Entergy

Entergy Operations, Inc.
1340 Echelon Parkway
Jackson MS 39213-8298
Tel 601 368 5758

Michael A. Krupa
Director
Nuclear Safety & Licensing

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U. S. Nuclear Regulatory Commission
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Mail Stop OP1-17
Washington, DC 20555-0001

Subject: Entergy Operations, Inc.
ASME Section XI Flaw Evaluation

Waterford Steam Electric Station – Unit 3
Docket No. 50-382
License No. NPF-38

CNRO-2001-00004

Ladies and Gentlemen:

During the recent refueling outage at the Waterford Steam Electric Station – Unit 3 (W3), a crack was discovered in the inside diameter of a pressurizer heater sleeve. Entergy Operations, Inc. (Entergy) contracted the services of Structural Integrity Associates, Inc. to evaluate the flaw and determine the potential of crack growth to a size exceeding the ASME Section XI allowable flaw size. This analysis demonstrated that a conservatively postulated flaw would not grow to exceed the allowable flaw size under application of the appropriate design basis loading conditions.

ASME Section XI, IWB-3134 requires the owner to submit such a flaw evaluation to the NRC staff for information purposes. Pursuant to this requirement, Entergy is submitting the evaluation as the enclosure to this letter.

This letter contains no commitments.

A047

Should you have any questions, please contact Guy Davant at (601) 368-5756.

Very truly yours,

M. A. Krupa

MAK/GHD/baa

attachments:
1. Report No. SIR-00-150, "Evaluation of Potential Crack Growth from Pressurizer Heater Sleeve-to-Lower Head Welds"
2. Calculation Package WSES-05Q-301, "Finite Element Stress Analyses of Pressurizer Heater Penetration"
3. Calculation Package WSES-05Q-302, "Crack Growth Evaluation

cc: Mr. J. T. Herron (W3) (w/o)
Mr. G. J. Taylor (ECH) (w/o)

Mr. T. R. Farnholtz, NRC Senior Resident Inspector (W3) (w/o)
Mr. N. Kalyanam, NRR Project Manager (W3) (w/o)
Mr. E. W. Merschoff, NRC Region IV Regional Administrator (w/o)

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December 2000

Evaluation of Potential Crack Growth
from Pressurizer Heater Sleeve-to-Lower Head Welds

Prepared for:

Entergy Operations, Inc.
Waterford, Unit 3

Contract #NHS00450

Prepared by:

Structural Integrity Associates, Inc.

Prepared by: Keith Evon Date: 12/8/2000
K. R. Evon

Reviewed by: [signature] for Angah Miessi Date: 12-8-00
G. A. Miessi

Approved by: A F Deardorff Date: 12/8/00
A. F. Deardorff, P.E.

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Section	Pages	Revision	Date	Comments
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3.0	3-1 – 3-4			
4.0	4-1 – 4-10			
5.0	5-1 – 5-17			
6.0	6-1			
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1.0 INTRODUCTION

During a recent examination of the pressurizer vessel at Waterford(WSES) Unit 3, pressurizer heater sleeve No. F4 was found to be leaking. A repair was designed which moved the pressure boundary from the inside surface to the outside surface of the pressurizer vessel.

In the existing pressurizer penetration design at WSES-3, the instrument nozzle passes through the vessel and is welded on the inside surface of the main component with a J-groove weld. The designed repair replaces the pressure boundary weld on the inside surface of the pressurizer nozzle with an Alloy 690 OD weld attached to a temperbead weld pad on the pressurizer OD as shown in Figure 1-1. Following the designed repair analysis completion, Entergy determined that the penetration would be plugged instead of replacing the heater, as shown in Figure 1-2. The design with the plug is similar to the modified heater penetration design with respect to this analysis. The loadings on the weld and pressurizer shell are exactly the same. The thermal conditions are essentially unchanged since the temperature gradients are mainly through the pressurizer wall. The weld details in both designs are the original plant construction. Therefore, the following analysis is valid for both the heater replacement or the penetration plug designs.

The analysis provided herein is also based on the outermost heater penetrations with the greatest angle between the heater axis and the penetration shell. Thus, it will remain valid for repair of any heater penetration in the future.

The objective of this report is to document the analyses performed to demonstrate that any cracking in the original Alloy 600 welds at the inboard end of the pressurizer heater penetrations will not grow to a size greater than allowed by Section XI of the ASME Code [1].

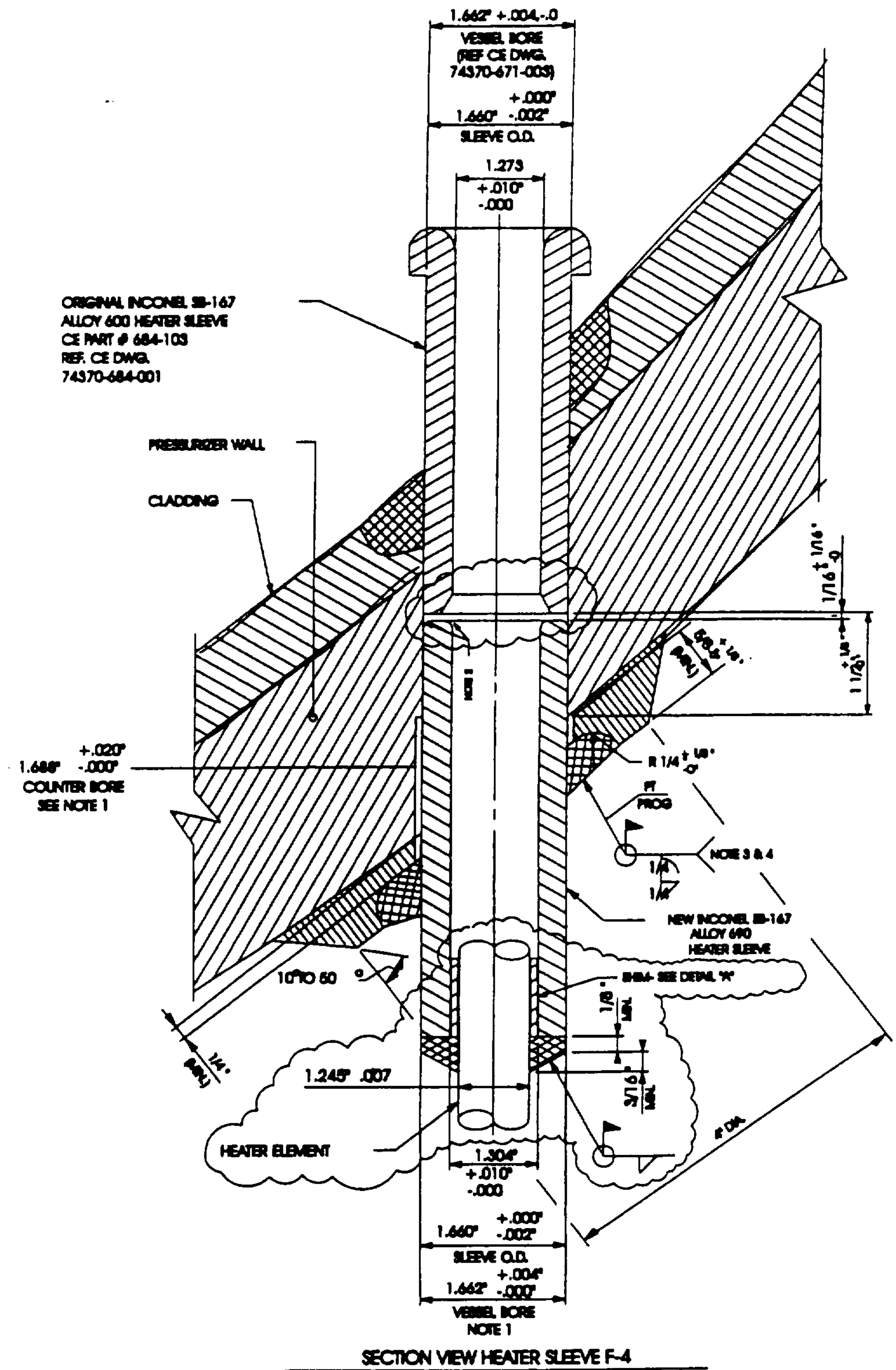

Figure 1-1. WSES-3 Pressurizer Heater Penetration, New Sleeve Design [13]

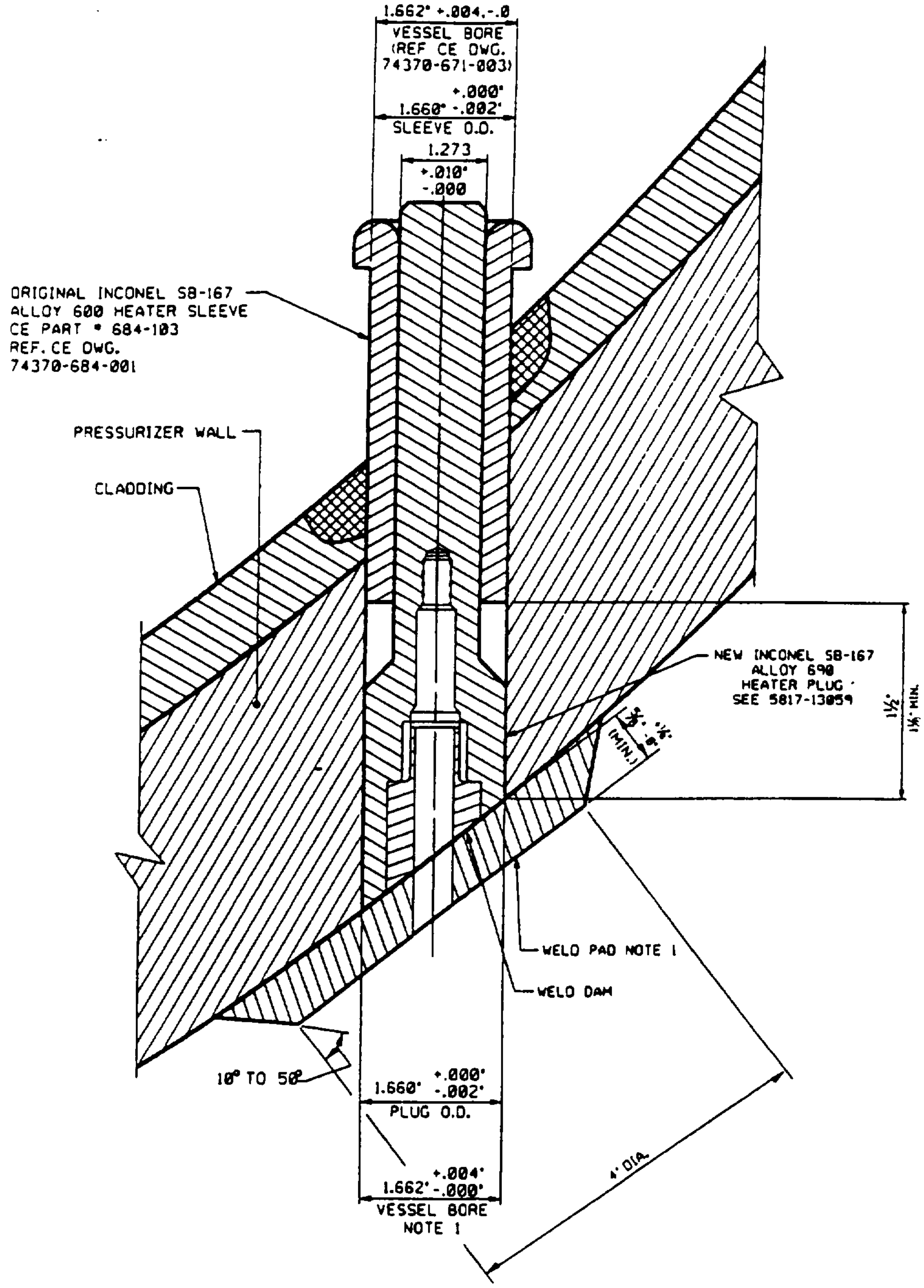

Figure 1-2. WSES-3 Pressurizer Heater Penetration, Plug Design [11]

2.0 METHODOLOGY

ASME Code Section XI [1] provides guidance for performing crack growth analyses and for determining allowable flaw sizes in structural components. The evaluation of the potential crack growth into the pressurizer vessel is based on the guidelines of the Code and includes the following tasks:

1. Develop a finite element model of the lower pressurizer head including the pressurizer-to-heater weld area and the modified repair design to determine local stresses so that a stress distribution away from the weld into the base metal can be determined. The analysis is based on an enlarged hole in the pressurizer shell to account for outermost heater locations with the largest side-hill angle. Thus, the analysis is applicable for a repair at any of the pressurizer heater locations.

2. Quantify the cyclic operating conditions expected for the bottom head. The cyclic operating conditions are combined such that maximum cyclic stress ranges at the penetrations are determined.

3. Perform stress analyses for internal pressure and transient thermal conditions to determine stress distributions for the most severe loading conditions.

4. Perform crack growth analyses for assumed cracking of the existing Alloy 600 weld. Since the pressurizer cladding is Alloy 600, perform evaluations for both a corner crack and a crack that extends further into the adjacent cladding.

5. Determine the ASME Section XI allowable flaw size for each of the assumed crack types.

6. For each of the assumed crack types, determine the number of cycles to reach the allowable flaw size if this is less than the allowable for the plant design cycles. Alternately, determine the crack depth based on all the plant design cycles.

3.0 DESIGN INPUT

3.1 Component Description

The pressurizer heater penetration that has exhibited leakage is located in the spherical bottom head of the pressurizer vessel. The penetration is longitudinal with respect to the axis of the pressurizer and part of a grouping of penetrations symmetrically spread around the centerline of the spherical bottom head. The basic dimensions of the pressurizer and its penetration nozzle used in this evaluation are based on the design input provided by Entergy [2], included as Appendix A of this report. The outermost heater penetration with the largest side-hill angle is located 38 inches from the centerline of the bottom head [2].

3.2 Material properties

The pressurizer vessel shell is made of SA-533, Grade B, Class 1 material and the cladding on its inside surface is Alloy 600 material. Reference 2 provides a list of materials for the pressurizer heater penetration components. The pressurizer heater sleeve is fabricated from SB-167 (Alloy 600) material. The existing penetration weld is assumed to be made of Alloy 600 material. The new heater sleeve and plug are made of Inconel SB-167 (Alloy 690) material. The weld material for the repair weld on the exterior of the pressurizer head is Alloy 690.

Temperature dependent material properties are used for all materials. The properties are taken from the 1992 edition of the ASME Code [5] and are shown in Table 3-1. Material properties in the Construction Code [15] were grouped into a very small number of generic material types (e.g., no difference between Alloy 600 and Alloy 690). In addition, the thermal conductivity of the low alloy base materials is much lower in the more recent code, such that higher thermal stresses will be predicted as compared to those based on the Construction Code. Thus, the 1992 ASME Code, which provides more specific material properties, is used in the stress analyses.

3.3 Design and Operating Conditions

The following design data is obtained from Reference [2]:

Design Pressure	=	2500 psia
Design Temperature	=	700°F
Operating pressure	=	2250 psia
Operating temperature	=	653°F

Cyclic conditions have been taken from the design input provided by Entergy [2] and include the following significant events:

1. Heatup/Cooldown – 500 lifetime cycles. The pressurizer rate is 200°F/hr, from 70°F to 653°F. The pressure cycles between 0 psig and 2235 psig.

2. Plant Loading/Unloading, Step Load Increase/Decrease and Normal Variations – 10^6 cycles. These are +/- 100 psig and +/- 20°F. It is assumed that the temperature and pressure variations are relatively slow since rapid changes do not normally occur with this high frequency. (There are 2000 variations per Heatup/Cooldown cycle.)

3. Reactor Trip, Loss of Primary Flow and Loss of Load – 480 cycles. This transient is a 2535 psig overpressure peaking at 50 seconds, followed by a reduction in pressure reaching 1685 psig at 100 seconds, and then a slow repressurization reaching 2235 psig at 2100 seconds. There is also a significant thermal transient with the temperature reducing to 613°F from normal operating temperature at the same time that the peak pressure occurs. The temperature then decreases further, reaching 593 °F at 600 seconds, before it slowly increases, reaching 653 °F at 2000 seconds. (For ease of calculation, it is assumed that there are 500 cycles, the same as the number of Heatup/Cooldown cycles.)

4. Leak Test – 200 cycles. This is assumed to be a separate cycle from zero pressure to normal pressure of 2235 psig. The heatup and cooldown rate for the pressurizer is

100°F/hour. (It is conservatively assumed that there are 250 of these cycles in the crack growth calculation.)

The five Emergency Condition Secondary Depressurization transients are not included since they are not normal expected events. ASME Code Section XI [1] provides lower safety factors for these transients and the resulting stresses are not expected to be significantly different than those already evaluated. The 10 ASME Hydrotests to 3125 psig are also not considered. ASME Code Section XI no longer requires elevated pressure testing of vessels in service.

Table 3-1. Material Properties

Material	Mechanical Properties	Temperature							
		70	100	200	300	400	500	600	650
SA-533[1] Grade B Class 1	E (10^6 psi)	29.2	29.0	28.5	28.0	27.4	27.0	26.4	26.1
	α (in/in/°Fx 10^{-6})	7.02	7.06	7.25	7.43	7.58	7.70	7.83	7.90
	k (Btu/sec-in-°F)	5.16E-04	5.23E-04	5.42E-04	5.51E-04	5.51E-04	5.44E-04	5.32E-04	5.26E-04
	C_p (Btu/lb-°F)	0.106	0.108	0.114	0.119	0.125	0.131	0.138	0.141
SB 167[1] Alloy 600	E (10^6 psi)	31.00	30.82	30.20	29.90	29.50	29.00	28.70	28.45
	α (in/in/°Fx 10^{-6})	6.76	6.90	7.20	7.40	7.57	7.70	7.82	7.88
	k (Btu/sec-in-°F)	1.99E-04	2.01E-04	2.11E-04	2.22E-04	2.34E-04	2.45E-04	2.57E-04	2.62E-04
	C_p (Btu/lb-°F)	0.107	0.109	0.112	0.115	0.118	0.119	0.123	0.123
SB-167[1] Alloy 690	E (10^6 psi)	30.30	30.12	29.50	29.10	28.80	28.30	28.10	27.85
	α (in/in/°Fx 10^{-6})	7.73	7.76	7.85	7.93	8.02	8.09	8.16	8.20
	k (Btu/sec-in-°F)	1.57E-04	1.62E-04	1.76E-04	1.90E-04	2.04E-04	2.18E-04	2.32E-04	2.38E-04
	C_p (Btu/lb-°F)	0.105	0.105	0.109	0.113	0.115	0.118	0.119	0.120

(1) A constant Poisson ratio of 0.3 is used for all materials at all temperatures. Similarly, constant density values of 0.283 lb/in^3 for the low alloy and 0.301 lb/in^3 for the Inconel alloys are used in all the analyses.

4.0 LOCAL STRESS EVALUATION

4.1 Finite Element Analysis

An axisymmetric finite element model of the pressurizer was developed using the ANSYS software package [6]. Although the actual penetrations are located on the side-hill of the spherical pressurizer lower head, the resulting axisymmetric model will be that of a penetration normal to the surface of a spherical shell. To more closely approximate the real configuration and the actual state of stresses, the finite element model is conservatively based on an enlarged hole in the pressurizer shell equal to the maximum side-hill dimensions to account for outermost heater locations with the largest side-hill angle as shown in Figure 4-1. The increased hole diameter results in higher local stresses around the penetration. Thus, the analysis will be applicable for a repair at any of the pressurizer heater locations. The thickness of the heater sleeve used in the model is the same as the actual sleeve thickness. The resulting dimensions based on these modifications are shown in Figure 4-2.

The resulting finite element model of the pressurizer is shown in Figure 4-3. The boundaries of the finite element model are set far enough from the nozzle weld region to avoid end effects as shown in Figures 4-4 and 4-6. The thermal analyses are performed with the two-dimensional thermal solid elements (PLANE55), and the stress analyses are performed with the two-dimensional structural solid elements (PLANE42).

4.2 Applied Loads

4.2.1 Internal pressure

Internal pressure (P) was applied to all the inside surfaces of the pressurizer . In addition, end cap loads are applied at the pressurizer penetration bore. Since the penetration plug is not explicitly modeled, the end cap load is applied as an equivalent force, F, calculated as

$$F = PA$$

where,

A = penetration bore opening area.

The applied internal pressure loading is illustrated in Figure 4-4 for the pressurizer penetration.

4.2.2 Thermal Transient Analyses

The thermal transient conditions specified for the pressurizer are discussed in Section 3. Two specific thermal transients were evaluated: the heatup/cooldown ramp transient, and the reactor trip transient. The thermal cycles are characterized as follows:

1. *Heatup/Cooldown at 200°F/*hr: The thermal stresses are small and of opposite sign from pressure stresses in the area of the assumed cracking. However, since thermal stresses develop prior to pressurization, they are considered for the initial part of the heatup transient. The cooldown cycle stresses may be neglected since they do not add to the stress ranges.
2. *Reactor Trip*: This is a significant thermal transient. The increasing pressure and decreasing temperature are additive at the pressure peak. At the low pressure point of the transient, the thermal stresses are not significant and may be neglected.
3. *Plant Loading/Unloading*: Since the thermal stress sign is opposite to the pressure sign, the thermal stresses are conservatively neglected.
4. *Leak Test*: As with normal heatup and cooldown, it is conservative to neglect the transient thermal stresses except for the initiation of the heatup. The magnitude of the thermal stresses will be one half of those due to normal heatup and cooldown.

In all thermal transient analyses, a very large conservative film coefficient of 25,000 BTU/hr-ft^2-°F is used on the inside surface of the pressurizer vessel. The inside surface of the penetration nozzle is conservatively assumed perfectly insulated in all the analyses since there will be essentially no heat transfer in the radial direction. The thermal boundary conditions for the analyses of the pressurizer are illustrated in Figure 4-5.

4.2.3 Residual Stress Considerations

It is expected that the Alloy 600 welds would have a high degree of residual tensile stresses at the time of initial construction. However, in initial vessel hydrotest and the first heatup to operating conditions, there will be additional tensile yielding of the material due to the applied thermal and pressure stress loadings. Pressurized transients such as the rapid temperature reduction for a reactor trip transient would further yield the material at the surface. Thus, at maximum pressure conditions, the state of stress in the weld is expected to be at the tensile yield stress level (with a small amount of hardening). Upon depressurization, the stress will elastically reduce such that residual stresses will be significantly reduced. At the locations considered in the analysis, the combination of pressure plus thermal stresses for the weld region exceeds 35 ksi for the reactor trip transient. Therefore, residual stresses can be neglected. The 35 ksi value is conservatively taken as equal to the room temperature minimum yield strength of Alloy 600 materials from the ASME Code [5], and accounts for some additional tensile stress above the Code value of 27.4 ksi at 650°F.

4.3 Analysis Results

The results of the two limiting thermal transient cases were processed to determine the time at which the nozzle weld region experiences the maximum compressive or tensile hoop stresses, which combine with the pressure induced hoop stresses to determine the maximum stress ranges.

The hoop stress at the pressurizer heater penetration due to internal pressure (applied as shown in Figure 4-3) is shown in Figure 4-7. Figure 4-8 shows the hoop stresses at the pressurizer penetration during the reactor trip transient.

The stress distributions along a through-wall path from the Alloy 600 weld to the OD of the pressurizer are extracted for use in the crack growth evaluations. These distributions are presented in Section 5 of this report.

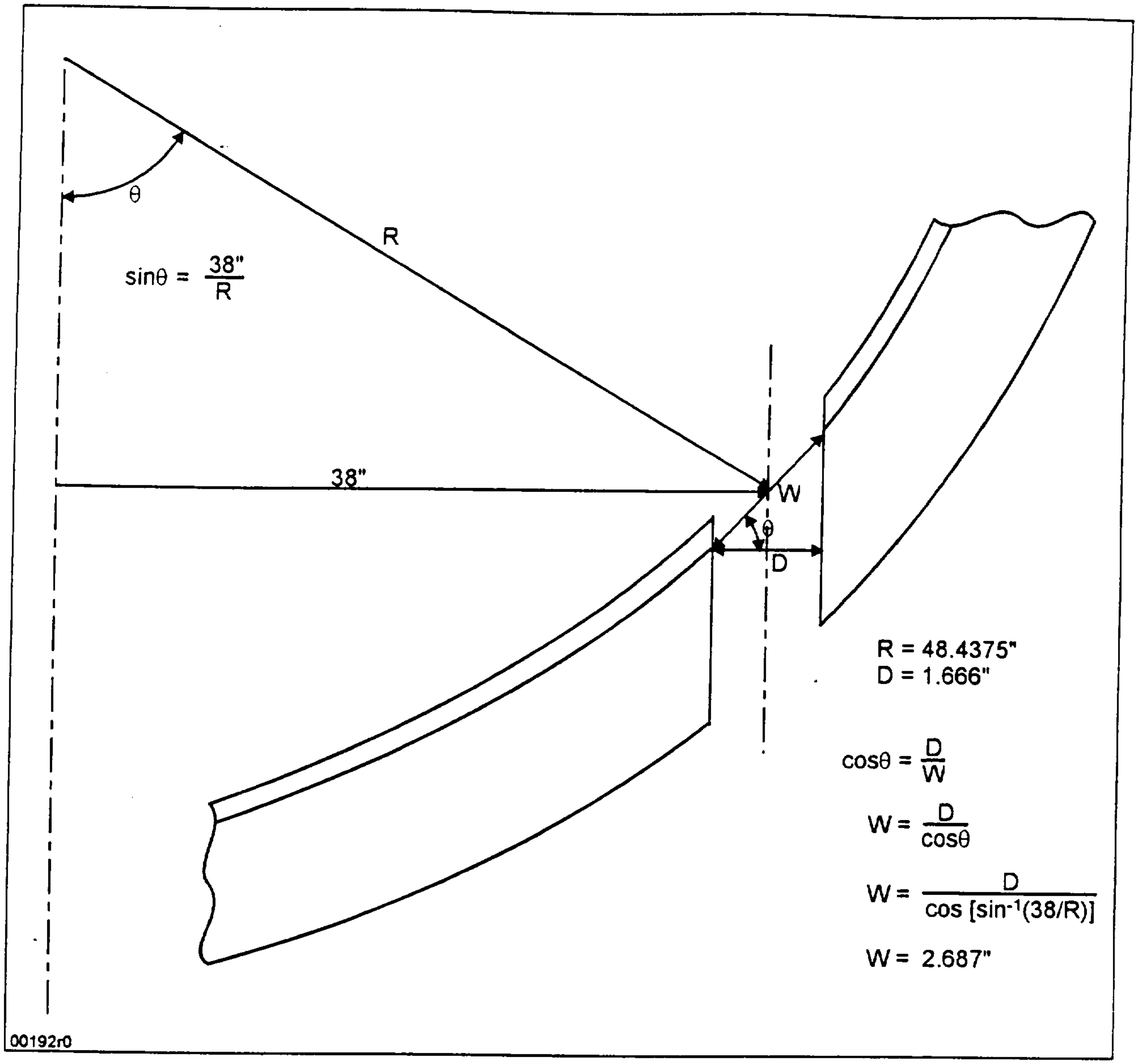

Figure 4-1. Calculation of Bore Size Used in the Finite Element Analyses

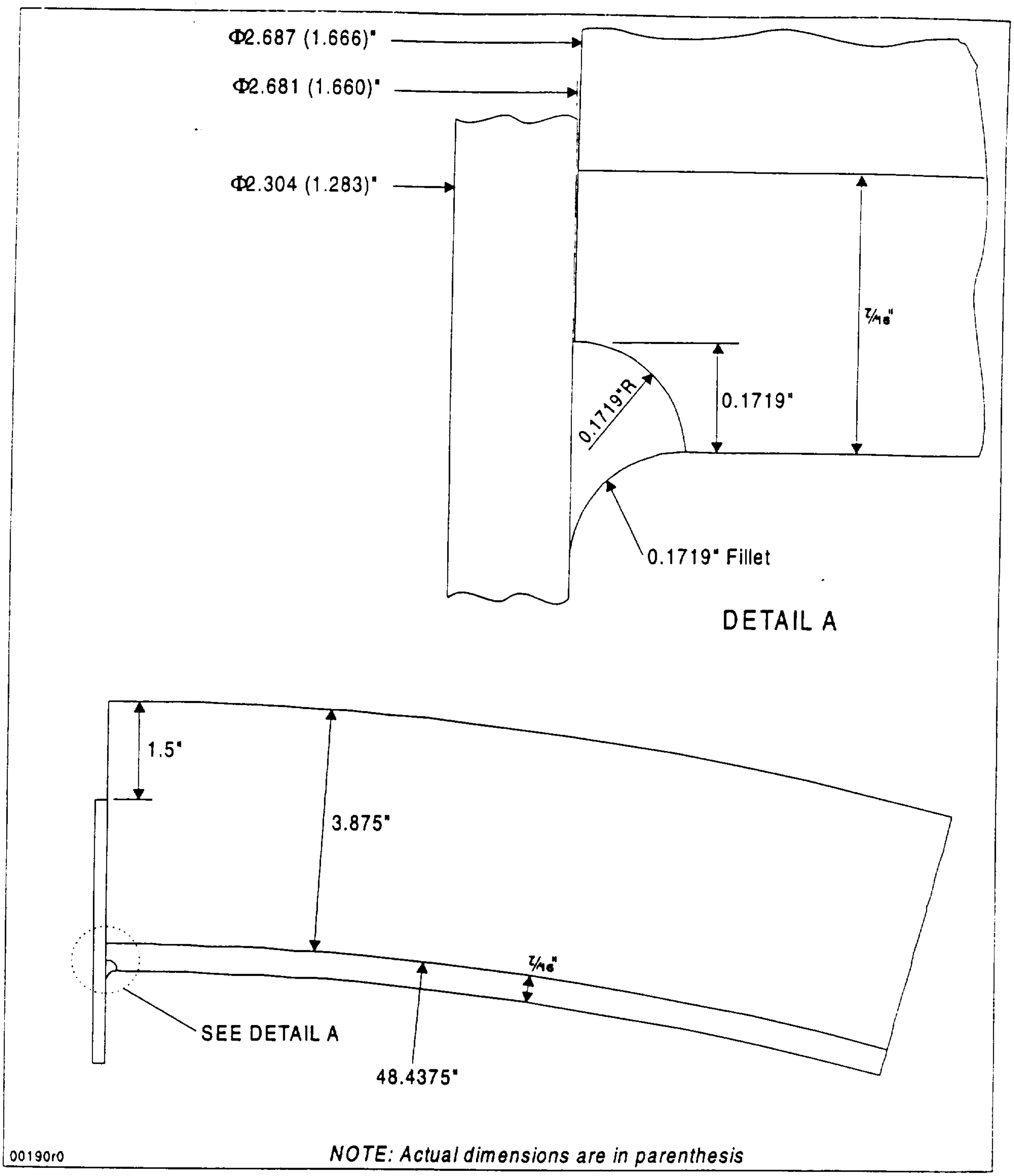

Figure 4-2. Geometry and Dimensions of Pressurizer Vessel Heater Penetration Used in the Finite Element Analyses

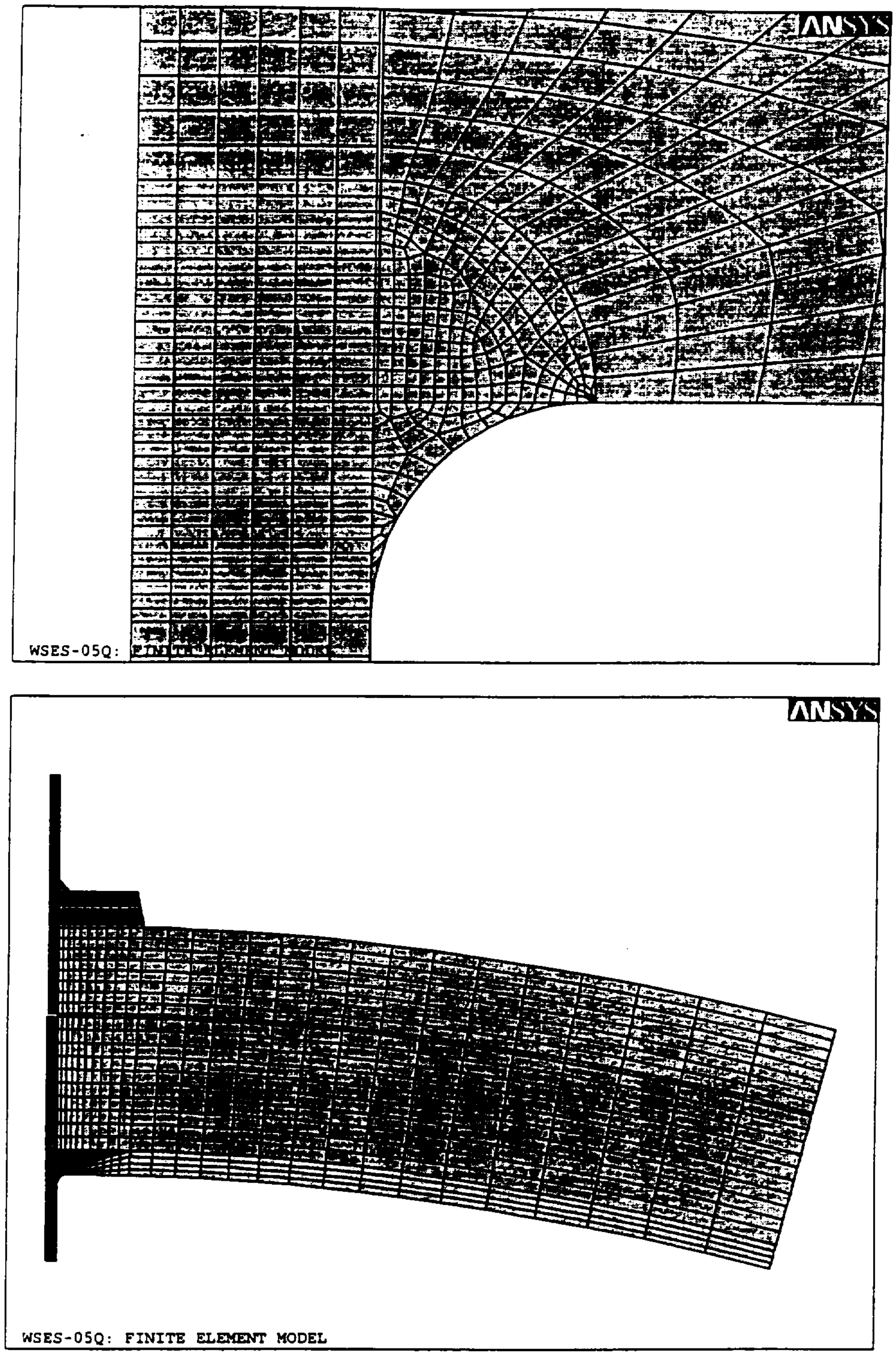

Figure 4-3. Pressurizer Heater Penetration Finite Element Model

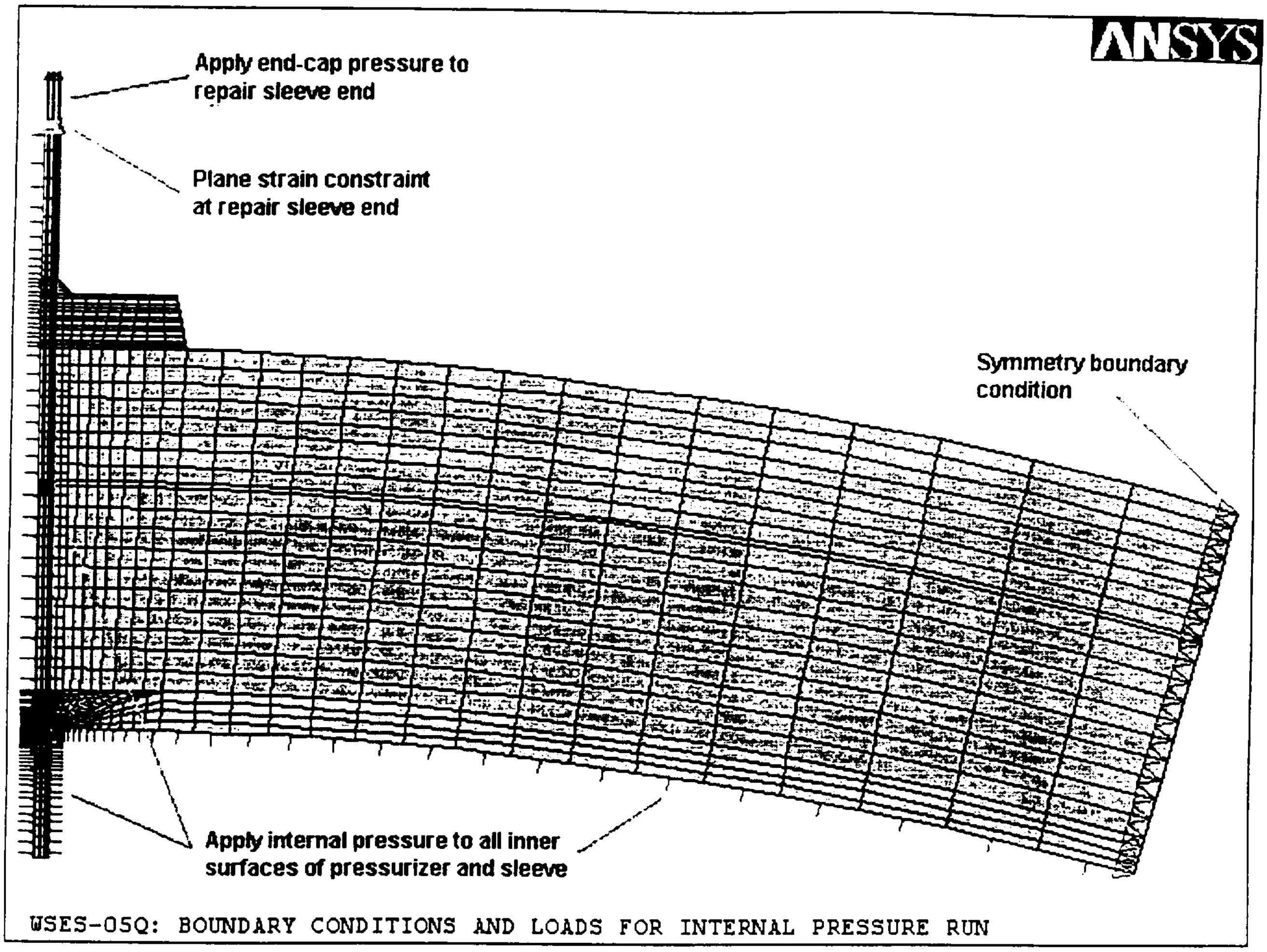

Figure 4-4. Applied Boundary Conditions and Loads for Internal Pressure Run

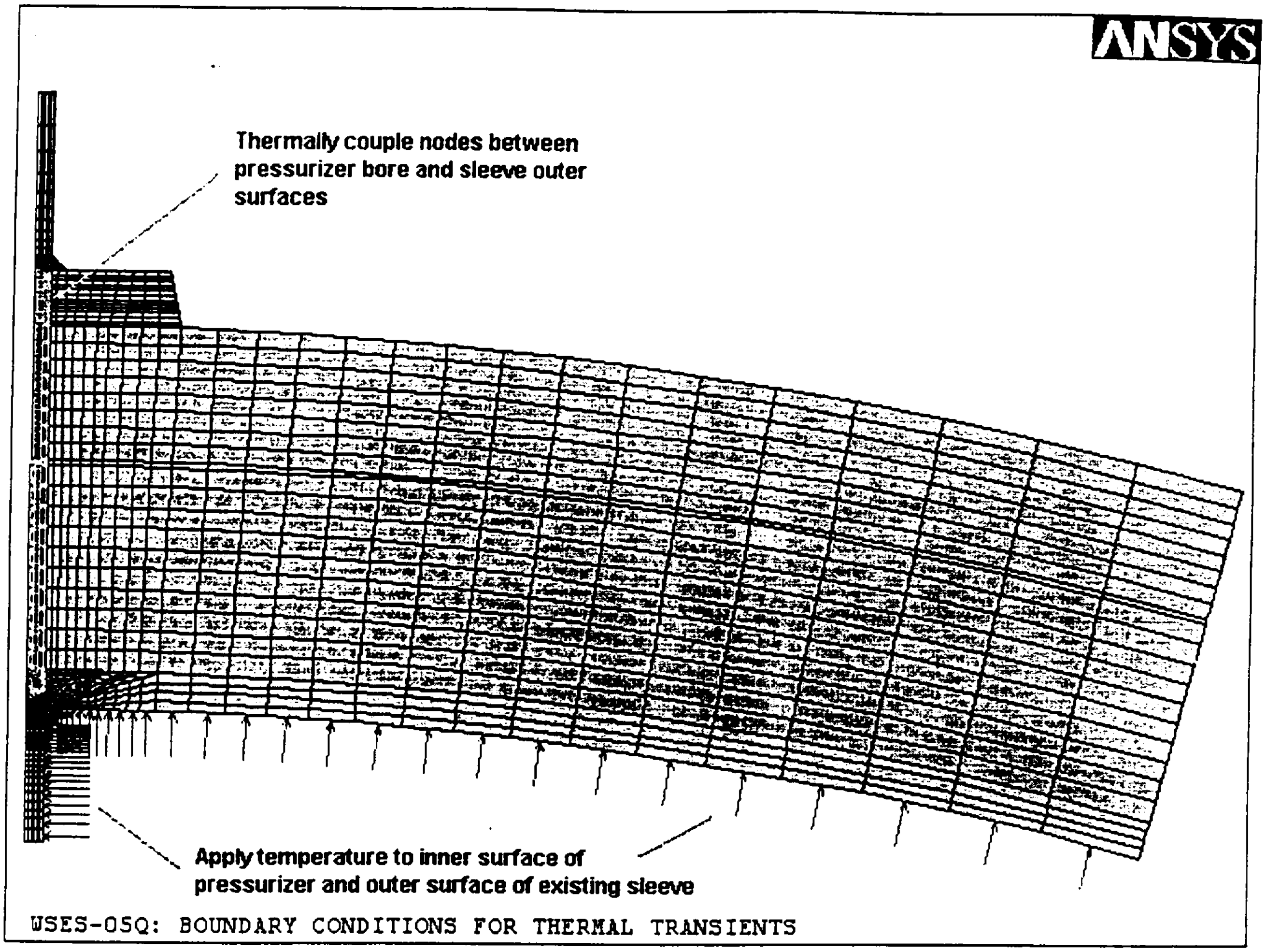

Figure 4-5. Applied Boundary Conditions for Thermal Transient Runs

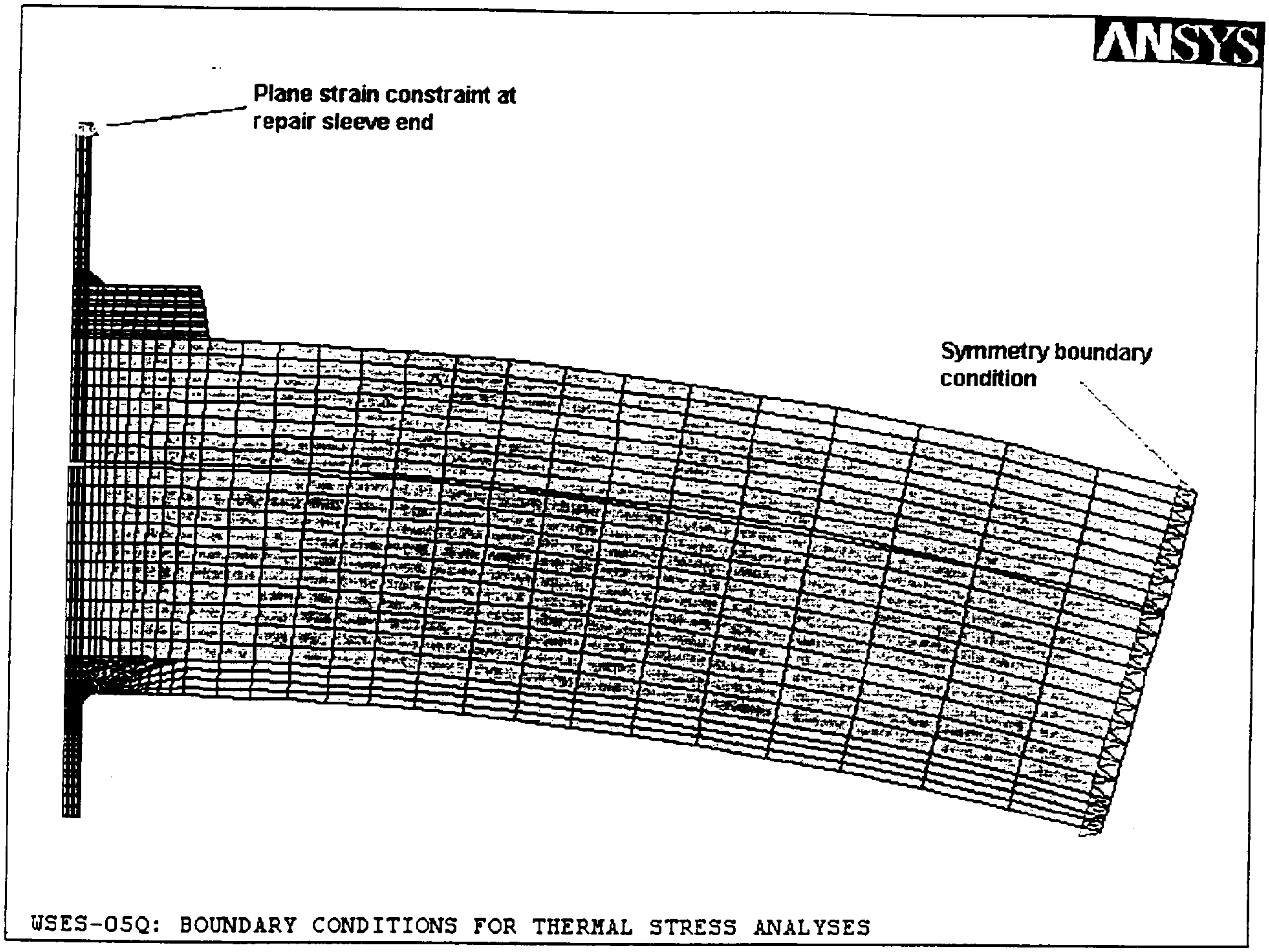

Figure 4-6. Applied Boundary Conditions and Loads for Thermal Stress Analyses

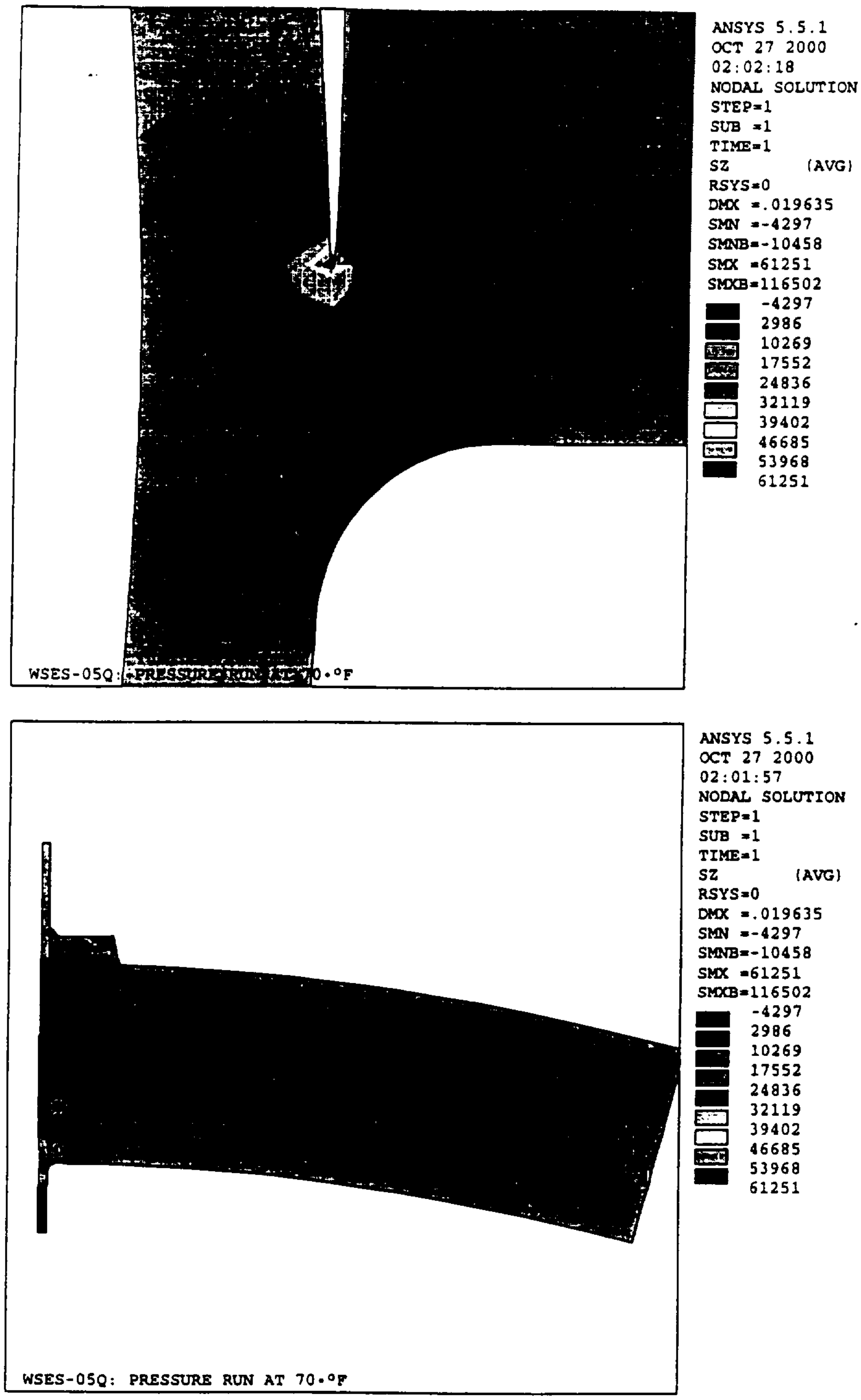

Figure 4-7. Pressurizer Heater Penetration Hoop Stresses Due to Internal Pressure

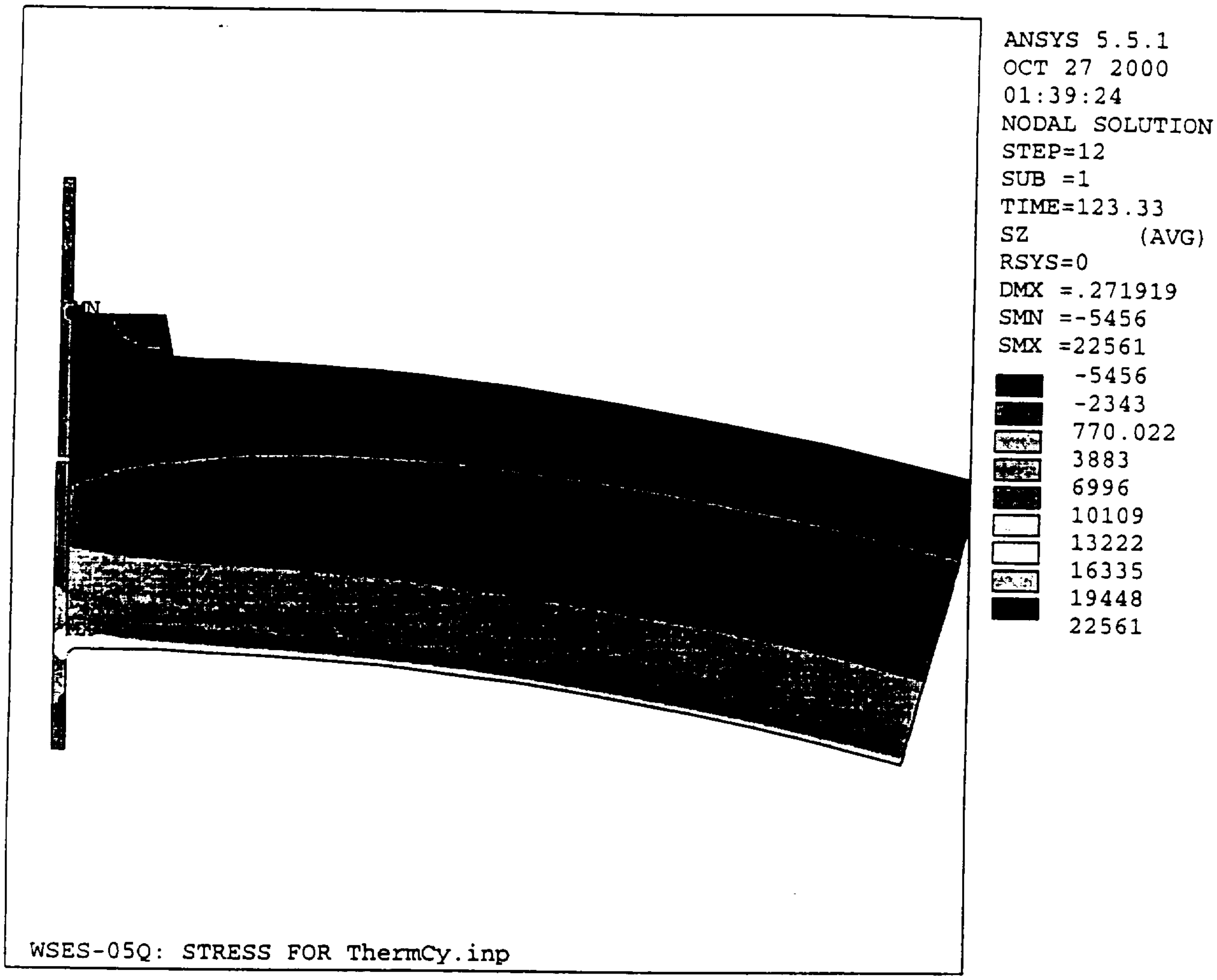

Figure 4-8. Pressurizer Heater Penetration Hoop Stresses Due to Reactor Trip

5.0 CRACK GROWTH EVALUATIONS

The evaluation of the potential for a crack in the existing pressurizer to propagate in the pressurizer vessel is summarized in the following paragraphs.

