Purchase Order No. 349991
Release No. YY-9

# ZION STEAM GENERATOR GIRTH WELD FLAW EVALUATION

Prepared for

**COMMONWEALTH EDISON COMPANY**
**ZION STATION**
**ZION, ILLINOIS**

November 24, 1993 - FINAL

Prepared By/Date 11/26/93

Quality Assurance/Date 11/26/93

Prepared By/Date 11/26/93

Verified By/Date 11/26/93

Approved By/Date 11/26/93

Verified By/Date 11/26/93


**Engineering Applied Sciences, Inc.**
505 Pleasant Valley Road
Trafford, PA 15085-9763


2032-0001-00
Document No.

| Rev. | 01 | 02 | 03 | 04 | |
|---|---|---|---|---|---|
| Date | 1/27/94 | 2/8/94 | 2/15/94 | 3/3/94 | |
| Appr | [illegible] | [illegible] | [illegible] | [illegible] | |
| QA | [illegible] | [illegible] | [illegible] | [illegible] | |


9403250217 940316
PDR ADOCK 05000295
Q PDR

## TABLE OF CONTENTS

## TABLE OF CONTENTS
(Continued)

## LIST OF TABLES

## LIST OF TABLES - continued

## LIST OF FIGURES

## LIST OF FIGURES - continued

## LIST OF FIGURES - continued

## LIST OF FIGURES - continued

## EXECUTIVE SUMMARY AND CONCLUSIONS

Engineering considerations and analytical methods used to determine acceptability of flaws detected in the upper shell to transition cone girth weld in the steam generators at Zion Nuclear Station Units 1 and 2 are presented and discussed. The calculations regarding flaw acceptability by fracture mechanics analysis are described and results are presented for surface and subsurface flaws. Final allowable flaw sizes and shapes are specifically illustrated for surface flaws, where flaw growth in service is complicated by environmentally enhanced crack growth considerations.

A maximum surface crack growth of 0.32 inches in depth for the next one cycle of operation is a reasonable conservative choice for a bounding growth rate. As described in this report, this conclusion is based upon the history of inspection results at Zion Units 1 and 2, the observed cracking response of similar steam generators, data in the literature on environmentally enhanced crack growth of pressure vessel steels in high temperature water, and ASME Code corrosion fatigue crack growth analyses.

Flaws found by inspection can be left in service if the present size plus the expected crack growth is less than the allowable flaw size. As an example, a surface crack with a present depth of 0.35 inches would not be expected to grow deeper than 0.67 inches after one cycle of operation. This size would be acceptable. Acceptability of this flaw for continued service beyond one cycle would depend on the actual measured end of cycle crack depth and reevaluated crack growth rates.

# ZION STEAM GENERATOR GIRTH WELD FLAW EVALUATION

## 1.0 INTRODUCTION

This report presents engineering considerations and analytical methods used to determine acceptability of flaws detected in the upper shell to transition girth weld in the steam generators at Zion Nuclear Station Units 1 and 2. The steam generator shells are Class 2 Components which are under the jurisdiction of Section III, Division 1, Subsection NC of the ASME Boiler and Pressure Vessel Code. The analyses were done to ASME 1989 Edition no addenda and the working edition of the code for Zion is 1980 through the Winter 1981 Addenda. However, additional guidance was sought from the 1992 Edition which is believed to be adopted by the NRC in the Federal Register, first quarter 1994. The reason for the reference to the 1992 Edition is the improvement in fatigue and fracture curve calculations. Flaws found during inservice inspections of Class 2 components are considered to be acceptable if they satisfy the requirements of Section XI Article IWC-3000 of the Code. Acceptability is demonstrated if one of the following two options is satisfied.

1. Flaw sizes satisfy the requirements of IWC-3500.

2. Analytical evaluation of flaw stress intensities satisfies the requirements of IWC-3600. Article IWC-3600 specifies that the analytical methods used to satisfy IWC requirements are those described in article IWB-3600 of the Code. Flaws satisfying these requirements are then subject to IWC requirements for subsequent inspections.

It is customary to conduct such evaluations of pressure vessels using the edition of the Code which was used for the construction of the vessels. However, it is permissible to use the current edition of the Code provided such usage is sufficiently broad to ensure a consistent set of rules for the evaluation conducted. This approach is particularly appropriate when the current Code edition provides coverage which was not contained in the Code edition of construction. This is the case for the flaw evaluation for the steam generators of Zion Units 1 and 2. Therefore, all applicable rules and data for this evaluation are taken from the 1992 Edition of the ASME B&PV Code with the 1992 Addenda (Reference 1).

Section 2 presents basic data on geometry and material properties. The flaws which were detected in the 1989, 1990 and 1992 inspections are recorded in Section 3. The results of UT and MT/grindout inspections are compared. The finite element analysis method is verified in Section 4. Section 5 describes the steam generator girth weld model and the applied loadings. Results of the stress analysis are presented in Section 6. Then, in Section 7, example fracture mechanics analyses of selected flaws are performed using the stress results of Section 6. Crack growth projections are made using several approaches. For subsurface flaws, only fatigue in the absence of environmental effects needs to be considered. For surface flaws, environmentally enhanced crack growth is a key consideration. A standard ASME Code corrosion fatigue crack growth analysis is presented and compared to previous inspection results. Data in the literature and stress corrosion cracking considerations are discussed. General growth projection for surface flaws for one cycle of operation is presented together with end-of-cycle allowable crack sizes and shapes.

## 2.0 TECHNICAL APPROACH

### 2.1 ZION STATION STEAM GENERATORS

Units 1 and 2 of Zion Nuclear Station are four loop pressurized water reactors. Each unit has four Westinghouse Model 51D feedring steam generators. Ultrasonic examinations of the upper shell to transition cone girth weld were performed for Zion Unit 1 during the fall 1989 refueling outage and for Zion Unit 2 during the spring 1990 refueling outage. The girth weld of Unit 1 was reinspected during the spring 1992 refueling outage. Numerous defects were recorded, associated with the girth weld, for each of the generators during each inspection. Many of the defects were shallow and surface connected, and were removed by grinding and blending. Subsurface indications were sized using ultrasonic data and were dispositioned according to the acceptability criteria in IWB-3511-1 per CECo, and W WCAP 12489. Flaws exceeding these criteria are evaluated using fracture mechanics methods for disposition according to the provisions of the Code. Use of fracture mechanics methods to disposition observed flaws requires a knowledge of the detailed stress state in the girth weld region. The detailed stress state is determined using finite element analysis.

### 2.2 STEAM GENERATOR GEOMETRY

A steam generator cross section is shown in Figure 2-1. Support locations are shown in Figure 2-2. The closest support to the girth weld is the upper lateral support which contacts the lower cylinder. As shown in Section 5 of this report, this support is sufficiently far from the girth weld that its influence on local stresses in the girth weld region may be neglected. This allows us to restrict the stress analysis to a limited region of the steam generator as shown in Figure 2-1. Figure 2-3 shows a detail of the upper girth weld. Figure 2-4 is a schematic of the finite element model used in this analysis.

## 2.3 MATERIAL PROPERTIES

The steam generator shell is fabricated from SA533 Grade A Class 1 material which is nearly identical in composition to SA302 Grade B and has similar properties. Material properties are given in the ASME Code Section II pages included as Tables 2-1, 2-2 and 2-3. These properties are temperature dependent as shown in the plots of Figures 2-5 to 2-8.

Additional material properties which are not temperature dependent are taken from Reference 2 for use in the finite element stress analysis.

Density = 490 $lb/ft^3$

Poisson Ratio = 0.3

To perform the analytical evaluation of the flaw stress intensities we must know the material fracture toughness and the fatigue crack growth rates. The fracture toughness of the material is determined by two properties $K_{Ia}$ and $K_{Ic}$, which represent critical values of the stress intensity factor $K_I$. $K_{Ia}$ is based on the lower bound of crack arrest critical $K_I$ values measured as a function of temperature. $K_{Ic}$ is based on the lower bound of static initial critical $K_I$ values measured as a function of temperature. Values of $K_{Ia}$ and $K_{Ic}$ are given by the reference curve shown in Figure 2-9. The reference toughness curve represents a conservative estimate of measured lower bounding values for pressure vessel steels of the type used in the NSSS island. It is published in Section XI of the ASME Boiler and Pressure Vessel Code and is indexed to a Reference Temperature (RT). RT is determined by mechanical testing of each piece of material used in construction (including welding consumable). The two tests applied are the Drop Weight Nil Ductility Temperature (DWNDT) and the Charpy Vee Notch tests. The Reference Temperature is either the DWNDT plus 60°F or the temperature at which the $C_v$ values 35 mils lateral expansion and 50 ft-lbs absorbed energy are achieved. By knowing these values, the reference toughness curve is entered and critical fracture toughness properties estimated. A comparison of the calculated stress intensity associated with a given flaw size and location to the appropriately scaled fracture toughness criterion determines the flaw acceptability.

During service loading, a flaw may extend or grow to a larger size over a given duration in time. It must be assumed that this possible extension will not exceed a critical flaw size determined from the fracture toughness. Crack extension is estimated typically by a fatigue crack growth analysis. The fatigue crack growth rate of the material is given in the ASME Code as:

$$da/dN = C_o (\Delta K)^n \qquad \text{(Eqn 1)}$$

where

$C_o$ = scaling constant

$\Delta K$ = range of applied stress intensity

$n$ = slope of the log (da/dN) versus log ($\Delta K$) curve

Fatigue crack growth rate curves reflecting values of $C_o$ and n are shown in Figure 2-10 for an air environment. Surface flaws on the inner diameter are exposed to a high temperature water environment which can accelerate fatigue crack growth rates. For this circumstance, the appropriate fatigue crack growth rates as given in the ASME Code are presented in Figure 2-11. A complete discussion of crack growth rates including historical performance at Zion Units 1 and 2 and data in the literature is presented in Section 3.

## Table 2-1. Coefficients of Thermal Conductivity and Diffusivity







TABLE TCD (CONT'D)
NOMINAL COEFFICIENTS OF THERMAL CONDUCTIVITY (TC) AND THERMAL DIFFUSIVITY (TD)

| | Carbon and Low Alloy Steels (Cont'd) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 3½Ni | | 3½Ni-1¾Cr-½Mo-V | | 5Ni-¼Mo | | 8Ni | | 9Ni | | Mn-½Mo | | Mn-½Mo-¼Ni | |
| Temp., °F | TC | TD | TC | TD | TC | TD | TC | TD | TC | TD | TC | TD | TC | TD |
| 70 | 22.9 | 0.436 | 21.9 | 0.418 | 19.4 | 0.367 | 17.6 | 0.328 | 17.4 | 0.326 | 23.3 | 0.455 | 22.7 | 0.437 |
| 100 | 23.2 | 0.432 | [illegible] | 0.415 | 19.7 | 0.366 | 17.8 | 0.326 | 17.8 | 0.325 | 23.6 | 0.451 | 23.1 | 0.436 |
| 150 | 23.6 | 0.426 | [illegible] | 0.411 | 20.2 | 0.364 | 18.1 | 0.322 | 18.3 | 0.325 | 24.1 | 0.444 | 23.5 | 0.433 |
| 200 | 23.8 | 0.418 | [illegible]3.0 | 0.406 | 20.7 | 0.361 | 18.5 | 0.319 | 18.8 | 0.324 | 24.4 | 0.437 | 23.8 | 0.429 |
| 250 | 24.0 | 0.411 | 23.3 | 0.401 | 21.0 | 0.357 | 18.6 | 0.314 | 19.1 | 0.322 | 24.6 | 0.429 | 24.1 | 0.423 |
| 300 | 24.1 | 0.407 | 23.4 | 0.394 | 21.2 | 0.353 | 19.0 | 0.310 | 19.4 | 0.319 | 24.7 | 0.420 | 24.2 | 0.415 |
| 350 | 24.0 | 0.3[illegible]4 | 23.4 | 0.386 | 21.4 | 0.348 | 19.2 | 0.306 | 19.6 | 0.315 | 24.7 | 0.409 | 24.2 | 0.405 |
| 400 | 23.9 | 0.[illegible]84 | 23.3 | 0.377 | 21.4 | 0.341 | 19.4 | 0.302 | 19.7 | 0.309 | 24.6 | 0.398 | 24.1 | 0.394 |
| 450 | 23.7 | 0.373 | 23.1 | 0.367 | 21.4 | 0.334 | 19.5 | 0.297 | 19.8 | 0.303 | 24.4 | 0.385 | 24.0 | 0.383 |
| 500 | 23.4 | 0.363 | 22.9 | 0.357 | 21.3 | 0.326 | 29.6 | 0.292 | 19.8 | 0.297 | 24.2 | 0.377 | 23.8 | 0.371 |
| 550 | 23.2 | 0.351 | 22.7 | 0.346 | 21.2 | 0.318 | 19.6 | 0.286 | 19.8 | 0.291 | 23.9 | 0.364 | 23.5 | 0.358 |
| 600 | 22.9 | 0.340 | 22.4 | 0.335 | 21.1 | 0.310 | 19.7 | 0.280 | 19.8 | 0.284 | 23.5 | 0.353 | 23.2 | 0.346 |
| 650 | 22.6 | 0.327 | 22.1 | 0.323 | 20.9 | 0.301 | 19.6 | 0.273 | 19.8 | 0.277 | 23.2 | 0.340 | 22.9 | 0.334 |
| 700 | 22.3 | 0.316 | 21.8 | 0.312 | 20.8 | 0.292 | 19.6 | 0.267 | 19.7 | 0.270 | 22.8 | 0.328 | 22.5 | 0.322 |
| 750 | 21.9 | 0.306 | 21.5 | 0.302 | 20.6 | 0.283 | 19.6 | 0.259 | 19.6 | 0.263 | 22.4 | 0.314 | 22.2 | 0.310 |
| 800 | 21.6 | 0.2[illegible] | 21.2 | 0.291 | 20.4 | 0.274 | 19.5 | 0.251 | 19.5 | 0.255 | 22.0 | 0.300 | 21.8 | 0.297 |
| 850 | 21.2 | 0.284 | 20.9 | 0.280 | 20.1 | 0.265 | 19.3 | 0.242 | 19.4 | 0.247 | 21.6 | 0.286 | 21.4 | 0.283 |
| 900 | 20.9 | 0.272 | 20.5 | 0.269 | 19.9 | 0.255 | 19.2 | 0.232 | 19.2 | 0.237 | 21.2 | 0.274 | 21.0 | 0.272 |
| 950 | 20.5 | 0.260 | 20.1 | 0.257 | 19.6 | 0.243 | 18.9 | 0.220 | 18.9 | 0.225 | 20.8 | 0.262 | 20.6 | 0.257 |
| 1000 | 20.1 | 0.246 | 19.6 | 0.243 | 19.2 | 0.231 | 18.5 | 0.205 | 18.6 | 0.212 | 20.4 | 0.249 | 20.2 | 0.243 |
| 1050 | 19.7 | 0.232 | 19.4 | 0.230 | 18.8 | 0.218 | 18.1 | 0.192 | 18.3 | 0.197 | 19.9 | 0.237 | 19.8 | 0.230 |
| 1100 | 19.2 | 0.217 | 18.9 | 0.215 | 18.4 | 0.203 | 17.7 | 0.176 | 17.9 | 0.181 | 19.5 | 0.223 | 19.4 | 0.215 |
| 1150 | 18.7 | 0.201 | 18.4 | 0.199 | 18.0 | 0.187 | 17.2 | 0.158 | 17.4 | 0.164 | 19.0 | 0.209 | 18.9 | 0.200 |
| 1200 | 18.2 | 0.183 | 17.9 | 0.182 | 17.5 | 0.170 | 16.8 | 0.140 | 17.0 | 0.144 | 18.6 | 0.193 | 18.5 | 0.186 |
| 1250 | 17.6 | 0.164 | 17.4 | 0.163 | 17.0 | 0.152 | 16.3 | 0.108 | 16.4 | 0.111 | 18.1 | 0.178 | 18.0 | 0.171 |
| 1300 | 16.9 | 0.141 | 16.7 | 0.141 | 16.4 | 0.129 | 15.9 | 0.169 | 15.6 | 0.170 | 17.6 | 0.161 | 17.6 | 0.155 |
| 1350 | 15.8 | 0.137 | 15.7 | 0.137 | 15.5 | 0.155 | 15.5 | 0.186 | 15.1 | 0.185 | 17.0 | 0.142 | 17.0 | 0.136 |
| 1400 | 15.5 | 0.174 | 15.3 | 0.174 | 15.2 | 0.178 | 15.3 | 0.198 | 15.0 | 0.199 | 16.1 | 0.103 | 16.0 | 0.102 |
| 1450 | 15.4 | 0.194 | 15.2 | 0.194 | 15.2 | 0.195 | 15.2 | 0.208 | 15.1 | 0.211 | 15.3 | 0.137 | 15.3 | 0.146 |
| 1500 | 15.3 | 0.208 | 15.2 | 0.208 | 15.2 | 0.208 | 15.4 | 0.218 | 15.2 | 0.221 | 15.5 | 0.164 | 15.4 | 0.166 |

K = Btu/hr ft °F   d = ft²/hr

Source: Reference 1

# Table 2-2 Moduli of Elasticity of Ferrous Materials

Table TM-1 1992 SECTION II

TABLE TM-1
MODULI OF ELASTICITY $E$ OF FERROUS MATERIALS FOR GIVEN TEMPERATURES

| Materials | Modulus of Elasticity $E$ = Value Given × $10^6$ psi, for Temp., °F, of | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | −325 | −200 | −100 | 70 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 |
| Carbon steels with C ≤ 0.30% | 31.4 | 30.8 | 30.2 | 29.5 | 28.8 | 28.3 | 27.7 | 27.3 | 26.7 | 25.5 | 24.2 | 22.4 |
| Carbon steels with C > 0.30% | 31.2 | 30.6 | 30.0 | 29.3 | 28.6 | 28.1 | 27.5 | 27.1 | 26.5 | 25.3 | 24.0 | 22.3 |
| Material Group A[1] | 31.1 | 30.5 | 29.9 | 29.2 | 28.5 | 28.0 | 27.4 | 27.0 | 26.4 | 25.3 | 23.9 | 22.2 |
| Material Group B[2] | 29.6 | 29.1 | 28.5 | 27.8 | 27.1 | 26.7 | 26.1 | 25.7 | 25.2 | 24.6 | 23.0 | ... |
| Material Group C[3] | 31.6 | 31.0 | 30.4 | 29.7 | 29.0 | 28.5 | 27.9 | 27.5 | 26.9 | 26.3 | 25.5 | 24.8 |
| Material Group D[4] | 32.6 | 32.0 | 31.4 | 30.6 | 29.8 | 29.4 | 28.8 | 28.3 | 27.7 | 27.1 | 26.3 | 25.6 |
| Material Group E[5] | 32.9 | 32.3 | 31.7 | 30.9 | 30.1 | 29.7 | 29.0 | 28.6 | 28.0 | 27.3 | 26.1 | 24.7 |
| Material Group F[6] | 31.2 | 30.7 | 30.1 | 29.2 | 28.5 | 27.9 | 27.3 | 26.7 | 26.1 | 25.6 | 24.7 | 23.2 |
| Material Group G[7] | 30.3 | 29.7 | 29.1 | 28.3 | 27.6 | 27.0 | 26.5 | 25.8 | 25.3 | 24.8 | 24.1 | 23.5 |

Source: Reference 1

NOTES:

(1) Material Group A consists of the following carbon–molybdenum steels:
- C–1/2Mo
- Mn–1/4Mo
- Mn–1/2Mo
- Mn–V

(2) Material Group B consists of the following Ni steels:
- 3/4Ni–1/2Mo–Cr–V
- 1Ni–1/2Cr–1/2Mo
- 1/2Ni–1/2Mo–V
- 3/4Ni–1Mo–3/4Cr
- 3/4Ni–1/2Mo–1/3Cr–V
- 1/2Ni–1/2Cr–1/4Mo–V
- 3/4Cr–3/4Ni–Cu–Al
- 2Ni–1Cu
- 3/4Cr–1/2Ni–Cu
- 2 1/2Ni
- 3/4Ni–1/2Cu–Mo
- 3 1/2Ni

(3) Material Group C consists of the following 1/2–2Cr steels:
- 1/2Cr–1/2Mo
- 1Cr–1/2Mo
- 1 1/4Cr–1/2Mo–Si
- 1 1/4Cr–1/2Mo
- 2Cr–1/2Mo

(4) Material Group D consists of the following 2 1/4–3Cr steels:
- 2 1/4Cr–1Mo
- 3Cr–1Mo

(5) Material Group E consists of the following 5–9Cr steels:
- 5Cr–1/2Mo
- 5Cr–1/2Mo–Si
- 5Cr–1/2Mo–Ti
- 7Cr–1/2Mo
- 9Cr–Mo

(6) Material Group F consists of the following chromium steels:
- 12Cr–Al
- 13Cr
- 15Cr
- 17Cr

(7) Material Group G consists of the following austenitic steels:
- 18Cr–8Ni
- 18Cr–10Ni–Cb
- 18Cr–8Ni–N
- 18Cr–18Ni–2Si
- 16Cr–12Ni
- 20Cr–6Ni–9Mn
- 18Cr–13Ni–3Mo
- 22Cr–13Ni–5Mn
- 16Cr–12Ni–2Mo–N
- 23Cr–12Ni
- 18Cr–3Ni–13Mn
- 25Cr–20Ni
- 18Cr–10Ni–Ti

664

TABLE TE-1
NOMINAL COEFFICIENTS OF THERMAL EXPANSION FOR FERROUS MATERIALS

| Materials | Coefficient | 70 | 100 | 150 | 200 | 250 | 300 | 350 | 400 | 450 | 500 | 550 | 600 | 650 | 700 | 750 | 800 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Temperature, °F | | | | | | | | | | | | | | | |
| **Carbon and Low Alloy Steels** | | | | | | | | | | | | | | | | | |
| Material Group A [Note (1)] | A | 6.41 | 6.53 | 6.73 | 6.93 | 7.12 | 7.30 | 7.49 | 7.66 | 7.84 | 8.03 | 8.21 | 8.35 | 8.51 | 8.64 | 8.78 | 8.90 |
| | B | ... | 6.50 | 6.57 | 6.67 | 6.77 | 6.87 | 6.98 | 7.07 | 7.15 | 7.25 | 7.34 | 7.42 | 7.52 | 7.59 | 7.68 | 7.76 |
| | C | 0 | 0.0023 | 0.0063 | 0.0104 | 0.0146 | 0.0190 | 0.0235 | 0.0280 | 0.0326 | 0.0374 | 0.0423 | 0.0472 | 0.0523 | 0.0574 | 0.0627 | 0.0680 |
| Material Group B [Note (2)] | A | 5.60 | 5.83 | 6.20 | 6.55 | 6.88 | 7.18 | 7.47 | 7.73 | 7.97 | 8.18 | 8.38 | 8.55 | 8.70 | 8.83 | 8.94 | 9.02 |
| | B | ... | 5.73 | 5.91 | 6.09 | 6.27 | 6.43 | 6.59 | 6.74 | 6.89 | 7.06 | 7.18 | 7.28 | 7.40 | 7.51 | 7.61 | 7.71 |
| | C | 0 | 0.0021 | 0.0057 | 0.0095 | 0.0135 | 0.0177 | 0.0221 | 0.0267 | 0.0314 | 0.0364 | 0.0414 | 0.0463 | 0.0515 | 0.0568 | 0.0621 | 0.0675 |
| Material Group C [Note (3)] | A | 5.42 | 5.65 | 6.03 | 6.39 | 6.73 | 7.04 | 7.33 | 7.60 | 7.85 | 8.07 | 8.28 | 8.46 | 8.62 | 8.75 | 8.87 | 8.96 |
| | B | ... | 5.53 | 5.71 | 5.89 | 6.09 | 6.26 | 6.43 | 6.61 | 6.77 | 6.91 | 7.06 | 7.17 | 7.30 | 7.41 | 7.50 | 7.59 |
| | C | 0 | 0.0020 | 0.0055 | 0.0092 | 0.0132 | 0.0173 | 0.0216 | 0.0262 | 0.0309 | 0.0357 | 0.0407 | 0.0456 | 0.0508 | 0.0560 | 0.0612 | 0.0665 |
| Material Group D [Note (4)] | A | [illegible] | 7.13 | 7.29 | 7.45 | 7.60 | 7.74 | 7.88 | 8.01 | 8.13 | 8.25 | 8.36 | 8.46 | 8.55 | 8.63 | 8.71 | 6.78 |
| | B | ... | 7.06 | 7.16 | 7.25 | 7.34 | 7.43 | 7.50 | 7.58 | 7.63 | 7.70 | 7.77 | 7.83 | 7.90 | 7.94 | 8.00 | 8.05 |
| | C | 0 | 0.0025 | 0.0069 | 0.0113 | 0.0158 | 0.0205 | 0.0252 | 0.0300 | 0.0348 | 0.0397 | 0.0448 | 0.0498 | 0.0550 | 0.0600 | 0.0653 | 0.0706 |
| Material Group E [Note (5)] | A | 6.20 | 6.37 | 6.62 | 6.85 | 7.05 | 7.25 | 7.43 | 7.39 | 7.75 | 7.90 | 8.04 | 8.16 | 8.28 | 8.39 | 8.49 | 8.57 |
| | B | ... | 6.27 | 6.41 | 6.54 | 6.65 | 6.78 | .88 | 6.98 | 7.07 | 7.16 | 7.24 | 7.32 | 7.41 | 7.47 | 7.55 | 7.61 |
| | C | 0 | 0.0022 | 0.0062 | 0.0102 | 0.0144 | 0.0187 | 0.0231 | 0.0276 | 0.0322 | 0.0369 | 0.0417 | 0.0466 | 0.0516 | 0.0565 | 0.0616 | 0.0667 |
| 2¼Cr–1Mo | A | 6.45 | 6.60 | 6.80 | 6.90 | 7.16 | 7.35 | 7.48 | 7.65 | 7.76 | 7.90 | 7.99 | 8.10 | 8.17 | 8.25 | 8.32 | 8.40 |
| | B | ... | 6.50 | 6.60 | 6.70 | 6.80 | 6.90 | 6.98 | 7.07 | 7.15 | 7.23 | 7.31 | 7.38 | 7.45 | 7.50 | 7.56 | 7.62 |
| | C | 0 | 0.0023 | 0.0063 | 0.0105 | 0.0147 | 0.0190 | 0.0235 | 0.0280 | 0.0326 | 0.0373 | 0.0421 | 0.0469 | 0.0519 | 0.0567 | 0.0617 | 0.0668 |
| 5Cr–½Mo, 5Cr–½Mo–Si, and 5Cr–½Mo–Ti | A | 6.52 | 6.59 | 6.71 | 6.83 | 6.94 | 7.04 | 7.15 | 7.25 | 7.35 | 7.44 | 7.53 | 7.62 | 7.71 | 7.79 | 7.87 | 7.95 |
| | B | ... | 6.50 | 6.65 | 6.73 | 6.80 | 6.87 | 6.93 | 6.97 | 7.00 | 7.05 | 7.10 | 7.15 | 7.19 | 7.24 | 7.28 | 7.32 |
| | C | 0 | 0.0026 | 0.0066 | 0.0107 | 0.0149 | 0.0190 | 0.0233 | 0.0276 | 0.0319 | 0.0364 | 0.0409 | 0.0455 | 0.0500 | 0.0547 | 0.0594 | 0.0641 |
| 7Cr–½Mo and 9Cr–1Mo | A | 5.82 | 5.90 | 6.03 | 6.16 | 6.29 | 6.41 | 6.53 | 6.64 | 6.75 | 6.87 | 6.97 | 7.07 | 7.17 | 7.27 | 7.36 | 7.44 |
| | B | ... | 5.85 | 5.93 | 6.02 | 6.10 | 6.15 | 6.23 | 6.29 | 6.34 | 6.40 | 6.46 | 6.51 | 6.57 | 6.62 | 6.66 | 6.71 |
| | C | 0 | 0.0021 | 0.0057 | 0.0094 | 0.0132 | 0.0170 | 0.0209 | 0.0249 | 0.0289 | 0.0330 | 0.0372 | 0.0414 | 0.0457 | 0.0500 | 0.0544 | 0.0588 |
| Mn–V | A | 6.60 | 6.79 | 7.00 | 7.20 | 7.40 | 7.58 | 7.75 | 7.90 | 8.05 | 8.17 | 8.30 | 8.40 | 8.50 | 8.60 | 6.70 | 8.78 |
| | B | ... | 6.68 | 6.80 | 6.90 | 7.05 | 7.15 | 7.25 | 7.33 | 7.40 | 7.50 | 7.58 | 7.65 | 7.74 | 7.80 | 7.87 | 7.93 |
| | C | 0 | 0.0024 | 0.0065 | 0.0108 | 0.0152 | 0.0197 | 0.0244 | 0.0290 | 0.0337 | 0.0388 | 0.0437 | 0.0486 | 0.0539 | 0.0590 | 0.0642 | 0.0695 |
| 5Ni–¼Mo | A | 6.20 | 6.34 | 6.55 | 6.74 | 6.90 | 7.06 | 7.21 | 7.35 | 7.50 | 7.63 | 7.76 | 7.89 | 8.00 | 8.12 | 8.23 | 8.33 |
| | B | ... | 6.27 | 6.41 | 6.50 | 6.59 | 6.68 | 6.76 | 6.84 | 6.92 | 6.99 | 7.06 | 7.14 | 7.21 | 7.27 | 7.34 | 7.40 |
| | C | 0 | 0.0023 | 0.0062 | 0.0101 | 0.0142 | 0.0184 | 0.0227 | 0.0271 | 0.0315 | 0.0361 | 0.0407 | 0.0454 | 0.0501 | 0.0549 | 0.0599 | 0.0649 |
| 8Ni and 9Ni | A | 5.50 | 5.70 | 6.00 | 6.25 | 6.45 | 6.60 | 6.75 | 6.90 | 7.04 | 7.16 | 7.27 | 7.37 | 7.45 | 7.52 | 7.57 | 7.64 |
| | B | ... | 5.63 | 5.80 | 5.94 | 6.06 | 6.17 | 6.28 | 6.39 | 6.47 | 6.56 | 6.63 | 6.70 | 6.72 | 6.78 | 6.84 | 6.89 |
| | C | 0 | 0.0020 | 0.0056 | 0.0093 | 0.0131 | 0.0170 | 0.0211 | 0.0253 | 0.0295 | 0.0338 | 0.0382 | 0.0426 | 0.0468 | 0.0513 | 0.0558 | 0.0604 |
| **High Chrome Steels** | | | | | | | | | | | | | | | | | |
| 12Cr, 12Cr–1Al, 13Cr, and 13Cr–4Ni | A | 5.92 | 6.03 | 6.18 | 6.30 | 6.41 | 6.50 | 6.59 | 6.66 | 6.72 | 6.77 | 6.83 | 6.88 | 6.94 | 6.99 | 7.05 | 7.11 |
| | B | ... | 5.98 | 6.08 | 6.15 | 6.23 | 6.30 | 6.35 | 6.40 | 6.44 | 6.48 | 6.51 | 6.53 | 6.57 | 6.60 | 6.64 | 6.67 |
| | C | 0 | 0.0022 | 0.0058 | 0.0096 | 0.0135 | 0.0174 | 0.0213 | 0.0253 | 0.0294 | 0.0334 | 0.0375 | 0.0415 | 0.0457 | 0.0499 | 0.0542 | 0.0584 |
| 15Cr and 17Cr | A | 5.33 | 5.41 | 5.54 | 5.66 | 5.77 | 5.88 | 5.99 | 6.09 | 6.19 | 6.28 | 6.37 | 6.46 | 6.54 | 6.62 | 6.70 | 6.77 |
| | B | ... | 5.37 | 5.45 | 5.52 | 5.59 | 5.65 | [illegible] | 5.75 | 5.80 | 5.85 | 5.90 | 5.95 | 6.00 | 6.05 | 6.09 | 6.13 |
| | C | 0 | 0.0019 | 0.0052 | [illegible] | 0.0121 | 0.0156 | 0.0192 | 0.0228 | 0.0264 | 0.0302 | 0.0340 | 0.0378 | 0.0418 | 0.0457 | 0.0497 | 0.0537 |

638 639

$\alpha$ = in/in°F

Source: Reference 1

Table 2-3. Coefficients of Thermal Expansion

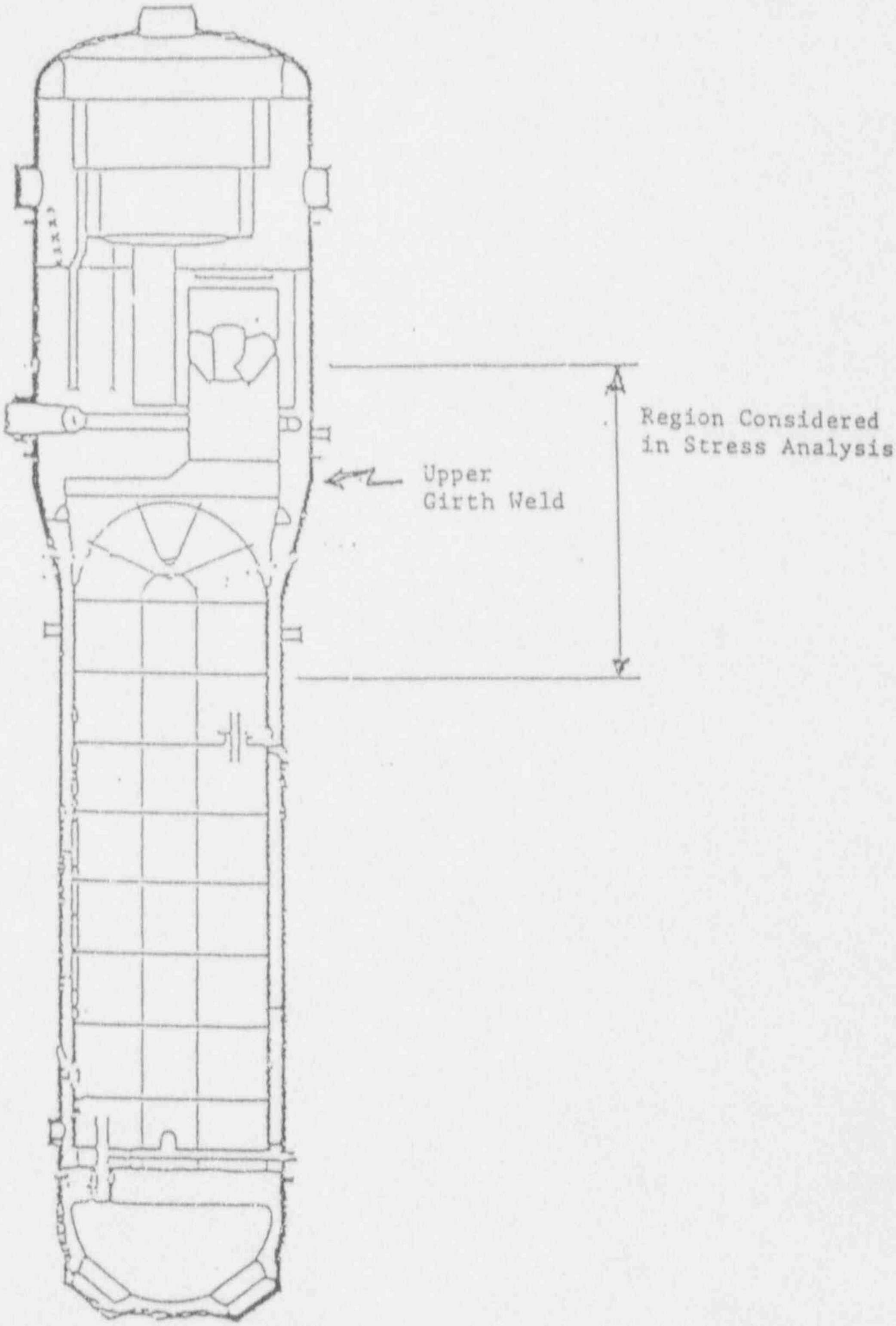



Figure 2-1. Steam Generator Cross Section

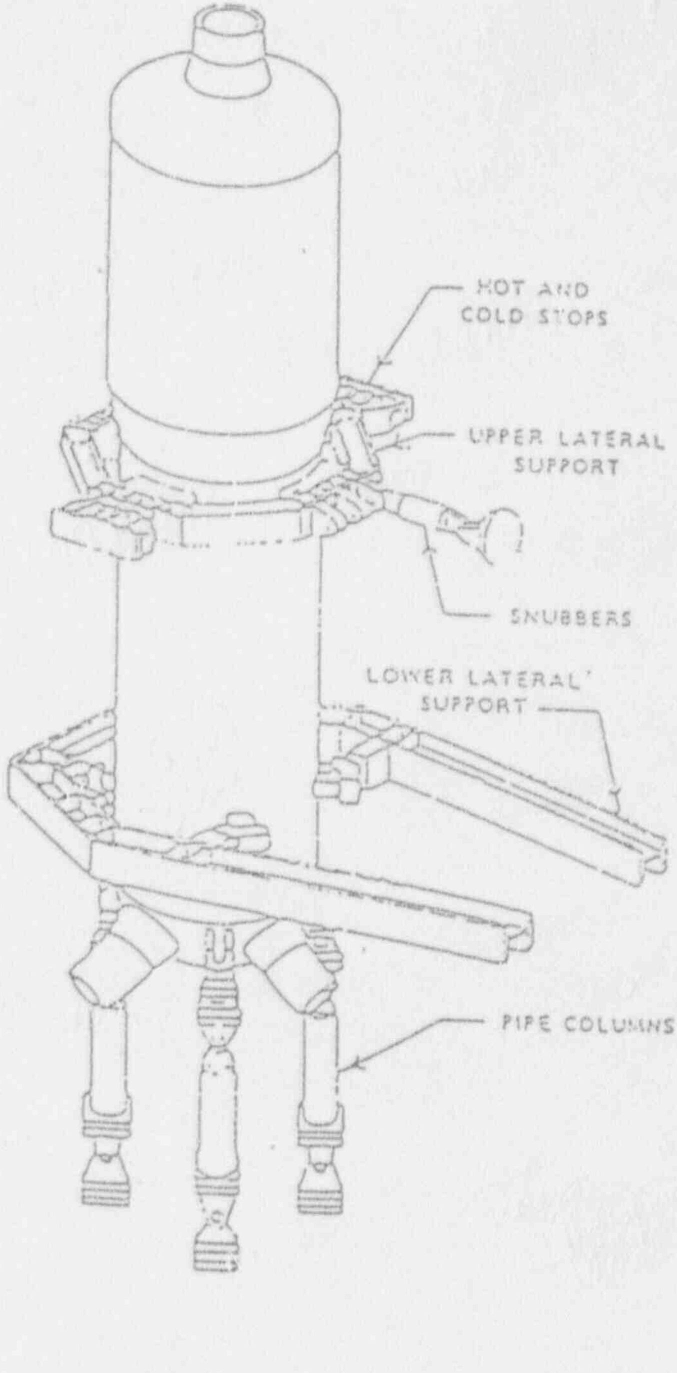



**Figure 2-2. Steam Generator Support Locations** Source: Reference 2

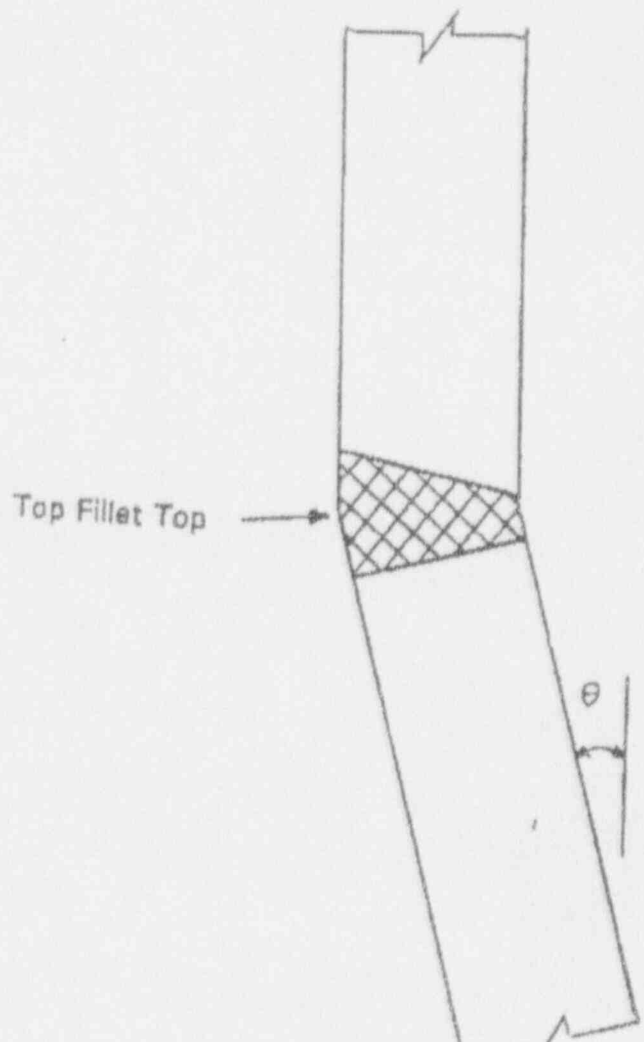
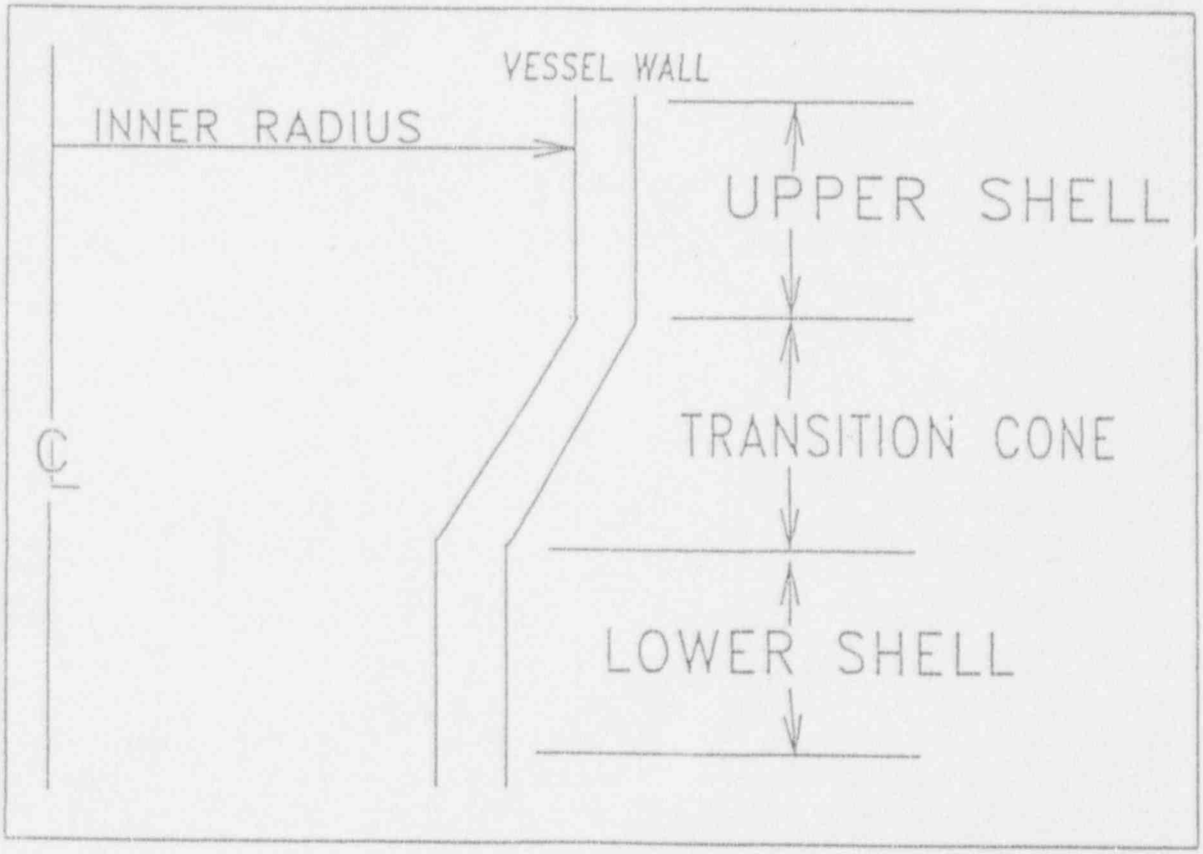



