	0	26380	2154	24226
0.4983	1.478	24202	3955	20248
0.4983	3.875	19246	8476	10770
1.0407	0	23223	1896	21327
1.0407	1.478	21055	3673	17382
1.0407	3.875	17506	7910	9596
4.12	0	21115	1939	19176
4.12	1.478	18858	3559	15298
4.12	3.875	17034	4553	12481

Calculation No.: AES-C-3247-1	Made by: RLC	Date: 5/8/98	Client: SCE
Title: Evaluation of Half-Nozzle Repair for Pressurizer and Steam Generator Instrumentation Nozzles Under Long-Term Service Conditions — SONGS 2 and 3	Checked by: MTC	Date: 8 MAY 98	Project No.: AES 97123247-1Q
	Revision No.: 0	Document Control No.: I-2	Sheet No.: A-8 of A-9

TABLE A-2 STRESS SUMMARY (PSI) FOR NOZZLE PENETRATION (Contd)

5) HYDRO TEST

X	Y	SIG_MAX	SIG_MIN	DEL_SIG
0	0	57331	0	57331
0	1.478	52666	0	52666
0	3.875	31291	0	31291
0.0576	0	50896	0	50896
0.0576	1.478	46696	0	46696
0.0576	3.875	28366	0	28366
0.4983	0	35491	0	35491
0.4983	1.478	32596	0	32596
0.4983	3.875	21466	0	21466
1.0407	0	30991	0	30991
1.0407	1.478	28696	0	28696
1.0407	3.875	19411	0	19411
4.12	0	27031	0	27031
4.12	1.478	26041	0	26041
4.12	3.875	24646	0	24646

Calculation No.: AES-C-3247-1	Made by: RLC	Date: 5/8/98	Client: SCE
Title: Evaluation of Half-Nozzle Repair for Pressurizer and Steam Generator Instrumentation Nozzles Under Long-Term Service Conditions — SONGS 2 and 3	Checked by: MTC	Date: 8 May 98	Project No.: AES 97123247-1Q
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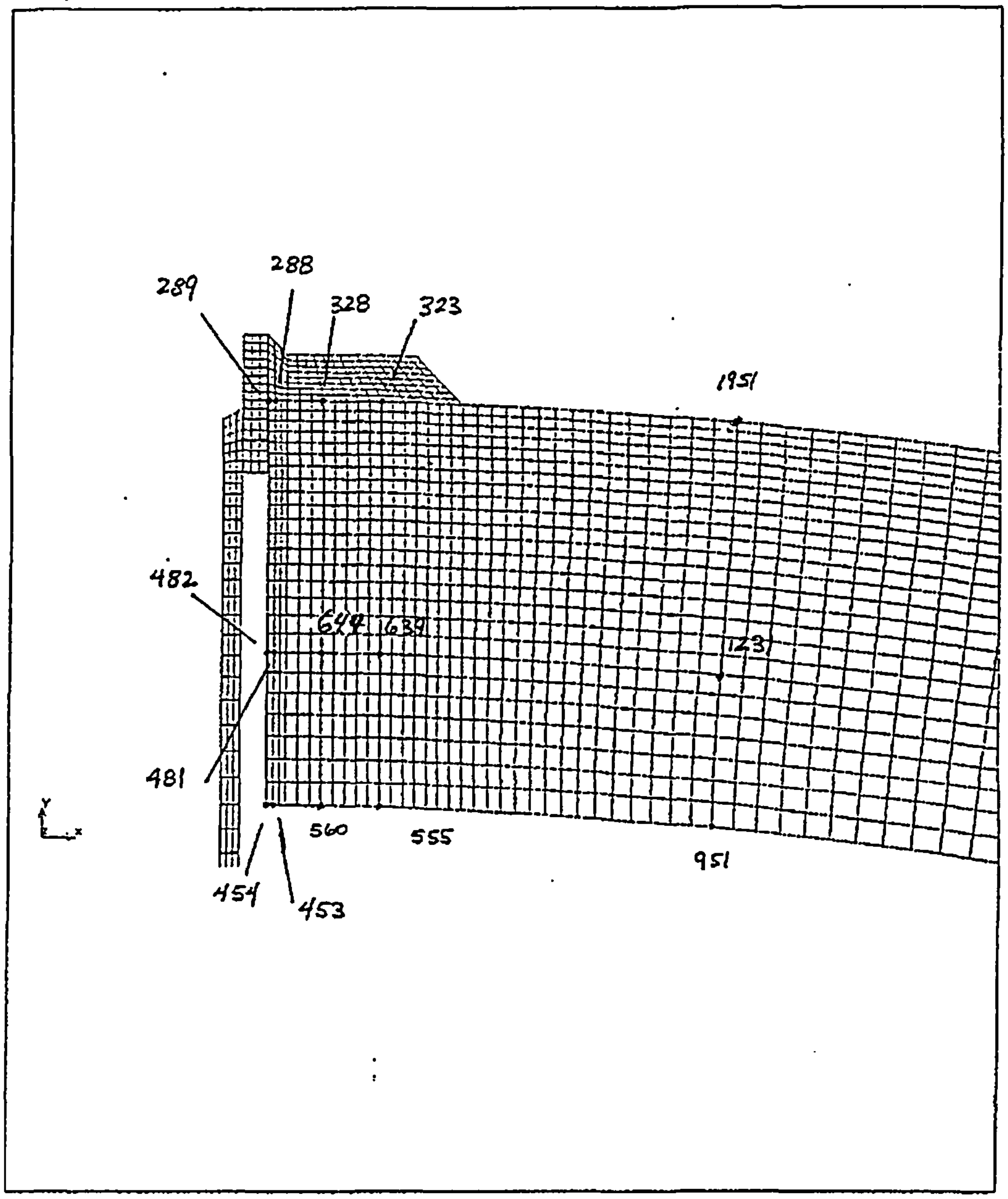

Figure A-1 — Finite Element Model and Node Positions for Stresses.

Calculation No.: AES-C-3247-1	Made by: [signature]	Date: 5/8/98	Client: SCE
Title: Evaluation of Half-Nozzle Repair for Pressurizer and Steam Generator Instrumentation Nozzles Under Long-Term Service Conditions — SONGS 2 and 3	Checked by: [signature]	Date: 8 May 98	Project No.: AES 97123247-1Q
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Appendix B

COMPUTER OUTPUT FROM BIGIF

Calculation No.: AES-C-3247-1	Made by: RCC	Date: 5/8/98	Client: SCE
Title: Evaluation of Half-Nozzle Repair for Pressurizer and Steam Generator Instrumentation Nozzles Under Long-Term Service Conditions — SONGS 2 and 3	Checked by: MTC	Date: 8 MAY 98	Project No.: AES 97123247-1Q
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```
PZR INSTRUMENT NOZZLE CORNER FLAW EVALUATION - SONGS UNIT 2 & 3

BIGIF:   BOUNDARY INTEGRAL EQUATION          IBM PC VERSION    REV. 0 - SEPTEMBER 23, 1985
         GENERATED INFLUENCE FUNCTIONS
         FOR USE IN FRACTURE MECHANICS
         PROBLEMS

           ANALYSIS SELECTION (IFAT)

                     1 FATIGUE ANALYSIS

           CRACK GEOMETRY MODEL INDEX NUMBER (IFI)

                   303 SURFACE 1/4 CIRCULAR CRACK

           VARIABLE THICKNESS SPECIFICATION (NTH)

                     0 CONSTANT BODY THICKNESS

           CRACK GROWTH RATE RULE (IDADN)

                     2 INPUT TABULAR DA/DN, DELTA-K DATA

           INTEGRATION INCREMENT SCHEME (INUM)

                     3 REFINED

           SINGLE OR MULT INTEGRATION SCHEMES (INCL)

                     0 SINGLE

           INCREMENTS USED TO DOUBLE CRACK SIZE (NDUB)

                       USER SPECIFIED NDUB =    20
GEOMETRY AND MATERIAL                        PZR INSTRUMENT NOZZLE CORNER FLAW EVALUATION - SONGS UNIT 2 & 3
 CRACK GROWTH INPUT

 NUMBER OF DEGREES OF FREEDOM = 1

        INITIAL A-VALUES FOR EACH DEGREE OF FREEDOM

             CRACK LENGTH AI(1) =    1.0000


         GEOMETRY FACTORS

            G(1)    3.8750        BODY WIDTH
            G(2)    .00000
            G(3)    .00000
            G(4)    .00000
            G(5)    .00000
            G(6)    .00000        X-COORD. TO CRACK CENTER (XC)
            G(7)    .00000        Y-COORD. TO CRACK CENTER (YC)
            G(8)    .00000        CRACK ORIENTATION ANGLE (PHI, DEGREES)