5.1 Applied Stresses

The loadings in the pressurizer include internal pressure and the thermal transients. The stress distributions at the pressurizer due to these loading conditions were obtained by finite element analyses discussed in Section 4. The relevant stress distributions due to pressure and thermal transients were extracted from the stress analyses along a through-wall path for input in the crack growth evaluations. Six through-wall paths were considered and can be seen in Figure 5-1.

For a nozzle corner crack fracture mechanics model, a stress distribution representing the stresses midway between the nozzle bore and the vessel inside surface is appropriate. As can be seen from Figures 5-1 and 5-2, paths closer to the penetration bore have higher stresses for the internal pressure run. Thus, a stress distribution along Path 1 which is inclined from the nozzle bore by approximately 30 degrees was conservatively used in evaluating crack growth. A similar path was chosen for a circumferential flaw fracture mechanics model that extended to the same point on the outside of the shell but started from the edge of the weld region on the cladding inside surface. This is Path 6 which is inclined at an angle of 25 degrees from the nozzle bore. The through-wall stress distributions for Paths 1 and 6 are presented in Figures 5-3 and 5-4. The through-wall stress distributions for all paths and conditions are in Tables 5-1 through 5-4.

The pressure loading on the crack face is also taken into consideration. This is done by determining a polynomial distribution that approximates the pressure up to the region of the crack tip. For this analysis, the crack face loading is taken as a series of data points with a pressure equal to the operating internal pressure up to the approximate final depth of the crack, and then zero beyond that depth.

5.2 Fatigue Cycle Definition

The Waterford-3 plant operation design transients are described in Section 3. The significant operating condition transients for the pressurizer are the heatup/cooldown, reactor trip, leak test and normal plant variations transients.

For the purpose of the crack growth evaluation, the heatup + reactor trip and cooldown transients were combined to form a complete maximum stress range cycle. In the crack growth analyses, the 500 heatup/cooldown cycles and the other operating transient cycles are assumed to be evenly distributed over the plant lifetime of 40 years. Coincident internal pressure levels described in Section 3 are combined appropriately with the thermal transient loads. The defined cyclic load ranges and corresponding number of cycles are presented in Table 5-5.

5.3 Fracture Mechanics Evaluation

5.3.1 Fracture Mechanics Models

A simulated 3-D nozzle corner crack model [16] was used for the crack growth analysis. This crack model is appropriate for this evaluation given the configuration of the pressurizer. From Reference 8, the stress intensity factor for this crack model is expressed as

$$K_I = \sqrt{\pi a}\left(0.706C_o + 0.537(2a/\pi)\,C_1 + 0.448\left(a^2/2\right)C_2 + 0.393\left(4a^3/3\pi\right)C_3\right)$$

where,

a	=	crack depth
C_0, C_1, C_2 and C_3	=	polynomial coefficients defining the stress distribution at the critical through-wall section of the hot leg pipe

A model for a 360° circumferential crack in a cylinder (t/R = 0.1) [9, 14] is also evaluated since the cracking could extend along the shell in the Alloy 600 cladding. This model conservatively represents a very long flaw through the Alloy 600 cladding on both sides of the penetration and between penetration.

All the crack growth analyses are performed with the **pc-CRACK for Windows** [7] fracture mechanics analysis program, which includes both the simulated corner crack and circumferential crack models.

5.3.2 Multiple Flaw Considerations

The effect of cracking on both sides of the nozzle is accounted for by multiplying the stress intensity factors by a scale factor. This factor is derived using the single crack-to-two crack multiplier for an assumed corner crack flaw size of 1.5 inches, the bore diameter of the actual heater penetration , and the model from Reference 10:

$$\frac{K_{2Flaws}}{K_{1Flaw}} = \sqrt{\frac{\frac{4}{\pi}+\frac{ac}{tr}}{\frac{4}{\pi}+\frac{ac}{2tr}}}$$

where: a = flaw depth into nozzle bore

c = flaw length along shell

t = shell thickness

r = nozzle bore radius

The multiplication factor calculations are summarized as follows:

Parameter	Pressurizer
a	1.5
c	1.5
t	3.875
r	0.831
Multiplication Factor	1.1024

Use of the actual heater penetration diameter increases the multiplication factor. The multiplication factor was conservatively based on the maximum expected crack size, not

recalculated for each crack size during the crack growth analysis. Thus, the multiplication factor of 1.1024 used in the analysis is conservative. This factor could be reduced by using the actual smaller flaw size computed in the analyses.

A model for a 360° circumferential surface crack in a cylinder (t/R = 0.1) [9, 14] was also evaluated for the pressurizer penetration since the cracking could extend along the shell in the Alloy 600 cladding. For the large aspect ratio model, relatively higher stress intensity factors are calculated. Since this assumes a continuous crack on either side of the penetration, no multiplier is needed to account for multiple flaws near the repaired heater tube when using this model.

5.3.3 Initial Flaw Size

The initial flaw size is taken as the maximum depth of the Alloy 600 material at each location. For the pressurizer penetration, it is assumed that the weld and underlying clad material contains a flaw to a depth of 0.4375 in. [2]. This conservatively assumes that the cracking extends to the Alloy 600/ferritic interface.

5.3.4 Crack Growth Law

For the flaw growth through the pressurizer wall, it was assumed that base metal fatigue is the primary propagation mechanism. The methodology of Section XI Appendix A of the ASME Code [1] was used to perform the fatigue crack growth. The ASME fatigue crack growth law for carbon and low alloy steels in water environment was used. This crack growth law has the form of a Paris law expressed as:

$$\frac{da}{dN} = C(\Delta K)^n$$

where,

a	=	flaw depth
N	=	number of stress cycles
C and n	=	experimentally determined parameters related to the material and operating environment
ΔK	=	stress intensity factor range ($K_{max} - K_{min}$)

5.3.5 Fracture Toughness

The major stress in the vicinity of the cracking is due to applied pressure. At conditions of high pressure, the temperature is also high. Thus, it is assumed that the material is on the upper shelf and the fracture toughness curve from Section XI, Appendix A is used, assuming a 200 ksi-in$^{1/2}$. A factor of $\sqrt{10}$ (3.1622) is used resulting in a 63.24 ksi-in$^{1/2}$ allowable fracture toughness.

5.4 Crack Growth Results

The applied stresses described in Section 5.1 were input to **pc-CRACK**. These stresses were represented as third order polynomial functions of distance from the base metal inside surface of the pressurizer. The calculated stress intensity factors corresponding to the applied stresses are shown in Figure 5-5 and Figure 5-6 for the pressurizer penetration corner crack and circumferential crack models, respectively. The **pc-CRACK** analyses are documented in detail in Reference 4 and the results included in Appendix B.

The postulated corner crack is predicted to grow to a depth of 0.5697 inches after 500 heatup/cooldown cycles (including all other transients described above). This is well below the predicted critical code allowable crack size of 3.084 inches which exceeds 80 percent of the vessel wall, bringing into question the validity of the crack model for such a depth. The end-of-period maximum stress intensity factor is controlled by the reactor trip cycle. The resulting value is 41.8 ksi-in$^{1/2}$ which is significantly less than the allowable. The stress intensity factor for the initial flaw size is 37.7 ksi-in$^{1/2}$.

For the circumferential crack, the crack grows to 0.6951 inches after the total design cycles. This is below the code allowable crack size of 0.77 inches. The stress intensity factor is 60.3 ksi-in$^{1/2}$. The stress intensity factor for the initial flaw size is 48.9 ksi-in$^{1/2}$.

Table 5-1. Hoop Stress Distributions for Internal Pressure

PATH 1			PATH 2			PATH 3		
Distance (inches)	Hoop Stress (psi)	(ksi)	Distance (inches)	Hoop Stress (psi)	(ksi)	Distance (inches)	Hoop Stress (psi)	(ksi)
0.000	26389	26.389	0.000	26389	26.389	0.000	26389	26.389
0.244	24638	24.638	0.286	24056	24.056	0.354	23158	23.158
0.488	22794	22.794	0.572	21729	21.729	0.707	20650	20.650
0.732	21200	21.200	0.858	19503	19.503	1.061	18073	18.073
0.975	20342	20.342	1.144	18420	18.420	1.415	16914	16.914
1.219	19610	19.610	1.430	17631	17.631	1.768	16211	16.211
1.463	18977	18.977	1.715	16995	16.995	2.122	15646	15.646
1.707	18408	18.408	2.001	16482	16.482	2.475	15259	15.259
1.951	17886	17.886	2.287	16088	16.088	2.829	14954	14.954
2.195	17458	17.458	2.573	15707	15.707	3.183	14693	14.693
2.439	17059	17.059	2.859	15454	15.454	3.536	14511	14.511
2.683	16725	16.725	3.145	15206	15.206	3.890	14339	14.339
2.926	16420	16.420	3.431	15011	15.011	4.244	14213	14.213
3.170	16215	16.215	3.717	14852	14.852	4.597	14094	14.094
3.414	15985	15.985	4.003	14690	14.690	4.951	14006	14.006
3.658	15800	15.800	4.288	14584	14.584	5.304	13911	13.911
3.902	15658	15.658	4.574	14488	14.488	5.658	13837	13.837
4.146	15552	15.552	4.860	14404	14.404	6.012	13760	13.760
4.390	15450	15.450	5.146	14331	14.331	6.365	13689	13.689
4.633	15479	15.479	5.432	14267	14.267	6.719	13621	13.621
4.877	15256	15.256	5.718	14194	14.194	7.073	13540	13.540

PATH 4			PATH 5			PATH 6		
Distance (inches)	Hoop Stress (psi)	(ksi)	Distance (inches)	Hoop Stress (psi)	(ksi)	Distance (inches)	Hoop Stress (psi)	(ksi)
0.000	26389	26.389	0.000	16064	16.064	0.000	22872	22.872
0.451	22115	22.115	0.242	15946	15.946	0.236	21611	21.611
0.901	19367	19.367	0.485	15395	15.395	0.471	20249	20.249
1.352	16964	16.964	0.727	14821	14.821	0.707	19006	19.006
1.803	15759	15.759	0.969	14674	14.674	0.942	18501	18.501
2.253	15173	15.173	1.211	14607	14.607	1.178	18102	18.102
2.704	14773	14.773	1.454	14545	14.545	1.414	17736	17.736
3.155	14484	14.484	1.696	14482	14.482	1.649	17397	17.397
3.605	14266	14.266	1.938	14416	14.416	1.885	17086	17.086
4.056	14094	14.094	2.180	14351	14.351	2.120	16811	16.811
4.507	13965	13.965	2.423	14304	14.304	2.356	16538	16.538
4.957	13855	13.855	2.665	14256	14.256	2.592	16335	16.335
5.408	13753	13.753	2.907	14210	14.210	2.827	16137	16.137
5.859	13665	13.665	3.149	14170	14.170	3.063	15978	15.978
6.309	13583	13.583	3.392	14123	14.123	3.298	15792	15.792
6.760	13498	13.498	3.634	14092	14.092	3.534	15656	15.656
7.211	13413	13.413	3.876	14063	14.063	3.770	15562	15.562
7.661	13329	13.329	4.118	14034	14.034	4.005	15478	15.478
8.112	13242	13.242	4.361	14007	14.007	4.241	15399	15.399
8.563	13155	13.155	4.603	13980	13.980	4.476	15464	15.464
9.013	13052	13.052	4.845	13944	13.944	4.712	15256	15.256

Table 5-2. Hoop Stress Distributions for Heat-Up

PATH 1			PATH 2			PATH 3		
Distance (inches)	Hoop Stress (psi)	(ksi)	Distance (inches)	Hoop Stress (psi)	(ksi)	Distance (inches)	Hoop Stress (psi)	(ksi)
0.000	-15213	-15.213	0.000	-15213	-15.213	0.000	-15213	-15.213
0.244	-11775	-11.775	0.286	-11926	-11.926	0.354	-11854	-11.854
0.488	-8498	-8.498	0.572	-8304	-8.304	0.707	-8187	-8.187
0.732	-6578	-6.578	0.858	-6209	-6.209	1.061	-5978	-5.978
0.975	-5041	-5.041	1.144	-4719	-4.719	1.415	-4569	-4.569
1.219	-3673	-3.673	1.430	-3437	-3.437	1.768	-3381	-3.381
1.463	-2450	-2.450	1.715	-2301	-2.301	2.122	-2317	-2.317
1.707	-1354	-1.354	2.001	-1288	-1.288	2.475	-1369	-1.369
1.951	-374	-0.374	2.287	-383	-0.383	2.829	-512	-0.512
2.195	498	0.498	2.573	426	0.426	3.183	260	0.260
2.439	1272	1.272	2.859	1146	1.146	3.536	958	0.958
2.683	1955	1.955	3.145	1780	1.780	3.890	1579	1.579
2.926	2549	2.549	3.431	2334	2.334	4.244	2134	2.134
3.170	3085	3.085	3.717	2819	2.819	4.597	2607	2.607
3.414	3508	3.508	4.003	3217	3.217	4.951	3029	3.029
3.658	3861	3.861	4.288	3547	3.547	5.304	3374	3.374
3.902	4143	4.143	4.574	3805	3.805	5.658	3650	3.650
4.146	4352	4.352	4.860	3995	3.995	6.012	3855	3.855
4.390	4481	4.481	5.146	4121	4.121	6.365	3998	3.998
4.633	4580	4.580	5.432	4183	4.183	6.719	4076	4.076
4.877	4503	4.503	5.718	4176	4.176	7.073	4084	4.084

PATH 4			PATH 5			PATH 6		
Distance (inches)	Hoop Stress (psi)	(ksi)	Distance (inches)	Hoop Stress (psi)	(ksi)	Distance (inches)	Hoop Stress (psi)	(ksi)
0.000	-15213	-15.213	0.000	-12079	-12.079	0.000	-14736	-14.736
0.451	-11699	-11.699	0.242	-9275	-9.275	0.236	-11079	-11.079
0.901	-8162	-8.162	0.485	-6445	-6.445	0.471	-7709	-7.709
1.352	-5957	-5.957	0.727	-5085	-5.085	0.707	-5992	-5.992
1.803	-4619	-4.619	0.969	-3965	-3.965	0.942	-4635	-4.635
2.253	-3525	-3.525	1.211	-2933	-2.933	1.178	-3405	-3.405
2.704	-2535	-2.535	1.454	-1973	-1.973	1.414	-2279	-2.279
3.155	-1625	-1.625	1.696	-1086	-1.086	1.649	-1252	-1.252
3.605	-793	-0.793	1.938	-273	-0.273	1.885	-320	-0.320
4.056	-29	-0.029	2.180	469	0.469	2.120	520	0.520
4.507	676	0.676	2.423	1142	1.142	2.356	1274	1.274
4.957	1318	1.318	2.665	1746	1.746	2.592	1944	1.944
5.408	1893	1.893	2.907	2277	2.277	2.827	2530	2.530
5.859	2406	2.406	3.149	2755	2.755	3.063	3062	3.062
6.309	2864	2.864	3.392	3143	3.143	3.298	3480	3.480
6.760	3243	3.243	3.634	3470	3.470	3.534	3834	3.834
7.211	3556	3.556	3.876	3730	3.730	3.770	4118	4.118
7.661	3793	3.793	4.118	3925	3.925	4.005	4329	4.329
8.112	3957	3.957	4.361	4057	4.057	4.241	4463	4.463
8.563	4052	4.052	4.603	4125	4.125	4.476	4574	4.574
9.013	4072	4.072	4.845	4128	4.128	4.712	4503	4.503

Table 5-3. Hoop Stress Distributions for Cool-Down

PATH 1			PATH 2			PATH 3		
Distance (inches)	Hoop Stress (psi)	(ksi)	Distance (inches)	Hoop Stress (psi)	(ksi)	Distance (inches)	Hoop Stress (psi)	(ksi)
0.000	15491	15.491	0.000	15491	15.491	0.000	15491	15.491
0.244	11929	11.929	0.286	12093	12.093	0.354	12028	12.028
0.488	8526	8.526	0.572	8354	8.354	0.707	8278	8.278
0.732	6491	6.491	0.858	6120	6.120	1.061	5894	5.894
0.975	4951	4.951	1.144	4626	4.626	1.415	4472	4.472
1.219	3596	3.596	1.430	3360	3.360	1.768	3302	3.302
1.463	2387	2.387	1.715	2240	2.240	2.122	2255	2.255
1.707	1305	1.305	2.001	1241	1.241	2.475	1322	1.322
1.951	338	0.338	2.287	349	0.349	2.829	478	0.478
2.195	-523	-0.523	2.573	-448	-0.448	3.183	-282	-0.282
2.439	-1287	-1.287	2.859	-1158	-1.158	3.536	-970	-0.970
2.683	-1962	-1.962	3.145	-1783	-1.783	3.890	-1583	-1.583
2.926	-2549	-2.549	3.431	-2330	-2.330	4.244	-2130	-2.130
3.170	-3077	-3.077	3.717	-2809	-2.809	4.597	-2598	-2.598
3.414	-3498	-3.498	4.003	-3203	-3.203	4.951	-3014	-3.014
3.658	-3851	-3.851	4.288	-3531	-3.531	5.304	-3356	-3.356
3.902	-4133	-4.133	4.574	-3790	-3.790	5.658	-3632	-3.632
4.146	-4343	-4.343	4.860	-3981	-3.981	6.012	-3838	-3.838
4.390	-4473	-4.473	5.146	-4108	-4.108	6.365	-3981	-3.981
4.633	-4570	-4.570	5.432	-4170	-4.170	6.719	-4059	-4.059
4.877	-4495	-4.495	5.718	-4163	-4.163	7.073	-4068	-4.068

PATH 4			PATH 5			PATH 6		
Distance (inches)	Hoop Stress (psi)	(ksi)	Distance (inches)	Hoop Stress (psi)	(ksi)	Distance (inches)	Hoop Stress (psi)	(ksi)
0.000	15491	15.491	0.000	12354	12.354	0.000	15020	15.020
0.451	11881	11.881	0.242	9441	9.441	0.236	11245	11.245
0.901	8266	8.266	0.485	6434	6.434	0.471	7718	7.718
1.352	5894	5.894	0.727	4983	4.983	0.707	5895	5.895
1.803	4517	4.517	0.969	3872	3.872	0.942	4543	4.543
2.253	3441	3.441	1.211	2858	2.858	1.178	3329	3.329
2.704	2468	2.468	1.454	1916	1.916	1.414	2218	2.218
3.155	1574	1.574	1.696	1044	1.044	1.649	1205	1.205
3.605	755	0.755	1.938	243	0.243	1.885	286	0.286
4.056	3	0.003	2.180	-487	-0.487	2.120	-544	-0.544
4.507	-691	-0.691	2.423	-1152	-1.152	2.356	-1288	-1.288
4.957	-1324	-1.324	2.665	-1747	-1.747	2.592	-1950	-1.950
5.408	-1891	-1.891	2.907	-2272	-2.272	2.827	-2528	-2.528
5.859	-2398	-2.398	3.149	-2743	-2.743	3.063	-3052	-3.052
6.309	-2849	-2.849	3.392	-3127	-3.127	3.298	-3469	-3.469
6.760	-3225	-3.225	3.634	-3452	-3.452	3.534	-3823	-3.823
7.211	-3536	-3.536	3.876	-3713	-3.713	3.770	-4108	-4.108
7.661	-3774	-3.774	4.118	-3909	-3.909	4.005	-4320	-4.320
8.112	-3938	-3.938	4.361	-4041	-4.041	4.241	-4455	-4.455
8.563	-4034	-4.034	4.603	-4111	-4.111	4.476	-4564	-4.564
9.013	-4054	-4.054	4.845	-4114	-4.114	4.712	-4495	-4.495

Table 5-4. Hoop Stress Distributions for Reactor Trip
(at 123 seconds)

PATH 1			PATH 2			PATH 3		
Distance (inches)	Hoop Stress (psi)	(ksi)	Distance (inches)	Hoop Stress (psi)	(ksi)	Distance (inches)	Hoop Stress (psi)	(ksi)
0.000	13865	13.865	0.000	13865	13.865	0.000	13865	13.865
0.244	10408	10.408	0.286	10604	10.604	0.354	10591	10.591
0.488	7018	7.018	0.572	6964	6.964	0.707	7044	7.044
0.732	4789	4.789	0.858	4530	4.530	1.061	4415	4.415
0.975	3333	3.333	1.144	3108	3.108	1.415	3026	3.026
1.219	2132	2.132	1.430	1982	1.982	1.768	1968	1.968
1.463	1119	1.119	1.715	1036	1.036	2.122	1068	1.068
1.707	273	0.273	2.001	245	0.245	2.475	310	0.310
1.951	-426	-0.426	2.287	-409	-0.409	2.829	-327	-0.327
2.195	-997	-0.997	2.573	-945	-0.945	3.183	-854	-0.854
2.439	-1458	-1.458	2.859	-1381	-1.381	3.536	-1288	-1.288
2.683	-1829	-1.829	3.145	-1729	-1.729	3.890	-1636	-1.636
2.926	-2120	-2.120	3.431	-2004	-2.004	4.244	-1914	-1.914
3.170	-2357	-2.357	3.717	-2222	-2.222	4.597	-2128	-2.128
3.414	-2528	-2.528	4.003	-2381	-2.381	4.951	-2293	-2.293
3.658	-2660	-2.660	4.288	-2503	-2.503	5.304	-2417	-2.417
3.902	-2762	-2.762	4.574	-2590	-2.590	5.658	-2505	-2.505
4.146	-2837	-2.837	4.860	-2649	-2.649	6.012	-2563	-2.563
4.390	-2886	-2.886	5.146	-2686	-2.686	6.365	-2598	-2.598
4.633	-2937	-2.937	5.432	-2702	-2.702	6.719	-2614	-2.614
4.877	-2916	-2.916	5.718	-2696	-2.696	7.073	-2608	-2.608

PATH 4			PATH 5			PATH 6		
Distance (inches)	Hoop Stress (psi)	(ksi)	Distance (inches)	Hoop Stress (psi)	(ksi)	Distance (inches)	Hoop Stress (psi)	(ksi)
0.000	13865	13.865	0.000	11357	11.357	0.000	13529	13.529
0.451	10502	10.502	0.242	8452	8.452	0.236	9909	9.909
0.901	7125	7.125	0.485	5287	5.287	0.471	6342	6.342
1.352	4536	4.536	0.727	3619	3.619	0.707	4319	4.319
1.803	3114	3.114	0.969	2520	2.520	0.942	3026	3.026
2.253	2115	2.115	1.211	1590	1.590	1.178	1940	1.940
2.704	1246	1.246	1.454	779	0.779	1.414	1005	1.005
3.155	493	0.493	1.696	84	0.084	1.649	210	0.210
3.605	-145	-0.145	1.938	-504	-0.504	1.885	-456	-0.456
4.056	-682	-0.682	2.180	-993	-0.993	2.120	-1007	-1.007
4.507	-1133	-1.133	2.423	-1395	-1.395	2.356	-1456	-1.456
4.957	-1502	-1.502	2.665	-1720	-1.720	2.592	-1819	-1.819
5.408	-1799	-1.799	2.907	-1979	-1.979	2.827	-2106	-2.106
5.859	-2035	-2.035	3.149	-2187	-2.187	3.063	-2341	-2.341
6.309	-2219	-2.219	3.392	-2340	-2.340	3.298	-2511	-2.511
6.760	-2355	-2.355	3.634	-2457	-2.457	3.534	-2645	-2.645
7.211	-2454	-2.454	3.876	-2543	-2.543	3.770	-2749	-2.749
7.661	-2520	-2.520	4.118	-2602	-2.602	4.005	-2825	-2.825
8.112	-2559	-2.559	4.361	-2639	-2.639	4.241	-2877	-2.877
8.563	-2577	-2.577	4.603	-2658	-2.658	4.476	-2934	-2.934
9.013	-2572	-2.572	4.845	-2656	-2.656	4.712	-2916	-2.916

Table 5-5. Crack Growth Evaluation Cyclic Loads

Load Cycle I.D.	Maximum		Minimum		Number of Cycles
	Pressure (psig)	Thermal	Pressure (psi)	Thermal	
Heatup/Cooldown + Reactor Trip Up	2535	Reactor Trip @ 50 sec	0	200 °F/hr Heatup @ 212 °F	500
Pressure Leak Test	2235	0	0	100 °F/hr Heatup @ 212 °F	500
Normal Variations	2335	0	2135	0	10^6
Normal Operation + Reactor Trip Down	2235	0	1685	0	500

Note: The "0" thermal conditions indicate steady state condition.

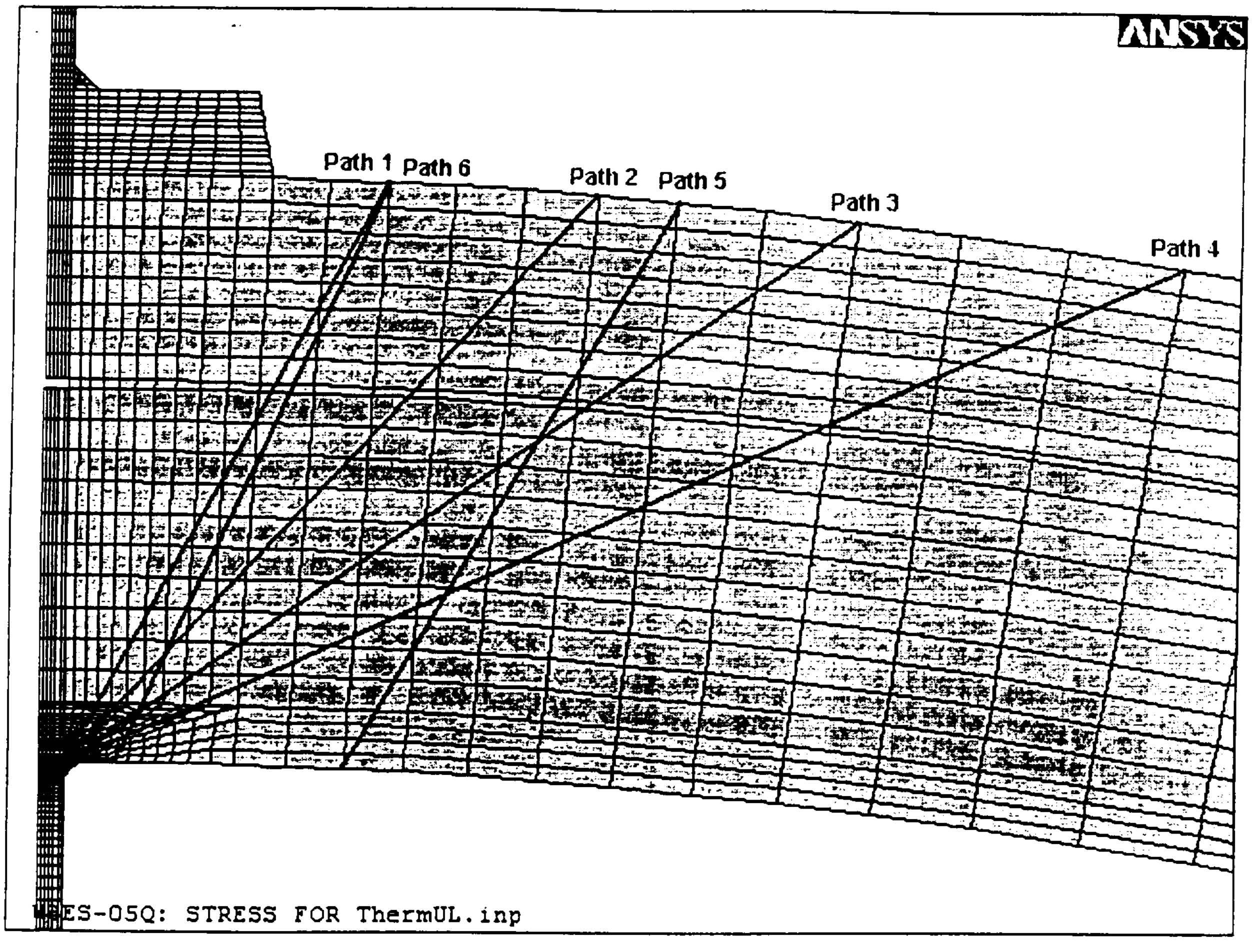

Figure 5-1. Through Wall Paths Considered for Crack Growth Evaluation [12]

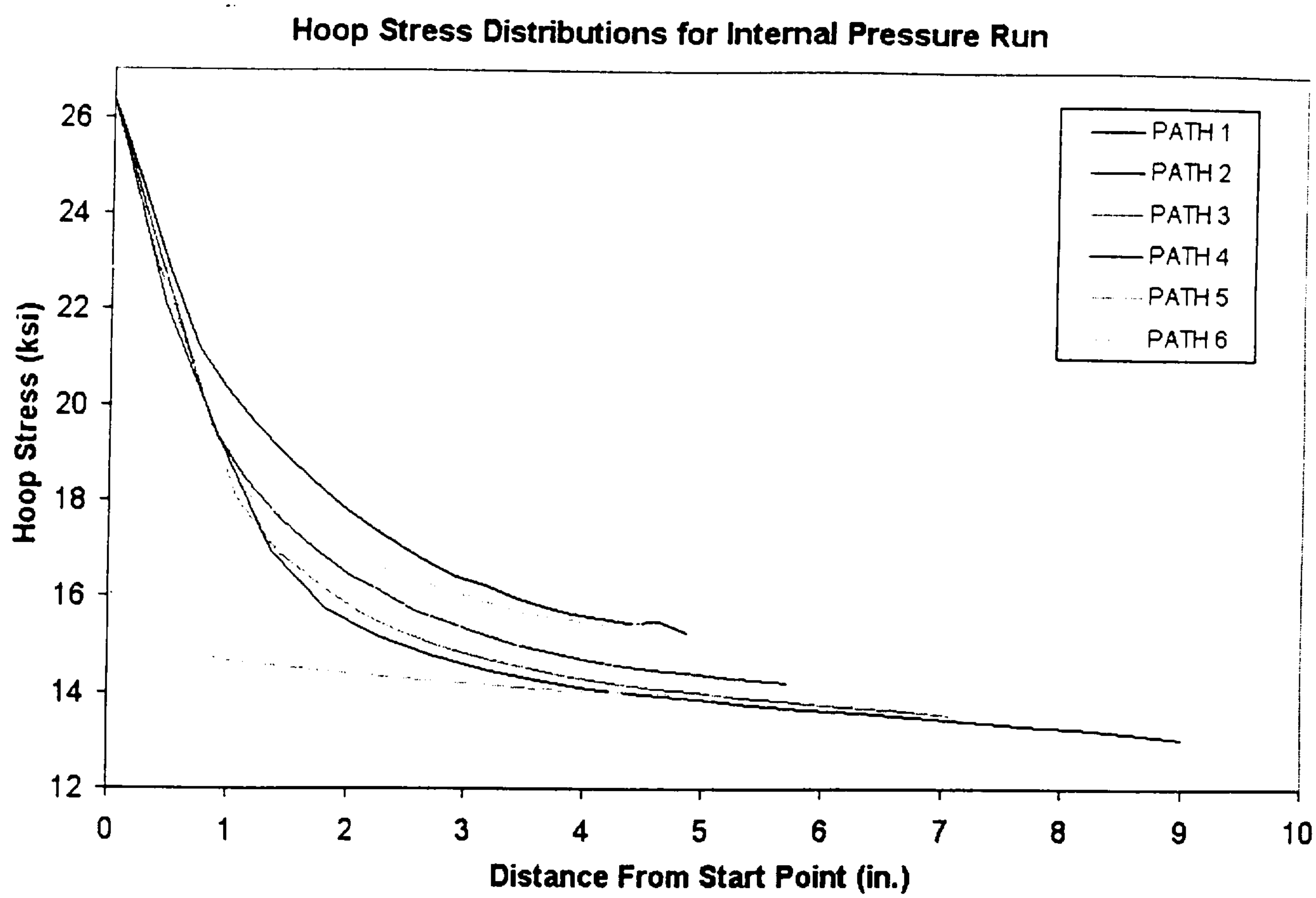

Figure 5-2. Hoop Stresses Along Given Paths for Internal Pressure Runs [12]

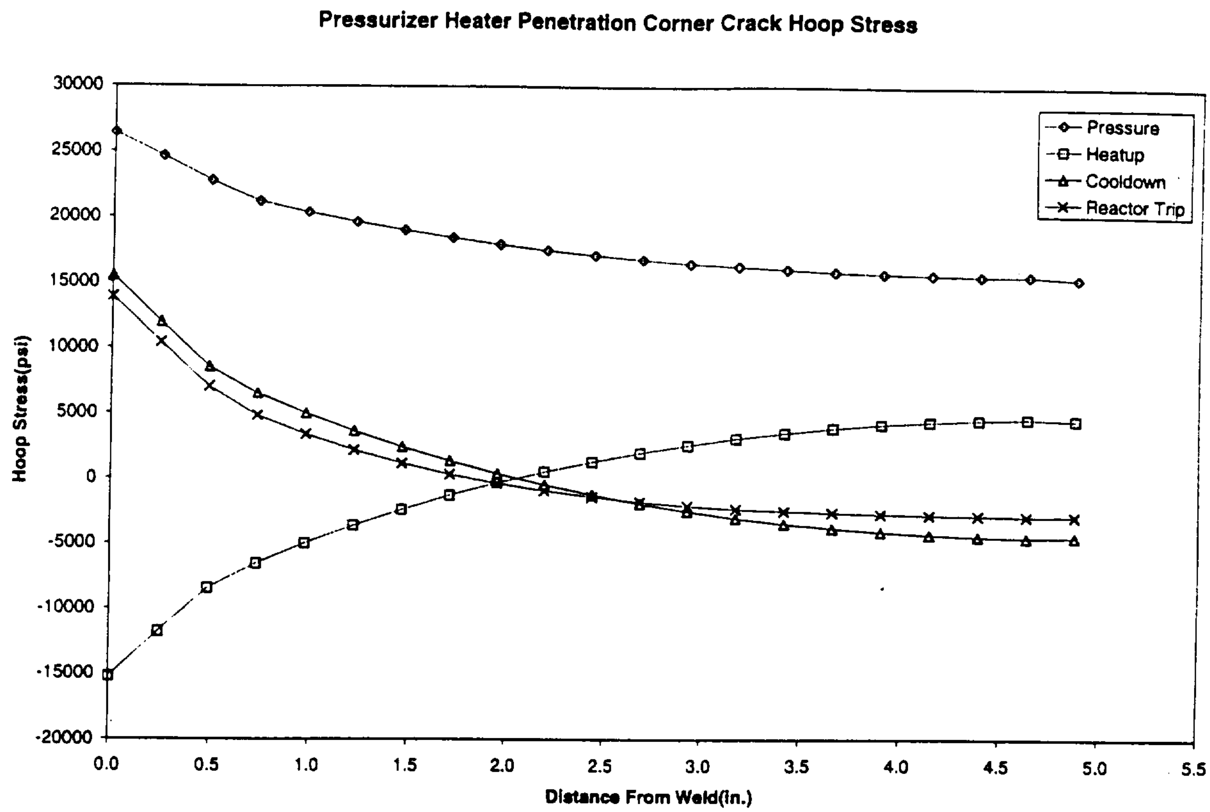

Figure 5-3. Pressurizer Penetration Corner Crack Hoop Stress Distributions for Path One

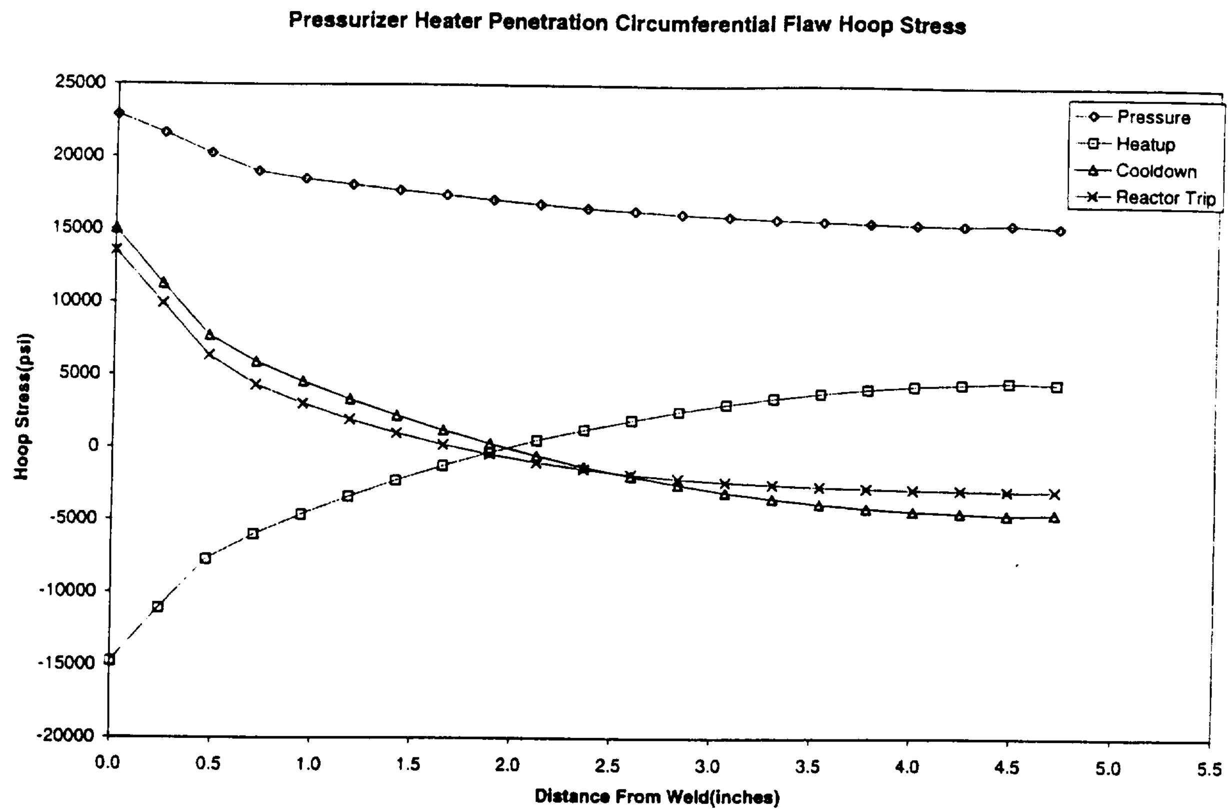

Figure 5-4. Pressurizer Penetration Circumferential Flaw Hoop Stress Distributions for Path 6

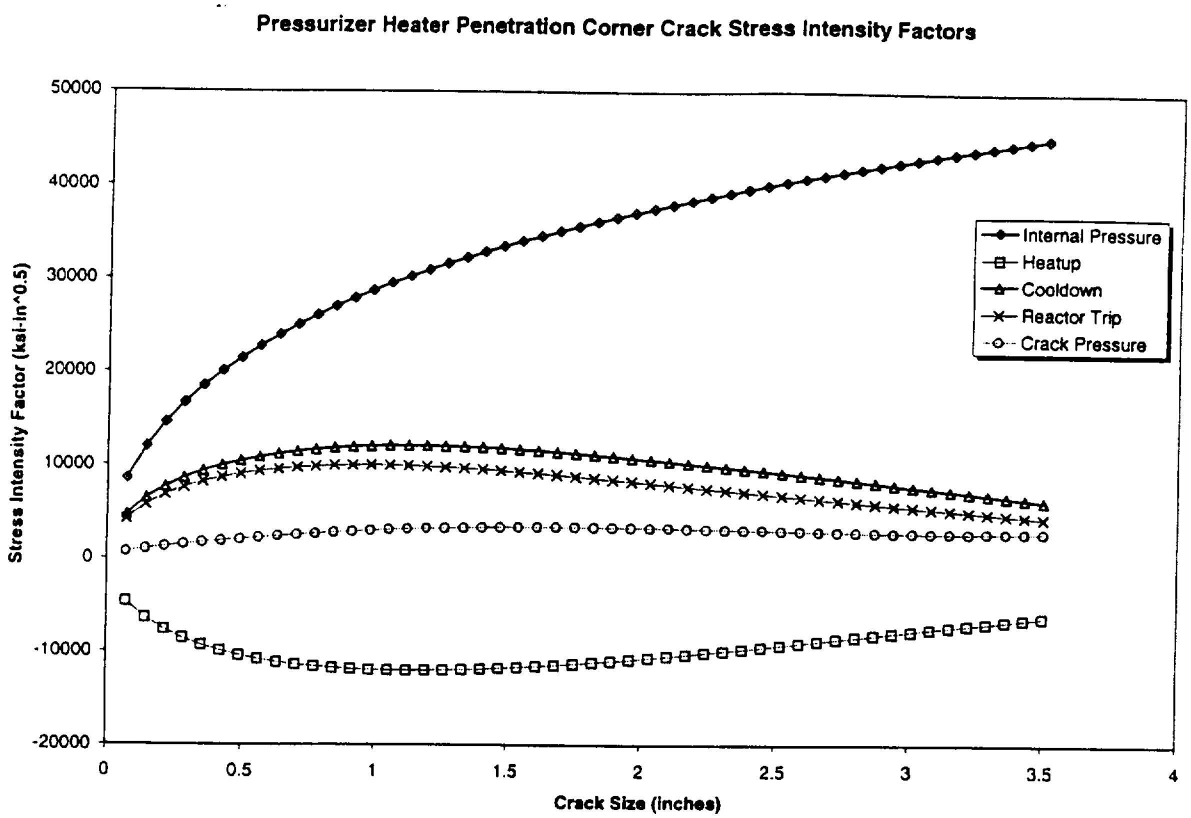

Figure 5-5. Pressurizer Heater Penetration Stress Intensity Factors, Corner Crack Model

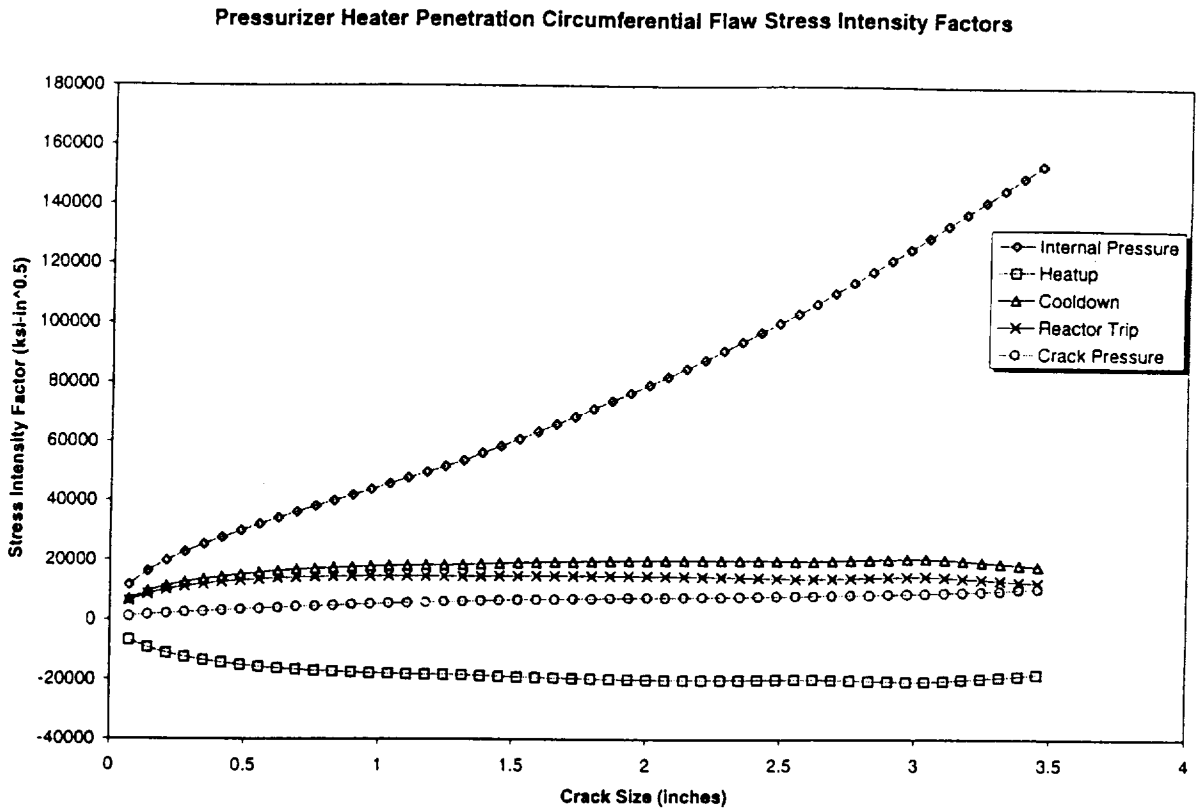

Figure 5-6. Pressurizer Heater Penetration Stress Intensity Factors Circumferential Crack in Cylinder (t/R= 0.1) Model

6.0 CONCLUSIONS

Fracture mechanics analyses have been performed to evaluate the potential for a crack in the pressurizer heater welds to grow to a depth greater than the ASME Code Section XI allowable flaw size. The fracture mechanics evaluations used stress input from detailed finite element stress analyses of the nozzle penetrations. The finite element model was conservatively based on an enlarged hole in the pressurizer shell equal to the maximum side-hill dimensions to account for outermost heater locations with the largest side-hill angle. This conservatism makes the analyses bounding for all the pressurizer heater locations at Waterford-3.

The analyses performed in this evaluation include some conservative assumptions. There is at least a 5% margin between the computed stress intensity factors and the allowable fracture toughness. The crack growth rate has been demonstrated to be small, even for the total expected number of transients for the plant design life. The end of cycle crack sizes are below critical for both a corner crack and circumferential crack.

In the uncracked configuration, there is a pressure loading on the inner sleeve that produces tensile stresses in the hoop direction. This can cause through-wall cracking of the sleeve that results in leakage. In the repaired condition, the pressure load is taken at the outside diameter of the piping. In the case of a leaking inner sleeve, there will no longer be an applied pressure load causing tensile stresses in the hoop direction, except locally near each end of the piping where the tube is welded. In the absence of the applied pressure loading, there will be no driving force to continue to grow a crack in the sleeve axial direction.

7.0 REFERENCES

1. ASME Boiler and Pressure Vessel Code, Section XI, 1992 Edition.

2. Design Input Record, "ASME Section XI, IWB-3600 Evaluation for Document SIR-00-135," Rev. 1, 10/27/00 (File WSES-05Q-201)

3. Entergy Operations Inc., Drawing No. 5010179 D, "Waterford Pressurizer Heater Nozzle Replacement, Location F-4," Rev. 0, by fax from G. Payne, Entergy, to A. Deardorff, SI, Oct. 19, 2000, SI File No. WSES-05Q-202.

4. Calculation File No. WSES-05Q-302, "Pressurizer Heater Weld Crack Growth Analysis," Rev. 0.

5. ASME Boiler and Pressure Vessel Code, Section II, Part D, 1992 Edition.

6. ANSYS/Mechanical, Revision 5.5.1, ANSYS, Inc., October 1998.

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

8. Riccardella, P. C., and Delvin, S. A., "Fracture Mechanics Analysis of JAERI Model Pressure Vessel Test", ASME Publication 78-PVP-91.

9. Buchalet, C. B., and Bamford, W. H., "Stress Intensity Factor Solutions for Continuous Surface Flaws in Reactor Pressure Vessels", ASTM STP-590, 1975.

10. Newman, J. C. and Raju, I. S., "Stress-Intensity Factor Equations for Cracks in Three Dimensional Bodies Subjected to Tension and Bending Loads", NASA Tech. Memorandum 85793, April 1984.

11. Drawing PDD-5817-13058, "Plug of Pressurizer Heater Sleeve F-4," Rev. A, (FAX from Prasanta Chowdhury, dated 10/30/00).

12. SI Calculation Package No. WSES-05Q-301, "Pressurizer Heater Weld Crack Growth Evaluation," Rev. 0.

13. Drawing PDD-5817-13054, "Repair of Pressurizer Heater Sleeve F-4," Rev. B, (email from Gary Payne, sent 10/27/00 7:08AM).

14. Labbens, R., et.al., "Practical Method for Calculating Stress Intensity Factors Through Weight Functions", ASTM STP-590, 1975.

15. ASME Boiler and Pressure Vessel Code, Section III, 1971 through the Summer 1971 Addenda.

16. Private Communication, P. M. Besuner to P. C. Riccardella, "Three-Dimensional Stress Intensity Factor Magnification Constraints for Radial Feedwater Nozzle Cracks", Failure Analysis Associates, June 1976.

APPENDIX A
DESIGN INPUT

WSES-050-201

Page 1 of 3

Design Input Revision 1

DESIGN INPUT RECORD

Document Type: ASME Section XI ,IWB-3600 Flaw Evaluation

Document Number: SIR-00-135, Document Revision: N/A

Problem Summary: (Attach additional sheets as required)

Pressurizer heater sleeve No. F4 has been found leaking during RF-10 and will be repaired using the half-nozzle technique.

Design Objective : (Attach additional sheets as required)

Perform a Bounding Flaw Evaluation for the PWSCC failure of pressurizer heater sleeves in accordance with ASME Section XI, IWB-3600,1992 Edition.

Discipline Review:

Contributing Disciplines:

X	Mechanical		Electrical
	I & C	X	Civil
	Structures	X	Piping
	Other		Engineering Programs

-Lead Discipline Mechanical

-Prepared by:	P. Chowdhury /	Date:	10/27/00
Reviewed by	J. Perez	Date:	10/27/00
Verified by	R. T. Finch	Date:	10/27/00
-Lead Design/Responsible Engineer	Gary E. Payne	Date:	10/27/00
-Responsible/Engineering Supervisor	David Viener	Date:	10/27/00

ES-P-001, Form No. 1 Rev. 1

DESIGN INPUT FOR IWB-3600 FLAW EVALUATION FOR THE PRESSURIZER HEATER SLEEVES

• Code	ASME Section III, 1971 through the Summer 1971 Addenda	1564-1028 Rev 1
• Identification/Details:	671-401- Assembly F4 –Leaking sleeve 684-103- Piece No NX-4886- Heat No.	DWG 5817-8943 Rev 0 CR-WF3-2000-1250 DWG. 5817-8943 DWG 1564-2752
• Orientation (Location of heater sleeve in the cross section of the PZR)	See Note 1	DWG 1564-1186, Rev 0
• Lower Head inside radius (Ri) • Lower Head minimum thickness (t_H)	Ri = 48 7/16" up to basemetal t_H = 3 7/8"	DWG. 1564-1186
• Clad thickness (t_c)	See Note 3	DWG. 74370-650-001
• Heater Sleeve Dimension & Vessel Bore (Repair)		PDD-5817-13054, Rev B
Sleeve: D_o = outside diameter; D_i = Inside Diameter;	D_o = 1.660" + 0.000 -0.002 D_i = 1.304"+0.010" -0.000	74370-684-001 5817-13054
Vessel : $D_{Vessel\ bore}$ – Bore diameter	$D_{Vessel\ bore}$ = 1.662" +0.004 - 0.000	74370-671-003
Weld ((a) Between Heater sleeve and Pressurizer heater lower sleeve; (b) Between heater and heater sleeve)- New Weld	See Drawing as noted	PDD-5817-13054, Rev B
• Heater Sleeve Dimension (Exist)		
D_o = outside diameter; D_i = Inside Diameter; t_n = Thickness Length = L_g Bore Diameter = D_{bore}	D_o = 1.660" + 0..000-0.002 D_i = 1.273"+0.010"/-0.000 L_g = 15 7/8" D_{bore} =1.662" + .004 / -0	Stress Report (EC-M94-011 Rev 1 (including all changes) ↓
• Existing Heater Sleeve Weld (Internal weld)		↓
Code Requirement: NB-3352.4 (d)		↓
- Peak Height (Depth of Groove plus fillet weld leg) (Min. Required = 1.5Tn = 1.5 x 0.194" = 0.2910");	0.3125"	↓
- Fillet weld width, Min. Reqd. = 0.75 x Tn - = 0.75 x 0.194" - = 0.1455"	0.1875"	↓
Furnished:		↓
Uphill Groove depth Fillet weld leg Peak height	0.1875" Radius 0.1875" (± 1/16) 0.375"	↓
Downhill J-Groove depth - Fillet weld - Peak Height	0.1563" (+1/16 –0) 0.1563" 0.3125"	↓

2

DESIGN INPUT FOR IWB-3600 FLAW EVALUATION FOR THE PRESSURIZER HEATER SLEEVES

Materials:			
Heater sleeve (new)		SB-167 A690	PDD-5817-13054 Rev B
Heater sleeve (existing)		SB167 A600	74370-684-001 Rev. 2
Bottom Head		SA-533 GR B CL 1	ECM94-011 Rev 1
Cladding		Equivalent to Inconel 600	
Weld (Exist /new)		Equivalent to Inconel 600 / 690	
Loading:			
Design Pressure		2500 psia	1564-1028 Rev 1
Design Temperature		700°F	1564-1028 Rev 1
Operating Pressure		2250 psia	1564-1028 Rev 1
Operating Temperature		653°F	1564-1028 Rev 1
Transient Conditions:		**Occurrences**	See Note 5
Plant Heatup		500	↓
Plant Cooldown		500	↓
Plant Loading	± 100 psi	10^6	↓
Plant Unloading			↓
Step Load increase	± 20°F		↓
Step load decrease			↓
Normal variations			↓
Reactor trip		480	↓
Loss of Primary Flow			↓
Loss of Load			↓
Loss of Secondary Pressure (Emergency)		5	↓
Leak Test (2250 psia, 100° -400°F)		200	↓
Hydro Test		10	↓

Notes:

1. The lower head inside radius is 48 7/16 inches. Clad thickness in the lower head near the heater sleeves is 7/16 inches. Lower head thickness is 3 7/8 in. min. (Source: 1564-1186 Rev. 0 and CE drawing 74370-650-001)
2. The heater sleeves that have the highest side hill angle are J1 and J2 which are located on the center line (90°-270°) at 38 inches from the center of the pressurizer (ref. CE drawing 74370-671-002).
3. Clad Thickness at the upper section of the bottom head = 3/16". Clad thickness increases towards the bottom; at approximately 26 3/8" down from the Tangent line; the clad thickness increases to 7/16" at the lower section of the bottom head as per Detail A on Drawing (74370-650-001, R2).
4. Repair process and applicable Code: | 1

DESIGN INPUT FOR IWB-3600 FLAW EVALUATION FOR THE PRESSURIZER HEATER SLEEVES

The new pressurizer heater sleeve design meets the original construction code, which is ASME Section III, 1971 through Summer Addenda of 1971. The fracture toughness of the welding is in accordance with ASME Section III, 1971 through Summer Addenda of 1972. The heater sleeve materials will be reconciled to the original construction code by Westinghouse (ref. Calculation EC-M94-011 R1, Change 7). The stresses meet the primary stress intensity per the ASME Code. The stresses meet the stress criteria as stipulated by ASME Subsection NB-3220. ASME Code Case 1361 contained a maximum diametrical clearance requirements of 0.045" for attaching appurtenances to Class 1 nozzles, and it was applied to the design clearance between the pressurizer heater sleeve and the heater element. The inside diameter of the replacement portion of the heater sleeve will be increased by 1/32" to reduce the possibility of weld distortion affecting the fit of the heater into the repaired sleeve. The diametrical clearance criteria contained in the Code Case 1361 will be met by the use of a cylindrical shim collar. The collar will fit over the heater element after it is positioned inside the heater sleeve and before making the heater element to heater sleeve pressure boundary weld. In addition, the profile of the 3/16" fillet weld between the heater sleeve and the heater element will be modified because of the decrease in the wall thickness of the replacement heater sleeve creates a smaller shoulder for welding. Calculation EC-M94-011, Revision 1, Change 7 will evaluate and qualify the redesigned heater sleeve and the modified pressure boundary weld at the heater element.