Figure 2-3. Upper Girth Weld Detail




Source: Reference 2

Figure 2-4. Schematic of Axisymmetric Finite Element Model

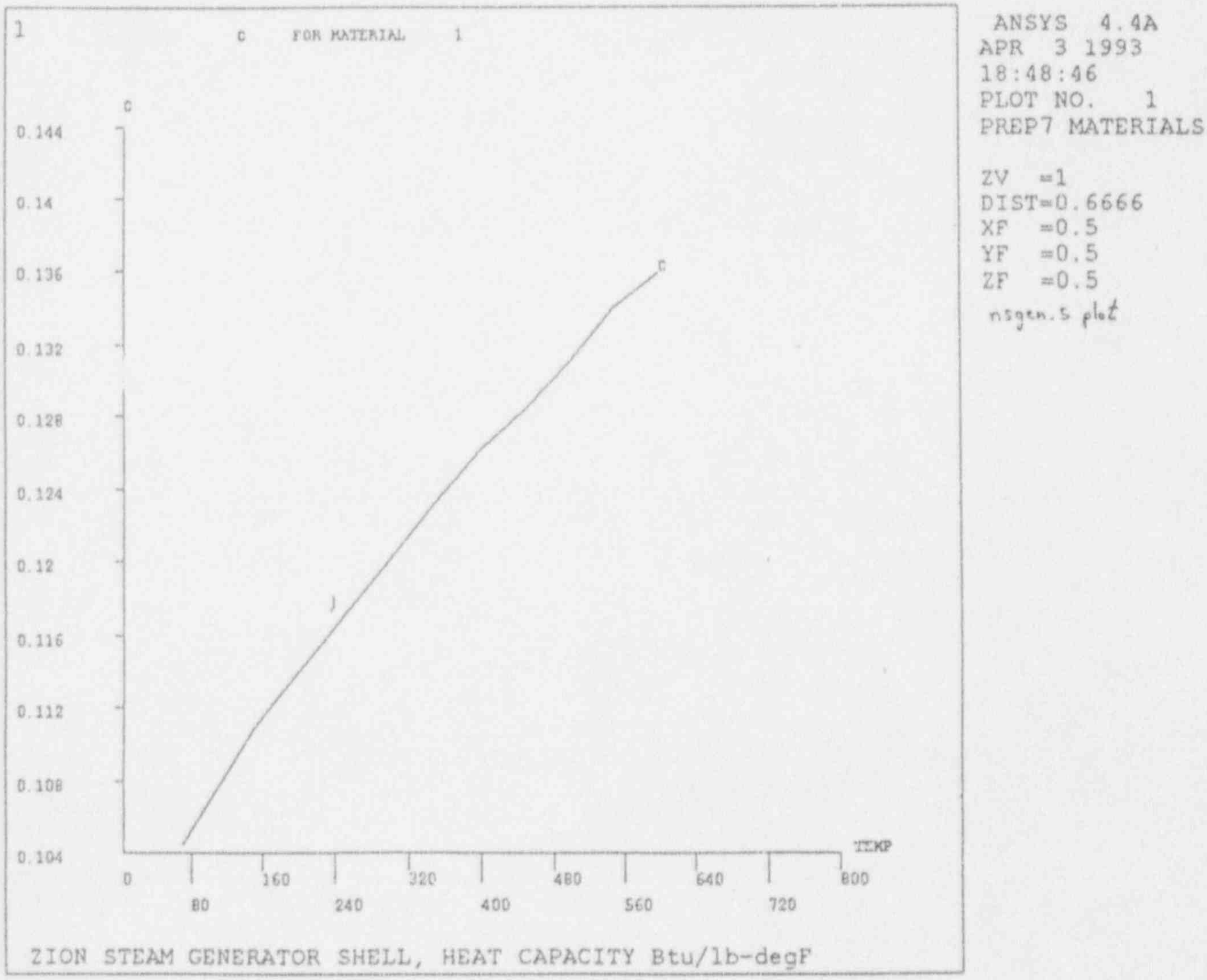



Figure 2-5. SA533 Grade A Class 1 Heat Capacity

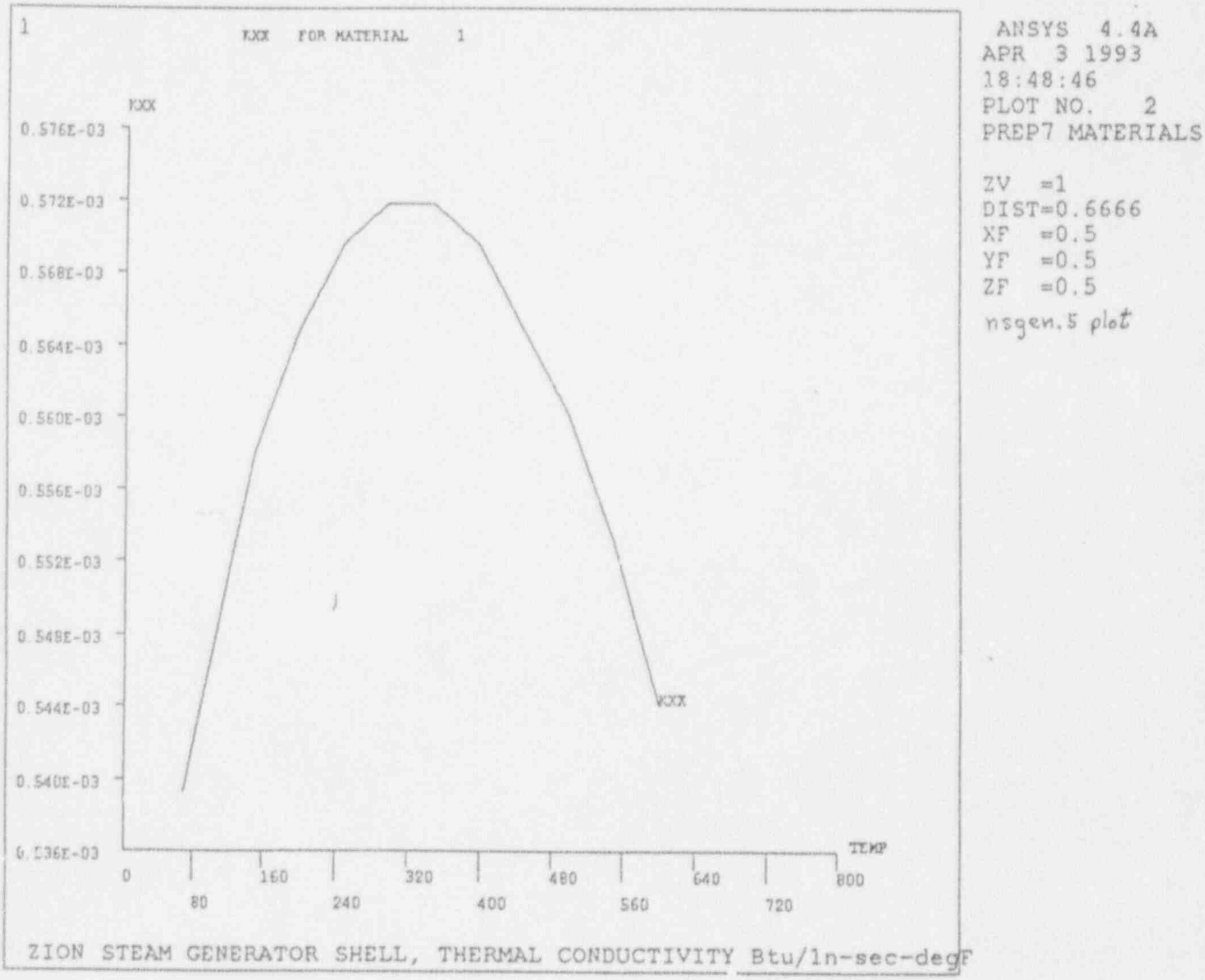



Figure 2-6. SA533 Grade A Class 1 Thermal Conductivity

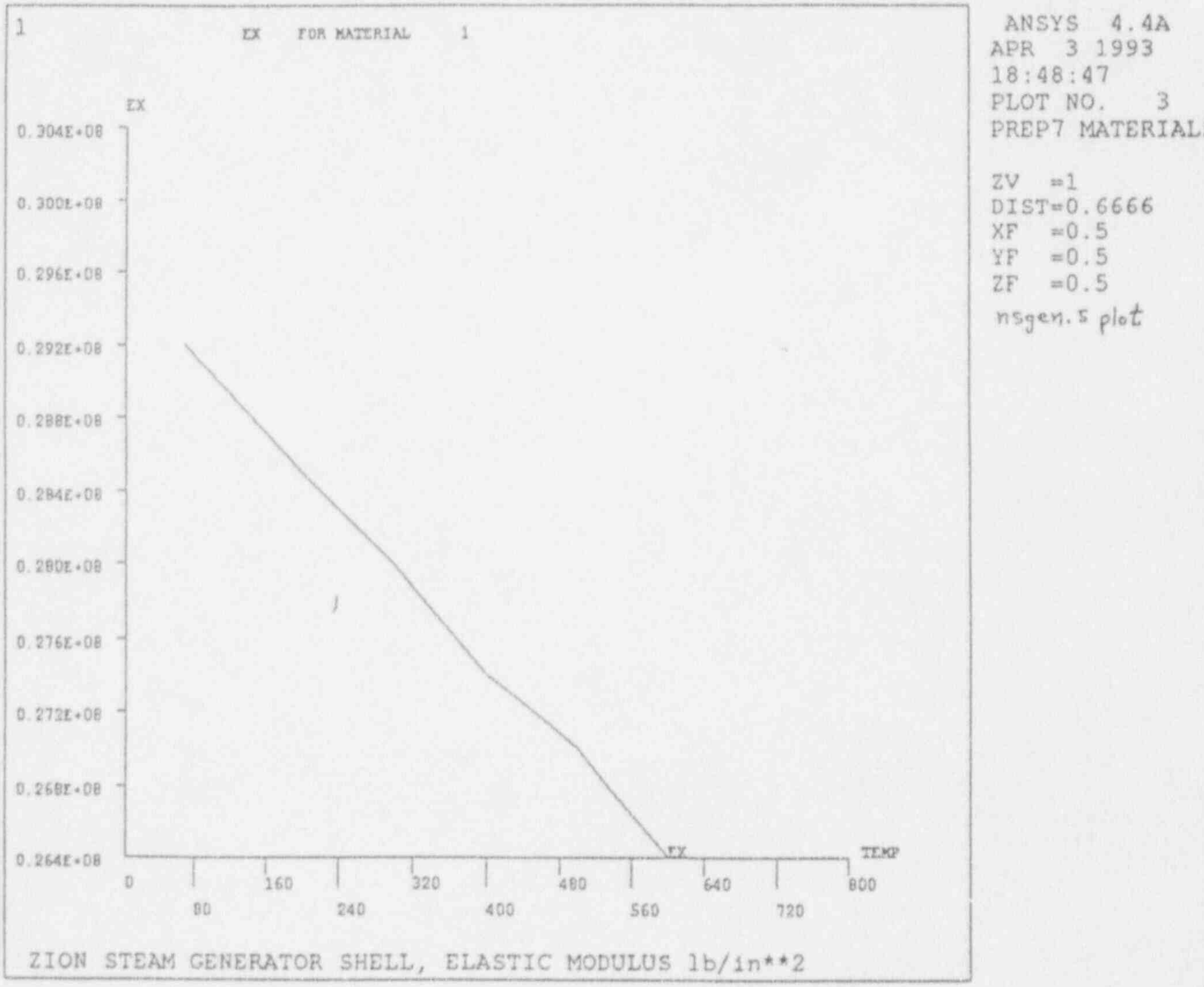



Figure 2-7. SA533 Grade B Class 1 Elastic Modulus

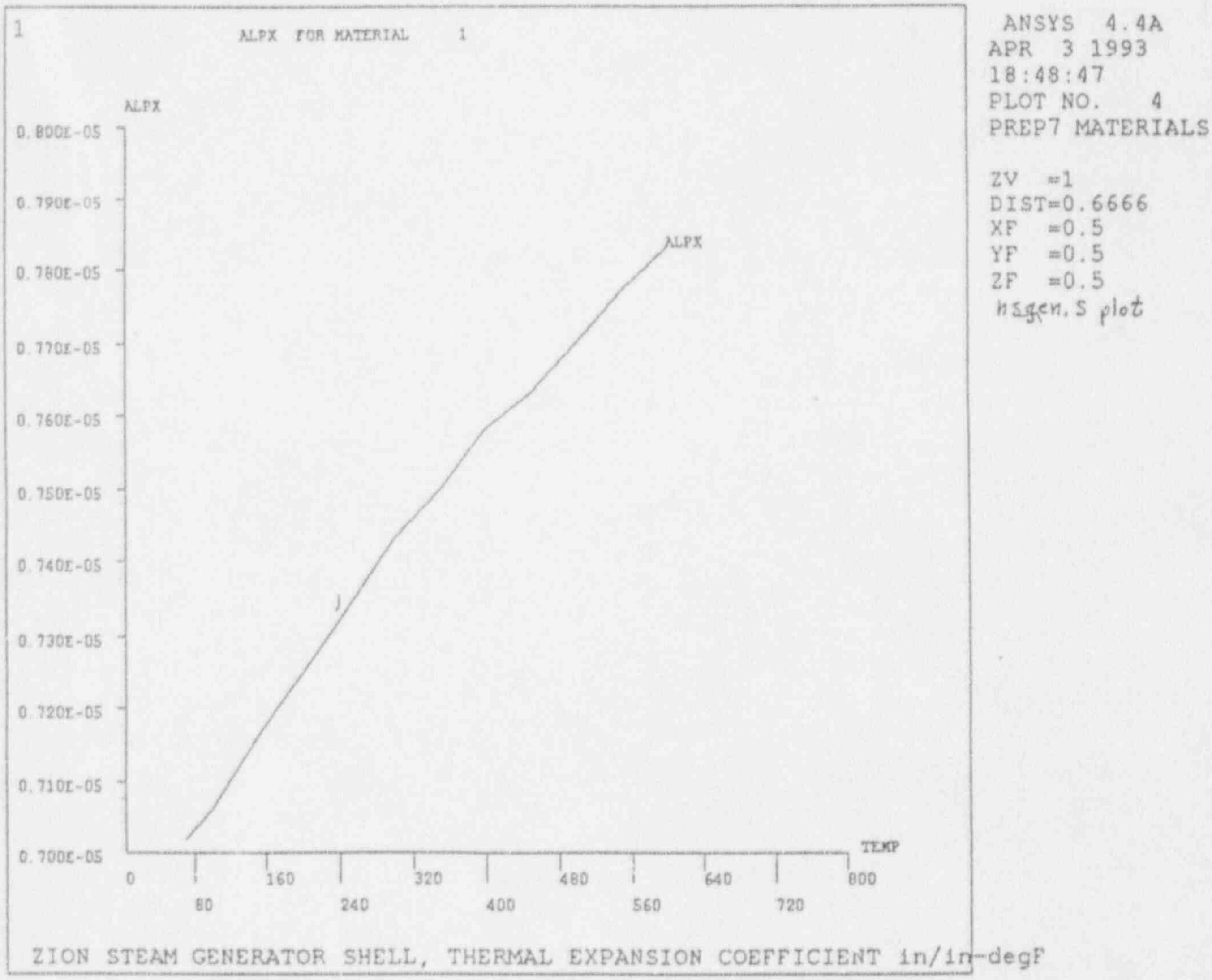



**Figure 2-8. SA533 Grade A Class 1 Thermal Expansion Coefficient**

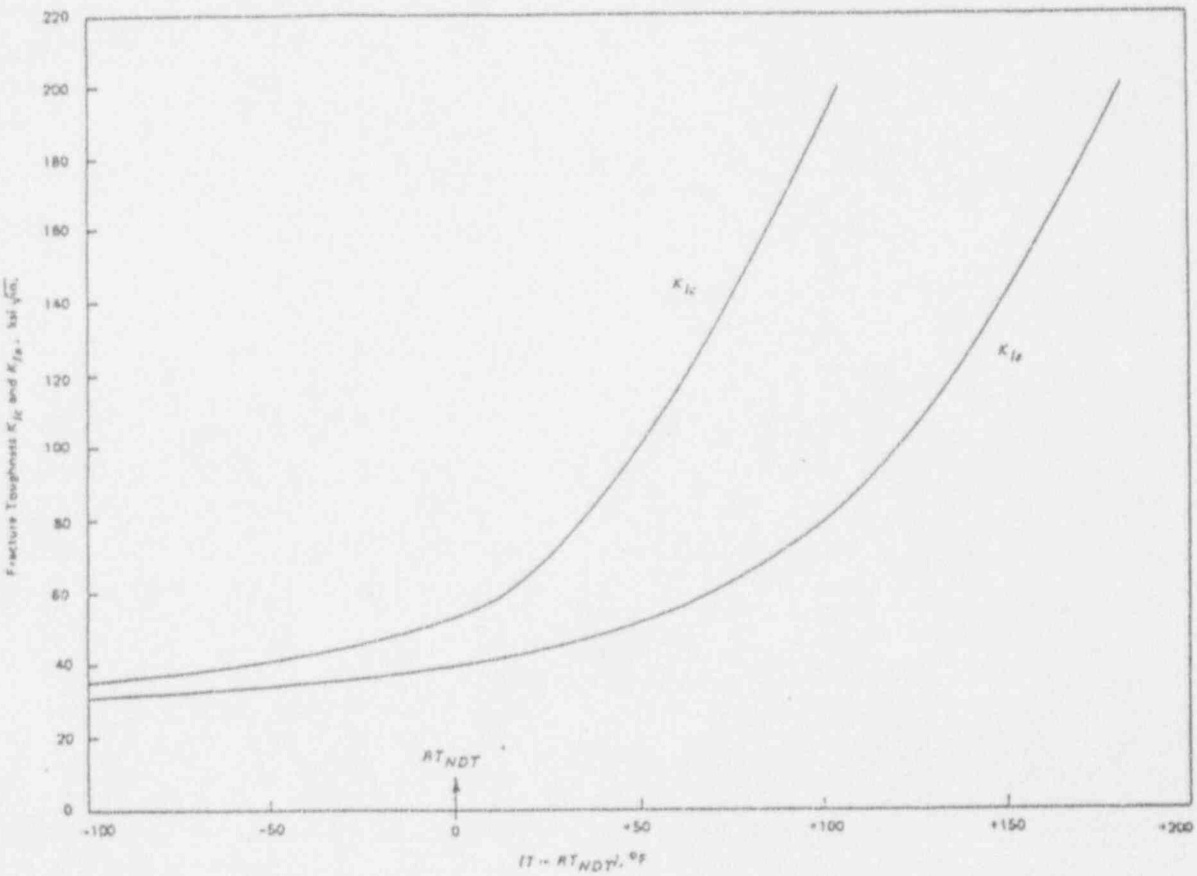
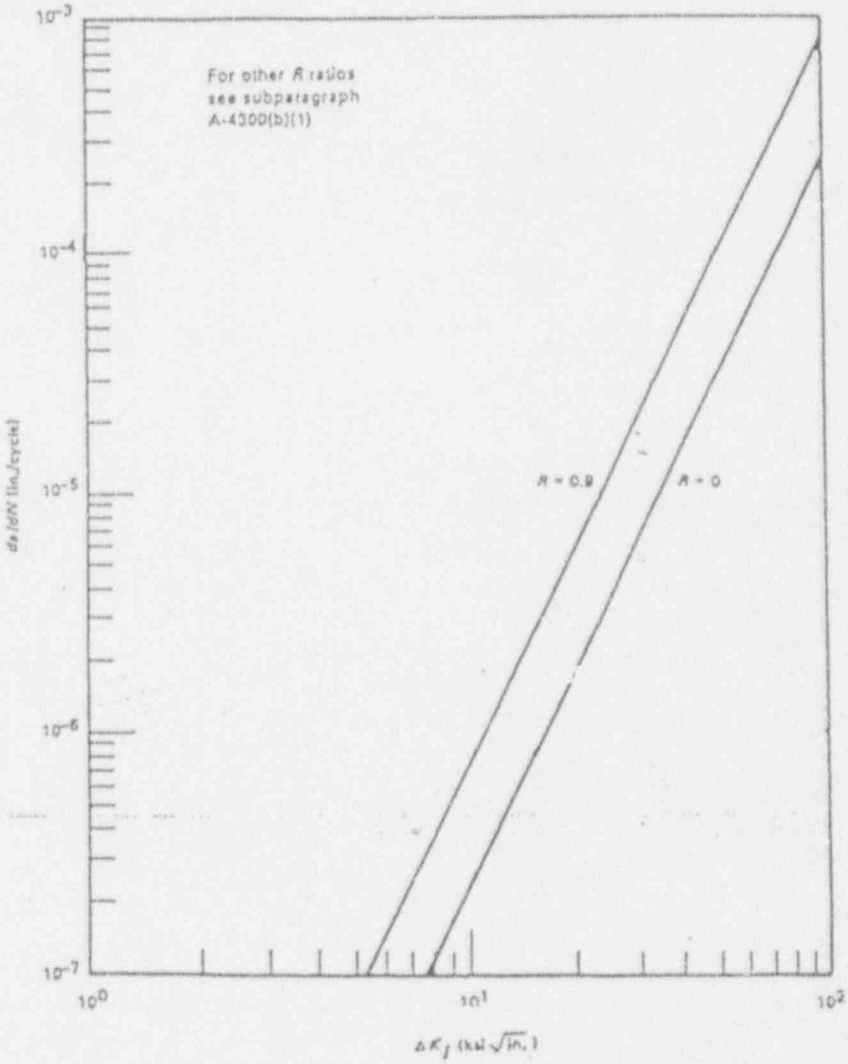



FIG. A-4200-1 LOWER BOUND $K_{Ia}$ AND $K_{Ic}$ TEST DATA FOR SA-533 GRADE B CLASS 1, SA-508 CLASS 2, AND SA-508 CLASS 3 STEELS

**Figure 2-9. Reference Fracture Toughness Curves**




A90 FIG. A-4300-1 REFERENCE FATIGUE CRACK GROWTH CURVES FOR CARBON AND LOW ALLOY FERRITIC STEELS EXPOSED TO AIR ENVIRONMENTS (SUBSURFACE FLAWS)

**Figure 2-10. Reference Fatigue Crack Growth Curves**

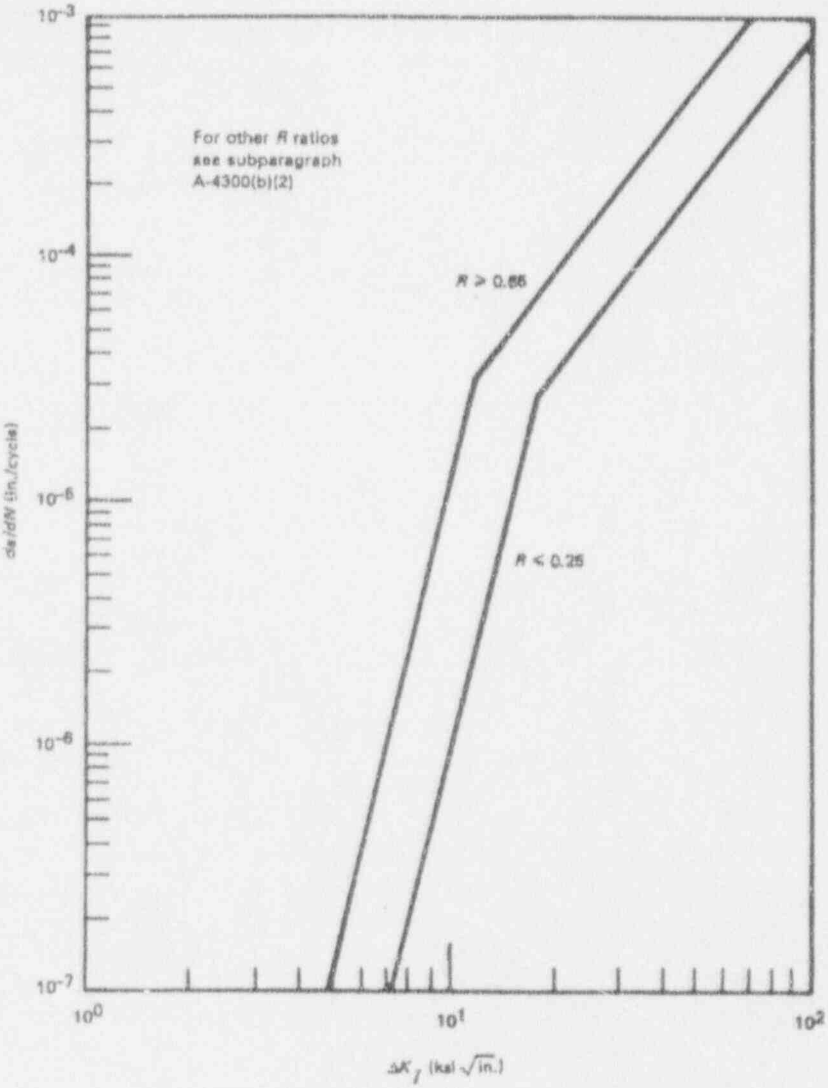



Figure 2-11. Reference Fatigue Crack Growth Curves for Carbon and Low Alloy Ferritic Steels Exposed to Water Environments

## 3.0 FLAW EVALUATION

### 3.1 APPLICABLE CODES AND PRESCRIBED METHODS

The steam generator shells are Class 2 nuclear components. Rules and requirements for in-service inspection, repair and replacement of Class 2 pressure retaining components and their integral attachments in light water cooled power plants are specified in Subsection IWC Section XI Division 1 of the ASME Boiler and Pressure Vessel Code.Flaws identified during in-service inspection are considered to be acceptable for continued operation if they do not exceed the standards of Table IWC-3510-1. For the steam generator upper girth weld, this table specifies that the acceptance standards described in article IWC-3500 apply. Basically, this article specifies allowable flaw sizes as a percentage of the vessel wall thickness. Flaws which do not satisfy the simple size criteria of IWC-3500 may still be acceptable if the analytical evaluation criteria of article IWC-3600 are satisfied. The prescribed analysis is based on fracture mechanics methods and considers critical flaw size, flaw stress intensity and flaw growth rate.

### 3.2 DESCRIPTION OF PAST FLAW OBSERVATIONS

The description or characterization of flaws is governed by article IWA-3300 of the Code. Characterization rules are provided for both surface and subsurface flaws. For purposes of description and dimensioning, the flaw is sized by a bounding rectangle. The length, "l", of the rectangle is drawn parallel to the inside surface of the pressure retaining part. The height of the rectangle is drawn normal to the inside pressure retaining surface of the component and is denoted as "a" for surface flaws and "2a" for subsurface flaws. The aspect ratio of the flaw is defined as "a/l". The flaw depth "S" is the distance from the flaw to the nearest surface. For subsurface flaws a flaw to surface proximity factor "Y" is defined as "S/a". This factor has been developed and is used to estimate the influence of the proximity of the surface on the behavior of a subsurface flaw.

Upper girth weld ultrasonic inspection data are available from examinations performed during the Zion Unit 1 1989 fall refueling outage and during the Zion Unit 2 spring 1990 refueling outage. UT indications which exceeded 20 percent of the distance amplitude curve are described in Tables 3-1 through 3-4 for the Zion Unit 1 steam generators. Similar data for the Zion Unit 2 steam generators are described in Tables 3-5 through 3-8.

**Table 3-1. Zion Unit 1 Steam Generator A UT Inspection Results, 1989**

| Dim. (2a) | Dim. (l) | Dim. (S) | Value (Y) | Surf./Sub. | Ampl. (% DAC) |
|---|---|---|---|---|---|
| 0.18" | 0.85" | 0.08" | 0.89 | Sub. | 25 |
| 0.25" | 2.70" | 0.06" | 0.48 | Sub. | 126 |
| 0.35" | 0.75" | 0.02" | 0.00 | Surf. | 178 |
| 0.24" | 1.00" | 0.02" | 0.00 | Surf. | 56 |
| 0.52" | 0.50" | 0.35" | 1.00 | Sub. | 35 |
| 0.24" | 1.60" | 0.02" | 0.00 | Surf. | 35 |
| 0.35" | 0.80" | 0.27" | 1.00 | Sub. | 100 |
| 0.53" | 0.60" | 0.09" | 0.00 | Surf. | 40 |
| 0.29" | 1.38" | 0.08" | 0.55 | Sub. | 316 |
| 0.54" | 0.90" | 0.08" | 0.00 | Surf. | 85 |
| 0.81" | 0.90" | 0.04" | 0.00 | Surf. | 80 |
| 0.36" | 2.30" | 0.20" | 1.00 | Sub. | 60 |
| 0.60" | 0.80" | 0.58" | 1.00 | Sub. | 60 |
| 1.68" | 0.60" | 0.31" | 0.00 | Surf. | 60 |
| 1.33" | 0.05" | 0.00" | 0.00 | Surf. | 50 |
| 0.34" | 2.10" | 0.09" | 0.53 | Sub. | 25 |
| 1.02 | 0.90 | 0.01" | 0.00 | Surf. | 75 |

**Table 3-2. Zion Unit 1 Steam Generator B UT Inspection Results, 1989**

| Dim. (2a) | Dim. (l) | Dim. (S) | Value (Y) | Surf./Sub. | Ampl. (% DAC) |
|---|---|---|---|---|---|
| 0.31" | 0.60" | 0.08" | 0.52 | Sub. | 32 |
| 0.37" | 1.70" | 0.52" | 1.00 | Sub. | 50 |
| 0.61" | 2.20" | 0.23" | 0.75 | Sub. | 25 |
| 0.31" | 0.70" | 0.08" | 0.52 | Sub. | 36 |
| 0.23" | 1.00" | 0.03" | 0.00 | Surf. | 32 |
| 0.35" | 0.90" | 0.68" | 1.00 | Sub. | 25 |
| 0.12" | 0.40" | 2.59" | 1.00 | Sub. | 25 |
| 0.29" | 0.40" | 0.73" | 1.00 | Sub. | 28 |
| 0.23" | 1.60" | 0.03" | 0.00 | Surf. | 32 |
| 0.59" | 1.20" | 0.31" | 1.00 | Sub. | 25 |
| 0.23" | 0.90" | 0.03" | 0.00 | Surf. | 36 |
| 0.41" | 0.80" | 0.43" | 1.00 | Sub. | 32 |
| 0.23" | 0.90" | 0.09" | 0.78 | Sub. | 100 |
| 0.23" | 0.70" | 2.65" | 1.00 | Sub. | 50 |
| 0.70" | 0.60" | 0.31" | 0.89 | Sub. | 50 |
| 1.05" | 0.50" | 1.95" | 1.00 | Sub. | 30 |
| 0.20" | 1.40" | 0.58" | 1.00 | Sub. | 25 |
| 0.59" | 3.70" | 0.78" | 1.00 | Sub. | 25 |
| 0.87" | 1.30" | 0.58" | 1.00 | Sub. | 50 |
| 0.36" | 0.80" | 0.14" | 0.78 | Sub. | 45 |
| 0.71" | 1.20" | 1.20" | 1.00 | Sub. | 25 |

**Table 3-3. Zion Unit 1 Steam Generator C UT Inspection Results, 1989**

| Dim. (2a) | Dim. (l) | Dim. (S) | Value (Y) | Surf./Sub. | Ampl. (% DAC) |
|---|---|---|---|---|---|
| 0.35" | 2.80" | 0.26" | 1.00 | Sub. | 28 |
| 0.29" | 0.50" | 0.96" | 1.00 | Sub. | 28 |
| 0.23" | 1.00" | 0.03" | 0.00 | Surf. | 158 |
| 0.12" | 0.40" | 1.48" | 1.00 | Sub. | 63 |
| 0.08" | 0.30" | 2.10" | 1.00 | Sub. | 63 |
| 0.34" | 0.80" | 0.29" | 1.00 | Sub. | 50 |
| 0.24" | 0.80" | 2.18" | 1.00 | Sub. | 28 |
| 0.44" | 0.90" | 0.03" | 0.00 | Surf. | 112 |
| 0.35" | 0.50" | 1.48" | 1.00 | Sub. | 79 |

Table 3-4. Zion Unit 1 Steam Generator D UT Inspection Results, 1989

| Dim. (2a) | Dim. (l) | Dim. (S) | Value (Y) | Surf./Sub. | Ampl. (% DAC) |
|---|---|---|---|---|---|
| 0.23" | 0.30" | 0.62" | 1.00 | Sub. | 32 |
| 0.31" | 1.70" | 0.57" | 1.00 | Sub. | 36 |
| 0.38" | 0.60" | 0.57" | 1.00 | Sub. | 28 |
| 0.21" | 0.60" | 1.36" | 1.00 | Sub. | 28 |
| 0.19" | 1.00" | 0.02" | 0.00 | Surf. | 45 |
| 0.19" | 0.90" | 0.02" | 0.00 | Surf. | 100 |
| 0.06" | 0.10" | 0.02" | 0.67 | Sub. | 55 |
| 0.34" | 1.50" | 0.96" | 1.00 | Sub. | 100 |
| 0.12" | 1.10" | 0.61" | 1.00 | Sub. | 28 |
| 0.18" | 0.90" | 0.09" | 1.00 | Sub. | 32 |
| 0.19" | 1.40" | 0.08" | 0.84 | Sub. | 126 |
| 0.15" | 0.80" | 0.03" | 0.00 | Surf. | 28 |
| 0.19" | 1.20" | 0.02" | 0.00 | Surf. | 63 |
| 0.18" | 1.00" | 0.08" | 0.89 | Sub. | 141 |
| 0.29" | 0.80" | 0.21" | 1.00 | Sub. | 32 |
| 0.24" | 1.60" | 0.03" | 0.00 | Surf. | 32 |
| 0.42" | 0.40" | 0.03" | 0.00 | Surf. | 50 |
| 0.23" | 0.50" | 0.03" | 0.00 | Surf. | 40 |
| 0.31" | 1.10" | 0.02" | 0.00 | Surf. | 178 |
| 0.19" | 0.60" | 0.08" | 0.84 | Sub. | 105 |
| 0.24" | 2.20" | 0.03" | 0.00 | Surf. | 40 |
| 0.09" | 0.20" | 0.16" | 1.00 | Sub. | 55 |
| 0.19" | 0.80" | 1.36" | 1.00 | Sub. | 25 |
| 0.17" | 0.50" | 1.32" | 1.00 | Sub. | 32 |
| 0.24" | 1.10" | 0.03" | 0.00 | Surf. | 60 |
| 0.30" | 0.60" | 0.67" | 1.00 | Sub. | 50 |
| ---- | Spot | ---- | ---- | ---- | 25 |
| 0.12" | 0.20" | 1.49" | 1.00 | Sub. | 63 |
| 0.65" | 0.50" | 0.51" | 1.00 | Sub. | 40 |
| 0.67" | 4.88" | 0.09" | 0.00 | Surf. | 100 |
| 0.46" | 0.75" | 1.05" | 1.00 | Sub. | 25 |
| 0.47" | 0.63" | 0.45" | 1.00 | Sub. | 100 |
| 0.66" | 0.50" | 0.02" | 0.00 | Surf. | 140 |
| 0.29" | 0.63" | 0.44" | 1.00 | Sub. | 50 |

**Table 3-5. Zion Unit 2 Steam Generator A UT Inspection Results, 1990**

| Dim. (2a) | Dim. (l) | Dim. (S) | Value (Y) | Surf./Sub. | Ampl. (% DAC) |
|---|---|---|---|---|---|
| 0.34" | 0.70" | 0.73" | 1.00 | Sub. | 36 |
| 0.17" | 0.80" | 0.09" | 1.00 | Sub. | 50 |
| 0.04" | 0.40" | 0.05" | 1.00 | Sub. | 56 |
| 0.32" | 1.90" | 0.00" | 0.00 | Surf. | 28 |
| 0.10" | 0.90" | 0.38" | 1.00 | Sub. | 28 |
| 0.41" | 1.00" | 0.26" | 1.00 | Sub. | 45 |

**Table 3-6. Zion Unit 2 Steam Generator B UT Inspection Results, 1990**

| Dim. (2a) | Dim. (l) | Dim. (S) | Value (Y) | Surf./Sub. | Ampl. (% DAC) |
|---|---|---|---|---|---|
| 0.40" | 0.40" | 0.28" | 1.00 | Sub. | 25 |
| 0.51" | 1.00" | 0.13" | 0.51 | Sub. | 45 |
| 0.25" | 0.60" | 0.02" | 0.16 | Surf. | 32 |
| 0.23" | 0.80" | 0.04" | 0.35 | Surf. | 45 |
| 0.36" | 0.60" | 0.03" | 0.17 | Surf. | 32 |
| 0.36" | 2.70" | 0.03" | 0.17 | Surf. | 71 |
| 0.36" | 2.70" | 0.03" | 0.17 | Surf. | 63 |
| 0.19" | 0.80" | 0.02" | 0.21 | Surf. | 71 |
| 0.27" | 3.80" | 0.06" | 0.44 | Sub. | 40 |
| 0.25" | 3.80" | 0.18" | 1.00 | Sub. | 32 |
| 1.88" | 1.20" | 0.06" | 0.06 | Surf. | 32 |
| 1.88" | 1.20" | 0.06" | 0.06 | Surf. | 40 |
| 0.32" | 1.10" | 0.09" | 0.56 | Sub. | 79 |
| 0.32" | 1.10" | 0.09" | 0.56 | Sub.. | 71 |
| 1.21" | 2.50" | 0.18" | 0.30 | Surf. | 63 |
| 1.21" | 2.50" | 0.18" | 0.30 | Surf. | 100 |
| 0.92" | 1.50" | 0.06" | 0.13 | Surf. | 50 |
| 0.69" | 3.10" | 0.04" | 0.12 | Surf. | 100 |
| 0.69" | 3.10" | 0.04" | 0.12 | Surf. | 36 |
| 0.87" | 2.80" | 0.13" | 0.30 | Surf. | 40 |
| 0.40" | 1.40" | 0.14" | 0.70 | Sub. | 36 |

### Table 3-7. Zion Unit 2 Steam Generator C UT Inspection Results, 1990

| Dim. (2a) | Dim. (l) | Dim. (S) | Value (Y) | Surf./Sub. | Ampl. (% DAC) |
|---|---|---|---|---|---|
| 0.53" | 1.38" | 0.01" | 0.04 | Surf. | 63 |
| 0.17" | 1.00" | 0.04" | 0.47 | Sub. | 79 |
| 0.51" | 0.90" | 0.02" | 0.08 | Surf. | 32 |
| 0.41" | 1.70" | 0.47" | 1.00 | Sub. | 36 |
| 0.44" | 0.90" | 0.05 | 0.23 | Surf. | 25 |
| 0.26" | 1.00" | 0.01" | 0.08 | Surf. | 32 |
| 0.24" | 1.00" | 0.09" | 0.75 | Sub. | 32 |
| 0.32" | 0.40" | 0.10" | 0.63 | Sub. | 25 |

### Table 3-8. Zion Unit 2 Steam Generator D UT Inspection Results, 1990

| Dim. (2a) | Dim. (l) | Dim. (S) | Value (Y) | Surf./Sub. | Ampl. (% DAC) |
|---|---|---|---|---|---|
| 0.21" | 1.10" | 0.17" | 1.00 | Sub. | 25 |
| 0.12" | 0.80" | 0.07" | 1.00 | Sub. | 40 |
| 0.12" | 1.30" | 0.07" | 1.00 | Sub. | 25 |
| 0.15" | 1.30" | 0.04" | 0.53 | Sub. | 36 |
| 0.27" | 0.90" | 0.08" | 0.59 | Sub. | 79 |
| 0.12" | 0.70" | 0.13" | 1.00 | Sub. | 56 |
| 0.23" | 0.90" | 0.02" | 0.17 | Surf. | 32 |
| 0.40" | 0.70" | 0.43" | 1.00 | Sub. | 63 |
| 0.47" | 0.60" | 0.49" | 1.00 | Sub. | 50 |
| 0.12" | 1.00" | 0.06" | 1.00 | Sub. | 36 |
| 0.34" | 0.70" | 0.78" | 1.00 | Sub. | 25 |
| 0.29" | 2.20" | 0.02" | 0.14 | Surf. | 100 |
| 1.27" | 1.00" | 0.03" | 0.05 | Surf. | 79 |
| 0.85" | 1.05" | 0.55" | 1.00 | Sub. | 32 |
| 2.10" | 1.20" | 0.12" | 0.11 | Surf. | 36 |
| 0.41" | 1.30" | 0.19" | 0.93 | Sub. | 32 |
| 0.42" | 0.70" | 0.21" | 1.00 | Sub. | 79 |
| 0.35" | 3.60" | 0.02" | 0.11 | Surf. | 56 |
| 1.02" | 0.90" | 0.31" | 0.61 | Sub. | 56 |
| 1.01" | 3.20" | 0.27" | 0.53 | Sub. | 40 |
| 1.01" | 3.20" | 0.27" | 0.53 | Sub. | 71 |
| 0.61" | 1.00" | 0.68" | 1.00 | Sub. | 36 |

Surface flaw depth observations near upper girth welds as revealed by successive MT inspections following surface grinding are listed in Tables 3-9, 3-10 and 3-11. Such inspections were performed at Zion, Unit 1 in 1989 and 1992 and at Zion, Unit 2 in 1990.