        DA/DN OPTION SELECTED:  2

             KIC =  80.000      FRACTURE TOUGHNESS

       THERE ARE SETS OF INPUT DATA FOR  1 R-RATIOS

       R-RATIO =    .65000          3 POINTS INPUT
            DELTA-K      DA/DN
         1.0000      1.20000E-11
         12.040      3.23000E-05
         100.00      2.01000E-03
```

Calculation No.: AES-C-3247-1	Made by: RCC	Date: 5/8/98	Client: SCE
Title: Evaluation of Half-Nozzle Repair for Pressurizer and Steam Generator Instrumentation Nozzles Under Long-Term Service Conditions — SONGS 2 and 3	Checked by: MTC	Date: 8 MAY 98	Project No.: AES 97123247-1Q
	Revision No.: 0	Document Control No.: I-2	Sheet No.: B-3 of B-9

LOAD TRANSIENTS: 5 TRANSIENT(S) IN PROBLEM — PZR INSTRUMENT NOZZLE CORNER FLAW EVALUATION - SONGS UNIT 2 & 3

NUMBER	NAME	NUMBER OF CYCLES PER BLOCK	SPECIFIER	AGLD	IPSRD	IPLD	NAME	IWO	NPX	NPY
1	STARTUP/SHUTDOWN	1.0420	1	1.0000	0	5	0	0	5	3

BIVARIATE STRESS TABLE

X	Y	SIGMA(X,Y)
.00000	.00000	53.830
.00000	1.4780	45.710
.00000	3.8750	20.120
5.76000E-02	.00000	47.740
5.76000E-02	1.4780	40.160
5.76000E-02	3.8750	18.580
.49830	.00000	33.200
.49830	1.4780	26.440
.49830	3.8750	14.470
1.0407	.00000	29.400
1.0407	1.4780	22.290
1.0407	3.8750	12.850
4.1200	.00000	27.080
4.1200	1.4780	19.190
4.1200	3.8750	13.870

THE DATA FOR THE STRESS FIELD HAS BEEN READ CORRECTLY

NUMBER	NAME	NUMBER OF CYCLES PER BLOCK	SPECIFIER	AGLD	IPSRD	IPLD	NAME	IWO	NPX	NPY
			2	.00000	3	0	0	0	0	0
2	PLANT LOAD/UNLOAD	2084.0	1	1.0000	0	5	0	0	5	3

BIVARIATE STRESS TABLE

X	Y	SIGMA(X,Y)
.00000	.00000	38.620
.00000	1.4780	38.160
.00000	3.8750	29.310
5.76000E-02	.00000	34.290
5.76000E-02	1.4780	33.830
5.76000E-02	3.8750	27.680
.49830	.00000	23.930
.49830	1.4780	23.570
.49830	3.8750	23.010
1.0407	.00000	21.060
1.0407	1.4780	20.700
1.0407	3.8750	21.090
4.1200	.00000	19.300
4.1200	1.4780	18.760
4.1200	3.8750	18.060

THE DATA FOR THE STRESS FIELD HAS BEEN READ CORRECTLY

SPECIFIER	AGLD	IPSRD	IPLD	NAME	IWO	NPX	NPY
2	1.0000	1	5	0	0	5	3

BIVARIATE STRESS TABLE

X	Y	SIGMA(X,Y)
.00000	.00000	32.620
.00000	1.4780	34.180
.00000	3.8750	29.650
5.76000E-02	.00000	28.980
5.76000E-02	1.4780	30.450
5.76000E-02	3.8750	27.970
.49830	.00000	20.270
.49830	1.4780	21.850
.49830	3.8750	23.300
1.0407	.00000	17.720
1.0407	1.4780	19.570
1.0407	3.8750	21.420
4.1200	.00000	15.950
4.1200	1.4780	17.970
4.1200	3.8750	18.220

THE DATA FOR THE STRESS FIELD HAS BEEN READ CORRECTLY

```
            3     REACTOR TRIP                 1.0000        1     1.0000        0    5    0    0    5    3
                 BIVARIATE STRESS TABLE

       X             Y           SIGMA(X,Y)

     .00000        .00000         51.300
     .00000        1.4780         46.940
     .00000        3.8750         30.560
   5.76000E-02     .00000         45.450
   5.76000E-02     1.4780         41.220
   5.76000E-02     3.8750         28.840
     .49830        .00000         31.600
     .49830        1.4780         27.200
     .49830        3.8750         23.880
     1.0407        .00000         28.130
     1.0407        1.4780         23.220
     1.0407        3.8750         21.850
     4.1200        .00000         26.290
     4.1200        1.4780         20.910
     4.1200        3.8750         19.440
  THE DATA FOR THE STRESS FIELD HAS BEEN READ CORRECTLY
                                                             2     1.0000        2    5    0    0    5    3
                 BIVARIATE STRESS TABLE

       X             Y           SIGMA(X,Y)

     .00000        .00000         24.290
     .00000        1.4780         26.370
     .00000        3.8750         24.960
   5.76000E-02     .00000         21.590
   5.76000E-02     1.4780         23.490
   5.76000E-02     3.8750         23.700
     .49830        .00000         15.100
     .49830        1.4780         16.870
     .49830        3.8750         20.000
     1.0407        .00000         13.230
     1.0407        1.4780         15.110
     1.0407        3.8750         18.460
     4.1200        .00000         12.070
     4.1200        1.4780         14.020
     4.1200        3.8750         14.940
  THE DATA FOR THE STRESS FIELD HAS BEEN READ CORRECTLY

            4     PLANT LEAK TEST              .41700        1     1.0000        0    5    0    0    5    3
                 BIVARIATE STRESS TABLE

       X             Y           SIGMA(X,Y)