The existing internal J-weld and a small portion of the original heater sleeve is not being removed. The internal J-weld is no longer considered part of the pressure boundary. 1

Although the new heater sleeve/weld pad configuration may be slightly heavier than the existing sleeve/weld configuration, this slight increase would be negligible when compared to the weight of the pressurizer.

The new weld buildup pad, to allow relocating the partial penetration weld joint from inside the pressurizer to the outside surface, will be performed in accordance with ASME Section XI, 1992 Edition.

Either Code Case 2142-1, F-Number Grouping for Ni-Cr-Fe, Classification UNS N06052 Filler Metal, Section IX, or Code Case 2143-1, F-Number Grouping for Ni-Cr-Fe, Classification UNS W86152 Welding Electrode Section XI will be used to establish welding classifications and other requirements for welding Alloy 690.

5. **Transients:** (Ref: Source: Figures 2, 3,4 and 5 from "Specification 00000-PE-130, "General Specification for a Pressurizer Assembly," Rev. 2, 6/2/1972):

DESIGN INPUT FOR IWB-3600 FLAW EVALUATION FOR THE PRESSURIZER HEATER SLEEVES

- Heatup/Cooldown – 500 lifetime cycles. For the pressurizer, the rate is 200°F/hr, from 70°F to 653°F. The pressure cycles between 0 psig and 2235 psig. The thermal stresses are relatively small and are of opposite sign from pressure stresses in the area of the assumed cracking. However, since thermal stresses develop prior to pressurization, they are considered for the initial part of the heatup transient. They need not be considered for cooldown.

- Plant Loading/Unloading- Step Load Increase/Decrease and Normal Variations – 10^6 cycles. These are +/- 100 psig and +/- 20°F. It is assumed that the temperature and pressure variations are relatively slow since rapid changes do not normally occur with this high frequency. In additions, the thermal stress sign would be opposite to the pressure stress sign such that it is conservative to neglect the thermal stresses. (There are 2000 variations per Heatup/Cooldown cycle.).

- Reactor Trip, Loss of Primary Flow and Loss of Load – 480 cycles. This transient is a 2535 psig overpressure, followed by a reduction in pressure to 1685 psig, and then a slow repressurization back to 2235 psig. There is also a significant thermal transient with the temperature reducing to 613°F from normal operating temperature at the same time that the peak pressure occurs. The temperature then decreases an additional 20°F in about 550 seconds before it slowly increases back to normal conditions in another 1400 seconds. (For ease of calculation, it is assumed that there are 500 cycles, the same as the number of Heatup/Cooldown cycles.). 1

- Leak Test – 200 cycles. This is assumed to be a separate cycle from zero pressure to normal pressure of 2235 psig. The heatup rate for both the pressurizer and hot leg is given as 100F/hour. As with normal heatup and cooldown, it is conservative to neglect the transient thermal stresses except for the initiation of the heatup. (It is conservatively assumed that there are 250 of these cycles in the crack growth calculation.).

APPENDIX B
PC-CRACK OUTPUT

WSES Corner Crack	B-2 – B-12
WSES 100 Percent Surface Crack	B-13 – B-23

pc-CRACK for Windows
Version 3.1-98348

Structural Integrity Associates, Inc.
3315 Almaden Expressway, Suite 24
San Jose, CA 95118-1557
Voice: 408-978-8200
Fax: 408-978-8964
E-mail: pccrack@structint.com

Linear Elastic Fracture Mechanics

Date: Fri Oct 27 14:21:13 2000
Input Data and Results File: CORNER.LFM

Title: WSES Corner Crack

Load Cases:

Case ID: 2235 Psig --- Stress Distribution

Depth	Stress
0.0000	26389.0000
0.2439	24638.0000
0.4877	22794.0000
0.7316	21200.0000
0.9754	20342.0000
1.2193	19610.0000
1.4632	18977.0000
1.7070	18408.0000
1.9509	17886.0000
2.1947	17458.0000
2.4386	17059.0000
2.6825	16725.0000
2.9263	16420.0000
3.1702	16215.0000
3.4140	15985.0000
3.6579	15800.0000
3.9017	15658.0000
4.1456	15552.0000
4.3895	15450.0000
4.6333	15479.0000
4.8772	15256.0000

Case ID: Heatup --- Stress Distribution

Depth	Stress
0.0000	-15213.0000
0.2439	-11775.0000
0.4877	-8498.4004
0.7316	-6577.5000
0.9754	-5040.7998
1.2193	-3672.8999
1.4632	-2449.8999
1.7070	-1353.9000

1.9509	-374.0000
2.1947	497.6200
2.4386	1271.5000
2.6825	1955.4000
2.9263	2549.1001
3.1702	3084.8999
3.4140	3507.8000
3.6579	3860.8999
3.9017	4142.7002
4.1456	4351.7998
4.3895	4481.3999
4.6333	4580.1001
4.8772	4502.7002

Case ID: Coodown --- Stress Distribution

Depth	Stress
0.0000	15491.0000
0.2439	11929.0000
0.4877	8526.0000
0.7316	6491.1001
0.9754	4951.3999
1.2193	3596.0000
1.4632	2387.0000
1.7070	1304.8000
1.9509	337.6400
2.1947	-522.6200
2.4386	-1286.5000
2.6825	-1961.9000
2.9263	-2548.8999
3.1702	-3076.8000
3.4140	-3498.0000
3.6579	-3850.8999
3.9017	-4132.8999
4.1456	-4342.7002
4.3895	-4473.0000
4.6333	-4569.7998
4.8772	-4495.2002

Case ID: Reactor Trip --- Stress Distribution

Depth	Stress
0.0000	13865.0000
0.2439	10408.0000
0.4877	7017.5000
0.7316	4789.1001
0.9754	3332.5000
1.2193	2131.7000
1.4632	1119.4000
1.7070	273.0100
1.9509	-426.2800
2.1947	-997.1900
2.4386	-1458.4000
2.6825	-1828.6000
2.9263	-2119.6001
3.1702	-2356.6001
3.4140	-2527.8999

3.6579	-2660.3000
3.9017	-2761.5000
4.1456	-2836.5000
4.3895	-2886.0000
4.6333	-2937.2000
4.8772	-2916.1001

Case ID: 2235 Crack Pressure --- Stress Distribution

Depth	Stress
0.0000	2235.0000
0.2000	2235.0000
0.6000	2235.0000
0.8000	2235.0000
1.0000	2235.0000
1.2000	2235.0000
1.4000	2235.0000
1.6000	2235.0000
1.6001	0.0000
1.8000	0.0000
2.0000	0.0000
2.2000	0.0000
2.4000	0.0000
2.6000	0.0000
2.8000	0.0000
3.0000	0.0000

Case ID	Stress Coefficients C0	C1	C2	C3	Type
2235 Psig	26105.5	-7243.42	1819.97	-163.548	StressDist
Heatup	-14409.7	11659.4	-2620.68	213.637	StressDist
Coodown	14630.4	-12074.7	2796.83	-234.506	StressDist
Reactor Trip	13140.7	-12813.4	3563.85	-334.304	StressDist
2235 Crack Pres	2018.21	2399.61	-2839.93	610.534	StressDist

Crack Model: Simulated 3-D Nozzle Corner Crack

WARNING: The stress intensity factor (K) is calculated at the deepest point only.
May be non-conservative in some cases.

Crack Parameters:
Max. crack size: 3.5000

	------------------Stress Intensity Factor------------------				
Crack Size	Case 2235 Psig	Case Heatup	Case Coodown	Case Reactor Tr	Case 2235 Crack
0.0700	8562.58	-4641.22	4709.71	4208.62	693.664
0.1400	11998.3	-6384.3	6474.94	5756.23	1013.03
0.2100	14562	-7604.01	7707.71	6816.44	1275.23
0.2800	16665	-8537.13	8648.78	7608.38	1507.11
0.3500	18468.5	-9278.59	9394.75	8220.58	1718.03
0.4200	20056.4	-9878.75	9996.9	8700.4	1912.24

0.4900	21479.1	-10368.6	10486.8	9077.14	2091.93
0.5600	22769.8	-10768.9	10885.6	9370.7	2258.34
0.6300	23952.1	-11094.6	11208.8	9595.46	2412.23
0.7000	25043.2	-11357.1	11467.7	9762.31	2554.08
0.7700	26056.4	-11565.2	11671.4	9879.8	2684.23
0.8400	27002	-11725.8	11827	9954.82	2802.93
0.9100	27888.5	-11844.7	11940.5	9993.02	2910.42
0.9800	28722.8	-11926.8	12016.8	9999.18	3006.89
1.0500	29510.6	-11976.1	12060	9977.33	3092.57
1.1200	30256.7	-11996.3	12073.9	9930.96	3167.69
1.1900	30965.5	-11990.2	12061.5	9863.1	3232.5
1.2600	31640.3	-11960.7	12025.5	9776.4	3287.27
1.3300	32284.4	-11910	11968.4	9673.21	3332.3
1.4000	32900.6	-11840.2	11892.3	9555.6	3367.93
1.4700	33491.2	-11753.4	11799.1	9425.46	3394.51
1.5400	34058.5	-11651	11690.6	9284.43	3412.44
1.6100	34604.3	-11534.7	11568.4	9134.02	3422.14
1.6800	35130.4	-11405.9	11433.7	8975.59	3424.06
1.7500	35638.4	-11265.7	11288	8810.35	3418.68
1.8200	36129.7	-11115.4	11132.4	8639.43	3406.51
1.8900	36605.5	-10956	10968	8463.81	3388.1
1.9600	37067	-10788.4	10795.6	8284.41	3364.01
2.0300	37515.3	-10613.6	10616.3	8102.05	3334.84
2.1000	37951.4	-10432.3	10430.9	7917.49	3301.21
2.1700	38376.1	-10245.3	10240	7731.39	3263.79
2.2400	38790.3	-10053.3	10044.4	7544.37	3223.24
2.3100	39194.7	-9856.88	9844.72	7356.98	3180.29
2.3800	39590	-9656.62	9641.54	7169.72	3135.64
2.4500	39976.8	-9453.07	9435.38	6983.02	3090.08
2.5200	40355.7	-9246.71	9226.73	6797.28	3044.37
2.5900	40727.1	-9037.99	9016.03	6612.85	2999.32
2.6600	41091.7	-8827.31	8803.68	6430.03	2955.76
2.7300	41449.9	-8615.05	8590.06	6249.09	2914.56
2.8000	41802	-8401.55	8375.5	6070.27	2876.58
2.8700	42148.4	-8187.13	8160.3	5893.73	2842.72
2.9400	42489.4	-7972.06	7944.72	5719.66	2813.91
3.0100	42825.5	-7756.59	7729.01	5548.16	2791.09
3.0800	43156.8	-7540.96	7513.39	5379.34	2775.23
3.1500	43483.6	-7325.36	7298.03	5213.25	2767.31
3.2200	43806.1	-7109.97	7083.11	5049.94	2768.34
3.2900	44124.5	-6894.95	6868.76	4889.41	2779.36
3.3600	44439.1	-6680.43	6655.09	4731.64	2801.4
3.4300	44749.9	-6466.53	6442.21	4576.59	2835.55
3.5000	45057.1	-6253.33	6230.19	4424.2	2882.88

Crack Growth Laws:

Law ID: LAS
Model: ASME Section XI - ferritic steel in water environment

da/dN = CL * SL * dK^5.95 for dK < dKtran
da/dN = CU * SU * dK^1.95 for dK >= dKtran
where
dK = Kmax - Kmin
R = Kmin / Kmax
for R <= 0.25:
SL = 1.0 SU = 1.0 dKtran = 17.74
for 0.25 < R <= 0.65:

SL = 26.9 * R - 5.725   SU = 3.75 * R + 0.06
dKtran = 17.74*{(3.75 * R + 0.06)/(26.9 * R - 5.725)}^0.25
for 0.65 < R:
SL = 11.76   SU = 2.5   dKtran = 12.04

where:
CL = 1.4408e-030
CU = 1.4267e-013
are for the selected units of:
force: lb
length: inch

Material Fracture Toughness KIc:

Material ID: LAS

Depth	KIc
0.0000	63245.0000
4.0000	63245.0000

Initial crack size= 0.4375
Max. crack size= 3.5000

Number of blocks= 250
Print increment of block= 5

Subblock	Cycles /Time	Calc. incre.	Print incre.	Crk. Grw. Law	Mat. K1c
HUCD+Trip	2	1	5	LAS	LAS
Normal and Trip	2	1	5	LAS	LAS
Leak Test	1	1	5	LAS	LAS
Variations	4000	40	4000	LAS	LAS

Subblock	Kmax Case ID	Kmax Scale Factor	Kmin Case ID	Kmin Scale Factor
HUCD+Trip	2235 Psig	1.2477	2235 Psig	0.0000
	Reactor Trip	1.1000	Heatup	1.1000
	2235 Crack Pressure	1.2477		
Normal and Trip	2235 Psig	1.1000	2235 Psig	0.8293
	2235 Crack Pressure	1.1000	2235 Crack Pressure	0.8293
Leak Test	2235 Psig	1.1000	2235 Psig	0.0000
	2235 Crack Pressure	1.1000	Heatup	0.5500
Variations	2235 Psig	1.1492	2235 Psig	1.0508
	2235 Crack Pressure	1.1492	2235 Crack Pressure	1.0508

Crack growth results:

Total Cycles /Time	Subblock Cycles /Time	Kmax	Kmin	DeltaK	R	DaDn /DaDt	Da	a	a/thk

Block: 5

16022	2	3.77e+004	-1.10e+004	4.87e+004	-0.29	1.97e-004	1.97e-004	0.4398	0.00
16024	2	2.47e+004	1.86e+004	6.07e+003	0.75	5.48e-007	5.48e-007	0.4398	0.00
16025	1	2.47e+004	-5.51e+003	3.02e+004	-0.22	7.74e-005	7.74e-005	0.4399	0.00
20025	4000	2.58e+004	2.36e+004	2.21e+003	0.91	1.33e-009	5.32e-008	0.4399	0.00

Block: 10

36047	2	3.77e+004	-1.10e+004	4.88e+004	-0.29	1.97e-004	1.97e-004	0.4422	0.00
36049	2	2.47e+004	1.86e+004	6.08e+003	0.75	5.56e-007	5.56e-007	0.4422	0.00
36050	1	2.47e+004	-5.52e+003	3.02e+004	-0.22	7.77e-005	7.77e-005	0.4423	0.00
40050	4000	2.58e+004	2.36e+004	2.21e+003	0.91	1.35e-009	5.40e-008	0.4423	0.00

Block: 15

56072	2	3.78e+004	-1.11e+004	4.89e+004	-0.29	1.98e-004	1.98e-004	0.4446	0.00
56074	2	2.48e+004	1.87e+004	6.10e+003	0.75	5.64e-007	5.64e-007	0.4446	0.00
56075	1	2.48e+004	-5.53e+003	3.03e+004	-0.22	7.81e-005	7.81e-005	0.4447	0.00
60075	4000	2.59e+004	2.37e+004	2.22e+003	0.91	1.37e-009	5.48e-008	0.4447	0.00

Block: 20

76097	2	3.79e+004	-1.11e+004	4.90e+004	-0.29	1.99e-004	1.99e-004	0.447	0.00
76099	2	2.48e+004	1.87e+004	6.11e+003	0.75	5.73e-007	5.73e-007	0.447	0.00
76100	1	2.48e+004	-5.54e+003	3.04e+004	-0.22	7.84e-005	7.84e-005	0.4471	0.00
80100	4000	2.60e+004	2.37e+004	2.22e+003	0.91	1.39e-009	5.56e-008	0.4471	0.00

Block: 25

96122	2	3.80e+004	-1.11e+004	4.91e+004	-0.29	2.00e-004	2.00e-004	0.4494	0.00
96124	2	2.49e+004	1.88e+004	6.13e+003	0.75	5.81e-007	5.81e-007	0.4494	0.00
96125	1	2.49e+004	-5.55e+003	3.05e+004	-0.22	7.88e-005	7.88e-005	0.4495	0.00
100125	4000	2.60e+004	2.38e+004	2.23e+003	0.91	1.41e-009	5.64e-008	0.4495	0.00

Block: 30

116147	2	3.81e+004	-1.11e+004	4.92e+004	-0.29	2.01e-004	2.01e-004	0.4519	0.00
116149	2	2.50e+004	1.88e+004	6.14e+003	0.75	5.90e-007	5.90e-007	0.4519	0.00
116150	1	2.50e+004	-5.56e+003	3.05e+004	-0.22	7.91e-005	7.91e-005	0.4519	0.00
120150	4000	2.61e+004	2.39e+004	2.23e+003	0.91	1.43e-009	5.72e-008	0.4519	0.00

Block: 35

136172	2	3.82e+004	-1.11e+004	4.93e+004	-0.29	2.01e-004	2.01e-004	0.4543	0.00
136174	2	2.50e+004	1.89e+004	6.16e+003	0.75	5.98e-007	5.98e-007	0.4543	0.00
136175	1	2.50e+004	-5.57e+003	3.06e+004	-0.22	7.95e-005	7.95e-005	0.4544	0.00
140175	4000	2.62e+004	2.39e+004	2.24e+003	0.91	1.45e-009	5.81e-008	0.4544	0.00

Block: 40

156197	2	3.82e+004	-1.11e+004	4.94e+004	-0.29	2.02e-004	2.02e-004	0.4568	0.00
156199	2	2.51e+004	1.89e+004	6.17e+003	0.75	6.07e-007	6.07e-007	0.4568	0.00
156200	1	2.51e+004	-5.57e+003	3.07e+004	-0.22	7.98e-005	7.98e-005	0.4568	0.00
160200	4000	2.62e+004	2.40e+004	2.24e+003	0.91	1.47e-009	5.89e-008	0.4568	0.00

Block: 45

176222	2	3.83e+004	-1.12e+004	4.95e+004	-0.29	2.03e-004	2.03e-004	0.4592	0.00
176224	2	2.52e+004	1.90e+004	6.19e+003	0.75	6.16e-007	6.16e-007	0.4592	0.00
176225	1	2.52e+004	-5.58e+003	3.07e+004	-0.22	8.02e-005	8.02e-005	0.4593	0.00
180225	4000	2.63e+004	2.40e+004	2.25e+003	0.91	1.49e-009	5.98e-008	0.4593	0.00

Block: 50

196247	2	3.84e+004	-1.12e+004	4.96e+004	-0.29	2.04e-004	2.04e-004	0.4617	0.00
196249	2	2.52e+004	1.90e+004	6.21e+003	0.75	6.25e-007	6.25e-007	0.4617	0.00
196250	1	2.52e+004	-5.59e+003	3.08e+004	-0.22	8.06e-005	8.06e-005	0.4618	0.00

200250 4000 2.63e+004 2.41e+004 2.26e+003 0.91 1.52e-009 6.07e-008 0.4618 0.00

Block: 55

216272 2 3.85e+004 -1.12e+004 4.97e+004 -0.29 2.05e-004 2.05e-004 0.4642 0.00
216274 2 2.53e+004 1.91e+004 6.22e+003 0.75 6.34e-007 6.34e-007 0.4642 0.00
216275 1 2.53e+004 -5.60e+003 3.09e+004 -0.22 8.09e-005 8.09e-005 0.4643 0.00
220275 4000 2.64e+004 2.41e+004 2.26e+003 0.91 1.54e-009 6.16e-008 0.4643 0.00

Block: 60

236297 2 3.86e+004 -1.12e+004 4.98e+004 -0.29 2.06e-004 2.06e-004 0.4667 0.00
236299 2 2.53e+004 1.91e+004 6.24e+003 0.75 6.44e-007 6.44e-007 0.4667 0.00
236300 1 2.53e+004 -5.61e+003 3.10e+004 -0.22 8.13e-005 8.13e-005 0.4667 0.00
240300 4000 2.65e+004 2.42e+004 2.27e+003 0.91 1.56e-009 6.25e-008 0.4668 0.00

Block: 65

256322 2 3.87e+004 -1.12e+004 4.99e+004 -0.29 2.06e-004 2.06e-004 0.4692 0.00
256324 2 2.54e+004 1.92e+004 6.25e+003 0.75 6.54e-007 6.54e-007 0.4692 0.00
256325 1 2.54e+004 -5.62e+003 3.10e+004 -0.22 8.17e-005 8.17e-005 0.4693 0.00
260325 4000 2.65e+004 2.43e+004 2.27e+003 0.91 1.59e-009 6.34e-008 0.4693 0.00

Block: 70

276347 2 3.88e+004 -1.13e+004 5.00e+004 -0.29 2.07e-004 2.07e-004 0.4717 0.00
276349 2 2.55e+004 1.92e+004 6.27e+003 0.75 6.63e-007 6.63e-007 0.4717 0.00
276350 1 2.55e+004 -5.63e+003 3.11e+004 -0.22 8.21e-005 8.21e-005 0.4718 0.00
280350 4000 2.66e+004 2.43e+004 2.28e+003 0.91 1.61e-009 6.44e-008 0.4718 0.00

Block: 75

296372 2 3.88e+004 -1.13e+004 5.01e+004 -0.29 2.08e-004 2.08e-004 0.4742 0.00
296374 2 2.55e+004 1.92e+004 6.28e+003 0.75 6.73e-007 6.73e-007 0.4742 0.00
296375 1 2.55e+004 -5.64e+003 3.12e+004 -0.22 8.24e-005 8.24e-005 0.4743 0.00
300375 4000 2.67e+004 2.44e+004 2.28e+003 0.91 1.63e-009 6.53e-008 0.4743 0.00

Block: 80

316397 2 3.89e+004 -1.13e+004 5.02e+004 -0.29 2.09e-004 2.09e-004 0.4767 0.00
316399 2 2.56e+004 1.93e+004 6.30e+003 0.75 6.83e-007 6.83e-007 0.4767 0.00
316400 1 2.56e+004 -5.65e+003 3.12e+004 -0.22 8.28e-005 8.28e-005 0.4768 0.00
320400 4000 2.67e+004 2.45e+004 2.29e+003 0.91 1.66e-009 6.63e-008 0.4768 0.00

Block: 85

336422 2 3.90e+004 -1.13e+004 5.03e+004 -0.29 2.10e-004 2.10e-004 0.4793 0.00
336424 2 2.57e+004 1.93e+004 6.31e+003 0.75 6.93e-007 6.93e-007 0.4793 0.00
336425 1 2.57e+004 -5.66e+003 3.13e+004 -0.22 8.32e-005 8.32e-005 0.4794 0.00
340425 4000 2.68e+004 2.45e+004 2.30e+003 0.91 1.68e-009 6.73e-008 0.4794 0.00

Block: 90

356447 2 3.91e+004 -1.13e+004 5.04e+004 -0.29 2.11e-004 2.11e-004 0.4818 0.00
356449 2 2.57e+004 1.94e+004 6.33e+003 0.75 7.04e-007 7.04e-007 0.4819 0.00
356450 1 2.57e+004 -5.67e+003 3.14e+004 -0.22 8.36e-005 8.36e-005 0.4819 0.00
360450 4000 2.69e+004 2.46e+004 2.30e+003 0.91 1.71e-009 6.83e-008 0.4819 0.00

Block: 95

376472 2 3.92e+004 -1.14e+004 5.06e+004 -0.29 2.12e-004 2.12e-004 0.4844 0.00
376474 2 2.58e+004 1.94e+004 6.35e+003 0.75 7.15e-007 7.15e-007 0.4844 0.00
376475 1 2.58e+004 -5.68e+003 3.15e+004 -0.22 8.40e-005 8.40e-005 0.4845 0.00
380475 4000 2.69e+004 2.46e+004 2.31e+003 0.91 1.73e-009 6.93e-008 0.4845 0.00

Block: 100

396497 2 3.93e+004 -1.14e+004 5.07e+004 -0.29 2.13e-004 2.13e-004 0.487 0.00
396499 2 2.59e+004 1.95e+004 6.36e+003 0.75 7.25e-007 7.25e-007 0.487 0.00

396500	1	2.59e+004	-5.69e+003	3.15e+004	-0.22	8.44e-005	8.44e-005	0.4871	0.00
400500	4000	2.70e+004	2.47e+004	2.31e+003	0.91	1.76e-009	7.04e-008	0.4871	0.00
Block: 105									
416522	2	3.94e+004	-1.14e+004	5.08e+004	-0.29	2.13e-004	2.13e-004	0.4896	0.00
416524	2	2.59e+004	1.95e+004	6.38e+003	0.75	7.36e-007	7.36e-007	0.4896	0.00
416525	1	2.59e+004	-5.70e+003	3.16e+004	-0.22	8.47e-005	8.47e-005	0.4897	0.00
420525	4000	2.71e+004	2.48e+004	2.32e+003	0.91	1.79e-009	7.14e-008	0.4897	0.00
Block: 110									
436547	2	3.95e+004	-1.14e+004	5.09e+004	-0.29	2.14e-004	2.14e-004	0.4922	0.00
436549	2	2.60e+004	1.96e+004	6.39e+003	0.75	7.47e-007	7.47e-007	0.4922	0.00
436550	1	2.60e+004	-5.71e+003	3.17e+004	-0.22	8.51e-005	8.51e-005	0.4923	0.00
440550	4000	2.71e+004	2.48e+004	2.32e+003	0.91	1.81e-009	7.24e-008	0.4923	0.00
Block: 115									
456572	2	3.95e+004	-1.14e+004	5.10e+004	-0.29	2.15e-004	2.15e-004	0.4948	0.00
456574	2	2.60e+004	1.96e+004	6.41e+003	0.75	7.57e-007	7.57e-007	0.4948	0.00
456575	1	2.60e+004	-5.72e+003	3.18e+004	-0.22	8.55e-005	8.55e-005	0.4949	0.00
460575	4000	2.72e+004	2.49e+004	2.33e+003	0.91	1.84e-009	7.34e-008	0.4949	0.00
Block: 120									
476597	2	3.96e+004	-1.15e+004	5.11e+004	-0.29	2.16e-004	2.16e-004	0.4974	0.00
476599	2	2.61e+004	1.97e+004	6.42e+003	0.75	7.67e-007	7.67e-007	0.4974	0.00
476600	1	2.61e+004	-5.73e+003	3.18e+004	-0.22	8.58e-005	8.58e-005	0.4975	0.00
480600	4000	2.73e+004	2.49e+004	2.33e+003	0.91	1.86e-009	7.44e-008	0.4975	0.00
Block: 125									
496622	2	3.97e+004	-1.15e+004	5.12e+004	-0.29	2.17e-004	2.17e-004	0.5001	0.00
496624	2	2.62e+004	1.97e+004	6.44e+003	0.75	7.78e-007	7.78e-007	0.5001	0.00
496625	1	2.62e+004	-5.73e+003	3.19e+004	-0.22	8.62e-005	8.62e-005	0.5001	0.00
500625	4000	2.73e+004	2.50e+004	2.34e+003	0.91	1.89e-009	7.55e-008	0.5002	0.00
Block: 130									
516647	2	3.98e+004	-1.15e+004	5.13e+004	-0.29	2.17e-004	2.17e-004	0.5027	0.00
516649	2	2.62e+004	1.98e+004	6.45e+003	0.75	7.89e-007	7.89e-007	0.5027	0.00
516650	1	2.62e+004	-5.74e+003	3.20e+004	-0.22	8.65e-005	8.65e-005	0.5028	0.00
520650	4000	2.74e+004	2.50e+004	2.35e+003	0.91	1.91e-009	7.65e-008	0.5028	0.00
Block: 135									
536672	2	3.99e+004	-1.15e+004	5.14e+004	-0.29	2.18e-004	2.18e-004	0.5053	0.00
536674	2	2.63e+004	1.98e+004	6.47e+003	0.75	8.00e-007	8.00e-007	0.5053	0.00
536675	1	2.63e+004	-5.75e+003	3.20e+004	-0.22	8.69e-005	8.69e-005	0.5054	0.00
540675	4000	2.75e+004	2.51e+004	2.35e+003	0.91	1.94e-009	7.76e-008	0.5054	0.00
Block: 140									
556697	2	3.99e+004	-1.15e+004	5.15e+004	-0.29	2.19e-004	2.19e-004	0.508	0.00
556699	2	2.63e+004	1.99e+004	6.48e+003	0.75	8.11e-007	8.11e-007	0.508	0.00
556700	1	2.63e+004	-5.76e+003	3.21e+004	-0.22	8.73e-005	8.73e-005	0.5081	0.00
560700	4000	2.75e+004	2.52e+004	2.36e+003	0.91	1.97e-009	7.87e-008	0.5081	0.00
Block: 145									
576722	2	4.00e+004	-1.15e+004	5.16e+004	-0.29	2.20e-004	2.20e-004	0.5107	0.00
576724	2	2.64e+004	1.99e+004	6.50e+003	0.75	8.22e-007	8.22e-007	0.5107	0.00
576725	1	2.64e+004	-5.77e+003	3.22e+004	-0.22	8.76e-005	8.76e-005	0.5108	0.00
580725	4000	2.76e+004	2.52e+004	2.36e+003	0.91	1.99e-009	7.98e-008	0.5108	0.00
Block: 150									
596747	2	4.01e+004	-1.16e+004	5.17e+004	-0.29	2.21e-004	2.21e-004	0.5134	0.00

596749	2	2.65e+004	2.00e+004	6.51e+003	0.75	8.33e-007	8.33e-007	0.5134	0.00
596750	1	2.65e+004	-5.78e+003	3.22e+004	-0.22	8.80e-005	8.80e-005	0.5134	0.00
600750	4000	2.76e+004	2.53e+004	2.37e+003	0.91	2.02e-009	8.09e-008	0.5135	0.00

Block: 155

616772	2	4.02e+004	-1.16e+004	5.18e+004	-0.29	2.22e-004	2.22e-004	0.516	0.00
616774	2	2.65e+004	2.00e+004	6.53e+003	0.75	8.45e-007	8.45e-007	0.516	0.00
616775	1	2.65e+004	-5.78e+003	3.23e+004	-0.22	8.84e-005	8.84e-005	0.5161	0.00
620775	4000	2.77e+004	2.53e+004	2.37e+003	0.91	2.05e-009	8.20e-008	0.5161	0.00

Block: 160

636797	2	4.03e+004	-1.16e+004	5.19e+004	-0.29	2.22e-004	2.22e-004	0.5187	0.00
636799	2	2.66e+004	2.00e+004	6.54e+003	0.75	8.57e-007	8.57e-007	0.5187	0.00
636800	1	2.66e+004	-5.79e+003	3.24e+004	-0.22	8.88e-005	8.88e-005	0.5188	0.00
640800	4000	2.78e+004	2.54e+004	2.38e+003	0.91	2.08e-009	8.31e-008	0.5188	0.00

Block: 165

656822	2	4.03e+004	-1.16e+004	5.20e+004	-0.29	2.23e-004	2.23e-004	0.5215	0.00
656824	2	2.66e+004	2.01e+004	6.56e+003	0.75	8.69e-007	8.69e-007	0.5215	0.00
656825	1	2.66e+004	-5.80e+003	3.25e+004	-0.22	8.91e-005	8.91e-005	0.5216	0.00
660825	4000	2.78e+004	2.55e+004	2.38e+003	0.91	2.11e-009	8.43e-008	0.5216	0.00

Block: 170

676847	2	4.04e+004	-1.16e+004	5.21e+004	-0.29	2.24e-004	2.24e-004	0.5242	0.00
676849	2	2.67e+004	2.01e+004	6.57e+003	0.75	8.81e-007	8.81e-007	0.5242	0.00
676850	1	2.67e+004	-5.81e+003	3.25e+004	-0.22	8.95e-005	8.95e-005	0.5243	0.00
680850	4000	2.79e+004	2.55e+004	2.39e+003	0.91	2.14e-009	8.55e-008	0.5243	0.00

Block: 175

696872	2	4.05e+004	-1.16e+004	5.22e+004	-0.29	2.25e-004	2.25e-004	0.5269	0.00
696874	2	2.68e+004	2.02e+004	6.59e+003	0.75	8.93e-007	8.93e-007	0.5269	0.00
696875	1	2.68e+004	-5.82e+003	3.26e+004	-0.22	8.99e-005	8.99e-005	0.527	0.00
700875	4000	2.80e+004	2.56e+004	2.39e+003	0.91	2.17e-009	8.67e-008	0.527	0.00

Block: 180

716897	2	4.06e+004	-1.17e+004	5.23e+004	-0.29	2.26e-004	2.26e-004	0.5297	0.00
716899	2	2.68e+004	2.02e+004	6.60e+003	0.75	9.06e-007	9.06e-007	0.5297	0.00
716900	1	2.68e+004	-5.83e+003	3.27e+004	-0.22	9.03e-005	9.03e-005	0.5297	0.00
720900	4000	2.80e+004	2.56e+004	2.40e+003	0.91	2.20e-009	8.79e-008	0.5298	0.00

Block: 185

736922	2	4.07e+004	-1.17e+004	5.24e+004	-0.29	2.27e-004	2.27e-004	0.5324	0.00
736924	2	2.69e+004	2.03e+004	6.62e+003	0.75	9.18e-007	9.18e-007	0.5324	0.00
736925	1	2.69e+004	-5.84e+003	3.27e+004	-0.22	9.07e-005	9.07e-005	0.5325	0.00
740925	4000	2.81e+004	2.57e+004	2.41e+003	0.91	2.23e-009	8.91e-008	0.5325	0.00

Block: 190

756947	2	4.08e+004	-1.17e+004	5.25e+004	-0.29	2.27e-004	2.27e-004	0.5352	0.00
756949	2	2.70e+004	2.03e+004	6.64e+003	0.75	9.31e-007	9.31e-007	0.5352	0.00
756950	1	2.70e+004	-5.84e+003	3.28e+004	-0.22	9.11e-005	9.11e-005	0.5353	0.00
760950	4000	2.82e+004	2.58e+004	2.41e+003	0.91	2.26e-009	9.04e-008	0.5353	0.00

Block: 195

776972	2	4.09e+004	-1.17e+004	5.26e+004	-0.29	2.28e-004	2.28e-004	0.538	0.00
776974	2	2.70e+004	2.04e+004	6.65e+003	0.75	9.45e-007	9.45e-007	0.538	0.00
776975	1	2.70e+004	-5.85e+003	3.29e+004	-0.22	9.15e-005	9.15e-005	0.5381	0.00
780975	4000	2.82e+004	2.58e+004	2.42e+003	0.91	2.29e-009	9.17e-008	0.5381	0.00

Block: 200

796997	2	4.09e+004	-1.17e+004	5.27e+004	-0.29	2.29e-004	2.29e-004	0.5408	0.00
796999	2	2.71e+004	2.04e+004	6.67e+003	0.75	9.58e-007	9.58e-007	0.5408	0.00
797000	1	2.71e+004	-5.86e+003	3.30e+004	-0.22	9.19e-005	9.19e-005	0.5409	0.00
801000	4000	2.83e+004	2.59e+004	2.42e+003	0.91	2.32e-009	9.30e-008	0.5409	0.00

Block: 205

817022	2	4.10e+004	-1.17e+004	5.28e+004	-0.29	2.30e-004	2.30e-004	0.5436	0.00
817024	2	2.72e+004	2.05e+004	6.68e+003	0.75	9.72e-007	9.72e-007	0.5436	0.00
817025	1	2.72e+004	-5.87e+003	3.30e+004	-0.22	9.23e-005	9.23e-005	0.5437	0.00
821025	4000	2.84e+004	2.59e+004	2.43e+003	0.91	2.36e-009	9.43e-008	0.5437	0.00

Block: 210

837047	2	4.11e+004	-1.18e+004	5.29e+004	-0.29	2.31e-004	2.31e-004	0.5465	0.00
837049	2	2.72e+004	2.05e+004	6.70e+003	0.75	9.86e-007	9.86e-007	0.5465	0.00
837050	1	2.72e+004	-5.88e+003	3.31e+004	-0.22	9.27e-005	9.27e-005	0.5466	0.00
841050	4000	2.84e+004	2.60e+004	2.44e+003	0.91	2.39e-009	9.57e-008	0.5466	0.00

Block: 215

857072	2	4.12e+004	-1.18e+004	5.30e+004	-0.29	2.32e-004	2.32e-004	0.5493	0.00
857074	2	2.73e+004	2.06e+004	6.72e+003	0.75	1.00e-006	1.00e-006	0.5493	0.00
857075	1	2.73e+004	-5.89e+003	3.32e+004	-0.22	9.31e-005	9.31e-005	0.5494	0.00
861075	4000	2.85e+004	2.61e+004	2.44e+003	0.91	2.43e-009	9.70e-008	0.5494	0.00

Block: 220

877097	2	4.13e+004	-1.18e+004	5.31e+004	-0.29	2.33e-004	2.33e-004	0.5522	0.00
877099	2	2.74e+004	2.06e+004	6.73e+003	0.75	1.01e-006	1.01e-006	0.5522	0.00
877100	1	2.74e+004	-5.90e+003	3.33e+004	-0.22	9.35e-005	9.35e-005	0.5523	0.00
881100	4000	2.86e+004	2.61e+004	2.45e+003	0.91	2.46e-009	9.84e-008	0.5523	0.00

Block: 225

897122	2	4.14e+004	-1.18e+004	5.32e+004	-0.29	2.34e-004	2.34e-004	0.5551	0.00
897124	2	2.74e+004	2.07e+004	6.75e+003	0.75	1.03e-006	1.03e-006	0.5551	0.00
897125	1	2.74e+004	-5.91e+003	3.33e+004	-0.22	9.39e-005	9.39e-005	0.5551	0.00
901125	4000	2.86e+004	2.62e+004	2.45e+003	0.91	2.50e-009	9.99e-008	0.5552	0.00

Block: 230

917147	2	4.15e+004	-1.18e+004	5.33e+004	-0.29	2.35e-004	2.35e-004	0.5579	0.00
917149	2	2.75e+004	2.07e+004	6.76e+003	0.75	1.04e-006	1.04e-006	0.5579	0.00
917150	1	2.75e+004	-5.92e+003	3.34e+004	-0.22	9.43e-005	9.43e-005	0.558	0.00
921150	4000	2.87e+004	2.63e+004	2.46e+003	0.91	2.53e-009	1.01e-007	0.558	0.00

Block: 235

937172	2	4.16e+004	-1.18e+004	5.34e+004	-0.29	2.35e-004	2.35e-004	0.5608	0.00
937174	2	2.75e+004	2.08e+004	6.78e+003	0.75	1.06e-006	1.06e-006	0.5608	0.00
937175	1	2.75e+004	-5.92e+003	3.35e+004	-0.22	9.47e-005	9.47e-005	0.5609	0.00
941175	4000	2.88e+004	2.63e+004	2.46e+003	0.91	2.57e-009	1.03e-007	0.5609	0.00

Block: 240

957197	2	4.16e+004	-1.19e+004	5.35e+004	-0.28	2.36e-004	2.36e-004	0.5637	0.00
957199	2	2.76e+004	2.08e+004	6.79e+003	0.75	1.07e-006	1.07e-006	0.5637	0.00
957200	1	2.76e+004	-5.93e+003	3.35e+004	-0.21	9.51e-005	9.51e-005	0.5638	0.00
961200	4000	2.88e+004	2.64e+004	2.47e+003	0.91	2.60e-009	1.04e-007	0.5638	0.00

Block: 245

977222	2	4.17e+004	-1.19e+004	5.36e+004	-0.28	2.37e-004	2.37e-004	0.5666	0.00
977224	2	2.77e+004	2.09e+004	6.81e+003	0.75	1.09e-006	1.09e-006	0.5666	0.00
977225	1	2.77e+004	-5.94e+003	3.36e+004	-0.21	9.55e-005	9.55e-005	0.5667	0.00
981225	4000	2.89e+004	2.64e+004	2.48e+003	0.91	2.64e-009	1.05e-007	0.5668	0.00

Block: 250

997247	2	4.18e+004	-1.19e+004	5.37e+004	-0.28	2.38e-004	2.38e-004	0.5696	0.00
997249	2	2.77e+004	2.09e+004	6.82e+003	0.75	1.10e-006	1.10e-006	0.5696	0.00
997250	1	2.77e+004	-5.95e+003	3.37e+004	-0.21	9.59e-005	9.59e-005	0.5697	0.00
1001250	.4000	2.90e+004	2.65e+004	2.48e+003	0.91	2.67e-009	1.07e-007	0.5697	0.00

End of pc-CRACK Output

tm

pc-CRACK for Windows
Version 3.1-98348

Structural Integrity Associates, Inc.
3315 Almaden Expressway, Suite 24
San Jose, CA 95118-1557
Voice: 408-978-8200
Fax: 408-978-8964
E-mail: pccrack@structint.com

Linear Elastic Fracture Mechanics

Date: Fri Oct 27 14:56:36 2000
Input Data and Results File: LONG.LFM

Title: WSES 100 percent Surface Crack

Load Cases:

Case ID: 2235 Psig --- Stress Distribution

Depth	Stress
0.0000	22872.0000
0.2356	21611.0000
0.4712	20249.0000
0.7068	19006.0000
0.9424	18501.0000
1.1780	18102.0000
1.4136	17736.0000
1.6492	17397.0000
1.8848	17086.0000
2.1204	16811.0000
2.3560	16538.0000
2.5916	16335.0000
2.8272	16137.0000
3.0628	15978.0000
3.2984	15792.0000
3.5340	15656.0000
3.7696	15562.0000
4.0052	15478.0000
4.2408	15399.0000
4.4764	15464.0000
4.7120	15256.0000

Case ID: Heatup --- Stress Distribution

Depth	Stress
0.0000	-14736.0000
0.2356	-11079.0000
0.4712	-7709.0000
0.7068	-5991.7002
0.9424	-4634.6001
1.1780	-3404.8000
1.4136	-2278.7000

1.6492	-1251.9000
1.8848	-320.3700
2.1204	520.4200
2.3560	1274.3000
2.5916	1944.3000
2.8272	2529.6001
3.0628	3061.6001
3.2984	3479.6001
3.5340	3833.5000
3.7696	4118.2002
4.0052	4328.7998
4.2408	4463.2998
4.4764	4574.2002
4.7120	4502.7002

Case ID: Coodown — Stress Distribution

Depth	Stress
0.0000	15020.0000
0.2356	11245.0000
0.4712	7718.0000
0.7068	5895.1001
0.9424	4543.2998
1.1780	3329.2000
1.4136	2218.1001
1.6492	1205.1000
1.8848	286.1400
2.1204	-543.6100
2.3560	-1287.7000
2.5916	-1949.6000
2.8272	-2528.3999
3.0628	-3052.3000
3.2984	-3468.8000
3.5340	-3822.6001
3.7696	-4108.1001
4.0052	-4319.6001
4.2408	-4454.8999
4.4764	-4563.6001
4.7120	-4495.2002

Case ID: Reactor Trip — Stress Distribution

Depth	Stress
0.0000	13529.0000
0.2356	9909.4004
0.4712	6341.5000
0.7068	4318.8999
0.9424	3025.8999
1.1780	1940.4000
1.4136	1004.8000
1.6492	210.0800
1.8848	-455.8800
2.1204	-1007.1000
2.3560	-1456.4000
2.5916	-1818.7000
2.8272	-2106.1001
3.0628	-2341.0000

3.2984	-2510.8999
3.5340	-2644.8000
3.7696	-2748.7000
4.0052	-2824.8000
4.2408	-2876.8999
4.4764	-2934.1001
4.7120	-2916.1001

Case ID: 2235 Crack Pressure --- Stress Distribution

Depth	Stress
0.0000	2235.0000
0.2000	2235.0000
0.6000	2235.0000
0.8000	2235.0000
1.0000	2235.0000
1.2000	2235.0000
1.4000	2235.0000
1.6000	2235.0000
1.6001	0.0000
1.8000	0.0000
2.0000	0.0000
2.2000	0.0000
2.4000	0.0000
2.6000	0.0000
2.8000	0.0000
3.0000	0.0000

Case ID	Stress Coefficients C0	C1	C2	C3	Type
2235 Psig	22583.8	-5253.75	1447.81	-142.193	StressDist
Heatup	-13689.3	11671.3	-2772.62	240.928	StressDist
Coodown	13911.6	-12107.7	2965.32	-264.652	StressDist
Reactor Trip	12593.1	-12961.7	3792.8	-374.081	StressDist
2235 Crack Pres	2018.21	2399.61	-2839.93	610.534	StressDist

Crack Model: Circumferential Crack in Cylinder (t/R=0.1)

Crack Parameters:
Wall thickness: 4.3125
Max. crack size: 3.4500

	-----------------Stress Intensity Factor-----------------				
Crack Size	Case 2235 Psig	Case Heatup	Case Coodown	Case Reactor Tr	Case 2235 Crack
0.0690	11554.9	-6829.18	6935.08	6237.28	1089.14
0.1380	16265.9	-9368.95	9507.39	8494.7	1605.07
0.2070	19833.4	-11127.8	11284	10014.9	2035.59
0.2760	22804.3	-12456.8	12622.5	11127	2420.46
0.3450	25392.1	-13497.1	13666.7	11964.6	2773.02
0.4140	27706.9	-14323.7	14493.1	12599.3	3099.04
0.4830	29979.6	-15067.4	15234.4	13149.7	3420.2

0.5520	32167.2	-15709.4	15871.9	13601.3	3729.14
0.6210	34245.7	-16242.6	16398.5	13949.5	4020.65
0.6900	36234.6	-16681.4	16829.1	14208.8	4294.87
0.7590	38148.9	-17037.3	17175.4	14390.8	4551.83
0.8280	40000	-17319.2	17446.5	14504.3	4791.5
0.8970	41913.2	-17587.6	17703.7	14602.6	5026.73
0.9660	43907.3	-17849.8	17954.4	14692.2	5258.46
1.0350	45875.1	-18057.8	18150.2	14732.8	5473.82
1.1040	47820.6	-18215.1	18294.8	14728.4	5672.49
1.1730	49747.5	-18325.1	18391.5	14682.6	5854.24
1.2420	51658.7	-18390.4	18443.3	14598.4	6018.91
1.3110	53684	-18479.4	18519.4	14537.6	6178.4
1.3800	56095.6	-18731.3	18761.2	14625.2	6357.64
1.4490	58522.1	-18954.1	18973.7	14689.9	6521.18
1.5180	60964.5	-19148.8	19158.5	14733.6	6669.04
1.5870	63423.3	-19316.9	19316.7	14757.8	6801.37
1.6560	65899.2	-19459.4	19449.7	14764.2	6918.43
1.7250	68392.8	-19577.4	19558.6	14754.3	7020.64
1.7940	71058.5	-19727.1	19699.4	14770.3	7135.06
1.8630	73746.9	-19852.4	19816.1	14769.6	7237.65
1.9320	76457.9	-19953.9	19909.4	14753.4	7329.25
2.0010	79191.7	-20032.2	19979.8	14722.4	7410.82
2.0700	81948.4	-20087.8	20028.1	14677.7	7483.46
2.1390	84728.1	-20121.5	20054.9	14619.9	7548.42
2.2080	87699.9	-20143.9	20069.4	14543.7	7633.34
2.2770	90754.3	-20142.2	20059.6	14446.9	7723.05
2.3460	93835.1	-20112.2	20021.8	14331.1	7810.68
2.4150	96942	-20054.2	19956.4	14196.8	7898.15
2.4840	100075	-19968.5	19863.6	14044.3	7987.56
2.5530	103233	-19855.3	19743.6	13874.2	8081.21
2.6220	106609	-19878.2	19764.5	13853.1	8174.24
2.6910	110214	-20050	19939.7	13995.5	8267.22
2.7600	113857	-20212.1	20106.2	14139.9	8369.65
2.8290	117538	-20364.9	20264.3	14286.9	8484.58
2.8980	121258	-20508.8	20414.3	14436.7	8615.32
2.9670	125016	-20644	20556.7	14589.8	8765.38
3.0360	128852	-20664	20581.6	14633.1	8938.94
3.1050	132847	-20337	20250.5	14323.8	9136.75
3.1740	136874	-19973	19882.8	13992.4	9359.18
3.2430	140935	-19572.4	19479.1	13639.1	9610.65
3.3120	145028	-19135.6	19039.6	13264.6	9895.86
3.3810	149152	-18662.8	18564.6	12869	10219.8
3.4500	153308	-18154.4	18054.4	12452.6	10587.9

Crack Growth Laws:

Law ID: LAS
Model: ASME Section XI - ferritic steel in water environment

da/dN = CL * SL * dK^5.95 for dK < dKtran
da/dN = CU * SU * dK^1.95 for dK >= dKtran
where
dK = Kmax - Kmin
R = Kmin / Kmax
for R <= 0.25:
SL = 1.0 SU = 1.0 dKtran = 17.74
for 0.25 < R <= 0.65:
SL = 26.9 * R - 5.725 SU = 3.75 * R + 0.06

dKtran = 17.74*{(3.75 * R + 0.06)/(26.9 * R - 5.725)}^0.25
for 0.65 < R:
SL = 11.76 SU = 2.5 dKtran = 12.04

where:
CL = 1.4408e-030
CU = 1.4267e-013
are for the selected units of:
force: lb
length: inch

Material Fracture Toughness KIc:

Material ID: LAS

Depth	KIc
0.0000	63245.0000
4.0000	63245.0000

Initial crack size= 0.4375
Max. crack size= 3.4500

Number of blocks= 250
Print increment of block= 5

Subblock	Cycles /Time	Calc. incre.	Print incre.	Crk. Grw. Law	Mat. K1c
HUCD+Trip	2	1	5	LAS	LAS
Normal and Trip	2	1	5	LAS	LAS
Leak Test	1	1	5	LAS	LAS
Variations	4000	40	4000	LAS	LAS

Subblock	Kmax Case ID	Scale Factor	Kmin Case ID	Scale Factor
HUCD+Trip	2235 Psig	1.1342	2235 Psig	0.0000
	Reactor Trip	1.0000	Heatup	1.0000
	2235 Crack Pressure	1.1342		
Normal and Trip	2235 Psig	1.0000	2235 Psig	0.7539
	2235 Crack Pressure	1.0000	2235 Crack Pressure	0.7539
Leak Test	2235 Psig	1.0000	2235 Psig	0.0000
	2235 Crack Pressure	1.0000	Heatup	0.5000
Variations	2235 Psig	1.0447	2235 Psig	0.9545
	2235 Crack Pressure	1.0447	2235 Crack Pressure	0.9545

Crack growth results:

Total Cycles /Time	Subblock Cycles /Time	Kmax	Kmin	DeltaK	R	DaDn /DaDt	Da	a	a/thk