**Table 3-9. Zion Unit 1 Steam Generator MT/Grindout Inspection Results, 1989**

| Steam Generator | Indication | MT/Grindout Depth (inches) |
|---|---|---|
| A | 1 | 0.22 |
| A | 2 | 0.35 |
| A | 3 | 0.30 |
| A | 4 | 0.00 |
| B | 1 | 0.25 |
| C | 1 | 0.25 |
| C | 2 | 0.15 |
| D | 1 | 0.25 |
| D | 2 | 0.20 |
| D | 3 | 0.20 |
| D | 4 | 0.38 |
| D | 5 | 0.35 |
| D | 6 | 0.50 |
| D | 7 | 0.50 |

Table 3-10. Zion Unit 1 Steam Generator MT/Grindout Inspection Results, 1992

| Steam Generator | Indication | MT/Grindout Depth (inches) |
|---|---|---|
| A | 1 | 0.04 |
| A | 2 | 0.04 |
| A | 3 | 0.04 |
| A | 4 | 0.04 |
| A | 5 | 0.04 |
| A | 6 | 0.04 |
| A | 7 | 0.04 |
| A | 8 | 0.247 |
| A | 9 | 0.025 |
| A | 10 | 0.06 |
| A | 11 | 0.01 |
| A | 12 | 0.06 |
| A | 13 | 0.06 |
| A | 14 | 0.02 |
| A | 15 | 0.02 |
| A | 16 | 0.02 |
| A | 17 | 0.04 |
| A | 18 | 0.04 |
| A | 19 | 0.04 |
| A | 20 | 0.025 |
| A | 21 | 0.025 |
| A | 22 | 0.025 |
| A | 23 | 0.025 |
| A | 24 | 0.025 |
| A | 25 | 0.025 |
| A | 26 | 0.06 |
| A | 27 | 0.00 |
| A | 28 | 0.06 |
| A | 29 | 0.06 |
| A | 30 | 0.00 |
| A | 31 | 0.06 |
| A | 32 | 0.06 |
| A | 33 | 0.06 |
| A | 34 | 0.06 |
| C | 1 | 0.06 |
| C | 2 | 0.00 |

Table 3-10. Zion Unit 1 Steam Generator MT/Grindout Inspection Results, 1992
(Continued)

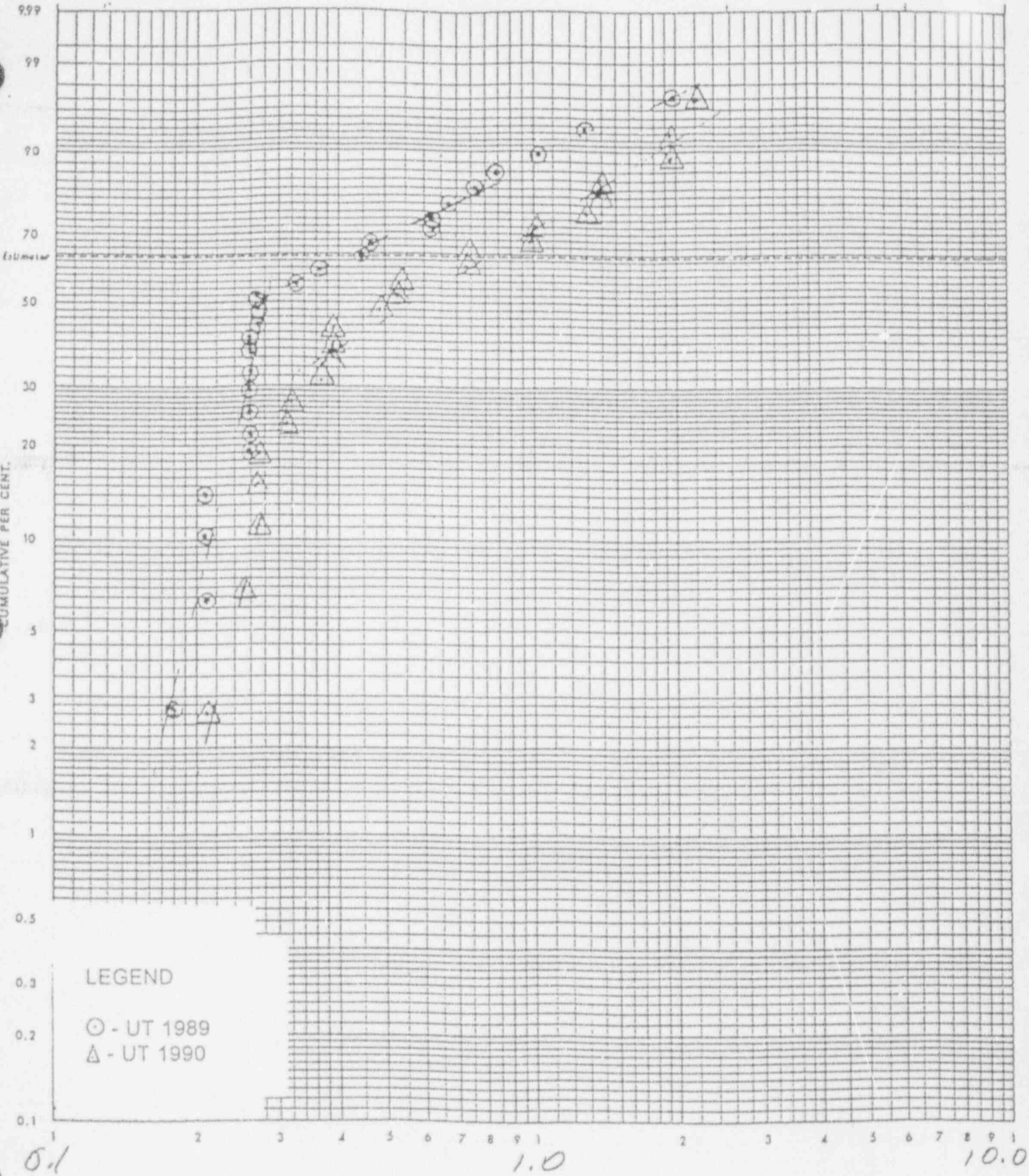
| Steam Generator | Indication | MT/Grindout Depth (inches) |
|---|---|---|
| C | 3 | 0.06 |
| C | 4 | 0.06 |
| C | 5 | 0.00 |
| C | 6 | 0.06 |
| C | 7 | 0.06 |
| C | 8 | 0.06 |
| C | 9 | 0.06 |
| C | 10 | 0.06 |
| C | 11 | 0.06 |
| C | 12 | 0.06 |
| C | 13 | 0.06 |
| C | 14 | 0.06 |
| C | 15 | 0.06 |
| C | 16 | 0.00 |
| C | 17 | 0.00 |
| C | 18 | 0.00 |
| C | 19 | 0.00 |
| C | 20 | 0.00 |
| C | 21 | 0.00 |
| C | 22 | 0.00 |
| C | 23 | 0.00 |
| C | 24 | 0.00 |
| C | 25 | 0.00 |
| C | 26 | 0.00 |
| C | 27 | 0.00 |
| C | 28 | 0.00 |
| C | 29 | 0.00 |
| C | 30 | 0.00 |
| C | 31 | 0.00 |
| C | 32 | 0.00 |
| C | 33 | 0.00 |
| C | 34 | 0.00 |
| C | 35 | 0.00 |
| C | 36 | 0.00 |
| C | 37 | 0.00 |

**Table 3-10. Zion Unit 1 Steam Generator MT/Grindout Inspection Results, 1992**
(Continued)

| Steam Generator | Indication | MT/Grindout Depth (inches) |
|---|---|---|
| C | 38 | 0.00 |
| C | 39 | 0.00 |
| D | 1 | 0.16 |
| D | 2 | 0.07 |
| D | 3 | 0.076 |
| D | 4 | 0.03 |
| D | 5 | 0.072 |
| D | 6 | 0.02 |
| D | 7 | 0.035 |
| D | 8 | 0.08 |
| D | 9 | 0.103 |
| D | 10 | 0.06 |
| D | 11 | 0.06 |
| D | 12 | 0.04 |
| D | 13 | 0.04 |
| D | 14 | 0.04 |
| D | 15 | 0.037 |
| D | 16 | 0.04 |
| D | 17 | 0.038 |
| D | 18 | 0.20 |
| D | 19 | 0.11 |
| D | 20 | 0.125 |
| D | 21 | 0.173 |
| D | 22 | 0.105 |
| D | 23 | 0.33 |
| D | 24 | 0.21 |
| D | 25 | 0.325 |
| D | 26 | 0.19 |

Table 3-11. Zion Unit 2 Steam Generator MT/Grindout Inspection Results, 1990

| Steam Generator | Indication | MT/Grindout Depth (inches) |
|---|---|---|
| A | 1 | 0.044 |
| A | 2 | 0.31 |
| B | 1 | 0.37 |
| B | 2 | 0.25 |
| B | 3 | 0.25 |
| B | 4 | 0.31 |
| B | 5 | 0.56 |
| B | 6 | 0.25 |
| B | 7 | 0.37 |
| B | 8 | 0.37 |
| C | 1 | 0.37 |
| C | 2 | 0.25 |
| C | 3 | 0.44 |
| C | 4 | 0.25 |
| C | 5A | 0.12 |
| C | 5B | 0.12 |
| C | 6A | 0.50 |
| C | 6B | 0.19 |
| C | 6C | 0.25 |
| C | 6D | 0.31 |
| C | 6E | 0.12 |
| D | 1A | 0.12 |
| D | 1B | 0.06 |
| D | 1C | 0.12 |
| D | 2A | 0.12 |
| D | 2B | 0.12 |
| D | 3A | 0.19 |
| D | 3B | 0.44 |
| D | 4 | 0.37 |
| D | 5 | 0.50 |
| D | 6 | 0.06 |




UT DEPTH, INCHES

Figure 3-1. Estimated Cumulative Probability Versus UT Flaw Depth for Surface Flaws in Zion Unit 1, 1989 and Unit 2, 1990.

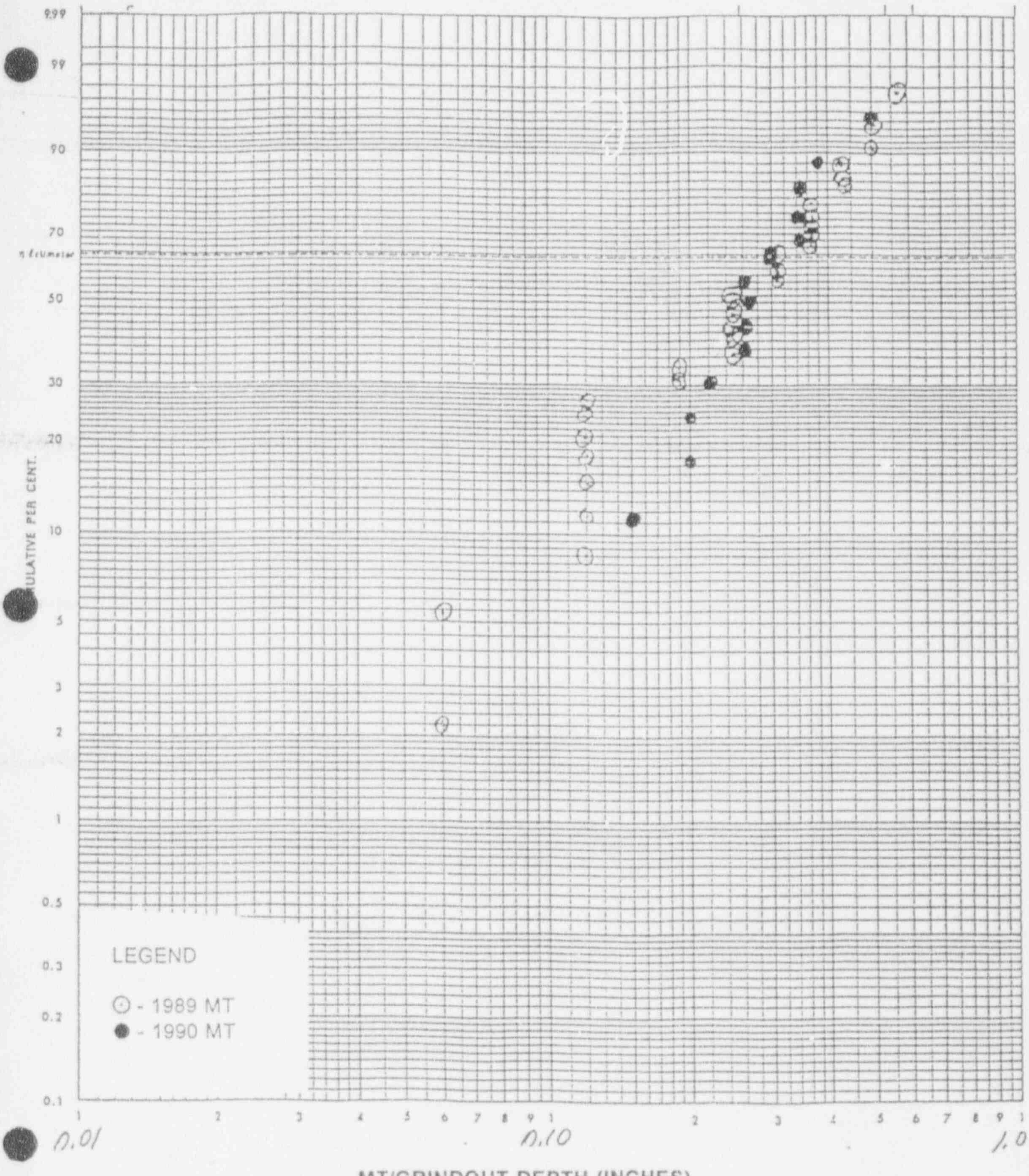



Figure 3-2. Estimated Cumulative Distribution Versus MT/Grindout Depth for Surface Flaws in Zion Unit 1, 1989 and Unit 2, 1990.

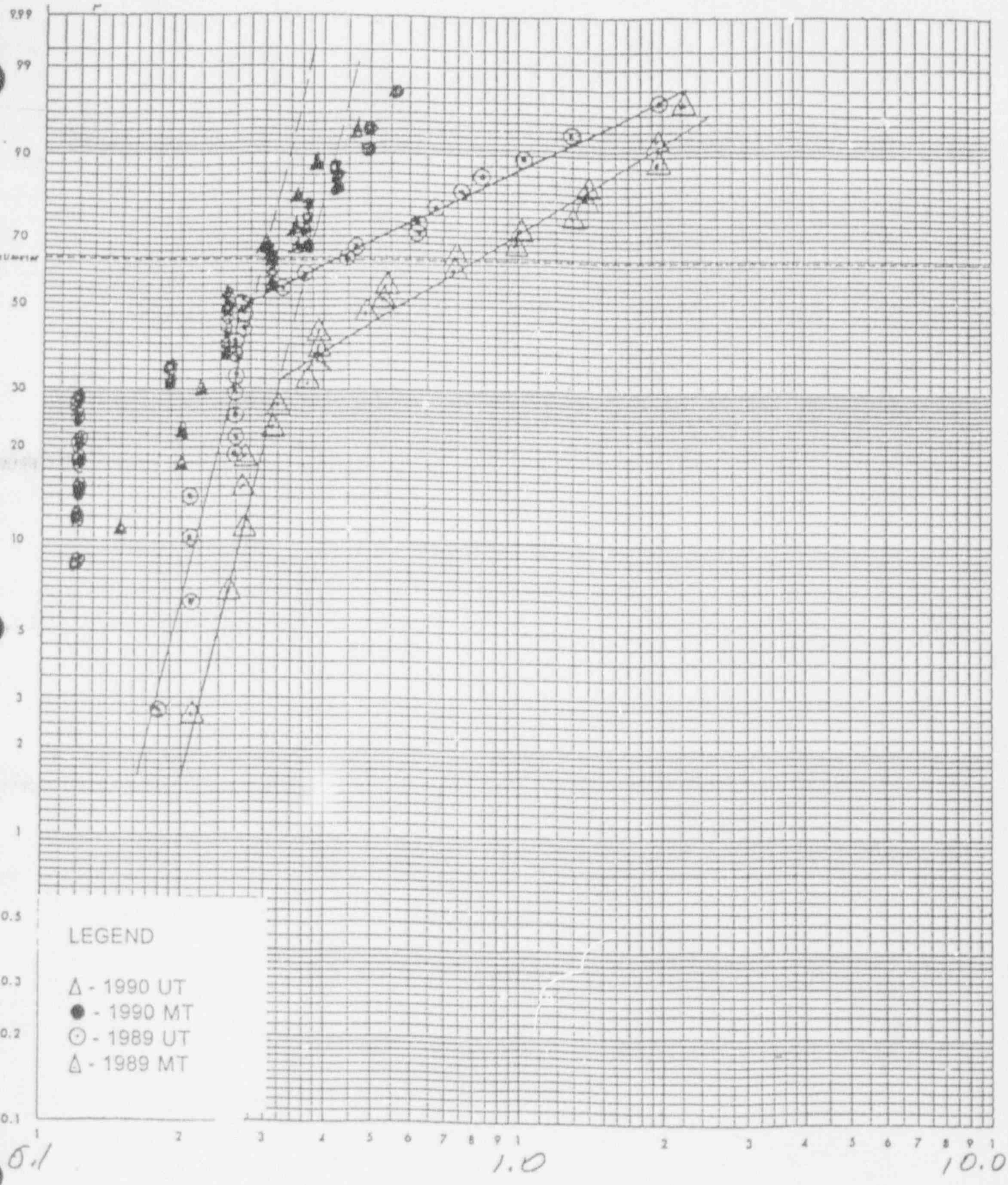



Figure 3-3. Comparison of UT and MT/Grindout Surface Flaw Depth Distribution for Zion Unit 1, 1989 and Unit 2, 1990.

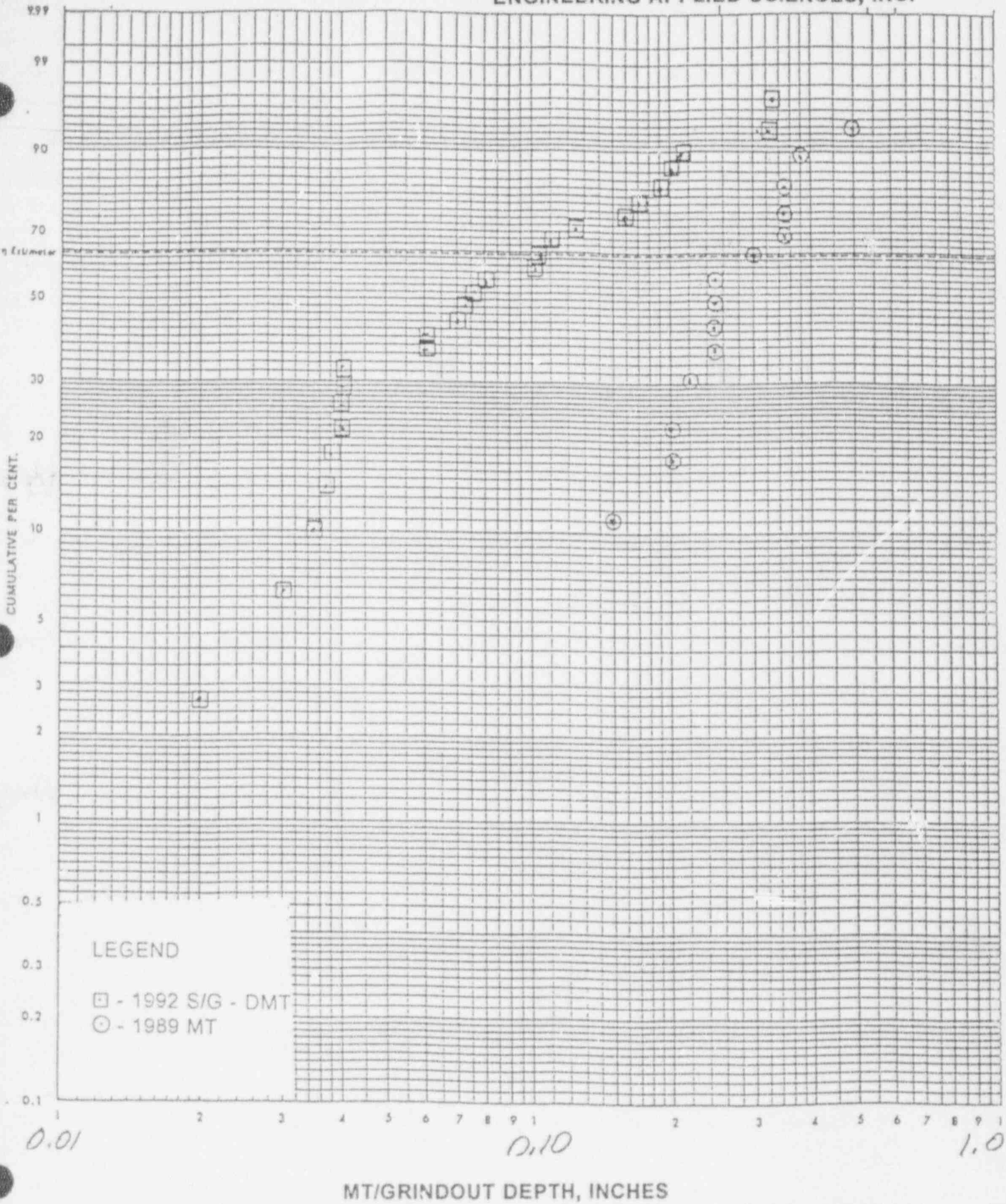



Figure 3-4. Comparison of MT/Grindout Surface Flaw Depth Distributions for Zion Unit 1, 1989 and 1992.

### 3.3 COMPARISON OF UT AND MT/GRINDOUT SURFACE FLAW DEPTHS

The term cumulative distribution or cumulative probability as applied to crack depths is an estimate of the percentage of a population of crack depths less than a given stated value. For example, a glance at Figure 3-1 shows that 90% of UT cracks depths for surface flaw indications in Unit 2 in 1989 are less than 1.0 inches. Or conversely, there is a 10% chance that a crack depth selected at random will be greater than 1.0 inches. In this plot, as in other probability plots in this report, the cumulative probability ordinate is scaled according to a Weibull distribution. Hence, if the plotted data is a reasonable match to a Weibull distribution, a straight line plot will be observed. Other probability scales could be selected. The Weibull scale is a typical choice for physical phenomena where the observed result is dictated by the weakest link in a set of links. The cumulative distributions of surface flaw depths as found by the first ultrasonic inspections of Zion Unit 1 and Unit 2 are shown in Figure 3-1. These UT inspection results for the two units are essentially equivalent. A similar circumstance is found for MT inspection results, where flaw depth is found by repeating the process of grinding and MT examination until no indications are evident. The cumulative distributions for MT/grindout flaws depths for Unit 1 in 1989 and Unit 2 in 1990 are presented in Figure 3-2. The plotted points are virtually coincident, illustrating that the surface flaw cracking experience of both units after several years of operation is the same.

A comparison of surface flaw depth distributions as revealed by UT and MT/grindout procedures is illustrated in Figure 3-3. Ultrasonic testing indicates substantially larger surface flaw depths than revealed by the MT/grindout technique. UT sizing techniques are sensitive to examination parameters such as transducer size and frequency. In general, UT inspection tends to oversize flaw depths due to beam spreading of the ultrasonic signal in a long metal path.

Surface flaws found in Unit 1 in 1989 were removed from service. Surface flaws were again found in Unit 1 in 1992 but since the interval of operation was substantially shorter prior to inspection, surface flaw depths were reduced compared to the 1989 inspection. Figure 3-4 compares the estimated cumulative distribution of MT/grindout depths for the 1989 and 1992 inspections. The maximum observed depth is reduced from 0.5 inches to 0.33 inches.

Differences in slopes of the two plots show a broader distribution of flaw depths for the shorter interval of operation. This would be consistent with a decreasing flaw growth rate with depth. At longer times, recently initiated cracks begin to approach the depths of cracks which form early in the interval of operation. Data of this type together with data in the literature and operating experience of other plants is used to develop crack growth projections in Section 7.

### 3.4 SELECTION OF FLAWS FOR EVALUATION BY FRACTURE MECHANICS

Table 3-12 shows allowable planar flaw sizes expressed as a percentage of wall thickness for a 3.62 inch wall thickness. These values are interpolated from Table IWC-3510-1 of Section XI Division 1 of the ASME B-PV Code. Flaws which exceed these limits must either be removed from service or found to be acceptable by fracture mechanics analyses. Examples of the appropriate fracture mechanics analyses are presented in Section 7.

**Table 3-12. Allowable Planar Flaw Sizes for 3.62 inch Thick Wall**

| Aspect Ratio, a/l | Surface Flaws, a/t % | | | Subsurface Flaws, a/t % | | |
|---|---|---|---|---|---|---|
| a/l | t=2.5 in. | t=3.62 in | t=4.0 in | t=2.5 in | t=3.62 in | t=4.0 in |
| 0.00 | 3.10 | 2.2 | 1.90 | 3.40Y | 2.35Y | 2.00Y |
| 0.05 | 3.30 | 2.32 | 2.00 | 3.80Y | 2.61Y | 2.20Y |
| 0.10 | 3.60 | 2.55 | 2.20 | 4.30Y | 2.96Y | 2.50Y |
| 0.15 | 4.10 | 2.90 | 2.50 | 4.90Y | 3.41Y | 2.90Y |
| 0.20 | 4.70 | 3.28 | 2.80 | 5.70Y | 3.91Y | 3.30Y |
| 0.25 | 5.50 | 3.85 | 3.30 | 6.60Y | 4.51Y | 3.80Y |
| 0.30 | 6.40 | 4.45 | 3.80 | 7.80Y | 5.26Y | 4.40Y |
| 0.35 | 7.40 | 5.15 | 4.40 | 9.00Y | 6.09Y | 5.10Y |
| 0.40 | 8.30 | 5.82 | 5.00 | 10.50Y | 6.99Y | 5.80Y |
| 0.45 | 8.50 | 5.95 | 5.10 | 12.30Y | 8.12Y | 6.70Y |
| 0.50 | 8.70 | 6.10 | 5.20 | 14.30Y | 9.30Y | 7.60Y |

Source: Reference 1

## 4.0 ANALYSIS VERIFICATION

### 4.1 INTRODUCTION

The upper girth weld region of the steam generator is analyzed using the ANSYS 4.4A Structural Analysis Code (Reference 3). An axisymmetric finite element model is applied. Verification of the computer program is carried out using pressure loading and transient thermal loading for a thick-walled cylinder for which the solution is known. Then, the upper girth weld region of the steam generator is analyzed.

### 4.2 SIMPLIFIED MODEL

For the simplified model a long cylindrical shell with closed ends is considered having the same radial dimensions as the steam generator upper cylinder (Figure 4-1). A unit length of this long cylinder is modeled explicitly. Generalized plane strain boundary conditions are applied. Material properties similar to those of the steam generator material are specified:

| | |
|---|---|
| Elastic Modulus (E) | $30 * 10^6$ psi |
| Poisson Ratio ($\nu$) | 0.3 |
| Thermal Expansion Coefficient ($\alpha$) | $6 * 10^{-6}$ in/in °F |
| Density ($\rho$) | 490 lb/ft$^3$ |
| Thermal Conductivity (k) | 25 Btu/hr ft °F |
| Specific Heat (c) | 0.11 Btu/lb °F |

### 4.2.1 Pressure Load

The first verification case considers isothermal conditions at 70°F and internal pressure of 1065 psig. The known solution for the case is given in Reference 4 as:

Radial Stress

$$\sigma_r = \frac{-qb^2 \, (a^2 - r^2)}{r^2 \, (a^2 - b^2)}$$

Hoop Stress

$$\sigma_h = \frac{qb^2 \, (a^2 + r^2)}{r^2 \, (a^2 - b^2)}$$

Axial Stress

$$\sigma_a = \frac{qb^2}{a^2 - b^2}$$

where r = radius value

a = outside radius

b = inside radius

q = pressure

The computer program input data listing ver1.5 in Appendix A is used to calculate the finite element results and the handbook results. The results are illustrated in the stress contour plots of Figure 4-2 and summarized in Table 4-1. Based upon the results in Table 4-1 it is concluded that the ANSYS computer program is verified for the pressure loading condition.

### 4.2.2 Thermal Transient Load

Verification of the thermal transient stress analysis is based upon a known thermal transient solution for stresses in Reference 3. This is a case of a constant temperature ramp rate applied to the external surface of the cylinder. The thermal stress state becomes constant even though the temperature of the cylinder continues to rise. The handbook solution for the hoop and axial stresses are the same at both the inside and outside surface of the cylinder and are given by

Inner Surface:

$$\sigma_a = \sigma_h = \frac{E\alpha m}{8d\,(1 - \nu)}\left(b^2 + c^2 - \frac{4b^2c^2}{c^2 - b^2}\log_e\frac{c}{b}\right)$$

Outer Surface:

$$\sigma_a = \sigma_h = \frac{E\alpha m}{8d\,(1 - \nu)}\left(3b^2 - c^2 - \frac{4b^4}{c^2 - b^2}\log_e\frac{c}{b}\right)$$

where b = inside radius

c = outside radius

m = ramp rate

d = diffusivity

The ANSYS finite element thermal solution for a ramp rate of 0.5°F/sec is illustrated in Figure 4-3. The curve T1 is the temperature transient for a point on the inside surface. The curve T2 is the temperature transient for a point on the outside surface. The temperature difference curve becomes constant in Figure 4-3 indicating that the thermal stress distribution has become constant even though the temperature of the cylinder continues to increase.

Figure 4-4 presents the axial and hoop thermal stress contours after the temperature difference curve of Figure 4-3 is stabilized. The stabilized stress values for the inside and outside surfaces which were obtained using ANSYS are shown in Table 4-2 alongside the values obtained using the formulas listed above from the handbook of References 3. The computer program input data listing ver2.5 in Appendix A is used to calculate the finite element results and the handbook results. Based upon the correlation of results in Table 4-2, it is concluded that the ANSYS computer program is verified for analysis of the thermal stress transients of the steam generator upper girth weld region.

**Table 4-1. Verification for Pressure Loading**

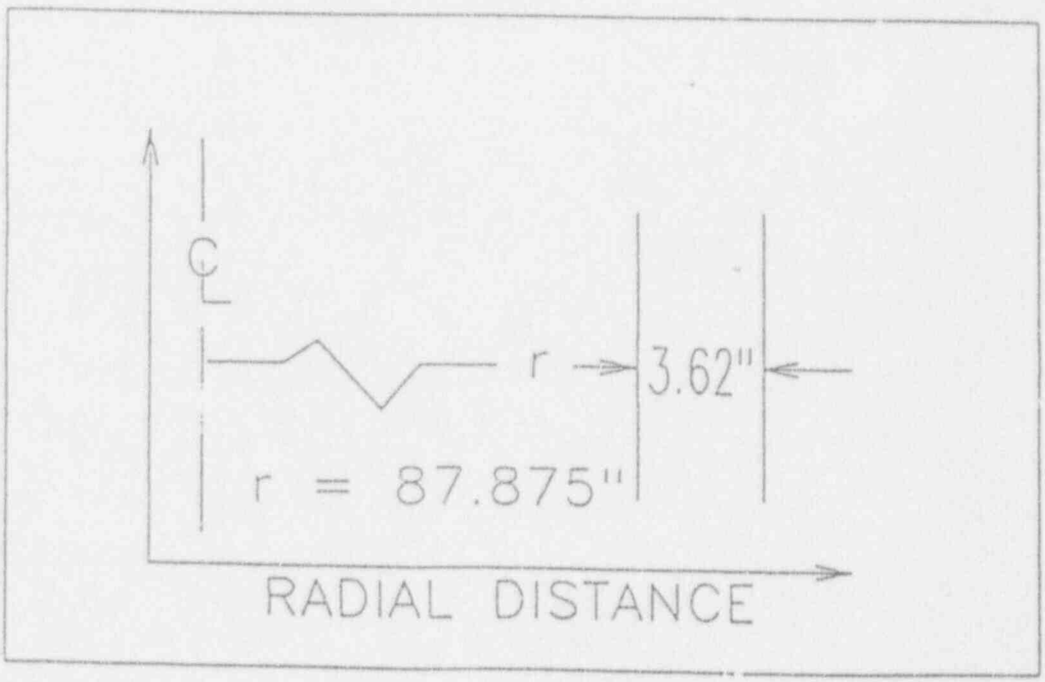
| Location | ANSYS | Handbook (3) | Difference |
|---|---|---|---|
| Inside Surface | | | |
| Radial Stress | -1,065 psi | -1,065 psi | 0 |
| Hoop Stress | 26,396 | 26,396 | 0 |
| Axial Stress | 12,665 | 12,665 | 0 |
| Outside Surface | | | |
| Radial Stress | 0 | 0 | 0 |
| Hoop Stress | 25,331 | 25,331 | 0 |
| Axial Stress | 12,665 | 12,665 | 0 |

ANSYS,ver1.5

**Table 4-2 Verification for Thermal Transient Loading**

| Location | ANSYS | Handbook (3) | Difference |
|---|---|---|---|
| Inside Surface | | | |
| Hoop Stress | 13,282 | 13,369 | 1% |
| Axial Stress | 13,282 | 13,369 | 1% |
| Outside Surface | | | |
| Hoop Stress | -25,801 | -26,206 | 1.5% |
| Axial Stress | -25,792 | -26,206 | 1.6% |

ANSYS,ver2.5




Source: Reference 2

**Figure 4-1. Cylinder for Simplified Model**

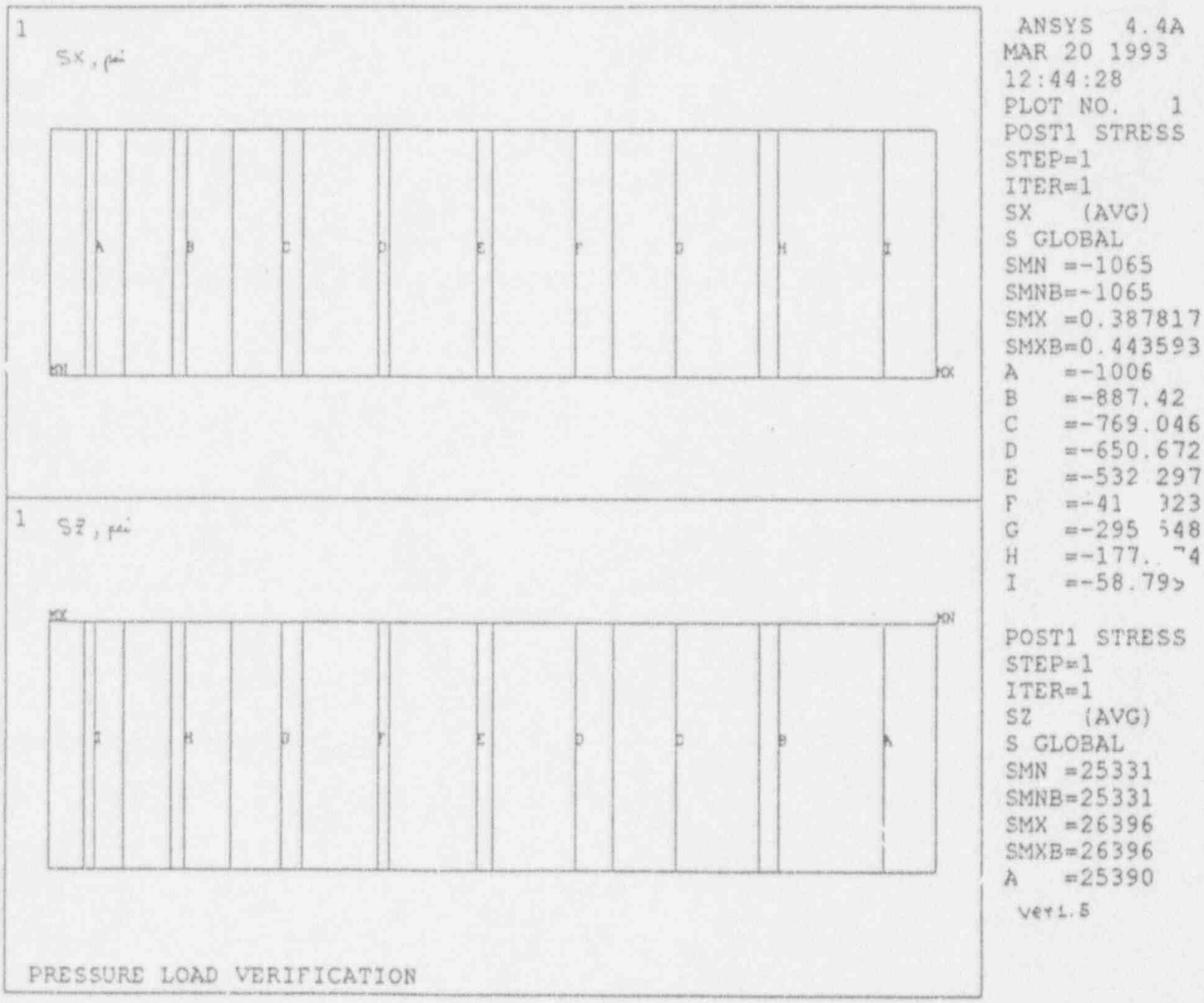



Figure 4-2. Pressure Load Verification


Figure 4-3. Thermal Stress Transient Verification, Temperature

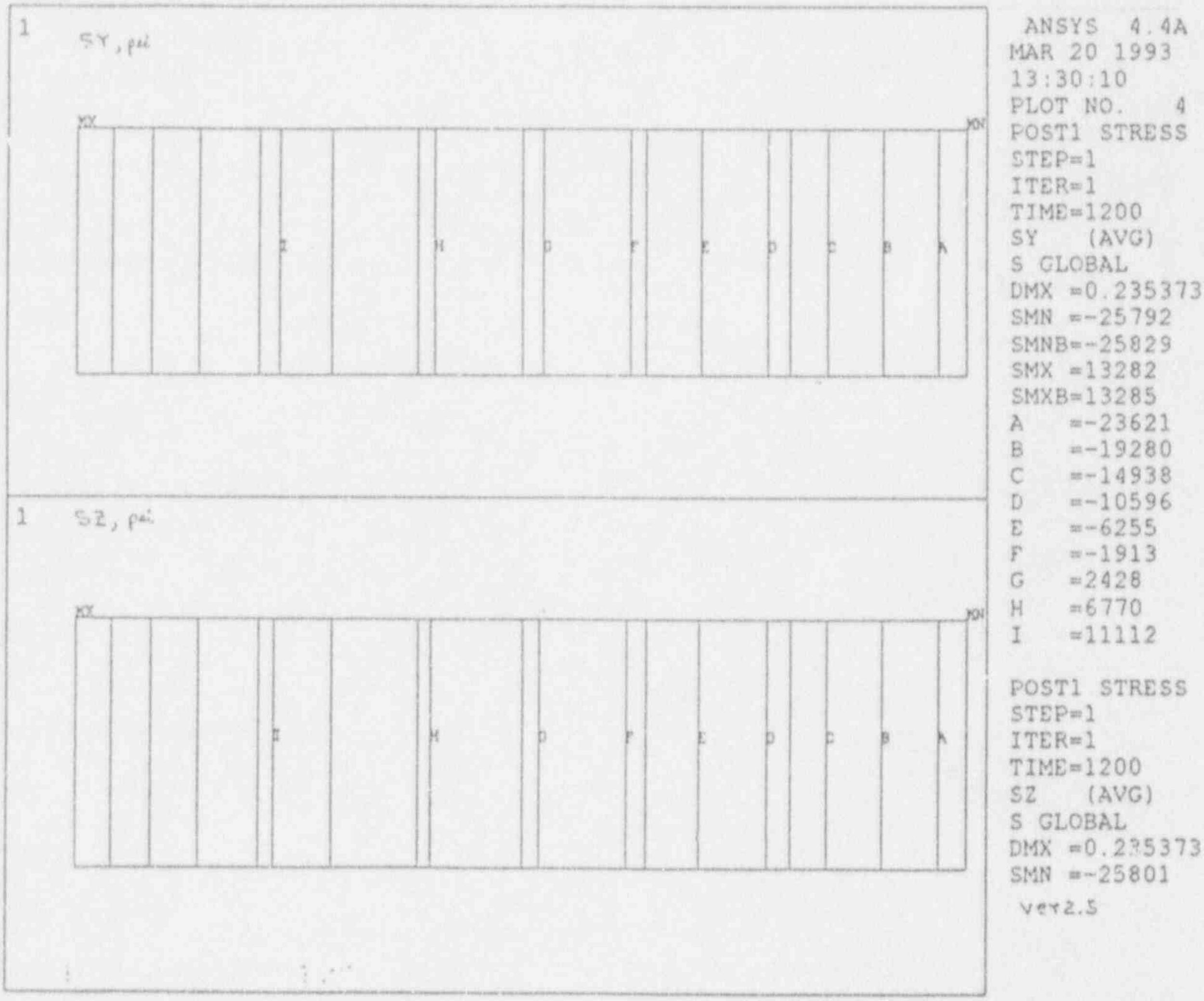



Figure 4-4. Thermal Stress Transient Verification, Stresses

## 5.0 STEAM GENERATOR MODEL

### 5.1 INTRODUCTION

An analysis problem is defined by its geometry, material properties and applied loading. The material properties for the steam generator and analysis model are as described in Section 2.3. The geometry and applied loading are described in the following subsections.

### 5.2 GEOMETRY

The geometry of the upper girth weld region is illustrated in Figure 5-1. The primary area of interest is the upper girth weld region as shown in Figure 5-1. However, the model is extended on both sides of the transition to eliminate the influence of end effects on the girth weld stresses. In order to assure that the boundaries of the finite element model are remote from the girth welds, a shell wave length is calculated. The shell wave length is given by, Reference 2.

$$\lambda = \sqrt{rt}$$

where $r$ = inner radius and

$t$ = shell wall thickness

Above the transition region

$$\lambda = 4\sqrt{(87.875)(3.62)}$$

$$= 71 \text{ in}$$

Below the transition region

$$\lambda = 4\sqrt{(67.50)(3.62)}$$

$$= 63 \text{ in}$$

Therefore, the finite element model is extended 71 inches above and 63 inches below the transition.

The thermal boundary conditions of finite element model specify no heat flow through the insulated external surface because heat flow through this surface is negligible compared to the inside surface. Furthermore, heat flow through the remote ends of the shell sections is negligible and a no-flow boundary condition is specified.

Heat exchange between the fluid and the inside surface of the shell takes place through a film coefficient which mitigates the fluid thermal transient. The metal temperature of the inside surface of the shell is conservatively specified to follow the thermal transient of the fluid for most of the events analyzed. Film coefficient data from Reference 7 is used in analysis of the reactor trip and feedwater cycling transients.

The structural boundary conditions take the form of pressure on the inside surface and displacement restraints on the upper and lower boundaries of the girth weld region model. The upper and lower boundaries of the girth weld region model are remote from the girth weld as described above. Therefore, it is appropriate to specify rotational restraint on these boundaries. Axial displacement constraints are applied at the lower end of the model.

End forces are applied to the upper end of the finite element model to represent the forces which arise from the restraint of the ends of the steam generator shell. These forces are automatically applied in the course of the ANSYS finite element analysis.

The initial transient time step size is defined in accord with the instructions of Reference 3. The applicable formula is;

$$\Delta t \leq (\Delta x)^2/10d$$

where

$\Delta t$ = Initial step size

$\Delta x$ = Radial thickness of smallest finite element

$d$ = Thermal diffusivity of the material

This step size is calculated as part of the analysis process. The automatic step size controls of the ANSYS computer program are invoked to set the step size during the course of the transient.

Quadratic finite elements are used to represent the upper girth weld section. The ANSYS designation for these elements is Type 77 for thermal analysis and Type 82 for the thermal stress analysis.