     .00000        .00000         42.640
     .00000        1.4780         39.840
     .00000        3.8750         25.580
   5.76000E-02     .00000         37.850
   5.76000E-02     1.4780         35.230
   5.76000E-02     3.8750         23.860
     .49830        .00000         26.380
     .49830        1.4780         24.200
     .49830        3.8750         19.250
     1.0407        .00000         23.220
     1.0407        1.4780         21.060
     1.0407        3.8750         17.510
     4.1200        .00000         21.120
     4.1200        1.4780         18.860
     4.1200        3.8750         17.030
  THE DATA FOR THE STRESS FIELD HAS BEEN READ CORRECTLY
                                                             2     1.0000        2    5    0    0    5    3
```

Calculation No.: AES-C-3247-1	Made by: ccc	Date: 5/8/98	Client: SCE
Title: Evaluation of Half-Nozzle Repair for Pressurizer and Steam Generator Instrumentation Nozzles Under Long-Term Service Conditions — SONGS 2 and 3	Checked by: MTC	Date: 8 May 98	Project No.: AES 97123247-1Q
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BIVARIATE STRESS TABLE

X	Y	SIGMA(X,Y)
.00000	.00000	3.4100
.00000	1.4780	5.7590
.00000	3.8750	9.6380
5.76000E-02	.00000	3.0420
5.76000E-02	1.4780	5.1850
5.76000E-02	3.8750	9.4260
.49830	.00000	2.1540
.49830	1.4780	3.9550
.49830	3.8750	8.4760
1.0407	.00000	1.8960
1.0407	1.4780	3.6730
1.0407	3.8750	7.9100
4.1200	.00000	1.9390
4.1200	1.4780	3.5590
4.1200	3.8750	4.5530

THE DATA FOR THE STRESS FIELD HAS BEEN READ CORRECTLY

5 HYDROTEST 2.10000E-02 1 1.0000 0 5 0 0 5 3

BIVARIATE STRESS TABLE

X	Y	SIGMA(X,Y)
.00000	.00000	57.330
.00000	1.4780	52.670
.00000	3.8750	31.290
5.76000E-02	.00000	50.900
5.76000E-02	1.4780	46.700
5.76000E-02	3.8750	28.370
.49830	.00000	35.490
.49830	1.4780	32.600
.49830	3.8750	21.470
1.0407	.00000	30.990
1.0407	1.4780	28.700
1.0407	3.8750	19.410
4.1200	.00000	27.030
4.1200	1.4780	26.040
4.1200	3.8750	24.650

THE DATA FOR THE STRESS FIELD HAS BEEN READ CORRECTLY

2 .00000 3 0 0 0 0 0

DETAILED OUTPUT FOR ALL LOAD TRANSIENT(S) AND CRACK DEGREE(S) OF FREEDOM

INTEGRATION BREAKUP ************* * REFINED * ************* PZR INSTRUMENT NOZZLE CORNER FLAW EVALUATION - SONGS UNIT 2 & 3

TRANSIENT NUMBER	DEGREE OF FREEDOM	CYCLES /BLOCK	KMAX	KMIN	KMEAN	DEL-K	R-RAT	TRANSIENT DA/DN (PER CYCLE)	DA/DN (PER BLOCK)	DOF CRACK SIZE	N
1	1	1.042	44.05	.00	22.03	44.05	.000	4.0590E-04	7.085E-04	1.00	.0000
2	1	2084.	33.65	29.24	31.44	4.41	.869	8.1496E-08			
3	1	1.000	42.97	20.90	31.93	22.07	.486	1.0535E-04			
4	1	.4170	36.31	32.48	34.40	3.83	.894	3.5522E-08			
5	1	2.1000E-02	48.71	.00	24.36	48.71	.000	4.9396E-04			
1	1	1.042	44.38	.00	22.19	44.38	.000	4.1177E-04	7.195E-04	1.04	49.39
2	1	2084.	33.98	29.56	31.77	4.42	.870	8.2615E-08			
3	1	1.000	43.33	21.00	32.16	22.32	.485	1.0774E-04			
4	1	.4170	36.64	32.74	34.69	3.90	.893	3.9676E-08			
5	1	2.1000E-02	49.15	.00	24.58	49.15	.000	5.0268E-04			
1	1	1.042	44.70	.00	22.35	44.70	.000	4.1769E-04	7.304E-04	1.07	99.75
2	1	2084.	34.32	29.90	32.11	4.42	.871	8.3594E-08			
3	1	1.000	43.69	21.10	32.40	22.58	.483	1.1022E-04			
4	1	.4170	36.99	33.00	34.99	3.98	.892	4.4408E-08			
5	1	2.1000E-02	49.60	.00	24.80	49.60	.000	5.1161E-04			

Calculation No.: AES-C-3247-1	Made by: RCC	Date: 5/8/98	Client: SCE
Title: Evaluation of Half-Nozzle Repair for Pressurizer and Steam Generator Instrumentation Nozzles Under Long-Term Service Conditions — SONGS 2 and 3	Checked by: MTC	Date: 8/14/98	Project No.: AES 97123247-1Q
	Revision No.: 0	Document Control No.: I-2	Sheet No.: B-6 of B-9

1	1	1.042	45.08	.00	22.54	45.08	.000	4.2456E-04	7.436E-04	1.11	151.0
2	1	2084.	34.70	30.27	32.48	4.44	.872	8.5049E-08			
3	1	1.000	44.10	21.23	32.67	22.88	.481	1.1301E-04			
4	1	.4170	37.35	33.29	35.32	4.06	.891	5.0069E-08			
5	1	2.1000E-02	50.10	.00	25.05	50.10	.000	5.2177E-04			
1	1	1.042	45.44	.00	22.72	45.44	.000	4.3134E-04	7.562E-04	1.15	203.2
2	1	2084.	35.09	30.64	32.86	4.45	.873	8.6236E-08			
3	1	1.000	44.51	21.34	32.93	23.17	.479	1.1586E-04			
4	1	.4170	37.73	33.58	35.66	4.14	.890	5.6522E-08			
5	1	2.1000E-02	50.60	.00	25.30	50.60	.000	5.3201E-04			
1	1	1.042	45.81	.00	22.91	45.81	.000	4.3815E-04	7.685E-04	1.19	256.3
2	1	2084.	35.48	31.02	33.25	4.46	.874	8.7179E-08			
3	1	1.000	44.92	21.45	33.19	23.47	.478	1.1881E-04			
4	1	.4170	38.11	33.88	35.99	4.23	.889	6.3925E-08			
5	1	2.1000E-02	51.11	.00	25.55	51.11	.000	5.4244E-04			
1	1	1.042	46.16	.00	23.08	46.16	.000	4.4473E-04	7.796E-04	1.23	310.5
2	1	2084.	35.86	31.40	33.63	4.46	.876	8.7711E-08			
3	1	1.000	45.32	21.55	33.44	23.77	.476	1.2180E-04			
4	1	.4170	38.48	34.16	36.32	4.32	.888	7.2340E-08			
5	1	2.1000E-02	51.61	.00	25.80	51.61	.000	5.5280E-04			
1	1	1.042	46.51	.00	23.26	46.51	.000	4.5139E-04	7.906E-04	1.27	365.8
2	1	2084.	36.25	31.79	34.02	4.46	.877	8.8024E-08			
3	1	1.000	45.73	21.65	33.69	24.08	.473	1.2492E-04			