Block: 5

16022	2	4.89e+004	-1.46e+004	6.35e+004	-0.30	3.30e-004	3.30e-004	0.4414	0.10
16024	2	3.18e+004	2.40e+004	7.84e+003	0.75	2.50e-006	2.50e-006	0.4414	0.10
16025	1	3.18e+004	-7.31e+003	3.91e+004	-0.23	1.29e-004	1.29e-004	0.4416	0.10
20025	4000	3.33e+004	3.04e+004	2.87e+003	0.91	6.39e-009	2.56e-007	0.4416	0.10

Block: 10

36047	2	4.91e+004	-1.47e+004	6.38e+004	-0.30	3.33e-004	3.33e-004	0.4455	0.10
36049	2	3.20e+004	2.41e+004	7.87e+003	0.75	2.58e-006	2.58e-006	0.4456	0.10
36050	1	3.20e+004	-7.33e+003	3.93e+004	-0.23	1.30e-004	1.30e-004	0.4457	0.10
40050	4000	3.34e+004	3.05e+004	2.89e+003	0.91	6.58e-009	2.63e-007	0.4457	0.10

Block: 15

56072	2	4.93e+004	-1.47e+004	6.40e+004	-0.30	3.36e-004	3.36e-004	0.4497	0.10
56074	2	3.21e+004	2.42e+004	7.91e+003	0.75	2.65e-006	2.65e-006	0.4497	0.10
56075	1	3.21e+004	-7.35e+003	3.95e+004	-0.23	1.31e-004	1.31e-004	0.4498	0.10
60075	4000	3.36e+004	3.07e+004	2.90e+003	0.91	6.78e-009	2.71e-007	0.4499	0.10

Block: 20

76097	2	4.95e+004	-1.47e+004	6.43e+004	-0.30	3.38e-004	3.38e-004	0.4539	0.11
76099	2	3.23e+004	2.44e+004	7.95e+003	0.75	2.73e-006	2.73e-006	0.4539	0.11
76100	1	3.23e+004	-7.38e+003	3.97e+004	-0.23	1.32e-004	1.32e-004	0.454	0.11
80100	4000	3.38e+004	3.08e+004	2.91e+003	0.91	6.98e-009	2.79e-007	0.4541	0.11

Block: 25

96122	2	4.98e+004	-1.48e+004	6.46e+004	-0.30	3.41e-004	3.41e-004	0.4581	0.11
96124	2	3.25e+004	2.45e+004	7.99e+003	0.75	2.81e-006	2.81e-006	0.4581	0.11
96125	1	3.25e+004	-7.40e+003	3.99e+004	-0.23	1.33e-004	1.33e-004	0.4583	0.11
100125	4000	3.39e+004	3.10e+004	2.93e+003	0.91	7.18e-009	2.87e-007	0.4583	0.11

Block: 30

116147	2	5.00e+004	-1.48e+004	6.48e+004	-0.30	3.44e-004	3.44e-004	0.4624	0.11
116149	2	3.26e+004	2.46e+004	8.03e+003	0.75	2.90e-006	2.90e-006	0.4624	0.11
116150	1	3.26e+004	-7.42e+003	4.00e+004	-0.23	1.34e-004	1.34e-004	0.4625	0.11
120150	4000	3.41e+004	3.11e+004	2.94e+003	0.91	7.40e-009	2.96e-007	0.4626	0.11

Block: 35

136172	2	5.02e+004	-1.49e+004	6.51e+004	-0.30	3.46e-004	3.46e-004	0.4667	0.11
136174	2	3.28e+004	2.47e+004	8.07e+003	0.75	2.98e-006	2.98e-006	0.4667	0.11
136175	1	3.28e+004	-7.45e+003	4.02e+004	-0.23	1.36e-004	1.36e-004	0.4668	0.11
140175	4000	3.43e+004	3.13e+004	2.96e+003	0.91	7.62e-009	3.05e-007	0.4669	0.11

Block: 40

156197	2	5.04e+004	-1.49e+004	6.53e+004	-0.30	3.49e-004	3.49e-004	0.471	0.11
156199	2	3.29e+004	2.48e+004	8.11e+003	0.75	3.07e-006	3.07e-006	0.471	0.11
156200	1	3.29e+004	-7.47e+003	4.04e+004	-0.23	1.37e-004	1.37e-004	0.4712	0.11
160200	4000	3.44e+004	3.15e+004	2.97e+003	0.91	7.85e-009	3.14e-007	0.4712	0.11

Block: 45

176222	2	5.06e+004	-1.50e+004	6.56e+004	-0.30	3.52e-004	3.52e-004	0.4754	0.11
176224	2	3.31e+004	2.50e+004	8.15e+003	0.75	3.16e-006	3.16e-006	0.4754	0.11
176225	1	3.31e+004	-7.49e+003	4.06e+004	-0.23	1.38e-004	1.38e-004	0.4756	0.11
180225	4000	3.46e+004	3.16e+004	2.99e+003	0.91	8.08e-009	3.23e-007	0.4756	0.11

Block: 50

196247	2	5.09e+004	-1.50e+004	6.59e+004	-0.30	3.55e-004	3.55e-004	0.4798	0.11
196249	2	3.33e+004	2.51e+004	8.19e+003	0.75	3.26e-006	3.26e-006	0.4798	0.11
196250	1	3.33e+004	-7.52e+003	4.08e+004	-0.23	1.39e-004	1.39e-004	0.48	0.11
200250	4000	3.48e+004	3.18e+004	3.00e+003	0.91	8.33e-009	3.33e-007	0.48	0.11

Block: 55

216272	2	5.11e+004	-1.51e+004	6.62e+004	-0.30	3.58e-004	3.58e-004	0.4843	0.11
216274	2	3.34e+004	2.52e+004	8.23e+003	0.75	3.36e-006	3.36e-006	0.4843	0.11
216275	1	3.34e+004	-7.54e+003	4.10e+004	-0.23	1.41e-004	1.41e-004	0.4844	0.11
220275	4000	3.49e+004	3.19e+004	3.02e+003	0.91	8.58e-009	3.43e-007	0.4845	0.11

Block: 60

236297	2	5.13e+004	-1.51e+004	6.64e+004	-0.29	3.60e-004	3.60e-004	0.4888	0.11
236299	2	3.36e+004	2.53e+004	8.27e+003	0.75	3.46e-006	3.46e-006	0.4888	0.11
236300	1	3.36e+004	-7.56e+003	4.12e+004	-0.22	1.42e-004	1.42e-004	0.489	0.11
240300	4000	3.51e+004	3.21e+004	3.03e+003	0.91	8.83e-009	3.53e-007	0.489	0.11

Block: 65

256322	2	5.15e+004	-1.52e+004	6.67e+004	-0.29	3.63e-004	3.63e-004	0.4933	0.11
256324	2	3.38e+004	2.55e+004	8.31e+003	0.75	3.56e-006	3.56e-006	0.4934	0.11
256325	1	3.38e+004	-7.58e+003	4.14e+004	-0.22	1.43e-004	1.43e-004	0.4935	0.11
260325	4000	3.53e+004	3.22e+004	3.05e+003	0.91	9.09e-009	3.64e-007	0.4935	0.11

Block: 70

276347	2	5.17e+004	-1.52e+004	6.69e+004	-0.29	3.66e-004	3.66e-004	0.4979	0.12
276349	2	3.39e+004	2.56e+004	8.35e+003	0.75	3.66e-006	3.66e-006	0.4979	0.12
276350	1	3.39e+004	-7.60e+003	4.15e+004	-0.22	1.44e-004	1.44e-004	0.4981	0.12
280350	4000	3.55e+004	3.24e+004	3.06e+003	0.91	9.36e-009	3.74e-007	0.4981	0.12

Block: 75

296372	2	5.19e+004	-1.52e+004	6.72e+004	-0.29	3.69e-004	3.69e-004	0.5025	0.12
296374	2	3.41e+004	2.57e+004	8.39e+003	0.75	3.77e-006	3.77e-006	0.5026	0.12
296375	1	3.41e+004	-7.62e+003	4.17e+004	-0.22	1.46e-004	1.46e-004	0.5027	0.12
300375	4000	3.56e+004	3.26e+004	3.08e+003	0.91	9.63e-009	3.85e-007	0.5027	0.12

Block: 80

316397	2	5.22e+004	-1.53e+004	6.75e+004	-0.29	3.71e-004	3.71e-004	0.5072	0.12
316399	2	3.43e+004	2.58e+004	8.44e+003	0.75	3.88e-006	3.88e-006	0.5072	0.12
316400	1	3.43e+004	-7.65e+003	4.19e+004	-0.22	1.47e-004	1.47e-004	0.5074	0.12
320400	4000	3.58e+004	3.27e+004	3.09e+003	0.91	9.92e-009	3.97e-007	0.5074	0.12

Block: 85

336422	2	5.24e+004	-1.53e+004	6.77e+004	-0.29	3.74e-004	3.74e-004	0.5119	0.12
336424	2	3.44e+004	2.60e+004	8.48e+003	0.75	4.00e-006	4.00e-006	0.5119	0.12
336425	1	3.44e+004	-7.67e+003	4.21e+004	-0.22	1.48e-004	1.48e-004	0.5121	0.12
340425	4000	3.60e+004	3.29e+004	3.11e+003	0.91	1.02e-008	4.09e-007	0.5121	0.12

Block: 90

356447	2	5.26e+004	-1.54e+004	6.80e+004	-0.29	3.77e-004	3.77e-004	0.5167	0.12
356449	2	3.46e+004	2.61e+004	8.52e+003	0.75	4.12e-006	4.12e-006	0.5167	0.12
356450	1	3.46e+004	-7.69e+003	4.23e+004	-0.22	1.50e-004	1.50e-004	0.5168	0.12
360450	4000	3.62e+004	3.31e+004	3.12e+003	0.91	1.05e-008	4.21e-007	0.5169	0.12

Block: 95

376472	2	5.28e+004	-1.54e+004	6.83e+004	-0.29	3.80e-004	3.80e-004	0.5215	0.12
376474	2	3.48e+004	2.62e+004	8.56e+003	0.75	4.25e-006	4.25e-006	0.5215	0.12
376475	1	3.48e+004	-7.71e+003	4.25e+004	-0.22	1.51e-004	1.51e-004	0.5216	0.12
380475	4000	3.64e+004	3.32e+004	3.14e+003	0.91	1.08e-008	4.34e-007	0.5217	0.12

Block: 100

396497	2	5.31e+004	-1.55e+004	6.85e+004	-0.29	3.83e-004	3.83e-004	0.5263	0.12
396499	2	3.50e+004	2.64e+004	8.61e+003	0.75	4.37e-006	4.37e-006	0.5263	0.12
396500	1	3.50e+004	-7.74e+003	4.27e+004	-0.22	1.52e-004	1.52e-004	0.5265	0.12

400500 4000 3.65e+004 3.34e+004 3.16e+003 0.91 1.12e-008 4.47e-007 0.5265 0.12

Block: 105
416522 2 5.33e+004 -1.55e+004 6.88e+004 -0.29 3.86e-004 3.86e-004 0.5312 0.12
416524 2 3.51e+004 2.65e+004 8.65e+003 0.75 4.51e-006 4.51e-006 0.5312 0.12
416525 1 3.51e+004 -7.76e+003 4.29e+004 -0.22 1.54e-004 1.54e-004 0.5314 0.12
420525 4000 3.67e+004 3.36e+004 3.17e+003 0.91 1.15e-008 4.61e-007 0.5314 0.12

Block: 110
436547 2 5.35e+004 -1.56e+004 6.91e+004 -0.29 3.89e-004 3.89e-004 0.5361 0.12
436549 2 3.53e+004 2.66e+004 8.69e+003 0.75 4.65e-006 4.65e-006 0.5361 0.12
436550 1 3.53e+004 -7.78e+003 4.31e+004 -0.22 1.55e-004 1.55e-004 0.5363 0.12
440550 4000 3.69e+004 3.37e+004 3.19e+003 0.91 1.19e-008 4.75e-007 0.5363 0.12

Block: 115
456572 2 5.38e+004 -1.56e+004 6.94e+004 -0.29 3.92e-004 3.92e-004 0.5411 0.13
456574 2 3.55e+004 2.68e+004 8.74e+003 0.75 4.79e-006 4.79e-006 0.5411 0.13
456575 1 3.55e+004 -7.80e+003 4.33e+004 -0.22 1.56e-004 1.56e-004 0.5413 0.13
460575 4000 3.71e+004 3.39e+004 3.20e+003 0.91 1.22e-008 4.89e-007 0.5413 0.13

Block: 120
476597 2 5.40e+004 -1.57e+004 6.97e+004 -0.29 3.96e-004 3.96e-004 0.5461 0.13
476599 2 3.57e+004 2.69e+004 8.78e+003 0.75 4.94e-006 4.94e-006 0.5461 0.13
476600 1 3.57e+004 -7.83e+003 4.35e+004 -0.22 1.58e-004 1.58e-004 0.5463 0.13
480600 4000 3.73e+004 3.41e+004 3.22e+003 0.91 1.26e-008 5.04e-007 0.5463 0.13

Block: 125
496622 2 5.43e+004 -1.57e+004 7.00e+004 -0.29 3.99e-004 3.99e-004 0.5512 0.13
496624 2 3.59e+004 2.70e+004 8.83e+003 0.75 5.09e-006 5.09e-006 0.5512 0.13
496625 1 3.59e+004 -7.85e+003 4.37e+004 -0.22 1.59e-004 1.59e-004 0.5514 0.13
500625 4000 3.75e+004 3.42e+004 3.24e+003 0.91 1.30e-008 5.20e-007 0.5514 0.13

Block: 130
516647 2 5.45e+004 -1.57e+004 7.02e+004 -0.29 4.02e-004 4.02e-004 0.5563 0.13
516649 2 3.60e+004 2.72e+004 8.87e+003 0.75 5.24e-006 5.24e-006 0.5563 0.13
516650 1 3.60e+004 -7.87e+003 4.39e+004 -0.22 1.61e-004 1.61e-004 0.5565 0.13
520650 4000 3.77e+004 3.44e+004 3.25e+003 0.91 1.34e-008 5.35e-007 0.5565 0.13

Block: 135
536672 2 5.47e+004 -1.58e+004 7.05e+004 -0.29 4.05e-004 4.05e-004 0.5615 0.13
536674 2 3.62e+004 2.73e+004 8.91e+003 0.75 5.40e-006 5.40e-006 0.5615 0.13
536675 1 3.62e+004 -7.89e+003 4.41e+004 -0.22 1.62e-004 1.62e-004 0.5616 0.13
540675 4000 3.79e+004 3.46e+004 3.27e+003 0.91 1.38e-008 5.51e-007 0.5617 0.13

Block: 140
556697 2 5.49e+004 -1.58e+004 7.08e+004 -0.29 4.08e-004 4.08e-004 0.5667 0.13
556699 2 3.64e+004 2.74e+004 8.96e+003 0.75 5.56e-006 5.56e-006 0.5667 0.13
556700 1 3.64e+004 -7.91e+003 4.43e+004 -0.22 1.64e-004 1.64e-004 0.5669 0.13
560700 4000 3.80e+004 3.48e+004 3.28e+003 0.91 1.42e-008 5.68e-007 0.5669 0.13

Block: 145
576722 2 5.52e+004 -1.59e+004 7.10e+004 -0.29 4.11e-004 4.11e-004 0.5719 0.13
576724 2 3.66e+004 2.76e+004 9.00e+003 0.75 5.72e-006 5.72e-006 0.572 0.13
576725 1 3.66e+004 -7.93e+003 4.45e+004 -0.22 1.65e-004 1.65e-004 0.5721 0.13
580725 4000 3.82e+004 3.49e+004 3.30e+003 0.91 1.46e-008 5.85e-007 0.5722 0.13

Block: 150
596747 2 5.54e+004 -1.59e+004 7.13e+004 -0.29 4.14e-004 4.14e-004 0.5773 0.13
596749 2 3.68e+004 2.77e+004 9.05e+003 0.75 5.89e-006 5.89e-006 0.5773 0.13

596750	1	3.68e+004	-7.95e+003	4.47e+004	-0.22	1.67e-004	1.67e-004	0.5774	0.13
600750	4000	3.84e+004	3.51e+004	3.32e+003	0.91	1.51e-008	6.02e-007	0.5775	0.13

Block: 155

616772	2	5.56e+004	-1.59e+004	7.16e+004	-0.29	4.17e-004	4.17e-004	0.5826	0.14
616774	2	3.69e+004	2.79e+004	9.09e+003	0.75	6.07e-006	6.07e-006	0.5826	0.14
616775	1	3.69e+004	-7.97e+003	4.49e+004	-0.22	1.68e-004	1.68e-004	0.5828	0.14
620775	4000	3.86e+004	3.53e+004	3.33e+003	0.91	1.55e-008	6.20e-007	0.5828	0.14

Block: 160

636797	2	5.59e+004	-1.60e+004	7.19e+004	-0.29	4.20e-004	4.20e-004	0.588	0.14
636799	2	3.71e+004	2.80e+004	9.14e+003	0.75	6.26e-006	6.26e-006	0.588	0.14
636800	1	3.71e+004	-7.99e+003	4.51e+004	-0.22	1.70e-004	1.70e-004	0.5882	0.14
640800	4000	3.88e+004	3.55e+004	3.35e+003	0.91	1.60e-008	6.39e-007	0.5883	0.14

Block: 165

656822	2	5.61e+004	-1.60e+004	7.21e+004	-0.29	4.23e-004	4.23e-004	0.5935	0.14
656824	2	3.73e+004	2.81e+004	9.18e+003	0.75	6.45e-006	6.45e-006	0.5935	0.14
656825	1	3.73e+004	-8.01e+003	4.53e+004	-0.21	1.71e-004	1.71e-004	0.5937	0.14
660825	4000	3.90e+004	3.56e+004	3.37e+003	0.91	1.65e-008	6.59e-007	0.5937	0.14

Block: 170

676847	2	5.64e+004	-1.61e+004	7.24e+004	-0.29	4.27e-004	4.27e-004	0.599	0.14
676849	2	3.75e+004	2.83e+004	9.23e+003	0.75	6.64e-006	6.64e-006	0.599	0.14
676850	1	3.75e+004	-8.04e+003	4.55e+004	-0.21	1.73e-004	1.73e-004	0.5992	0.14
680850	4000	3.92e+004	3.58e+004	3.38e+003	0.91	1.70e-008	6.79e-007	0.5992	0.14

Block: 175

696872	2	5.66e+004	-1.61e+004	7.27e+004	-0.28	4.30e-004	4.30e-004	0.6045	0.14
696874	2	3.77e+004	2.84e+004	9.28e+003	0.75	6.85e-006	6.85e-006	0.6046	0.14
696875	1	3.77e+004	-8.06e+003	4.58e+004	-0.21	1.74e-004	1.74e-004	0.6047	0.14
700875	4000	3.94e+004	3.60e+004	3.40e+003	0.91	1.75e-008	7.00e-007	0.6048	0.14

Block: 180

716897	2	5.69e+004	-1.62e+004	7.30e+004	-0.28	4.33e-004	4.33e-004	0.6102	0.14
716899	2	3.79e+004	2.86e+004	9.33e+003	0.75	7.06e-006	7.06e-006	0.6102	0.14
716900	1	3.79e+004	-8.08e+003	4.60e+004	-0.21	1.76e-004	1.76e-004	0.6104	0.14
720900	4000	3.96e+004	3.62e+004	3.42e+003	0.91	1.80e-008	7.21e-007	0.6104	0.14

Block: 185

736922	2	5.71e+004	-1.62e+004	7.33e+004	-0.28	4.37e-004	4.37e-004	0.6158	0.14
736924	2	3.81e+004	2.87e+004	9.37e+003	0.75	7.28e-006	7.28e-006	0.6158	0.14
736925	1	3.81e+004	-8.10e+003	4.62e+004	-0.21	1.77e-004	1.77e-004	0.616	0.14
740925	4000	3.98e+004	3.64e+004	3.44e+003	0.91	1.86e-008	7.44e-007	0.6161	0.14

Block: 190

756947	2	5.74e+004	-1.62e+004	7.36e+004	-0.28	4.40e-004	4.40e-004	0.6216	0.14
756949	2	3.83e+004	2.89e+004	9.42e+003	0.75	7.50e-006	7.50e-006	0.6216	0.14
756950	1	3.83e+004	-8.12e+003	4.64e+004	-0.21	1.79e-004	1.79e-004	0.6218	0.14
760950	4000	4.00e+004	3.66e+004	3.45e+003	0.91	1.92e-008	7.67e-007	0.6218	0.14

Block: 195

776972	2	5.76e+004	-1.63e+004	7.39e+004	-0.28	4.43e-004	4.43e-004	0.6273	0.15
776974	2	3.85e+004	2.90e+004	9.47e+003	0.75	7.73e-006	7.73e-006	0.6274	0.15
776975	1	3.85e+004	-8.14e+003	4.66e+004	-0.21	1.81e-004	1.81e-004	0.6275	0.15
780975	4000	4.02e+004	3.67e+004	3.47e+003	0.91	1.97e-008	7.90e-007	0.6276	0.15

Block: 200

796997	2	5.78e+004	-1.63e+004	7.41e+004	-0.28	4.47e-004	4.47e-004	0.6332	0.15

796999 2 3.87e+004 2.92e+004 9.52e+003 0.75 7.96e-006 7.96e-006 0.6332 0.15
797000 1 3.87e+004 -8.16e+003 4.68e+004 -0.21 1.82e-004 1.82e-004 0.6334 0.15
801000 4000 4.04e+004 3.69e+004 3.49e+003 0.91 2.03e-008 8.13e-007 0.6335 0.15

Block: 205
817022 2 5.81e+004 -1.64e+004 7.44e+004 -0.28 4.50e-004 4.50e-004 0.6391 0.15
817024 2 3.89e+004 2.93e+004 9.56e+003 0.75 8.20e-006 8.20e-006 0.6391 0.15
817025 1 3.89e+004 -8.18e+003 4.70e+004 -0.21 1.84e-004 1.84e-004 0.6393 0.15
821025 4000 4.06e+004 3.71e+004 3.51e+003 0.91 2.09e-008 8.38e-007 0.6394 0.15

Block: 210
837047 2 5.83e+004 -1.64e+004 7.47e+004 -0.28 4.53e-004 4.53e-004 0.645 0.15
837049 2 3.91e+004 2.94e+004 9.61e+003 0.75 8.44e-006 8.44e-006 0.645 0.15
837050 1 3.91e+004 -8.20e+003 4.73e+004 -0.21 1.86e-004 1.86e-004 0.6452 0.15
841050 4000 4.08e+004 3.73e+004 3.52e+003 0.91 2.16e-008 8.63e-007 0.6453 0.15

Block: 215
857072 2 5.86e+004 -1.64e+004 7.50e+004 -0.28 4.57e-004 4.57e-004 0.651 0.15
857074 2 3.93e+004 2.96e+004 9.66e+003 0.75 8.70e-006 8.70e-006 0.651 0.15
857075 1 3.93e+004 -8.22e+003 4.75e+004 -0.21 1.87e-004 1.87e-004 0.6512 0.15
861075 4000 4.10e+004 3.75e+004 3.54e+003 0.91 2.22e-008 8.89e-007 0.6513 0.15

Block: 220
877097 2 5.88e+004 -1.65e+004 7.53e+004 -0.28 4.60e-004 4.60e-004 0.6571 0.15
877099 2 3.95e+004 2.97e+004 9.71e+003 0.75 8.97e-006 8.97e-006 0.6571 0.15
877100 1 3.95e+004 -8.24e+003 4.77e+004 -0.21 1.89e-004 1.89e-004 0.6573 0.15
881100 4000 4.12e+004 3.77e+004 3.56e+003 0.91 2.29e-008 9.16e-007 0.6574 0.15

Block: 225
897122 2 5.91e+004 -1.65e+004 7.56e+004 -0.28 4.63e-004 4.63e-004 0.6632 0.15
897124 2 3.97e+004 2.99e+004 9.76e+003 0.75 9.24e-006 9.24e-006 0.6632 0.15
897125 1 3.97e+004 -8.26e+003 4.79e+004 -0.21 1.91e-004 1.91e-004 0.6634 0.15
901125 4000 4.14e+004 3.79e+004 3.58e+003 0.91 2.36e-008 9.45e-007 0.6635 0.15

Block: 230
917147 2 5.93e+004 -1.65e+004 7.59e+004 -0.28 4.67e-004 4.67e-004 0.6694 0.16
917149 2 3.99e+004 3.00e+004 9.81e+003 0.75 9.53e-006 9.53e-006 0.6694 0.16
917150 1 3.99e+004 -8.28e+003 4.81e+004 -0.21 1.92e-004 1.92e-004 0.6696 0.16
921150 4000 4.16e+004 3.81e+004 3.60e+003 0.91 2.43e-008 9.74e-007 0.6697 0.16

Block: 235
937172 2 5.96e+004 -1.66e+004 7.62e+004 -0.28 4.71e-004 4.71e-004 0.6756 0.16
937174 2 4.01e+004 3.02e+004 9.86e+003 0.75 9.82e-006 9.82e-006 0.6756 0.16
937175 1 4.01e+004 -8.30e+003 4.84e+004 -0.21 1.94e-004 1.94e-004 0.6758 0.16
941175 4000 4.19e+004 3.82e+004 3.61e+003 0.91 2.51e-008 1.00e-006 0.6759 0.16

Block: 240
957197 2 5.98e+004 -1.66e+004 7.65e+004 -0.28 4.74e-004 4.74e-004 0.6819 0.16
957199 2 4.03e+004 3.04e+004 9.91e+003 0.75 1.01e-005 1.01e-005 0.682 0.16
957200 1 4.03e+004 -8.32e+003 4.86e+004 -0.21 1.96e-004 1.96e-004 0.6822 0.16
961200 4000 4.21e+004 3.84e+004 3.63e+003 0.91 2.59e-008 1.04e-006 0.6823 0.16

Block: 245
977222 2 6.01e+004 -1.67e+004 7.68e+004 -0.28 4.78e-004 4.78e-004 0.6883 0.16
977224 2 4.05e+004 3.05e+004 9.96e+003 0.75 1.04e-005 1.04e-005 0.6883 0.16
977225 1 4.05e+004 -8.34e+003 4.88e+004 -0.21 1.98e-004 1.98e-004 0.6885 0.16
981225 4000 4.23e+004 3.86e+004 3.65e+003 0.91 2.67e-008 1.07e-006 0.6886 0.16

Block: 250

997247	2	6.03e+004	-1.67e+004	7.70e+004	-0.28	4.81e-004	4.81e-004	0.6947	0.16
997249	2	4.07e+004	3.07e+004	1.00e+004	0.75	1.08e-005	1.08e-005	0.6948	0.16
997250	1	4.07e+004	-8.35e+003	4.90e+004	-0.21	1.99e-004	1.99e-004	0.695	0.16
1001250	4000	4.25e+004	3.88e+004	3.67e+003	0.91	2.75e-008	1.10e-006	0.6951	0.16

End of pc-CRACK Output

STRUCTURAL INTEGRITY Associates, Inc.	# CALCULATION PACKAGE	FILE No.: WSES-05Q-301 PROJECT No.: WSES-05Q

PROJECT NAME: Pressurizer Heater Weld Crack Growth Evaluation

CLIENT: Entergy Operations, Inc.

CALCULATION TITLE: Finite Element Stress Analyses of Pressurizer Heater Penetration

Document Revision	Affected Pages	Revision Description	Project Mgr. Approval Signature & Date	Preparer(s) & Checker(s) Signatures & Date
0	1-27 A0-A4 B0-B38 Project CD-ROM	**Original Issue**	A. F. Deardorf 10/31/00	F. H. Ku FHK 10/31/00 G. A. Miessi GAM 10/31/00
1	1,4	Typographical error in equation 2 on page 4. The calculations and analyses are not affected.	AF Deardorf 12/6/00	Keith Evon KRE 12/06/2000 Miessi AG GAM 12/06/00

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1.0 INTRODUCTION

Stress analyses have been performed on the Pressurizer Heater Penetration using the ANSYS finite element analysis package. The stresses determined are those due to internal pressure, heat-up transient, cool-down transient, reactor trip transient, and loss of secondary pressure transient. Hoop stress distributions through the vessel wall from the heater sleeve-to-shell weld have been determined for use in crack growth analyses.

2.0 TECHNICAL APPROACH OR METHODOLOGY

ANSYS 5.5 [1] was used to perform the stress analyses. 2-D Thermal Solid elements (PLANE55) were used to model the pressurizer heater penetration in the thermal transient analyses; 2-D Structural Solid elements (PLANE42) were used in the stress analyses.

A 15° spherical section model representing the pressurizer lower head region with a single heater penetration is developed. The geometry of the pressurizer heater penetration is treated as an axisymmetric model, with symmetry boundary conditions applied to the end of the pressurizer shell, and plane strain constraints applied to the end of the repair sleeve.

The stress analysis is to be conservative for any of the pressurizer heater penetrations on the pressurizer bottom head. Therefore, a heater penetration location farthest from the pressurizer centerline is modeled.

3.0 DESIGN INPUTS / ASSUMPTIONS

Design inputs are given in References 2 and 3.

There are five types of loadings in total (the temperature loading histories for these runs are shown in Figures 1 to 4):

1. Internal pressure at 2235 psig
2. Thermal heat-up transient from 70 °F to 653 °F at 200 °F/hr
3. Thermal cool-down transient from 653 °F to 70 °F at 200 °F/hr
4. Reactor trip thermal transient
5. Loss of secondary pressure transient

The ANSYS input files for the thermal, if applicable, and the stress runs for the above loading cases are as follows (these input files are on the project CD-ROM):

1.	Internal pressure:	N/A	*Pressure.inp*
2.	Heat-up transient:	*ThermHU.inp*	*StressHU.inp*

3. Cool-down transient: *ThermCD.inp* *StressCD.inp*
4. Reactor trip transient: *ThermCy.inp* *StressCy.inp*
5. Loss in secondary pressure: *ThermUl.inp* *StressUl.inp*

The developed finite element model is shown in Figure 5. Assumptions are made for the purpose of modeling simplicity and reducing analysis time. They are:

- The model is axisymmetric
- The penetration is radial to the pressurizer center
- The repair weld is of triangular geometry
- The outer surface of the pressurizer and the inner wall surfaces of the sleeves are insulated

The applied boundary conditions and loads to the model are shown in Figures 6 to 8.

The actual modeled heater penetration is vertical, entering the bottom head 38" from the centerline. It is assumed that the stresses around this location can be bounded by using an axisymmetric model that has an equivalent diameter bore equal to the maximum side-hill dimension of the intersection of the bottom head and the heater penetration.

4.0 ANALYSIS OR CALCULATIONS

According to the design inputs, the outermost heater penetration is located 38" from the centerline of the pressurizer, while the modeled penetration is radial to the pressurizer center, so it is necessary to calculate the projected bore diameter of the penetration hole. The pressurizer has an internal radius (*IR*) of 48.4375" and a maximum bore diameter (*BD*) of 1.666". Therefore, the projected bore diameter of the penetration (*W*) is:

$$W = \frac{BD}{\cos\left[\sin^{-1}\left(\frac{38}{IR}\right)\right]} = \frac{1.666}{\cos\left[\sin^{-1}\left(\frac{38}{48.4375}\right)\right]} = 2.6866''. \qquad (1)$$

The J-weld fillet radius (*JwR*) used in the model is taken as the average of the uphill and downhill fillet weld leg dimensions provided in the design input:

$$\text{JwR} = \frac{.1875 + .1563}{2} = .1719''. \qquad (2)$$

The necessary length of the repair sleeve (L) in order to minimize the end effects on the model is [4]:

$$L = 3\sqrt{R_m t} = 3\sqrt{\left(\frac{OD+ID}{4}\right)\left(\frac{OD-ID}{2}\right)} = 3\sqrt{\left(\frac{1.660+1.314}{4}\right)\left(\frac{1.660-1.314}{2}\right)} = 1.076", \quad (3)$$

where R_m is the mean radius, t is the thickness, OD the outside diameter, and ID is the inside diameter of the repair sleeve. This is the minimum length such that the effects at the model end due to displacement, bending, and moment all go to zero [4]. A convenient value of L = 2" is used in the finite element model.

A conservative value for the convection heat transfer coefficient, h = 25000 BTU/ft^2-hr-°F, is used.

5.0 RESULTS OF ANALYSIS

The internal pressure run shows that the hoop stress peaks at the inside of the J-weld (see Figure 9).

The hoop stress histories at a point in the middle of the J-weld and at a point on the inner vessel surface away from the J-weld for the thermal transient runs are plotted in Figures 10 to13. The numerical values of these hoop stresses are listed in Appendix A. The hoop stress distributions at peak stress time steps for the thermal transient runs are shown in Figures 14 to 17.

Four paths across the body of the J-weld to the outer vessel surface (Figure 18) and two paths across the vessel thickness adjacent to the J-weld (r = 48") have been defined to evaluate the hoop stress distributions across the vessel wall from the region of the heater-to-shell weld (paths are defined from the inside of the pressurizer to the outside). These paths were chosen in order to be able to select a conservative stress distribution for the crack growth analysis. Paths with a more vertical orientation were not chosen, as stresses would be representative of only a small part of a growing corner crack. The hoop stress distributions for the runs are plotted in Figures 19-23; the numerical results are listed in Appendix B.

One design input drawing [5] shows that there is a 1.688" diameter counter bore at the repair sleeve penetration. However, the main interest is the stress distributions on the existing J-weld. Therefore, this change in design is not significant and hence ignored in the finite element analyses.

6.0 REFERENCES

1. ANSYS/Mechanical, Revision 5.5.1, ANSYS Inc., Oct. 1998.

2. Entergy Operations Inc., Design Input: "ASME Section XI, IWB-3600 Flaw Evaluation for SIR-00-135." Rev..1, Oct. 27. 2000, SI File No. WSES-05Q-201.

3. Entergy Operations Inc., Drawing No. 5010179 D. "Waterford Pressurizer Heater Nozzle Replacement, Location F-4," Rev. 0, by fax from G. Payne, Entergy, to A. Deardorff, SI, Oct. 19, 2000, SI File No. WSES-05Q-202.

4. Timoshenko, S., and Woinowsky-Krieger, S., "Theory of Plates and Shells," 2nd ed., McGraw-Hill Book Co., New York, 1959.

5. Entergy Operations Inc., Drawing No. PDD-5817-13054, Rev. B, "Repair of Pressurizer Heater Sleeve F-4," per Reference 2, SI File No. WSES-05Q-202.

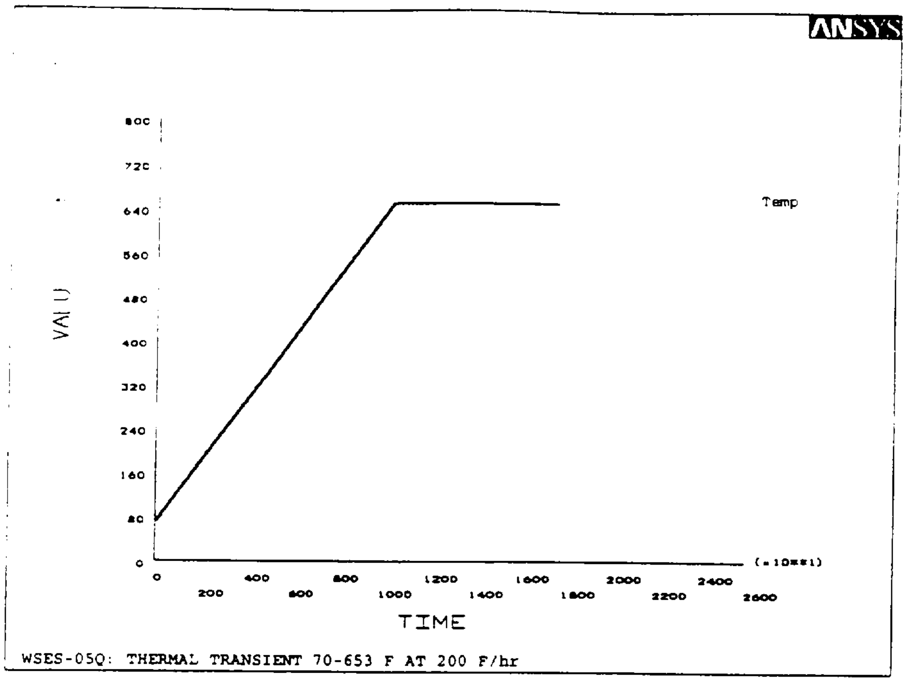

Figure 1: Temperature History for Heat-Up Transient.

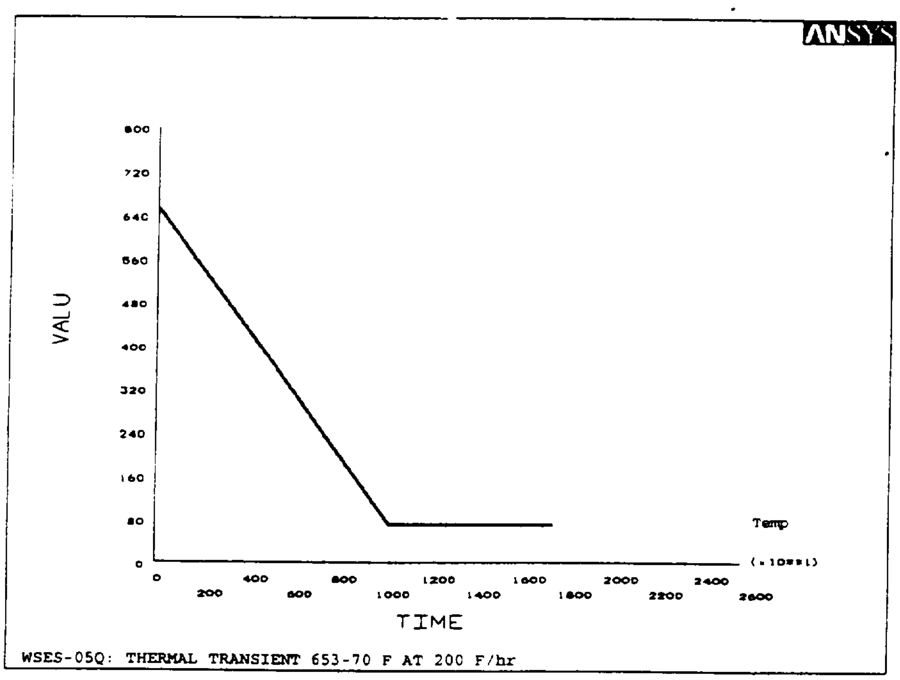

Figure 2: Temperature History for Cool-Down Transient.

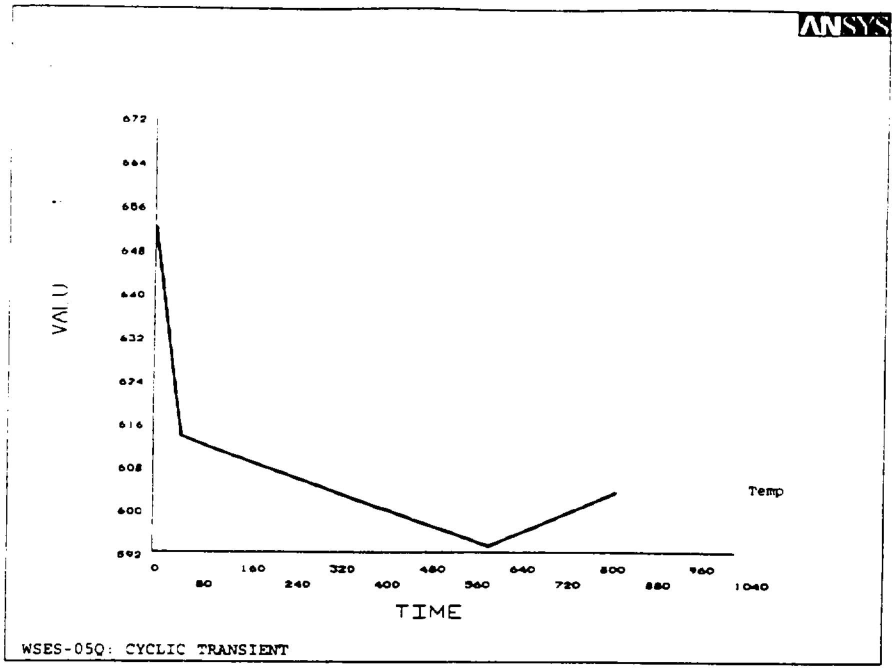

Figure 3: Temperature History for Reactor Trip Transient.

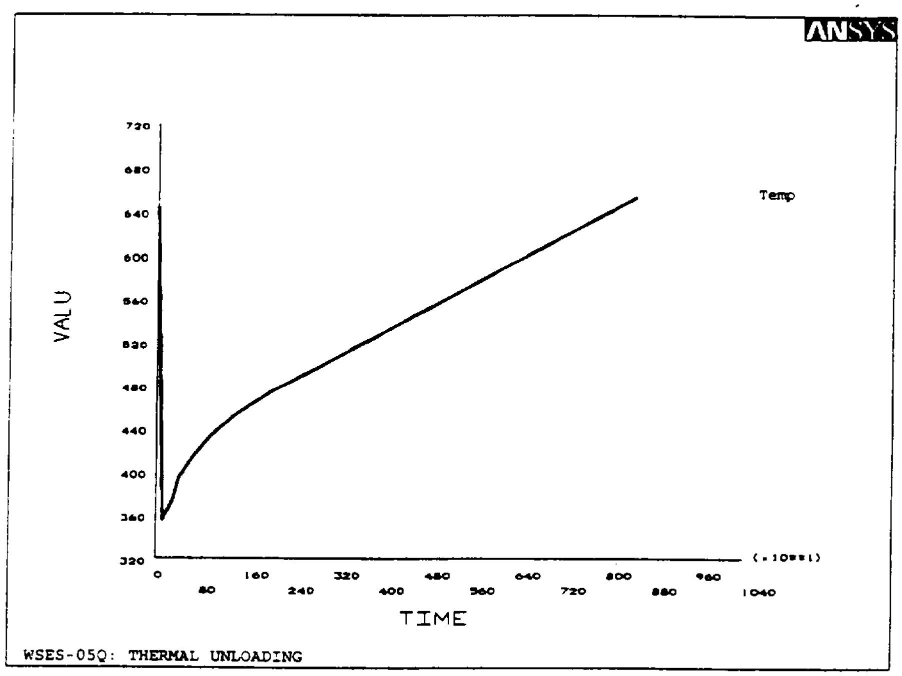

Figure 4: Temperature History for Loss of Secondary Pressure Transient.

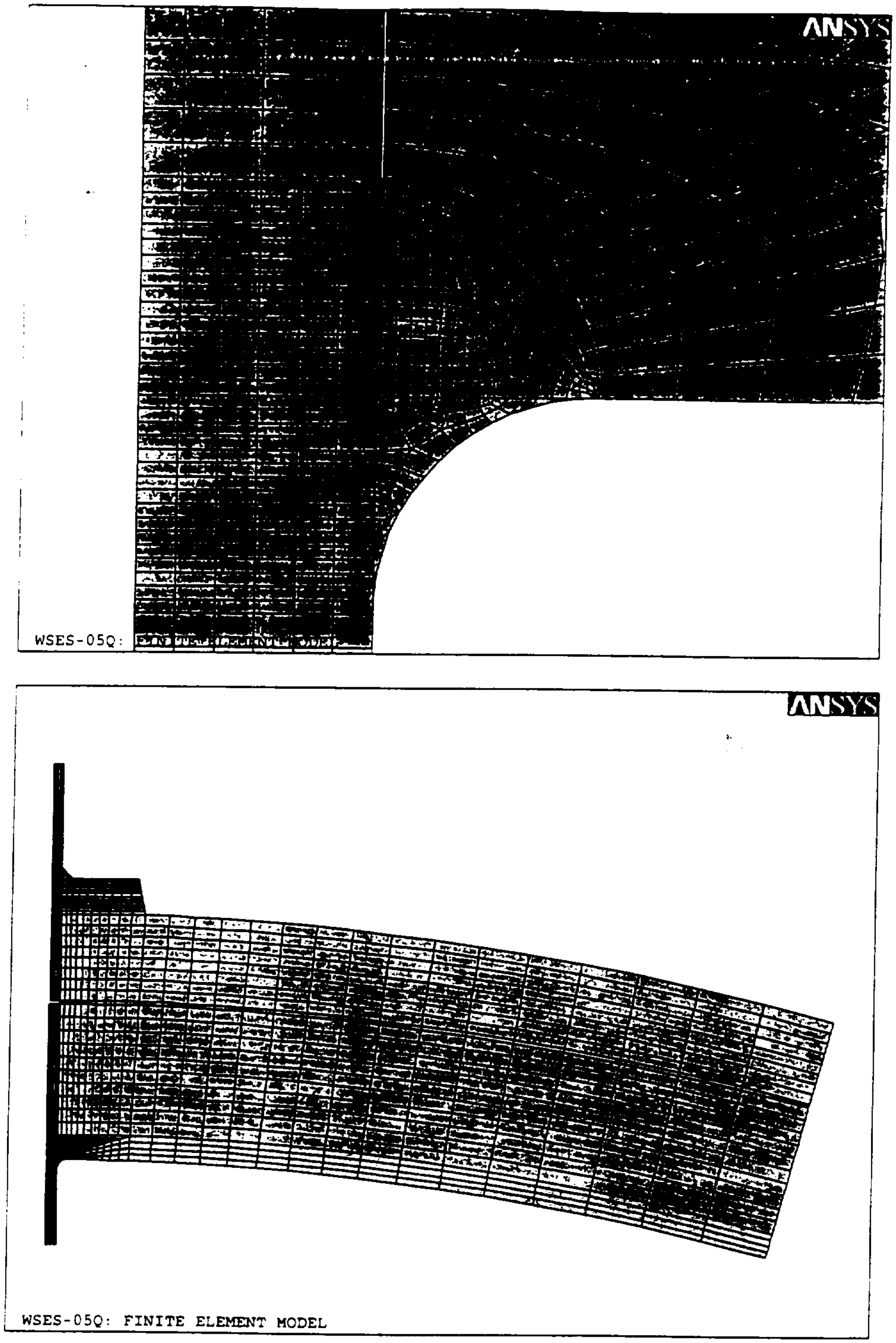

Figure 5: ANSYS Finite Element Model of the Pressurizer Heater Penetration.

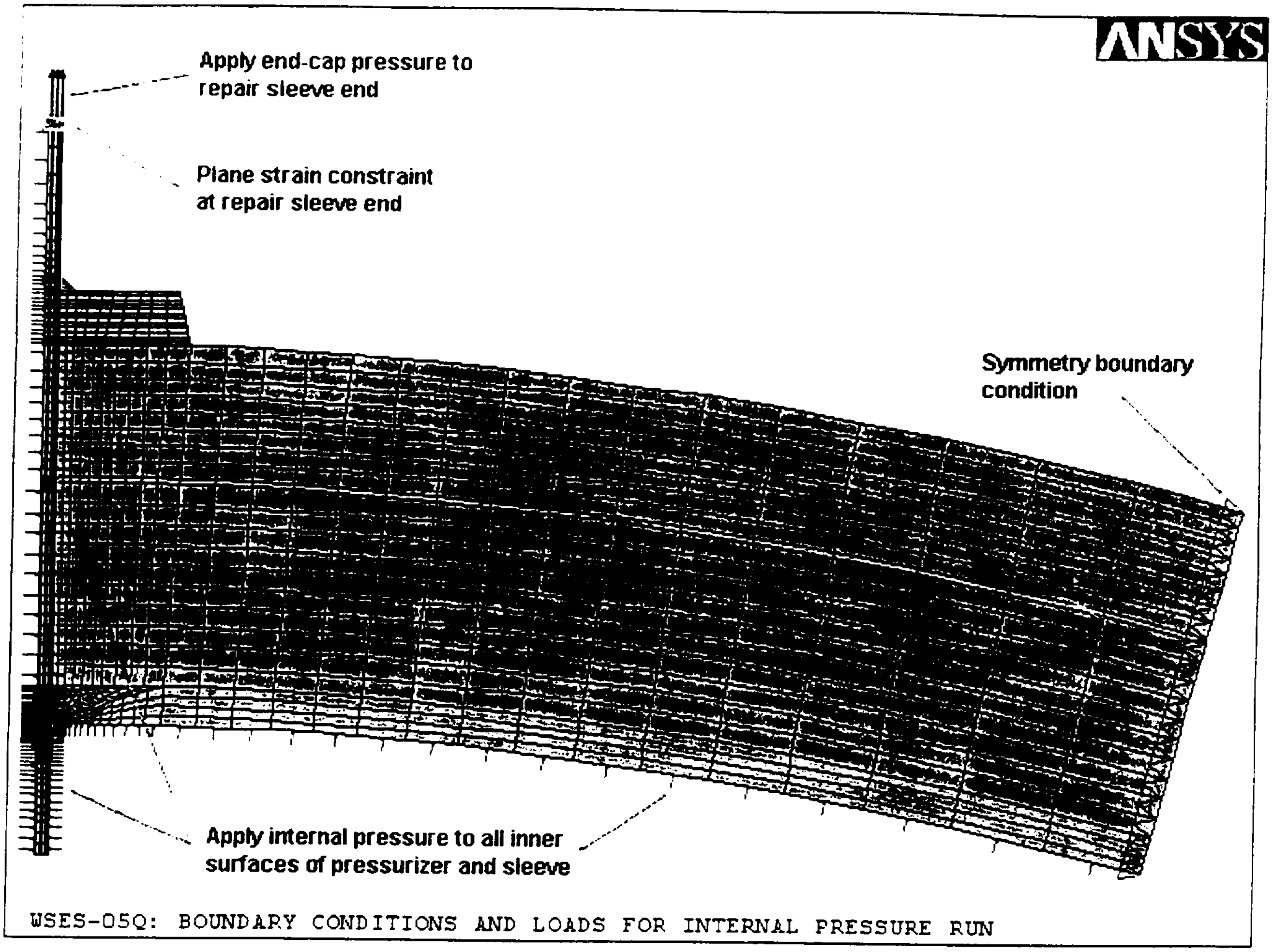

Figure 6: Applied Boundary Conditions and Loads for Internal Pressure Run.

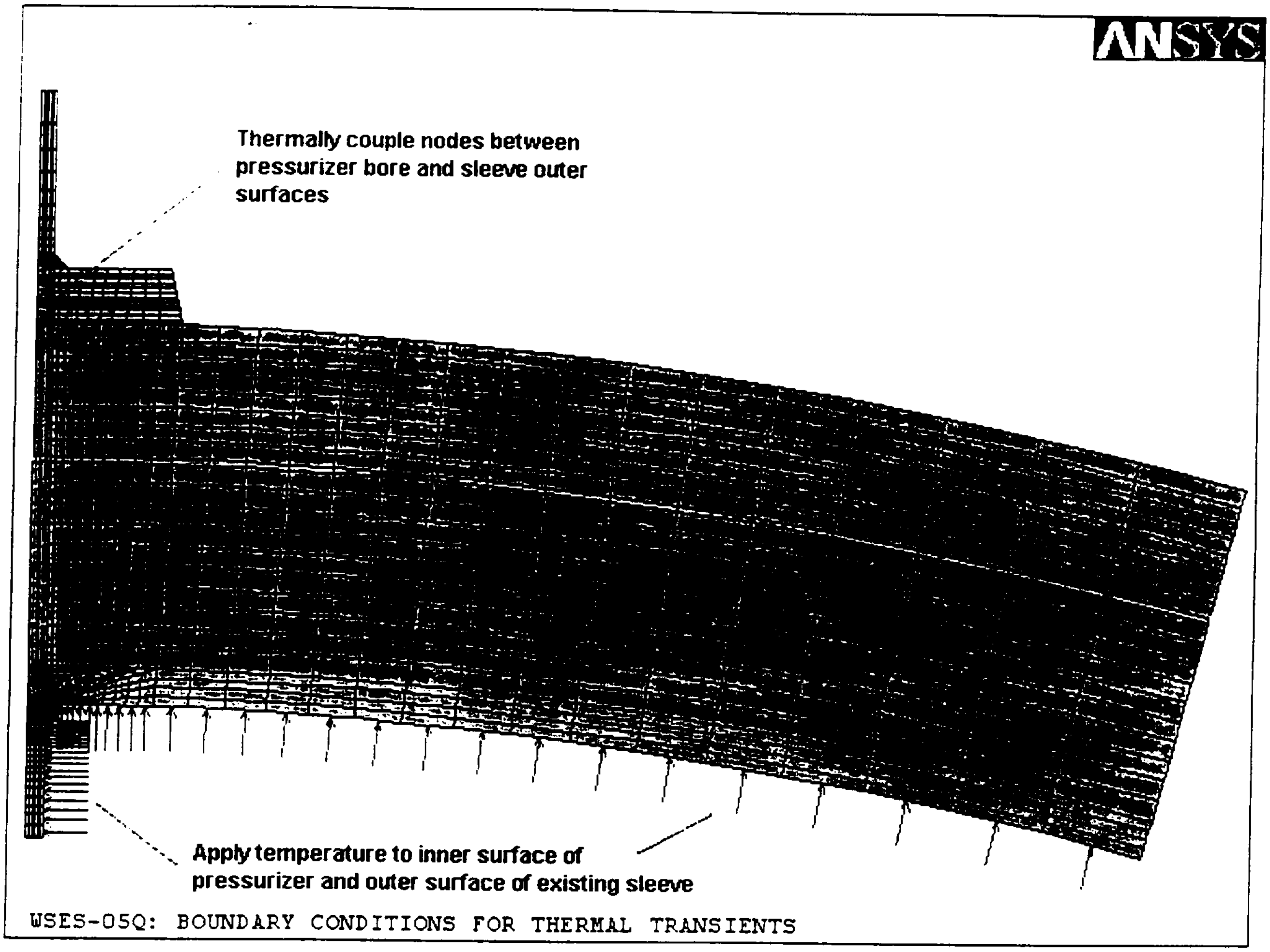

Figure 7: Applied Boundary Conditions for Thermal Transient Runs.