The geometry of the finite element model is shown in Figure 5-2. The nodes and boundary conditions are shown on the left. The finite elements are shown on the right. Complete and precise details of the geometry and boundary conditions are contained in the input data listings in Appendix A.

### 5.3 APPLIED LOADING

A subset of the transients in the design specification for the steam generator is specified in Reference 5 for use in this stress analysis for evaluation of flaws in the upper girth weld region. The specified transients are given in Table 5-1.

Transients 1, 2, 3 and 6 are represented as linear transitions between the states in Table 5-1. The temperatures are specified directly as metal surface temperatures.

Transients 4 and 5 in Table 5-1 use a modified model in which the fluid temperature and film coefficients are specified in detail according to the data tables referenced in Table 5-1. The pressure is uniform over the internal surface as given in Table 5-2. The fluid temperature and film coefficient histories are specified by region in Tables 5-3 and 5-4. The regions are defined in Figure 5-3 and 5-4.

Complete and precise specifications of the finite element models and applied loadings are given in the input data listings in Appendix A, B and C.

Results from these transient thermal and thermal stress analyses are used to calculate the maximum size to which detected flaws are expected to grow in a specified time period, which can be the next scheduled inspection of the component, or until the end of vessel design lifetime. Knowing the maximum flaw size and expected loads, we can compare flaw size and stress intensity with the critical values to demonstrate acceptability under the requirements of Article IWC-3600.

Table 5-1. Transients for Stress Analysis

| Transient | Total Occurrences | Time Interval, sec | Pressure-psia | Temperature -°F | Reference |
|---|---|---|---|---|---|
| Heatup @ 100°F/hour | 200 | | 0 | 70 | |
| | | 5*3600 | | | 5 |
| | | | 1020 | 547 | |
| | | | | | |
| 2. Cooldown @ 100°F/hour | 200 | | 1020 | 547 | |
| | | 5*3600 | | | 5 |
| | | | 0 | 70 | |
| | | | | | |
| 3. Large Step Load Decrease | 200 | | 720 | 506 | |
| | | 60 | | | |
| | | | 1091 | 546 | |
| | | after @ 180 | | | 5 |
| | | | 802 | 510 | |
| | | after @ 200*60 | | | |
| | | | 938 | 537 | |
| | | | | | |
| 4. Reactor Trip | 400 | | 1020 | 546.99 | |
| | | 11.5*60 | See Tables 5-1 and 5-3 | | 7 |
| | | | 220 | 389.86 | |
| | | | | | |
| 5. Auxiliary Feedwater Cycling at Hot Standby | 1 | | 1020 | 547 | |
| | | 60 | | | 5 |
| | | | 0 | 70 | |
| | | | | | |
| 6. Bounding Faulted Event | 18300 | | 1020 | 547 | |
| | | 60 | See Tables 5-1 and 5-4 | | 7 |
| | | | 0 | 70 | |

Source: Reference 5

**Table 5-2. Feedwater Cycling and Reactor Trip Pressure Transients**

Source: Reference 7

Report, "Zion Unit 1 Steam Generator Girth Weld Repair Report Fall 1989, and Zion Unit 2 Steam Generator Girth Weld Repair Report Spring 1990," Westinghouse Electric Corporation Report WCAP-12489, June 1991. (Table 3.3.-3)

**Table 5-3. Thermal Boundary Conditions, Reactor Trip Transients**

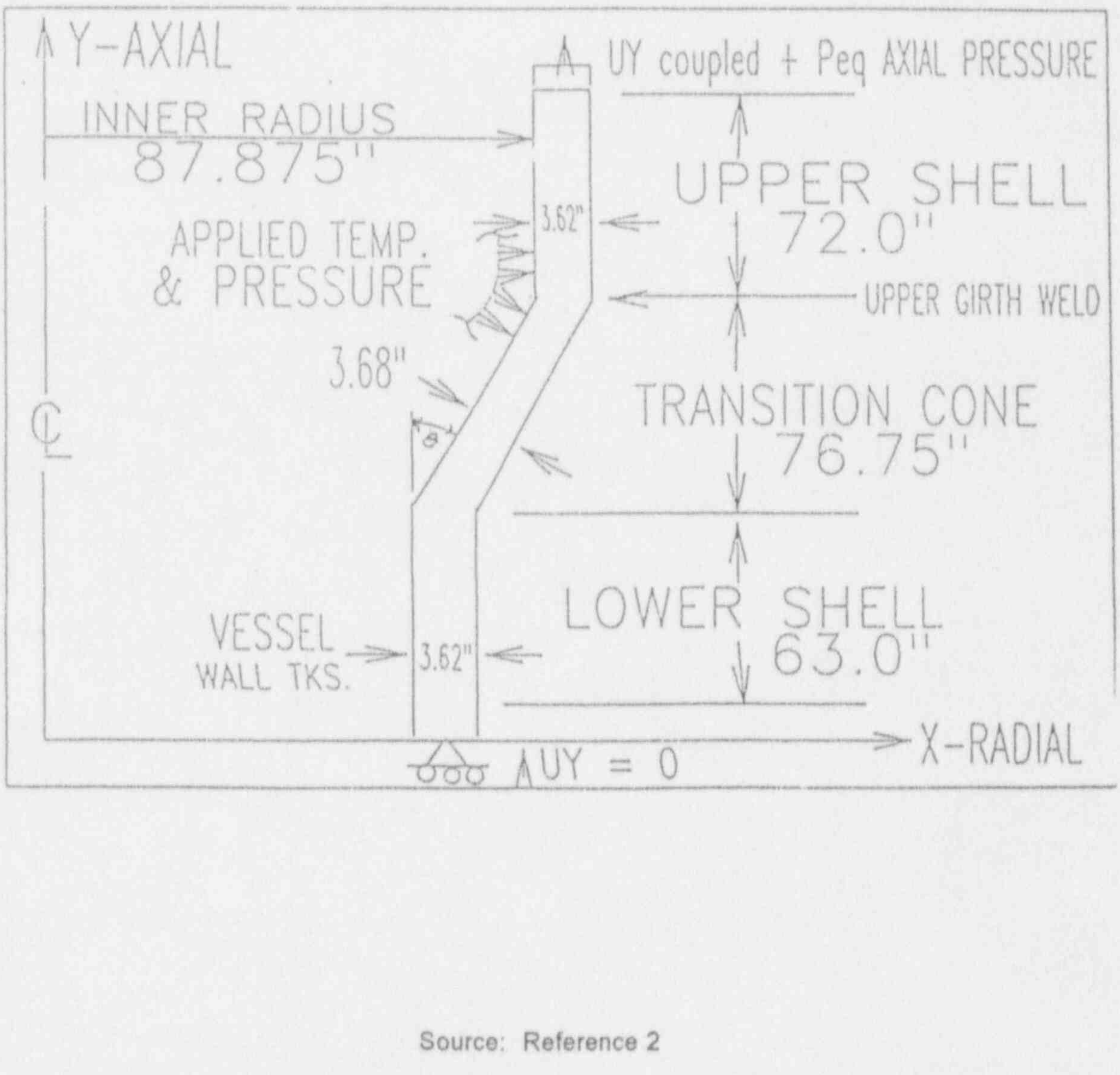
Source: Reference 7

Report, "Zion Unit 1 Steam Generator Girth Weld Repair Report Fall 1989, and Zion Unit 2 Steam Generator Girth Weld Repair Report Spring 1990," Westinghouse Electric Corporation Report WCAP-12489, June 1991. (Table 3.3-6)

**Table 5-4. Thermal Boundary Conditions, Feedwater Cycling Transient**

Source: Reference 7

Report, "Zion Unit 1 Steam Generator Girth Weld Repair Report Fall 1989, and Zion Unit 2 Steam Generator Girth Weld Repair Report Spring 1990," Westinghouse Electric Corporation Report WCAP-12489, June 1991. (Table 3.3-7)




Source: Reference 2

**Figure 5-1. Steam Generator Shell Finite Element Model**

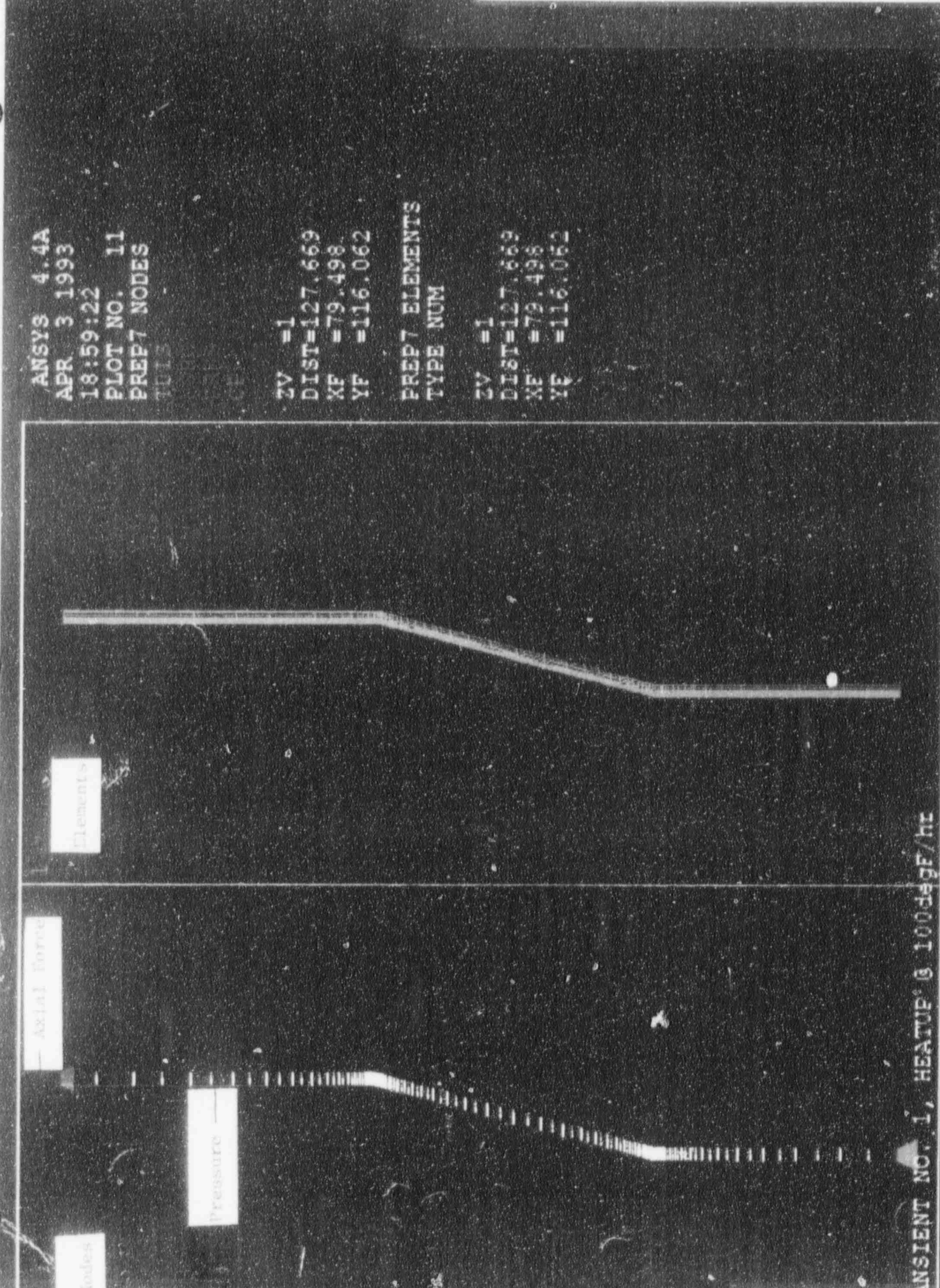



Figure 5-2. Steam Generator Girth Weld, Finite Element Model

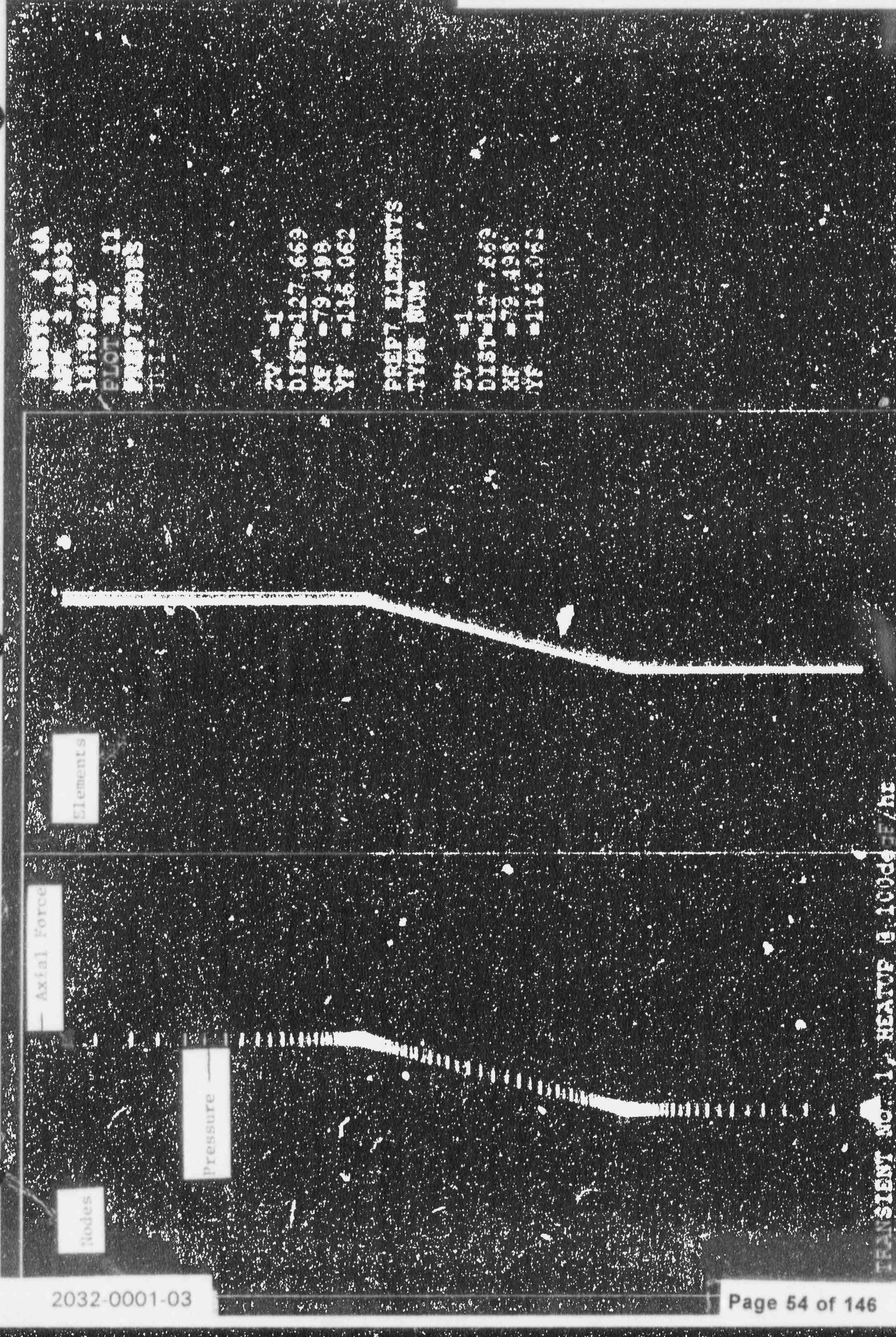



Figure 5-2. Steam Generator Girth Weld, Finite Element Model

Figure 5-3. Region Definition Reactor Trip Transient

Source: Reference 7

Report, "Zion Unit 1 Steam Generator Girth Weld Repair Report Fall 1989, and Zion Unit 2 Steam Generator Girth Weld Repair Report Spring 1990," Westinghouse Electric Corporation Report WCAP-12489, June 1991. (Figure 3.3-2)

**Figure 5-4. Region Definition Feedwater Cycling Transient**

Source: Reference 7

Report, "Zion Unit 1 Steam Generator Girth Weld Repair Report Fall 1989, and Zion Unit 2 Steam Generator Girth Weld Repair Report Spring 1990," Westinghouse Electric Corporation Report WCAP-12489, June 1991. (Figure 3.3-3)

# 6.0 STEAM GENERATOR STRESS ANALYSIS

## 6.1 INTRODUCTION

The analysis model of Section 5 is used to obtain the results in this section. These results are needed for the fracture mechanics analyses of Section 7.

## 6.2 HEATUP @ 100°F/HOUR

The heatup transient begins at an isothermal condition of 70°F and rises to 547°F over a period of 5 hours. The internal pressure is zero at the initial state and rises to 1020 psi at the 547°F end state.

Figure 6-1 presents the temperature history for the inside and outside surfaces at the girth weld in the finite element model. The figure contains three curves. One curve is for a point on the inside surface. One curve is for a point on the outside surface. The lower curve is the difference of the other two curves. The thermal stress level is dependent upon the temperature difference curve. The temperature difference curve is used to determine the time at which thermal stresses are greatest.

The maximum temperature difference for the curve of the heatup transient is very small at all times.

Figure 6-2 shows the temperature profile through the wall at 5 hours when the pressure is greatest. The temperature gradient through the wall is less than 14°F and is essentially constant throughout the heatup.

Figure 6-3 illustrates the stress intensity distribution in the girth weld region at 5 hours when the pressure is 1020 psi. The figure on the left is drawn to scale. The figure on the right is exaggerated to show the thickness variation more clearly.

Figure 6-4 shows the key results of the structural analysis of the heatup transient. The figure has three curves; membrane, membrane-plus-bending and total axial stress. These axial stress results are the data needed for fracture mechanics analysis of circumferential flaws. The results in the figure for the upper girth weld are listed in Table 6-1. A detailed tabulation of the total axial stress at the girth weld section is given in Table 6-2.

### 6.3 COOLDOWN @ 100°F/HOUR

The cooldown transient begins at a steady state temperature distribution at 547°F and a pressure of 1020 psi. The cooldown occurs over a period of 5 hours to near isothermal conditions at 70°F and zero pressure.

The cooldown is just the reverse of the heatup transient. Figure 6-5 corresponds to Figure 6-1. The temperature through the wall during this transient is the reverse of that shown in Figure 6-2. Figure 6-6 shows the through-wall temperatures upon reaching the 70°F level during the cooldown.

The worst-case stress condition during the cooldown occurs at the outset when the pressure level is 1020 psi. The stress intensity at this condition is shown in Figure 6-7. The axial stress contributions needed for the fracture mechanics analyses are shown in Figure 6-8. The key stress values are summarized in Table 6-3. The detailed tabulation of axial stress for use in the fracture mechanics analysis is given in Table 6-4.

## 6.4 LARGE STEP LOAD DECREASE

The large step load decrease transient is defined as follows:

| Time(sec) | Temperature (°F) | Pressure(psi) |
|---|---|---|
| 0 | 506 | 720 |
| 60 | 548 | 1091 |
| 180 | 510 | 802 |
| 1200 | 537 | 938 |

Figure 6-9 presents the temperature history at the girth weld during the large step load decrease transient. The maximum through-wall temperature difference occurs at 60 seconds into the transient. At this time, the through-wall temperature distributions are as shown in Figure 6-10.

The stress intensity distributions and the axial stress contributions are given as follows:

| Time | Stress Intensity Contours(psi) | Axial Stress Contributions |
|---|---|---|
| 0 | Figure 6-11 | Figure 6-12 |
| 60 | Figure 6-13 | Figure 6-14 |
| 180 | Figure 6-15 | Figure 6-16 |
| 1200 | Figure 6-17 | Figure 6-18 |

Stress contributions are given in Table 6-5. Detailed axial stress profile data are given in Table 6-6 for use in the fracture mechanics analysis.

The worst stress conditions during the transient occur at 60 seconds into the transient. The maximum stress intensity is 35,422 psi as shown in Figure 6-13. The maximum axial stress at this time is 25,711 psi for use in the fracture mechanics analysis.

## 6.5 REACTOR TRIP

The reactor trip transient begins at 547°F and 1020 psi as specified in Table 5-1. Figure 6-19 presents the temperature history of the shell wall at the upper girth weld during this reactor trip transient.

The maximum temperature difference through this wall at the upper girth weld is about 95°F at 560 seconds into the transient. The temperature profile through the wall at this time is illustrated in Figure 6-20. The temperature along the inside surface from the bottom of the model to top of the model at 560 seconds is shown in Figure 6-21. The temperature at the upper girth weld is at 400°F.

The stress time history at the upper girth weld during the reactor trip transient is presented in Figure 6-22. The highest stress at the girth weld occurs at the initial conditions when the pressure is 1020 psi. The stress profile up the inside surface of the model at the initial conditions is shown in Figure 6-23. The highest stress occurs at the upper girth weld.

Figure 6-24 shows the stress profile up the inside surface at 685 seconds into the transient. At this time, the stresses in the region of the upper girth weld are reduced. It is useful to compare the results of Figure 6-24 with results reported previously in Reference 7. The results are similar. Slightly more severe stresses are obtained herein because the film coefficients are not smoothed between regions as in Reference 7.

Figures 6-26 and 6-27 illustrate the distributions of stress in the shell wall at the initial condition and at 685 seconds. The maximum stress is initially at the upper girth weld and then moves down onto the interior region of the conical section.

The distribution of axial stress through the wall is shown in Figure 6-28 for the initial 547°F and 1020 psi condition. The same distribution is shown at 685 seconds in

Figure 6-29. These through-wall axial stress distributions are summarized in Table 6-7 and listed in detail in Table 6-8 for use in fracture mechanics analyses.

## 6.6 AUXILIARY FEEDWATER CYCLING

The auxiliary feedwater cycling event begins at 547°F and 1020 psi and ends at 512°F and 812 psi over a period of 10 minutes. These states are given in Table 5.1. Five temperature subcycles occur within this period although the pressure is reduced monotonically. These details are given in Table 5-2 and 5-4.

The temperature history in the shell wall at the upper girth weld during the auxiliary feedwater cycling transient is shown in Figure 6-30. The maximum temperature difference through the wall occurs at 560 seconds. The temperature profile up the inside surface of the wall at this time is plotted in Figure 6-31 and the temperature distribution through the wall is given in Figure 6-32. The through-wall temperature data are listed in Table 6-9.

The stress time history at the upper girth weld during the auxiliary feedwater recycling event is presented in Figure 6-33. The maximum stress occurs at 275 seconds. The stress at 560 seconds reaches almost the same level at lower pressure and temperature conditions.

Figure 6-34 shows the distribution of stress up the inside surface at 560 seconds. The maximum stress occurs at the upper girth weld. The distribution of stress intensity in the shell wall is illustrated in Figure 6-35.

The key stress results for the upper girth weld for the auxiliary feedwater cycling event are plotted in Figures 6-36 and 6-37. These plots give the axial stress distributions through the wall at 275 seconds and 560 seconds. The detailed data are listed in Table 6-10 and 6-11 for use in the fracture mechanics evaluation of flow indications in the upper girth weld.

## 6.7 BOUNDING FAULTED EVENT

The bounding faulted event begins at the steady state conditions of 547°F and 1020 psi and ramps to 70°F and 0 psi over 60 seconds as shown in Figure 6-38.

Figures 6-39, 6-40 and 6-41 present the through-wall temperature distributions at t=60, 196 and 347 seconds.

The stress intensity distributions and the axial stress contributions are given as follows:

| Time | Stress Intensity Contours (psi) | Axial Stress Contributions (psi) |
|---|---|---|
| 0 | Figure 6-42 | Figure 6-43 |
| 60 | Figure 6-44 | Figure 6-45 |
| 180 | Figure 6-46 | Figure 6-47 |
| 300 | Figure 6-48 | Figure 6-49 |

Stress contributions ar given in Table 6-12. Detailed axial stress profile data are given in Table 6-13 for use in the fracture mechanics analysis.

Table 6-1. Girth Weld Axial Stress, Heatup @ 100 °F/hour

| Location | Axial Stress (psi) | | |
|---|---|---|---|
| | Membrane | Membrane + Bending | Total |
| Inside | 12,130 | 26,620 | 27,920 |
| Midsurface | 12,130 | 12,230 | 11,920 |
| Outside | 12,130 | -2,172 | -1,971 |

nsgen1.5
state 2

Table 6-2. Girth Weld Axial Stress, Heatup @ 100°F/hour

| Distance (in) Inside to Outside | Axial Stress (psi) |
|---|---|
| 0. | 27921. |
| 0.75417E-01 | 27090. |
| 0.15083 | 26264. |
| 0.22625 | 25474. |
| 0.30167 | 24684. |
| 0.37708 | 23935. |
| 0.45250 | 23193. |
| 0.52792 | 22459. |
| 0.60333 | 21767. |
| 0.67875 | 21074. |
| 0.75417 | 20382. |
| 0.82958 | 19734. |
| 0.90500 | 19089. |
| 0.98042 | 18444. |
| 1.0558 | 17802. |
| 1.1313 | 17198. |
| 1.2067 | 16594. |
| 1.2821 | 15989. |
| 1.3575 | 15385. |
| 1.4329 | 14794. |
| 1.5083 | 14219. |
| 1.5838 | 13644. |
| 1.6592 | 13068. |
| 1.7346 | 12493. |
| 1.8100 | 11918. |
| 1.8854 | 11356. |
| 1.9608 | 10795. |
| 2.0363 | 10234. |
| 2.1117 | 9672.6 |
| 2.1871 | 9111.5 |
| 2.2625 | 8550.3 |
| 2.3379 | 7987.9 |
| 2.4133 | 7423.0 |
| 2.4888 | 6858.1 |
| 2.5642 | 6293.1 |
| 2.6396 | 5728.2 |
| 2.7150 | 5163.3 |
| 2.7904 | 4598.3 |
| 2.8658 | 4033.4 |
| 2.9413 | 3452.0 |
| 3.0167 | 2849.3 |
| 3.0921 | 2246.7 |
| 3.1675 | 1644.1 |
| 3.2429 | 1041.5 |
| 3.3183 | 438.93 |
| 3.3938 | -163.68 |
| 3.4692 | -766.28 |
| 3.5446 | -1368.9 |
| 3.6200 | -1971.5 |

t=5*3600 sec

sgen1.5
state 2

Table 6-3. Girth Weld Axial Stress, Cooldown @ 100°F/hour

| Location | Axial Stress (psi) | | |
|---|---|---|---|
| | Membrane | Membrane + Bending | Total |
| Inside | 12,100 | 28,260 | 28,620 |
| Midsurface | 12,100 | 12,200 | 11,830 |
| Outside | 12,100 | -3,852 | -3,414 |

sgen2.5
state 1

**Table 6-4. Girth Weld Axial Stress, Cooldown @ 100°F/hour**

| Distance (in) inside to Outside | Axial Stress (psi) |
|---|---|
| 0. | 30529. |
| 0.75417E-01 | 29522. |
| 0.15083 | 28521. |
| 0.22625 | 27560. |
| 0.30167 | 26599. |
| 0.37708 | 25691. |
| 0.45250 | 24792. |
| 0.52792 | 23903. |
| 0.60333 | 23069. |
| 0.67875 | 22235. |
| 0.75417 | 21401. |
| 0.82958 | 20628. |
| 0.90500 | 19860. |
| 0.98042 | 19091. |
| 1.0558 | 18327. |
| 1.1313 | 17618. |
| 1.2067 | 16910. |
| 1.2821 | 16202. |
| 1.3575 | 15493. |
| 1.4329 | 14808. |
| 1.5083 | 14151. |
| 1.5838 | 13494. |
| 1.6592 | 12837. |
| 1.7346 | 12179. |
| 1.8100 | 11522. |
| 1.8854 | 10901. |
| 1.9608 | 10282. |
| 2.0363 | 9663.2 |
| 2.1117 | 9044.6 |
| 2.1871 | 8425.9 |
| 2.2625 | 7807.2 |
| 2.3379 | 7196.4 |
| 2.4133 | 6601.5 |
| 2.4888 | 6006.7 |
| 2.5642 | 5411.8 |
| 2.6396 | 4816.9 |
| 2.7150 | 4222.1 |
| 2.7904 | 3627.2 |
| 2.8658 | 3032.4 |
| 2.9413 | 2434.8 |
| 3.0167 | 1833.6 |
| 3.0921 | 1232.5 |
| 3.1675 | 631.38 |
| 3.2429 | 30.248 |
| 3.3183 | -570.88 |
| 3.3938 | -1172.0 |
| 3.4692 | -1773.1 |
| 3.5446 | -2374.3 |
| 3.6200 | -2975.4 |

t=0 sec

sgen2.5
state 1

Table 6-5. Girth Weld Axial Stress, Large Step Load Decrease

| Location | Axial Stress (psi) | | |
|---|---|---|---|
| | Membrane | Membrane + Bending | Total |
| t=0 Inside | 8,562 | 20,030 | 21,550 |
| Midsurface | | 8,640 | 8,133 |
| Outside | | -2,756 | -2,100 |
| t=60 inside | 12,970 | 25,710 | 22,100 |
| Midsurface | | 13,060 | 14,070 |
| Outside | | 401 | -1,123 |
| t=180 Inside | 9,538 | 21,740 | 25,490 |
| Midsurface | | 9,619 | 8,626 |
| Outside | | -2,502 | -1,512 |
| t=1200 Inside | 11,150 | 24,410 | 25,570 |
| Midsurface | | 11,240 | 10,970 |
| Outside | | -1,923 | -1,760 |

nsgen3.5

Table 6-6. Girth Weld Axial Stress Detail, Large Step Load Decrease

| Distance (in) Inside to Outside | Axial Stress (psi) | | | |
|---|---|---|---|---|
| | t-0 sec | t=60 sec | t=180 sec | t=1200 sec |
| DISTANCE | SY | SY | SY | SY |
| 0. | 21550. | 22098. | 25492. | 25570. |
| 0.75417E-01 | 20839. | 22176. | 24350. | 24813. |
| 0.15083 | 20133. | 22244. | 23219. | 24061. |
| 0.22625 | 19454. | 22234. | 22174. | 23341. |
| 0.30167 | 18776. | 22224. | 21130. | 2261[illegible]. |
| 0.37708 | 18135. | 22100. | 20197. | 21940. |
| 0.45250 | 17500. | 21956. | 19284. | 21265. |
| 0.52792 | 16872. | 21793. | 18391. | 20594. |
| 0.60333 | 16284. | 21519. | 17613. | 19963. |
| 0.67875 | 15695. | 21245. | 16834. | 19332. |
| 0.75417 | 15107. | 20971. | 16056. | 18701. |
| 0.82958 | 14561. | 20586. | 15399. | 18109. |
| 0.90500 | 14019. | 20193. | 14752. | 17521. |
| 0.98042 | 13476. | 19799. | 14105. | 16933. |
| 1.0558 | 12936. | 19399. | 13465. | 16347. |
| 1.1313 | 12436. | 18905. | 12934. | 15795. |
| 1.2067 | 11937. | 18412. | 12402. | 15244. |
| 1.2821 | 11437. | 17918. | 11871. | 14692. |
| 1.3575 | 10937. | 17424. | 11340. | 14140. |
| 1.4329 | 10453. | 16899. | 10847. | 13600. |
| 1.5083 | 9989.0 | 16334. | 10403. | 13075. |
| 1.5838 | 9525.0 | 15769. | 9958.8 | 12549. |
| 1.6592 | 9061.1 | 15204. | 9514.5 | 12023. |
| 1.7346 | 8597.2 | 14639. | 9070.2 | 11498. |
| 1.8100 | 8133.2 | 14074. | 8625.9 | 10972. |
| 1.8854 | 7694.6 | 13470. | 8224.2 | 10458. |
| 1.9608 | 7257.9 | 12863. | 7825.7 | 9944.2 |
| 2.0363 | 6821.2 | 12256. | 7427.2 | 9430.7 |
| 2.1117 | 6384.4 | 11649. | 7028.7 | 8917.2 |
| 2.1871 | 5947.7 | 11042. | 6630.2 | 8403.7 |
| 2.2625 | 5511.0 | 10435. | 6231.7 | 7890.2 |
| 2.3379 | 5079.8 | 9821.3 | 5832.6 | 7375.4 |
| 2.4133 | 4659.9 | 9194.0 | 5432.3 | 6857.8 |
| 2.4888 | 4240.0 | 8566.6 | 5032.0 | 6340.2 |
| 2.5642 | 3820.1 | 7939.2 | 4631.8 | 5822.6 |
| 2.6396 | 3400.2 | 7311.9 | 4231.5 | 5305.1 |
| 2.7150 | 2980.3 | 6684.5 | 3831.2 | 4787.5 |
| 2.7904 | 2560.4 | 6057.1 | 3430.9 | 4269.9 |
| 2.8658 | 2140.5 | 5429.8 | 3030.7 | 3752.3 |
| 2.9413 | 1718.7 | 4789.4 | 2605.3 | 3219.1 |
| 3.0167 | 1294.3 | 4132.5 | 2147.8 | 2665.9 |
| 3.0921 | 870.00 | 3475.5 | 1690.2 | 2112.7 |
| 3.1675 | 445.68 | 2818.6 | 1232.7 | 1559.4 |
| 3.2429 | 21.352 | 2161.6 | 775.20 | 1006.2 |
| 3.3183 | -402.97 | 1504.7 | 317.67 | 452.98 |
| 3.3938 | -827.30 | 847.75 | -139.85 | -100.25 |
| 3.4692 | -1251.6 | 190.80 | -597.37 | -653.48 |
| 3.5446 | -1675.9 | -466.14 | -1054.9 | -1206.7 |
| 3.6200 | -2100.3 | -1123.1 | -1512.4 | -1759.9 |

sgen9.5

**Table 6-7. Girth Weld Axial Stress Contributions, Reactor Trip**

| Location | Axial Stress (psi) | | |
| --- | --- | --- | --- |
| | Membrane | Membrane + Bending | Total |
| t = 0 Inside | 11,620 | 25,900 | 27,580 |
| Midsurface | 11,620 | 11,700 | 11,150 |
| Outside | 11,620 | -2,468 | -1,803 |
| t = 685 Inside | 2,514 | 6,378 | 10,130 |
| Midsurface | 2,514 | 2,541 | 571 |
| Outside | 2,514 | -1,295 | 2,437 |

rtrp 1.5

Table 6-8. Girth Weld Axial Stress Detail, Reactor Trip

| Distance (in) Inside to Outside | Axial Stress (psi) | | | |
|---|---|---|---|---|
| | t-0 sec | t=50 sec | t=560 sec | t=685sec |
| 0. | 27583. | 26882. | 14977. | 10132. |
| 0.75417E-01 | 26731. | 25898. | 14020. | 9538.1 |
| 0.15083 | 25883. | 24922. | 13070. | 8947.2 |
| 0.22625 | 25078. | 24006. | 12168. | 8377.9 |
| 0.30167 | 24272. | 23091. | 11266. | 7808.5 |
| 0.37708 | 23496. | 22235. | 10435. | 7283.0 |
| 0.45250 | 22724. | 21389. | 9616.8 | 6765.1 |
| 0.52792 | 21960. | 20557. | 8814.0 | 6255.3 |
| 0.60333 | 21236. | 19796. | 8096.1 | 5790.2 |
| 0.67875 | 20512. | 19036. | 7378.2 | 5325.0 |
| 0.75417 | 19788. | 18275. | 6660.2 | 4859.9 |
| 0.82958 | 19113. | 17595. | 6044.1 | 4454.8 |
| 0.90500 | 18442. | 16922. | 5435.9 | 4054.4 |
| 0.98042 | 17771. | 16248. | 4827.8 | 3654.0 |
| 1.0558 | 17104. | 15580. | 4227.9 | 3259.0 |
| 1.1313 | 16484. | 14987. | 3742.8 | 2938.2 |
| 1.2067 | 15864. | 14394. | 3257.6 | 2617.4 |
| 1.2821 | 15245. | 13801. | 2772.5 | 2296.7 |
| 1.3575 | 14625. | 13208. | 2287.4 | 1975.9 |
| 1.4329 | 14025. | 12644. | 1867.9 | 1698.2 |
| 1.5083 | 13449. | 12116. | 1528.0 | 1472.8 |
| 1.5838 | 12874. | 11589. | 1188.2 | 1247.3 |
| 1.6592 | 12298. | 11061. | 848.33 | 1021.9 |
| 1.7346 | 11722. | 10533. | 508.48 | 796.40 |
| 1.8100 | 11147. | 10006. | 168.63 | 570.95 |
| 1.8854 | 10600. | 9520.3 | -16.817 | 456.32 |
| 1.9608 | 10056. | 9037.8 | -191.01 | 349.78 |
| 2.0363 | 9512.4 | 8555.3 | -365.20 | 243.23 |
| 2.1117 | 8968.4 | 8072.9 | -539.39 | 136.69 |
| 2.1871 | 8424.3 | 7590.4 | -713.59 | 30.140 |
| 2.2625 | 7880.3 | 7108.0 | -887.78 | -76.406 |
| 2.3379 | 7341.5 | 6633.1 | -1001.4 | -132.43 |
| 2.4133 | 6813.0 | 6173.6 | -992.74 | -86.597 |
| 2.4888 | 6284.5 | 5714.2 | -984.13 | -40.763 |
| 2.5642 | 5756.0 | 5254.7 | -975.51 | 5.0711 |
| 2.6396 | 5227.6 | 4795.2 | -966.89 | 50.905 |
| 2.7150 | 4699.1 | 4335.7 | -958.27 | 96.739 |
| 2.7904 | 4170.6 | 3876.2 | -949.66 | 142.57 |
| 2.8658 | 3642.1 | 3416.7 | -941.04 | 188.41 |
| 2.9413 | 3106.2 | 2951.0 | -843.51 | 317.41 |
| 3.0167 | 2560.7 | 2477.4 | -632.14 | 552.90 |
| 3.0921 | 2015.2 | 2003.7 | -420.77 | 788.38 |
| 3.1675 | 1469.7 | 1530.1 | -209.41 | 1023.9 |
| 3.2429 | 924.25 | 1056.4 | 1.9598 | 1259.4 |
| 3.3183 | 378.77 | 582.78 | 213.33 | 1494.8 |
| 3.3938 | -166.71 | 109.14 | 424.69 | 1730.3 |
| 3.4692 | -712.19 | -364.51 | 636.06 | 1965.8 |
| 3.5446 | -1257.7 | -838.16 | 847.42 | 2201.3 |
| 3.6200 | -1803.1 | -1311.8 | 1058.8 | 2436.8 |

Table 6-9. Girth Weld Temperature Detail, Reactor Trip

| Distance ( in) Inside to Outside | Axial Stress (psi) | |
|---|---|---|
| | t = 275 sec | t = 560 sec |
| 0. | 478.65 | 454.50 |
| 0.75417E-01 | 482.46 | 458.75 |
| 0.15083 | 486.23 | 462.95 |
| 0.22625 | 489.60 | 466.70 |
| 0.30167 | 492.97 | 470.46 |
| 0.37708 | 495.94 | 473.75 |
| 0.45250 | 498.84 | 476.97 |
| 0.52792 | 501.66 | 480.10 |
| 0.60333 | 504.07 | 482.75 |
| 0.67875 | 506.48 | 485.41 |
| 0.75417 | 508.89 | 488.06 |
| 0.82958 | 510.84 | 490.18 |
| 0.90500 | 512.76 | 492.26 |
| 0.98042 | 514.68 | 494.34 |
| 1.0558 | 516.56 | 496.38 |
| 1.1313 | 518.01 | 497.91 |
| 1.2067 | 519.45 | 499.44 |
| 1.2821 | 520.89 | 500.98 |
| 1.3575 | 522.34 | 502.51 |
| 1.4329 | 523.59 | 503.82 |
| 1.5083 | 524.61 | 504.86 |
| 1.5838 | 525.62 | 505.90 |
| 1.6592 | 526.64 | 506.95 |
| 1.7346 | 527.66 | 507.99 |
| 1.8100 | 528.67 | 509.03 |
| 1.8854 | 529.36 | 509.70 |
| 1.9608 | 530.02 | 510.34 |
| 2.0363 | 530.68 | 510.98 |
| 2.1117 | 531.33 | 511.63 |
| 2.1871 | 531.99 | 512.27 |
| 2.2625 | 532.65 | 512.91 |
| 2.3379 | 533.21 | 513.45 |
| 2.4133 | 533.58 | 513.78 |
| 2.4888 | 533.95 | 514.12 |
| 2.5642 | 534.32 | 514.46 |
| 2.6396 | 534.69 | 514.79 |
| 2.7150 | 535.06 | 515.13 |
| 2.7904 | 535.43 | 515.46 |
| 2.8658 | 535.80 | 515.80 |
| 2.9413 | 536.06 | 516.03 |
| 3.0167 | 536.18 | 516.13 |
| 3.0921 | 536.30 | 516.23 |
| 3.1675 | 536.42 | 516.34 |
| 3.2429 | 536.54 | 516.44 |
| 3.3183 | 536.66 | 516.54 |
| 3.3938 | 536.78 | 516.64 |
| 3.4692 | 536.90 | 516.74 |
| 3.5446 | 537.02 | 516.85 |
| 3.6200 | 537.14 | 516.95 |

**Table 6.10. Girth Weld Axial Stress Contributions, Auxiliary Feedwater Cycling**

| Location | | Axial Stress (psi) | | |
|---|---|---|---|---|
| | | Membrane | Membrane + Bending | Total |
| t = 60 | Inside | 11,370 | 28,350 | 33,720 |
| | Midsurface | 11,370 | 11,490 | 9,732 |
| | Outside | 11,370 | -5,372 | -3,086 |
| t = 75 | Inside | 11,280 | 27,870 | 30,020 |
| | Midsurface | 11,280 | 11,390 | 9,921 |
| | Outside | 11,280 | -5,087 | -3,193 |
| t = 150 | Inside | 10,990 | 30,940 | 38,730 |
| | Midsurface | 10,990 | 11,120 | 8,581 |
| | Outside | 10,990 | -8,690 | -5,096 |
| t = 175 | Inside | 10,880 | 29,490 | 29,150 |
| | Midsurface | 10,880 | 11,010 | 9,372 |
| | Outside | 10,880 | -7,474 | -5,117 |
| t = 275 | Inside | 10,490 | 31,890 | 39,660 |
| | Midsurface | 10,490 | 10,630 | 7,808 |
| | Outside | 10,490 | -10,620 | -6,491 |
| t = 300 | Inside | 10,300 | 29,370 | 27,730 |
| | Midsurface | 10,300 | 10,430 | 8,921 |
| | Outside | 10,300 | -8,502 | -6,151 |
| t = 385 | Inside | 10,070 | 30,130 | 36,380 |
| | Midsurface | 10,070 | 10,210 | 7,856 |
| | Outside | 10,070 | -9,704 | -6,232 |
| t = 450 | Inside | 9,820 | 26,030 | 24,750 |
| | Midsurface | 9,820 | 9,933 | 9,513 |
| | Outside | 9,820 | -6,169 | -5,176 |
| t = 560 | Inside | 9,415 | 30,680 | 39,140 |
| | Midsurface | 9,415 | 9,563 | 6,512 |
| | Outside | 9,415 | -11,550 | -7,410 |
| t = 600 | Inside | 9,251 | 26,860 | 23,690 |
| | Midsurface | 9,251 | 9,374 | 8,561 |
| | Outside | 9,251 | -8,111 | -6,543 |