4	1	.4170	38.86	34.45	36.65	4.41	.886	8.2057E-08			
5	1	2.1000E-02	52.11	.00	26.06	52.11	.000	5.6345E-04			
1	1	1.042	46.85	.00	23.43	46.85	.000	4.5778E-04	8.003E-04	1.32	422.3
2	1	2084.	36.64	32.18	34.41	4.46	.878	8.7863E-08			
3	1	1.000	46.12	21.73	33.92	24.39	.471	1.2807E-04			
4	1	.4170	39.23	34.72	36.97	4.51	.885	9.3134E-08			
5	1	2.1000E-02	52.61	.00	26.30	52.61	.000	5.7400E-04			
1	1	1.042	47.18	.00	23.59	47.18	.000	4.6401E-04	8.090E-04	1.37	480.2
2	1	2084.	37.03	32.57	34.80	4.46	.880	8.7291E-08			
3	1	1.000	46.50	21.80	34.15	24.70	.469	1.3130E-04			
4	1	.4170	39.59	34.99	37.29	4.60	.884	1.0584E-07			
5	1	2.1000E-02	53.10	.00	26.55	53.10	.000	5.8457E-04			
1	1	1.042	47.51	.00	23.75	47.51	.000	4.7041E-04	8.178E-04	1.41	539.4
2	1	2084.	37.43	32.98	35.21	4.45	.881	8.6531E-08			
3	1	1.000	46.89	21.86	34.38	25.03	.466	1.3470E-04			
4	1	.4170	39.97	35.27	37.62	4.71	.882	1.2067E-07			
5	1	2.1000E-02	53.62	.00	26.81	53.62	.000	5.9560E-04			
1	1	1.042	47.84	.00	23.92	47.84	.000	4.7682E-04	8.259E-04	1.46	600.1
2	1	2084.	37.84	33.40	35.62	4.44	.883	8.5433E-08			
3	1	1.000	47.29	21.93	34.61	25.36	.464	1.3825E-04			
4	1	.4170	40.36	35.55	37.95	4.81	.881	1.3792E-07			
5	1	2.1000E-02	54.13	.00	27.07	54.13	.000	6.0690E-04			
1	1	1.042	48.24	.00	24.12	48.24	.000	4.8458E-04	8.374E-04	1.52	662.1
2	1	2084.	38.31	33.88	36.10	4.44	.884	8.4965E-08			
3	1	1.000	47.76	22.02	34.89	25.74	.461	1.4229E-04			
4	1	.4170	40.80	35.87	38.34	4.93	.879	1.5917E-07			
5	1	2.1000E-02	54.73	.00	27.37	54.73	.000	6.2005E-04			
1	1	1.042	48.64	.00	24.32	48.64	.000	4.9259E-04	8.491E-04	1.57	725.5
2	1	2084.	38.80	34.37	36.59	4.43	.886	8.4403E-08			
3	1	1.000	48.25	22.11	35.18	26.14	.458	1.4657E-04			
4	1	.4170	41.26	36.21	38.74	5.05	.878	1.8467E-07			
5	1	2.1000E-02	55.35	.00	27.67	55.35	.000	6.3373E-04			
1	1	1.042	49.03	.00	24.52	49.03	.000	5.0034E-04	8.599E-04	1.62	790.3
2	1	2084.	39.29	34.87	37.08	4.42	.887	8.3438E-08			
3	1	1.000	48.73	22.19	35.46	26.54	.455	1.5097E-04			
4	1	.4170	41.72	36.53	39.13	5.19	.876	2.1491E-07			
5	1	2.1000E-02	55.95	.00	27.98	55.95	.000	6.4731E-04			
1	1	1.042	49.40	.00	24.70	49.40	.000	5.0774E-04	8.694E-04	1.68	856.6
2	1	2084.	39.78	35.37	37.57	4.41	.889	8.1991E-08			
3	1	1.000	49.20	22.26	35.73	26.94	.452	1.5547E-04			
4	1	.4170	42.16	36.84	39.50	5.32	.874	2.5075E-07			
5	1	2.1000E-02	56.54	.00	28.27	56.54	.000	6.6070E-04			
1	1	1.042	49.75	.00	24.88	49.75	.000	5.1476E-04	8.777E-04	1.74	924.4
2	1	2084.	40.26	35.87	38.06	4.39	.891	8.0127E-08			
3	1	1.000	49.66	22.32	35.99	27.34	.449	1.6008E-04			
4	1	.4170	42.60	37.14	39.87	5.46	.872	2.9341E-07			
5	1	2.1000E-02	57.12	.00	28.56	57.12	.000	6.7384E-04			

Calculation No.: AES-C-3247-1	Made by: RCC	Date: 5/8/98	Client: SCE
Title: Evaluation of Half-Nozzle Repair for Pressurizer and Steam Generator Instrumentation Nozzles Under Long-Term Service Conditions — SONGS 2 and 3	Checked by: MTC	Date: 8 MAY 98	Project No.: AES 97123247-1Q
	Revision No.: 0	Document Control No.: I-2	Sheet No.: B-7 of B-9

1	1	1.042	50.09	.00	25.05	50.09	.000	5.2162E-04	8.855E-04	1.80	994.1
2	1	2084.	40.75	36.37	38.56	4.37	.893	7.7984E-08			
3	1	1.000	50.12	22.37	36.24	27.76	.446	1.6486E-04			
4	1	.4170	43.04	37.42	40.23	5.61	.870	3.4450E-07			
5	1	2.1000E-02	57.69	.00	28.84	57.69	.000	6.8699E-04			
1	1	1.042	50.44	.00	25.22	50.44	.000	5.2872E-04	8.938E-04	1.87	1066.
2	1	2084.	41.26	36.90	39.08	4.35	.894	7.5862E-08			
3	1	1.000	50.61	22.42	36.51	28.19	.443	1.6993E-04			
4	1	.4170	43.49	37.72	40.60	5.77	.867	4.0655E-07			
5	1	2.1000E-02	58.27	.00	29.13	58.27	.000	7.0062E-04			
1	1	1.042	50.77	.00	25.38	50.77	.000	5.3543E-04	9.012E-04	1.93	1139.
2	1	2084.	41.76	37.43	39.60	4.33	.896	7.3398E-08			
3	1	1.000	51.09	22.45	36.77	28.63	.440	1.7513E-04			
4	1	.4170	43.93	38.00	40.96	5.94	.865	4.8109E-07			
5	2	2.1000E-02	58.84	.00	29.42	58.84	.000	7.1398E-04			
1	1	1.042	51.07	.00	25.54	51.07	.000	5.4173E-04	9.075E-04	2.00	1214.
2	1	2084.	42.27	37.97	40.12	4.30	.898	7.0565E-08			
3	1	1.000	51.56	22.48	37.02	29.08	.436	1.8047E-04			
4	1	.4170	44.37	38.26	41.31	6.11	.862	5.7064E-07			
5	1	2.1000E-02	59.39	.00	29.69	59.39	.000	7.2706E-04			
1	1	1.042	51.36	.00	25.68	51.36	.000	5.4759E-04	9.129E-04	2.07	1292.
2	1	2084.	42.77	38.51	40.64	4.27	.900	6.7414E-08			
3	1	1.000	52.02	22.49	37.25	29.53	.432	1.8595E-04			
4	1	.4170	44.79	38.50	41.65	6.29	.860	6.7848E-07			
5	1	2.1000E-02	59.92	.00	29.96	59.92	.000	7.3982E-04			
1	1	1.042	51.61	.00	25.81	51.61	.000	5.5298E-04	9.173E-04	2.14	1371.
2	1	2084.	43.27	39.04	41.16	4.23	.902	6.4012E-08			
3	1	1.000	52.47	22.49	37.48	29.98	.429	1.9159E-04			
4	1	.4170	45.21	38.73	41.97	6.48	.857	8.0870E-07			
5	1	2.1000E-02	60.43	.00	30.21	60.43	.000	7.5220E-04			
1	1	1.042	51.85	.00	25.92	51.85	.000	5.5787E-04	9.209E-04	2.22	1454.
2	1	2084.	43.77	39.58	41.68	4.19	.904	6.0350E-08			
3	1	1.000	52.92	22.47	37.70	30.44	.425	1.9737E-04			
4	1	.4170	45.61	38.94	42.28	6.68	.854	9.6600E-07			