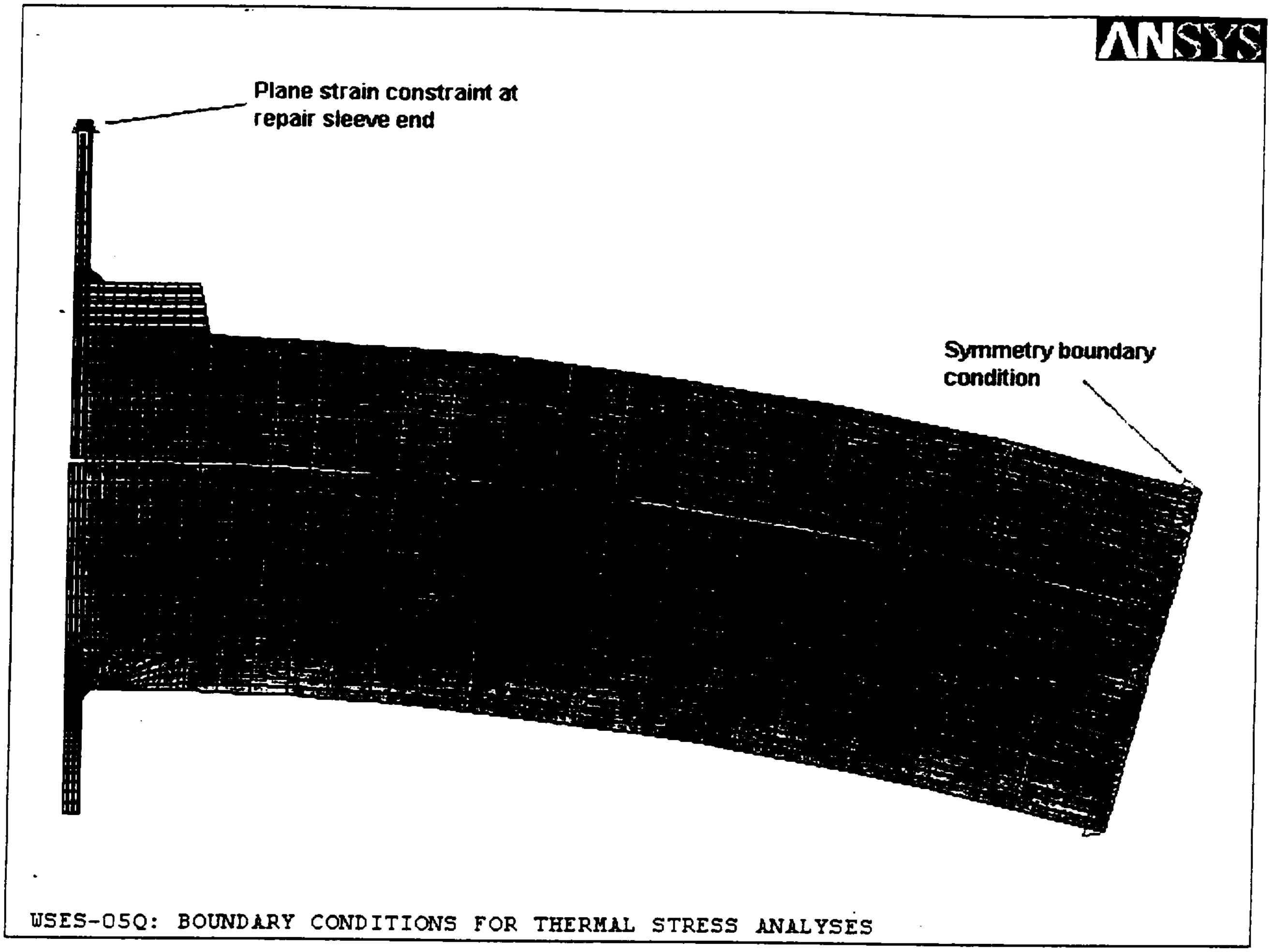

Figure 8: Applied Boundary Conditions and Loads for Thermal Stress Analyses.

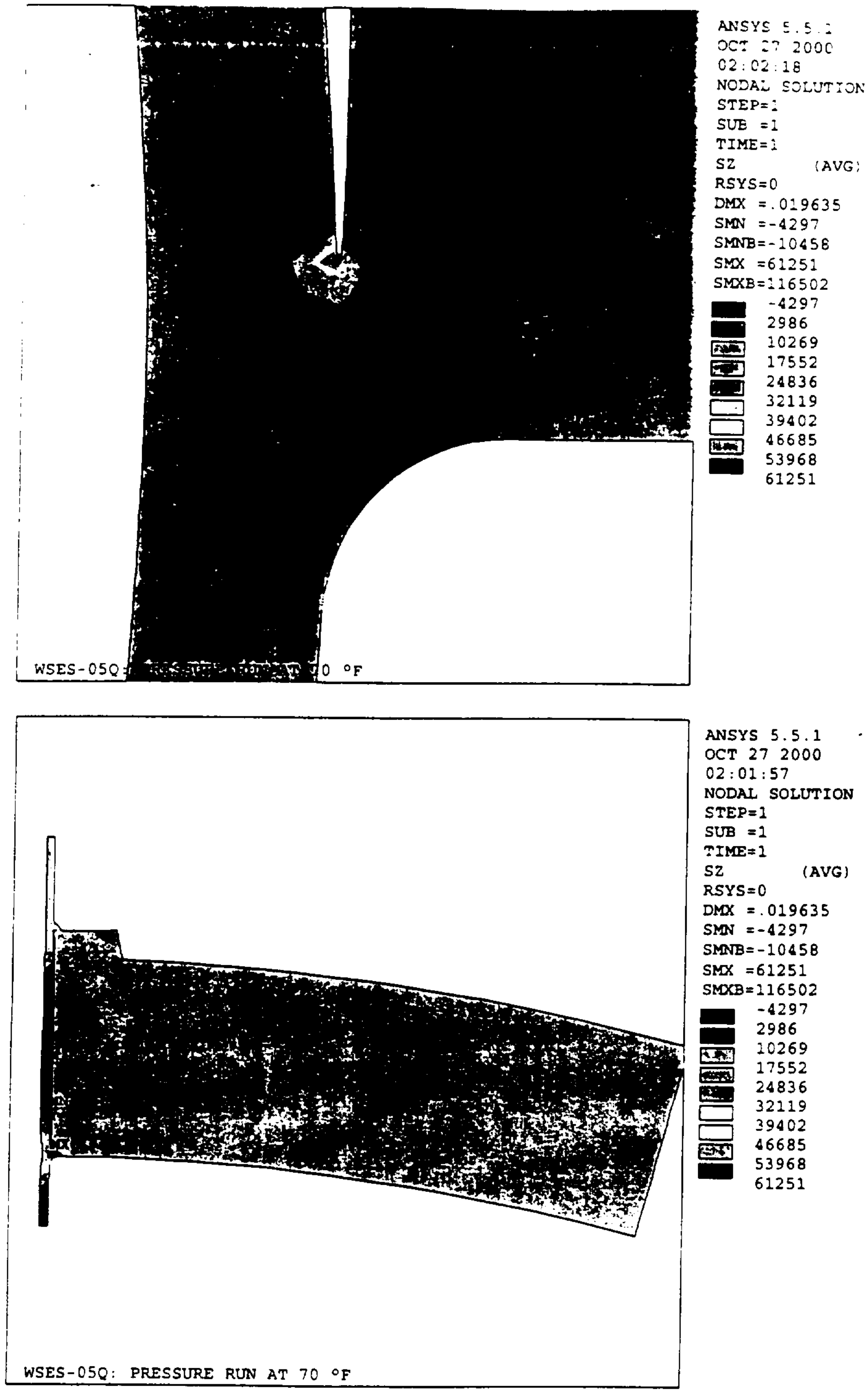

Figure 9: Hoop Stress Distribution for Internal Pressure Run.

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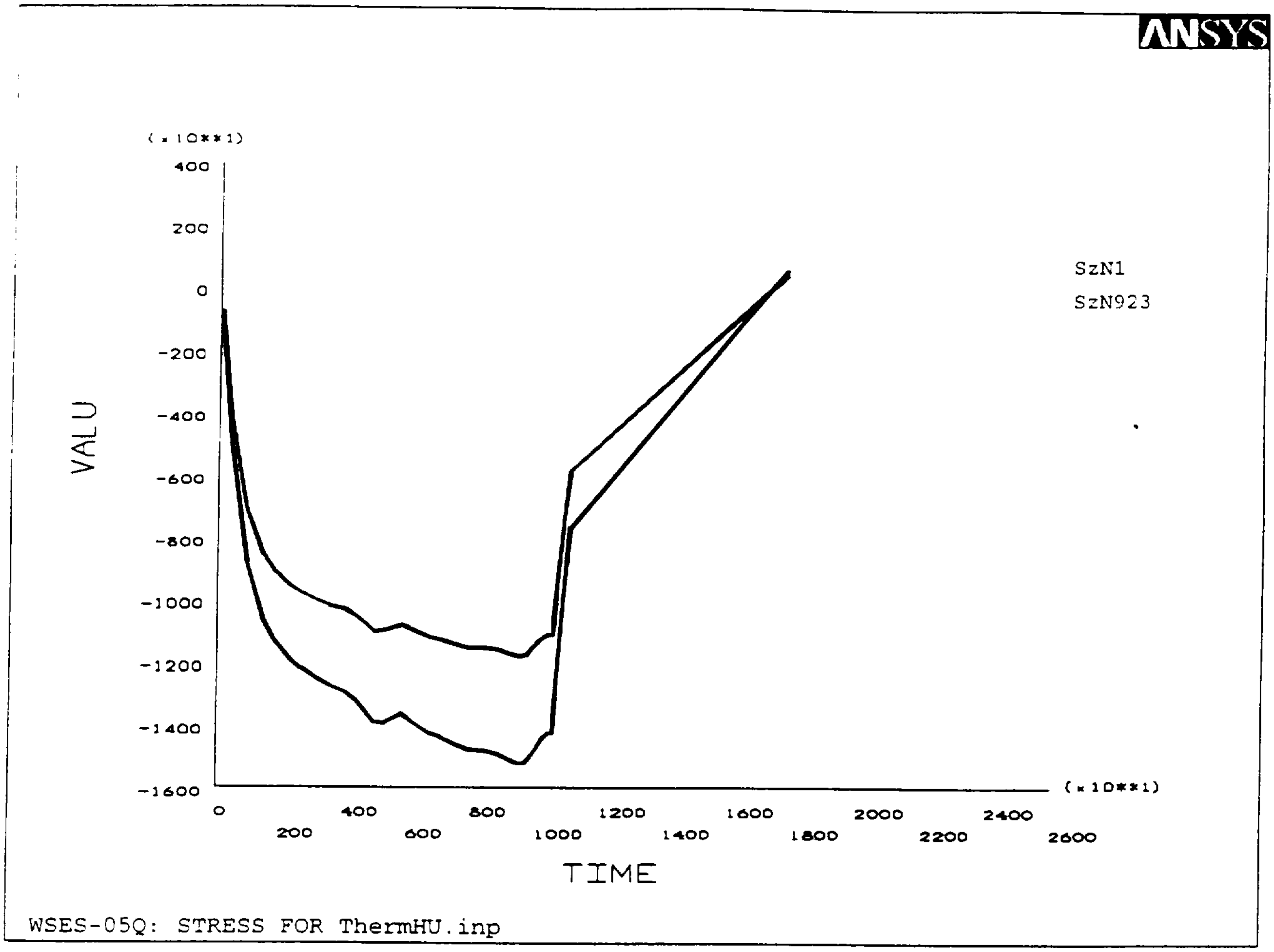

Figure 10: Hoop Stress History for Heat-Up Transient.

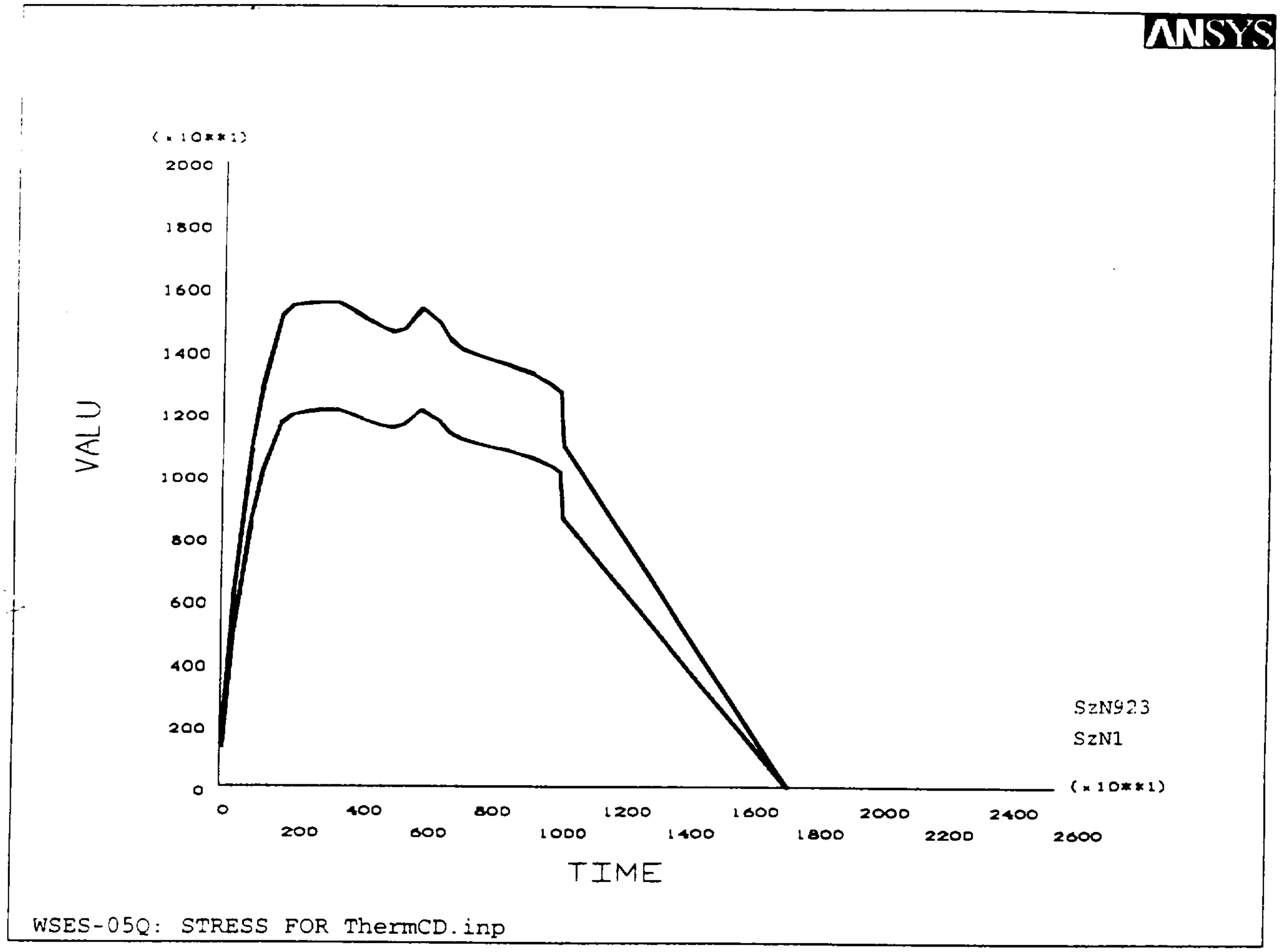

Figure 11: Hoop Stress History for Cool-Down Transient.

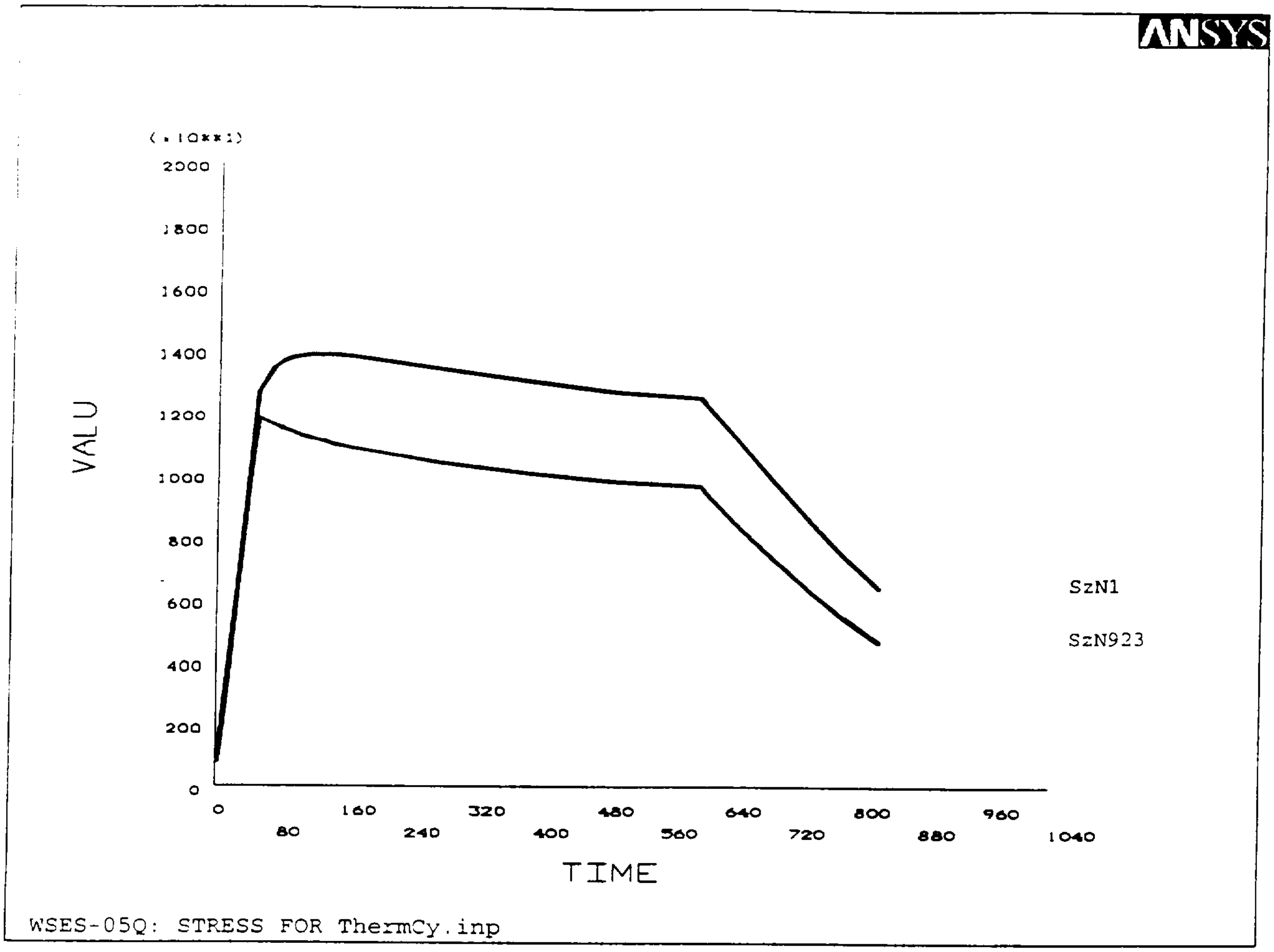

Figure 12: Hoop Stress History for Reactor Trip Transient.

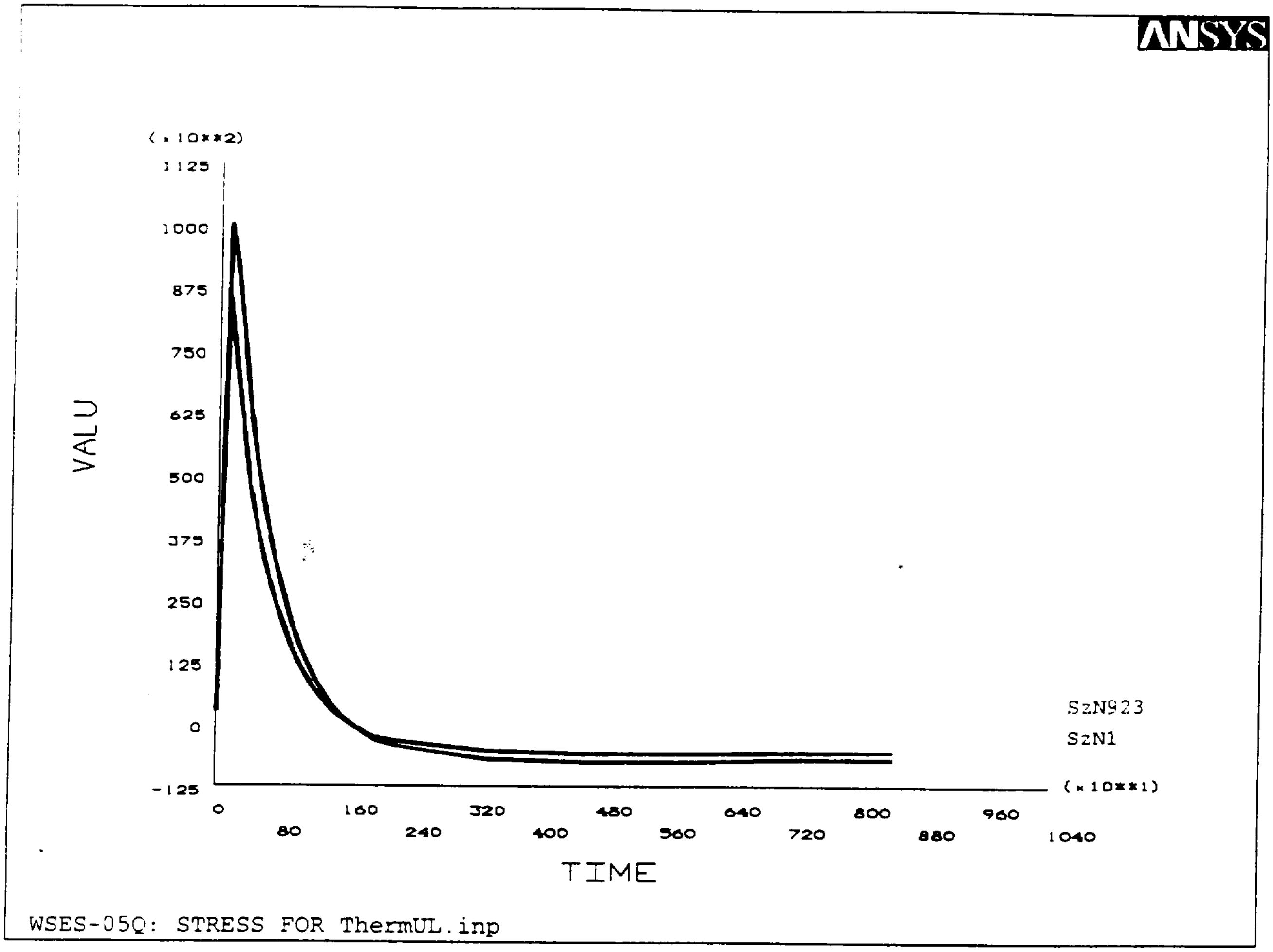

Figure 13: Hoop Stress History for Loss of Secondary Pressure Transient.

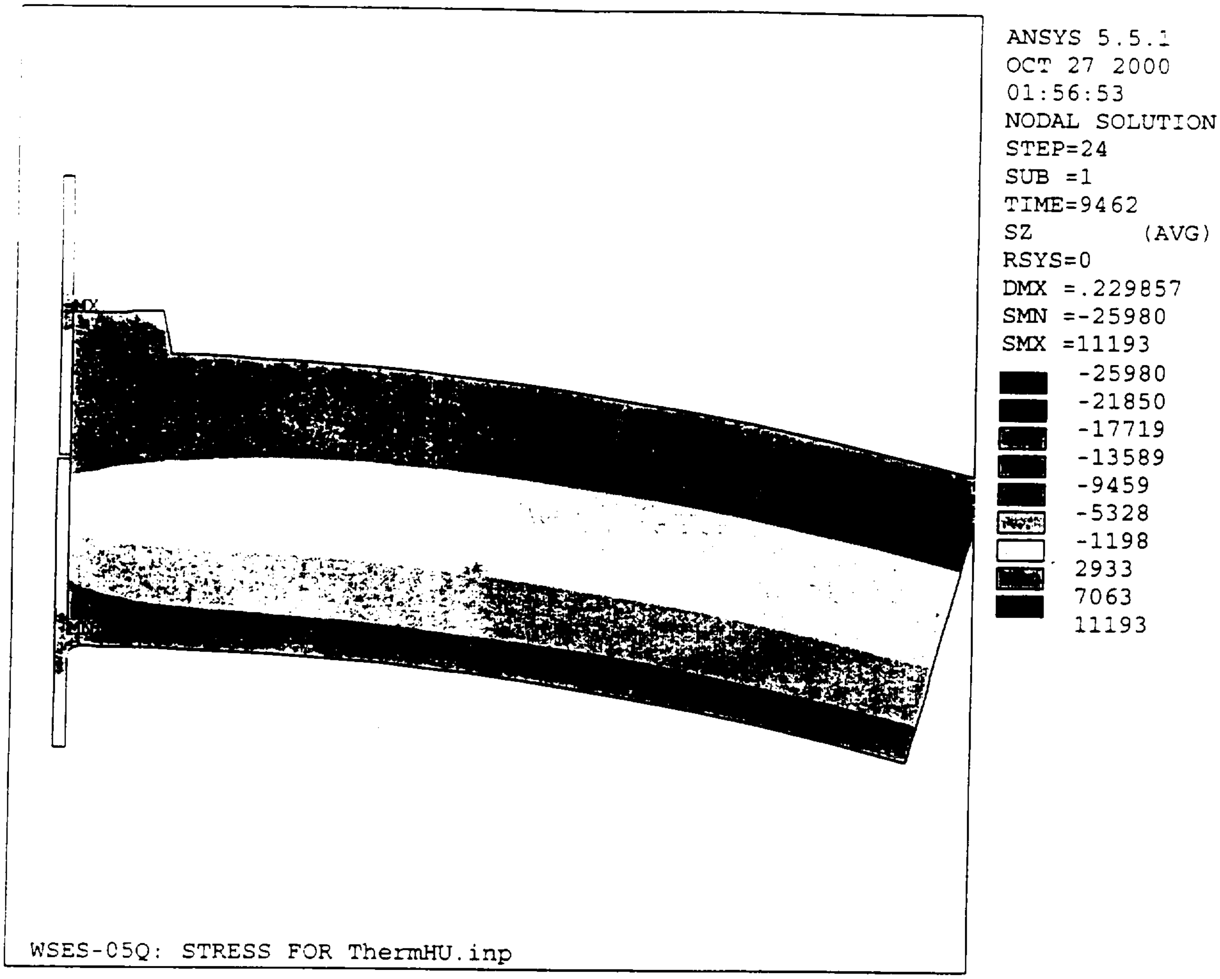

Figure 14: Hoop Stress Distribution for Heat-Up Transient.

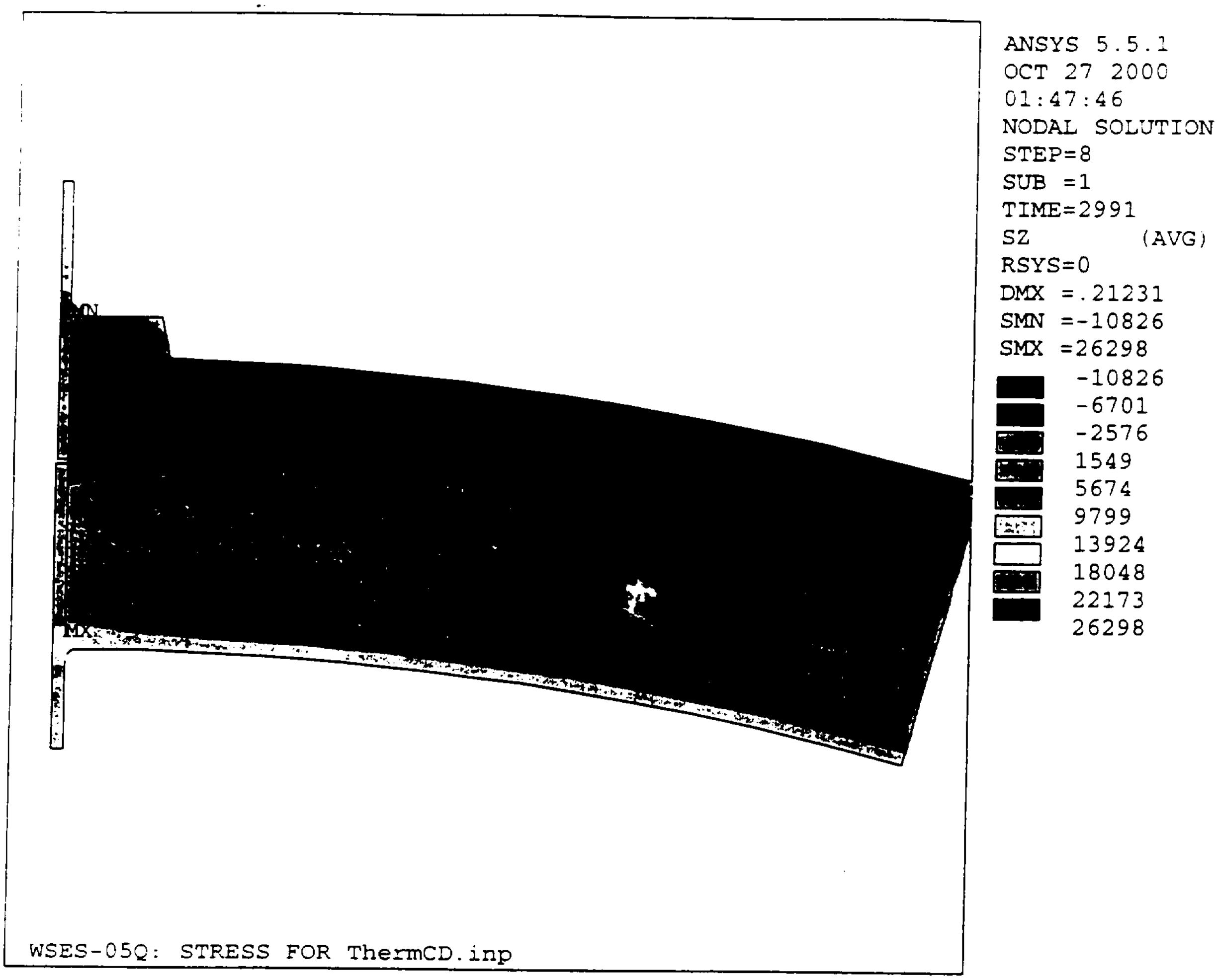

Figure 15: Hoop Stress Distribution for Cool-Down Transient.

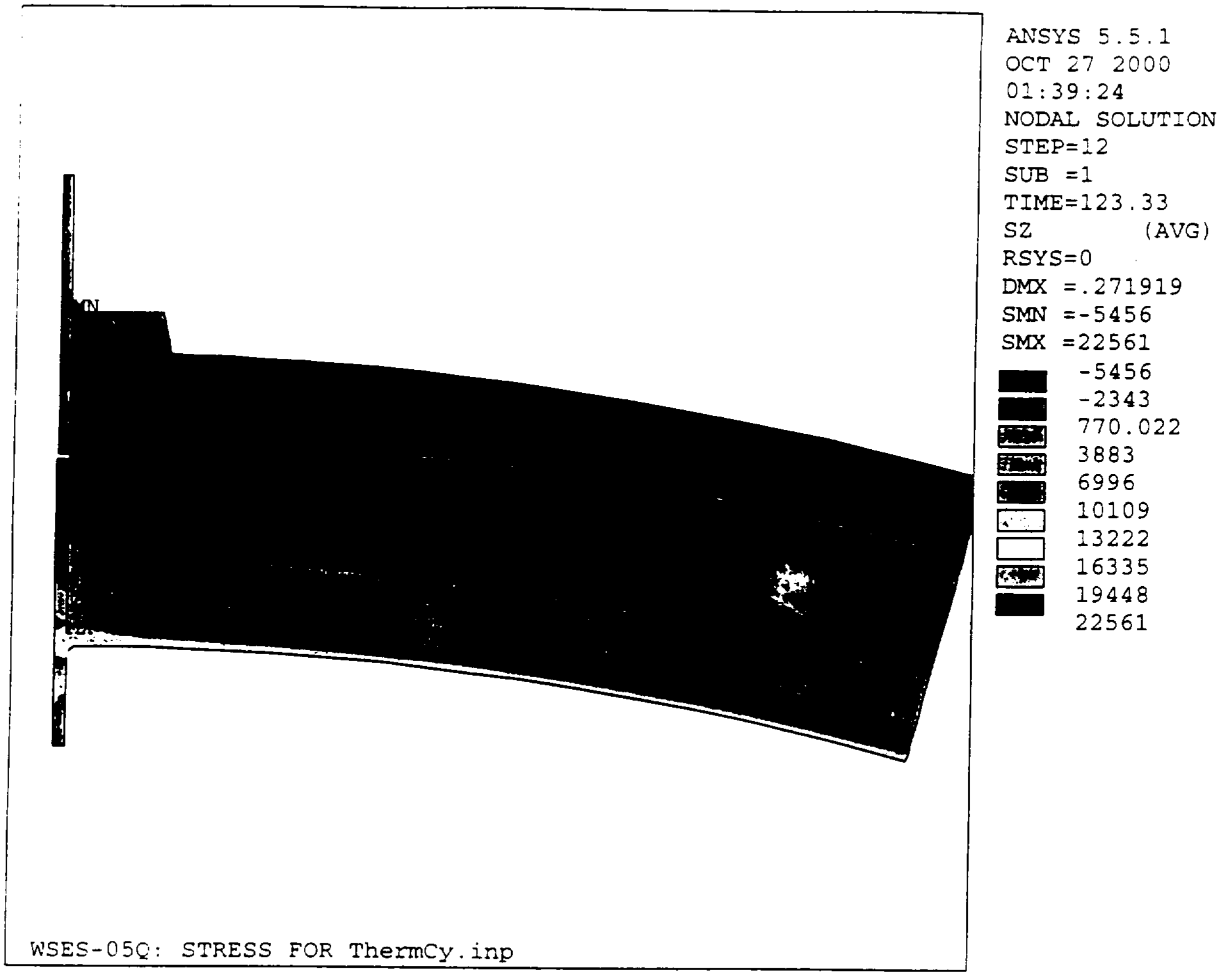

Figure 16: Hoop Stress Distribution for Reactor Trip Transient.

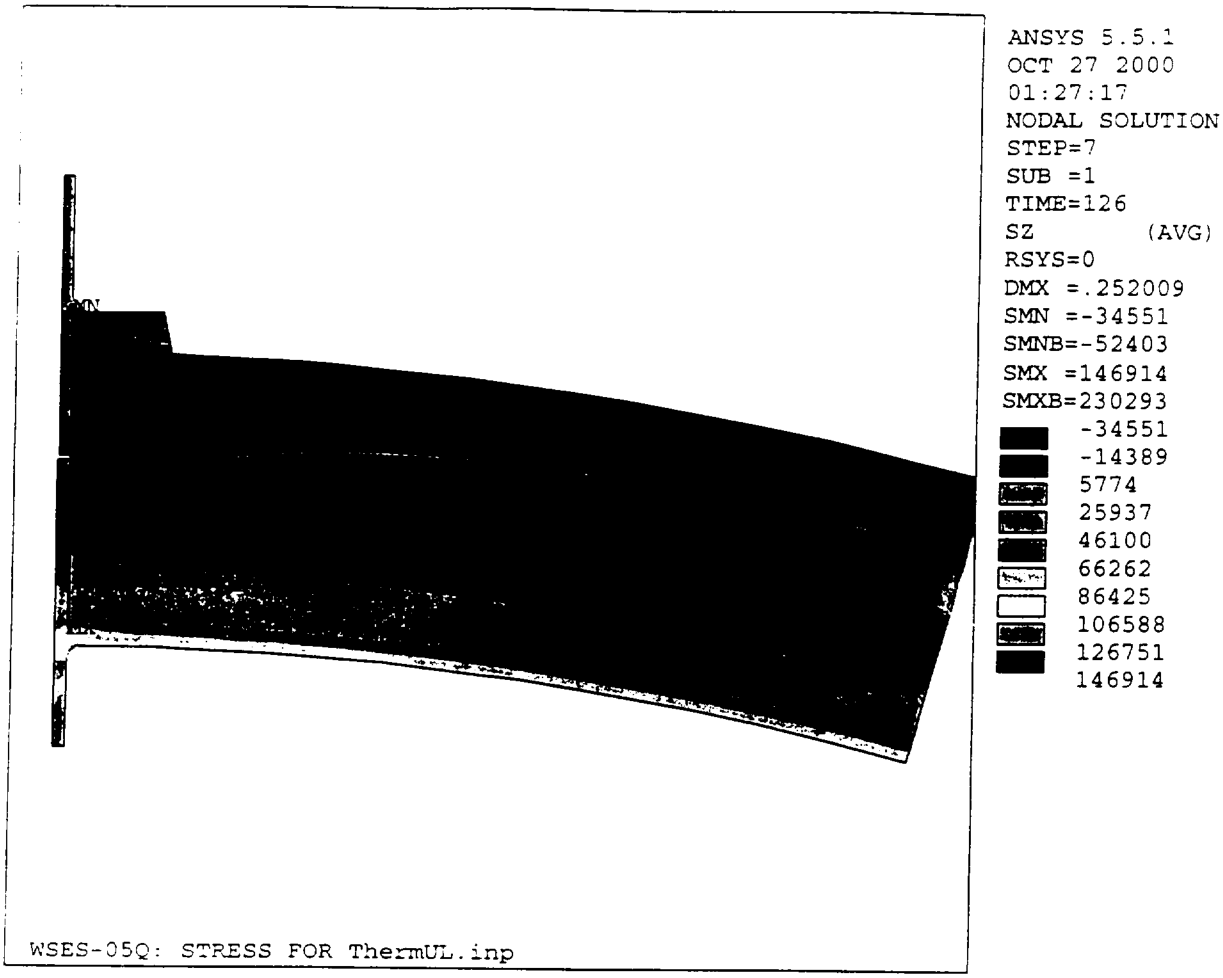

Figure 17: Hoop Stress Distribution for Loss of Secondary Pressure Transient.

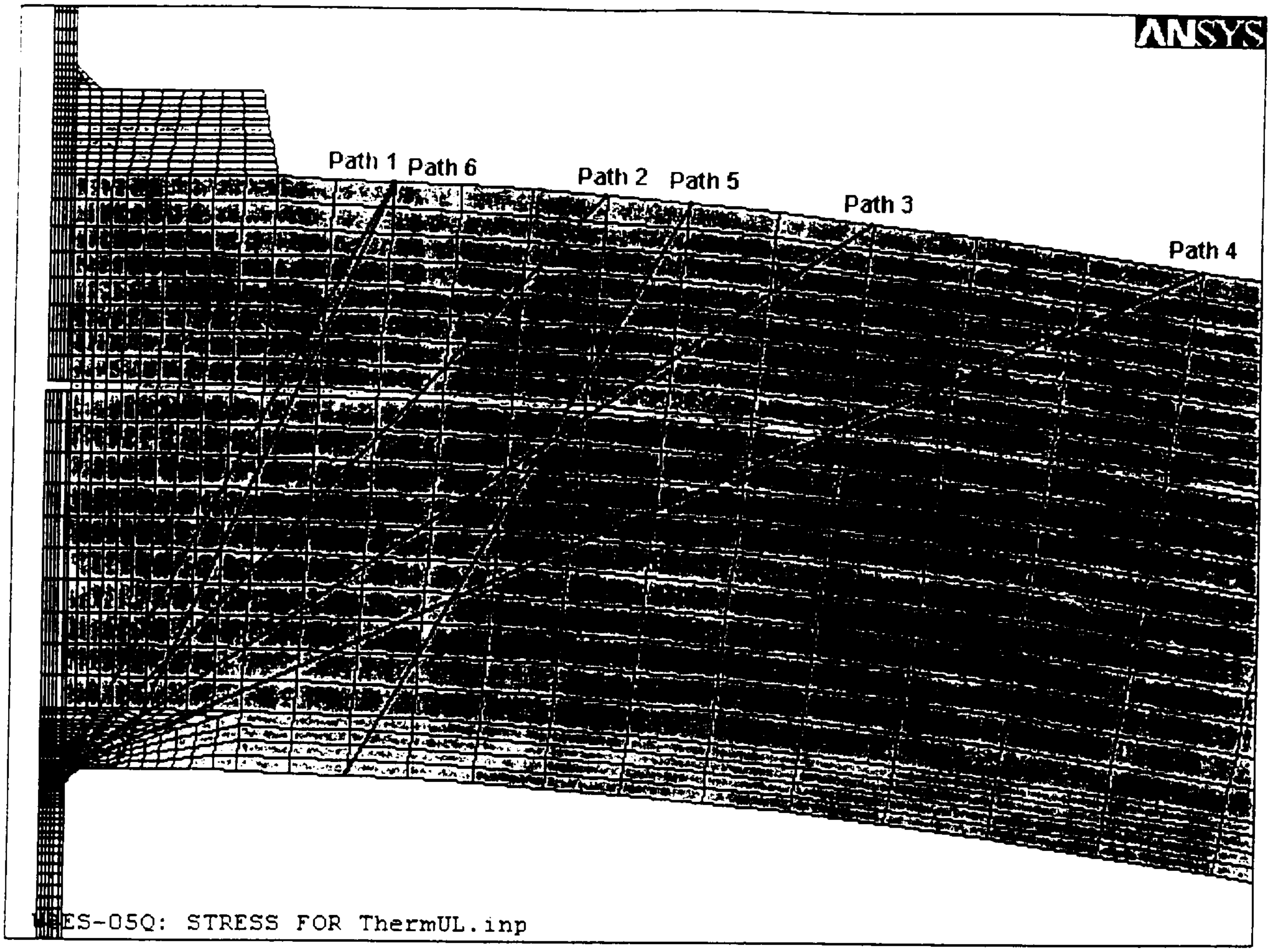

Figure 18: Path Definitions for Determining Hoop Stress.

Distributions.

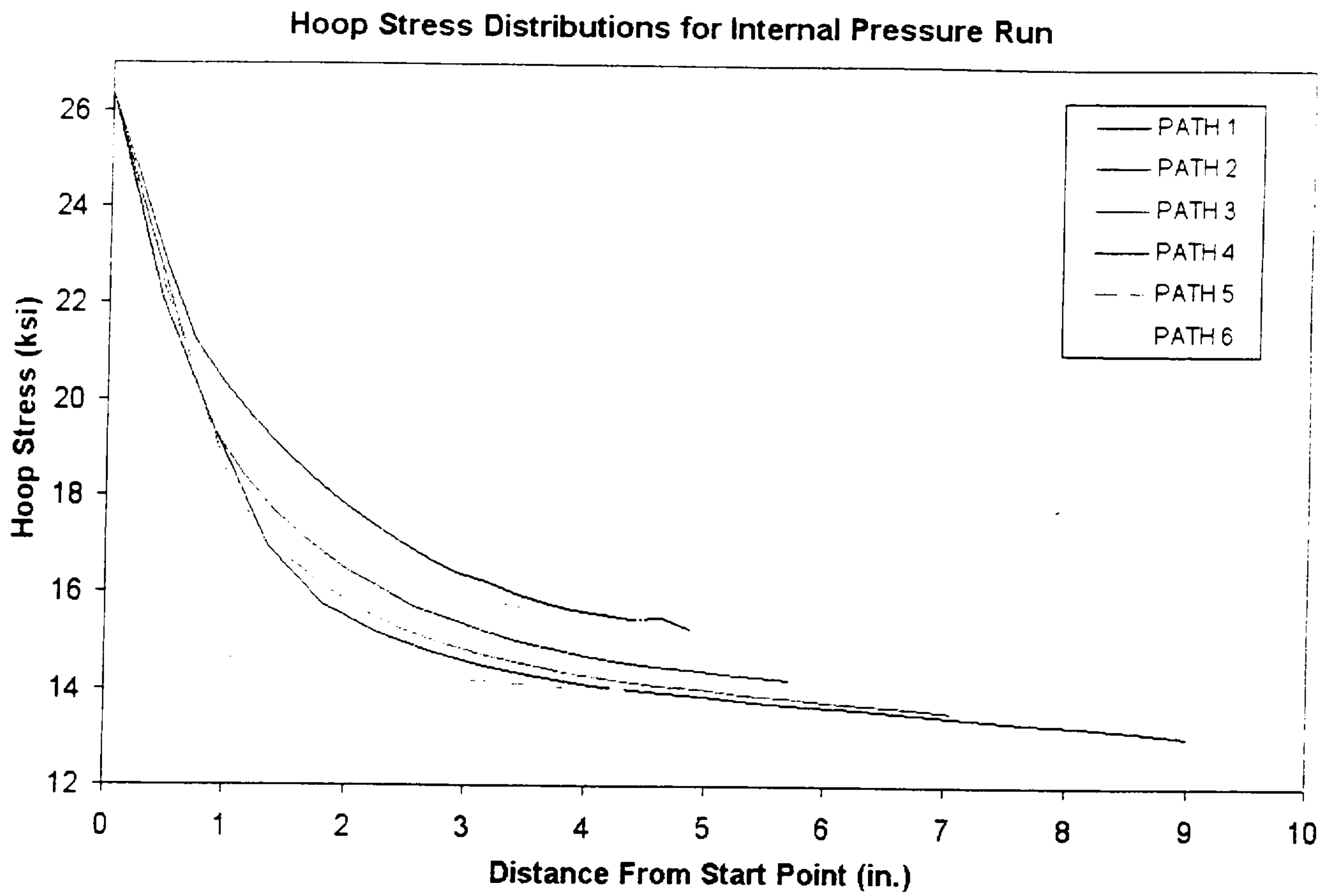

Figure 19: Hoop Stresses Along Given Paths for Internal Pressure Run.

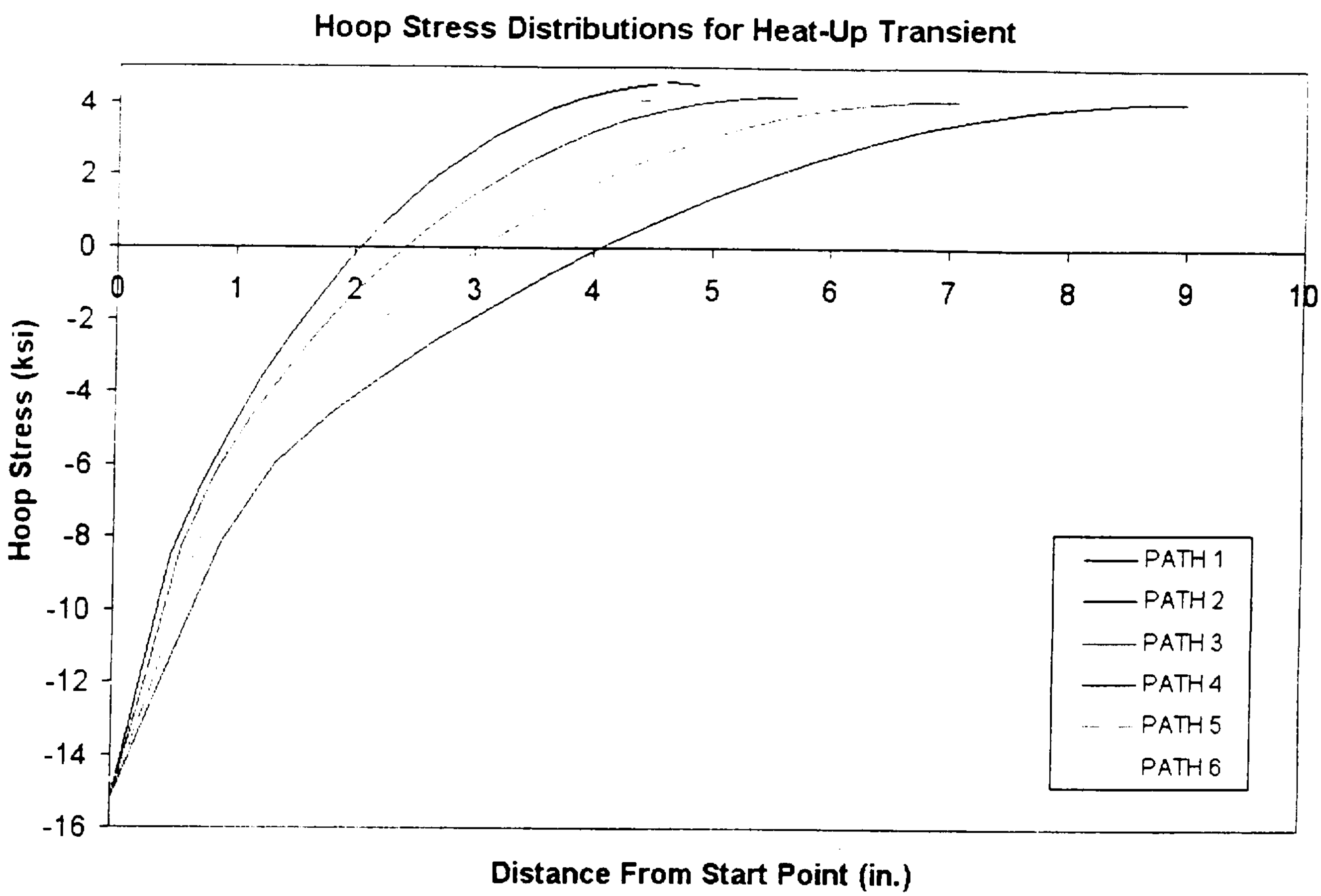

Figure 20: Hoop Stresses Along Given Paths for Heat-Up Transient.

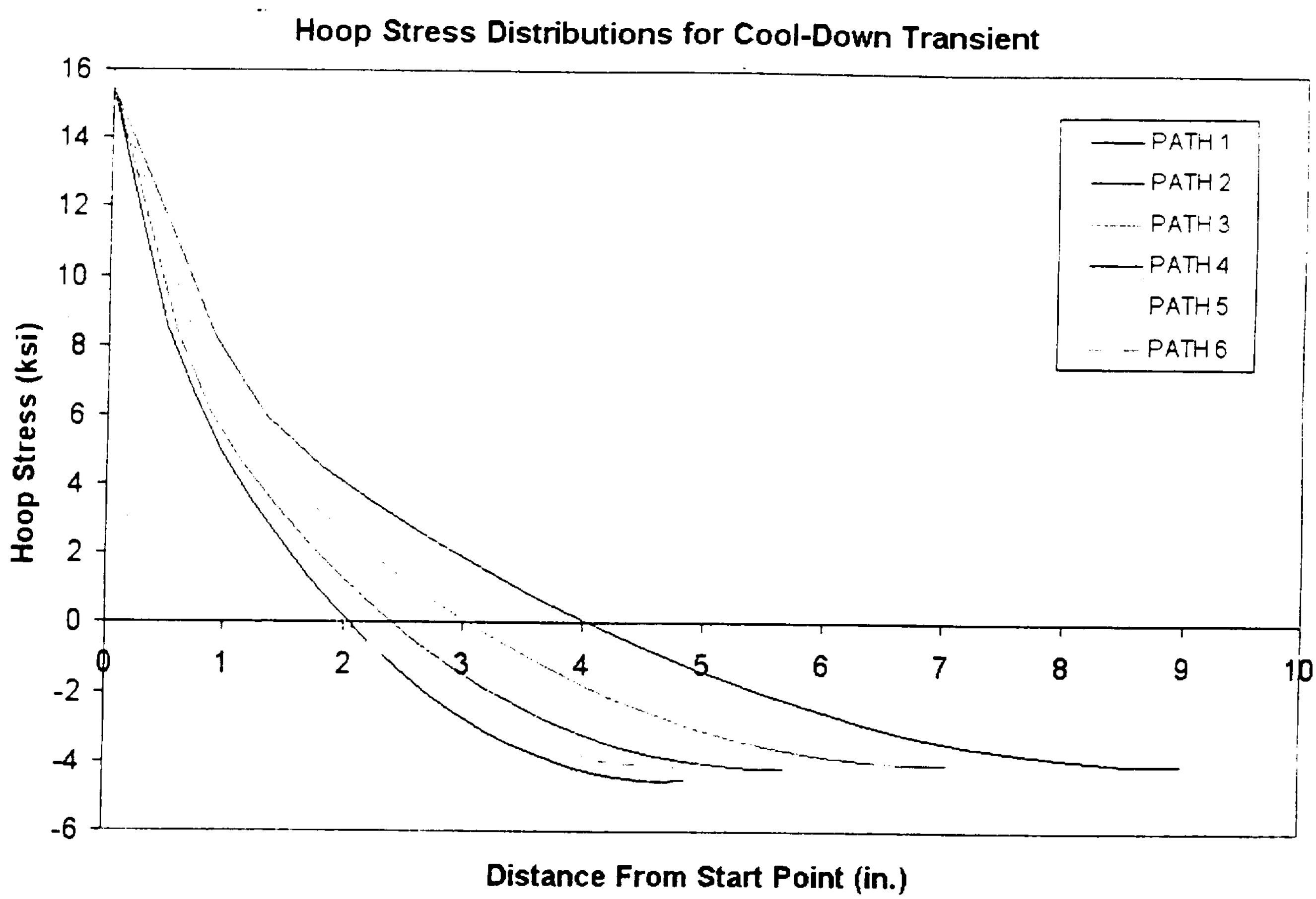

Figure 21: Hoop Stresses Along Given Paths for Cool-Down Transient.