## Table 6-11. Girth Weld Axial Stress Detail, Auxiliary Feedwater Cycling

| Distance (in) Inside to Outside | Axial Stress (psi) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | t = 60 | t = 75 | t = 150 | t = 175 | t = 275 | t = 300 | t = 385 | t = 450 | t = 560 | t = 600 |
| 0. | 33720. | 30019. | 38734. | 29147. | 39661. | 27735. | 36376. | 24745. | 39137. | 23693 |
| 0.75417E-01 | 32240. | 29310. | 36674. | 29061. | 37619. | 27905. | 34699. | 24484. | 36993. | 24004. |
| 0.15083 | 30765. | 28585. | 34635. | 28932. | 35594. | 28025. | 33028. | 24211. | 34867. | 24278. |
| 0.22625 | 29335. | 27733. | 32760. | 28464. | 33705. | 27751. | 31404. | 23840. | 32889. | 24252. |
| 0.30167 | 27905. | 26881. | 30884. | 27995. | 31815. | 27477. | 29779. | 23470. | 30911. | 24227. |
| 0.37708 | 26579. | 25934. | 2[illegible]203. | 27249. | 30088. | 26865. | 28250. | 22973. | 29112. | 23872. |
| 0.45250 | 25271. | 24970. | 27555. | 26455. | 28388. | 26197. | 26736. | 22454. | 27344. | 23462. |
| 0.52792 | 23990. | 29004. | 25945. | 25632. | 26721. | 25488. | 25249. | 21917. | 25613. | 23009. |
| 0.60333 | 22855. | 23021. | 24543. | 24648. | 25236. | 24562. | 23904. | 21279. | 24083. | 22327. |
| 0.67875 | 21721. | 22037. | 23141. | 23665. | 23751. | 23637. | 22558. | 20640. | 22553. | 21645. |
| 0.75417 | 20586. | 21054. | 21738. | 22681. | 22265. | 22711. | 21212. | 20002. | 21023. | 20963. |
| 0.82958 | 19625. | 20127. | 20559. | 21635. | 20988. | 21669. | 20046. | 19285. | 19720. | 20123. |
| 0.90500 | 18677. | 19204. | 19397. | 20585. | 19727. | 20618. | 18894. | 18561. | 18435. | 19270. |
| 0.98042 | 17730. | 18281. | 18234. | 19534. | 18466. | 19567. | 17742. | 17838. | 17150. | 18417. |
| 1.0558 | 16794. | 17365. | 17087. | 18488. | 17219. | 18518. | 16602. | 17112. | 15881. | 17559. |
| 1.1313 | 16015. | 16554. | 16140. | 17504. | 16174. | 17494. | 15639. | 16347. | 14831. | 16635. |
| 1.2067 | 15237. | 15742. | 15194. | 16519. | 15129. | 16471. | 14677. | 15582. | 13781. | 15710. |
| 1.2821 | 14459. | 14931. | 14248. | 15535. | 14084. | 15447. | 13714. | 14818. | 12731. | 14786. |
| 1.3575 | 13681. | 14120. | 13301. | 14550. | 13039. | 14423. | 12751. | 14053. | 11681. | 13861. |
| 1.4329 | 12963. | 13364. | 12434. | 13626. | 12080. | 13453. | 11861. | 13293. | 10725. | 12957. |
| 1.5083 | 12317. | 12675. | 11663. | 12775. | 11225. | 12546. | 11060. | 12537. | 9882.1 | 12078. |
| 1.5838 | 11671. | 11986. | 10893. | 11924. | 10371. | 11640. | 10259. | 11781. | 9039.6 | 11199. |
| 1.6592 | 11024. | 11298. | 10122. | 11073. | 9516.4 | 10734. | 9457.9 | 11025. | 8197.0 | 10320. |
| 1.7346 | 10378. | 10609. | 9351.3 | 10223. | 8662.0 | 9827.5 | 8656.7 | 10269. | 7354.5 | 9440.6 |
| 1.8100 | 9732.1 | 9920.7 | 8580.6 | 9371.7 | 7807.6 | 8921.3 | 7855.5 | 9512.7 | 6512.0 | 8561.4 |
| 1.8854 | 9165.9 | 9324.9 | 7929.3 | 8654.4 | 7096.2 | 8152.8 | 7170.5 | 8806.9 | 5823.9 | 7788.4 |
| 1.9608 | 8605.5 | 8735.8 | 7286.7 | 7946.7 | 6395.2 | 7394.4 | 6493.9 | 8104.7 | 5147.1 | 7023.2 |
| 2.0363 | 8045.1 | 8146.8 | 6644.2 | 7239.1 | 5694.2 | 6636.0 | 5817.4 | 7402.6 | 4470.2 | 6258.0 |
| 2.1117 | 7484.7 | 7557.7 | 6001.6 | 6531.4 | 4993.1 | 5877.6 | 5140.8 | 6700.4 | 3793.4 | 5492.7 |
| 2.1871 | 6924.3 | 6968.7 | 5359.0 | 5823.8 | 4292.1 | 5119.1 | 4464.2 | 5998.3 | 3116.6 | 4727.5 |
| 2.2625 | 6364.0 | 6379.6 | 4716.4 | 5116.1 | 3591.1 | 4360.7 | 3787.6 | 5296.1 | 2439.7 | 3962.2 |
| 2.3379 | 5817.4 | 5809.8 | 4101.4 | 4446.0 | 2927.2 | 3646.5 | 3141.6 | 4621.4 | 1801.8 | 3240.9 |
| 2.4133 | 5298.5 | 5278.8 | 3541.9 | 3851.4 | 2338.1 | 3021.5 | 2557.3 | 4001.7 | 1242.3 | 2608.1 |
| 2.4888 | 4779.7 | 4747.9 | 2982.5 | 3256.9 | 1749.0 | 2396.4 | 1973.0 | 3382.1 | 682.80 | 1975.2 |
| 2.5642 | 4260.8 | 4216.9 | 2423.0 | 2662.3 | 1159.9 | 1771.3 | 1388.6 | 2762.5 | 123.29 | 1342.4 |
| 2.6396 | 3742.0 | 3685.9 | 1863.6 | 2067.8 | 570.87 | 1146.2 | 804.30 | 2142.9 | -436.22 | 709.58 |
| 2.7150 | 3223.1 | 3154.9 | 1304.1 | 1473.2 | -18.216 | 521.15 | 219.97 | 1523.3 | -995.73 | 76.749 |
| 2.7904 | 2704.3 | 2623.9 | 744.70 | 878.67 | -607.30 | -103.92 | -364.37 | 903.71 | -1555.2 | -556.08 |
| 2.8658 | 2185.4 | 2093.0 | 185.25 | 284.12 | -1196.4 | -728.99 | -948.70 | 284.10 | -2114.7 | -1188.9 |
| 2.9413 | 1662.7 | 1563.1 | -359.65 | -285.14 | -1757.8 | -1315.6 | -1507.0 | -301.31 | -2647.8 | -1776.5 |
| 3.0167 | 1135.1 | 1034.6 | -885.92 | -822.01 | -2283.7 | -1852.9 | -2031.9 | -842.94 | -3147.0 | -2306.1 |
| 3.0921 | 607.56 | 506.11 | -1412.2 | -1358.9 | -2809.6 | -2390.2 | -2556.9 | -1384.6 | -3646.1 | -2835.7 |
| 3.1675 | 79.977 | -22.368 | -1938.5 | -1895.7 | -3335.5 | -2927.6 | -3081.9 | -1926.2 | -4145.3 | -3365.3 |
| 3.2429 | -447.61 | -550.85 | -2464.7 | -2432.6 | -3861.5 | -3464.9 | -3606.8 | -2467.8 | -4644.5 | -3894.9 |
| 3.3183 | -975.19 | -1079.3 | -2991.0 | -2969.5 | -4387.4 | -4002.2 | -4131.8 | -3009.5 | -5143.6 | -4424.5 |
| 3.3938 | -1502.8 | -1607.8 | -3517.3 | -3506.3 | -4913.3 | -4539.5 | -4656.7 | -3551.1 | -5642.8 | -4954.1 |
| 3.4692 | -2030.4 | -2136.3 | -4043.6 | -4043.2 | -5439.2 | -5076.8 | -5181.7 | -4092.7 | -6142.0 | -5483.7 |
| 3.5446 | -2558.0 | -2664.8 | -4569.8 | -4580.1 | -5965.2 | -5614.2 | -5706.6 | -4634.4 | -6641.2 | -6013.3 |
| 3.6200 | -3085.5 | -3193.2 | -5096.1 | -5116.9 | -6491.1 | -6151.5 | -6231.6 | -5176.0 | -7140.3 | -6543.0 |

**Table 6-12. Girth Weld Axial Stress Contributions, Bounding Faulted Event**

| Location | | Axial Stress (psi) | | |
|---|---|---|---|---|
| | | Membrane | Membrane + Bending | Total |
| t=0 | Inside | 12,130 | 28,380 | 30,530 |
| | Midsurface | 12,130 | 12,240 | 11,520 |
| | Outside | 12,130 | -3,904 | -2,975 |
| t=60 | Inside | 44 | 56,010 | 122,400 |
| | Midsurface | 44 | 418 | -20,870 |
| | Outside | 44 | -55,170 | -25,250 |
| t=196 | Inside | 40 | 60,810 | 83,340 |
| | Midsurface | 40 | 446 | -11,790 |
| | Outside | 40 | -59,920 | -37,180 |
| t=347 | Inside | 25 | 42,060 | 56,800 |
| | Midsurface | 25 | 306 | -7,828 |
| | Outside | 25 | -41,450 | -25,660 |

nsgen5.5

**Table 6-13. Girth Weld Axial Stress Detail, Bounding Faulted Event**

| Distance (in) Inside to Outside | Axial Stress (psi) | | | |
|---|---|---|---|---|
| | t=0 sec | t=60 | t=196 | t=347 sec |
| 0. | 30529. | 0.12239E+06 | 83342. | 56795. |
| 0.75417E-01 | 29522. | 0.10949E+06 | 78340. | 53441. |
| 0.15083 | 28521. | 96760. | 73345. | 50093. |
| 0.22625 | 27560. | 85410. | 68417. | 46802. |
| 0.30167 | 26599. | 74061. | 63488. | 43512. |
| 0.37708 | 25691. | 64459. | 58775. | 40350. |
| 0.45250 | 24792. | 55153. | 54097. | 37210. |
| 0.52792 | 23903. | 46170. | 49467. | 34100. |
| 0.60333 | 23069. | 38939. | 45090. | 31153. |
| 0.67875 | 22235. | 31709. | 40713. | 28206. |
| 0.75417 | 21401. | 24479. | 36337. | 25259. |
| 0.82958 | 20628. | 19181. | 32299. | 22528. |
| 0.90500 | 19860. | 14033. | 28287. | 19813. |
| 0.98042 | 19091. | 8885.6 | 24275. | 17099. |
| 1.0558 | 18327. | 3863.5 | 20296. | 14404. |
| 1.1313 | 17618. | 572.52 | 16759. | 11978. |
| 1.2067 | 16910. | -2718.4 | 13221. | 9552.6 |
| 1.2821 | 16202. | -6009.4 | 9683.9 | 7126.9 |
| 1.3575 | 15493. | -9300.3 | 6146.6 | 4701.2 |
| 1.4329 | 14808. | -11914. | 2881.6 | 2443.3 |
| 1.5083 | 14151. | -13706. | -52.954 | 389.10 |
| 1.5838 | 13494. | -15498. | -2987.5 | -1665.1 |
| 1.6592 | 12837. | -17291. | -5922.1 | -3719.4 |
| 1.7346 | 12179. | -19083. | -8856.7 | -5773.6 |
| 1.8100 | 11522. | -20875. | -11791. | -7827.8 |
| 1.8854 | 10901. | -21670. | -14009. | -9413.8 |
| 1.9608 | 10282. | -22393. | -16176. | -10966. |
| 2.0363 | 9663.3 | -23116. | -18342. | -12517. |
| 2.1117 | 9044.6 | -23839. | -20508. | -14069. |
| 2.1871 | 8425.9 | -24562. | -22674. | -15621. |
| 2.2625 | 7807.2 | -25285. | -24840. | -17173. |
| 2.3379 | 7196.4 | -25809. | -26697. | -18507. |
| 2.4133 | 6601.5 | -25932. | -27933. | -19402. |
| 2.4888 | 6006.7 | -26055. | -29170. | -20297. |
| 2.5642 | 5411.8 | -26178. | -30406. | -21192. |
| 2.6396 | 4816.9 | -26301. | -31642. | -2[illegible]8. |
| 2.7150 | 4222.1 | -26424. | -32878. | -22983. |
| 2.7904 | 3627.2 | -26547. | -34114. | -23878. |
| 2.8658 | 3032.4 | -26670. | -35350. | -24773. |
| 2.9413 | 2434.8 | -26670. | -36097. | -25294. |
| 3.0167 | 1833.6 | -26513. | -36217. | -25335. |
| 3.0921 | 1232.5 | -26355. | -36337. | -25376. |
| 3.1675 | 631.38 | -26198. | -36457. | -25417. |
| 3.2429 | 30.248 | -26040. | -36578. | -25458. |
| 3.3183 | -570.88 | -25883. | -36698. | -25499. |
| 3.3938 | -1172.0 | -25725. | -36818. | -25540. |
| 3.4692 | -1773.1 | -25568. | -36938. | -25581. |
| 3.5446 | -2374.3 | -25410. | -37058. | -25622. |
| 3.6200 | -2975.4 | -25253. | -37178. | -25664. |

nsgen5.5

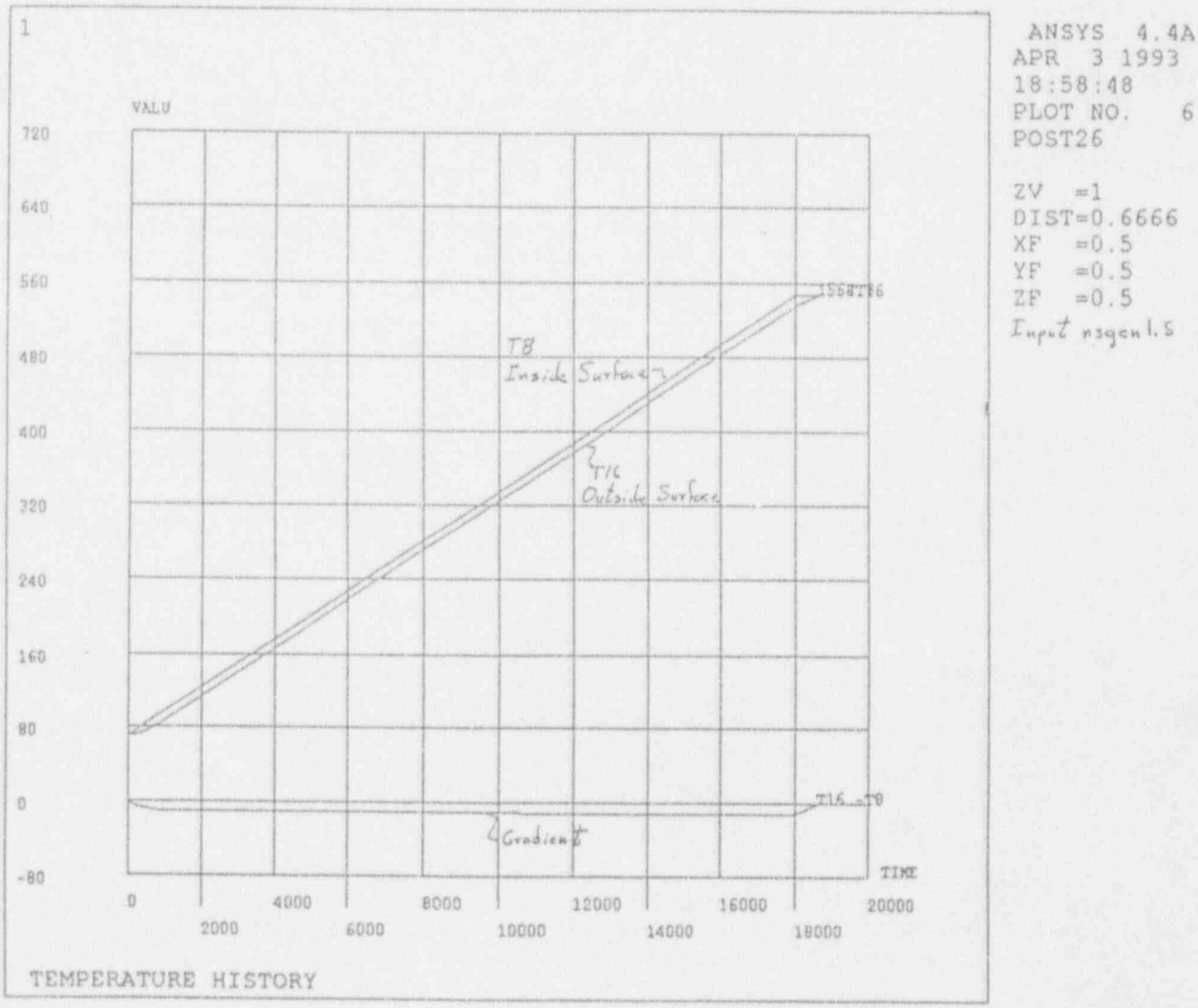



Figure 6-1. Heatup @ 100°F/hour, Temperature Transient

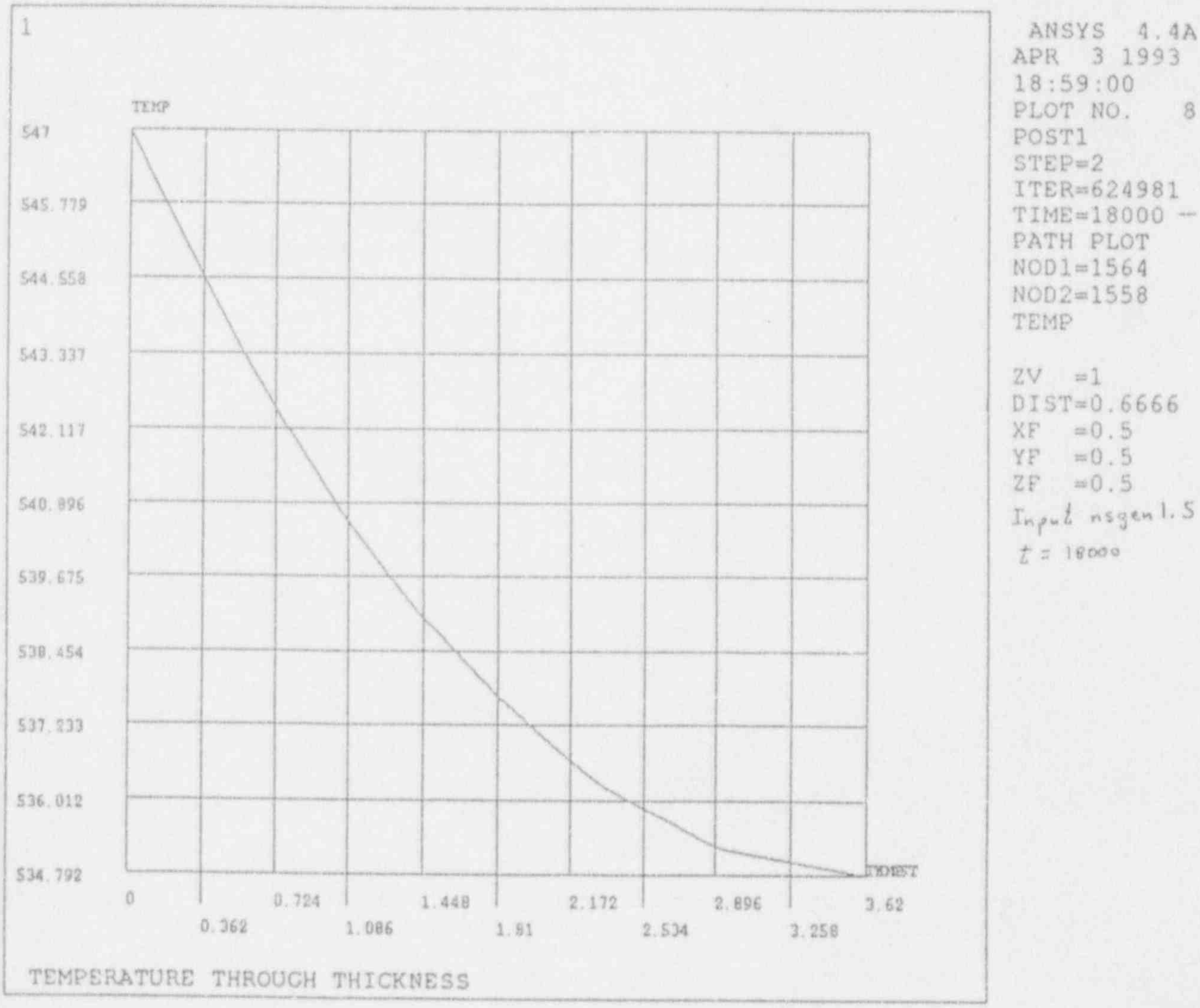



Figure 6-2. Heatup @ 100°F/hour, Temperature Profiles, t=18,000 sec.

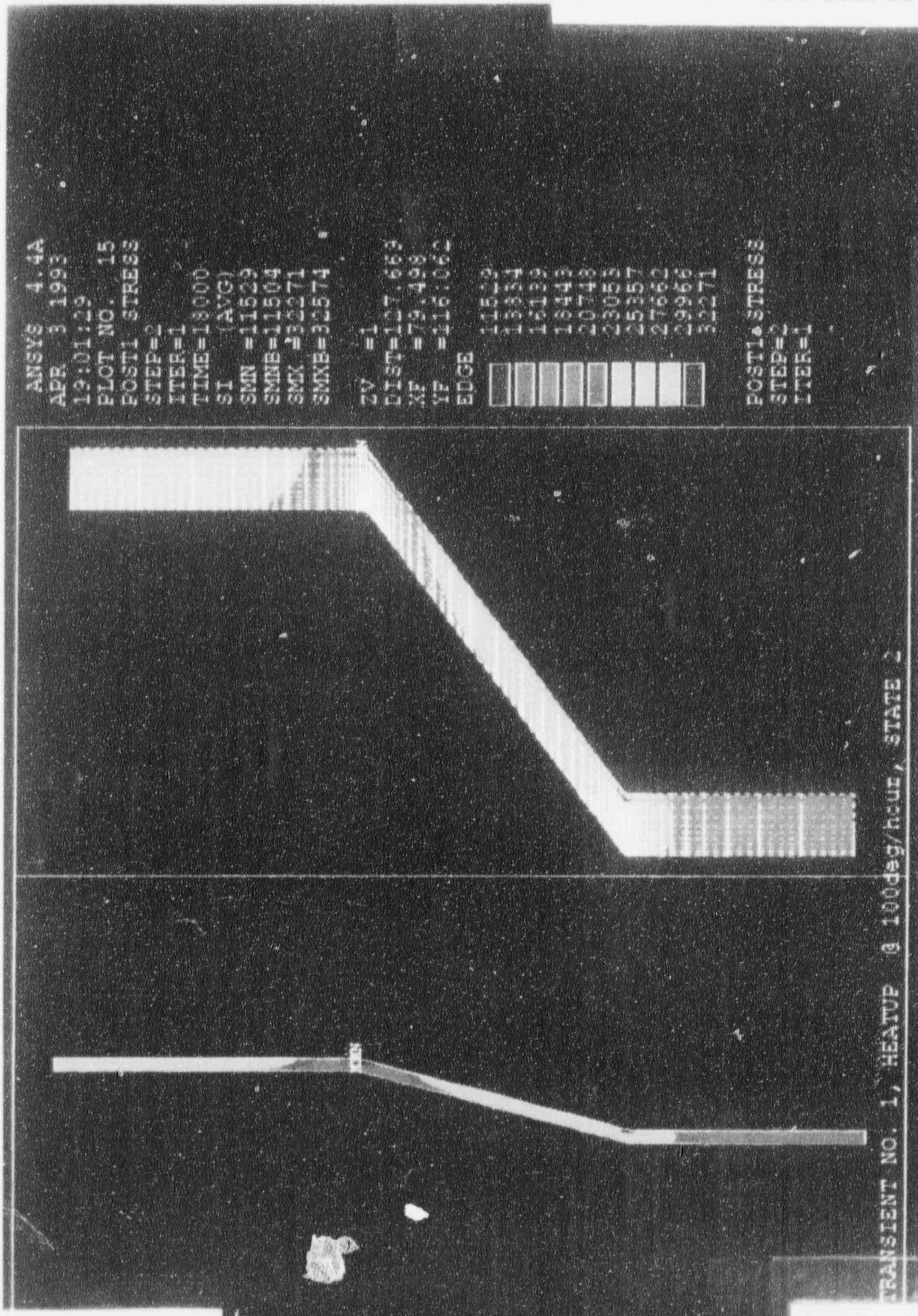



Figure 6-3. Heatup @ 100°F/Hour, Stress Intensity, t=18,000 sec

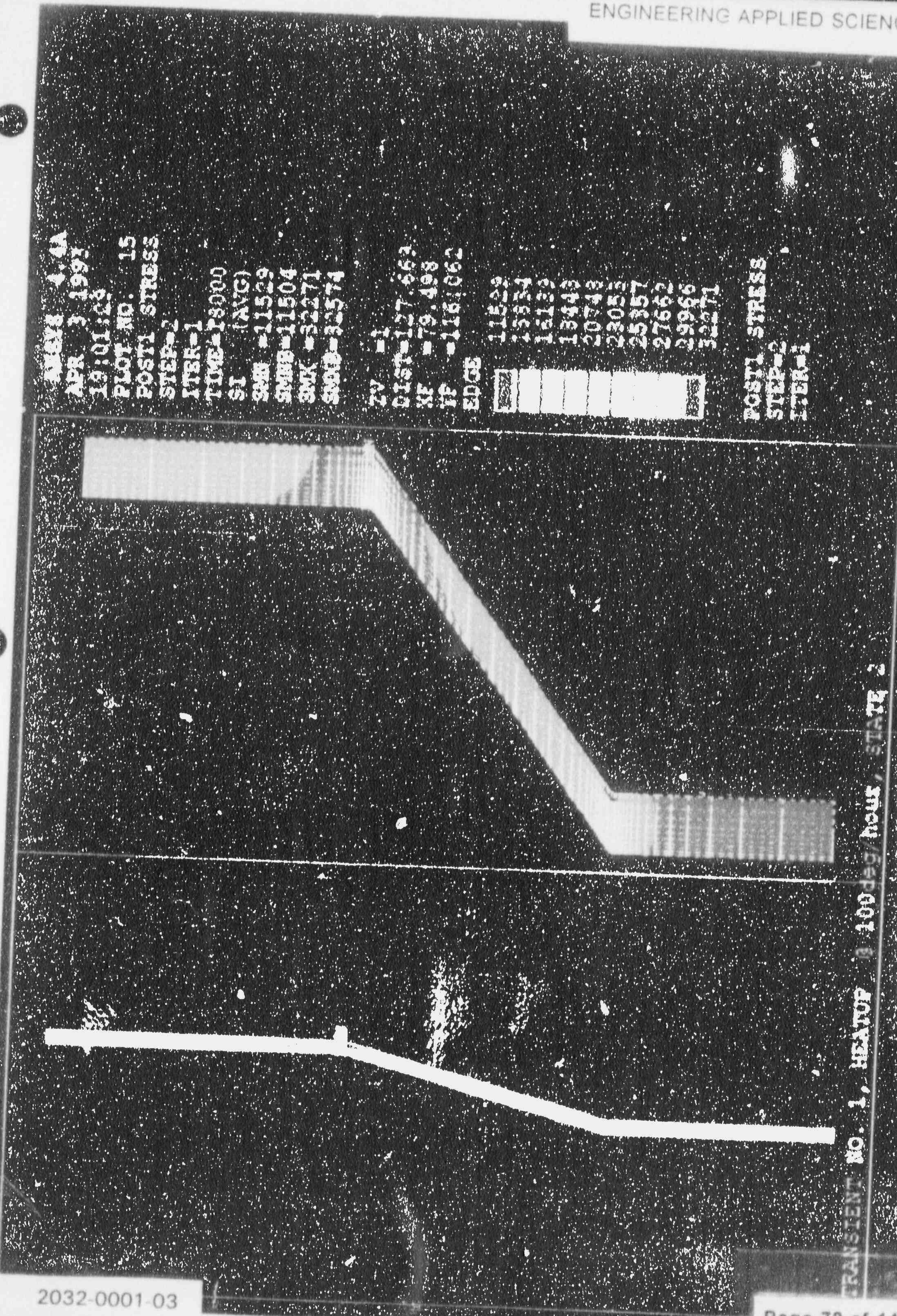



Figure 6-3. Heatup @ 100°F/Hour, Stress Intensity, t=18.000 sec

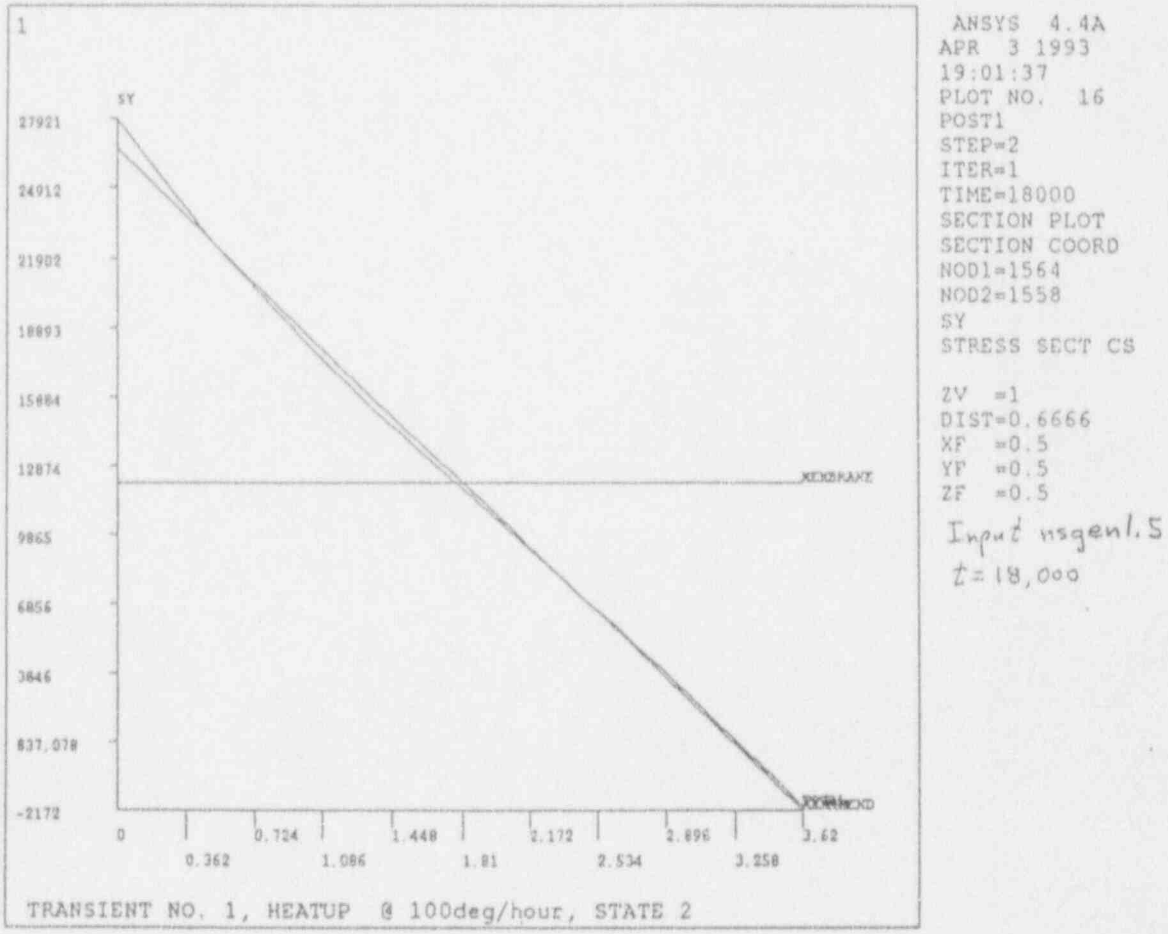



Figure 6-4. Heatup @ 100°F/hour, Axial Stress Contributions, t-18,000 sec.

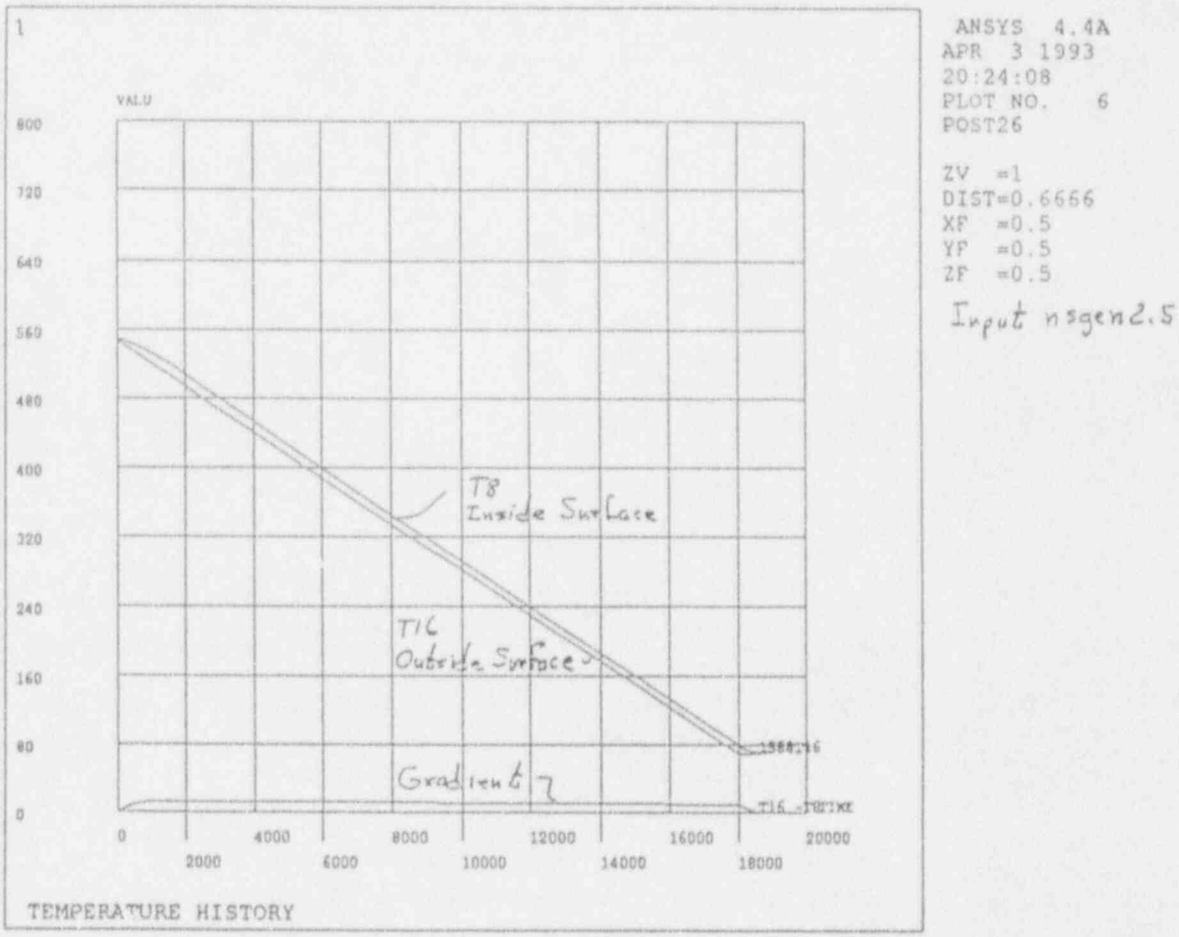



Figure 6-5. Cooldown @ 100°F/hour, Temperature Transient

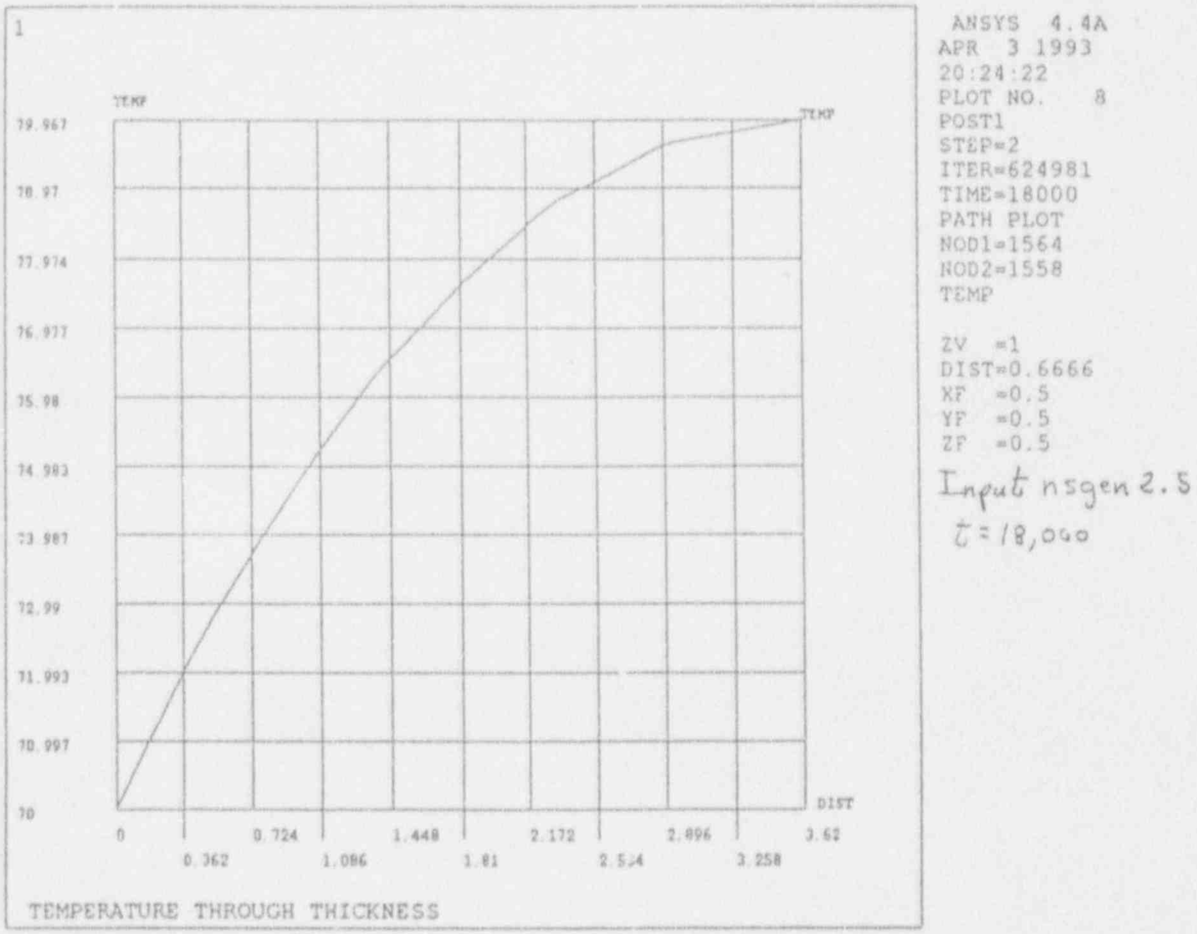



Figure 6-6. Cooldown @ 100°F/hour, Temperature Profiles, t=18,000 sec.