5	1	2.1000E-02	60.92	.00	30.46	60.92	.000	7.6418E-04			
1	1	1.042	52.11	.00	26.05	52.11	.000	5.6331E-04	9.262E-04	2.30	1538.
2	1	2084.	44.31	40.16	42.23	4.15	.906	5.7008E-08			
3	1	1.000	53.40	22.47	37.94	30.93	.421	2.0360E-04			
4	1	.4170	46.05	39.17	42.61	6.88	.851	1.1600E-06			
5	1	2.1000E-02	61.44	.00	30.72	61.44	.000	7.7705E-04			
1	1	1.042	52.34	.00	26.17	52.34	.000	5.6831E-04	9.309E-04	2.38	1626.
2	1	2084.	44.84	40.74	42.79	4.10	.908	5.3495E-08			
3	1	1.000	53.88	22.45	38.17	31.43	.417	2.1004E-04			
4	1	.4170	46.48	39.38	42.93	7.10	.847	1.3957E-06			
5	1	2.1000E-02	61.95	.00	30.98	61.95	.000	7.8961E-04			
1	1	1.042	52.55	.00	26.28	52.55	.000	5.7281E-04	9.350E-04	2.46	1716.
2	1	2084.	45.38	41.32	43.35	4.06	.911	4.9850E-08			
3	1	1.000	54.35	22.42	38.39	31.93	.413	2.1666E-04			
4	1	.4170	46.89	39.57	43.23	7.33	.844	1.6825E-06			
5	1	2.1000E-02	62.44	.00	31.22	62.44	.000	8.0176E-04			
1	1	1.042	52.77	.00	26.39	52.77	.000	5.7749E-04	9.400E-04	2.55	1808.
2	1	2084.	45.94	41.93	43.93	4.01	.913	4.6349E-08			
3	1	1.000	54.86	22.40	38.63	32.46	.408	2.2372E-04			
4	1	.4170	47.33	39.76	43.55	7.57	.840	2.0368E-06			
5	1	2.1000E-02	62.94	.00	31.47	62.94	.000	8.1442E-04			
1	1	1.042	53.05	.00	26.53	53.05	.000	5.8348E-04	9.483E-04	2.64	1903.
2	1	2084.	46.56	42.60	44.58	3.96	.915	4.3338E-08			
3	1	1.000	55.44	22.40	38.92	33.04	.404	2.3159E-04			
4	1	.4170	47.83	40.00	43.92	7.82	.836	2.4837E-06			
5	1	2.1000E-02	63.52	.00	31.76	63.52	.000	8.2909E-04			
1	1	1.042	53.31	.00	26.65	53.31	.000	5.8897E-04	9.562E-04	2.73	2001.
2	1	2084.	47.19	43.28	45.23	3.91	.917	4.0188E-08			
3	1	1.000	56.02	22.39	39.20	33.63	.400	2.3973E-04			
4	1	.4170	48.32	40.23	44.27	8.09	.833	3.0328E-06			
5	1	2.1000E-02	64.08	.00	32.04	64.08	.000	8.4346E-04			

1	1	1.042	53.54	.00	26.77	53.54	.000	5.9394E-04	9.636E-04	2.83	2102.
2	1	2084.	47.82	43.96	45.89	3.86	.919	3.6960E-08			
3	1	1.000	56.60	22.36	39.48	34.23	.395	2.4815E-04			
4	1	.4170	48.80	40.43	44.62	8.37	.829	3.7070E-06			
5	1	2.1000E-02	64.63	.00	32.31	64.63	.000	8.5752E-04			
1	1	1.042	53.74	.00	26.87	53.74	.000	5.9836E-04	9.708E-04	2.93	2205.
2	1	2084.	48.45	44.65	46.55	3.80	.922	3.3689E-08			
3	1	1.000	57.17	22.33	39.75	34.84	.391	2.5687E-04			
4	1	.4170	49.28	40.62	44.95	8.66	.824	4.5355E-06			
5	1	2.1000E-02	65.15	.00	32.58	65.15	.000	8.7121E-04			
1	1	1.042	53.92	.00	26.96	53.92	.000	6.0220E-04	9.776E-04	3.03	2311.
2	1	2084.	49.09	45.35	47.22	3.73	.924	3.0409E-08			
3	1	1.000	57.74	22.27	40.01	35.46	.386	2.6588E-04			
4	1	.4170	49.74	40.79	45.27	8.96	.820	5.5527E-06			
5	1	2.1000E-02	65.66	.00	32.83	65.66	.000	8.8455E-04			
1	1	1.042	54.11	.00	27.06	54.11	.000	6.0643E-04	9.862E-04	3.14	2420.
2	1	2084.	49.76	46.09	47.92	3.67	.926	2.7406E-08			
3	1	1.000	58.35	22.23	40.29	36.12	.381	2.7552E-04			
4	1	.4170	50.24	40.97	45.60	9.27	.815	6.8149E-06			
5	1	2.1000E-02	66.20	.00	33.10	66.20	.000	8.9880E-04			
1	1	1.042	54.30	.00	27.15	54.30	.000	6.1049E-04	9.955E-04	3.25	2531.
2	1	2084.	50.44	46.84	48.64	3.60	.929	2.4518E-08			
3	1	1.000	58.97	22.18	40.58	36.79	.376	2.8564E-04			
4	1	.4170	50.74	41.14	45.94	9.60	.811	8.3720E-06			
5	1	2.1000E-02	66.75	.00	33.37	66.75	.000	9.1333E-04			
1	1	1.042	54.45	.00	27.23	54.45	.000	6.1392E-04	1.005E-03	3.36	2646.
2	1	2084.	51.13	47.60	49.37	3.53	.931	2.1666E-08			
3	1	1.000	59.59	22.11	40.85	37.48	.371	2.9612E-04			
4	1	.4170	51.23	41.30	46.27	9.93	.806	1.0285E-05			
5	1	2.1000E-02	67.28	.00	33.64	67.28	.000	9.2757E-04			
1	1	1.042	54.58	.00	27.29	54.58	.000	6.1668E-04	1.014E-03	3.48	2763.
2	1	2084.	51.82	48.37	50.10	3.45	.933	1.8902E-08			
3	1	1.000	60.21	22.03	41.12	38.17	.366	3.0697E-04			
4	1	.4170	51.72	41.44	46.58	10.28	.801	1.2633E-05			
5	1	2.1000E-02	67.80	.00	33.90	67.80	.000	9.4148E-04			
1	1	1.042	54.68	.00	27.34	54.68	.000	6.1880E-04	1.023E-03	3.61	2884.
2	1	2084.	52.51	49.15	50.83	3.36	.936	1.6278E-08			
3	1	1.000	60.82	21.94	41.38	38.88	.361	3.1819E-04			
4	1	.4170	52.20	41.56	46.88	10.64	.796	1.5508E-05			
5	1	2.1000E-02	68.29	.00	34.15	68.29	.000	9.5506E-04			
1	1	1.042	54.74	.00	27.37	54.74	.000	6.2020E-04	1.033E-03	3.73	3008.
2	1	2084.	53.21	49.94	51.57	3.27	.939	1.3801E-08			
3	1	1.000	61.43	21.82	41.62	39.60	.355	3.2980E-04			
4	1	.4170	52.67	41.65	47.16	11.02	.791	1.9023E-05			
5	1	2.1000E-02	68.78	.00	34.39	68.78	.000	9.6832E-04			
1	1	1.042	54.77	.00	27.38	54.77	.000	6.2085E-04	1.043E-03	3.86	3134.
2	1	2084.	53.90	50.73	52.32	3.17	.941	1.1511E-08			
3	1	1.000	62.03	21.69	41.86	40.34	.350	3.4180E-04			
4	1	.4170	53.13	41.73	47.43	11.40	.785	2.3317E-05			
5	1	2.1000E-02	69.25	.00	34.62	69.25	.000	9.8121E-04			

NOTE: CRACK SIZE OF 1ST DOF WILL EXCEED BODY WIDTH, G(1), ON NEXT ITERATION. PROCESSING TERMINATED.

REFINED BREAKUP

PZR INSTRUMENT NOZZLE CORNER FLAW EVALUATION - SONGS UNIT 2 & 3

FATIGUE CRACK GROWTH ANALYSIS SUMMARY