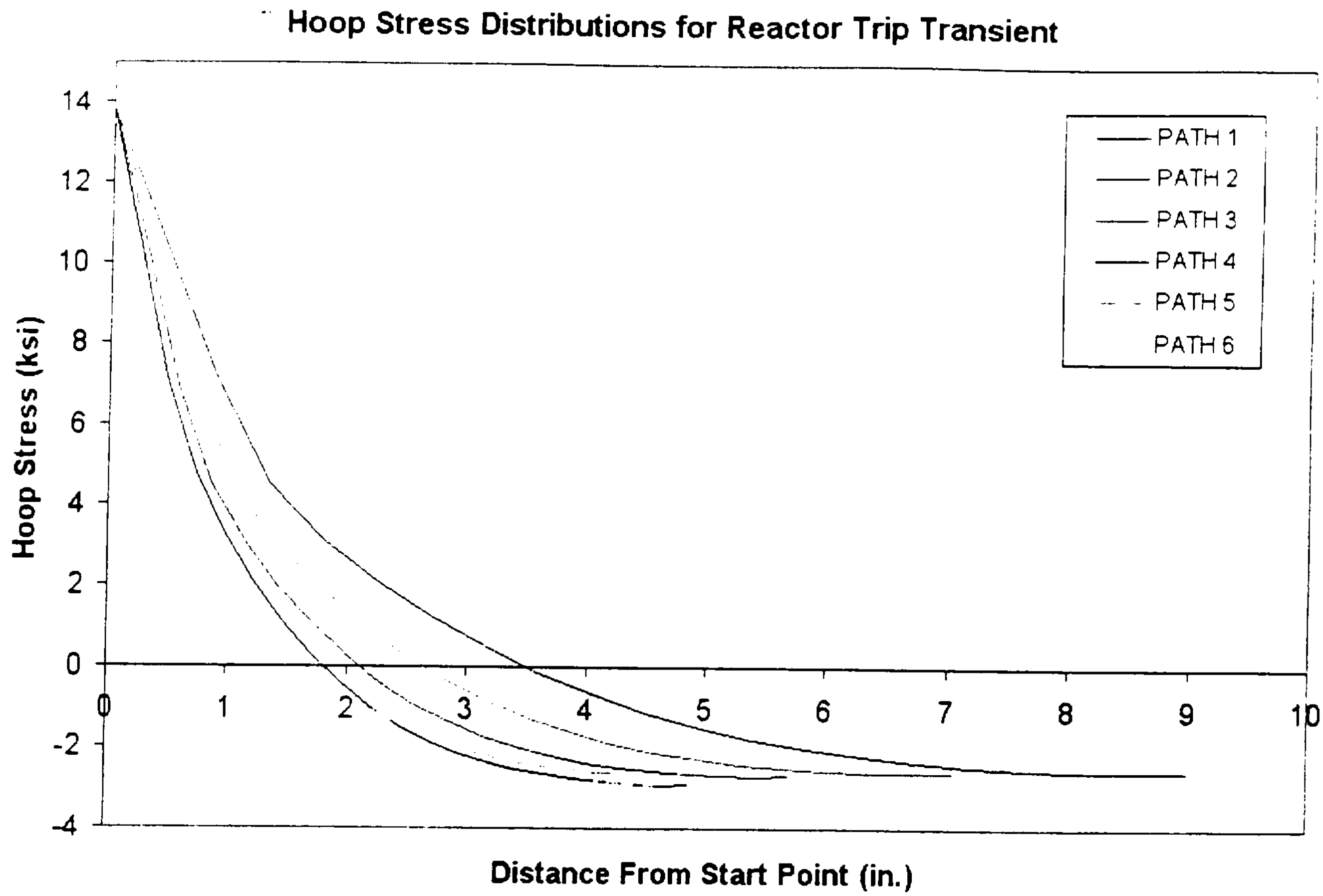

Figure 22: Hoop Stresses Along Given Paths for Reactor Trip.

Hoop Stress Distributions for Loss in Secondary Pressure Transient

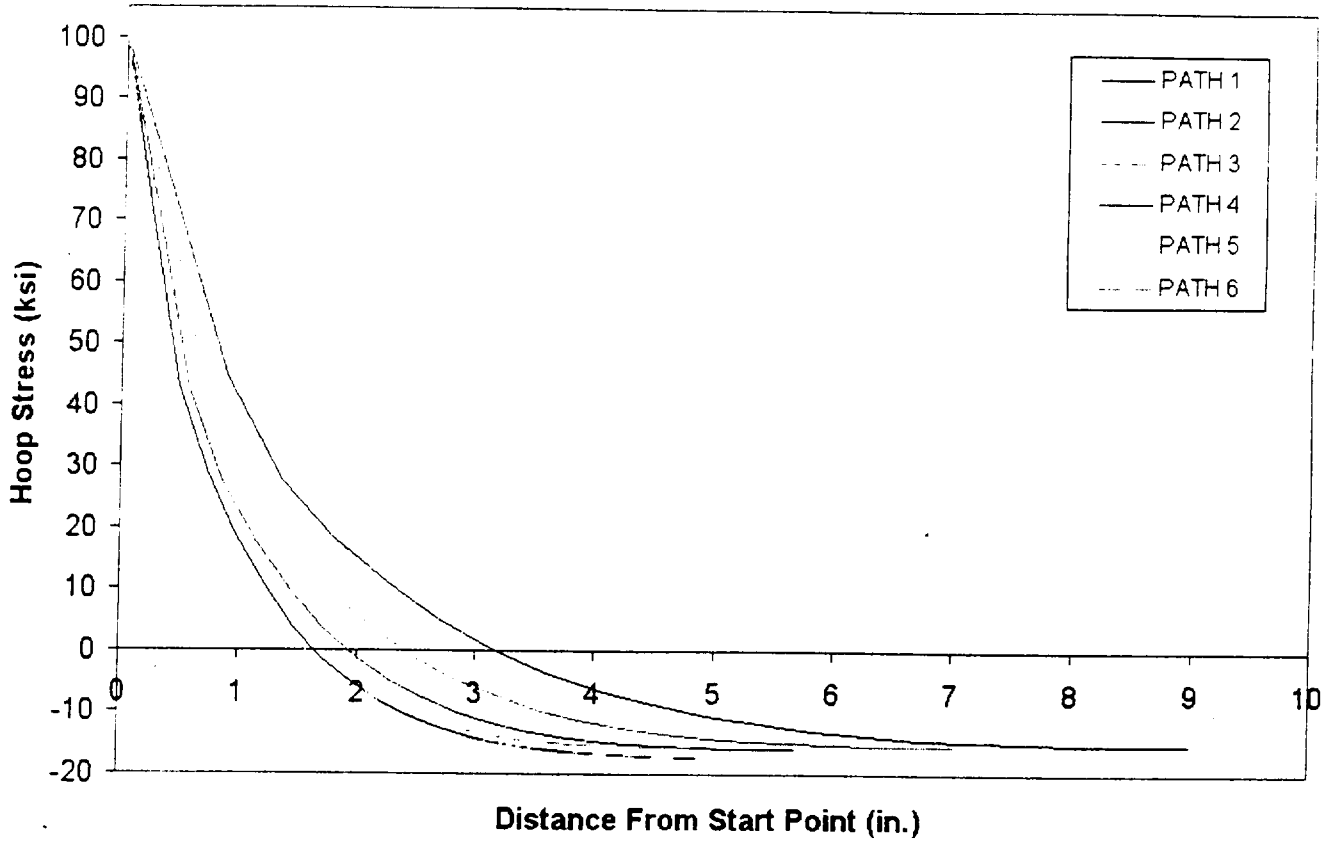

Figure 23: Hoop Stresses Along Given Paths for Loss of Secondary Pressure Transient.

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APPENDIX A

HOOP STRESS HISTORIES FOR THERMAL TRANSIENT RUNS

***** ANSYS POST26 VARIABLE LISTING *****

TIME	43 S Z SzN1	867 S Z SzN923
52.470	-803.279	-741.589
367.29	-4970.95	-4079.85
891.99	-8790.29	-7085.77
1416.7	-10619.6	-8530.90
1766.5	-11281.1	-9049.38
2291.2	-11901.5	-9537.78
2641.0	-12190.9	-9758.94
3165.7	-12540.0	-10027.3
3515.5	-12726.0	-10160.8
4040.2	-12941.1	-10309.1
4390.0	-13227.7	-10547.4
4914.7	-13888.2	-10990.8
5264.5	-13916.0	-10952.2
5789.2	-13629.6	-10786.6
6139.0	-13901.6	-10968.8
6663.7	-14246.7	-11182.1
7013.5	-14379.1	-11267.4
7538.2	-14626.9	-11440.1
7888.0	-14766.8	-11523.2
8412.7	-14811.1	-11531.0

***** ANSYS POST26 VARIABLE LISTING *****

TIME	43 S Z SzN1	867 S Z SzN923
8762.5	-14893.9	-11583.4
9112.3	-15055.4	-11696.0
9287.2	-15141.6	-11749.4
9462.1	-15217.6	-11795.1
9637.0	-15193.4	-11748.4
9811.9	-14973.2	-11545.0
9986.8	-14711.3	-11356.6
10162.	-14446.5	-11198.9
10337.	-14240.4	-11089.8
10494.	-14232.9	-11086.6
10497.	-14207.5	-11045.9
10499.	-14174.4	-11004.7
10507.	-14056.6	-10883.7
10529.	-13671.8	-10538.3
10597.	-12536.7	-9612.35
10799.	-9773.14	-7470.13
10994.	-7647.28	-5843.76
17694.	584.894	428.033

***** ANSYS POST26 VARIABLE LISTING *****

TIME	43 S Z SzN1	867 S Z SzN923
52.470	1461.13	1222.66
367.29	6158.66	4898.66
891.99	10801.0	8433.39
1241.8	12922.9	10099.2
1766.5	15047.5	11627.6
2116.3	15401.6	11915.4
2641.0	15466.9	12010.2
2990.8	15495.3	12066.3
3515.5	15493.5	12081.9
4040.2	15211.2	11889.7
4390.0	14984.0	11736.6
4914.7	14711.6	11564.5
5264.5	14564.7	11485.4
5614.3	14664.4	11611.9
6139.0	15306.1	12072.2
6663.7	14887.9	11731.5
7013.5	14338.1	11354.2
7363.3	14040.0	11146.6
7888.0	13829.7	10996.8
8412.7	13657.7	10870.2

***** ANSYS POST26 VARIABLE LISTING *****

TIME	43 S Z SzN1	867 S Z SzN923
8762.5	13553.5	10790.3
9112.3	13423.9	10691.6
9637.0	13232.6	10541.2
10162.	12920.1	10291.1
10494.	12648.0	10067.5
10497.	12621.4	10026.4
10507.	12468.1	9863.24
10597.	10962.6	8594.51
17694.	0.311841E-10	0.111389E-10

***** ANSYS POST26 VARIABLE LISTING *****

TIME	43 S Z SzN1	867 S Z SzN923
1.6667	807.552	821.876
10.667	2707.16	2972.12
20.667	5158.91	5298.66
30.667	7700.47	7569.74
40.667	10274.2	9792.24
50.000	12684.8	11826.8
68.333	13442.2	11607.2
79.333	13646.8	11488.7
90.333	13758.2	11384.6
101.33	13821.4	11291.4
112.33	13854.8	11206.6
123.33	13868.4	11128.8
134.33	13867.7	11056.6
145.33	13856.5	10989.3
167.33	13812.5	10866.6
277.33	13429.8	10397.1
387.33	13021.7	10051.3
497.33	12691.9	9806.56
600.00	12500.4	9679.99
607.50	12326.8	9479.81

***** ANSYS POST26 VARIABLE LISTING *****

TIME	43 S Z SzN1	867 S Z SzN923
648.00	11163.4	8438.30
693.00	9848.36	7364.71
738.00	8585.40	6362.58
783.00	7431.20	5468.90
825.00	6409.97	4685.09

***** ANSYS POST26 VARIABLE LISTING *****

TIME	43 S Z SzN1	867 S Z SzN923
4.0000	2738.65	3405.99
25.600	18809.8	19182.4
49.600	39533.9	37199.9
73.600	60018.1	54187.6
97.600	80541.7	70760.4
120.00	99171.2	85652.8
126.00	100149.	84577.8
204.00	92179.2	72279.6
300.00	78536.0	60117.4
303.33	78000.9	59634.4
329.85	73531.5	55874.3
359.23	68598.3	51894.0
388.61	63742.9	48073.7
400.00	61909.4	46642.2
408.00	60892.6	45951.8
490.78	51783.7	39203.1
583.12	42917.6	32472.6
640.00	37989.1	28713.8
650.67	37168.5	28109.5
713.76	32625.1	24687.3

***** ANSYS POST26 VARIABLE LISTING *****

TIME	43 S Z SzN1	867 S Z SzN923
783.68	28046.7	21205.1
853.60	23883.6	18029.9
923.52	20088.8	15135.5
960.00	18249.4	13731.5
974.67	17611.9	13266.4
1053.9	14456.6	10892.4
1141.9	11362.2	8533.92
1229.9	8630.05	6444.92
1317.9	6215.50	4597.44
1400.0	4204.90	3056.64
1420.0	3825.87	2784.16
1528.0	2012.03	1419.50
1648.0	310.137	117.801
1768.0	-1127.85	-985.344
1888.0	-2344.42	-1919.22
2000.0	-3311.12	-2661.32
2215.0	-4308.32	-3409.62
3376.0	-6825.81	-5325.32
4666.0	-7362.62	-5728.06
5956.0	-7549.00	-5858.95

***** ANSYS POST26 VARIABLE LISTING *****

TIME	43 S Z SzN1	867 S Z SzN923
7246.0	-7015.59	-5459.38
8450.0	-6959.45	-5430.91

APPENDIX B

HOOP STRESS RESULTS ALONG PREDEFINED PATHS

```
***** POST1 CALCULATION MODULE STATUS *****

 Node for moment summation           0
 Moment summation location         0.00000        0.00000        0.00000
 Abs val key for operation           0
        Safety factor type           0
 Temps of allowed stresses        0.0000      0.0000      0.0000
                                  0.0000      0.0000      0.0000
        Allowable stresses        0.0000      0.0000      0.0000
                                  0.0000      0.0000      0.0000
         Current load case           0
                  Load set           1
                   Substep           1

 *****  Path PATH6
 Header=      2     30     20     21     16      0     30     31
 Header=      0      0      0      0      0      0
     1
     2
     3
     4
     5
     6
     7
     8
     9
    10
    11
    12
    13
    14
    15
    16
    17
    18
    19
    20
    21
    22
    23
    24
    25
    26
    27
    28
    29
    30
Point  Node      X           Y            Z        CS
  1     459    1.71336    47.99888    0.00000    0
  2     594    3.68288    52.27952    0.00000    0
                              NO ELEMENT TABLE ITEMS DEFINED

CURRENT PATH SET TO PATH1

                    ***** PATH DATA STATUS *****

                     CURRENT PATH NAME= PATH1
```

Pressure.res

Point	Node	X	Y	Z	CS
1	1	1.343500	48.00000	0.000000	0
2	594	3.682875	52.27952	0.000000	0

USE GLOBAL COORDINATES FOR SOLUTION RESULTS

CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT VALUES AVERAGED AT EACH NODE

USE 0.0000 AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN CALCULATIONS

DEFINE PATH IN PATH COORDINATE SYSTEM 0

DIRECTION	MAX	MIN
X	3.6829	1.3435
Y	52.280	48.000
Z	0.0000	0.0000

TOTAL PATH LENGTH = 4.8772

DEFINE PATH VARIABLE SZ AS THE NODAL DATA ITEM=S COMP=Z AVGLAB=AVG
ROTATED INTO COORDINATE SYSTEM 0 AND MOVED TO THE PATH
NUMBER OF PATH VARIABLES DEFINED IS 5

*** WARNING *** CP= 1.883 TIME= 12:09:04
The selected element set contains mixed materials.
This could invalidate error estimation.
SUMMARY OF VARIABLE SZ MAX = 26389. MIN = 15256.

PATH BOUNDARY CONDITION DISPLAY KEY = 0

PRINT ALONG PATH DEFINED BY LPATH COMMAND. DSYS= 0

***** PATH VARIABLE SUMMARY *****

S	SZ
0.0000	26389.
0.24386	24638.
0.48772	22794.
0.73158	21200.
0.97544	20342.
1.2193	19610.
1.4632	18977.
1.7070	18408.
1.9509	17886.
2.1947	17458.
2.4386	17059.
2.6825	16725.
2.9263	16420.
3.1702	16215.
3.4140	15985.
3.6579	15800.
3.9017	15658.
4.1456	15552.
4.3895	15450.
4.6333	15479.
4.8772	15256.

CURRENT PATH SET TO PATH2

***** PATH DATA STATUS *****

CURRENT PATH NAME= PATH2

Point	Node	X	Y	Z	CS
1	1	1.343500	48.00000	0.000000	0
2	597	5.240768	52.18388	0.000000	0

USE GLOBAL COORDINATES FOR SOLUTION RESULTS

CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT
VALUES AVERAGED AT EACH NODE

USE 0.0000 AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN
CALCULATIONS

DEFINE PATH IN PATH COORDINATE SYSTEM 0

DIRECTION	MAX	MIN
X	5.2408	1.3435
Y	52.184	48.000
Z	0.0000	0.0000

TOTAL PATH LENGTH = 5.7178

DEFINE PATH VARIABLE SZ AS THE NODAL DATA ITEM=S COMP=Z AVGLAB=AVG
ROTATED INTO COORDINATE SYSTEM 0 AND MOVED TO THE PATH
NUMBER OF PATH VARIABLES DEFINED IS 5

*** WARNING *** CP= 2.754 TIME= 12:09:05
The selected element set contains mixed materials.
This could invalidate error estimation.
SUMMARY OF VARIABLE SZ MAX = 26389. MIN = 14194.

PATH BOUNDARY CONDITION DISPLAY KEY = 0

PRINT ALONG PATH DEFINED BY LPATH COMMAND. DSYS= 0

***** PATH VARIABLE SUMMARY *****

S	SZ
0.0000	26389.
0.28589	24056.
0.57178	21729.
0.85767	19503.
1.1436	18420.
1.4295	17631.
1.7153	16995.
2.0012	16482.
2.2871	16088.
2.5730	15707.
2.8589	15454.
3.1448	15206.
3.4307	15011.
3.7166	14852.
4.0025	14690.
4.2884	14584.
4.5743	14488.
4.8602	14404.

```
  5.1460        14331.
  5.4319        14267.
  5.7178        14194.

 CURRENT PATH SET TO PATH3

                   ***** PATH DATA STATUS *****

                    CURRENT PATH NAME= PATH3

 Point  Node         X             Y             Z           CS
   1       1    1.343500      48.00000      0.000000         0
   2     600    7.176364      51.99980      0.000000         0

 USE GLOBAL COORDINATES FOR SOLUTION RESULTS

 CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT
  VALUES AVERAGED AT EACH NODE

 USE  0.0000     AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN
  CALCULATIONS

 DEFINE PATH IN PATH COORDINATE SYSTEM    0
  DIRECTION        MAX            MIN
     X           7.1764        1.3435
     Y           52.000        48.000
     Z           0.0000        0.0000
  TOTAL PATH LENGTH =    7.0725


 DEFINE PATH VARIABLE SZ       AS THE NODAL DATA ITEM=S    COMP=Z    AVGLAB=AVG
  ROTATED INTO COORDINATE SYSTEM  0 AND MOVED TO THE PATH
  NUMBER OF PATH VARIABLES DEFINED IS    5

 *** WARNING ***                           CP=       3.625   TIME= 12:09:06
 The selected element set contains mixed materials.
  This could invalidate error estimation.
 SUMMARY OF VARIABLE SZ         MAX =    26389.     MIN =    13540.


 PATH BOUNDARY CONDITION DISPLAY KEY =  0

 PRINT ALONG PATH DEFINED BY LPATH COMMAND.  DSYS=  0

 ***** PATH VARIABLE SUMMARY *****

     S           SZ
  0.0000       26389.
 0.35363       23158.
 0.70725       20650.
  1.0609       18073.
  1.4145       16914.
  1.7681       16211.
  2.1218       15646.
  2.4754       15259.
  2.8290       14954.
  3.1826       14693.
  3.5363       14511.
  3.8899       14339.
  4.2435       14213.
```

```
   4.5971        14094.
   4.9508        14006.
   5.3044        13911.
   5.6580        13837.
   6.0117        13760.
   6.3653        13689.
   6.7189        13621.
   7.0725        13540.

 CURRENT PATH SET TO PATH4

                    ***** PATH DATA STATUS *****

                     CURRENT PATH NAME= PATH4

 Point  Node        X            Y            Z           CS
   1       1    1.343500     48.00000     0.000000        0
   2     603    9.575852     51.67010     0.000000        0

  USE GLOBAL COORDINATES FOR SOLUTION RESULTS

 CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT
  VALUES AVERAGED AT EACH NODE

 USE  0.0000     AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN
  CALCULATIONS

 DEFINE PATH IN PATH COORDINATE SYSTEM   0
  DIRECTION       MAX           MIN
     X          9.5759        1.3435
     Y          51.670        48.000
     Z          0.0000        0.0000
  TOTAL PATH LENGTH =    9.0134


 DEFINE PATH VARIABLE SZ       AS THE NODAL DATA ITEM=S    COMP=Z    AVGLAB=AVG
  ROTATED INTO COORDINATE SYSTEM  0 AND MOVED TO THE PATH
  NUMBER OF PATH VARIABLES DEFINED IS   5

 *** WARNING ***                            CP=      4.486   TIME= 12:09:08
 The selected element set contains mixed materials.
  This could invalidate error estimation.
 SUMMARY OF VARIABLE SZ        MAX =    26389.     MIN =    13052.


 PATH BOUNDARY CONDITION DISPLAY KEY =  0

 PRINT ALONG PATH DEFINED BY LPATH COMMAND.  DSYS=  0

 ***** PATH VARIABLE SUMMARY *****

     S           SZ
   0.0000      26389.
  0.45067      22115.
  0.90134      19367.
   1.3520      16964.
   1.8027      15759.
   2.2533      15173.
   2.7040      14773.
   3.1547      14484.
```

3.6054	14266.
4.0560	14094.
4.5067	13965.
4.9574	13855.
5.4080	13753.
5.8587	13665.
6.3094	13583.
6.7600	13498.
7.2107	13413.
7.6614	13329.
8.1121	13242.
8.5627	13155.
9.0134	13052.

CURRENT PATH SET TO PATH5

***** PATH DATA STATUS *****

CURRENT PATH NAME= PATH5

Point	Node	X	Y	Z	CS
1	917	3.386236	47.95678	0.000000	0
2	598	5.840043	52.13464	0.000000	0

USE GLOBAL COORDINATES FOR SOLUTION RESULTS

CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT
VALUES AVERAGED AT EACH NODE

USE 0.0000 AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN
CALCULATIONS

DEFINE PATH IN PATH COORDINATE SYSTEM 0

DIRECTION	MAX	MIN
X	5.8400	3.3862
Y	52.135	47.957
Z	0.0000	0.0000

TOTAL PATH LENGTH = 4.8452

DEFINE PATH VARIABLE SZ AS THE NODAL DATA ITEM=S COMP=Z AVGLAB=AVG
ROTATED INTO COORDINATE SYSTEM 0 AND MOVED TO THE PATH
NUMBER OF PATH VARIABLES DEFINED IS 5

*** WARNING *** CP= 5.348 TIME= 12:09:09
The selected element set contains mixed materials.
This could invalidate error estimation.
SUMMARY OF VARIABLE SZ MAX = 16064. MIN = 13944.

PATH BOUNDARY CONDITION DISPLAY KEY = 0

PRINT ALONG PATH DEFINED BY LPATH COMMAND. DSYS= 0

***** PATH VARIABLE SUMMARY *****

S	SZ
0.0000	16064.
0.24226	15946.
0.48452	15395.

```
 0.72678       14821.
 0.96904       14674.
  1.2113       14607.
  1.4536       14545.
  1.6958       14482.
  1.9381       14416.
  2.1803       14351.
  2.4226       14304.
  2.6648       14256.
  2.9071       14210.
  3.1494       14170.
  3.3916       14123.
  3.6339       14092.
  3.8761       14063.
  4.1184       14034.
  4.3607       14007.
  4.6029       13980.
  4.8452       13944.

 CURRENT PATH SET TO PATH6

                    ***** PATH DATA STATUS *****

                     CURRENT PATH NAME= PATH6

 Point  Node        X            Y            Z            CS
   1     459    1.713356     47.99888     0.000000          0
   2     594    3.682875     52.27952     0.000000          0

  USE GLOBAL COORDINATES FOR SOLUTION RESULTS

 CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT
  VALUES AVERAGED AT EACH NODE

 USE  0.0000     AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN
  CALCULATIONS

 DEFINE PATH IN PATH COORDINATE SYSTEM    0
  DIRECTION         MAX             MIN
     X          3.6829          1.7134
     Y          52.280          47.999
     Z          0.0000          0.0000
  TOTAL PATH LENGTH =    4.7120


 DEFINE PATH VARIABLE SZ       AS THE NODAL DATA ITEM=S    COMP=Z    AVGLAB=AVG
  ROTATED INTO COORDINATE SYSTEM  0 AND MOVED TO THE PATH
  NUMBER OF PATH VARIABLES DEFINED IS    5

 *** WARNING ***                          CP=      6.209   TIME= 12:09:10
 The selected element set contains mixed materials.
  This could invalidate error estimation.
 SUMMARY OF VARIABLE SZ        MAX =     22872.     MIN =    15256.


 PATH BOUNDARY CONDITION DISPLAY KEY =  0

 PRINT ALONG PATH DEFINED BY LPATH COMMAND.  DSYS=  0

 ***** PATH VARIABLE SUMMARY *****
```

S	SZ
0.0000	22872.
0.23560	21611.
0.47120	20249.
0.70680	19006.
0.94240	18501.
1.1780	18102.
1.4136	17736.
1.6492	17397.
1.8848	17086.
2.1204	16811.
2.3560	16538.
2.5916	16335.
2.8272	16137.
3.0628	15978.
3.2984	15792.
3.5340	15656.
3.7696	15562.
4.0052	15478.
4.2408	15399.
4.4764	15464.
4.7120	15256.

***** POST1 CALCULATION MODULE STATUS *****

Node for moment summation	0		
Moment summation location	0.00000	0.00000	0.00000
Abs val key for operation	0		
Safety factor type	0		
Temps of allowed stresses	0.0000	0.0000	0.0000
..	0.0000	0.0000	0.0000
Allowable stresses	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000
Current load case	0		
Load set	8		
Substep	1		

***** Path PATH6

Header=	2	30	20	21	16	0	30	31
Header=	0	0	0	0	0	0		

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30

Point	Node	X	Y	Z	CS
1	459	1.71336	47.99888	0.00000	0
2	594	3.68288	52.27952	0.00000	0

NO ELEMENT TABLE ITEMS DEFINED

CURRENT PATH SET TO PATH1

***** PATH DATA STATUS *****

CURRENT PATH NAME= PATH1

Point	Node	X	Y	Z	CS
1	1	1.343500	48.00000	0.000000	0
2	594	3.682875	52.27952	0.000000	0

USE GLOBAL COORDINATES FOR SOLUTION RESULTS

CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT VALUES AVERAGED AT EACH NODE

USE 0.0000 AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN CALCULATIONS

DEFINE PATH IN PATH COORDINATE SYSTEM 0

DIRECTION	MAX	MIN
X	3.6829	1.3435
Y	52.280	48.000
Z	0.0000	0.0000

TOTAL PATH LENGTH = 4.8772

DEFINE PATH VARIABLE SZ AS THE NODAL DATA ITEM=S COMP=Z AVGLAB=AVG
ROTATED INTO COORDINATE SYSTEM 0 AND MOVED TO THE PATH
NUMBER OF PATH VARIABLES DEFINED IS 5
SUMMARY OF VARIABLE SZ MAX = 15491. MIN = -4569.8

PATH BOUNDARY CONDITION DISPLAY KEY = 0

PRINT ALONG PATH DEFINED BY LPATH COMMAND. DSYS= 0

***** PATH VARIABLE SUMMARY *****

S	SZ
0.0000	15491.
0.24386	11929.
0.48772	8526.0
0.73158	6491.1
0.97544	4951.4
1.2193	3596.0
1.4632	2387.0
1.7070	1304.8
1.9509	337.64
2.1947	-522.62
2.4386	-1286.5
2.6825	-1961.9
2.9263	-2548.9
3.1702	-3076.8
3.4140	-3498.0
3.6579	-3850.9
3.9017	-4132.9
4.1456	-4342.7
4.3895	-4473.0
4.6333	-4569.8
4.8772	-4495.2

CURRENT PATH SET TO PATH2

***** PATH DATA STATUS *****

CURRENT PATH NAME= PATH2

Point	Node	X	Y	Z	CS
1	1	1.343500	48.00000	0.000000	0
2	597	5.240768	52.18388	0.000000	0

USE GLOBAL COORDINATES FOR SOLUTION RESULTS

CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT
VALUES AVERAGED AT EACH NODE

USE 0.0000 AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN
CALCULATIONS

DEFINE PATH IN PATH COORDINATE SYSTEM 0

DIRECTION	MAX	MIN
X	5.2408	1.3435
Y	52.184	48.000
Z	0.0000	0.0000

TOTAL PATH LENGTH = 5.7178

DEFINE PATH VARIABLE SZ AS THE NODAL DATA ITEM=S COMP=Z AVGLAB=AVG
ROTATED INTO COORDINATE SYSTEM 0 AND MOVED TO THE PATH
NUMBER OF PATH VARIABLES DEFINED IS 5
SUMMARY OF VARIABLE SZ MAX = 15491. MIN = -4169.7

PATH BOUNDARY CONDITION DISPLAY KEY = 0

PRINT ALONG PATH DEFINED BY LPATH COMMAND. DSYS= 0

***** PATH VARIABLE SUMMARY *****

S	SZ
0.0000	15491.
0.28589	12093.
0.57178	8353.8
0.85767	6119.8
1.1436	4626.2
1.4295	3359.7
1.7153	2239.5
2.0012	1241.1
2.2871	349.11
2.5730	-448.05
2.8589	-1157.7
3.1448	-1783.0
3.4307	-2330.1
3.7166	-2809.2
4.0025	-3202.7
4.2884	-3531.4
4.5743	-3790.0
4.8602	-3980.8
5.1460	-4107.5
5.4319	-4169.7
5.7178	-4162.6

CURRENT PATH SET TO PATH3

***** PATH DATA STATUS *****

CURRENT PATH NAME= PATH3

Point	Node	X	Y	Z	CS
1	1	1.343500	48.00000	0.000000	0
2	600	7.176364	51.99980	0.000000	0

USE GLOBAL COORDINATES FOR SOLUTION RESULTS

CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT
VALUES AVERAGED AT EACH NODE

USE 0.0000 AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN
CALCULATIONS

DEFINE PATH IN PATH COORDINATE SYSTEM 0

DIRECTION	MAX	MIN
X	7.1764	1.3435
Y	52.000	48.000
Z	0.0000	0.0000

TOTAL PATH LENGTH = 7.0725

DEFINE PATH VARIABLE SZ AS THE NODAL DATA ITEM=S COMP=Z AVGLAB=AVG
ROTATED INTO COORDINATE SYSTEM 0 AND MOVED TO THE PATH
NUMBER OF PATH VARIABLES DEFINED IS 5
SUMMARY OF VARIABLE SZ MAX = 15491. MIN = -4068.1

PATH BOUNDARY CONDITION DISPLAY KEY = 0

PRINT ALONG PATH DEFINED BY LPATH COMMAND. DSYS= 0

***** PATH VARIABLE SUMMARY *****

S	SZ
0.0000	15491.
0.35363	12028.
0.70725	8278.3
1.0609	5893.6
1.4145	4472.2
1.7681	3302.0
2.1218	2254.8
2.4754	1322.2
2.8290	478.28
3.1826	-282.15
3.5363	-970.18
3.8899	-1582.5
4.2435	-2129.8
4.5971	-2598.3
4.9508	-3013.8
5.3044	-3355.6
5.6580	-3631.5
6.0117	-3837.8
6.3653	-3980.8
6.7189	-4059.2
7.0725	-4068.1

CURRENT PATH SET TO PATH4

***** PATH DATA STATUS *****

CURRENT PATH NAME= PATH4

Point	Node	X	Y	Z	CS
1	1	1.343500	48.00000	0.000000	0
2	603	9.575852	51.67010	0.000000	0

USE GLOBAL COORDINATES FOR SOLUTION RESULTS

CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT
VALUES AVERAGED AT EACH NODE

USE 0.0000 AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN
CALCULATIONS

DEFINE PATH IN PATH COORDINATE SYSTEM 0

DIRECTION	MAX	MIN
X	9.5759	1.3435
Y	51.670	48.000
Z	0.0000	0.0000

TOTAL PATH LENGTH = 9.0134

DEFINE PATH VARIABLE SZ AS THE NODAL DATA ITEM=S COMP=Z AVGLAB=AVG
ROTATED INTO COORDINATE SYSTEM 0 AND MOVED TO THE PATH
NUMBER OF PATH VARIABLES DEFINED IS 5
SUMMARY OF VARIABLE SZ MAX = 15491. MIN = -4053.9

PATH BOUNDARY CONDITION DISPLAY KEY = 0

PRINT ALONG PATH DEFINED BY LPATH COMMAND. DSYS= 0

***** PATH VARIABLE SUMMARY *****

S	SZ
0.0000	15491.
0.45067	11881.
0.90134	8265.6
1.3520	5894.4
1.8027	4516.6
2.2533	3441.2
2.7040	2468.1
3.1547	1574.1
3.6054	754.93
4.0560	3.1133
4.5067	-690.81
4.9574	-1323.8
5.4080	-1891.4
5.8587	-2397.9
6.3094	-2849.1
6.7600	-3224.5
7.2107	-3535.7
7.6614	-3774.0
8.1121	-3938.0
8.5627	-4033.6
9.0134	-4053.9

CURRENT PATH SET TO PATH5

***** PATH DATA STATUS *****

CURRENT PATH NAME= PATH5

Point	Node	X	Y	Z	CS
1	917	3.386236	47.95678	0.000000	0
2	598	5.840043	52.13464	0.000000	0

USE GLOBAL COORDINATES FOR SOLUTION RESULTS

CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT
VALUES AVERAGED AT EACH NODE

USE 0.0000 AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN
CALCULATIONS

DEFINE PATH IN PATH COORDINATE SYSTEM 0

DIRECTION	MAX	MIN
X	5.8400	3.3862
Y	52.135	47.957
Z	0.0000	0.0000

TOTAL PATH LENGTH = 4.8452

DEFINE PATH VARIABLE SZ AS THE NODAL DATA ITEM=S COMP=Z AVGLAB=AVG
ROTATED INTO COORDINATE SYSTEM 0 AND MOVED TO THE PATH
NUMBER OF PATH VARIABLES DEFINED IS 5
SUMMARY OF VARIABLE SZ MAX = 12354. MIN = -4114.1

PATH BOUNDARY CONDITION DISPLAY KEY = 0

PRINT ALONG PATH DEFINED BY LPATH COMMAND. DSYS= 0

***** PATH VARIABLE SUMMARY *****

S	SZ
0.0000	12354.
0.24226	9441.3
0.48452	6434.0
0.72678	4982.9
0.96904	3871.7
1.2113	2858.3
1.4536	1915.6
1.6958	1043.8
1.9381	243.03
2.1803	-487.41
2.4226	-1151.6
2.6648	-1746.6
2.9071	-2271.7
3.1494	-2742.5
3.3916	-3127.2
3.6339	-3452.4
3.8761	-3712.9
4.1184	-3908.6
4.3607	-4041.1
4.6029	-4110.5
4.8452	-4114.1

CURRENT PATH SET TO PATH6

***** PATH DATA STATUS *****

CURRENT PATH NAME= PATH6

Point	Node	X	Y	Z	CS
1	459	1.713356	47.99888	0.000000	0
2	594	3.682875	52.27952	0.000000	0

USE GLOBAL COORDINATES FOR SOLUTION RESULTS

CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT
VALUES AVERAGED AT EACH NODE

USE 0.0000 AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN
CALCULATIONS

DEFINE PATH IN PATH COORDINATE SYSTEM 0

DIRECTION	MAX	MIN
X	3.6829	1.7134
Y	52.280	47.999
Z	0.0000	0.0000

TOTAL PATH LENGTH = 4.7120

DEFINE PATH VARIABLE SZ AS THE NODAL DATA ITEM=S COMP=Z AVGLAB=AVG
ROTATED INTO COORDINATE SYSTEM 0 AND MOVED TO THE PATH
NUMBER OF PATH VARIABLES DEFINED IS 5
SUMMARY OF VARIABLE SZ MAX = 15020. MIN = -4563.6

PATH BOUNDARY CONDITION DISPLAY KEY = 0

PRINT ALONG PATH DEFINED BY LPATH COMMAND. DSYS= 0

***** PATH VARIABLE SUMMARY *****

S	SZ
0.0000	15020.
0.23560	11245.
0.47120	7718.0
0.70680	5895.1
0.94240	4543.3
1.1780	3329.2
1.4136	2218.1
1.6492	1205.1
1.8848	286.14
2.1204	-543.61
2.3560	-1287.7
2.5916	-1949.6
2.8272	-2528.4
3.0628	-3052.3
3.2984	-3468.8
3.5340	-3822.6
3.7696	-4108.1
4.0052	-4319.6
4.2408	-4454.9
4.4764	-4563.6
4.7120	-4495.2

```
                    ***** POST1 CALCULATION MODULE STATUS *****

 Node for moment summation             0
 Moment summation location          0.00000        0.00000        0.00000
 Abs val key for operation             0
       Safety factor type              0
 Temps of allowed stresses         0.0000         0.0000         0.0000
                                   0.0000         0.0000         0.0000
       Allowable stresses          0.0000         0.0000         0.0000
                                   0.0000         0.0000         0.0000
        Current load case              0
                 Load set             12
                  Substep              1

 *****  Path PATH6
 Header=      2     30     20     21     16      0     30     31
 Header=      0      0      0      0      0      0
     1
     2
     3
     4
     5
     6
     7
     8
     9
    10
    11
    12
    13
    14
    15
    16
    17
    18
    19
    20
    21
    22
    23
    24
    25
    26
    27
    28
    29
    30
Point  Node      X           Y            Z       CS
  1     459     1.71336    47.99888    0.00000    0
  2     594.    3.68288    52.27952    0.00000    0
                              NO ELEMENT TABLE ITEMS DEFINED

CURRENT PATH SET TO PATH1

                       ***** PATH DATA STATUS *****

                        CURRENT PATH NAME= PATH1
```

Point	Node	X	Y	Z	CS
1	1	1.343500	48.00000	0.000000	0
2	594	3.682875	52.27952	0.000000	0

USE GLOBAL COORDINATES FOR SOLUTION RESULTS

CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT
VALUES AVERAGED AT EACH NODE

USE 0.0000 AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN
CALCULATIONS

DEFINE PATH IN PATH COORDINATE SYSTEM 0

DIRECTION	MAX	MIN
X	3.6829	1.3435
Y	52.280	48.000
Z	0.0000	0.0000

TOTAL PATH LENGTH = 4.8772

DEFINE PATH VARIABLE SZ AS THE NODAL DATA ITEM=S COMP=Z AVGLAB=AVG
ROTATED INTO COORDINATE SYSTEM 0 AND MOVED TO THE PATH
NUMBER OF PATH VARIABLES DEFINED IS 5

*** WARNING *** CP= 1.933 TIME= 12:05:54
The selected element set contains mixed materials.
This could invalidate error estimation.
SUMMARY OF VARIABLE SZ MAX = 13865. MIN = -2937.2

PATH BOUNDARY CONDITION DISPLAY KEY = 0

PRINT ALONG PATH DEFINED BY LPATH COMMAND. DSYS= 0

***** PATH VARIABLE SUMMARY *****

S	SZ
0.0000	13865.
0.24386	10408.
0.48772	7017.5
0.73158	4789.1
0.97544	3332.5
1.2193	2131.7
1.4632	1119.4
1.7070	273.01
1.9509	-426.28
2.1947	-997.19
2.4386	-1458.4
2.6825	-1828.6
2.9263	-2119.6
3.1702	-2356.6
3.4140	-2527.9
3.6579	-2660.3
3.9017	-2761.5
4.1456	-2836.5
4.3895	-2886.0
4.6333	-2937.2
4.8772	-2916.1

CURRENT PATH SET TO PATH2

***** PATH DATA STATUS *****

CURRENT PATH NAME= PATH2

Point	Node	X	Y	Z	CS
1	1	1.343500	48.00000	0.000000	0
2	597	5.240768	52.18388	0.000000	0

USE GLOBAL COORDINATES FOR SOLUTION RESULTS

CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT
VALUES AVERAGED AT EACH NODE

USE 0.0000 AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN
CALCULATIONS

DEFINE PATH IN PATH COORDINATE SYSTEM 0

DIRECTION	MAX	MIN
X	5.2408	1.3435
Y	52.184	48.000
Z	0.0000	0.0000

TOTAL PATH LENGTH = 5.7178

DEFINE PATH VARIABLE SZ AS THE NODAL DATA ITEM=S COMP=Z AVGLAB=AVG
ROTATED INTO COORDINATE SYSTEM 0 AND MOVED TO THE PATH
NUMBER OF PATH VARIABLES DEFINED IS 5

*** WARNING *** CP= 2.794 TIME= 12:05:55
The selected element set contains mixed materials.
This could invalidate error estimation.
SUMMARY OF VARIABLE SZ MAX = 13865. MIN = -2701.5

PATH BOUNDARY CONDITION DISPLAY KEY = 0

PRINT ALONG PATH DEFINED BY LPATH COMMAND. DSYS= 0

***** PATH VARIABLE SUMMARY *****

S	SZ
0.0000	13865.
0.28589	10604.
0.57178	6964.3
0.85767	4529.9
1.1436	3108.2
1.4295	1981.9
1.7153	1035.9
2.0012	244.93
2.2871	-409.10
2.5730	-944.87
2.8589	-1381.3
3.1448	-1729.2
3.4307	-2004.4
3.7166	-2222.0
4.0025	-2381.4
4.2884	-2502.7
4.5743	-2590.1
4.8602	-2649.4

```
    5.1460      -2685.6
    5.4319      -2701.5
    5.7178      -2695.5

 CURRENT PATH SET TO PATH3

                        ***** PATH DATA STATUS *****

                        CURRENT PATH NAME= PATH3

 Point  Node        X              Y              Z              CS
   1       1    1.343500       48.00000       0.000000           0
   2     600    7.176364       51.99980       0.000000           0

 USE GLOBAL COORDINATES FOR SOLUTION RESULTS

 CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT
  VALUES AVERAGED AT EACH NODE

 USE  0.0000     AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN
  CALCULATIONS

 DEFINE PATH IN PATH COORDINATE SYSTEM    0
  DIRECTION        MAX             MIN
     X           7.1764          1.3435
     Y           52.000          48.000
     Z           0.0000          0.0000
  TOTAL PATH LENGTH =     7.0725


 DEFINE PATH VARIABLE SZ        AS THE NODAL DATA ITEM=S    COMP=Z    AVGLAB=AVG
  ROTATED INTO COORDINATE SYSTEM  0 AND MOVED TO THE PATH
  NUMBER OF PATH VARIABLES DEFINED IS   5

 *** WARNING ***                          CP=       3.635   TIME= 12:05:56
 The selected element set contains mixed materials.
  This could invalidate error estimation.
 SUMMARY OF VARIABLE SZ         MAX =     13865.      MIN =    -2613.5


 PATH BOUNDARY CONDITION DISPLAY KEY =  0

 PRINT ALONG PATH DEFINED BY LPATH COMMAND.  DSYS=  0

 ***** PATH VARIABLE SUMMARY *****

      S            SZ
    0.0000       13865.
   0.35363       10591.
   0.70725       7043.9
    1.0609       4414.7
    1.4145       3025.9
    1.7681       1968.2
    2.1218       1067.7
    2.4754       310.09
    2.8290      -326.82
    3.1826      -854.17
    3.5363      -1287.8
    3.8899      -1635.9
    4.2435      -1914.3
```

4.5971	-2128.3
4.9508	-2293.3
5.3044	-2416.9
5.6580	-2504.8
6.0117	-2562.8
6.3653	-2598.1
6.7189	-2613.5
7.0725	-2607.8

CURRENT PATH SET TO PATH4

***** PATH DATA STATUS *****

CURRENT PATH NAME= PATH4

Point	Node	X	Y	Z	CS
1	1	1.343500	48.00000	0.000000	0
2	603	9.575852	51.67010	0.000000	0

USE GLOBAL COORDINATES FOR SOLUTION RESULTS

CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT
VALUES AVERAGED AT EACH NODE

USE 0.0000 AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN
CALCULATIONS

DEFINE PATH IN PATH COORDINATE SYSTEM 0

DIRECTION	MAX	MIN
X	9.5759	1.3435
Y	51.670	48.000
Z	0.0000	0.0000

TOTAL PATH LENGTH = 9.0134

DEFINE PATH VARIABLE SZ AS THE NODAL DATA ITEM=S COMP=Z AVGLAB=AVG
ROTATED INTO COORDINATE SYSTEM 0 AND MOVED TO THE PATH
NUMBER OF PATH VARIABLES DEFINED IS 5

*** WARNING *** CP= 4.486 TIME= 12:05:57
The selected element set contains mixed materials.
This could invalidate error estimation.
SUMMARY OF VARIABLE SZ MAX = 13865. MIN = -2576.8

PATH BOUNDARY CONDITION DISPLAY KEY = 0

PRINT ALONG PATH DEFINED BY LPATH COMMAND. DSYS= 0

***** PATH VARIABLE SUMMARY *****

S	SZ
0.0000	13865.
0.45067	10502.
0.90134	7124.6
1.3520	4536.0
1.8027	3114.1
2.2533	2114.9
2.7040	1246.1
3.1547	492.62

3.6054	-145.19
4.0560	-682.16
4.5067	-1132.5
4.9574	-1502.4
5.4080	-1798.8
5.8587	-2034.9
6.3094	-2216.7
6.7600	-2354.9
7.2107	-2454.0
7.6614	-2520.2
8.1121	-2559.0
8.5627	-2576.8
9.0134	-2572.4

CURRENT PATH SET TO PATH5

***** PATH DATA STATUS *****

CURRENT PATH NAME= PATH5

Point	Node	X	Y	Z	CS
1	917	3.386236	47.95678	0.000000	0
2	598	5.840043	52.13464	0.000000	0

USE GLOBAL COORDINATES FOR SOLUTION RESULTS

CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT
VALUES AVERAGED AT EACH NODE

USE 0.0000 AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN
CALCULATIONS

DEFINE PATH IN PATH COORDINATE SYSTEM 0

DIRECTION	MAX	MIN
X	5.8400	3.3862
Y	52.135	47.957
Z	0.0000	0.0000

TOTAL PATH LENGTH = 4.8452

DEFINE PATH VARIABLE SZ AS THE NODAL DATA ITEM=S COMP=Z AVGLAB=AVG
ROTATED INTO COORDINATE SYSTEM 0 AND MOVED TO THE PATH
NUMBER OF PATH VARIABLES DEFINED IS 5

*** WARNING *** CP= 5.368 TIME= 12:05:59
The selected element set contains mixed materials.
This could invalidate error estimation.
SUMMARY OF VARIABLE SZ MAX = 11357. MIN = -2657.5

PATH BOUNDARY CONDITION DISPLAY KEY = 0

PRINT ALONG PATH DEFINED BY LPATH COMMAND. DSYS= 0

***** PATH VARIABLE SUMMARY *****

S	SZ
0.0000	11357.
0.24226	8451.6
0.48452	5287.2

0.72678	3619.1
0.96904	2519.7
1.2113	1589.8
1.4536	779.10
1.6958	83.629
1.9381	-503.47
2.1803	-992.58
2.4226	-1395.1
2.6648	-1720.3
2.9071	-1979.2
3.1494	-2187.0
3.3916	-2340.2
3.6339	-2456.9
3.8761	-2542.6
4.1184	-2601.9
4.3607	-2639.4
4.6029	-2657.5
4.8452	-2655.9

CURRENT PATH SET TO PATH6

***** PATH DATA STATUS *****

CURRENT PATH NAME= PATH6

Point	Node	X	Y	Z	CS
1	459	1.713356	47.99888	0.000000	0
2	594	3.682875	52.27952	0.000000	0

USE GLOBAL COORDINATES FOR SOLUTION RESULTS

CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT
VALUES AVERAGED AT EACH NODE

USE 0.0000 AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN
CALCULATIONS

DEFINE PATH IN PATH COORDINATE SYSTEM 0

DIRECTION	MAX	MIN
X	3.6829	1.7134
Y	52.280	47.999
Z	0.0000	0.0000

TOTAL PATH LENGTH = 4.7120

DEFINE PATH VARIABLE SZ AS THE NODAL DATA ITEM=S COMP=Z AVGLAB=AVG
ROTATED INTO COORDINATE SYSTEM 0 AND MOVED TO THE PATH
NUMBER OF PATH VARIABLES DEFINED IS 5

*** WARNING *** CP= 6.219 TIME= 12:06:00
The selected element set contains mixed materials.
This could invalidate error estimation.
SUMMARY OF VARIABLE SZ MAX = 13529. MIN = -2934.1

PATH BOUNDARY CONDITION DISPLAY KEY = 0

PRINT ALONG PATH DEFINED BY LPATH COMMAND. DSYS= 0

***** PATH VARIABLE SUMMARY *****

S	SZ
0.0000	13529.
0.23560	9909.4
0.47120	6341.5
0.70680	4318.9
0.94240	3025.9
1.1780	1940.4
1.4136	1004.8
1.6492	210.08
1.8848	-455.88
2.1204	-1007.1
2.3560	-1456.4
2.5916	-1818.7
2.8272	-2106.1
3.0628	-2341.0
3.2984	-2510.9
3.5340	-2644.8
3.7696	-2748.7
4.0052	-2824.8
4.2408	-2876.9
4.4764	-2934.1
4.7120	-2916.1

***** POST1 CALCULATION MODULE STATUS *****

Node for moment summation	0		
Moment summation location	0.00000	0.00000	0.00000
Abs val key for operation	0		
Safety factor type	0		
Temps of allowed stresses	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000
Allowable stresses	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000
Current load case	0		
Load set	24		
Substep	1		

***** Path PATH6

Header=	2	30	20	21	16	0	30	31
Header=	0	0	0	0	0	0		

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30

Point	Node	X	Y	Z	CS
1	459	1.71336	47.99888	0.00000	0
2	594	3.68288	52.27952	0.00000	0

NO ELEMENT TABLE ITEMS DEFINED

CURRENT PATH SET TO PATH1

***** PATH DATA STATUS *****

CURRENT PATH NAME= PATH1

Point	Node	X	Y	Z	CS
1	1	1.343500	48.00000	0.000000	0
2	594	3.682875	52.27952	0.000000	0

USE GLOBAL COORDINATES FOR SOLUTION RESULTS

CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT
VALUES AVERAGED AT EACH NODE

USE 0.0000 AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN
CALCULATIONS

DEFINE PATH IN PATH COORDINATE SYSTEM 0

DIRECTION	MAX	MIN
X	3.6829	1.3435
Y	52.280	48.000
Z	0.0000	0.0000

TOTAL PATH LENGTH = 4.8772

DEFINE PATH VARIABLE SZ AS THE NODAL DATA ITEM=S COMP=Z AVGLAB=AVG
ROTATED INTO COORDINATE SYSTEM 0 AND MOVED TO THE PATH
NUMBER OF PATH VARIABLES DEFINED IS 5
SUMMARY OF VARIABLE SZ MAX = 4580.1 MIN = -15213.