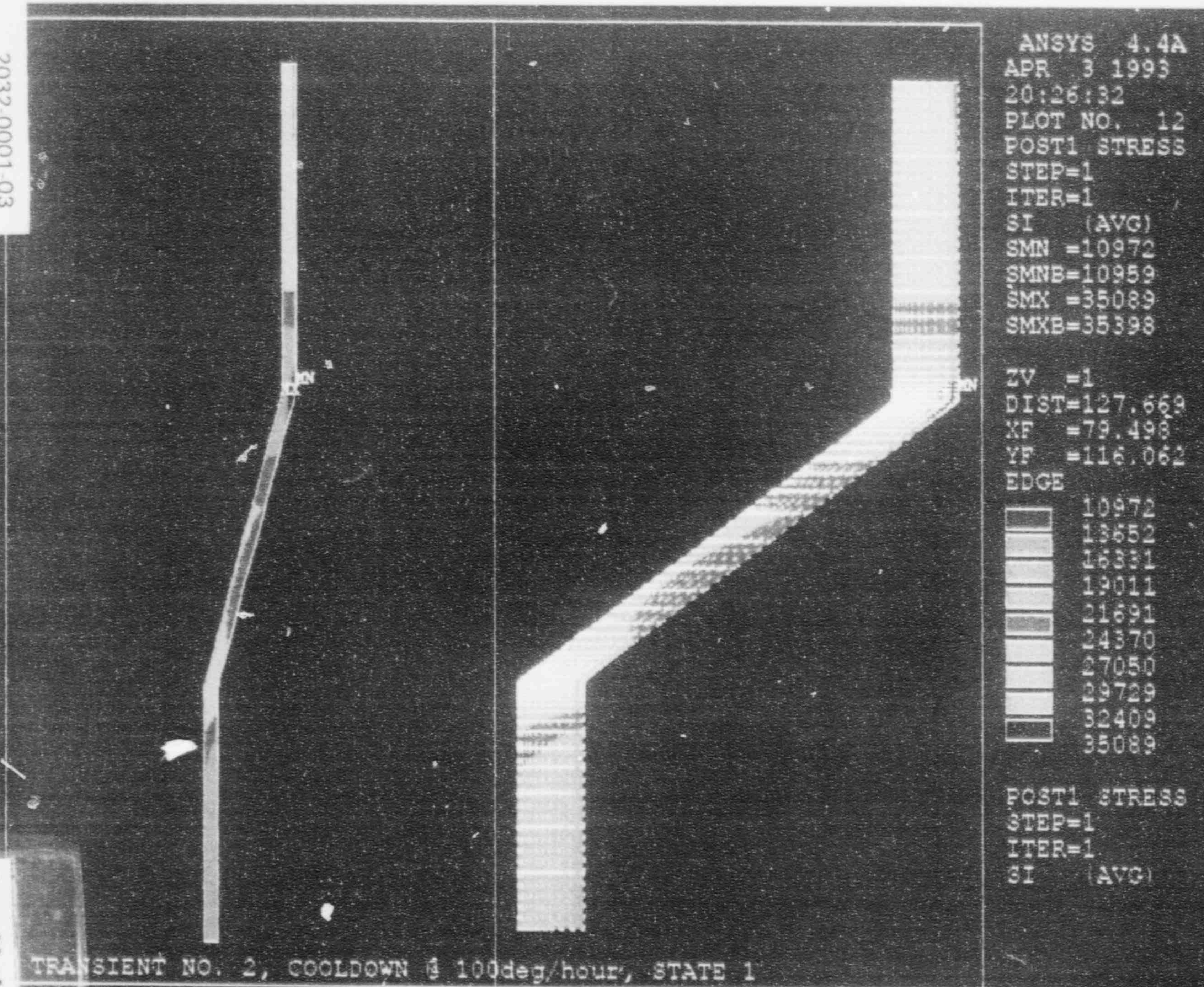



Figure 6-7. Cooldown @ 100°F/Hour, Stress Intensity, t=0 sec

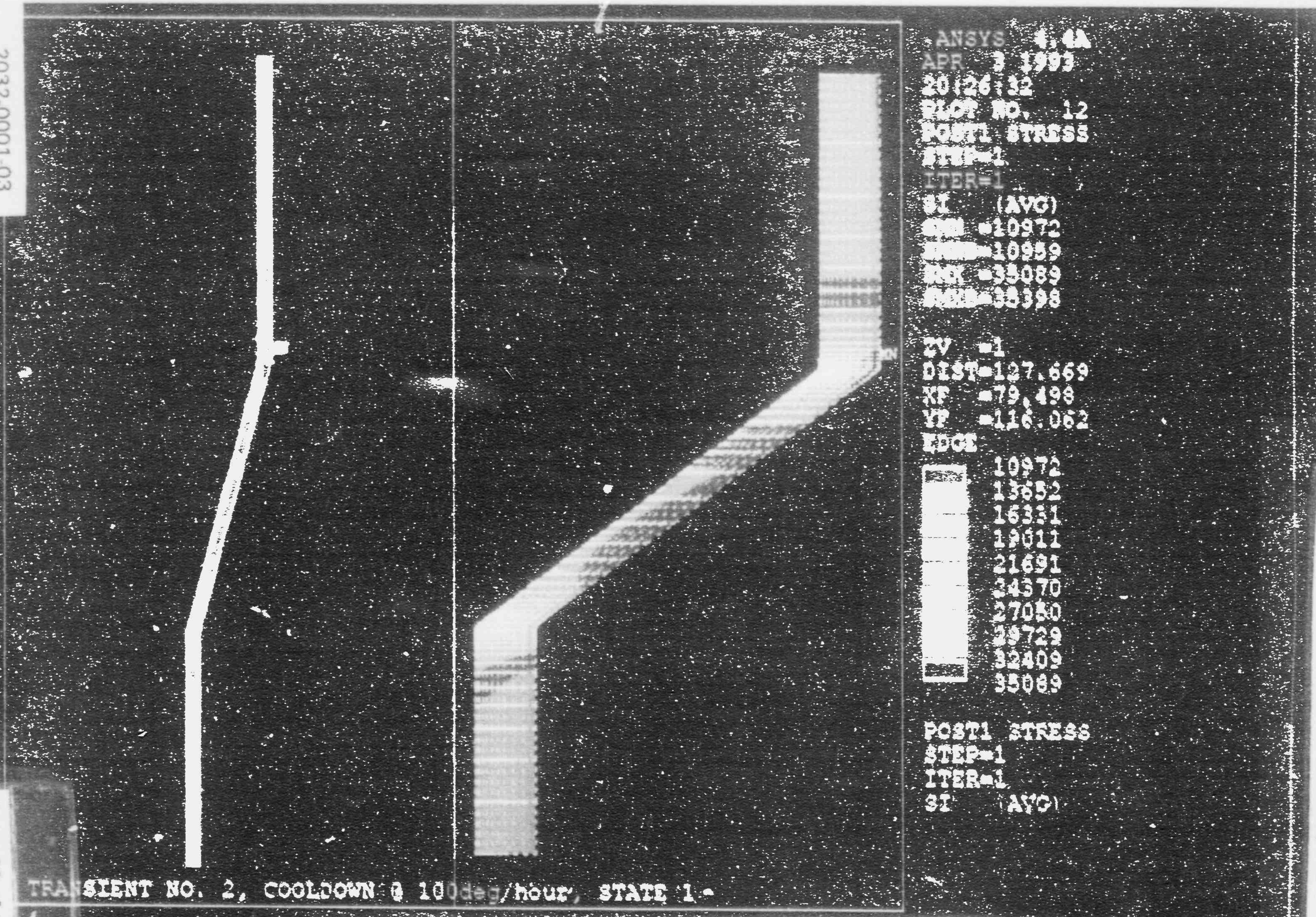
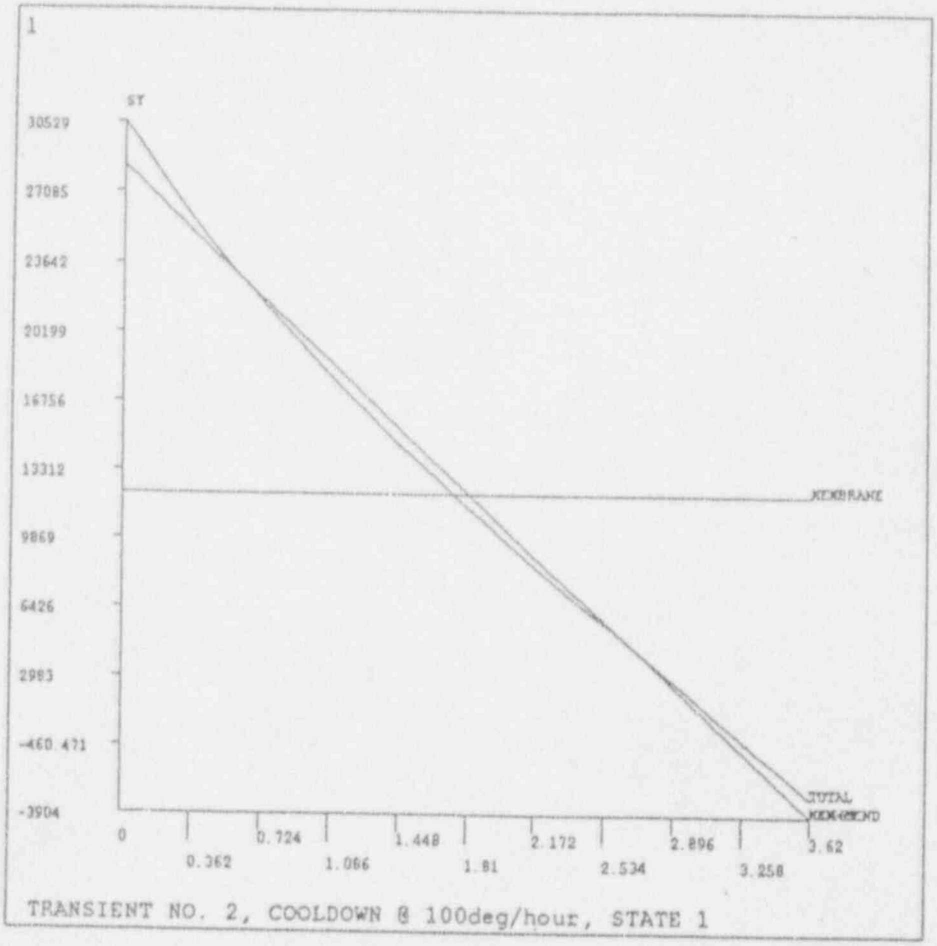



Figure 6-7. Cooldown @ 100°F/Hour, Stress Intensity, t=0 sec




ANSYS 4.4A
APR 3 1993
20:26:40
PLOT NO. 13
POST1
STEP=1
ITER=1
SECTION PLOT
SECTION COORD
NOD1=1564
NOD2=1558
SY
STRESS SECT CS

ZV =1
DIST=0.6666
XF =0.5
YF =0.5
ZF =0.5

Input nsgen2.5

Figure 6-8. Cooldown @ 100°F/hour, Axial Stress Contributions, t=0 sec.

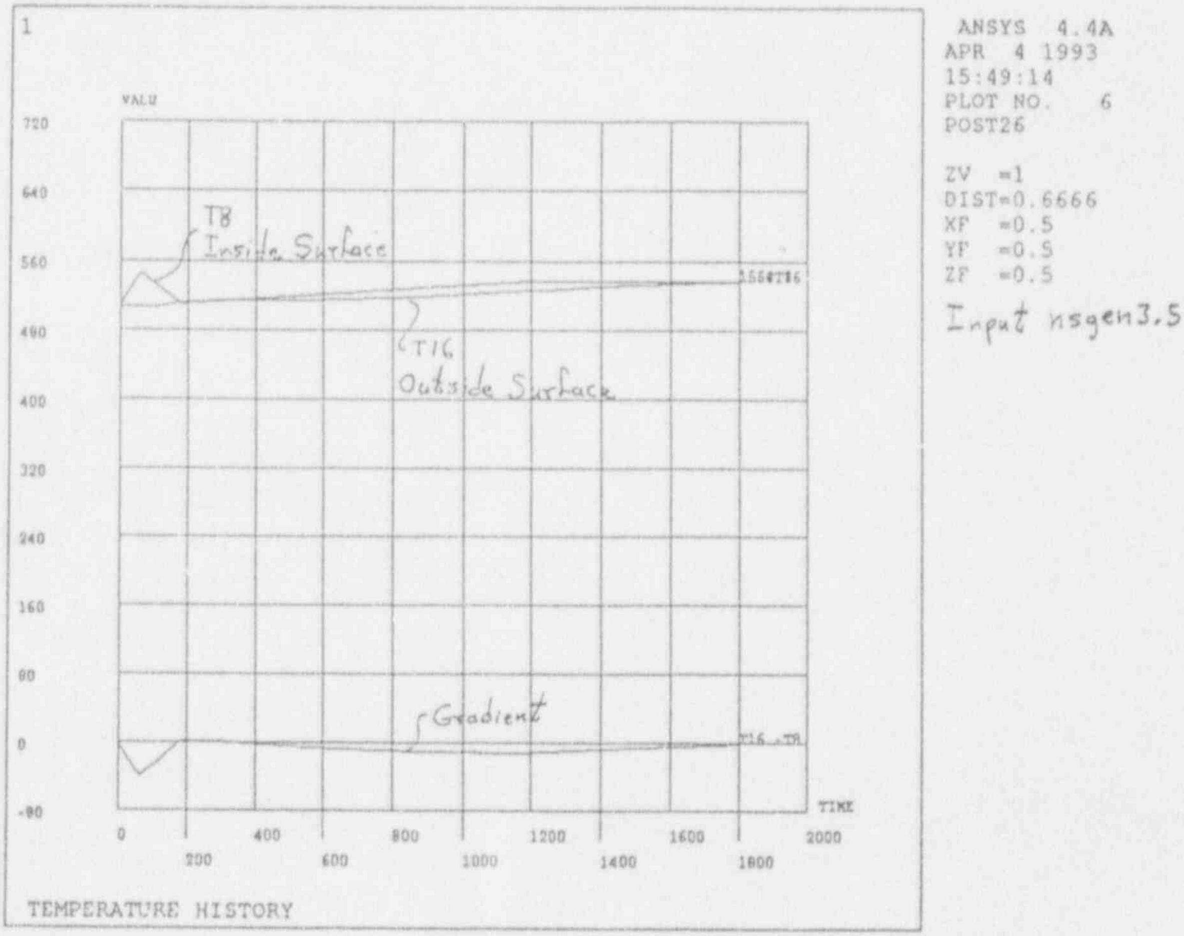



Figure 6-9. Large Step Load Decrease, Temperature Transient

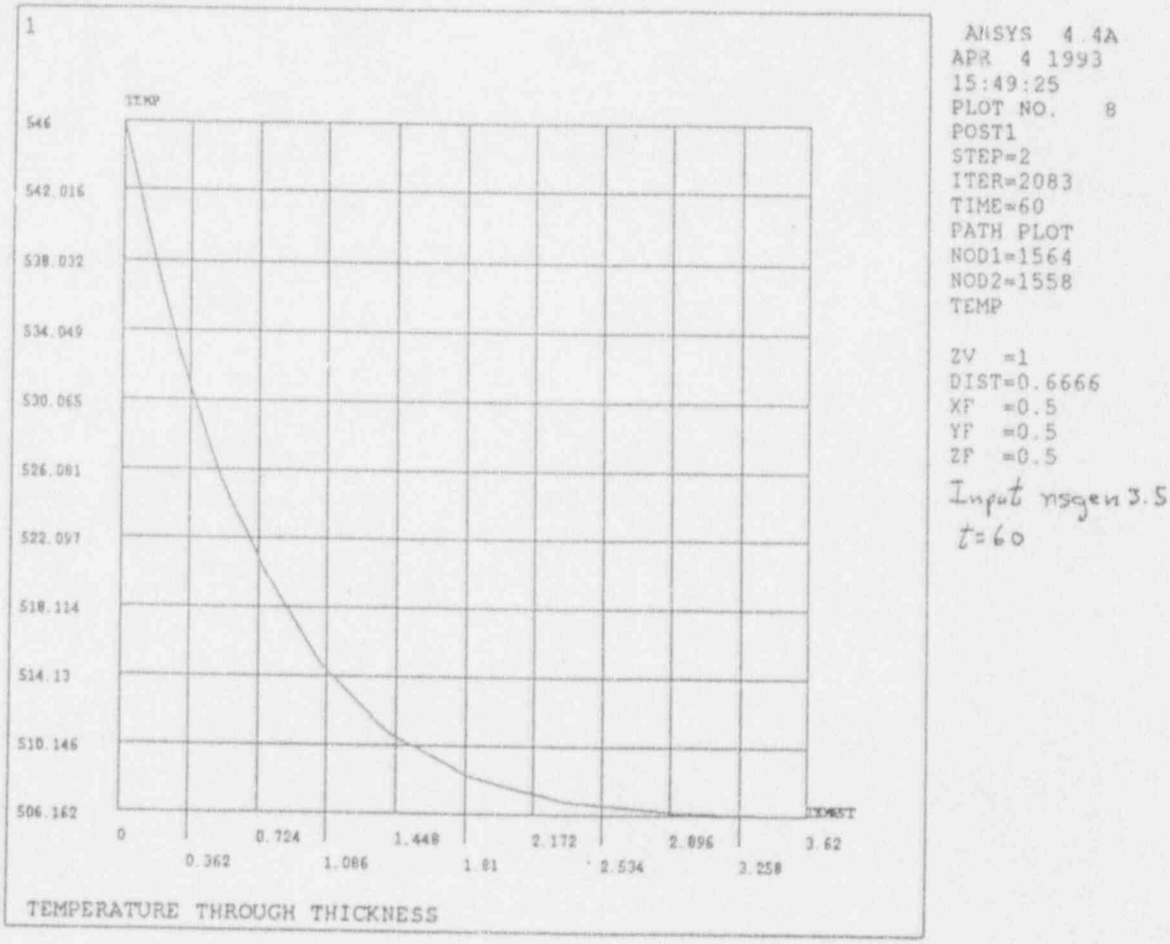



Figure 6-10. Large Step Load Decrease, Temperature Profiles, t=60 sec.

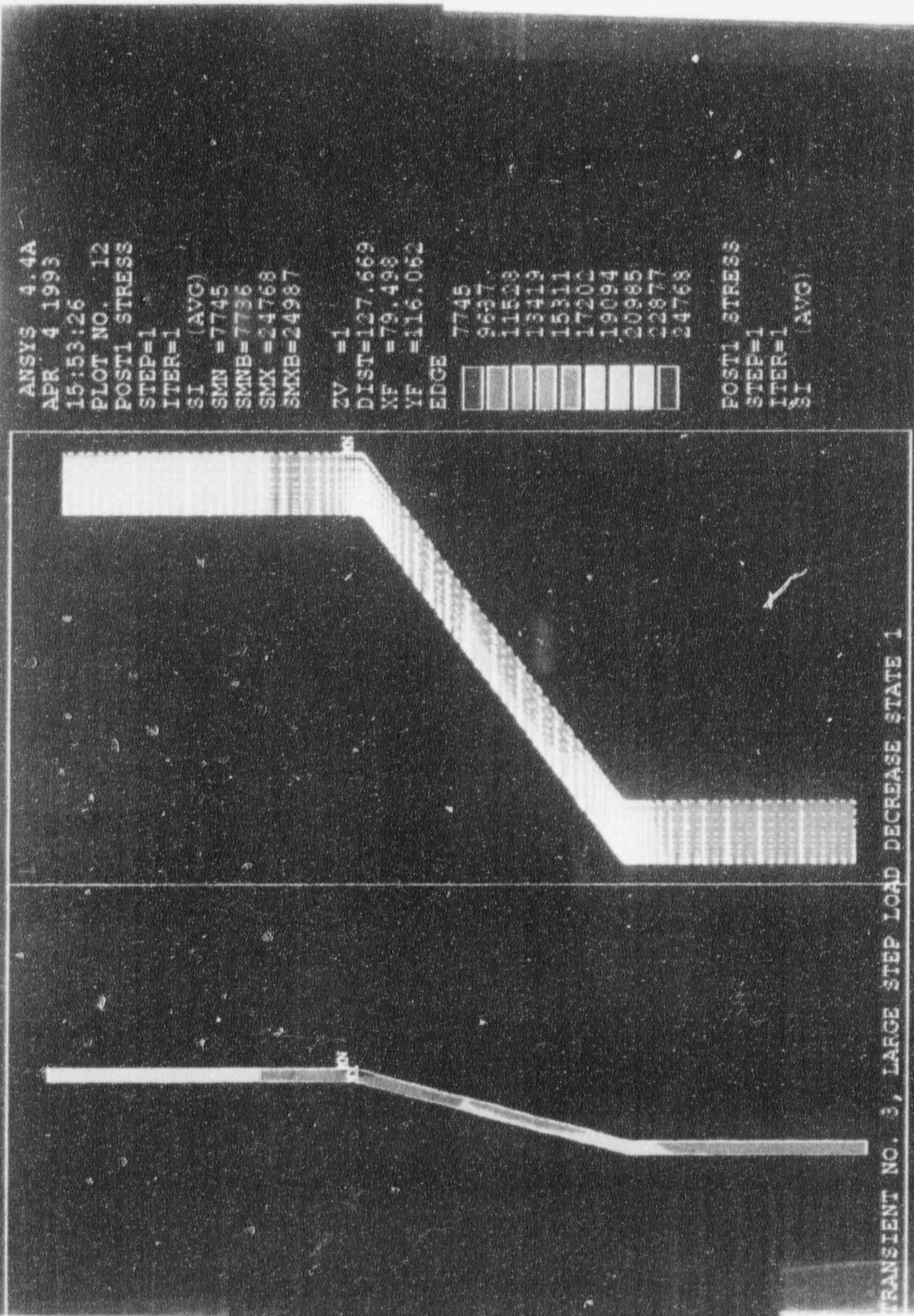



Figure 6-11 Large Step Load Decrease, Stress Intensity, t=0 sec

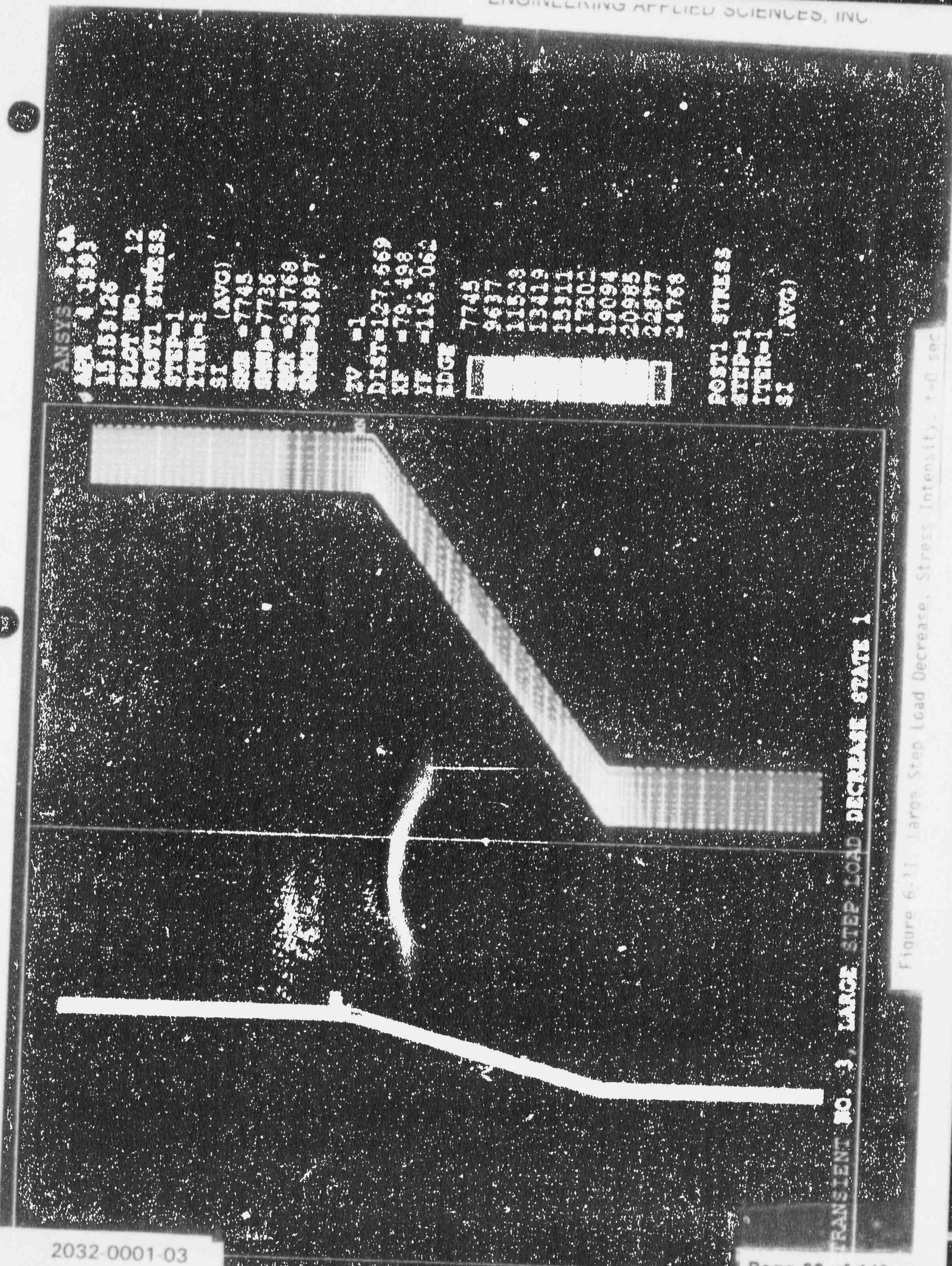



Figure 6-11. Large Step Load Decrease, Stress Intensity, t=0 sec

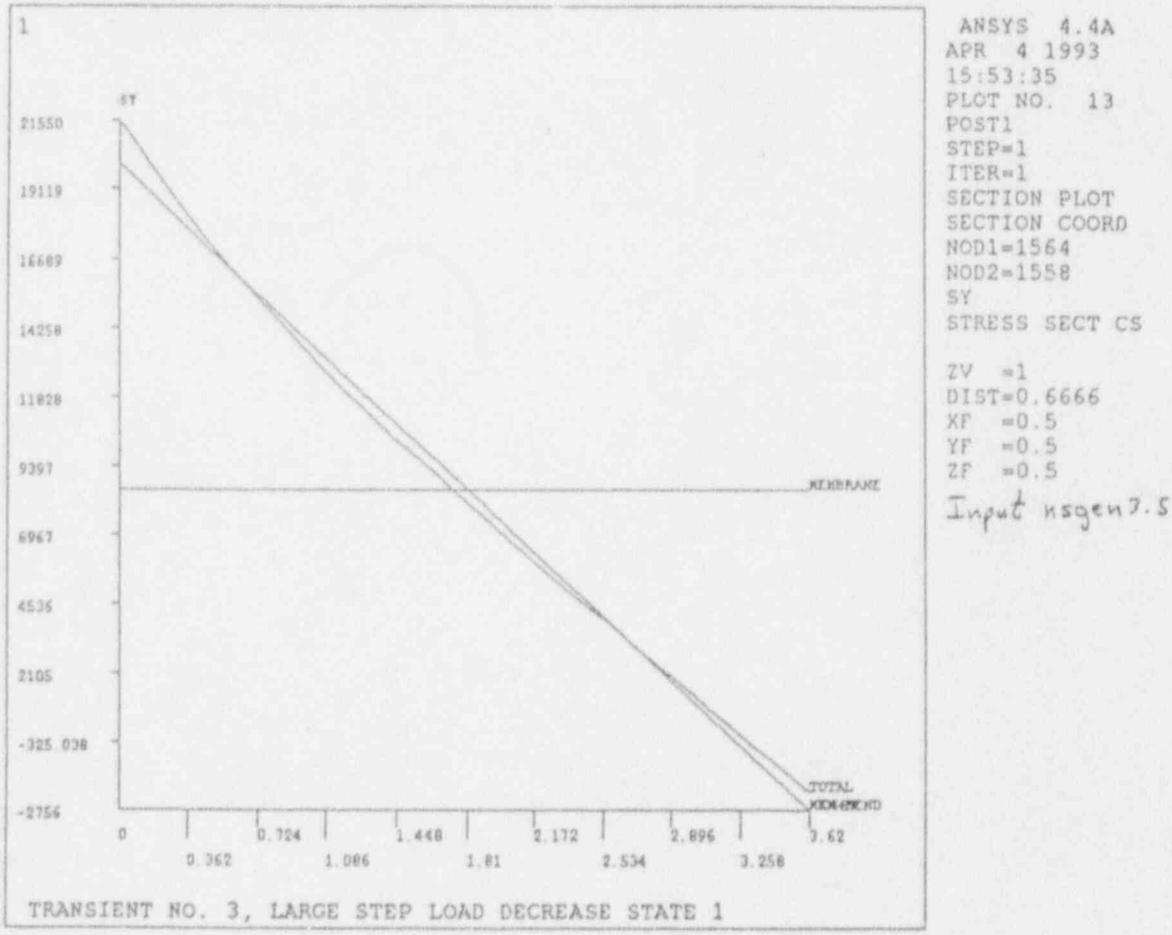



Figure 6-12. Large Step Load Decrease, Axial Stress Contributions, t=0 sec.

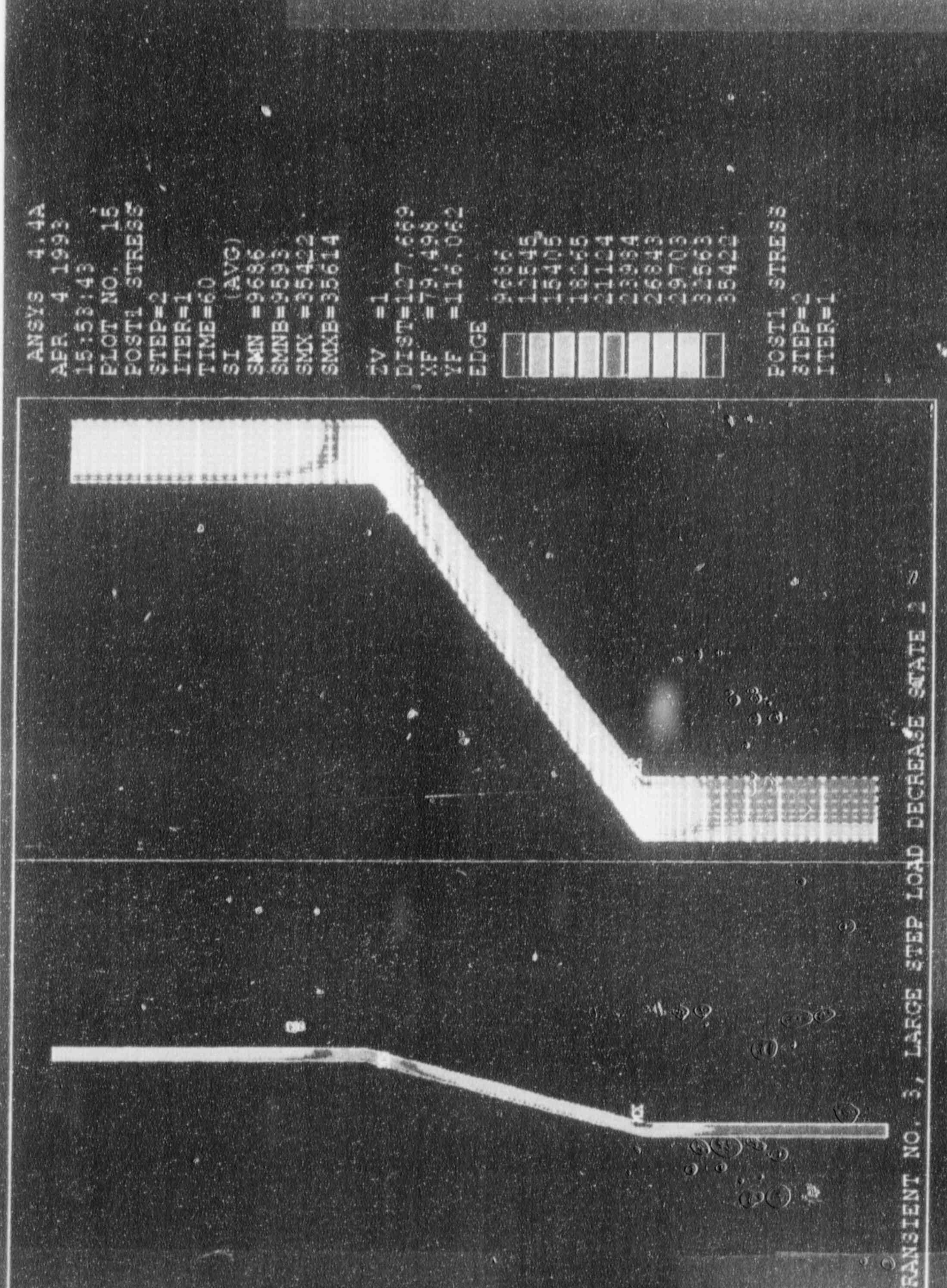



Figure 6-13. Large Step Load Decrease, Stress Intensity, t=60 sec

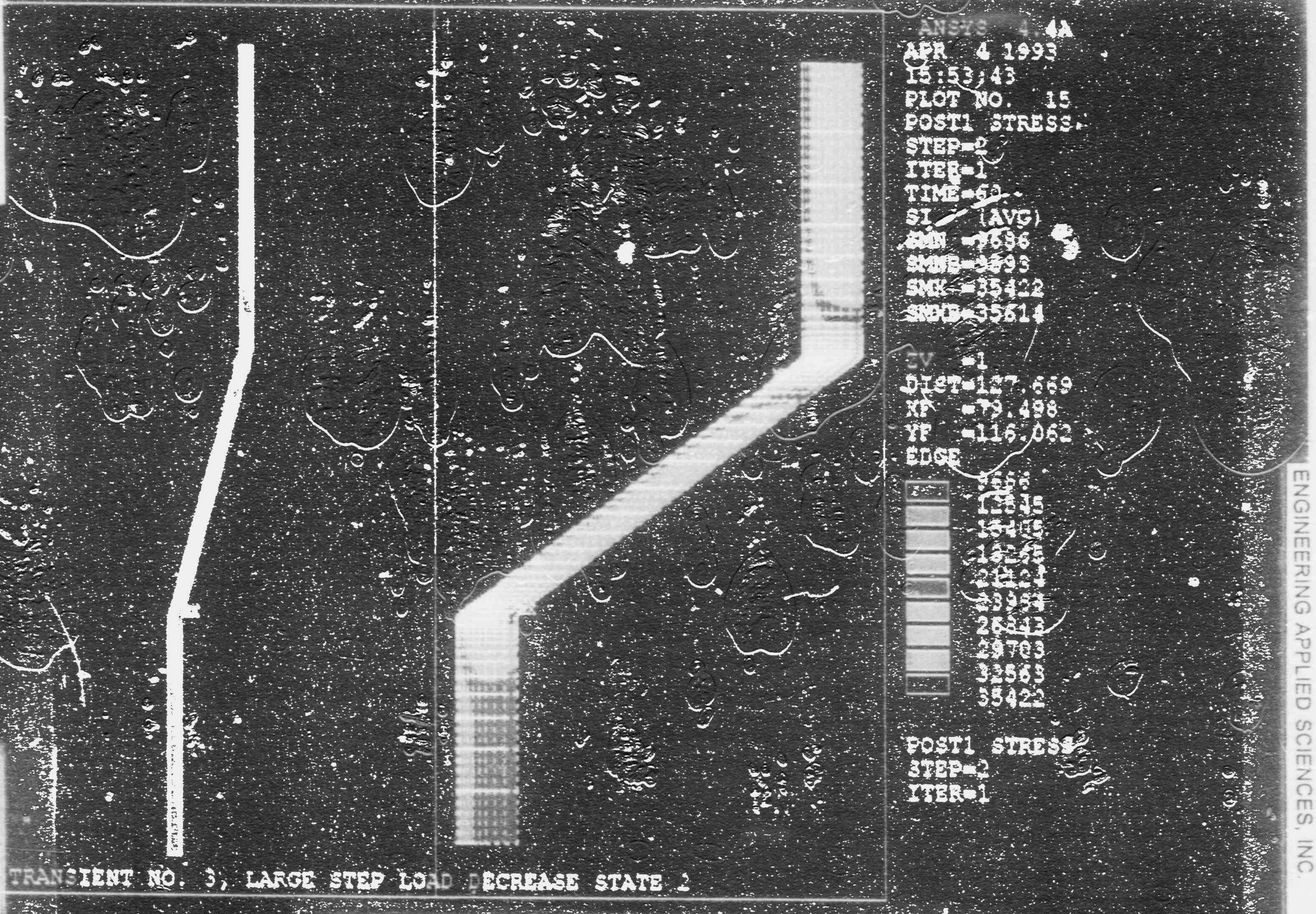



Figure 6-13. Large Step Load Decrease, Stress Intensity, t=60 sec

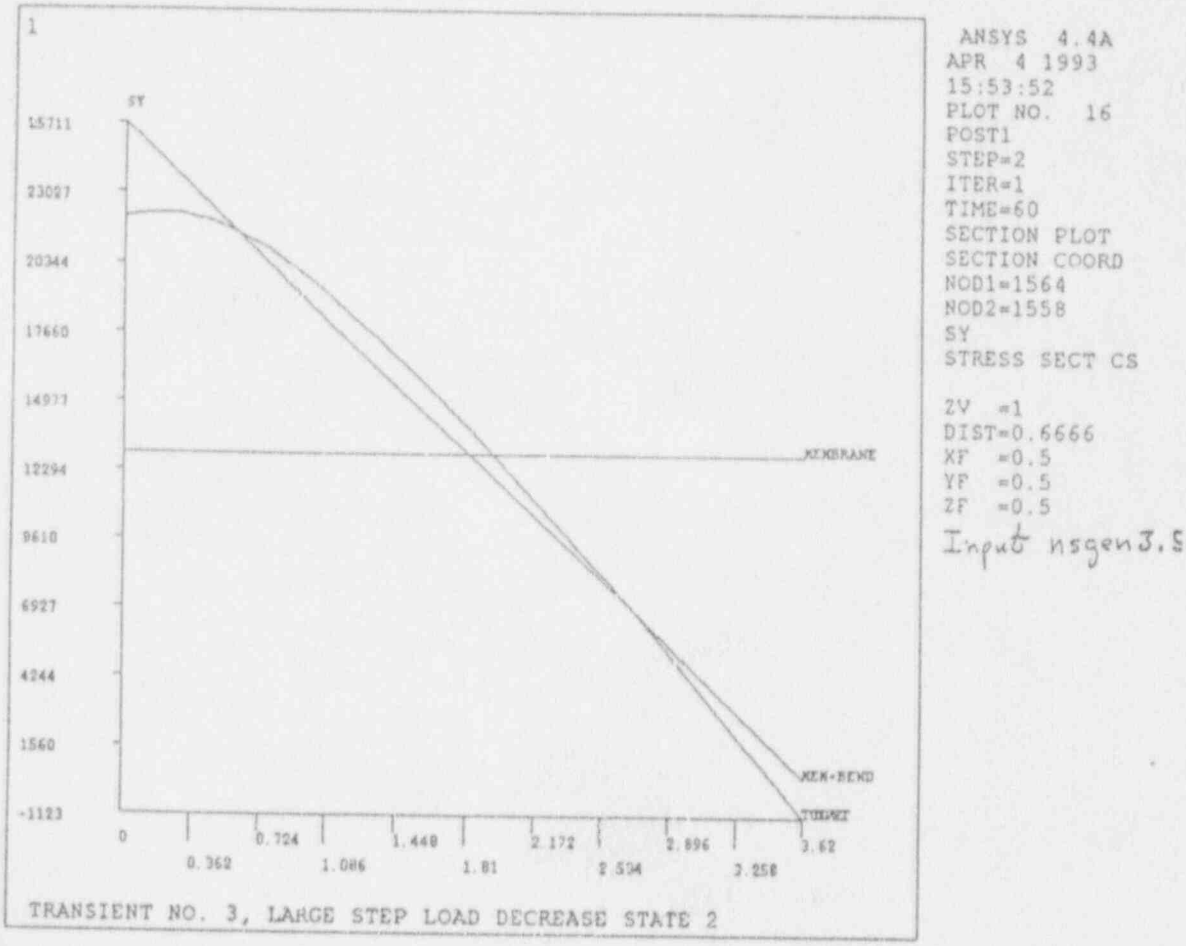



Figure 6-14. Large Step Load Decrease, Axial Stress Contributions, t=60 sec.

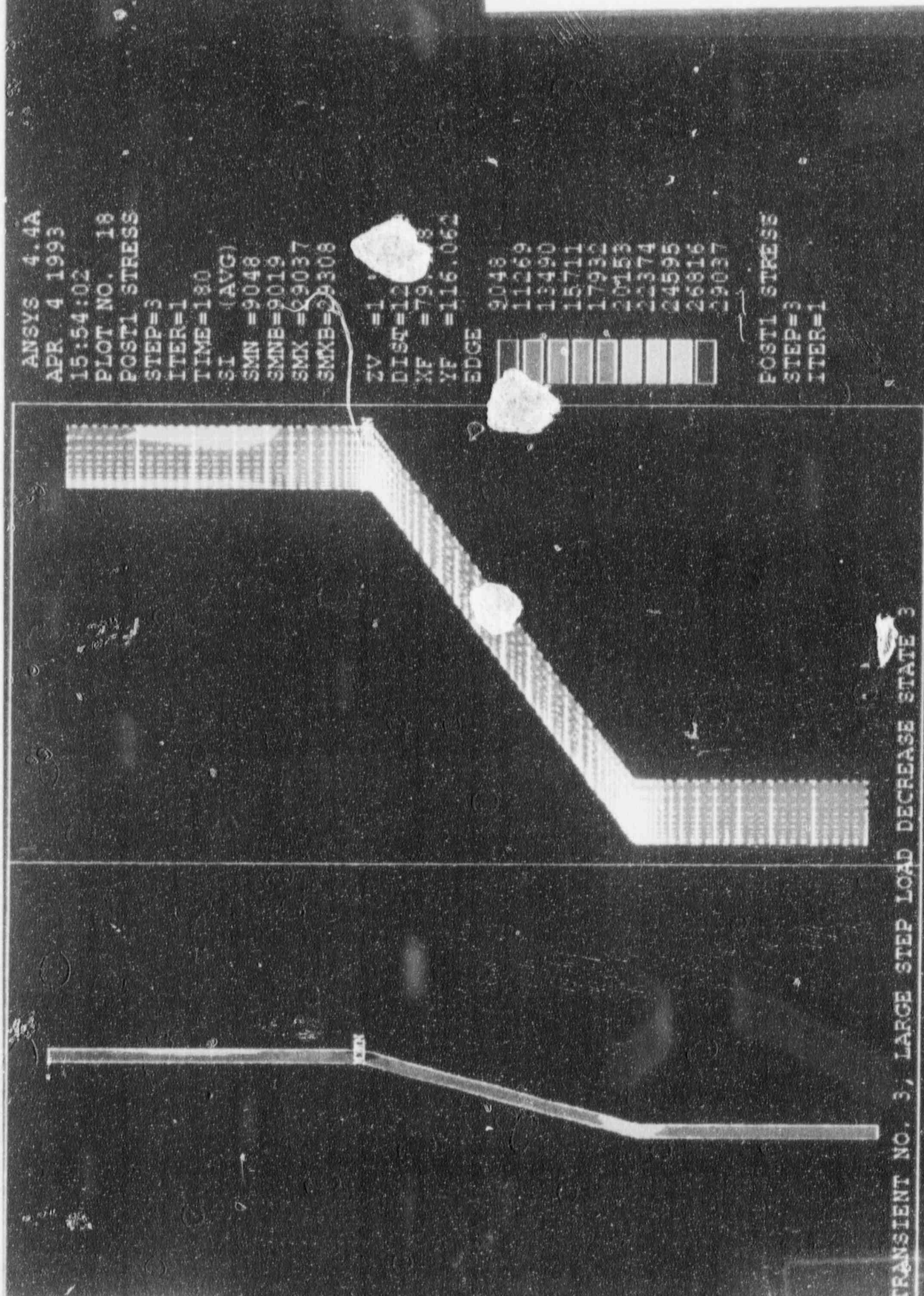



Figure 6-15. Large Step Load Decrease, Stress Intensity, t=180 sec

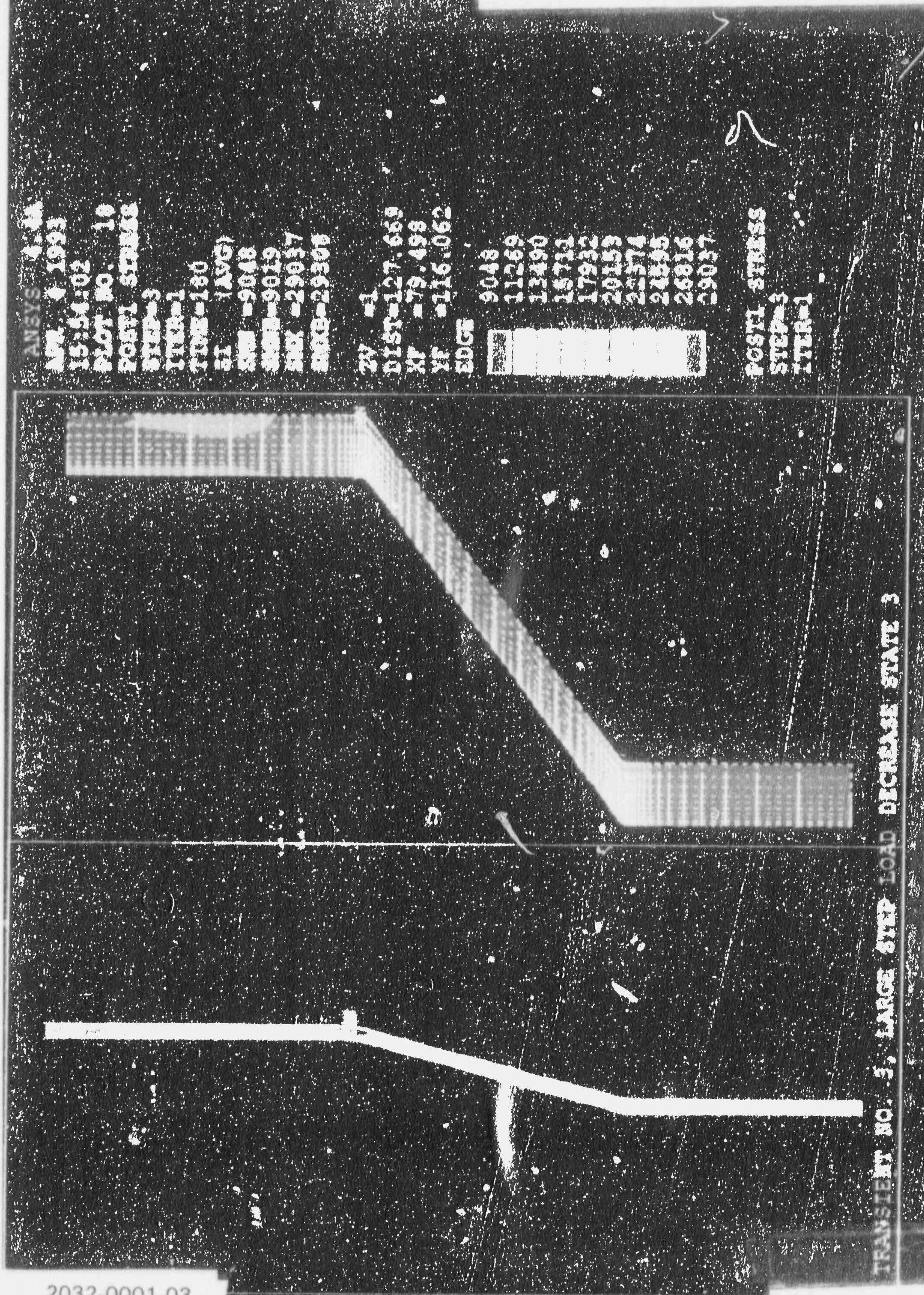



Figure 6-15. Large Step Load Decrease. Stress Intensity t=180 sec

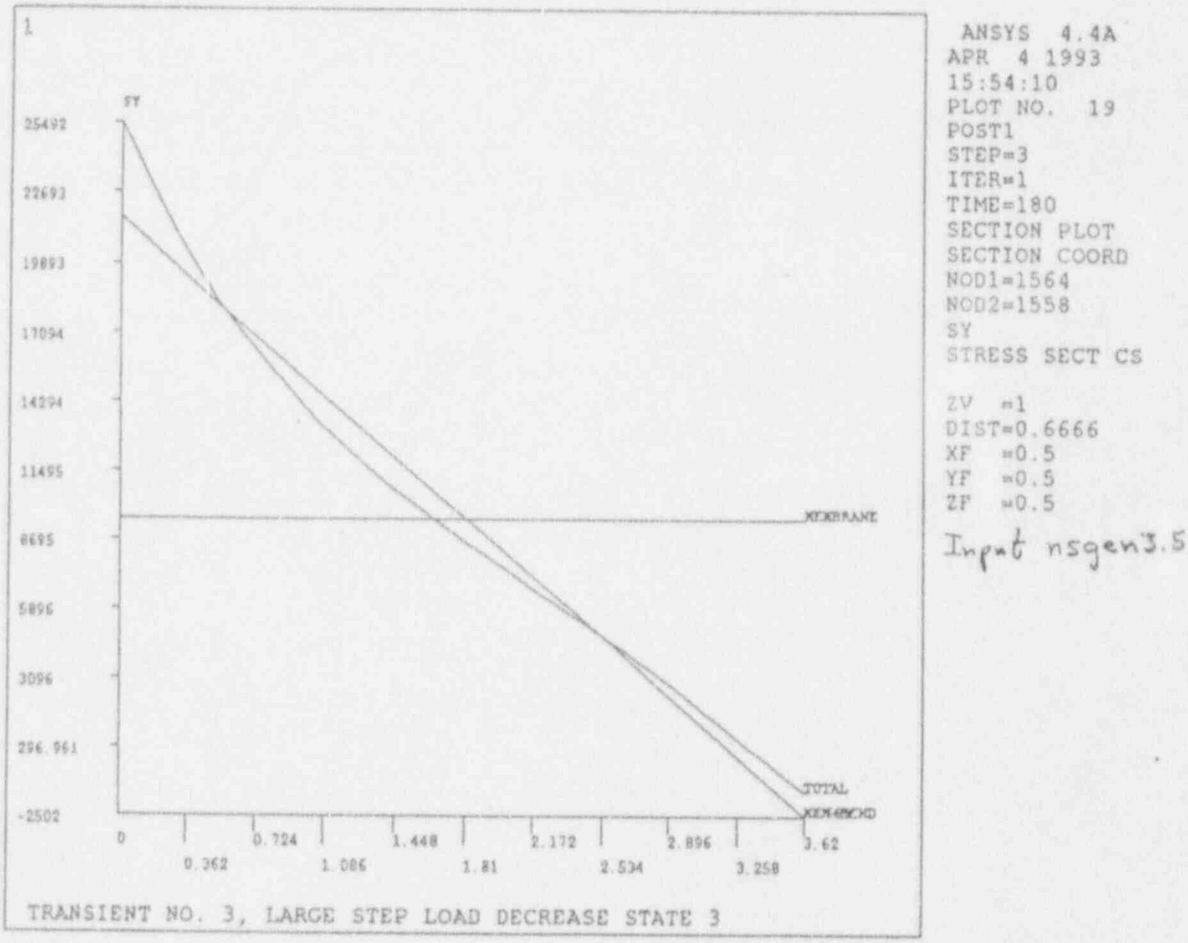



Figure 6-16. Large Step Load Decrease, Axial Stress Contributions, t=180 sec.