CRACK DIMENSION(S) A(I)	MAXIMUM STRESS INTENSITY FACTOR(S) FOR WORST INPUT LOAD TRANSIENT KMAX	TOTAL CRACK GROWTH RATE(S) DADN(I)	NUMBER OF CYCLES OR BLOCKS TO GROW CRACK FROM INITIAL SIZE N
A1	K1	DADN1	N
1.000	48.713	7.0852E-04	.0000
1.035	49.152	7.1954E-04	49.39
1.072	49.597	7.3043E-04	99.75
1.110	50.100	7.4362E-04	151.0
1.149	50.601	7.5623E-04	203.2
1.189	51.107	7.6846E-04	256.3
1.231	51.605	7.7964E-04	310.5
1.275	52.112	7.9057E-04	365.8
1.320	52.610	8.0028E-04	422.3
1.366	53.104	8.0903E-04	480.2
1.414	53.616	8.1776E-04	539.4
1.464	54.134	8.2593E-04	600.1

1.516	54.732	8.3737E-04	662.1
1.569	55.348	8.4913E-04	725.5
1.625	55.953	8.5989E-04	790.3
1.682	56.543	8.6938E-04	856.6
1.741	57.116	8.7772E-04	924.4
1.803	57.685	8.8548E-04	994.1
1.866	58.269	8.9383E-04	1066.
1.932	58.835	9.0120E-04	1139.
2.000	59.385	9.0752E-04	1214.
2.071	59.917	9.1285E-04	1292.
2.144	60.429	9.1732E-04	1371.
2.219	60.920	9.2088E-04	1454.
2.297	61.444	9.2618E-04	1538.
2.378	61.951	9.3086E-04	1626.
2.462	62.437	9.3495E-04	1716.
2.549	62.941	9.4001E-04	1808.
2.639	63.519	9.4834E-04	1903.
2.732	64.081	9.5616E-04	2001.
2.828	64.626	9.6362E-04	2102.
2.928	65.153	9.7075E-04	2205.
3.031	65.662	9.7764E-04	2311.
3.138	66.202	9.8625E-04	2420.
3.249	66.749	9.9553E-04	2531.
3.364	67.280	1.0047E-03	2646.
3.482	67.795	1.0140E-03	2763.
3.605	68.295	1.0234E-03	2884.
3.732	68.779	1.0331E-03	3008.
3.864	69.247	1.0431E-03	3134.

Calculation No.: AES-C-3247-1	Made by: RCC	Date: 5/8/98	Client: SCE
Title: Evaluation of Half-Nozzle Repair for Pressurizer and Steam Generator Instrumentation Nozzles Under Long-Term Service Conditions — SONGS 2 and 3	Checked by: MTC	Date: 8 MAY 98	Project No.: AES 97123247-1Q
	Revision No.: 0	Document Control No.: I-2	Sheet No.: C-1 of C-3

Appendix C

ALLOWABLE DEPTHS FOR POSTULATED CORROSION DEGRADATION

Calculation No.: AES-C-3247-1	Made by: RCC	Date: 5/8/98	Client: SCE
Title: Evaluation of Half-Nozzle Repair for Pressurizer and Steam Generator Instrumentation Nozzles Under Long-Term Service Conditions — SONGS 2 and 3	Checked by: MTC	Date: 8 MAY 98	Project No.: AES 97123247-1Q
	Revision No.: 0	Document Control No.: I-2	Sheet No.: C-2 of C-3

TABLE C-1

LIMIT LOAD ANALYSIS OF BWC - PZR & SG NOZZLES

Gap Region (e=0.6875")

Geometry		Material Properties		Loading	
tp (in)	0.4375	Sy (ksi)	27.6	P (psig)	2485
e (in)	0.6875	Su (ksi)	85.0	F (lbs)	2242.9
L (in)	0.184	Sf (ksi)	56.3	Fa (lbs)	101
dh/2 (in)	0.536	SF	2.77	Fb (lbs)	178
Alpha	0.16212			Fc (lbs)	35
r1 (in)	3.3207			Ma (in-lbs)	816
r2 (in)	4.4607			Mb (in-lbs)	420
w (in)	1.1399			Mc (in-lbs)	1776
A (in^2)	4.4981			FA (lbs)	2556.9
Z (in^3)	0.2031			MB (in-lbs)	1999.1
r1/w	2.913			SM (ksi)	0.568
				SB (ksi)	9.842

Theta/Pi	Theta (rads)	d (in)	a (in)	a/w	Beta (rads)	Theta + Beta (rads)	SBc (ksi)	SBc+SM / SB+SM
0.050	0.15708	21.800	7.037	6.173	1.07008	1.22715	28.270	2.77
0.100	0.31416	10.991	3.548	3.113	1.06602	1.38018	28.270	2.77
0.150	0.47124	7.430	2.398	2.104	1.05920	1.53043	28.270	2.77
0.200	0.62832	5.681	1.834	1.609	1.04952	1.67783	28.270	2.77
0.250	0.78540	4.659	1.504	1.319	1.03685	1.82225	28.270	2.77
0.300	0.94248	4.001	1.292	1.133	1.02105	1.96352	28.270	2.77
0.350	1.09956	3.552	1.147	1.006	1.00191	2.10147	28.270	2.77
0.400	1.25664	3.235	1.044	0.916	0.97924	2.23587	28.270	2.77
0.450	1.41372	3.008	0.971	0.852	0.95280	2.36652	28.270	2.77
0.500	1.57080	2.844	0.918	0.805	0.92240	2.49320	28.270	2.77
0.550	1.72788	2.727	0.880	0.772	0.88782	2.61570	28.270	2.77
0.600	1.88496	2.645	0.854	0.749	0.84894	2.73389	28.270	2.77
0.650	2.04204	2.591	0.837	0.734	0.80567	2.84771	28.270	2.77
0.700	2.19911	2.559	0.826	0.725	0.75807	2.95718	28.270	2.77
0.750	2.35619	2.544	0.821	0.720	0.70632	3.06252	28.270	2.77
0.800	2.51327	2.540	0.820	0.719	0.66355	3.17683	28.270	2.77
0.850	2.67035	2.540	0.820	0.719	0.66355	3.33391	28.270	2.77
0.900	2.82743	2.540	0.820	0.719	0.66355	3.49099	28.270	2.77
0.950	2.98451	2.540	0.820	0.719	0.66355	3.64807	28.270	2.77
1.000	3.14159	2.540	0.820	0.719	0.66355	3.80515	28.270	2.77

Table C-2

LIMIT LOAD ANALYSIS OF BWC - PZR & SG NOZZLES

Crevice Location (e=0)

Geometry			Material Properties			Loading		
tp (in)	0.4375		Sy (ksi)	27.6		P (psig)	2485	
e (in)	0		Su (ksi)	85.0		F (lbs)	2242.9	
L (in)	0.184		Sf (ksi)	56.3		Fa (lbs)	101	
dh/2 (in)	0.536		SF	2.77		Fb (lbs)	178	
Alpha	0.39811					Fc (lbs)	35	
r1 (in)	1.3826					Ma (in-lbs)	816	
r2 (in)	1.8572					Mb (in-lbs)	420	
w (in)	0.4746					Mc (in-lbs)	1776	
A (in^2)	1.8728					FA (lbs)	2556.9	
Z (in^3)	0.2031					MB (in-lbs)	1999.1	
						SM (ksi)	1.365	
						SB (ksi)	9.842	

Theta/Pi	Theta (rads)	d (in)	a (in)	a/w	Beta (rads)	Theta + Beta (rads)	SBc (ksi)	SBc+SM SB+SM
0.050	0.15708	3.619	2.806	5.912	1.06841	1.22549	29.680	2.77
0.100	0.31416	1.824	1.415	2.981	1.06452	1.37868	29.680	2.77
0.150	0.47124	1.233	0.956	2.015	1.05800	1.52924	29.680	2.77
0.200	0.62832	0.943	0.731	1.541	1.04873	1.67705	29.680	2.77
0.250	0.78540	0.773	0.600	1.263	1.03661	1.82201	29.680	2.77