PATH BOUNDARY CONDITION DISPLAY KEY = 0

PRINT ALONG PATH DEFINED BY LPATH COMMAND. DSYS= 0

***** PATH VARIABLE SUMMARY *****

S	SZ
0.0000	-15213.
0.24386	-11775.
0.48772	-8498.4
0.73158	-6577.5
0.97544	-5040.8
1.2193	-3672.9
1.4632	-2449.9
1.7070	-1353.9
1.9509	-374.00
2.1947	497.62
2.4386	1271.5
2.6825	1955.4
2.9263	2549.1
3.1702	3084.9
3.4140	3507.8
3.6579	3860.9
3.9017	4142.7
4.1456	4351.8
4.3895	4481.4
4.6333	4580.1
4.8772	4502.7

CURRENT PATH SET TO PATH2

***** PATH DATA STATUS *****

CURRENT PATH NAME= PATH2

```
 Point  Node          X              Y              Z             CS
   1      1      1.343500       48.00000       0.000000           0
   2    597      5.240768       52.18388       0.000000           0

 USE GLOBAL COORDINATES FOR SOLUTION RESULTS

 CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT
  VALUES AVERAGED AT EACH NODE

 USE  0.0000      AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN
  CALCULATIONS

 DEFINE PATH IN PATH COORDINATE SYSTEM    0
  DIRECTION        MAX             MIN
     X            5.2408          1.3435
     Y            52.184          48.000
     Z            0.0000          0.0000
  TOTAL PATH LENGTH =      5.7178


 DEFINE PATH VARIABLE SZ        AS THE NODAL DATA ITEM=S    COMP=Z     AVGLAB=AVG
  ROTATED INTO COORDINATE SYSTEM  0 AND MOVED TO THE PATH
  NUMBER OF PATH VARIABLES DEFINED IS   5
 SUMMARY OF VARIABLE SZ        MAX =    4183.0      MIN =   -15213.


 PATH BOUNDARY CONDITION DISPLAY KEY =  0

 PRINT ALONG PATH DEFINED BY LPATH COMMAND.  DSYS=  0

 ***** PATH VARIABLE SUMMARY *****

     S          SZ
  0.0000     -15213.
  0.28589    -11926.
  0.57178    -8303.6
  0.85767    -6209.4
   1.1436    -4719.1
   1.4295    -3436.6
   1.7153    -2300.7
   2.0012    -1287.7
   2.2871    -382.54
   2.5730     426.32
   2.8589     1145.9
   3.1448     1779.8
   3.4307     2333.6
   3.7166     2819.1
   4.0025     3216.9
   4.2884     3546.8
   4.5743     3804.8
   4.8602     3995.2
   5.1460     4121.2
   5.4319     4183.0
   5.7178     4175.7

 CURRENT PATH SET TO PATH3

                    ***** PATH DATA STATUS *****
```

CURRENT PATH NAME= PATH3

Point	Node	X	Y	Z	CS
1	1	1.343500	48.00000	0.000000	0
2	600	7.176364	51.99980	0.000000	0

USE GLOBAL COORDINATES FOR SOLUTION RESULTS

CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT
VALUES AVERAGED AT EACH NODE

USE 0.0000 AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN
CALCULATIONS

DEFINE PATH IN PATH COORDINATE SYSTEM 0

DIRECTION	MAX	MIN
X	7.1764	1.3435
Y	52.000	48.000
Z	0.0000	0.0000

TOTAL PATH LENGTH = 7.0725

DEFINE PATH VARIABLE SZ AS THE NODAL DATA ITEM=S COMP=Z AVGLAB=AVG
ROTATED INTO COORDINATE SYSTEM 0 AND MOVED TO THE PATH
NUMBER OF PATH VARIABLES DEFINED IS 5
SUMMARY OF VARIABLE SZ MAX = 4084.4 MIN = -15213.

PATH BOUNDARY CONDITION DISPLAY KEY = 0

PRINT ALONG PATH DEFINED BY LPATH COMMAND. DSYS= 0

***** PATH VARIABLE SUMMARY *****

S	SZ
0.0000	-15213.
0.35363	-11854.
0.70725	-8186.5
1.0609	-5978.0
1.4145	-4568.8
1.7681	-3380.9
2.1218	-2316.9
2.4754	-1369.4
2.8290	-512.06
3.1826	260.05
3.5363	958.15
3.8899	1579.1
4.2435	2133.7
4.5971	2606.8
4.9508	3029.1
5.3044	3373.7
5.6580	3649.6
6.0117	3855.3
6.3653	3997.7
6.7189	4075.8
7.0725	4084.4

CURRENT PATH SET TO PATH4

***** PATH DATA STATUS *****

CURRENT PATH NAME= PATH4

Point	Node	X	Y	Z	CS
1	1	1.343500	48.00000	0.000000	0
2	603	9.575852	51.67010	0.000000	0

USE GLOBAL COORDINATES FOR SOLUTION RESULTS

CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT
VALUES AVERAGED AT EACH NODE

USE 0.0000 AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN
CALCULATIONS

DEFINE PATH IN PATH COORDINATE SYSTEM 0

DIRECTION	MAX	MIN
X	9.5759	1.3435
Y	51.670	48.000
Z	0.0000	0.0000

TOTAL PATH LENGTH = 9.0134

DEFINE PATH VARIABLE SZ AS THE NODAL DATA ITEM=S COMP=Z AVGLAB=AVG
ROTATED INTO COORDINATE SYSTEM 0 AND MOVED TO THE PATH
NUMBER OF PATH VARIABLES DEFINED IS 5
SUMMARY OF VARIABLE SZ MAX = 4072.0 MIN = -15213.

PATH BOUNDARY CONDITION DISPLAY KEY = 0

PRINT ALONG PATH DEFINED BY LPATH COMMAND. DSYS= 0

***** PATH VARIABLE SUMMARY *****

S	SZ
0.0000	-15213.
0.45067	-11699.
0.90134	-8162.0
1.3520	-5957.1
1.8027	-4618.7
2.2533	-3525.0
2.7040	-2534.9
3.1547	-1625.4
3.6054	-792.66
4.0560	-28.807
4.5067	675.72
4.9574	1317.9
5.4080	1893.3
5.8587	2405.5
6.3094	2864.0
6.7600	3242.7
7.2107	3555.5
7.6614	3793.3
8.1121	3956.7
8.5627	4051.8
9.0134	4072.0

CURRENT PATH SET TO PATH5

***** PATH DATA STATUS *****

CURRENT PATH NAME= PATH5

Point	Node	X	Y	Z	CS
1	917	3.386236	47.95678	0.000000	0
2	598	5.840043	52.13464	0.000000	0

USE GLOBAL COORDINATES FOR SOLUTION RESULTS

CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT VALUES AVERAGED AT EACH NODE

USE 0.0000 AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN CALCULATIONS

DEFINE PATH IN PATH COORDINATE SYSTEM 0

DIRECTION	MAX	MIN
X	5.8400	3.3862
Y	52.135	47.957
Z	0.0000	0.0000

TOTAL PATH LENGTH = 4.8452

DEFINE PATH VARIABLE SZ AS THE NODAL DATA ITEM=S COMP=Z AVGLAB=AVG
ROTATED INTO COORDINATE SYSTEM 0 AND MOVED TO THE PATH
NUMBER OF PATH VARIABLES DEFINED IS 5
SUMMARY OF VARIABLE SZ MAX = 4128.4 MIN =. -12079.

PATH BOUNDARY CONDITION DISPLAY KEY = 0

PRINT ALONG PATH DEFINED BY LPATH COMMAND. DSYS= 0

***** PATH VARIABLE SUMMARY *****

S	SZ
0.0000	-12079.
0.24226	-9274.5
0.48452	-6445.0
0.72678	-5085.4
0.96904	-3965.2
1.2113	-2932.6
1.4536	-1973.0
1.6958	-1086.4
1.9381	-272.76
2.1803	468.76
2.4226	1142.4
2.6648	1745.5
2.9071	2276.9
3.1494	2754.8
3.3916	3143.0
3.6339	3469.8
3.8761	3729.8
4.1184	3924.7
4.3607	4056.5
4.6029	4125.2
4.8452	4128.4

CURRENT PATH SET TO PATH6

***** PATH DATA STATUS *****

CURRENT PATH NAME= PATH6

Point	Node	X	Y	Z	CS
1	459	1.713356	47.99888	0.000000	0
2	594	3.682875	52.27952	0.000000	0

USE GLOBAL COORDINATES FOR SOLUTION RESULTS

CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT
VALUES AVERAGED AT EACH NODE

USE 0.0000 AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN
CALCULATIONS

DEFINE PATH IN PATH COORDINATE SYSTEM 0

DIRECTION	MAX	MIN
X	3.6829	1.7134
Y	52.280	47.999
Z	0.0000	0.0000

TOTAL PATH LENGTH = 4.7120

DEFINE PATH VARIABLE SZ AS THE NODAL DATA ITEM=S COMP=Z AVGLAB=AVG
ROTATED INTO COORDINATE SYSTEM 0 AND MOVED TO THE PATH
NUMBER OF PATH VARIABLES DEFINED IS 5
SUMMARY OF VARIABLE SZ MAX = 4574.2 MIN = -14736.

PATH BOUNDARY CONDITION DISPLAY KEY = 0

PRINT ALONG PATH DEFINED BY LPATH COMMAND. DSYS= 0

***** PATH VARIABLE SUMMARY *****

S	SZ
0.0000	-14736.
0.23560	-11079.
0.47120	-7709.0
0.70680	-5991.7
0.94240	-4634.6
1.1780	-3404.8
1.4136	-2278.7
1.6492	-1251.9
1.8848	-320.37
2.1204	520.42
2.3560	1274.3
2.5916	1944.3
2.8272	2529.6
3.0628	3061.6
3.2984	3479.6
3.5340	3833.5
3.7696	4118.2
4.0052	4328.8
4.2408	4463.3
4.4764	4574.2
4.7120	4502.7

***** POST1 CALCULATION MODULE STATUS *****

Node for moment summation	0		
Moment summation location	0.00000	0.00000	0.00000
Abs val key for operation	0		
Safety factor type	0		
Temps of allowed stresses	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000
Allowable stresses	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000
Current load case	0		
Load set	7		
Substep	1		

***** Path PATH6

Header=	2	30	20	21	16	0	30	31
Header=	0	0	0	0	0	0		

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Point	Node	X	Y	Z	CS
1	459	1.71336	47.99888	0.00000	0
2	594	3.68288	52.27952	0.00000	0

NO ELEMENT TABLE ITEMS DEFINED

CURRENT PATH SET TO PATH1

***** PATH DATA STATUS *****

CURRENT PATH NAME= PATH1

Point	Node	X	Y	Z	CS
1	1	1.343500	48.00000	0.000000	0
2	594	3.682875	52.27952	0.000000	0

USE GLOBAL COORDINATES FOR SOLUTION RESULTS

CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT
VALUES AVERAGED AT EACH NODE

USE 0.0000 AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN
CALCULATIONS

DEFINE PATH IN PATH COORDINATE SYSTEM 0

DIRECTION	MAX	MIN
X	3.6829	1.3435
Y	52.280	48.000
Z	0.0000	0.0000

TOTAL PATH LENGTH = 4.8772

DEFINE PATH VARIABLE SZ AS THE NODAL DATA ITEM=S COMP=Z AVGLAB=AVG
ROTATED INTO COORDINATE SYSTEM 0 AND MOVED TO THE PATH
NUMBER OF PATH VARIABLES DEFINED IS 5

*** WARNING *** CP= 7.200 TIME= 11:52:10
The selected element set contains mixed materials.
This could invalidate error estimation.
SUMMARY OF VARIABLE SZ MAX = 0.10020E+06 MIN = -17399.

PATH BOUNDARY CONDITION DISPLAY KEY = 0

PRINT ALONG PATH DEFINED BY LPATH COMMAND. DSYS= 0

***** PATH VARIABLE SUMMARY *****

S	SZ
0.0000	0.10020E+06
0.24386	69895.
0.48772	43094.
0.73158	29150.
0.97544	18866.
1.2193	10551.
1.4632	3932.0
1.7070	-1205.4
1.9509	-5142.6
2.1947	-8180.0
2.4386	-10533.
2.6825	-12352.
2.9263	-13728.
3.1702	-14822.
3.4140	-15579.
3.6579	-16155.
3.9017	-16594.
4.1456	-16916.
4.3895	-17124.
4.6333	-17399.
4.8772	-17244.

CURRENT PATH SET TO PATH2

***** PATH DATA STATUS *****

CURRENT PATH NAME= PATH1

Point	Node	X	Y	Z	CS
1	1	1.343500	48.00000	0.000000	0
2	597	5.240768	52.18388	0.000000	0

USE GLOBAL COORDINATES FOR SOLUTION RESULTS

CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT
VALUES AVERAGED AT EACH NODE

USE 0.0000 AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN
CALCULATIONS

DEFINE PATH IN PATH COORDINATE SYSTEM 0

DIRECTION	MAX	MIN
X	5.2408	1.3435
Y	52.184	48.000
Z	0.0000	0.0000

TOTAL PATH LENGTH = 5.7178

DEFINE PATH VARIABLE SZ AS THE NODAL DATA ITEM=S COMP=Z AVGLAB=AVG
ROTATED INTO COORDINATE SYSTEM 0 AND MOVED TO THE PATH
NUMBER OF PATH VARIABLES DEFINED IS 5

*** WARNING *** CP= 8.052 TIME= 11:52:11
The selected element set contains mixed materials.
This could invalidate error estimation.
SUMMARY OF VARIABLE SZ MAX = 0.10020E+06 MIN = -15929.

PATH BOUNDARY CONDITION DISPLAY KEY = 0

PRINT ALONG PATH DEFINED BY LPATH COMMAND. DSYS= 0

***** PATH VARIABLE SUMMARY *****

S	SZ
0.0000	0.10020E+06
0.28589	71884.
0.57178	42592.
0.85767	27541.
1.1436	17613.
1.4295	9770.7
1.7153	3533.7
2.0012	-1310.4
2.2871	-5000.9
2.5730	-7834.4
2.8589	-10049.
3.1448	-11739.
3.4307	-13024.
3.7166	-14004.
4.0025	-14687.
4.2884	-15192.
4.5743	-15541.
4.8602	-15766.

5.1460	-15890.
5.4319	-15929.
5.7178	-15871.

CURRENT PATH SET TO PATH3

***** PATH DATA STATUS *****

CURRENT PATH NAME= PATH3

Point	Node	X	Y	Z	CS
1	1	1.343500	48.00000	0.000000	0
2	600	7.176364	51.99980	0.000000	0

USE GLOBAL COORDINATES FOR SOLUTION RESULTS

CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT
VALUES AVERAGED AT EACH NODE

USE 0.0000 AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN
CALCULATIONS

DEFINE PATH IN PATH COORDINATE SYSTEM 0

DIRECTION	MAX	MIN
X	7.1764	1.3435
Y	52.000	48.000
Z	0.0000	0.0000

TOTAL PATH LENGTH = 7.0725

DEFINE PATH VARIABLE SZ AS THE NODAL DATA ITEM=S COMP=Z AVGLAB=AVG
ROTATED INTO COORDINATE SYSTEM 0 AND MOVED TO THE PATH
NUMBER OF PATH VARIABLES DEFINED IS 5

*** WARNING *** CP= 8.903 TIME= 11:52:12
The selected element set contains mixed materials.
This could invalidate error estimation.
SUMMARY OF VARIABLE SZ MAX = 0.10020E+06 MIN = -15378.

PATH BOUNDARY CONDITION DISPLAY KEY = 0

PRINT ALONG PATH DEFINED BY LPATH COMMAND. DSYS= 0

***** PATH VARIABLE SUMMARY *****

S	SZ
0.0000	0.10020E+06
0.35363	72394.
0.70725	42937.
1.0609	26852.
1.4145	17312.
1.7681	9853.2
2.1218	3829.0
2.4754	-894.57
2.8290	-4534.9
3.1826	-7334.1
3.5363	-9532.1
3.8899	-11219.
4.2435	-12513.

4.5971	-13466.
4.9508	-14173.
5.3044	-14678.
5.6580	-15021.
6.0117	-15231.
6.3653	-15345.
6.7189	-15378.
7.0725	-15323.

CURRENT PATH SET TO PATH4

***** PATH DATA STATUS *****

CURRENT PATH NAME= PATH4

Point	Node	X	Y	Z	CS
1	1	1.343500	48.00000	0.000000	0
2	603	9.575852	51.67010	0.000000	0

USE GLOBAL COORDINATES FOR SOLUTION RESULTS

CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT
VALUES AVERAGED AT EACH NODE

USE 0.0000 AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN
CALCULATIONS

DEFINE PATH IN PATH COORDINATE SYSTEM 0

DIRECTION	MAX	MIN
X	9.5759	1.3435
Y	51.670	48.000
Z	0.0000	0.0000

TOTAL PATH LENGTH = 9.0134

DEFINE PATH VARIABLE SZ AS THE NODAL DATA ITEM=S COMP=Z AVGLAB=AVG
ROTATED INTO COORDINATE SYSTEM 0 AND MOVED TO THE PATH
NUMBER OF PATH VARIABLES DEFINED IS 5

*** WARNING *** CP= 9.754 TIME= 11:52:13
The selected element set contains mixed materials.
This could invalidate error estimation.
SUMMARY OF VARIABLE SZ MAX = 0.10020E+06 MIN = -15155.

PATH BOUNDARY CONDITION DISPLAY KEY = 0

PRINT ALONG PATH DEFINED BY LPATH COMMAND. DSYS= 0

***** PATH VARIABLE SUMMARY *****

S	SZ
0.0000	0.10020E+06
0.45067	72498.
0.90134	44232.
1.3520	27633.
1.8027	18191.
2.2533	11002.
2.7040	5031.9
3.1547	186.78

```
  3.6054      -3529.8
  4.0560      -6416.8
  4.5067      -8724.4
  4.9574      -10538.
  5.4080      -11931.
  5.8587      -12994.
  6.3094      -13791.
  6.7600      -14353.
  7.2107      -14742.
  7.6614      -14985.
  8.1121      -15112.
  8.5627      -15155.
  9.0134      -15106.

 CURRENT PATH SET TO PATH5

                    ***** PATH DATA STATUS *****

                    CURRENT PATH NAME= PATH5

 Point  Node       X            Y            Z           CS
   1     917    3.386236     47.95678     0.000000       0
   2     598    5.840043     52.13464     0.000000       0

  USE GLOBAL COORDINATES FOR SOLUTION RESULTS

 CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT
  VALUES AVERAGED AT EACH NODE

 USE  0.0000     AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN
  CALCULATIONS

 DEFINE PATH IN PATH COORDINATE SYSTEM   0
  DIRECTION      MAX            MIN
     X          5.8400         3.3862
     Y          52.135         47.957
     Z          0.0000         0.0000
  TOTAL PATH LENGTH =    4.8452


 DEFINE PATH VARIABLE SZ       AS THE NODAL DATA ITEM=S    COMP=Z    AVGLAB=AVG
  ROTATED INTO COORDINATE SYSTEM  0 AND MOVED TO THE PATH
  NUMBER OF PATH VARIABLES DEFINED IS   5

 *** WARNING ***                           CP=     10.605   TIME= 11:52:14
 The selected element set contains mixed materials.
  This could invalidate error estimation.
 SUMMARY OF VARIABLE SZ       MAX =    85906.     MIN =   -15651.


 PATH BOUNDARY CONDITION DISPLAY KEY =  0

 PRINT ALONG PATH DEFINED BY LPATH COMMAND.  DSYS=  0

 ***** PATH VARIABLE SUMMARY *****

    S           SZ
  0.0000      85906.
  0.24226     58306.
  0.48452     32792.
```

```
   0.72678       21936.
 ' 0.96904       13973.
   1.2113        7391.1
   1.4536        2023.8
   1.6958       -2200.2
   1.9381       -5472.2
   2.1803       -8028.1
   2.4226       -10044.
   2.6648       -11608.
   2.9071       -12807.
   3.1494       -13738.
   3.3916       -14396.
   3.6339       -14884.
   3.8761       -15229.
   4.1184       -15459.
   4.3607       -15595.
   4.6029       -15651.
   4.8452       -15622.

 CURRENT PATH SET TO PATH6

                        ***** PATH DATA STATUS *****

                         CURRENT PATH NAME= PATH6

 Point   Node          X              Y              Z            CS
   1      459     1.713356       47.99888       0.000000          0
   2      594     3.682875       52.27952       0.000000          0

  USE GLOBAL COORDINATES FOR SOLUTION RESULTS

 CALCULATE NODAL PRINCIPAL VALUES FROM ELEMENT COMPONENT
  VALUES AVERAGED AT EACH NODE

 USE  0.0000     AS THE EFFECTIVE POISSON'S RATIO FOR EQUIVALENT STRAIN
  CALCULATIONS

 DEFINE PATH IN PATH COORDINATE SYSTEM    0
  DIRECTION        MAX              MIN
     X          3.6829           1.7134
     Y          52.280           47.999
     Z          0.0000           0.0000
  TOTAL PATH LENGTH =     4.7120


 DEFINE PATH VARIABLE SZ        AS THE NODAL DATA ITEM=S    COMP=Z    AVGLAB=AVG
  ROTATED INTO COORDINATE SYSTEM  0 AND MOVED TO THE PATH
  NUMBER OF PATH VARIABLES DEFINED IS    5

 *** WARNING ***                            CP=     11.466   TIME= 11:52:15
 The selected element set contains mixed materials.
  This could invalidate error estimation.
 SUMMARY OF VARIABLE SZ        MAX =   0.10059E+06 MIN =   -17381.


 PATH BOUNDARY CONDITION DISPLAY KEY =  0

 PRINT ALONG PATH DEFINED BY LPATH COMMAND.  DSYS=  0

 ***** PATH VARIABLE SUMMARY *****
```

S	SZ
0.0000	0.10059E+06
0.23560	67497.
0.47120	38931.
0.70680	26211.
0.94240	16992.
1.1780	9420.5
1.4136	3283.0
1.6492	-1538.5
1.8848	-5278.9
2.1204	-8205.4
2.3560	-10495.
2.5916	-12272.
2.8272	-13633.
3.0628	-14718.
3.2984	-15472.
3.5340	-16060.
3.7696	-16513.
4.0052	-16843.
4.2408	-17068.
4.4764	-17381.
4.7120	-17244.

RECORD COPY

STRUCTURAL INTEGRITY Associates, Inc.	CALCULATION PACKAGE	FILE No.: WSES-05Q-302 PROJECT No.: WSES-05Q

PROJECT NAME: Pressurizer Heater Weld Crack Growth Analysis

CLIENT: Entergy Operations, Inc.

CALCULATION TITLE: Crack Growth Evaluation

Document Revision	Affected Pages	Revision Description	Project Mgr. Approval Signature & Date	Preparer(s) & Checker(s) Signatures & Date
0	1-8 A1 – A23 FILES ON CD-ROM	Original Issue	[signature] 11/1/00	[signature] 11/1/00 [signature] 11/1/00

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APPENDIX A pc-CRACK Output A1

1.0 PROBLEM STATEMENT/OBJECTIVE

Perform crack growth analysis in the pressurizer heater sleeve-to-pressurizer weld cladding.

2.0 ANALYTICAL APPROACH

1. Develop a finite element model of the lower pressurizer head including the pressurizer-to-heater weld area and the modified repair design to determine local stresses so that a stress distribution away from the weld into the base metal can be determined. The analysis will be based on an enlarged hole in the pressurizer shell to account for outermost heater locations with the largest side-hill angle. Thus, the analysis will be applicable for a repair at any of the pressurizer heater locations.

2. Quantify the cyclic operating conditions expected for the bottom head. Maximum stress and cyclic operations must be determined.

3. Perform stress analysis for the transient thermal conditions and pressure so that the most severe loading condition stress distributions can be determined.

4. Perform a crack growth analysis for assumed cracking at the inner surface. Since the pressurizer cladding is Alloy 600, perform evaluations for both a corner crack and for a crack that extends further into the adjacent cladding.

5. Determine the ASME Section XI allowable flaw size for each crack.

6. Determine the number of cycles to reach the allowable flaw size if this is less than the allowable for the plant life.

3.0 DESIGN CONDITIONS

Operating conditions and geometry have been based on the design input provided by Entergy [1]. Operating conditions include the following significant events;

1. Heatup/Cooldown – 500 lifetime cycles. For the pressurizer, the rate is 200°F/hr, from 70°F to 653°F. The pressure cycles between 0 psig and 2235 psig. The thermal stresses are relatively small and are of opposite sign from pressure stresses in the area of the assumed cracking. However, since thermal stresses develop prior to pressurization, they are considered for the initial part of the heatup transient.

2. Plant Loading/Unloading, Step Load Increase/Decrease and Normal Variations – 10^6 cycles. These are +/- 100 psig and +/- 20°F. It is assumed that the temperature and pressure variations are relatively slow since rapid changes do not normally occur with this high frequency. In additions, the thermal stress sign would be opposite to the pressure stress sign such that it is conservative to neglect the thermal stresses. (There are 2000 variations per Heatup/Cooldown cycle.)

3. Reactor Trip, Loss of Primary Flow and Loss of Load – 480 cycles. This transient is a 2535 psig overpressure, followed by a reduction in pressure to 1685 psig, and then a slow repressurization back to 2235 psig. There is also a significant thermal transient with the temperature reducing to 613°F from normal operating temperature at the same time that the peak pressure occurs. The temperature then decreases an additional 20°F in about 550 seconds before it slowly increases back to normal conditions in another 1400 seconds. (For ease of calculation, it is assumed that there are 500 cycles, the same as the number of Heatup/Cooldown cycles.)

4. Leak Test – 200 cycles. This is assumed to be a separate cycle from zero pressure to normal pressure of 2235 psig. The heatup rate for the pressurizer is given as 100°F/hour. As with normal heatup and cooldown, it is conservative to neglect the transient thermal stresses except for the initiation of the heatup. (It is conservatively assumed that there are 250 of these cycles in the crack growth calculation.)

The five Emergency Condition Loss of Secondary Pressure transients are not included since they are not normal expected events. Section XI [2] provides lower safety factors for these transients and the resulting stresses are not expected to be significantly different than those already evaluated. The 10 ASME Hydrotests to 3125 psig are also not considered. ASME Section XI no longer requires elevated pressure testing of vessels in service.

4.0 STRESS EVALUATION

A local axisymmetric finite element model was created to generate local stress distributions in the vicinity of the heater penetration [3]. This model included a penetration diameter of 2.687 inches to conservatively account for the maximum sidehill dimension of the heater penetration that is furthest from the centerline of the pressurizer. The model also included external modifications to the heater penetration.

For purposes of determining stress intensity factors, a stress distribution across the wall of the vessel was required. For a nozzle corner crack fracture mechanics model, a stress distribution representing the stresses midway between the nozzle bore and the vessel inside surface is appropriate. However, since the stresses increased toward the bore [3], a stress distribute along a path inclined from the

nozzle bore by approximately 30 degrees was conservatively used. A similar path was chosen for a circumferential flaw fracture mechanics model that extended to the same point on the outside of the shell but started from the edge of the weld region on the cladding inside surface. Stresses for all other paths inclined at larger angle were found to have lower stresses as a function of distance from the nozzle-to-shell intersection.

The pressure stress distribution across the wall of the vessel from the region of the Alloy 600 weld along these paths for normal operating pressure of 2235 psig was determined to be 26.4 ksi locally at the heater-to-cladding weld, 22.9 ksi at the edge of the weld and 15.3 ksi at the outside of the pressurizer shell. Since pressure was the major loading condition, the thermal stresses were obtained along the same paths.

During heatup, there is a compressive stress developed prior to pressurization due to the rapid heatup. Pressurization does not begin until the pressurizer exceeds 212°F. The maximum heatup thermal stress was determined to be –15.2 ksi compression at the weld (-14.7 ksi adjacent to the weld) increasing to about 4.5 ksi at the outside of the pressurizer and was used in the evaluation. (One half of this value is used for the leak tests which have a specified heatup rate one half of that for the normal Heatup.)

It is conservatively assumed that the pressure on the crack face increases stress intensity factors. This is done by determining polynomial distribution that approximates the pressure up to a distance of 1.6 inches into the wall (to conservatively allow for cracks up to this depth in the analysis). Subsequent evaluation of crack growth indicates that the assumed distance was conservatively overestimated by about a factor of two.

It is expected that the Alloy 600 welds would have a high degree of residual stresses at the time of initial construction. However, in initial vessel hydrotest and the first heatup to operating conditions, there will be additional tensile yielding of the material due to the applied thermal and pressure stress loadings. Pressurized transients such as the rapid temperature reduction for a reactor trip transient would further yield the material at the surface. However, at both locations considered in the analysis, the combination of pressure plus thermal stresses for the weld region exceeded 35 ksi. Since the maximum stress due to pressure plus thermal for the reactor trip transient was greater than 35 ksi, residual stresses can be neglected. The 35 ksi value is conservatively taken as equal to the room temperature minimum yield strength of Alloy 600 materials from the ASME Code [4], and accounts for some additional tensile stress above the Code value of 27.4 ksi at 650°F.

5.0 FRACTURE MECHANICS ANALYSIS

5.1 Crack Growth Law

The crack growth law for ferritic materials in a water environment from Appendix A of Section XI [2] is used.

5.2 Fracture Toughness

The major stresses in the vicinity of the cracking is due to applied pressure. At conditions of high pressure, the temperature is also high. Thus, it is assumed that the material is on the upper shelf and the fracture toughness curve from Section XI, Appendix A is used, assuming 200 ksi-in$^{1/2}$. A factor of 3.1623 (square root of 10) is used resulting in an allowable fracture toughness is 63.24 ksi-in$^{1/2}$.

5.3 Initial Flaw Size

The initial flaw size is taken as the maximum depth of the Alloy 600 material, resulting in an initial depth of 0.4375 in. [1]. This conservatively assumes that the initial cracking extends to the Alloy 600/ferritic interface.

5.4 Crack Growth Analysis

The crack growth analysis is conducted with **pc-CRACK for Windows** [5], SI's program for performing fracture mechanics analysis. This allows determination of critical crack sizes and crack growth.

5.5 Fracture Mechanics Models

The cracking in the Alloy 600 welds is evaluated using the **pc-CRACK** simulated corner crack model [6]. This model takes into account the local high stresses at the intersection of a nozzle bore and vessel shell. For this model, the effect of cracking on both sides of the nozzle is accounted for by multiplying the stress intensity factors by a factor of 1.1. This factor was arrived at using the single crack-to-two crack multiplier for an assumed corner crack flaw size of 1.5 inches, using the bore diameter of the actual heater penetration (1.662 inches), and the model from Reference 7:

$$\frac{K_{2Flaws}}{K_{1Flaw}} = \sqrt{\frac{\frac{4}{\pi} + \frac{ac}{tr}}{\frac{4}{\pi} + \frac{ac}{2tr}}}$$

where: a = flaw depth into nozzle bore
c = flaw length along shell
t = shell thickness
r = nozzle bore radius

This factor could be reduced by using the actual flaw sizes determined in the analysis.

In addition, a model for a long surface crack in a cylinder (t/R = 0.1) [8] was also evaluated since the cracking could extend along the shell in the Alloy 600 cladding. For the large aspect ratio, relatively higher stress intensity factors are calculated. Since this assumes an infinitely long crack, no multiplier needs to be applied to account for multiple flaws near the repaired heater tube.

6.0 RESULTS

The corner crack model predicts that the crack will grow to 0.5697 inches after 500 heatup/cooldown cycles (including all other transients described above). The end-of-period maximum stress intensity factor is 41.8 ksi-in$^{1/2}$ and is significantly less than the allowable, and is controlled by the reactor trip cycle. The stress intensity factor for the initial flaw size is 37.7 ksi-in$^{1/2}$.

For the assumed circumferential crack model, the crack grows to 0.6951 inches after the total design cycles. The stress intensity factor is 60.3 ksi-in$^{1/2}$.

The **pc-CRACK** output files are included in Appendix A (CORNER.OUT for the corner crack model and LONG.OUT for the long surface crack model). These files include the throughwall stress distributions, stress coefficients, stress intensity factors as a function of crack size, crack growth laws, fracture toughness, initial crack size, fatigue crack growth load combinations, and resulting crack growth, either input or predicted by the analysis for each flaw model.

7.0 DISCUSSION

This analysis demonstrates that there is significant margin to protect against growth of cracks from the Alloy 600 weld material into the base material. The approach taken to show this is believed to be quite conservative. It is based on design transients and assumes that there is a crack that extends completely to the base metal surface at beginning of life. The evaluation which considered a complete circumferential crack shows even more conservatism.

Following completion of the analysis described above, Entergy determined that the penetration would be plugged instead of replacing the heater. Replacement design [9] is not unlike the heater, with respect to this analysis. The loadings on the weld and pressurizer shell are exactly the same. The thermal conditions are essentially unchanged since the temperature gradients are mainly through the pressurizer wall. The weld details in both are the original plant construction. Therefore, the analysis described above is applicable for both the heater replacement or the penetration plug design.

8.0 REFERENCES

1. Design Input Record, "ASME Section XI, IWB-3600 Evaluation for Document SIR-00-135," Rev. 1, 10/27/00 (File WSES-05Q-201)

2. ASME Boiler and Pressure Vessel Code, Section XI, 1992 Edition.

3. Calculation File No. WSES-05Q-301, "Finite Element Stress Analyses of Pressurizer Heater Penetration," Rev. 0.

4. ASME Boiler and Pressure Vessel Code, Section II, Part D, 1992 Edition.

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

6. Riccardella, P. C., and Delvin, S. A., "Fracture Mechanics Analysis of JAERI Model Pressure Vessel Test," ASME Publication 78-PVP-91.

7. Newman, J. C. and Raju, I. S., "Stress-Intensity Factor Equations for Cracks in Three-Dimensional Bodies Subjected to Tension and Bending Loads," NASA Tech. Memorandum 85793, April 1984.

8. Buchalet, C. B., and Bamford, W. H., "Stress Intensity Factor Solutions for Continuous Surface Flaws in Reactor Pressure Vessels," ASTM STP-590, 1975.

9. Drawing PDD-5817-13058, "Plug of Pressurizer Heater Sleeve F-4," Rev. A, (FAX from Prasanta Chowdhury, dated 10/30/00).

APPENDIX A

pc-CRACK Output

pc-CRACK for Windows
Version 3.1-98348

Structural Integrity Associates, Inc.
3315 Almaden Expressway, Suite 24
San Jose, CA 95118-1557
Voice: 408-978-8200
Fax: 408-978-8964
E-mail: pccrack@structint.com

Linear Elastic Fracture Mechanics

Date: Fri Oct 27 14:21:13 2000
Input Data and Results File: CORNER.LFM

Title: WSES Corner Crack

Load Cases:

Case ID: 2235 Psig --- Stress Distribution

Depth	Stress
0.0000	26389.0000
0.2439	24638.0000
0.4877	22794.0000
0.7316	21200.0000
0.9754	20342.0000
1.2193	19610.0000
1.4632	18977.0000
1.7070	18408.0000
1.9509	17886.0000
2.1947	17458.0000
2.4386	17059.0000
2.6825	16725.0000
2.9263	16420.0000
3.1702	16215.0000
3.4140	15985.0000
3.6579	15800.0000
3.9017	15658.0000
4.1456	15552.0000
4.3895	15450.0000
4.6333	15479.0000
4.8772	15256.0000

Case ID: Heatup --- Stress Distribution

Depth	Stress
0.0000	-15213.0000
0.2439	-11775.0000
0.4877	-8498.4004
0.7316	-6577.5000
0.9754	-5040.7998
1.2193	-3672.8999

1.4632	-2449.8999
1.7070	-1353.9000
1.9509	-374.0000
2.1947	497.6200
2.4386	1271.5000
2.6825	1955.4000
2.9263	2549:1001
3.1702	3084.8999
3.4140	3507.8000
3.6579	3860.8999
3.9017	4142.7002
4.1456	4351.7998
4.3895	4481.3999
4.6333	4580.1001
4.8772	4502.7002

Case ID: Coodown --- Stress Distribution

Depth	Stress
0.0000	15491.0000
0.2439	11929.0000
0.4877	8526.0000
0.7316	6491.1001
0.9754	4951.3999
1.2193	3596.0000
1.4632	2387.0000
1.7070	1304.8000
1.9509	337.6400
2.1947	-522.6200
2.4386	-1286.5000
2.6825	-1961.9000
2.9263	-2548.8999
3.1702	-3076.8000
3.4140	-3498.0000
3.6579	-3850.8999
3.9017	-4132.8999
4.1456	-4342.7002
4.3895	-4473.0000
4.6333	-4569.7998
4.8772	-4495.2002

Case ID: Reactor Trip --- Stress Distribution

Depth	Stress
0.0000	13865.0000
0.2439	10408.0000
0.4877	7017.5000
0.7316	4789.1001
0.9754	3332.5000
1.2193	2131.7000
1.4632	1119.4000
1.7070	273.0100
1.9509	-426.2800
2.1947	-997.1900
2.4386	-1458.4000
2.6825	-1828.6000

2.9263	-2119.6001
3.1702	-2356.6001
3.4140	-2527.8999
3.6579	-2660.3000
3.9017	-2761.5000
4.1456	-2836.5000
4.3895	-2886.0000
4.6333	-2937.2000
4.8772	-2916.1001

Case ID: 2235 Crack Pressure --- Stress Distribution

Depth	Stress
0.0000	2235.0000
0.2000	2235.0000
0.6000	2235.0000
0.8000	2235.0000
1.0000	2235.0000
1.2000	2235.0000
1.4000	2235.0000
1.6000	2235.0000
1.6001	0.0000
1.8000	0.0000
2.0000	0.0000
2.2000	0.0000
2.4000	0.0000
2.6000	0.0000
2.8000	0.0000
3.0000	0.0000

Case ID	Stress Coefficients C0	C1	C2	C3	Type
2235 Psig	26105.5	-7243.42	1819.97	-163.548	StressDist
Heatup	-14409.7	11659.4	-2620.68	213.637	StressDist
Coodown	14630.4	-12074.7	2796.83	-234.506	StressDist
Reactor Trip	13140.7	-12813.4	3563.85	-334.304	StressDist
2235 Crack Pres	2018.21	2399.61	-2839.93	610.534	StressDist

Crack Model: Simulated 3-D Nozzle Corner Crack

WARNING: The stress intensity factor (K) is calculated at the deepest point only.
May be non-conservative in some cases.

Crack Parameters:
Max. crack size: 3.5000

--------------------Stress Intensity Factor--------------------

Crack Size	Case 2235 Psig	Case Heatup	Case Coodown	Case Reactor Tr	Case 2235 Crack
0.0700	8562.58	-4641.22	4709.71	4208.62	693.664
0.1400	11998.3	-6384.3	6474.94	5756.23	1013.03

0.2100	14562	-7604.01	7707.71	6816 44	1275.23
0.2800	16665	-8537.13	8648.78	7608.38	1507.11
0.3500	18468.5	-9278.59	9394.75	8220.58	1718.03
0.4200	20056.4	-9878.75	9996.9	8700.4	1912.24
0.4900	21479.1	-10368.6	10486.8	9077.14	2091.93
0.5600	22769.8	-10768.9	10885.6	9370.7	2258.34
0.6300	23952.1	-11094.6	11208.8	9595.46	2412.23
0.7000	25043.2	-11357.1	11467.7	9762.31	2554.08
0.7700	26056.4	-11565.2	11671.4	9879.8	2684.23
0.8400	27002	-11725.8	11827	9954.82	2802.93
0.9100	27888.5	-11844.7	11940.5	9993.02	2910.42
0.9800	28722.8	-11926.8	12016.8	9999.18	3006.89
1.0500	29510.6	-11976.1	12060	9977.33	3092.57
1.1200	30256.7	-11996.3	12073.9	9930.96	3167.69
1.1900	30965.5	-11990.2	12061.5	9863.1	3232.5
1.2600	31640.3	-11960.7	12025.5	9776.4	3287.27
1.3300	32284.4	-11910	11968.4	9673.21	3332.3
1.4000	32900.6	-11840.2	11892.3	9555.6	3367.93
1.4700	33491.2	-11753.4	11799.1	9425.46	3394.51
1.5400	34058.5	-11651	11690.6	9284.43	3412.44
1.6100	34604.3	-11534.7	11568.4	9134.02	3422.14
1.6800	35130.4	-11405.9	11433.7	8975.59	3424.06
1.7500	35638.4	-11265.7	11288	8810.35	3418.68
1.8200	36129.7	-11115.4	11132.4	8639.43	3406.51
1.8900	36605.5	-10956	10968	8463.81	3388.1
1.9600	37067	-10788.4	10795.6	8284.41	3364.01
2.0300	37515.3	-10613.6	10616.3	8102.05	3334.84
2.1000	37951.4	-10432.3	10430.9	7917.49	3301.21
2.1700	38376.1	-10245.3	10240	7731.39	3263.79
2.2400	38790.3	-10053.3	10044.4	7544.37	3223.24
2.3100	39194.7	-9856.88	9844.72	7356.98	3180.29
2.3800	39590	-9656.62	9641.54	7169.72	3135.64
2.4500	39976.8	-9453.07	9435.38	6983.02	3090.08
2.5200	40355.7	-9246.71	9226.73	6797.28	3044.37
2.5900	40727.1	-9037.99	9016.03	6612.85	2999.32
2.6600	41091.7	-8827.31	8803.68	6430.03	2955.76
2.7300	41449.9	-8615.05	8590.06	6249.09	2914.56
2.8000	41802	-8401.55	8375.5	6070.27	2876.58
2.8700	42148.4	-8187.13	8160.3	5893.73	2842.72
2.9400	42489.4	-7972.06	7944.72	5719.66	2813.91
3.0100	42825.5	-7756.59	7729.01	5548.16	2791.09
3.0800	43156.8	-7540.96	7513.39	5379.34	2775.23
3.1500	43483.6	-7325.36	7298.03	5213.25	2767.31
3.2200	43806.1	-7109.97	7083.11	5049.94	2768.34
3.2900	44124.5	-6894.95	6868.76	4889.41	2779.36
3.3600	44439.1	-6680.43	6655.09	4731.64	2801.4
3.4300	44749.9	-6466.53	6442.21	4576.59	2835.55
3.5000	45057.1	-6253.33	6230.19	4424.2	2882.88

Crack Growth Laws:

Law ID: LAS
Model: ASME Section XI - ferritic steel in water environment

da/dN = CL * SL * dK^5.95 for dK < dKtran
da/dN = CU * SU * dK^1.95 for dK >= dKtran
where

dK = Kmax - Kmin
R = Kmin / Kmax
for R <= 0.25:
SL = 1.0 SU = 1.0 dKtran = 17.74
for 0.25 < R <= 0.65:
SL = 26.9 * R - 5.725 SU = 3.75 * R + 0.06
dKtran = 17.74*{(3.75 * R + 0.06)/(26.9 * R - 5.725)}^0.25
for 0.65 < R:
SL = 11.76 SU = 2.5 dKtran = 12.04

where:
CL = 1.4408e-030
CU = 1.4267e-013
are for the selected units of:
force: lb
length: inch

Material Fracture Toughness KIc:

Material ID: LAS

Depth	KIc
0.0000	63245.0000
4.0000	63245.0000

Initial crack size= 0.4375
Max. crack size= 3.5000

Number of blocks= 250
Print increment of block= 5

Subblock	Cycles /Time	Calc. incre.	Print incre.	Crk. Grw. Law	Mat. K1c
HUCD+Trip	2	1	5	LAS	LAS
Normal and Trip	2	1	5	LAS	LAS
Leak Test	1	1	5	LAS	LAS
Variations	4000	40	4000	LAS	LAS

Subblock	Kmax Case ID	Kmax Scale Factor	Kmin Case ID	Kmin Scale Factor
HUCD+Trip	2235 Psig	1.2477	2235 Psig	0.0000
	Reactor Trip	1.1000	Heatup	1.1000
	2235 Crack Pressure	1.2477		
Normal and Trip	2235 Psig	1.1000	2235 Psig	0.8293
	2235 Crack Pressure	1.1000	2235 Crack Pressure	0.8293
Leak Test	2235 Psig	1.1000	2235 Psig	0.0000
	2235 Crack Pressure	1.1000	Heatup	0.5500
Variations	2235 Psig	1.1492	2235 Psig	1.0508
	2235 Crack Pressure	1.1492	2235 Crack Pressure	1.0508

Crack growth results:

Total Cycles /Time	Subblock Cycles /Time	Kmax	Kmin	DeltaK	R	DaDn /DaDt	Da	a	a/thk
Block: 5									
16022	2	3.77e+004	-1.10e+004	4.87e+004	-0.29	1.97e-004	1.97e-004	0.4398	0.00
16024	2	2.47e+004	1.86e+004	6.07e+003	0.75	5.48e-007	5.48e-007	0.4398	0.00
16025	1	2.47e+004	-5.51e+003	3.02e+004	-0.22	7.74e-005	7.74e-005	0.4399	0.00
20025	4000	2.58e+004	2.36e+004	2.21e+003	0.91	1.33e-009	5.32e-008	0.4399	0.00
Block: 10									
36047	2	3.77e+004	-1.10e+004	4.88e+004	-0.29	1.97e-004	1.97e-004	0.4422	0.00
36049	2	2.47e+004	1.86e+004	6.08e+003	0.75	5.56e-007	5.56e-007	0.4422	0.00
36050	1	2.47e+004	-5.52e+003	3.02e+004	-0.22	7.77e-005	7.77e-005	0.4423	0.00
40050	4000	2.58e+004	2.36e+004	2.21e+003	0.91	1.35e-009	5.40e-008	0.4423	0.00
Block: 15									
56072	2	3.78e+004	-1.11e+004	4.89e+004	-0.29	1.98e-004	1.98e-004	0.4446	0.00
56074	2	2.48e+004	1.87e+004	6.10e+003	0.75	5.64e-007	5.64e-007	0.4446	0.00
56075	1	2.48e+004	-5.53e+003	3.03e+004	-0.22	7.81e-005	7.81e-005	0.4447	0.00
60075	4000	2.59e+004	2.37e+004	2.22e+003	0.91	1.37e-009	5.48e-008	0.4447	0.00
Block: 20									
76097	2	3.79e+004	-1.11e+004	4.90e+004	-0.29	1.99e-004	1.99e-004	0.447	0.00
76099	2	2.48e+004	1.87e+004	6.11e+003	0.75	5.73e-007	5.73e-007	0.447	0.00
76100	1	2.48e+004	-5.54e+003	3.04e+004	-0.22	7.84e-005	7.84e-005	0.4471	0.00
80100	4000	2.60e+004	2.37e+004	2.22e+003	0.91	1.39e-009	5.56e-008	0.4471	0.00
Block: 25									
96122	2	3.80e+004	-1.11e+004	4.91e+004	-0.29	2.00e-004	2.00e-004	0.4494	0.00
96124	2	2.49e+004	1.88e+004	6.13e+003	0.75	5.81e-007	5.81e-007	0.4494	0.00
96125	1	2.49e+004	-5.55e+003	3.05e+004	-0.22	7.88e-005	7.88e-005	0.4495	0.00
100125	4000	2.60e+004	2.38e+004	2.23e+003	0.91	1.41e-009	5.64e-008	0.4495	0.00
Block: 30									
116147	2	3.81e+004	-1.11e+004	4.92e+004	-0.29	2.01e-004	2.01e-004	0.4519	0.00
116149	2	2.50e+004	1.88e+004	6.14e+003	0.75	5.90e-007	5.90e-007	0.4519	0.00
116150	1	2.50e+004	-5.56e+003	3.05e+004	-0.22	7.91e-005	7.91e-005	0.4519	0.00
120150	4000	2.61e+004	2.39e+004	2.23e+003	0.91	1.43e-009	5.72e-008	0.4519	0.00
Block: 35									
136172	2	3.82e+004	-1.11e+004	4.93e+004	-0.29	2.01e-004	2.01e-004	0.4543	0.00
136174	2	2.50e+004	1.89e+004	6.16e+003	0.75	5.98e-007	5.98e-007	0.4543	0.00
136175	1	2.50e+004	-5.57e+003	3.06e+004	-0.22	7.95e-005	7.95e-005	0.4544	0.00
140175	4000	2.62e+004	2.39e+004	2.24e+003	0.91	1.45e-009	5.81e-008	0.4544	0.00
Block: 40									
156197	2	3.82e+004	-1.11e+004	4.94e+004	-0.29	2.02e-004	2.02e-004	0.4568	0.00
156199	2	2.51e+004	1.89e+004	6.17e+003	0.75	6.07e-007	6.07e-007	0.4568	0.00
156200	1	2.51e+004	-5.57e+003	3.07e+004	-0.22	7.98e-005	7.98e-005	0.4568	0.00
160200	4000	2.62e+004	2.40e+004	2.24e+003	0.91	1.47e-009	5.89e-008	0.4568	0.00
Block: 45									
176222	2	3.83e+004	-1.12e+004	4.95e+004	-0.29	2.03e-004	2.03e-004	0.4592	0.00
176224	2	2.52e+004	1.90e+004	6.19e+003	0.75	6.16e-007	6.16e-007	0.4592	0.00

176225	1	2.52e+004	-5.58e+003	3.07e+004	-0.22	8.02e-005	8.02e-005	0.4593	0.00
180225	4000	2.63e+004	2.40e+004	2.25e+003	0.91	1.49e-009	5.98e-008	0.4593	0.00
Block: 50									
196247	2	3.84e+004	-1.12e+004	4.96e+004	-0.29	2.04e-004	2.04e-004	0.4617	0.00
196249	2	2.52e+004	1.90e+004	6.21e+003	0.75	6.25e-007	6.25e-007	0.4617	0.00
196250	1	2.52e+004	-5.59e+003	3.08e+004	-0.22	8.06e-005	8.06e-005	0.4618	0.00
200250	4000	2.63e+004	2.41e+004	2.26e+003	0.91	1.52e-009	6.07e-008	0.4618	0.00
Block: 55									
216272	2	3.85e+004	-1.12e+004	4.97e+004	-0.29	2.05e-004	2.05e-004	0.4642	0.00
216274	2	2.53e+004	1.91e+004	6.22e+003	0.75	6.34e-007	6.34e-007	0.4642	0.00
216275	1	2.53e+004	-5.60e+003	3.09e+004	-0.22	8.09e-005	8.09e-005	0.4643	0.00
220275	4000	2.64e+004	2.41e+004	2.26e+003	0.91	1.54e-009	6.16e-008	0.4643	0.00
Block: 60									
236297	2	3.86e+004	-1.12e+004	4.98e+004	-0.29	2.06e-004	2.06e-004	0.4667	0.00
236299	2	2.53e+004	1.91e+004	6.24e+003	0.75	6.44e-007	6.44e-007	0.4667	0.00
236300	1	2.53e+004	-5.61e+003	3.10e+004	-0.22	8.13e-005	8.13e-005	0.4667	0.00
240300	4000	2.65e+004	2.42e+004	2.27e+003	0.91	1.56e-009	6.25e-008	0.4668	0.00
Block: 65									
256322	2	3.87e+004	-1.12e+004	4.99e+004	-0.29	2.06e-004	2.06e-004	0.4692	0.00
256324	2	2.54e+004	1.92e+004	6.25e+003	0.75	6.54e-007	6.54e-007	0.4692	0.00
256325	1	2.54e+004	-5.62e+003	3.10e+004	-0.22	8.17e-005	8.17e-005	0.4693	0.00
260325	4000	2.65e+004	2.43e+004	2.27e+003	0.91	1.59e-009	6.34e-008	0.4693	0.00
Block: 70									
276347	2	3.88e+004	-1.13e+004	5.00e+004	-0.29	2.07e-004	2.07e-004	0.4717	0.00
276349	2	2.55e+004	1.92e+004	6.27e+003	0.75	6.63e-007	6.63e-007	0.4717	0.00
276350	1	2.55e+004	-5.63e+003	3.11e+004	-0.22	8.21e-005	8.21e-005	0.4718	0.00
280350	4000	2.66e+004	2.43e+004	2.28e+003	0.91	1.61e-009	6.44e-008	0.4718	0.00
Block: 75									
296372	2	3.88e+004	-1.13e+004	5.01e+004	-0.29	2.08e-004	2.08e-004	0.4742	0.00
296374	2	2.55e+004	1.92e+004	6.28e+003	0.75	6.73e-007	6.73e-007	0.4742	0.00
296375	1	2.55e+004	-5.64e+003	3.12e+004	-0.22	8.24e-005	8.24e-005	0.4743	0.00
300375	4000	2.67e+004	2.44e+004	2.28e+003	0.91	1.63e-009	6.53e-008	0.4743	0.00
Block: 80									
316397	2	3.89e+004	-1.13e+004	5.02e+004	-0.29	2.09e-004	2.09e-004	0.4767	0.00
316399	2	2.56e+004	1.93e+004	6.30e+003	0.75	6.83e-007	6.83e-007	0.4767	0.00
316400	1	2.56e+004	-5.65e+003	3.12e+004	-0.22	8.28e-005	8.28e-005	0.4768	0.00
320400	4000	2.67e+004	2.45e+004	2.29e+003	0.91	1.66e-009	6.63e-008	0.4768	0.00
Block: 85									
336422	2	3.90e+004	-1.13e+004	5.03e+004	-0.29	2.10e-004	2.10e-004	0.4793	0.00
336424	2	2.57e+004	1.93e+004	6.31e+003	0.75	6.93e-007	6.93e-007	0.4793	0.00
336425	1	2.57e+004	-5.66e+003	3.13e+004	-0.22	8.32e-005	8.32e-005	0.4794	0.00
340425	4000	2.68e+004	2.45e+004	2.30e+003	0.91	1.68e-009	6.73e-008	0.4794	0.00
Block: 90									
356447	2	3.91e+004	-1.13e+004	5.04e+004	-0.29	2.11e-004	2.11e-004	0.4818	0.00
356449	2	2.57e+004	1.94e+004	6.33e+003	0.75	7.04e-007	7.04e-007	0.4819	0.00
356450	1	2.57e+004	-5.67e+003	3.14e+004	-0.22	8.36e-005	8.36e-005	0.4819	0.00
360450	4000	2.69e+004	2.46e+004	2.30e+003	0.91	1.71e-009	6.83e-008	0.4819	0.00
Block: 95									

376472 2 3.92e+004 -1.14e+004 5.06e+004 -0.29 2.12e-004 2.12e-004 0.4844 0.00
376474 2 2.58e+004 1.94e+004 6.35e+003 0.75 7.15e-007 7.15e-007 0.4844 0.00
376475 1 2.58e+004 -5.68e+003 3.15e+004 -0.22 8.40e-005 8.40e-005 0.4845 0.00
380475 4000 2.69e+004 2.46e+004 2.31e+003 0.91 1.73e-009 6.93e-008 0.4845 0.00