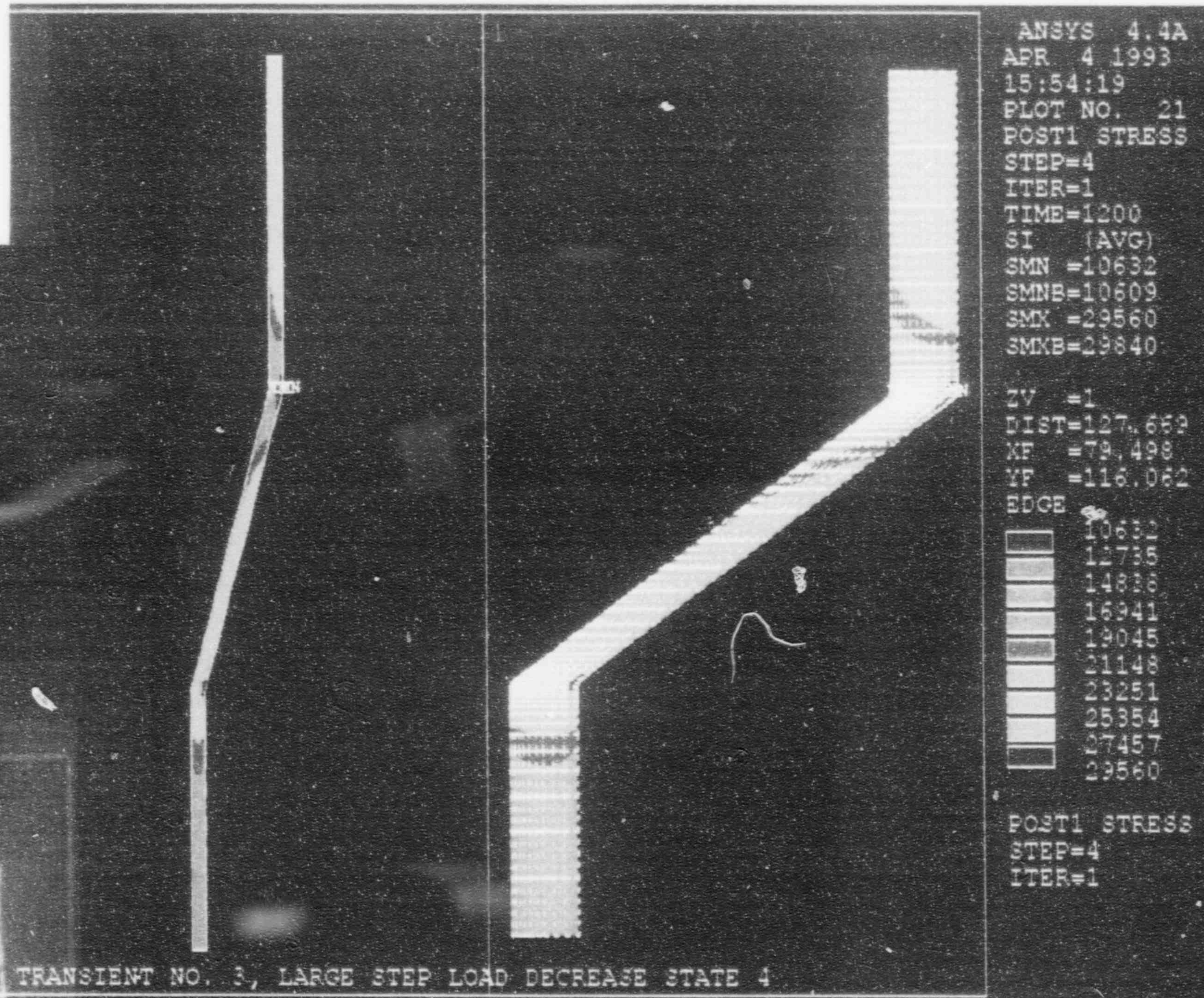



Figure 6-17. Large Step Load Decrease. Stress Intensity, t=1200 sec

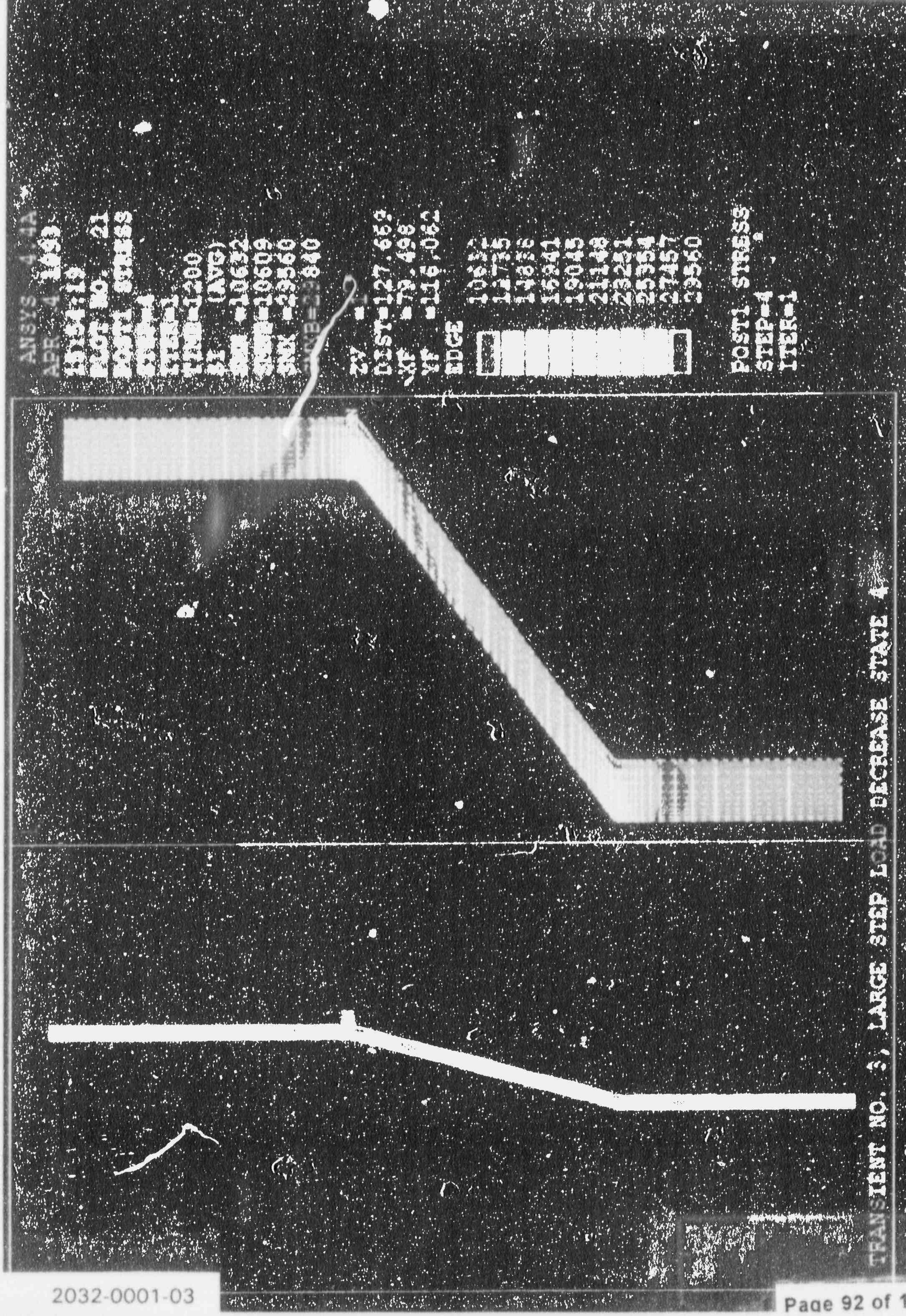



Figure 6-17. Large Step Load Decrease, Stress Intensity, t=1200 sec

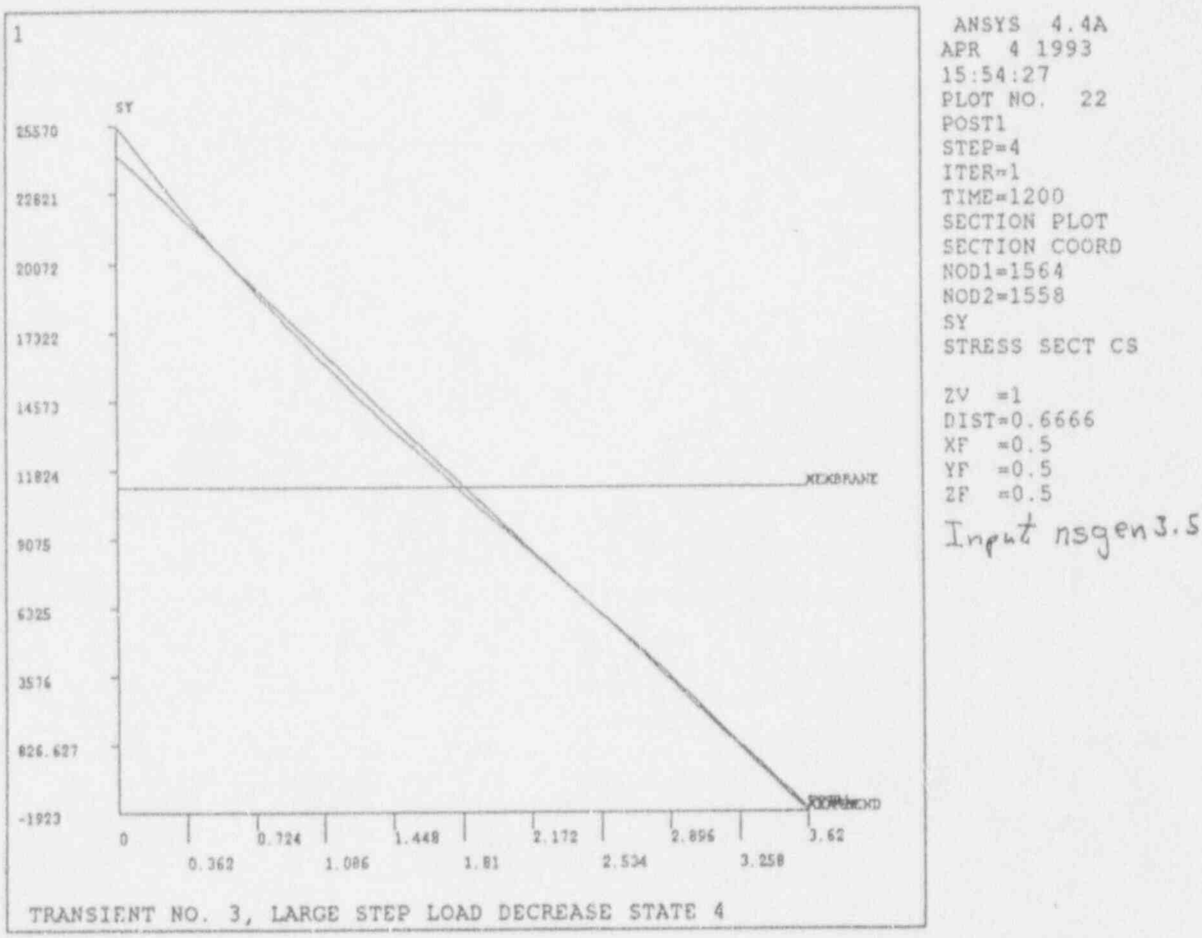



Figure 6-18. Large Step Load Decrease, Axial Stress Contributions, t= 1200 sec.

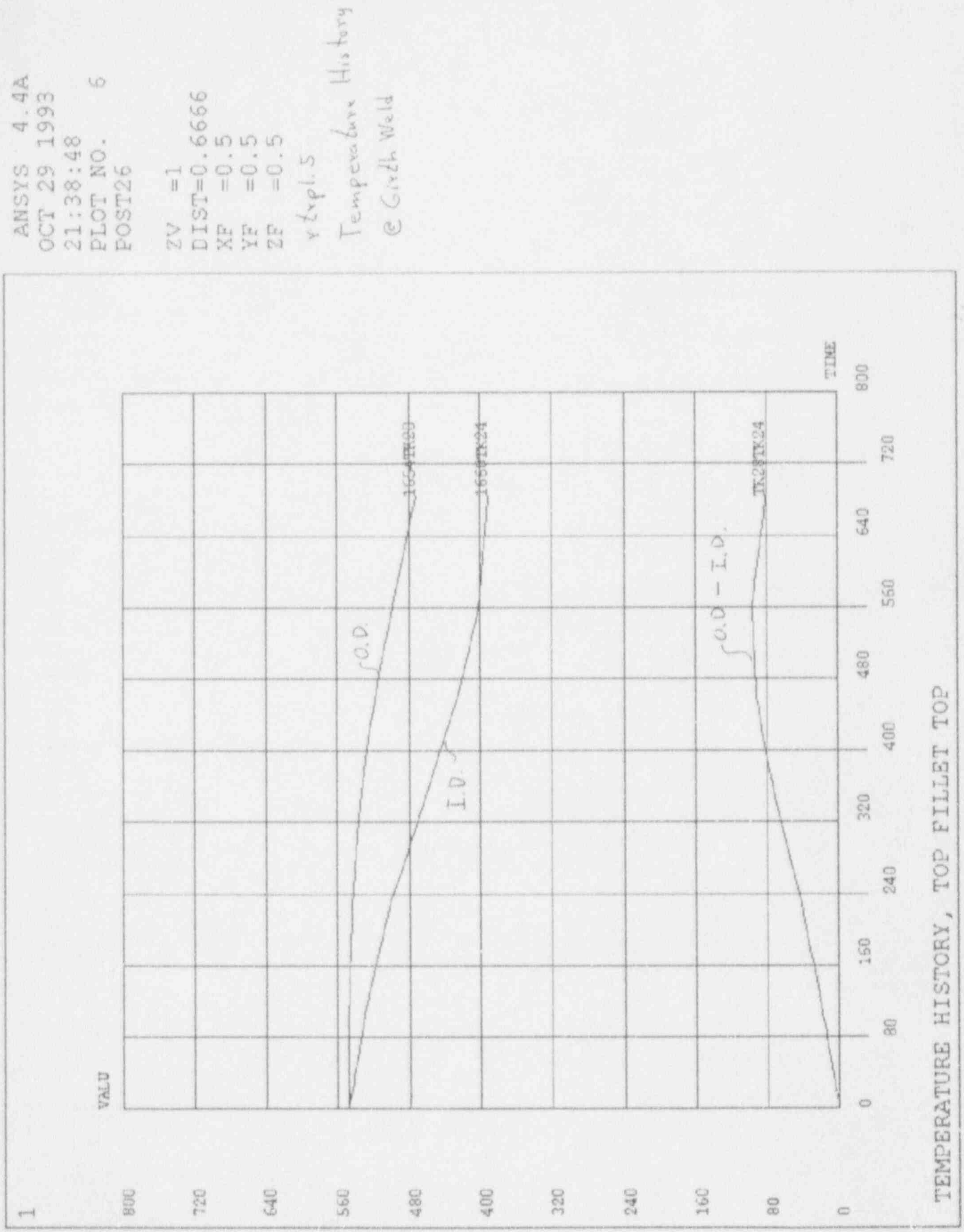



Figure 6-19 Reactor Trip, Temperature Transient at Girth Weld

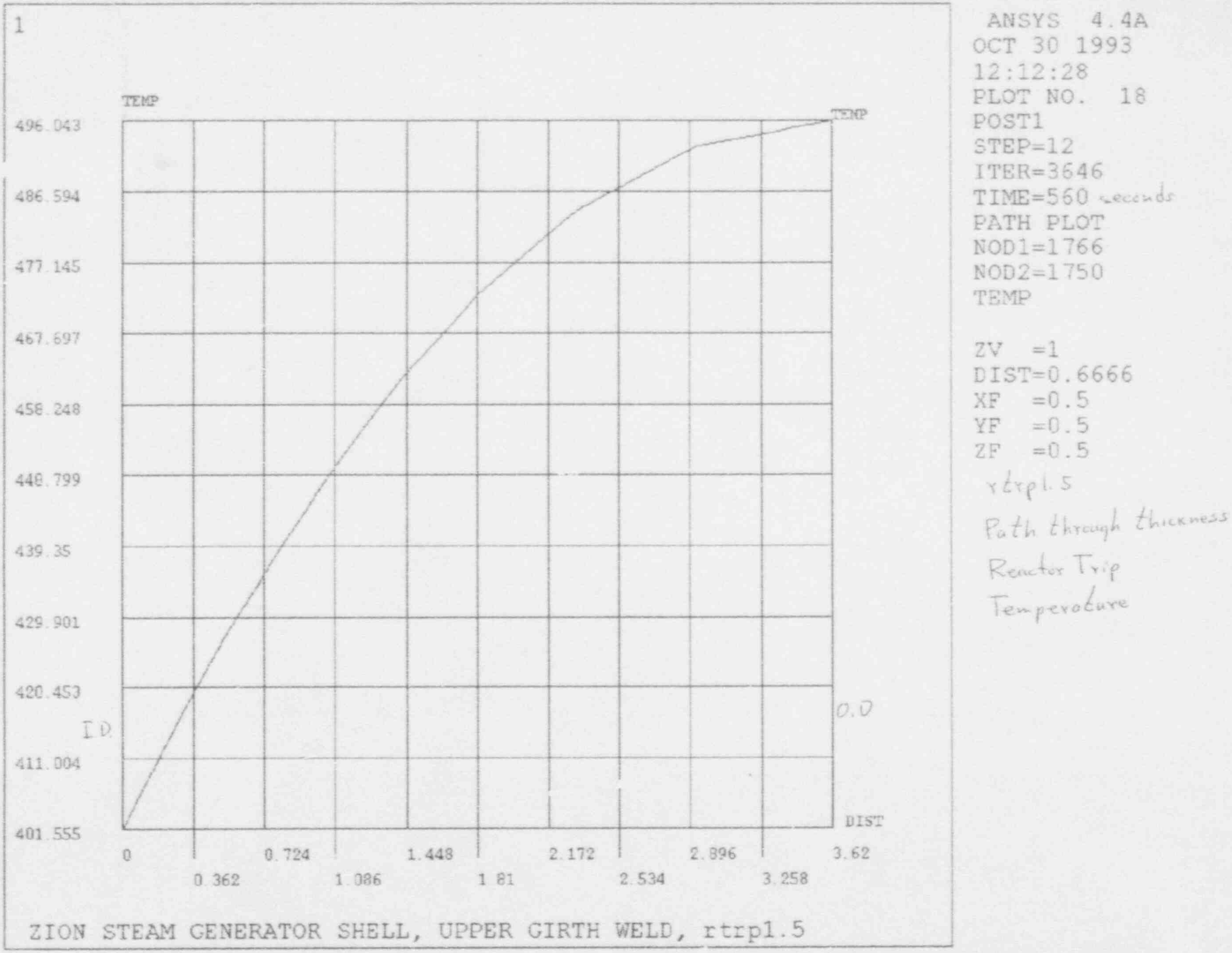



Figure 6-20 Reactor Trip, Temperature Profiles Through Wall at Girth Weld, t=560 sec

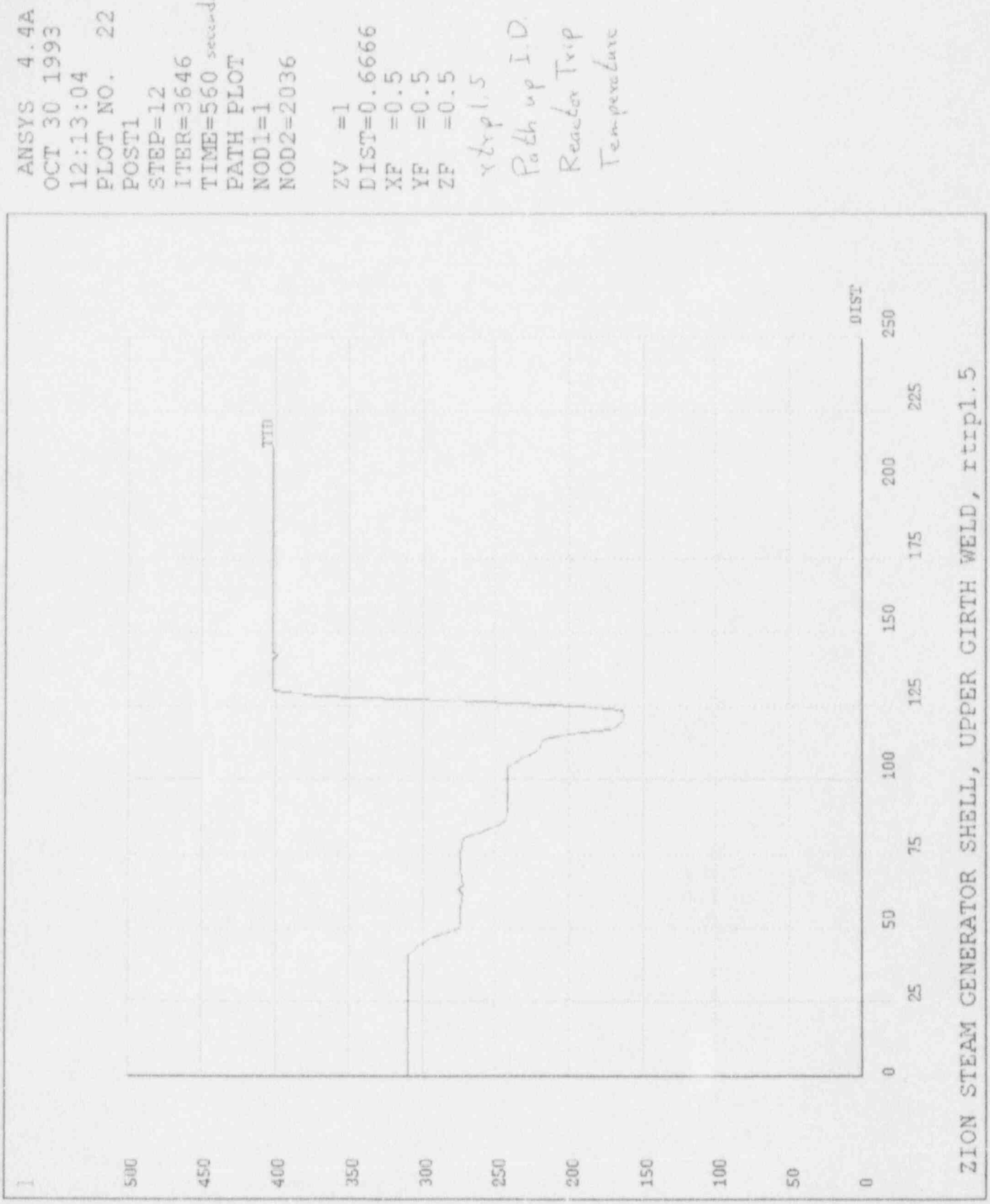



Figure 6-21 Reactor Trip, Temperature Profile Up Inside Surface, t=560 sec

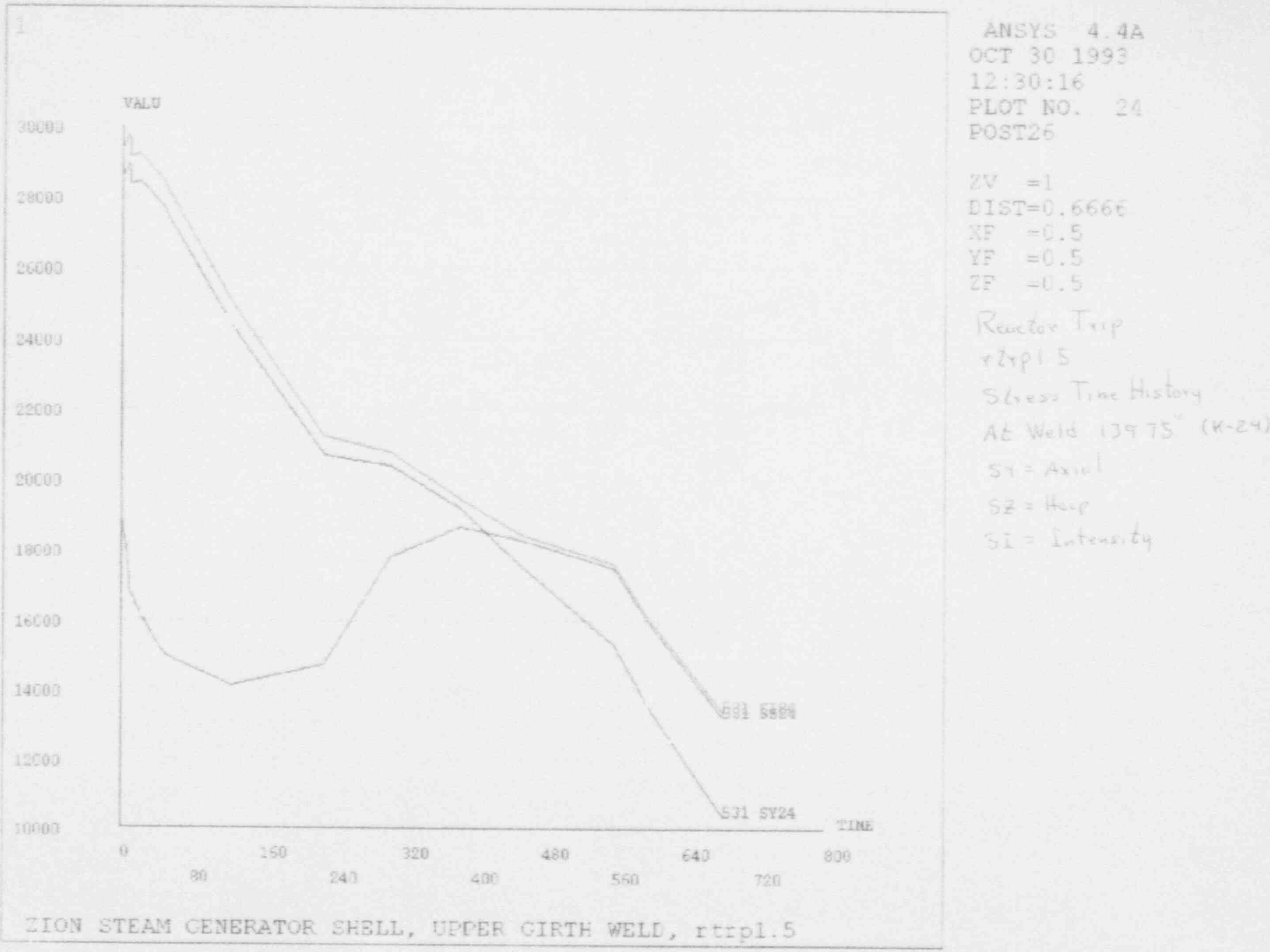



Figure 6-22 Reactor Trip, Stress History at Girth Weld

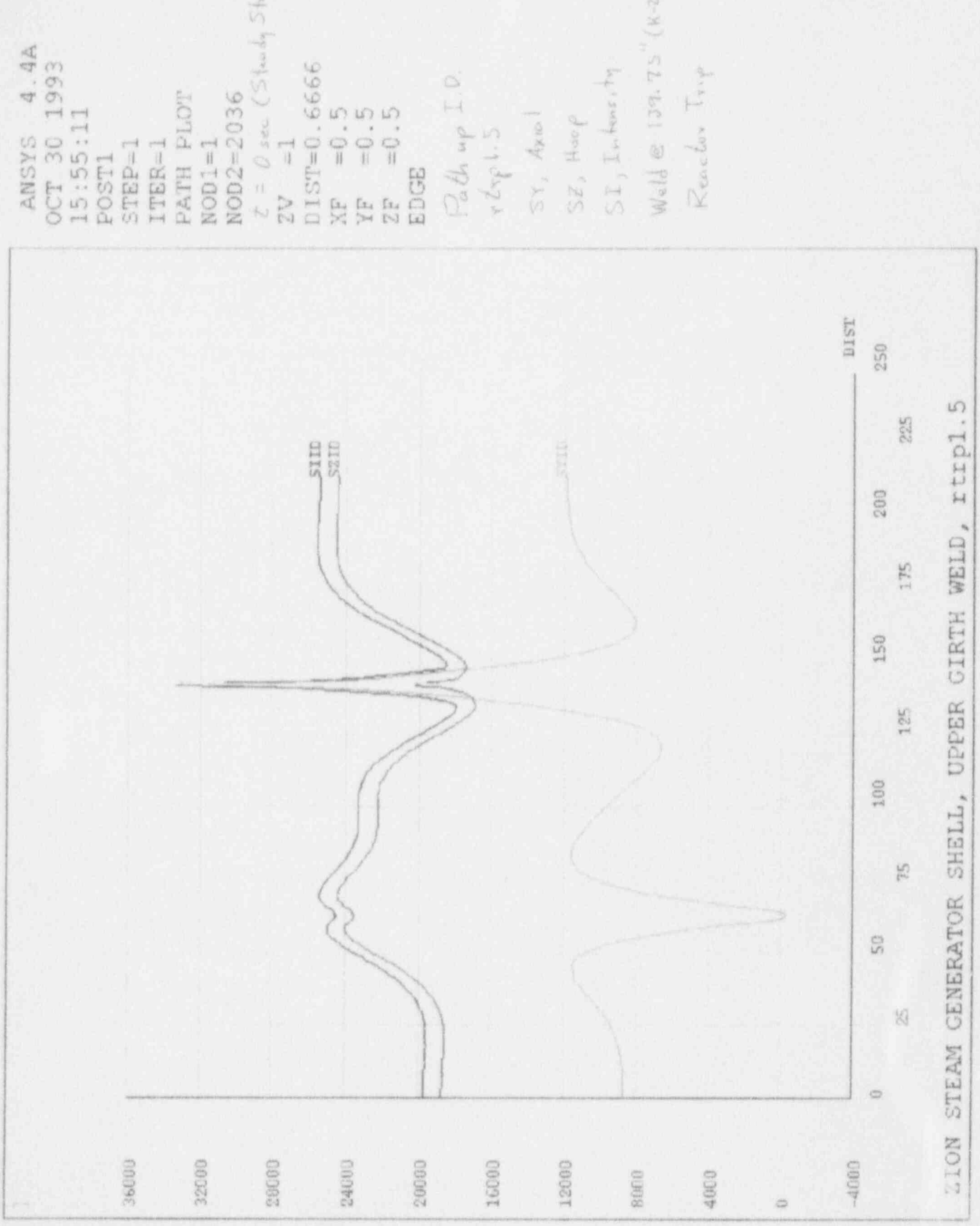



Figure 6-23 Reactor Trip. Stress Profile Up Inside Surface, T=547°F

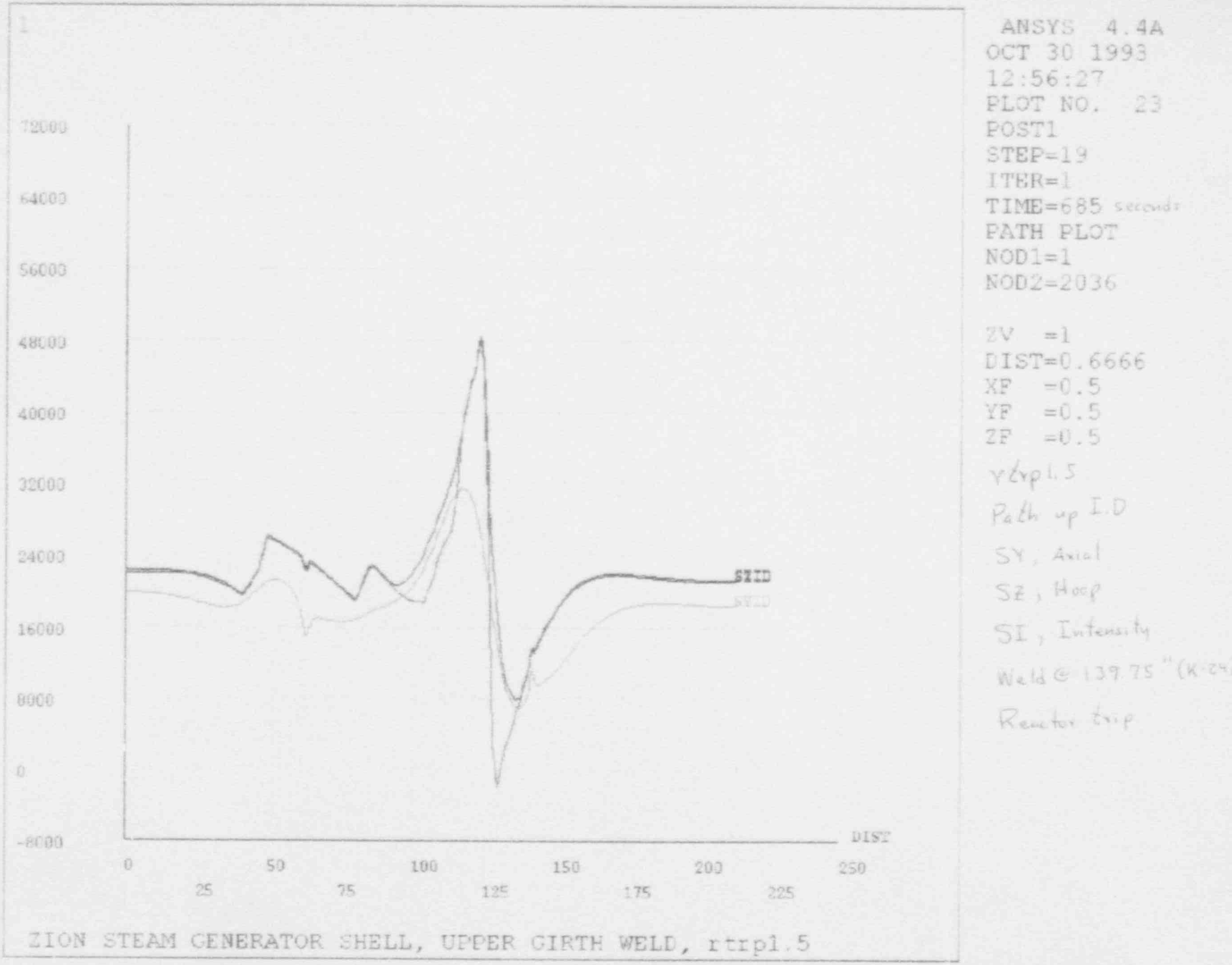



Figure 6-24 Reactor Trip, Stress Profile Up Inside Surface, t=685 sec

**Figure 6-25. Reactor Trip, Stress Profile Up Inside Surface, t=685 sec.**

Source: Reference 7

Report, "Zion Unit 1 Steam Generator Girth Weld Repair Report Fall 1989, and Zion Unit 2 Steam Generator Girth Weld Repair Report Spring 1990," Westinghouse Electric Corporation Report WCAP-12489, June 1991. (Figure 3.3-11)