0.300	0.94248	0.664	0.515	1.085	1.02147	1.96395	29.680	2.77
0.350	1.09956	0.590	0.457	0.963	1.00314	2.10270	29.680	2.77
0.400	1.25664	0.537	0.416	0.877	0.98141	2.23804	29.680	2.77
0.450	1.41372	0.499	0.387	0.816	0.95605	2.36977	29.680	2.77
0.500	1.57080	0.472	0.366	0.771	0.92686	2.49765	29.680	2.77
0.550	1.72788	0.453	0.351	0.740	0.89363	2.62150	29.680	2.77
0.600	1.88496	0.439	0.341	0.718	0.85621	2.74117	29.680	2.77
0.650	2.04204	0.431	0.334	0.703	0.81453	2.85657	29.680	2.77
0.700	2.19911	0.425	0.330	0.695	0.76861	2.96773	29.680	2.77
0.750	2.35619	0.423	0.328	0.691	0.71863	3.07482	29.680	2.77
0.800	2.51327	0.423	0.328	0.690	0.68454	3.19781	29.680	2.77
0.850	2.67035	0.423	0.328	0.690	0.68454	3.35489	29.680	2.77
0.900	2.82743	0.423	0.328	0.690	0.68454	3.51197	29.680	2.77
0.950	2.98451	0.423	0.328	0.690	0.68454	3.66905	29.680	2.77
1.000	3.14159	0.423	0.328	0.690	0.68454	3.82613	29.680	2.77

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	Nabil M. El-Akily	07/24/98	Jun Gaor	07/24/98						

Appendix D

EVALUATION OF THE EFFECT OF THE MNSA HOLES ON THE NOZZLE STRESSES

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	Nabil M. El-Akily	07/24/98	Jun Gaor	07/24/98						

1 PURPOSE/BACKGROUND

The purpose of this Appendix is to evaluate the effect of the bolt holes of the Mechanical Nozzle Seal Assemblies (MNSA) on the stress concentration at the nozzle hole, and consequently on the flaw evaluation performed in the base calculation. The MNSAs were installed on SONGS Unit 2 pressurizer and steam generator E089 to address the problem of instrument nozzle leaks during Units 2 & 3 Cycle 9 mid-cycle outages in 1998. In Unit 3 pressurizer, holes were drilled without installing a MNSA. Each MNSA installation requires drilling four bolt holes in the vicinity of the nozzle (pressurizer RTD nozzle), and an additional two shoulder screw holes (steam generator PDT and pressurizer level nozzle), as shown in Figures 1.1 through 1.4. These figures depict different MNSA installations for a steam generator PDT, a pressurizer level instrument nozzle and a pressurizer RTD nozzle.

The MNSA is installed externally, and relies on a grafoil seal arrangement, for the gap between the nozzle and the outside surface of the vessel, to prevent leaks. Each MNSA is attached to the outside surface of the vessel by means of bolts, as shown in Figures1.1 through 1.4. The nozzle through-wall hole and the bolt holes act as stress raisers in the vessel. The bolt holes are drilled, close to the nozzle, on a bolt circle diameter of 3.812", for the pressurizer RTD MNSA, and 6" and 6.5" for the pressurizer level MNSA and the steam generator PDT MNSA. It follows that the center-to-center distance between the nozzle and the bolt holes varies between 1.906" to 3.25". Accordingly, there is a potential for interaction between the regions of stress concentration of the nozzle and the bolt holes.

In the event a decision is made to replace the MNSA installations in the future, the half-nozzle design will be used to replace them (a typical half-nozzle design is described in detail in the base calculation). The new nozzles will be welded to the outside surface of the vessel, and threaded plugs will be installed in the bolt holes. Reference 1, Appendix G, provides a quantitative evaluation of the interaction between the nozzle and the MNSA bolt holes, for the hot leg MNSAs, in order to assess its effect on the hot leg stresses when they are replaced by the permanent half nozzle design. Results of this evaluation will be used in this appendix to assess the effect of the MNSA bolt holes on the flaw analysis performed in the base calculation to evaluate the long-term

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acceptance of the half nozzle design since the flaw evaluation was made prior to the MNSA installation.

2 RESULTS/CONCLUSIONS

The interaction between the MNSA bolt holes and the nozzle hole was evaluated in Section 8 of this appendix. It was concluded that the effect of the bolt holes on the stresses at the nozzle connection is insignificant. The postulated flaws, in the flaw evaluation in the base calculation, are located at the nozzle area where the presence of the MNSA bolt holes does not impact the stresses and allowable flaw size. It is, therefore, concluded that the flaw evaluation is valid, and is not impacted by the MNSA bolt holes.

3 ASSUMPTIONS

See Reference 6.1, Appendix G.

4 DESIGN INPUT

See Reference 1, Appendix G.

5. METHODOLOGY

See Reference 1, Appendix G.

6 REFERENCES

6.1 Calculation No. M-DSC-279, Revision 0,"Hot and Cold Leg Instrument Nozzle Modification."

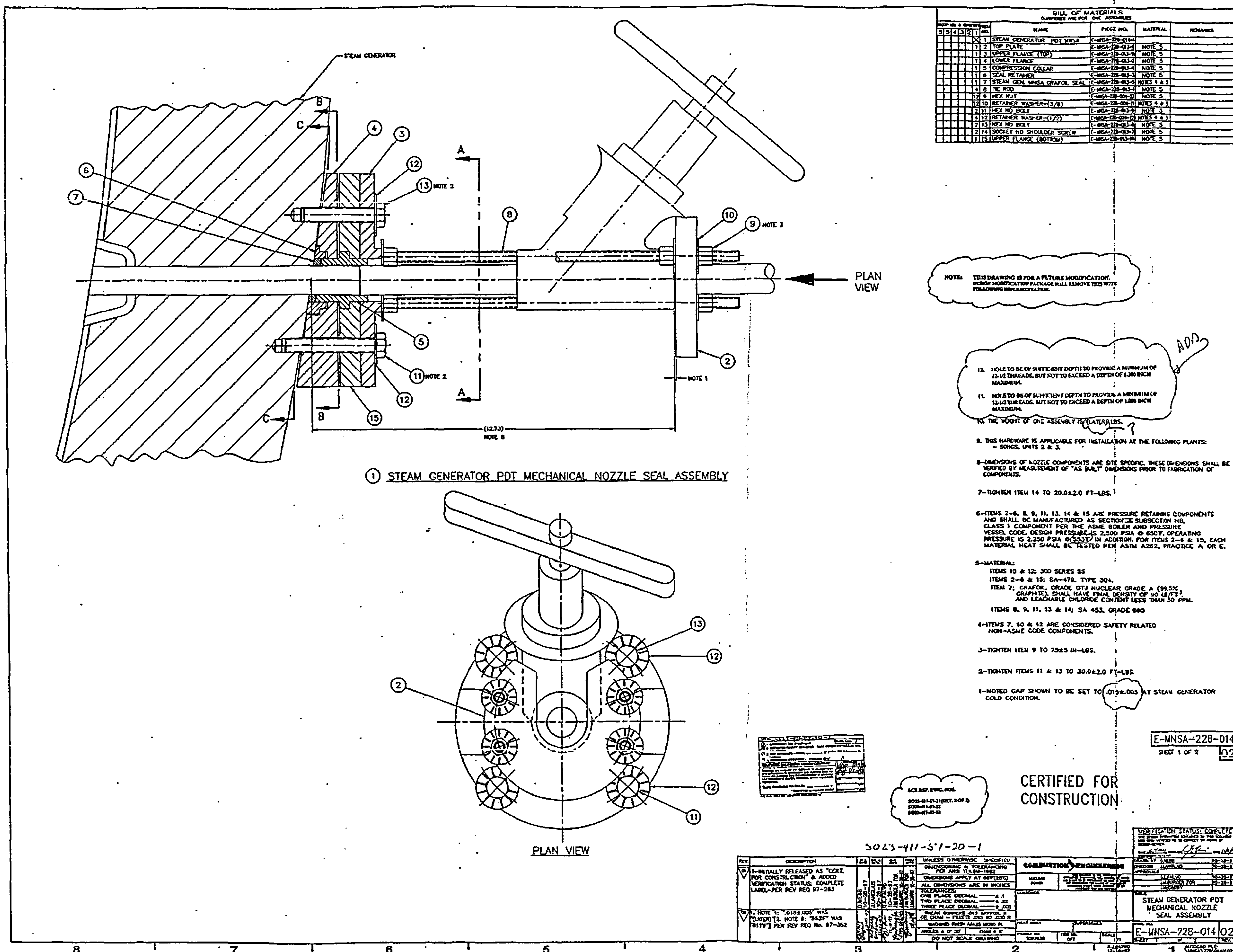

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Figure 1.1
Steam Generator PDT MNSA Installation
(Reference 6.2)

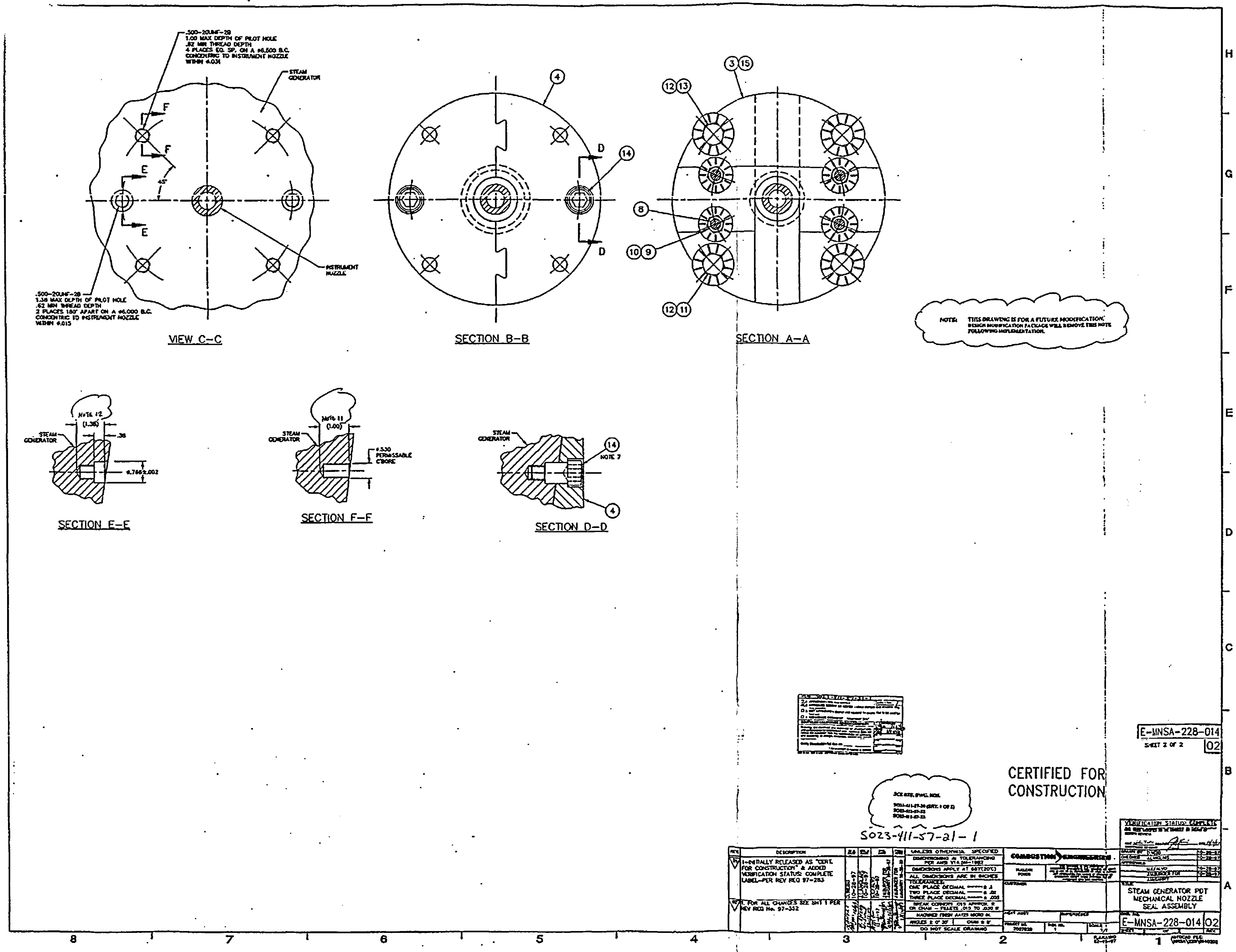

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Figure 1.2