Block: 100
396497 2 3.93e+004 -1.14e+004 5.07e+004 -0.29 2.13e-004 2.13e-004 0.487 0.00
396499 2 2.59e+004 1.95e+004 6.36e+003 0.75 7.25e-007 7.25e-007 0.487 0.00
396500 1 2.59e+004 -5.69e+003 3.15e+004 -0.22 8.44e-005 8.44e-005 0.4871 0.00
400500 4000 2.70e+004 2.47e+004 2.31e+003 0.91 1.76e-009 7.04e-008 0.4871 0.00

Block: 105
416522 2 3.94e+004 -1.14e+004 5.08e+004 -0.29 2.13e-004 2.13e-004 0.4896 0.00
416524 2 2.59e+004 1.95e+004 6.38e+003 0.75 7.36e-007 7.36e-007 0.4896 0.00
416525 1 2.59e+004 -5.70e+003 3.16e+004 -0.22 8.47e-005 8.47e-005 0.4897 0.00
420525 4000 2.71e+004 2.48e+004 2.32e+003 0.91 1.79e-009 7.14e-008 0.4897 0.00

Block: 110
436547 2 3.95e+004 -1.14e+004 5.09e+004 -0.29 2.14e-004 2.14e-004 0.4922 0.00
436549 2 2.60e+004 1.96e+004 6.39e+003 0.75 7.47e-007 7.47e-007 0.4922 0.00
436550 1 2.60e+004 -5.71e+003 3.17e+004 -0.22 8.51e-005 8.51e-005 0.4923 0.00
440550 4000 2.71e+004 2.48e+004 2.32e+003 0.91 1.81e-009 7.24e-008 0.4923 0.00

Block: 115
456572 2 3.95e+004 -1.14e+004 5.10e+004 -0.29 2.15e-004 2.15e-004 0.4948 0.00
456574 2 2.60e+004 1.96e+004 6.41e+003 0.75 7.57e-007 7.57e-007 0.4948 0.00
456575 1 2.60e+004 -5.72e+003 3.18e+004 -0.22 8.55e-005 8.55e-005 0.4949 0.00
460575 4000 2.72e+004 2.49e+004 2.33e+003 0.91 1.84e-009 7.34e-008 0.4949 0.00

Block: 120
476597 2 3.96e+004 -1.15e+004 5.11e+004 -0.29 2.16e-004 2.16e-004 0.4974 0.00
476599 2 2.61e+004 1.97e+004 6.42e+003 0.75 7.67e-007 7.67e-007 0.4974 0.00
476600 1 2.61e+004 -5.73e+003 3.18e+004 -0.22 8.58e-005 8.58e-005 0.4975 0.00
480600 4000 2.73e+004 2.49e+004 2.33e+003 0.91 1.86e-009 7.44e-008 0.4975 0.00

Block: 125
496622 2 3.97e+004 -1.15e+004 5.12e+004 -0.29 2.17e-004 2.17e-004 0.5001 0.00
496624 2 2.62e+004 1.97e+004 6.44e+003 0.75 7.78e-007 7.78e-007 0.5001 0.00
496625 1 2.62e+004 -5.73e+003 3.19e+004 -0.22 8.62e-005 8.62e-005 0.5001 0.00
500625 4000 2.73e+004 2.50e+004 2.34e+003 0.91 1.89e-009 7.55e-008 0.5002 0.00

Block: 130
516647 2 3.98e+004 -1.15e+004 5.13e+004 -0.29 2.17e-004 2.17e-004 0.5027 0.00
516649 2 2.62e+004 1.98e+004 6.45e+003 0.75 7.89e-007 7.89e-007 0.5027 0.00
516650 1 2.62e+004 -5.74e+003 3.20e+004 -0.22 8.65e-005 8.65e-005 0.5028 0.00
520650 4000 2.74e+004 2.50e+004 2.35e+003 0.91 1.91e-009 7.65e-008 0.5028 0.00

Block: 135
536672 2 3.99e+004 -1.15e+004 5.14e+004 -0.29 2.18e-004 2.18e-004 0.5053 0.00
536674 2 2.63e+004 1.98e+004 6.47e+003 0.75 8.00e-007 8.00e-007 0.5053 0.00
536675 1 2.63e+004 -5.75e+003 3.20e+004 -0.22 8.69e-005 8.69e-005 0.5054 0.00
540675 4000 2.75e+004 2.51e+004 2.35e+003 0.91 1.94e-009 7.76e-008 0.5054 0.00

Block: 140
556697 2 3.99e+004 -1.15e+004 5.15e+004 -0.29 2.19e-004 2.19e-004 0.508 0.00
556699 2 2.63e+004 1.99e+004 6.48e+003 0.75 8.11e-007 8.11e-007 0.508 0.00
556700 1 2.63e+004 -5.76e+003 3.21e+004 -0.22 8.73e-005 8.73e-005 0.5081 0.00
560700 4000 2.75e+004 2.52e+004 2.36e+003 0.91 1.97e-009 7.87e-008 0.5081 0.00

Block: 145

576722	2	4.00e+004	-1.15e+004	5.16e+004	-0.29	2.20e-004	2.20e-004	0.5107	0.00
576724	2	2.64e+004	1.99e+004	6.50e+003	0.75	8.22e-007	8.22e-007	0.5107	0.00
576725	1	2.64e+004	-5.77e+003	3.22e+004	-0.22	8.76e-005	8.76e-005	0.5108	0.00
580725	4000	2.76e+004	2.52e+004	2.36e+003	0.91	1.99e-009	7.98e-008	0.5108	0.00

Block: 150

596747	2	4.01e+004	-1.16e+004	5.17e+004	-0.29	2.21e-004	2.21e-004	0.5134	0.00
596749	2	2.65e+004	2.00e+004	6.51e+003	0.75	8.33e-007	8.33e-007	0.5134	0.00
596750	1	2.65e+004	-5.78e+003	3.22e+004	-0.22	8.80e-005	8.80e-005	0.5134	0.00
600750	4000	2.76e+004	2.53e+004	2.37e+003	0.91	2.02e-009	8.09e-008	0.5135	0.00

Block: 155

616772	2	4.02e+004	-1.16e+004	5.18e+004	-0.29	2.22e-004	2.22e-004	0.516	0.00
616774	2	2.65e+004	2.00e+004	6.53e+003	0.75	8.45e-007	8.45e-007	0.516	0.00
616775	1	2.65e+004	-5.78e+003	3.23e+004	-0.22	8.84e-005	8.84e-005	0.5161	0.00
620775	4000	2.77e+004	2.53e+004	2.37e+003	0.91	2.05e-009	8.20e-008	0.5161	0.00

Block: 160

636797	2	4.03e+004	-1.16e+004	5.19e+004	-0.29	2.22e-004	2.22e-004	0.5187	0.00
636799	2	2.66e+004	2.00e+004	6.54e+003	0.75	8.57e-007	8.57e-007	0.5187	0.00
636800	1	2.66e+004	-5.79e+003	3.24e+004	-0.22	8.88e-005	8.88e-005	0.5188	0.00
640800	4000	2.78e+004	2.54e+004	2.38e+003	0.91	2.08e-009	8.31e-008	0.5188	0.00

Block: 165

656822	2	4.03e+004	-1.16e+004	5.20e+004	-0.29	2.23e-004	2.23e-004	0.5215	0.00
656824	2	2.66e+004	2.01e+004	6.56e+003	0.75	8.69e-007	8.69e-007	0.5215	0.00
656825	1	2.66e+004	-5.80e+003	3.25e+004	-0.22	8.91e-005	8.91e-005	0.5216	0.00
660825	4000	2.78e+004	2.55e+004	2.38e+003	0.91	2.11e-009	8.43e-008	0.5216	0.00

Block: 170

676847	2	4.04e+004	-1.16e+004	5.21e+004	-0.29	2.24e-004	2.24e-004	0.5242	0.00
676849	2	2.67e+004	2.01e+004	6.57e+003	0.75	8.81e-007	8.81e-007	0.5242	0.00
676850	1	2.67e+004	-5.81e+003	3.25e+004	-0.22	8.95e-005	8.95e-005	0.5243	0.00
680850	4000	2.79e+004	2.55e+004	2.39e+003	0.91	2.14e-009	8.55e-008	0.5243	0.00

Block: 175

696872	2	4.05e+004	-1.16e+004	5.22e+004	-0.29	2.25e-004	2.25e-004	0.5269	0.00
696874	2	2.68e+004	2.02e+004	6.59e+003	0.75	8.93e-007	8.93e-007	0.5269	0.00
696875	1	2.68e+004	-5.82e+003	3.26e+004	-0.22	8.99e-005	8.99e-005	0.527	0.00
700875	4000	2.80e+004	2.56e+004	2.39e+003	0.91	2.17e-009	8.67e-008	0.527	0.00

Block: 180

716897	2	4.06e+004	-1.17e+004	5.23e+004	-0.29	2.26e-004	2.26e-004	0.5297	0.00
716899	2	2.68e+004	2.02e+004	6.60e+003	0.75	9.06e-007	9.06e-007	0.5297	0.00
716900	1	2.68e+004	-5.83e+003	3.27e+004	-0.22	9.03e-005	9.03e-005	0.5297	0.00
720900	4000	2.80e+004	2.56e+004	2.40e+003	0.91	2.20e-009	8.79e-008	0.5298	0.00

Block: 185

736922	2	4.07e+004	-1.17e+004	5.24e+004	-0.29	2.27e-004	2.27e-004	0.5324	0.00
736924	2	2.69e+004	2.03e+004	6.62e+003	0.75	9.18e-007	9.18e-007	0.5324	0.00
736925	1	2.69e+004	-5.84e+003	3.27e+004	-0.22	9.07e-005	9.07e-005	0.5325	0.00
740925	4000	2.81e+004	2.57e+004	2.41e+003	0.91	2.23e-009	8.91e-008	0.5325	0.00

Block: 190

756947	2	4.08e+004	-1.17e+004	5.25e+004	-0.29	2.27e-004	2.27e-004	0.5352	0.00
756949	2	2.70e+004	2.03e+004	6.64e+003	0.75	9.31e-007	9.31e-007	0.5352	0.00

756950 1 2.70e+004 -5.84e+003 3.28e+004 -0.22 9.11e-005 9.11e-005 0.5353 0.00
760950 4000 2.82e+004 2.58e+004 2.41e+003 0.91 2.26e-009 9.04e-008 0.5353 0.00

Block: 195
776972 2 4.09e+004 -1.17e+004 5.26e+004 -0.29 2.28e-004 2.28e-004 0.538 0.00
776974 2 2.70e+004 2.04e+004 6.65e+003 0.75 9.45e-007 9.45e-007 0.538 0.00
776975 1 2.70e+004 -5.85e+003 3.29e+004 -0.22 9.15e-005 9.15e-005 0.5381 0.00
780975 4000 2.82e+004 2.58e+004 2.42e+003 0.91 2.29e-009 9.17e-008 0.5381 0.00

Block: 200
796997 2 4.09e+004 -1.17e+004 5.27e+004 -0.29 2.29e-004 2.29e-004 0.5408 0.00
796999 2 2.71e+004 2.04e+004 6.67e+003 0.75 9.58e-007 9.58e-007 0.5408 0.00
797000 1 2.71e+004 -5.86e+003 3.30e+004 -0.22 9.19e-005 9.19e-005 0.5409 0.00
801000 4000 2.83e+004 2.59e+004 2.42e+003 0.91 2.32e-009 9.30e-008 0.5409 0.00

Block: 205
817022 2 4.10e+004 -1.17e+004 5.28e+004 -0.29 2.30e-004 2.30e-004 0.5436 0.00
817024 2 2.72e+004 2.05e+004 6.68e+003 0.75 9.72e-007 9.72e-007 0.5436 0.00
817025 1 2.72e+004 -5.87e+003 3.30e+004 -0.22 9.23e-005 9.23e-005 0.5437 0.00
821025 4000 2.84e+004 2.59e+004 2.43e+003 0.91 2.36e-009 9.43e-008 0.5437 0.00

Block: 210
837047 2 4.11e+004 -1.18e+004 5.29e+004 -0.29 2.31e-004 2.31e-004 0.5465 0.00
837049 2 2.72e+004 2.05e+004 6.70e+003 0.75 9.86e-007 9.86e-007 0.5465 0.00
837050 1 2.72e+004 -5.88e+003 3.31e+004 -0.22 9.27e-005 9.27e-005 0.5466 0.00
841050 4000 2.84e+004 2.60e+004 2.44e+003 0.91 2.39e-009 9.57e-008 0.5466 0.00

Block: 215
857072 2 4.12e+004 -1.18e+004 5.30e+004 -0.29 2.32e-004 2.32e-004 0.5493 0.00
857074 2 2.73e+004 2.06e+004 6.72e+003 0.75 1.00e-006 1.00e-006 0.5493 0.00
857075 1 2.73e+004 -5.89e+003 3.32e+004 -0.22 9.31e-005 9.31e-005 0.5494 0.00
861075 4000 2.85e+004 2.61e+004 2.44e+003 0.91 2.43e-009 9.70e-008 0.5494 0.00

Block: 220
877097 2 4.13e+004 -1.18e+004 5.31e+004 -0.29 2.33e-004 2.33e-004 0.5522 0.00
877099 2 2.74e+004 2.06e+004 6.73e+003 0.75 1.01e-006 1.01e-006 0.5522 0.00
877100 1 2.74e+004 -5.90e+003 3.33e+004 -0.22 9.35e-005 9.35e-005 0.5523 0.00
881100 4000 2.86e+004 2.61e+004 2.45e+003 0.91 2.46e-009 9.84e-008 0.5523 0.00

Block: 225
897122 2 4.14e+004 -1.18e+004 5.32e+004 -0.29 2.34e-004 2.34e-004 0.5551 0.00
897124 2 2.74e+004 2.07e+004 6.75e+003 0.75 1.03e-006 1.03e-006 0.5551 0.00
897125 1 2.74e+004 -5.91e+003 3.33e+004 -0.22 9.39e-005 9.39e-005 0.5551 0.00
901125 4000 2.86e+004 2.62e+004 2.45e+003 0.91 2.50e-009 9.99e-008 0.5552 0.00

Block: 230
917147 2 4.15e+004 -1.18e+004 5.33e+004 -0.29 2.35e-004 2.35e-004 0.5579 0.00
917149 2 2.75e+004 2.07e+004 6.76e+003 0.75 1.04e-006 1.04e-006 0.5579 0.00
917150 1 2.75e+004 -5.92e+003 3.34e+004 -0.22 9.43e-005 9.43e-005 0.558 0.00
921150 4000 2.87e+004 2.63e+004 2.46e+003 0.91 2.53e-009 1.01e-007 0.558 0.00

Block: 235
937172 2 4.16e+004 -1.18e+004 5.34e+004 -0.29 2.35e-004 2.35e-004 0.5608 0.00
937174 2 2.75e+004 2.08e+004 6.78e+003 0.75 1.06e-006 1.06e-006 0.5608 0.00
937175 1 2.75e+004 -5.92e+003 3.35e+004 -0.22 9.47e-005 9.47e-005 0.5609 0.00
941175 4000 2.88e+004 2.63e+004 2.46e+003 0.91 2.57e-009 1.03e-007 0.5609 0.00

Block: 240

957197	2	4.16e+004	-1.19e+004	5.35e+004	-0.28	2.36e-004	2.36e-004	0.5637	0.00
957199	2	2.76e+004	2.08e+004	6.79e+003	0.75	1.07e-006	1.07e-006	0.5637	0.00
957200	1	2.76e+004	-5.93e+003	3.35e+004	-0.21	9.51e-005	9.51e-005	0.5638	0.00
961200	4000	2.88e+004	2.64e+004	2.47e+003	0.91	2.60e-009	1.04e-007	0.5638	0.00

Block: 245

977222	2	4.17e+004	-1.19e+004	5.36e+004	-0.28	2.37e-004	2.37e-004	0.5666	0.00
977224	2	2.77e+004	2.09e+004	6.81e+003	0.75	1.09e-006	1.09e-006	0.5666	0.00
977225	1	2.77e+004	-5.94e+003	3.36e+004	-0.21	9.55e-005	9.55e-005	0.5667	0.00
981225	4000	2.89e+004	2.64e+004	2.48e+003	0.91	2.64e-009	1.05e-007	0.5668	0.00

Block: 250

997247	2	4.18e+004	-1.19e+004	5.37e+004	-0.28	2.38e-004	2.38e-004	0.5696	0.00
997249	2	2.77e+004	2.09e+004	6.82e+003	0.75	1.10e-006	1.10e-006	0.5696	0.00
997250	1	2.77e+004	-5.95e+003	3.37e+004	-0.21	9.59e-005	9.59e-005	0.5697	0.00
1001250	4000	2.90e+004	2.65e+004	2.48e+003	0.91	2.67e-009	1.07e-007	0.5697	0.00

End of pc-CRACK Output

tm

pc-CRACK for Windows
Version 3.1-98348

Structural Integrity Associates, Inc.
3315 Almaden Expressway, Suite 24
San Jose, CA 95118-1557
Voice: 408-978-8200
Fax: 408-978-8964
E-mail: pccrack@structint.com

Linear Elastic Fracture Mechanics

Date: Fri Oct 27 14:56:36 2000
Input Data and Results File: LONG.LFM

Title: WSES 100 percent Surface Crack

Load Cases:

Case ID: 2235 Psig --- Stress Distribution

Depth	Stress
0.0000	22872.0000
0.2356	21611.0000
0.4712	20249.0000
0.7068	19006.0000
0.9424	18501.0000
1.1780	18102.0000
1.4136	17736.0000
1.6492	17397.0000
1.8848	17086.0000
2.1204	16811.0000
2.3560	16538.0000
2.5916	16335.0000
2.8272	16137.0000
3.0628	15978.0000
3.2984	15792.0000
3.5340	15656.0000
3.7696	15562.0000
4.0052	15478.0000
4.2408	15399.0000
4.4764	15464.0000
4.7120	15256.0000

Case ID: Heatup --- Stress Distribution

Depth	Stress
0.0000	-14736.0000
0.2356	-11079.0000
0.4712	-7709.0000
0.7068	-5991.7002
0.9424	-4634.6001
1.1780	-3404.8000

1.4136	-2278.7000
1.6492	-1251.9000
1.8848	-320.3700
2.1204	520.4200
2.3560	1274.3000
2.5916	1944.3000
2.8272	2529.6001
3.0628	3061.6001
3.2984	3479.6001
3.5340	3833.5000
3.7696	4118.2002
4.0052	4328.7998
4.2408	4463.2998
4.4764	4574.2002
4.7120	4502.7002

Case ID: Coodown --- Stress Distribution

Depth	Stress
0.0000	15020.0000
0.2356	11245.0000
0.4712	7718.0000
0.7068	5895.1001
0.9424	4543.2998
1.1780	3329.2000
1.4136	2218.1001
1.6492	1205.1000
1.8848	286.1400
2.1204	-543.6100
2.3560	-1287.7000
2.5916	-1949.6000
2.8272	-2528.3999
3.0628	-3052.3000
3.2984	-3468.8000
3.5340	-3822.6001
3.7696	-4108.1001
4.0052	-4319.6001
4.2408	-4454.8999
4.4764	-4563.6001
4.7120	-4495.2002

Case ID: Reactor Trip --- Stress Distribution

Depth	Stress
0.0000	13529.0000
0.2356	9909.4004
0.4712	6341.5000
0.7068	4318.8999
0.9424	3025.8999
1.1780	1940.4000
1.4136	1004.8000
1.6492	210.0800
1.8848	-455.8800
2.1204	-1007.1000
2.3560	-1456.4000
2.5916	-1818.7000

2.8272	-2106.1001
3.0628	-2341.0000
3.2984	-2510.8999
3.5340	-2644.8000
3.7696	-2748.7000
4.0052	-2824.8000
4.2408	-2876.8999
4.4764	-2934.1001
4.7120	-2916.1001

Case ID: 2235 Crack Pressure --- Stress Distribution

Depth	Stress
0.0000	2235.0000
0.2000	2235.0000
0.6000	2235.0000
0.8000	2235.0000
1.0000	2235.0000
1.2000	2235.0000
1.4000	2235.0000
1.6000	2235.0000
1.6001	0.0000
1.8000	0.0000
2.0000	0.0000
2.2000	0.0000
2.4000	0.0000
2.6000	0.0000
2.8000	0.0000
3.0000	0.0000

Case ID	Stress Coefficients C0	C1	C2	C3	Type
2235 Psig	22583.8	-5253.75	1447.81	-142.193	StressDist
Heatup	-13689.3	11671.3	-2772.62	240.928	StressDist
Coodown	13911.6	-12107.7	2965.32	-264.652	StressDist
Reactor Trip	12593.1	-12961.7	3792.8	-374.081	StressDist
2235 Crack Pres	2018.21	2399.61	-2839.93	610.534	StressDist

Crack Model: Circumferential Crack in Cylinder (t/R=0.1)

Crack Parameters:
Wall thickness: 4.3125
Max. crack size: 3.4500

-------------------Stress Intensity Factor-------------------

Crack Size	Case 2235 Psig	Case Heatup	Case Coodown	Case Reactor Tr	Case 2235 Crack
0.0690	11554.9	-6829.18	6935.08	6237.28	1089.14
0.1380	16265.9	-9368.95	9507.39	8494.7	1605.07
0.2070	19833.4	-11127.8	11284	10014.9	2035.59
0.2760	22804.3	-12456.8	12622.5	11127	2420.46

0.3450	25392.1	-13497.1	13666.7	11964.6	2773.02
0.4140	27706.9	-14323.7	14493.1	12599.3	3099.04
0.4830	29979.6	-15067.4	15234.4	13149.7	3420.2
0.5520	32167.2	-15709.4	15871.9	13601.3	3729.14
0.6210	34245.7	-16242.6	16398.5	13949.5	4020.65
0.6900	36234.6	-16681.4	16829.1	14208.8	4294.87
0.7590	38148.9	-17037.3	17175.4	14390.8	4551.83
0.8280	40000	-17319.2	17446.5	14504.3	4791.5
0.8970	41913.2	-17587.6	17703.7	14602.6	5026.73
0.9660	43907.3	-17849.8	17954.4	14692.2	5258.46
1.0350	45875.1	-18057.8	18150.2	14732.8	5473.82
1.1040	47820.6	-18215.1	18294.8	14728.4	5672.49
1.1730	49747.5	-18325.1	18391.5	14682.6	5854.24
1.2420	51658.7	-18390.4	18443.3	14598.4	6018.91
1.3110	53684	-18479.4	18519.4	14537.6	6178.4
1.3800	56095.6	-18731.3	18761.2	14625.2	6357.64
1.4490	58522.1	-18954.1	18973.7	14689.9	6521.18
1.5180	60964.5	-19148.8	19158.5	14733.6	6669.04
1.5870	63423.3	-19316.9	19316.7	14757.8	6801.37
1.6560	65899.2	-19459.4	19449.7	14764.2	6918.43
1.7250	68392.8	-19577.4	19558.6	14754.3	7020.64
1.7940	71058.5	-19727.1	19699.4	14770.3	7135.06
1.8630	73746.9	-19852.4	19816.1	14769.6	7237.65
1.9320	76457.9	-19953.9	19909.4	14753.4	7329.25
2.0010	79191.7	-20032.2	19979.8	14722.4	7410.82
2.0700	81948.4	-20087.8	20028.1	14677.7	7483.46
2.1390	84728.1	-20121.5	20054.9	14619.9	7548.42
2.2080	87699.9	-20143.9	20069.4	14543.7	7633.34
2.2770	90754.3	-20142.2	20059.6	14446.9	7723.05
2.3460	93835.1	-20112.2	20021.8	14331.1	7810.68
2.4150	96942	-20054.2	19956.4	14196.8	7898.15
2.4840	100075	-19968.5	19863.6	14044.3	7987.56
2.5530	103233	-19855.3	19743.6	13874.2	8081.21
2.6220	106609	-19878.2	19764.5	13853.1	8174.24
2.6910	110214	-20050	19939.7	13995.5	8267.22
2.7600	113857	-20212.1	20106.2	14139.9	8369.65
2.8290	117538	-20364.9	20264.3	14286.9	8484.58
2.8980	121258	-20508.8	20414.3	14436.7	8615.32
2.9670	125016	-20644	20556.7	14589.8	8765.38
3.0360	128852	-20664	20581.6	14633.1	8938.94
3.1050	132847	-20337	20250.5	14323.8	9136.75
3.1740	136874	-19973	19882.8	13992.4	9359.18
3.2430	140935	-19572.4	19479.1	13639.1	9610.65
3.3120	145028	-19135.6	19039.6	13264.6	9895.86
3.3810	149152	-18662.8	18564.6	12869	10219.8
3.4500	153308	-18154.4	18054.4	12452.6	10587.9

Crack Growth Laws:

Law ID: LAS
Model: ASME Section XI - ferritic steel in water environment

da/dN = CL * SL * dK^5.95 for dK < dKtran
da/dN = CU * SU * dK^1.95 for dK >= dKtran
where
dK = Kmax - Kmin
R = Kmin / Kmax

for R <= 0.25:
SL = 1.0 SU = 1.0 dKtran = 17.74
for 0.25 < R <= 0.65:
SL = 26.9 * R - 5.725 SU = 3.75 * R + 0.06
dKtran = 17.74*{(3.75 * R + 0.06)/(26.9 * R - 5.725)}^0.25
for 0.65 < R:
SL = 11.76 SU = 2.5 dKtran = 12.04

where:
CL = 1.4408e-030
CU = 1.4267e-013
are for the selected units of:
force: lb
length: inch

Material Fracture Toughness KIc:

Material ID: LAS

Depth	KIc
0.0000	63245.0000
4.0000	63245.0000

Initial crack size= 0.4375
Max. crack size= 3.4500

Number of blocks= 250
Print increment of block= 5

Subblock	Cycles /Time	Calc. incre.	Print incre.	Crk. Grw. Law	Mat. K1c
HUCD+Trip	2	1	5	LAS	LAS
Normal and Trip	2	1	5	LAS	LAS
Leak Test	1	1	5	LAS	LAS
Variations	4000	40	4000	LAS	LAS

Subblock	Kmax Case ID	Scale Factor	Kmin Case ID	Scale Factor
HUCD+Trip	2235 Psig	1.1342	2235 Psig	0.0000
	Reactor Trip	1.0000	Heatup	1.0000
	2235 Crack Pressure	1.1342		
Normal and Trip	2235 Psig	1.0000	2235 Psig	0.7539
	2235 Crack Pressure	1.0000	2235 Crack Pressure	0.7539
Leak Test	2235 Psig	1.0000	2235 Psig	0.0000
	2235 Crack Pressure	1.0000	Heatup	0.5000
Variations	2235 Psig	1.0447	2235 Psig	0.9545
	2235 Crack Pressure	1.0447	2235 Crack Pressure	0.9545

Crack growth results:

Total Cycles /Time	Subblock Cycles /Time	Kmax	Kmin	DeltaK	R	DaDn /DaDt	Da	a	a/thk
Block: 5									
16022	2	4.89e+004	-1.46e+004	6.35e+004	-0.30	3.30e-004	3.30e-004	0.4414	0.10
16024	2	3.18e+004	2.40e+004	7.84e+003	0.75	2.50e-006	2.50e-006	0.4414	0.10
16025	1	3.18e+004	-7.31e+003	3.91e+004	-0.23	1.29e-004	1.29e-004	0.4416	0.10
20025	4000	3.33e+004	3.04e+004	2.87e+003	0.91	6.39e-009	2.56e-007	0.4416	0.10
Block: 10									
36047	2	4.91e+004	-1.47e+004	6.38e+004	-0.30	3.33e-004	3.33e-004	0.4455	0.10
36049	2	3.20e+004	2.41e+004	7.87e+003	0.75	2.58e-006	2.58e-006	0.4456	0.10
36050	1	3.20e+004	-7.33e+003	3.93e+004	-0.23	1.30e-004	1.30e-004	0.4457	0.10
40050	4000	3.34e+004	3.05e+004	2.89e+003	0.91	6.58e-009	2.63e-007	0.4457	0.10
Block: 15									
56072	2	4.93e+004	-1.47e+004	6.40e+004	-0.30	3.36e-004	3.36e-004	0.4497	0.10
56074	2	3.21e+004	2.42e+004	7.91e+003	0.75	2.65e-006	2.65e-006	0.4497	0.10
56075	1	3.21e+004	-7.35e+003	3.95e+004	-0.23	1.31e-004	1.31e-004	0.4498	0.10
60075	4000	3.36e+004	3.07e+004	2.90e+003	0.91	6.78e-009	2.71e-007	0.4499	0.10
Block: 20									
76097	2	4.95e+004	-1.47e+004	6.43e+004	-0.30	3.38e-004	3.38e-004	0.4539	0.11
76099	2	3.23e+004	2.44e+004	7.95e+003	0.75	2.73e-006	2.73e-006	0.4539	0.11
76100	1	3.23e+004	-7.38e+003	3.97e+004	-0.23	1.32e-004	1.32e-004	0.454	0.11
80100	4000	3.38e+004	3.08e+004	2.91e+003	0.91	6.98e-009	2.79e-007	0.4541	0.11
Block: 25									
96122	2	4.98e+004	-1.48e+004	6.46e+004	-0.30	3.41e-004	3.41e-004	0.4581	0.11
96124	2	3.25e+004	2.45e+004	7.99e+003	0.75	2.81e-006	2.81e-006	0.4581	0.11
96125	1	3.25e+004	-7.40e+003	3.99e+004	-0.23	1.33e-004	1.33e-004	0.4583	0.11
100125	4000	3.39e+004	3.10e+004	2.93e+003	0.91	7.18e-009	2.87e-007	0.4583	0.11
Block: 30									
116147	2	5.00e+004	-1.48e+004	6.48e+004	-0.30	3.44e-004	3.44e-004	0.4624	0.11
116149	2	3.26e+004	2.46e+004	8.03e+003	0.75	2.90e-006	2.90e-006	0.4624	0.11
116150	1	3.26e+004	-7.42e+003	4.00e+004	-0.23	1.34e-004	1.34e-004	0.4625	0.11
120150	4000	3.41e+004	3.11e+004	2.94e+003	0.91	7.40e-009	2.96e-007	0.4626	0.11
Block: 35									
136172	2	5.02e+004	-1.49e+004	6.51e+004	-0.30	3.46e-004	3.46e-004	0.4667	0.11
136174	2	3.28e+004	2.47e+004	8.07e+003	0.75	2.98e-006	2.98e-006	0.4667	0.11
136175	1	3.28e+004	-7.45e+003	4.02e+004	-0.23	1.36e-004	1.36e-004	0.4668	0.11
140175	4000	3.43e+004	3.13e+004	2.96e+003	0.91	7.62e-009	3.05e-007	0.4669	0.11
Block: 40									
156197	2	5.04e+004	-1.49e+004	6.53e+004	-0.30	3.49e-004	3.49e-004	0.471	0.11
156199	2	3.29e+004	2.48e+004	8.11e+003	0.75	3.07e-006	3.07e-006	0.471	0.11
156200	1	3.29e+004	-7.47e+003	4.04e+004	-0.23	1.37e-004	1.37e-004	0.4712	0.11
160200	4000	3.44e+004	3.15e+004	2.97e+003	0.91	7.85e-009	3.14e-007	0.4712	0.11
Block: 45									
176222	2	5.06e+004	-1.50e+004	6.56e+004	-0.30	3.52e-004	3.52e-004	0.4754	0.11
176224	2	3.31e+004	2.50e+004	8.15e+003	0.75	3.16e-006	3.16e-006	0.4754	0.11
176225	1	3.31e+004	-7.49e+003	4.06e+004	-0.23	1.38e-004	1.38e-004	0.4756	0.11
180225	4000	3.46e+004	3.16e+004	2.99e+003	0.91	8.08e-009	3.23e-007	0.4756	0.11

Block: 50

196247	2	5.09e+004	-1.50e+004	6.59e+004	-0.30	3.55e-004	3.55e-004	0.4798	0.11
196249	2	3.33e+004	2.51e+004	8.19e+003	0.75	3.26e-006	3.26e-006	0.4798	0.11
196250	1	3.33e+004	-7.52e+003	4.08e+004	-0.23	1.39e-004	1.39e-004	0.48	0.11
200250	4000	3.48e+004	3.18e+004	3.00e+003	0.91	8.33e-009	3.33e-007	0.48	0.11

Block: 55

216272	2	5.11e+004	-1.51e+004	6.62e+004	-0.30	3.58e-004	3.58e-004	0.4843	0.11
216274	2	3.34e+004	2.52e+004	8.23e+003	0.75	3.36e-006	3.36e-006	0.4843	0.11
216275	1	3.34e+004	-7.54e+003	4.10e+004	-0.23	1.41e-004	1.41e-004	0.4844	0.11
220275	4000	3.49e+004	3.19e+004	3.02e+003	0.91	8.58e-009	3.43e-007	0.4845	0.11

Block: 60

236297	2	5.13e+004	-1.51e+004	6.64e+004	-0.29	3.60e-004	3.60e-004	0.4888	0.11
236299	2	3.36e+004	2.53e+004	8.27e+003	0.75	3.46e-006	3.46e-006	0.4888	0.11
236300	1	3.36e+004	-7.56e+003	4.12e+004	-0.22	1.42e-004	1.42e-004	0.489	0.11
240300	4000	3.51e+004	3.21e+004	3.03e+003	0.91	8.83e-009	3.53e-007	0.489	0.11

Block: 65

256322	2	5.15e+004	-1.52e+004	6.67e+004	-0.29	3.63e-004	3.63e-004	0.4933	0.11
256324	2	3.38e+004	2.55e+004	8.31e+003	0.75	3.56e-006	3.56e-006	0.4934	0.11
256325	1	3.38e+004	-7.58e+003	4.14e+004	-0.22	1.43e-004	1.43e-004	0.4935	0.11
260325	4000	3.53e+004	3.22e+004	3.05e+003	0.91	9.09e-009	3.64e-007	0.4935	0.11

Block: 70

276347	2	5.17e+004	-1.52e+004	6.69e+004	-0.29	3.66e-004	3.66e-004	0.4979	0.12
276349	2	3.39e+004	2.56e+004	8.35e+003	0.75	3.66e-006	3.66e-006	0.4979	0.12
276350	1	3.39e+004	-7.60e+003	4.15e+004	-0.22	1.44e-004	1.44e-004	0.4981	0.12
280350	4000	3.55e+004	3.24e+004	3.06e+003	0.91	9.36e-009	3.74e-007	0.4981	0.12

Block: 75

296372	2	5.19e+004	-1.52e+004	6.72e+004	-0.29	3.69e-004	3.69e-004	0.5025	0.12
296374	2	3.41e+004	2.57e+004	8.39e+003	0.75	3.77e-006	3.77e-006	0.5026	0.12
296375	1	3.41e+004	-7.62e+003	4.17e+004	-0.22	1.46e-004	1.46e-004	0.5027	0.12
300375	4000	3.56e+004	3.26e+004	3.08e+003	0.91	9.63e-009	3.85e-007	0.5027	0.12

Block: 80

316397	2	5.22e+004	-1.53e+004	6.75e+004	-0.29	3.71e-004	3.71e-004	0.5072	0.12
316399	2	3.43e+004	2.58e+004	8.44e+003	0.75	3.88e-006	3.88e-006	0.5072	0.12
316400	1	3.43e+004	-7.65e+003	4.19e+004	-0.22	1.47e-004	1.47e-004	0.5074	0.12
320400	4000	3.58e+004	3.27e+004	3.09e+003	0.91	9.92e-009	3.97e-007	0.5074	0.12

Block: 85

336422	2	5.24e+004	-1.53e+004	6.77e+004	-0.29	3.74e-004	3.74e-004	0.5119	0.12
336424	2	3.44e+004	2.60e+004	8.48e+003	0.75	4.00e-006	4.00e-006	0.5119	0.12
336425	1	3.44e+004	-7.67e+003	4.21e+004	-0.22	1.48e-004	1.48e-004	0.5121	0.12
340425	4000	3.60e+004	3.29e+004	3.11e+003	0.91	1.02e-008	4.09e-007	0.5121	0.12

Block: 90

356447	2	5.26e+004	-1.54e+004	6.80e+004	-0.29	3.77e-004	3.77e-004	0.5167	0.12
356449	2	3.46e+004	2.61e+004	8.52e+003	0.75	4.12e-006	4.12e-006	0.5167	0.12
356450	1	3.46e+004	-7.69e+003	4.23e+004	-0.22	1.50e-004	1.50e-004	0.5168	0.12
360450	4000	3.62e+004	3.31e+004	3.12e+003	0.91	1.05e-008	4.21e-007	0.5169	0.12

Block: 95

376472	2	5.28e+004	-1.54e+004	6.83e+004	-0.29	3.80e-004	3.80e-004	0.5215	0.12
376474	2	3.48e+004	2.62e+004	8.56e+003	0.75	4.25e-006	4.25e-006	0.5215	0.12

376475	1	3.48e+004	-7.71e+003	4.25e+004	-0.22	1.51e-004	1.51e-004	0.5216	0.12
380475	4000	3.64e+004	3.32e+004	3.14e+003	0.91	1.08e-008	4.34e-007	0.5217	0.12

Block: 100

396497	2	5.31e+004	-1.55e+004	6.85e+004	-0.29	3.83e-004	3.83e-004	0.5263	0.12
396499	2	3.50e+004	2.64e+004	8.61e+003	0.75	4.37e-006	4.37e-006	0.5263	0.12
396500	1	3.50e+004	-7.74e+003	4.27e+004	-0.22	1.52e-004	1.52e-004	0.5265	0.12
400500	4000	3.65e+004	3.34e+004	3.16e+003	0.91	1.12e-008	4.47e-007	0.5265	0.12

Block: 105

416522	2	5.33e+004	-1.55e+004	6.88e+004	-0.29	3.86e-004	3.86e-004	0.5312	0.12
416524	2	3.51e+004	2.65e+004	8.65e+003	0.75	4.51e-006	4.51e-006	0.5312	0.12
416525	1	3.51e+004	-7.76e+003	4.29e+004	-0.22	1.54e-004	1.54e-004	0.5314	0.12
420525	4000	3.67e+004	3.36e+004	3.17e+003	0.91	1.15e-008	4.61e-007	0.5314	0.12

Block: 110

436547	2	5.35e+004	-1.56e+004	6.91e+004	-0.29	3.89e-004	3.89e-004	0.5361	0.12
436549	2	3.53e+004	2.66e+004	8.69e+003	0.75	4.65e-006	4.65e-006	0.5361	0.12
436550	1	3.53e+004	-7.78e+003	4.31e+004	-0.22	1.55e-004	1.55e-004	0.5363	0.12
440550	4000	3.69e+004	3.37e+004	3.19e+003	0.91	1.19e-008	4.75e-007	0.5363	0.12

Block: 115

456572	2	5.38e+004	-1.56e+004	6.94e+004	-0.29	3.92e-004	3.92e-004	0.5411	0.13
456574	2	3.55e+004	2.68e+004	8.74e+003	0.75	4.79e-006	4.79e-006	0.5411	0.13
456575	1	3.55e+004	-7.80e+003	4.33e+004	-0.22	1.56e-004	1.56e-004	0.5413	0.13
460575	4000	3.71e+004	3.39e+004	3.20e+003	0.91	1.22e-008	4.89e-007	0.5413	0.13

Block: 120

476597	2	5.40e+004	-1.57e+004	6.97e+004	-0.29	3.96e-004	3.96e-004	0.5461	0.13
476599	2	3.57e+004	2.69e+004	8.78e+003	0.75	4.94e-006	4.94e-006	0.5461	0.13
476600	1	3.57e+004	-7.83e+003	4.35e+004	-0.22	1.58e-004	1.58e-004	0.5463	0.13
480600	4000	3.73e+004	3.41e+004	3.22e+003	0.91	1.26e-008	5.04e-007	0.5463	0.13

Block: 125

496622	2	5.43e+004	-1.57e+004	7.00e+004	-0.29	3.99e-004	3.99e-004	0.5512	0.13
496624	2	3.59e+004	2.70e+004	8.83e+003	0.75	5.09e-006	5.09e-006	0.5512	0.13
496625	1	3.59e+004	-7.85e+003	4.37e+004	-0.22	1.59e-004	1.59e-004	0.5514	0.13
500625	4000	3.75e+004	3.42e+004	3.24e+003	0.91	1.30e-008	5.20e-007	0.5514	0.13

Block: 130

516647	2	5.45e+004	-1.57e+004	7.02e+004	-0.29	4.02e-004	4.02e-004	0.5563	0.13
516649	2	3.60e+004	2.72e+004	8.87e+003	0.75	5.24e-006	5.24e-006	0.5563	0.13
516650	1	3.60e+004	-7.87e+003	4.39e+004	-0.22	1.61e-004	1.61e-004	0.5565	0.13
520650	4000	3.77e+004	3.44e+004	3.25e+003	0.91	1.34e-008	5.35e-007	0.5565	0.13

Block: 135

536672	2	5.47e+004	-1.58e+004	7.05e+004	-0.29	4.05e-004	4.05e-004	0.5615	0.13
536674	2	3.62e+004	2.73e+004	8.91e+003	0.75	5.40e-006	5.40e-006	0.5615	0.13
536675	1	3.62e+004	-7.89e+003	4.41e+004	-0.22	1.62e-004	1.62e-004	0.5616	0.13
540675	4000	3.79e+004	3.46e+004	3.27e+003	0.91	1.38e-008	5.51e-007	0.5617	0.13

Block: 140

556697	2	5.49e+004	-1.58e+004	7.08e+004	-0.29	4.08e-004	4.08e-004	0.5667	0.13
556699	2	3.64e+004	2.74e+004	8.96e+003	0.75	5.56e-006	5.56e-006	0.5667	0.13
556700	1	3.64e+004	-7.91e+003	4.43e+004	-0.22	1.64e-004	1.64e-004	0.5669	0.13
560700	4000	3.80e+004	3.48e+004	3.28e+003	0.91	1.42e-008	5.68e-007	0.5669	0.13

Block: 145

576722	2	5.52e+004	-1.59e+004	7.10e+004	-0.29	4.11e-004	4.11e-004	0.5719	0.13
576724	2	3.66e+004	2.76e+004	9.00e+003	0.75	5.72e-006	5.72e-006	0.572	0.13
576725	1	3.66e+004	-7.93e+003	4.45e+004	-0.22	1.65e-004	1.65e-004	0.5721	0.13
580725	4000	3.82e+004	3.49e+004	3.30e+003	0.91	1.46e-008	5.85e-007	0.5722	0.13
Block: 150									
596747	2	5.54e+004	-1.59e+004	7.13e+004	-0.29	4.14e-004	4.14e-004	0.5773	0.13
596749	2	3.68e+004	2.77e+004	9.05e+003	0.75	5.89e-006	5.89e-006	0.5773	0.13
596750	1	3.68e+004	-7.95e+003	4.47e+004	-0.22	1.67e-004	1.67e-004	0.5774	0.13
600750	4000	3.84e+004	3.51e+004	3.32e+003	0.91	1.51e-008	6.02e-007	0.5775	0.13
Block: 155									
616772	2	5.56e+004	-1.59e+004	7.16e+004	-0.29	4.17e-004	4.17e-004	0.5826	0.14
616774	2	3.69e+004	2.79e+004	9.09e+003	0.75	6.07e-006	6.07e-006	0.5826	0.14
616775	1	3.69e+004	-7.97e+003	4.49e+004	-0.22	1.68e-004	1.68e-004	0.5828	0.14
620775	4000	3.86e+004	3.53e+004	3.33e+003	0.91	1.55e-008	6.20e-007	0.5828	0.14
Block: 160									
636797	2	5.59e+004	-1.60e+004	7.19e+004	-0.29	4.20e-004	4.20e-004	0.588	0.14
636799	2	3.71e+004	2.80e+004	9.14e+003	0.75	6.26e-006	6.26e-006	0.588	0.14
636800	1	3.71e+004	-7.99e+003	4.51e+004	-0.22	1.70e-004	1.70e-004	0.5882	0.14
640800	4000	3.88e+004	3.55e+004	3.35e+003	0.91	1.60e-008	6.39e-007	0.5883	0.14
Block: 165									
656822	2	5.61e+004	-1.60e+004	7.21e+004	-0.29	4.23e-004	4.23e-004	0.5935	0.14
656824	2	3.73e+004	2.81e+004	9.18e+003	0.75	6.45e-006	6.45e-006	0.5935	0.14
656825	1	3.73e+004	-8.01e+003	4.53e+004	-0.21	1.71e-004	1.71e-004	0.5937	0.14
660825	4000	3.90e+004	3.56e+004	3.37e+003	0.91	1.65e-008	6.59e-007	0.5937	0.14
Block: 170									
676847	2	5.64e+004	-1.61e+004	7.24e+004	-0.29	4.27e-004	4.27e-004	0.599	0.14
676849	2	3.75e+004	2.83e+004	9.23e+003	0.75	6.64e-006	6.64e-006	0.599	0.14
676850	1	3.75e+004	-8.04e+003	4.55e+004	-0.21	1.73e-004	1.73e-004	0.5992	0.14
680850	4000	3.92e+004	3.58e+004	3.38e+003	0.91	1.70e-008	6.79e-007	0.5992	0.14
Block: 175									
696872	2	5.66e+004	-1.61e+004	7.27e+004	-0.28	4.30e-004	4.30e-004	0.6045	0.14
696874	2	3.77e+004	2.84e+004	9.28e+003	0.75	6.85e-006	6.85e-006	0.6046	0.14
696875	1	3.77e+004	-8.06e+003	4.58e+004	-0.21	1.74e-004	1.74e-004	0.6047	0.14
700875	4000	3.94e+004	3.60e+004	3.40e+003	0.91	1.75e-008	7.00e-007	0.6048	0.14
Block: 180									
716897	2	5.69e+004	-1.62e+004	7.30e+004	-0.28	4.33e-004	4.33e-004	0.6102	0.14
716899	2	3.79e+004	2.86e+004	9.33e+003	0.75	7.06e-006	7.06e-006	0.6102	0.14
716900	1	3.79e+004	-8.08e+003	4.60e+004	-0.21	1.76e-004	1.76e-004	0.6104	0.14
720900	4000	3.96e+004	3.62e+004	3.42e+003	0.91	1.80e-008	7.21e-007	0.6104	0.14
Block: 185									
736922	2	5.71e+004	-1.62e+004	7.33e+004	-0.28	4.37e-004	4.37e-004	0.6158	0.14
736924	2	3.81e+004	2.87e+004	9.37e+003	0.75	7.28e-006	7.28e-006	0.6158	0.14
736925	1	3.81e+004	-8.10e+003	4.62e+004	-0.21	1.77e-004	1.77e-004	0.616	0.14
740925	4000	3.98e+004	3.64e+004	3.44e+003	0.91	1.86e-008	7.44e-007	0.6161	0.14
Block: 190									
756947	2	5.74e+004	-1.62e+004	7.36e+004	-0.28	4.40e-004	4.40e-004	0.6216	0.14
756949	2	3.83e+004	2.89e+004	9.42e+003	0.75	7.50e-006	7.50e-006	0.6216	0.14
756950	1	3.83e+004	-8.12e+003	4.64e+004	-0.21	1.79e-004	1.79e-004	0.6218	0.14
760950	4000	4.00e+004	3.66e+004	3.45e+003	0.91	1.92e-008	7.67e-007	0.6218	0.14

Block: 195

776972	2	5.76e+004	-1.63e+004	7.39e+004	-0.28	4.43e-004	4.43e-004	0.6273	0.15
776974	2	3.85e+004	2.90e+004	9.47e+003	0.75	7.73e-006	7.73e-006	0.6274	0.15
776975	1	3.85e+004	-8.14e+003	4.66e+004	-0.21	1.81e-004	1.81e-004	0.6275	0.15
780975	4000	-4.02e+004	3.67e+004	3.47e+003	0.91	1.97e-008	7.90e-007	0.6276	0.15

Block: 200

796997	2	5.78e+004	-1.63e+004	7.41e+004	-0.28	4.47e-004	4.47e-004	0.6332	0.15
796999	2	3.87e+004	2.92e+004	9.52e+003	0.75	7.96e-006	7.96e-006	0.6332	0.15
797000	1	3.87e+004	-8.16e+003	4.68e+004	-0.21	1.82e-004	1.82e-004	0.6334	0.15
801000	4000	4.04e+004	3.69e+004	3.49e+003	0.91	2.03e-008	8.13e-007	0.6335	0.15

Block: 205

817022	2	5.81e+004	-1.64e+004	7.44e+004	-0.28	4.50e-004	4.50e-004	0.6391	0.15
817024	2	3.89e+004	2.93e+004	9.56e+003	0.75	8.20e-006	8.20e-006	0.6391	0.15
817025	1	3.89e+004	-8.18e+003	4.70e+004	-0.21	1.84e-004	1.84e-004	0.6393	0.15
821025	4000	4.06e+004	3.71e+004	3.51e+003	0.91	2.09e-008	8.38e-007	0.6394	0.15

Block: 210

837047	2	5.83e+004	-1.64e+004	7.47e+004	-0.28	4.53e-004	4.53e-004	0.645	0.15
837049	2	3.91e+004	2.94e+004	9.61e+003	0.75	8.44e-006	8.44e-006	0.645	0.15
837050	1	3.91e+004	-8.20e+003	4.73e+004	-0.21	1.86e-004	1.86e-004	0.6452	0.15
841050	4000	4.08e+004	3.73e+004	3.52e+003	0.91	2.16e-008	8.63e-007	0.6453	0.15

Block: 215

857072	2	5.86e+004	-1.64e+004	7.50e+004	-0.28	4.57e-004	4.57e-004	0.651	0.15
857074	2	3.93e+004	2.96e+004	9.66e+003	0.75	8.70e-006	8.70e-006	0.651	0.15
857075	1	3.93e+004	-8.22e+003	4.75e+004	-0.21	1.87e-004	1.87e-004	0.6512	0.15
861075	4000	4.10e+004	3.75e+004	3.54e+003	0.91	2.22e-008	8.89e-007	0.6513	0.15

Block: 220

877097	2	5.88e+004	-1.65e+004	7.53e+004	-0.28	4.60e-004	4.60e-004	0.6571	0.15
877099	2	3.95e+004	2.97e+004	9.71e+003	0.75	8.97e-006	8.97e-006	0.6571	0.15
877100	1	3.95e+004	-8.24e+003	4.77e+004	-0.21	1.89e-004	1.89e-004	0.6573	0.15
881100	4000	4.12e+004	3.77e+004	3.56e+003	0.91	2.29e-008	9.16e-007	0.6574	0.15

Block: 225

897122	2	5.91e+004	-1.65e+004	7.56e+004	-0.28	4.63e-004	4.63e-004	0.6632	0.15
897124	2	3.97e+004	2.99e+004	9.76e+003	0.75	9.24e-006	9.24e-006	0.6632	0.15
897125	1	3.97e+004	-8.26e+003	4.79e+004	-0.21	1.91e-004	1.91e-004	0.6634	0.15
901125	4000	4.14e+004	3.79e+004	3.58e+003	0.91	2.36e-008	9.45e-007	0.6635	0.15

Block: 230

917147	2	5.93e+004	-1.65e+004	7.59e+004	-0.28	4.67e-004	4.67e-004	0.6694	0.16
917149	2	3.99e+004	3.00e+004	9.81e+003	0.75	9.53e-006	9.53e-006	0.6694	0.16
917150	1	3.99e+004	-8.28e+003	4.81e+004	-0.21	1.92e-004	1.92e-004	0.6696	0.16
921150	4000	4.16e+004	3.81e+004	3.60e+003	0.91	2.43e-008	9.74e-007	0.6697	0.16

Block: 235

937172	2	5.96e+004	-1.66e+004	7.62e+004	-0.28	4.71e-004	4.71e-004	0.6756	0.16
937174	2	4.01e+004	3.02e+004	9.86e+003	0.75	9.82e-006	9.82e-006	0.6756	0.16
937175	1	4.01e+004	-8.30e+003	4.84e+004	-0.21	1.94e-004	1.94e-004	0.6758	0.16
941175	4000	4.19e+004	3.82e+004	3.61e+003	0.91	2.51e-008	1.00e-006	0.6759	0.16

Block: 240

957197	2	5.98e+004	-1.66e+004	7.65e+004	-0.28	4.74e-004	4.74e-004	0.6819	0.16
957199	2	4.03e+004	3.04e+004	9.91e+003	0.75	1.01e-005	1.01e-005	0.682	0.16

957200	1	4.03e+004	-8.32e+003	4.86e+004	-0.21	1.96e-004	1.96e-004	0.6822	0.16
961200	4000	4.21e+004	3.84e+004	3.63e+003	0.91	2.59e-008	1.04e-006	0.6823	0.16

Block: 245

977222	2	6.01e+004	-1.67e+004	7.68e+004	-0.28	4.78e-004	4.78e-004	0.6883	0.16
977224	2	4.05e+004	3.05e+004	9.96e+003	0.75	1.04e-005	1.04e-005	0.6883	0.16
977225	1	4.05e+004	-8.34e+003	4.88e+004	-0.21	1.98e-004	1.98e-004	0.6885	0.16
981225	4000	4.23e+004	3.86e+004	3.65e+003	0.91	2.67e-008	1.07e-006	0.6886	0.16

Block: 250

997247	2	6.03e+004	-1.67e+004	7.70e+004	-0.28	4.81e-004	4.81e-004	0.6947	0.16
997249	2	4.07e+004	3.07e+004	1.00e+004	0.75	1.08e-005	1.08e-005	0.6948	0.16
997250	1	4.07e+004	-8.35e+003	4.90e+004	-0.21	1.99e-004	1.99e-004	0.695	0.16
1001250	4000	4.25e+004	3.88e+004	3.67e+003	0.91	2.75e-008	1.10e-006	0.6951	0.16

End of pc-CRACK Output