Steam Generator PDT MNSA
Installation
(Reference 6.3)

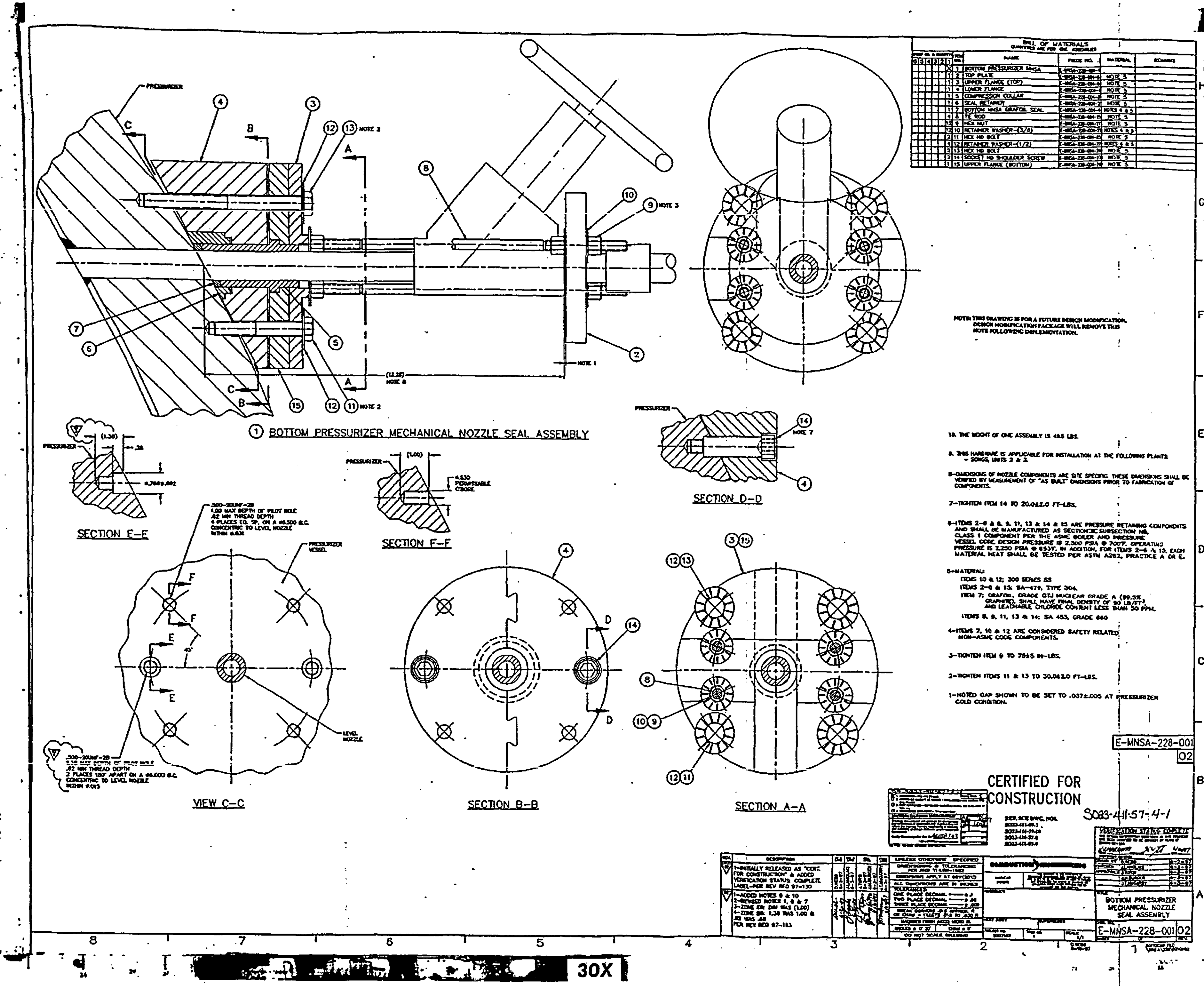

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Figure 1.3
Bottom Pressurizer Level MNSA Installation
(Reference 6.4)

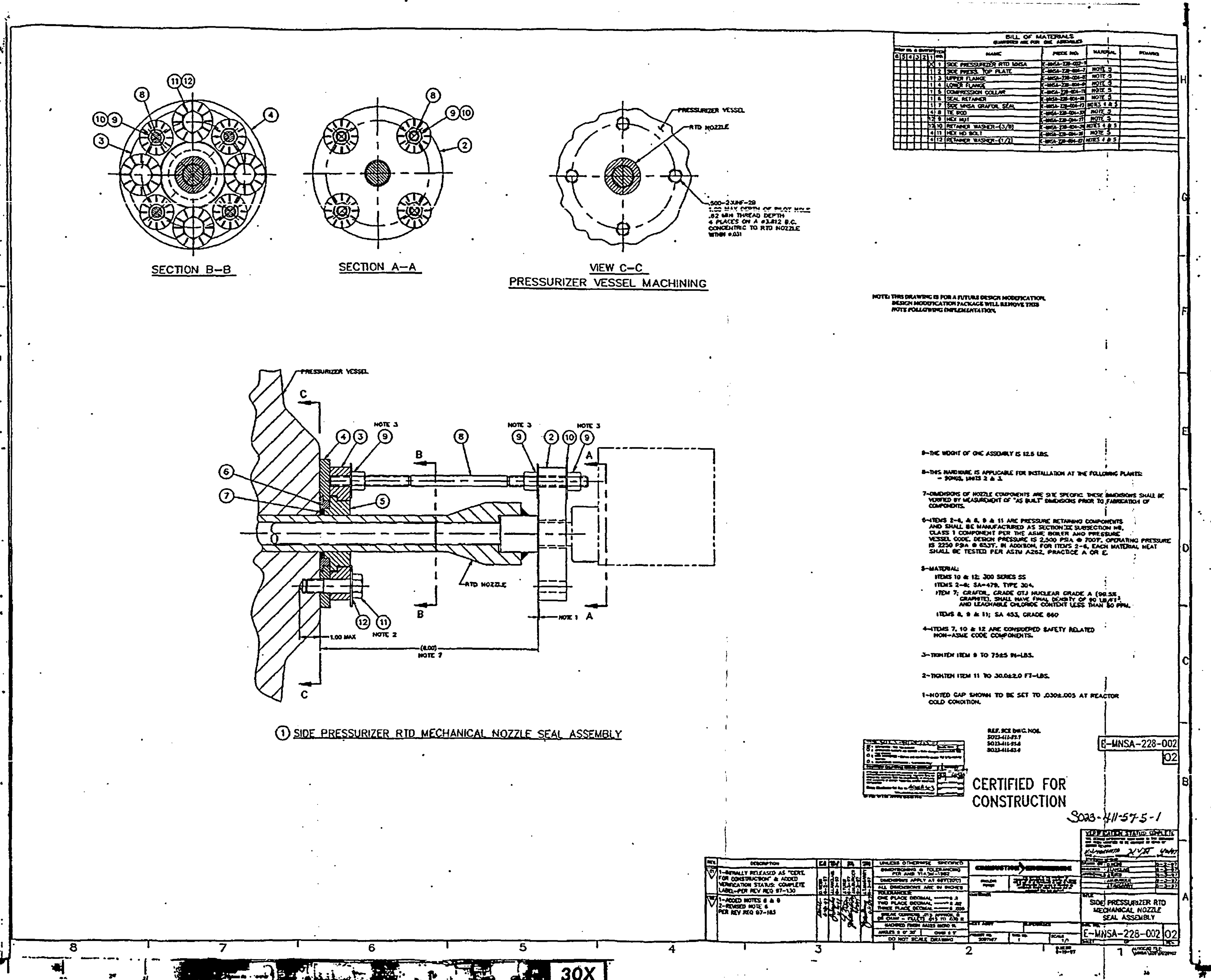

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Figure 1.4
Side Pressurizer RTD MNSA Installation
(Reference 6.7)

6.2 Drawing No. SO23-411-57-20, Revision 1,"Steam Generator PDT Mechanical Nozzle Seal Assembly."

6.3 Drawing No. SO23-411-57-21, Revision 1,"Steam Generator PDT Mechanical Nozzle Seal Assembly."

6.4 Drawing No. SO23-411-57-4, Revision 1,"Bottom Pressurizer Mechanical Nozzle Seal Assembly."

6.5 Drawing No. SO23-411-57-33, Revision 0,"Bottom Pressurizer Mechanical Nozzle Seal Assembly & Details."

6.6 Drawing No. SO23-411-57-34, Revision 0,"Bottom Pressurizer Mechanical Nozzle Seal Assembly & Details."

6.7 Drawing No. SO23-411-57-5, Revision 1,"Side Pressurizer RTD Mechanical Nozzle Seal Assembly."

7 NOMENCLATURE

k =stress concentration factor
MNSA =Mechanical Nozzle Seal Assembly

8 CALCULATIONS

During Cycle 9 mid-cycle outage, MNSAs were installed on the PDT instrument nozzle in steam generator primary head, bottom pressurizer head level instrument nozzle and pressurizer RTD nozzle. As described in Section 1 of this appendix, each MNSA is attached to the outside surface of the vessel by means of bolts. Figures 1.1 through 1.4 show the details of the MNSAs installed on the primary head of the steam generator and the pressurizer based on References 6.2 through 6.7. The nozzle through-wall hole and the 1"-inch maximum depth bolt holes act as stress raisers in the hot leg. The bolt holes are drilled in close proximity to the nozzle, on a bolt circle diameter from 3.812" to 6.5", i.e., the center-to-center distance between the nozzle and the bolt holes varies between 1.906" to 3.25". In addition, 1⅝" deep holes, for the shoulder screws in the steam generator and pressurizer bottom head MNSAs, are located on a 6" bolt circle. Accordingly, there is a potential for interaction between the regions of stress concentration of the nozzle and the bolt holes.

The MNSA installations may be replaced by the permanent half-nozzle design in the future. In the event that the MNSAs are replaced, threaded plugs will be installed in the bolt holes as part of replacing the MNSA installations with the half-nozzle design. The interaction between the nozzle and the MNSA bolt holes was evaluated, using the finite element method, for the MNSAs installed on the RCS hot leg (Reference 1, Appendix G). In that evaluation, the hot leg wall was modeled with a nozzle hole only, with a nozzle hole and four bolt holes on the nominal bolt circle diameter, and with a nozzle hole and four bolt holes on 150% nominal bolt circle diameter. Loading included biaxial tension to model internal pressure. Stress on the surface of the nozzle hole, and the stress concentration factor, k, were calculated to assess the interaction between the nozzle hole and the bolt holes. Based on the analysis results, it was concluded that the increase in the value of k due to the presence of the bolt holes is insignificant; therefore, does not affect the nozzle stresses. The results of this analysis will be used to assess the acceptability of the MNSA holes in the steam generator and pressurizer in the evaluation below.

(1) The pressurizer RTD bolt holes are located on a 3.812" bolt circle diameter, i.e., the same as the hot leg MNSA installations. On the other hand, the major differences between the steam generator and pressurizer bottom head MNSA, and the RCS hot leg MNSA are:

  a) The bolt circle diameter on the steam generator MNSA is larger than the bolt circle diameter on the RCS hot leg (6.5" and 6" versus 3.8"). The larger separation between the bolt holes and the nozzle hole will result in a smaller interaction between the different holes, i.e., smaller effect on the nozzle stress concentration factor.

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b) The steam generator and pressurizer wall thickness is larger than the hot leg wall thickness (7⅜" and 4⅞" versus 3¾"). The larger wall thickness will not result in increasing the value of k since the depth of the bolt holes relative to the wall thickness is smaller in the steam generator, and the pressurizer, than the hot leg, which would decrease the effect of these holes on the stresses.

(2) Slight differences exist between the RCS hot leg instrument diameters and wall thicknesses, and the steam generator and pressurizer instrument nozzles (the difference in outside diameter is 3% only). This difference is considered insignificant.

Based on the above considerations, it is concluded that the effect of the MNSA bolt holes on the stresses in the nozzle connection is insignificant.