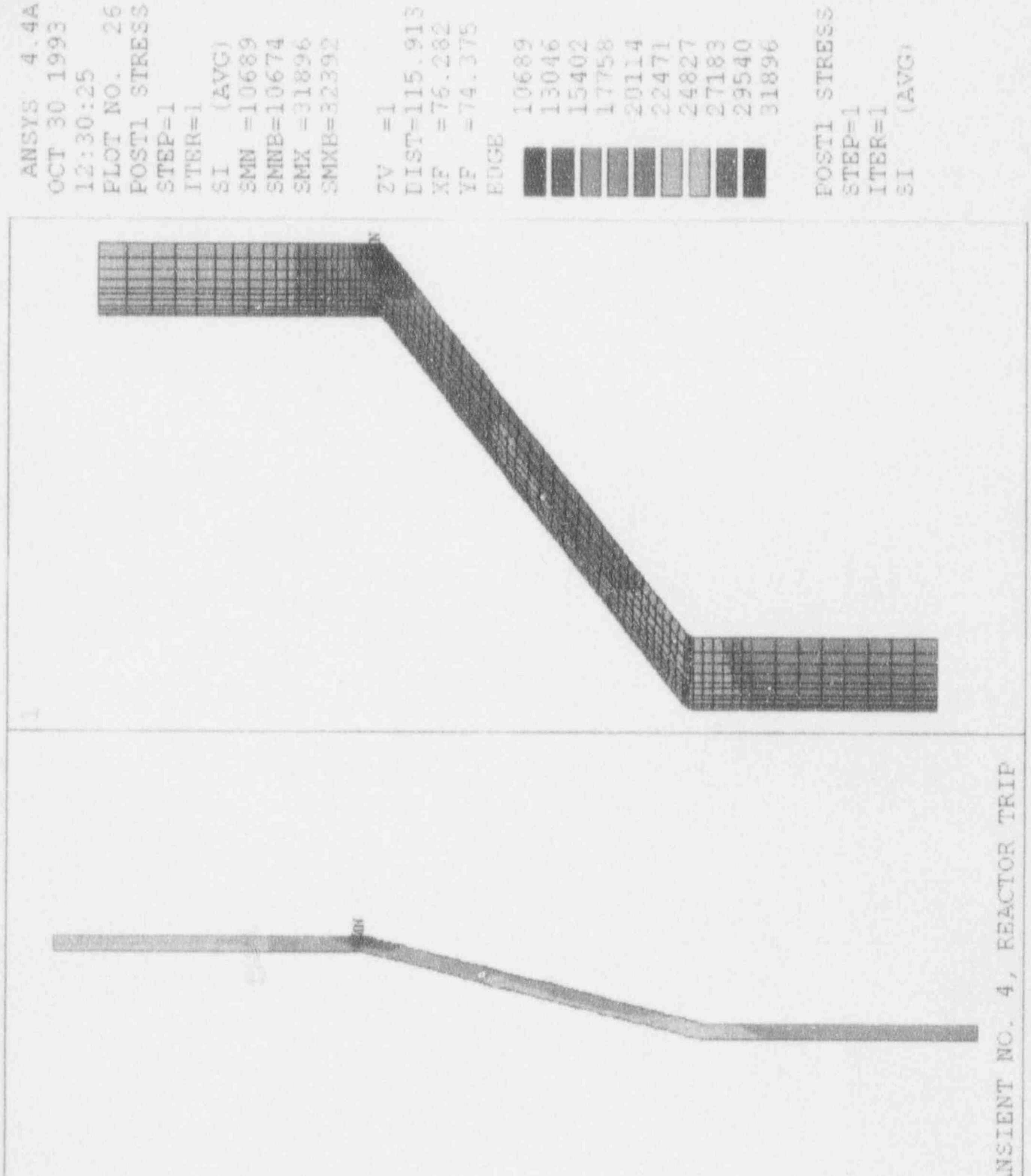



Figure 6-26 Reactor Trip, Stress Intensity Contours, T=547°F, p=1020psi

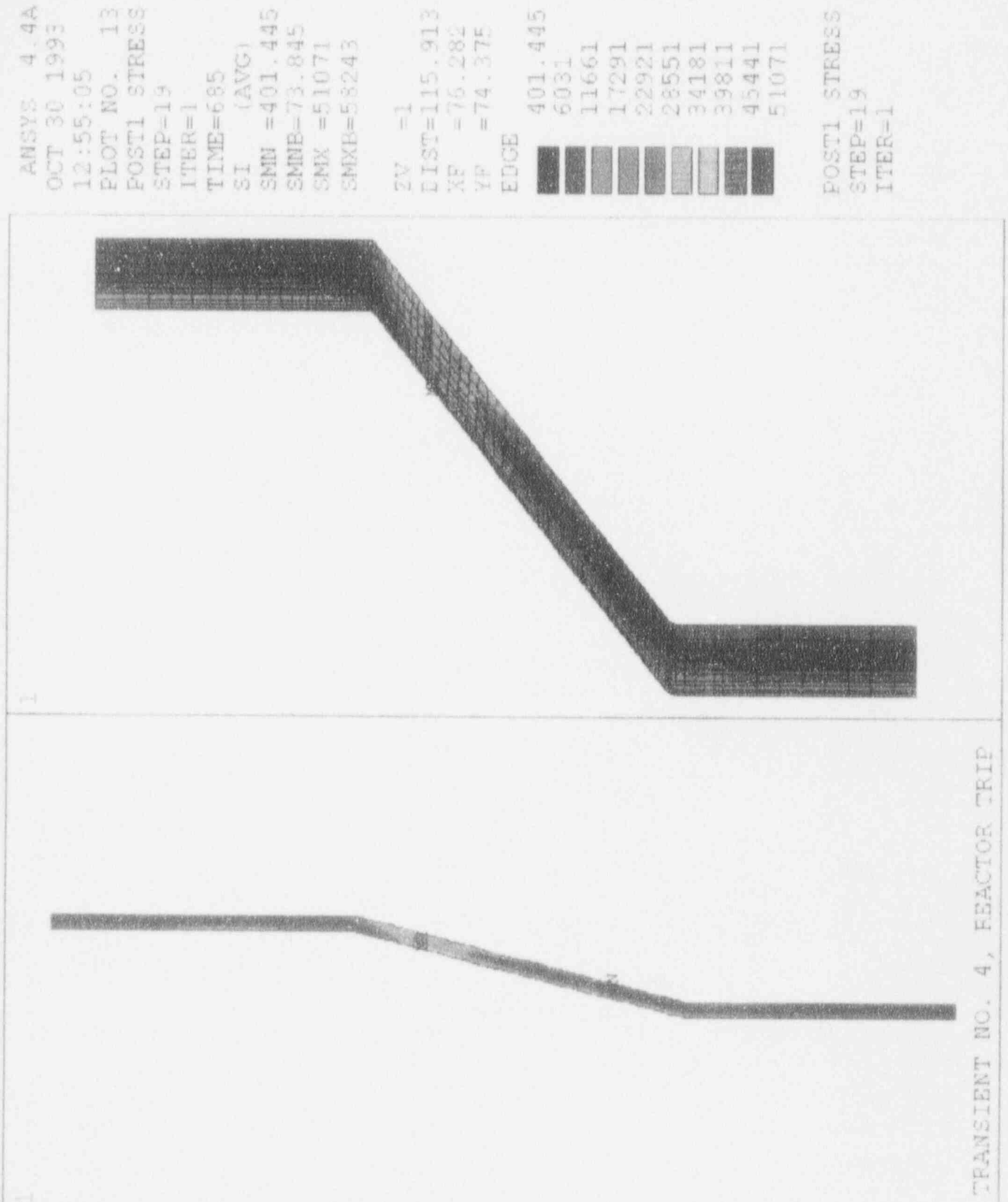
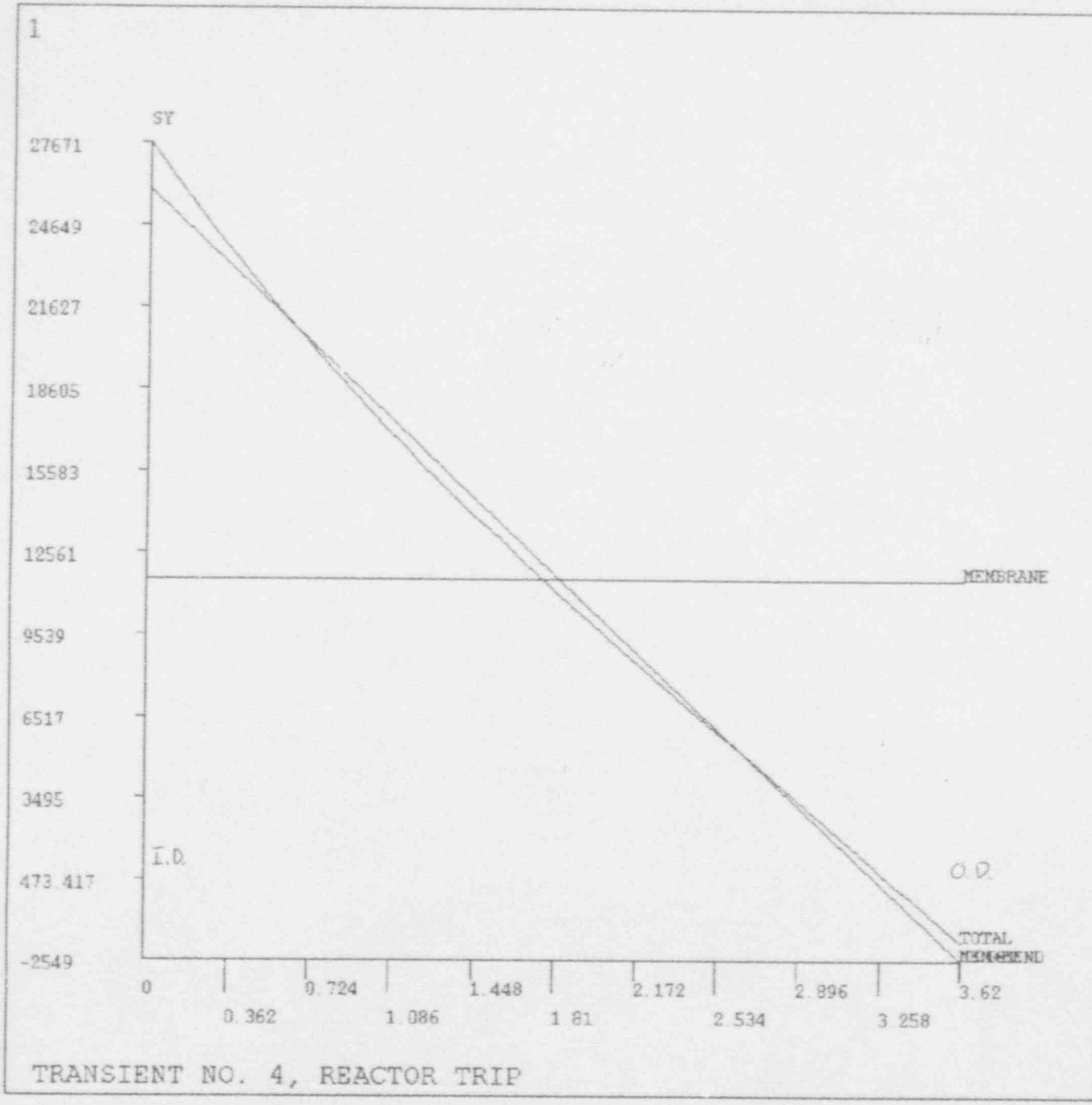



Figure 6-27 Reactor Trip, Stress Intensity Contours, t=685 sec




ANSYS 4.4A
OCT 30 1993
12:54:06
PLOT NO. 5
POST1
STEP=2
ITER=1
TIME=0.556 seconds
SECTION PLOT
SECTION COORD
NOD1=1660
NOD2=1654
SY
STRESS SECT CS

ZV =1
DIST=0.6666
XF =0.5
YF =0.5
ZF =0.5

@ Girth Weld (K24, K28)

$P_m$, $(P_L+P_b)$, Total

Figure 6-28 Reactor Trip, Axial Stress Contributions, T=547°F, p=1020psi

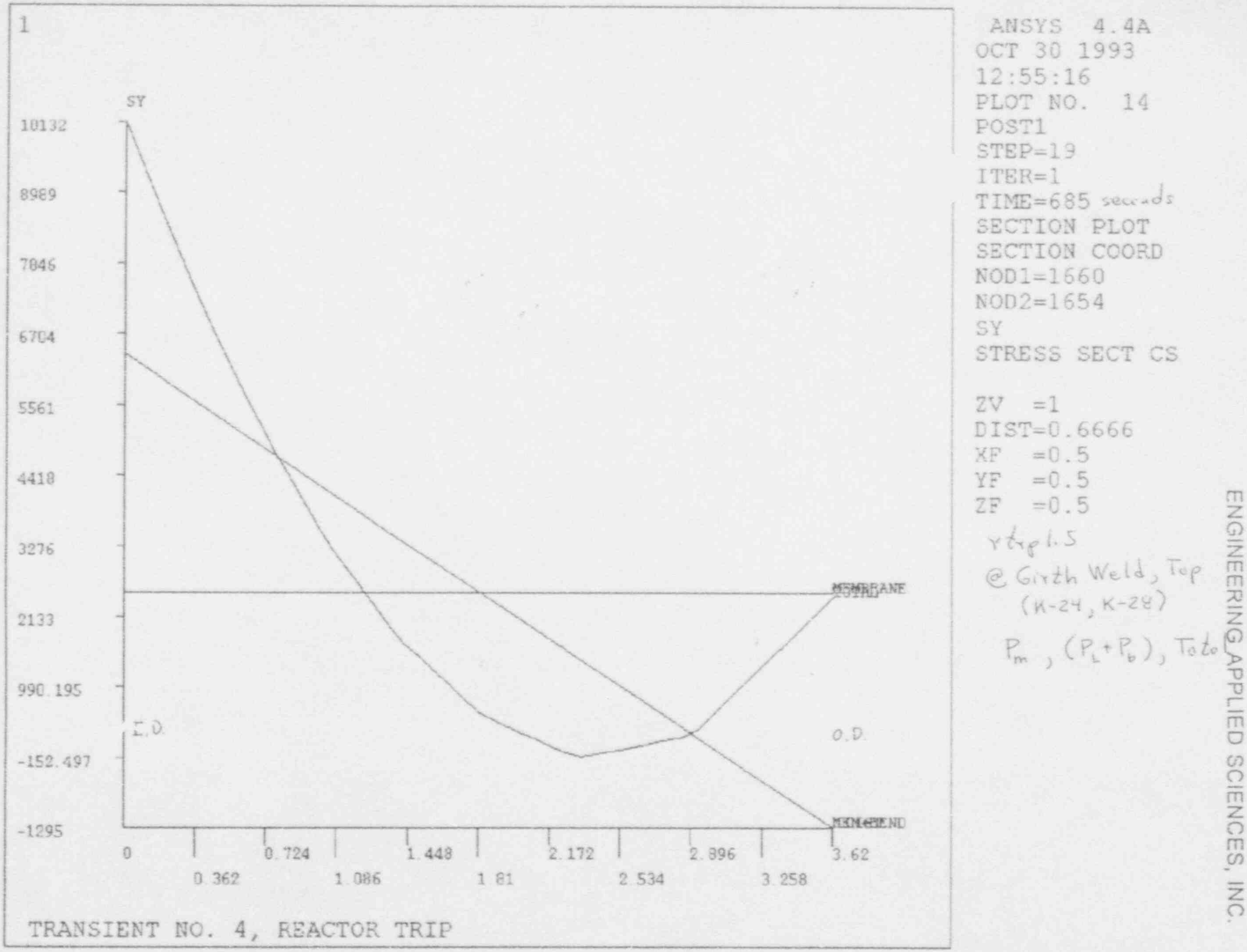



Figure 6-29 Reactor Trip, Axial Stress Contributions, t=685 sec

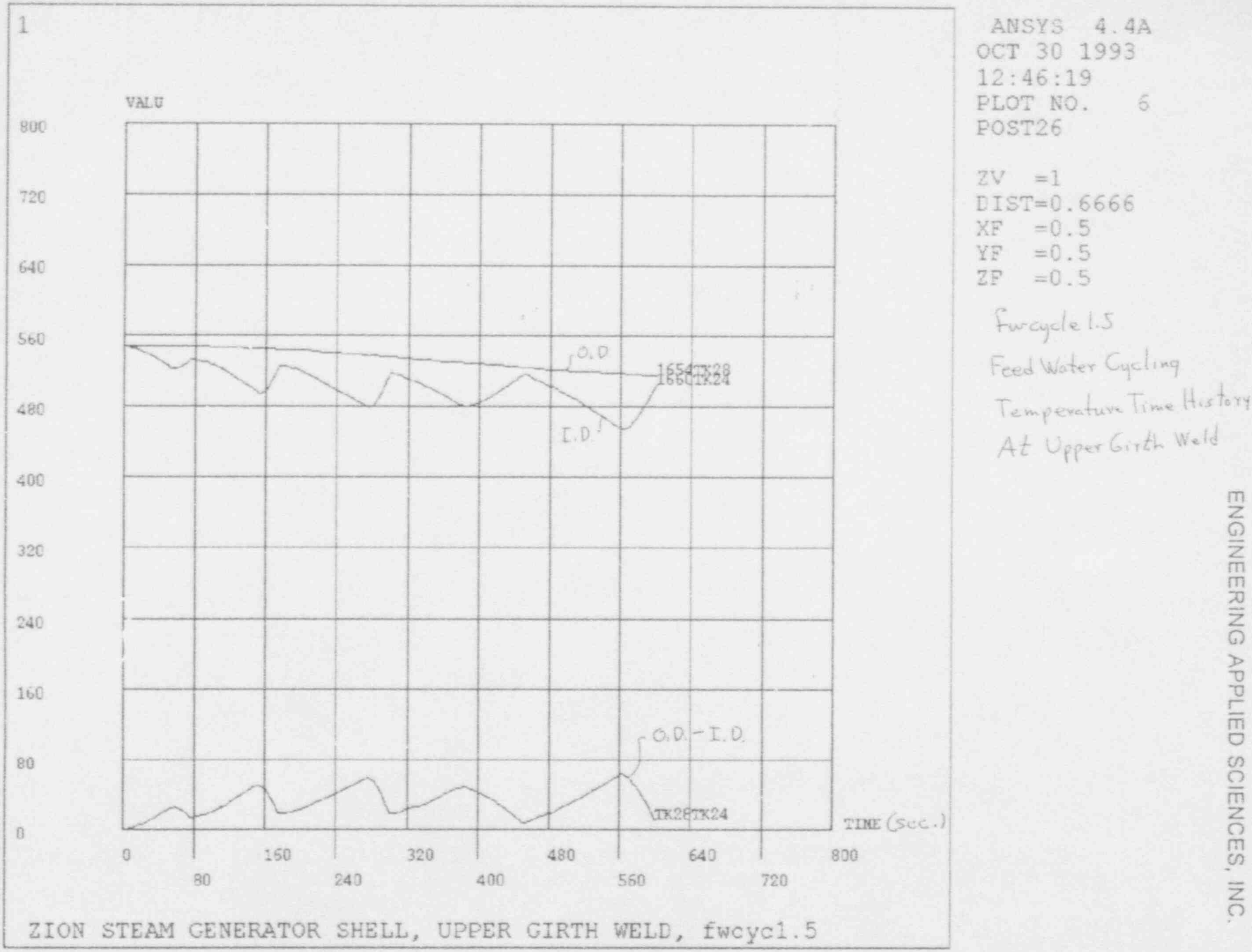



**Figure 6-30. Auxiliary Feedwater Cycling, Temperature Transient at Girth Weld**

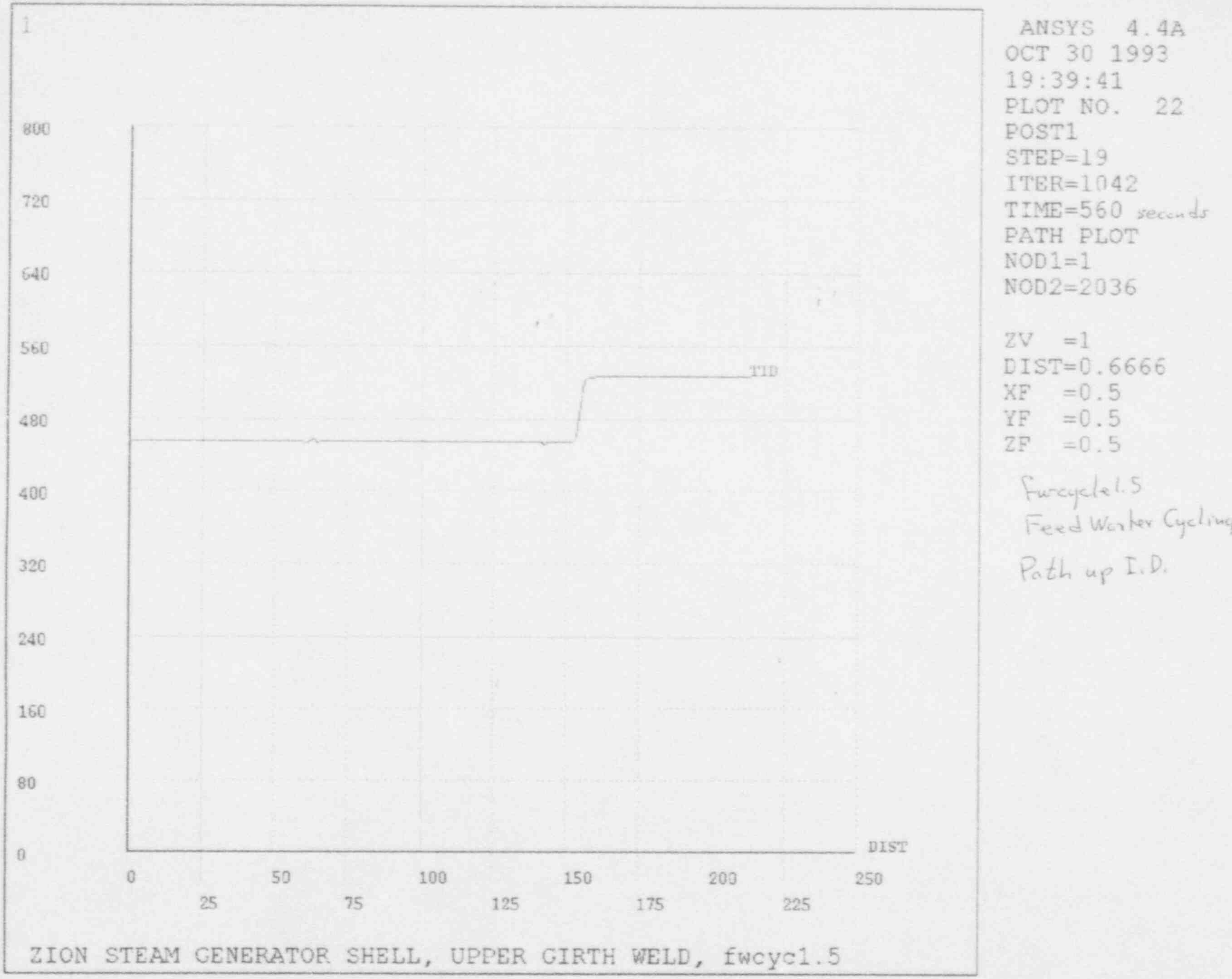



**Figure 6-31. Auxiliary Feedwater Cycling, Temperature Profile Up Inside Surface, t = 560 sec.**

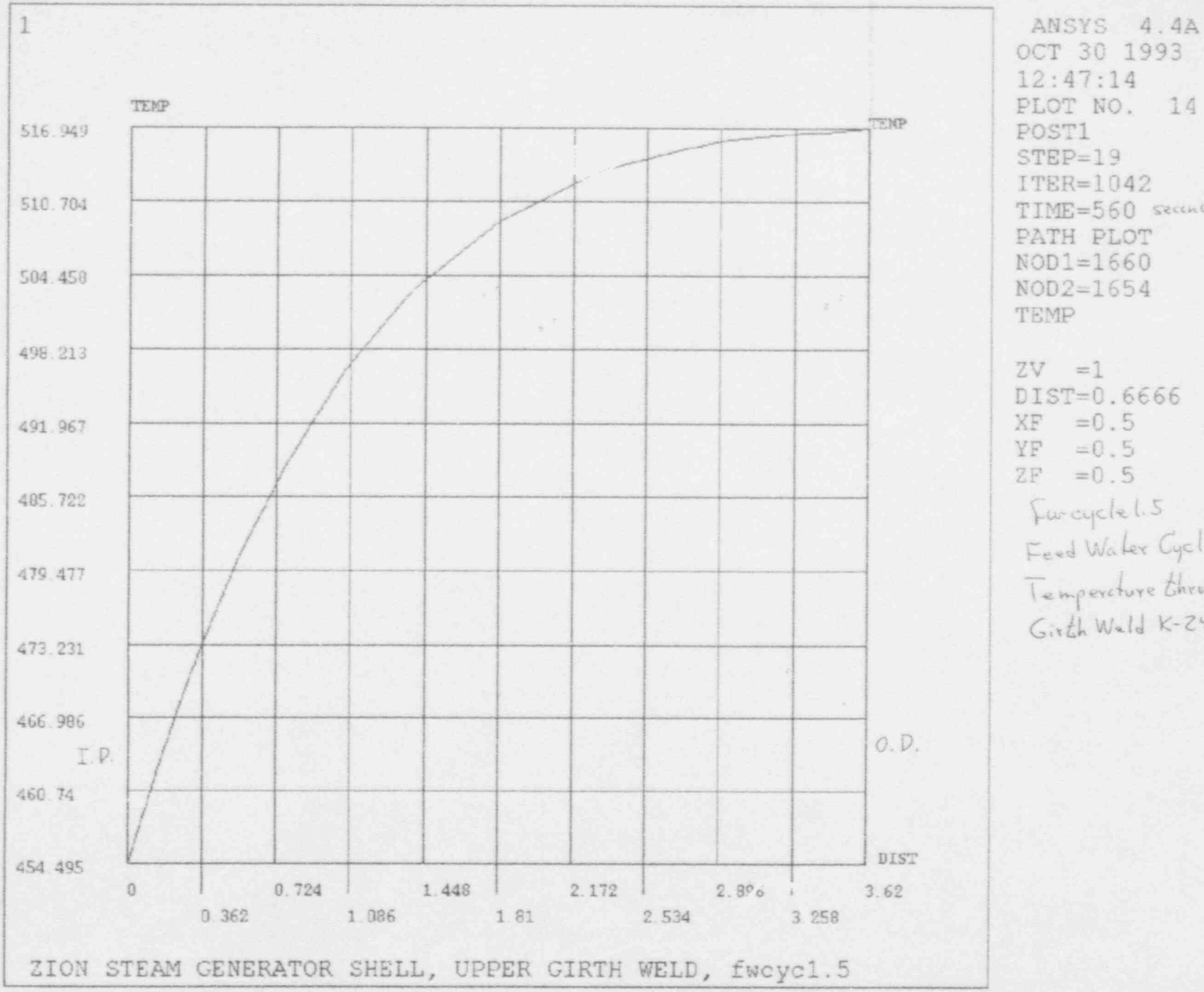



**Figure 6-32. Auxiliary Feedwater Cycling, Temperature Profile Through Wall at Girth Weld, t = 560 sec.**

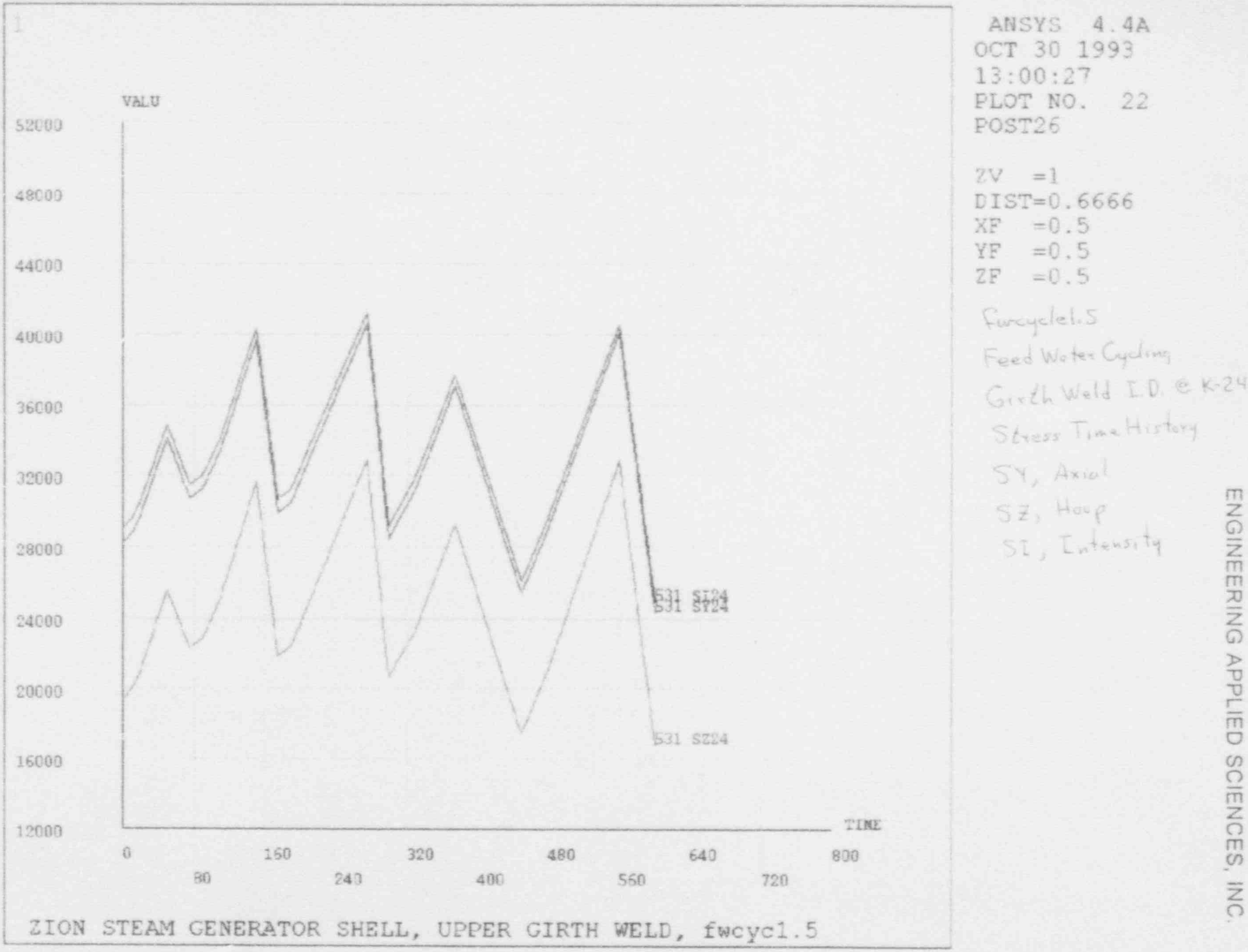



Figure 6-33. Auxiliary Feedwater Cycling, Stress History at Girth Weld

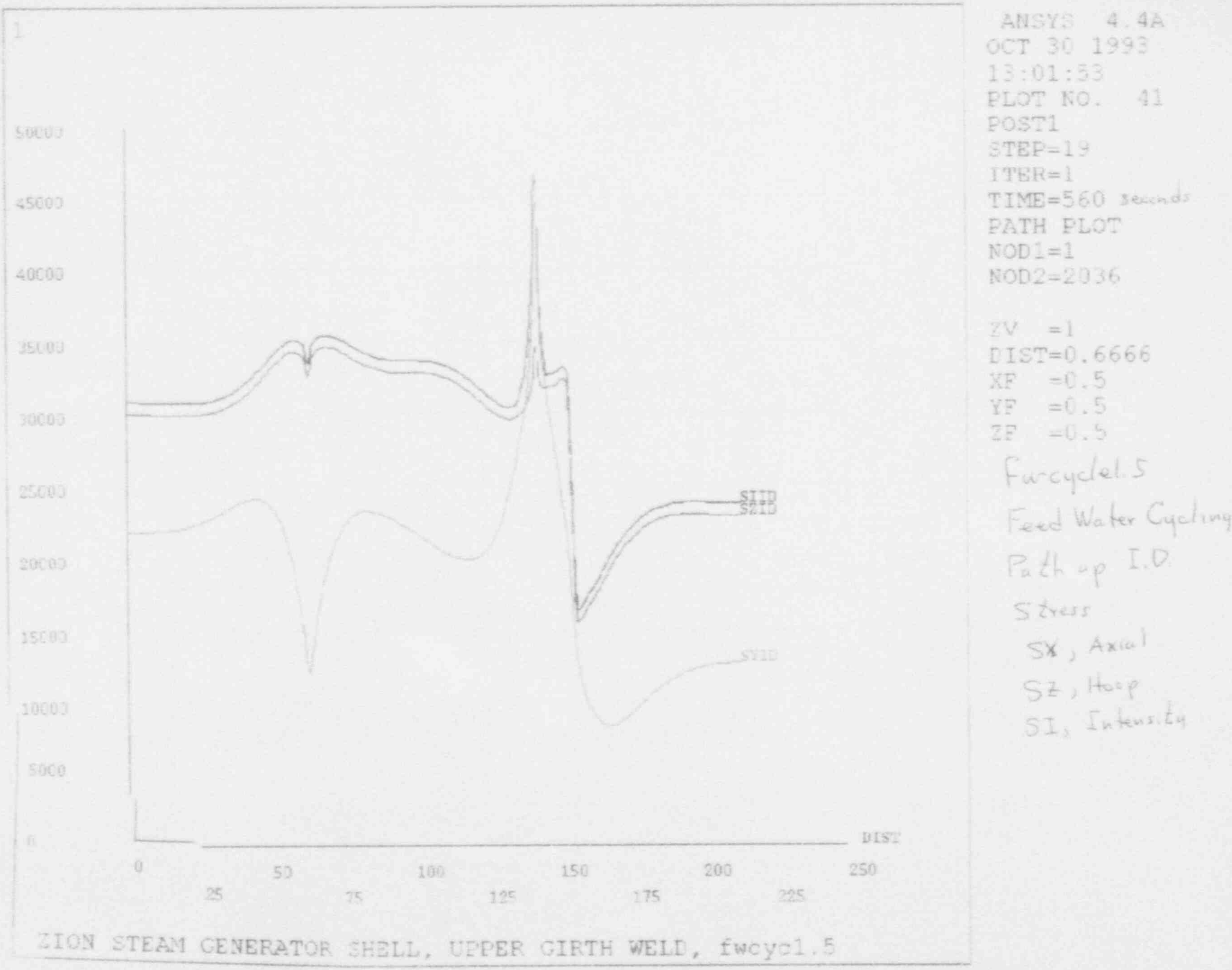



Figure 6-34. Auxiliary Feedwater Cycling, Stress Profile Up Inside Surface, t = 560 sec.

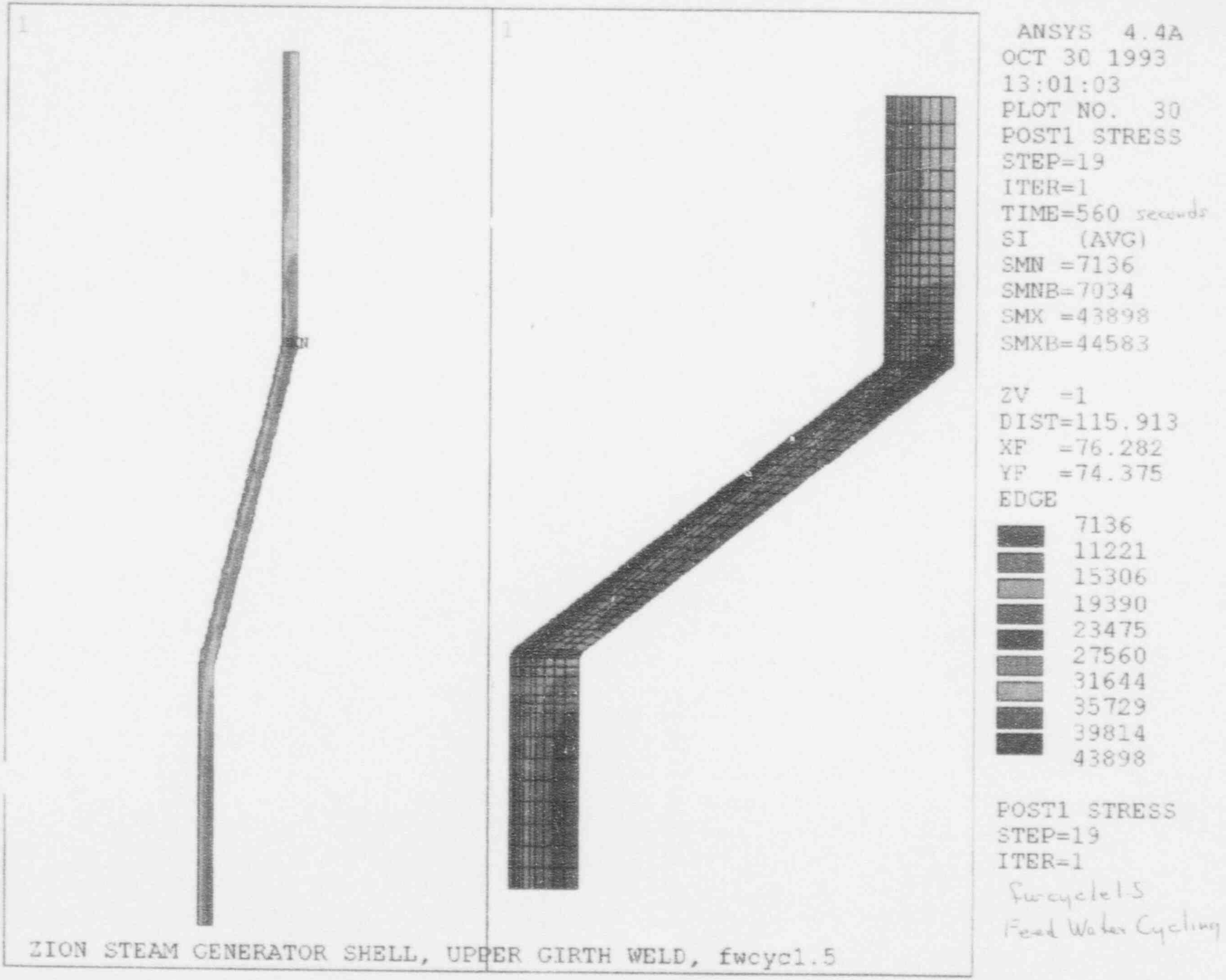



Figure 6-35. Auxiliary Feedwater Cycling, Stress Intensity Contours, t = 560 sec.

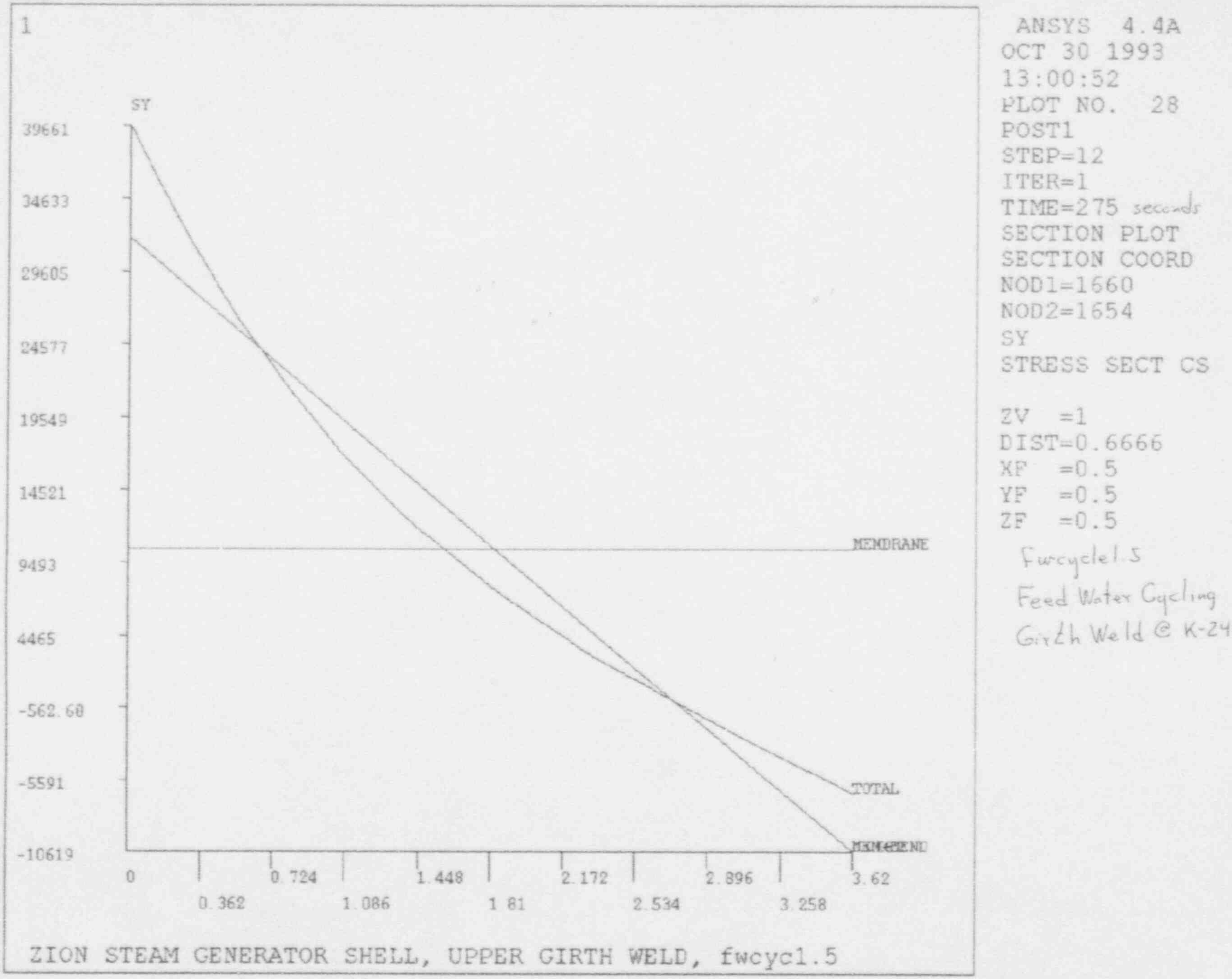



Figure 6-36. Auxiliary Feedwater Cycling, Axial Stress Contributions, t = 275 sec.

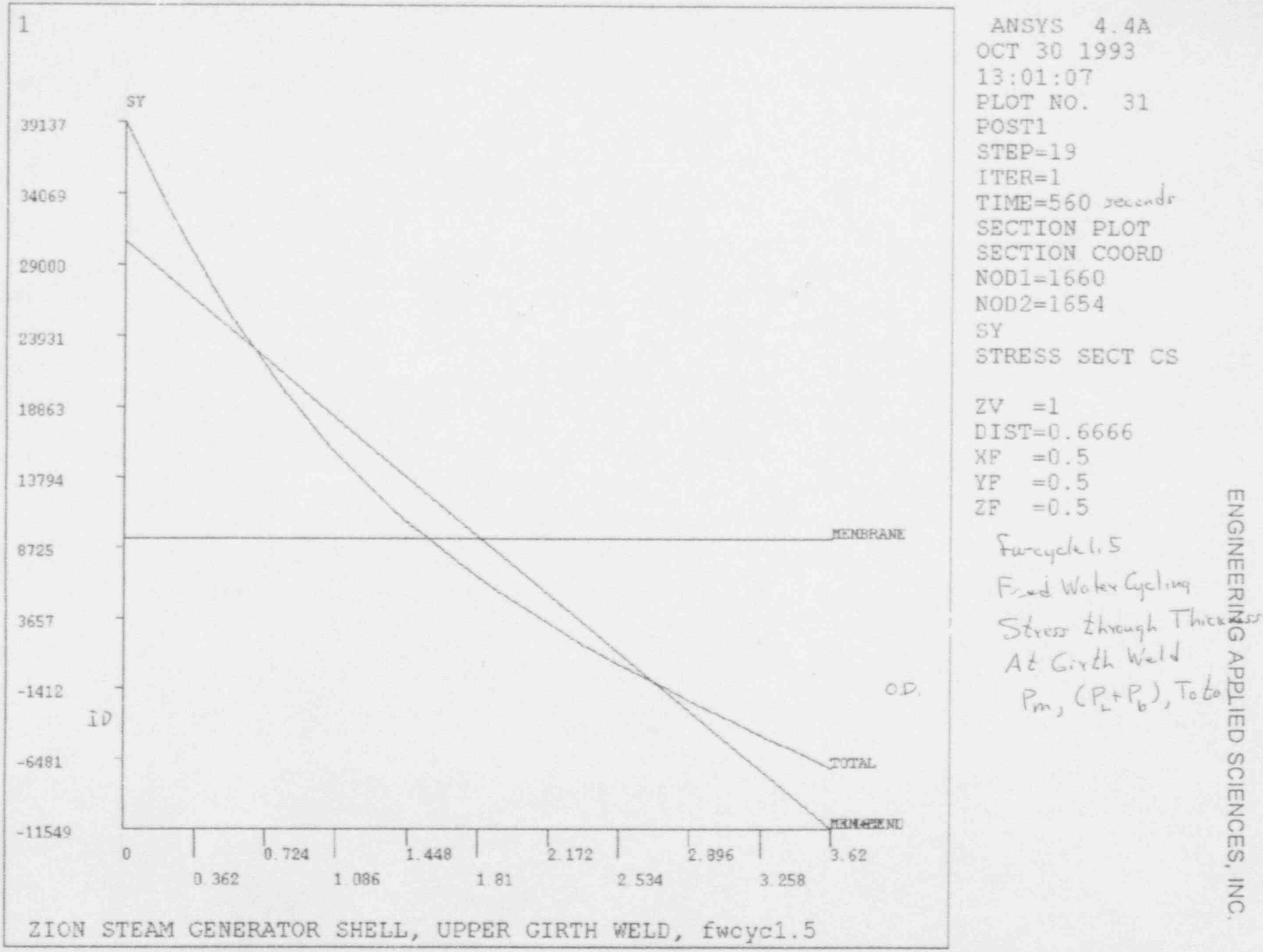
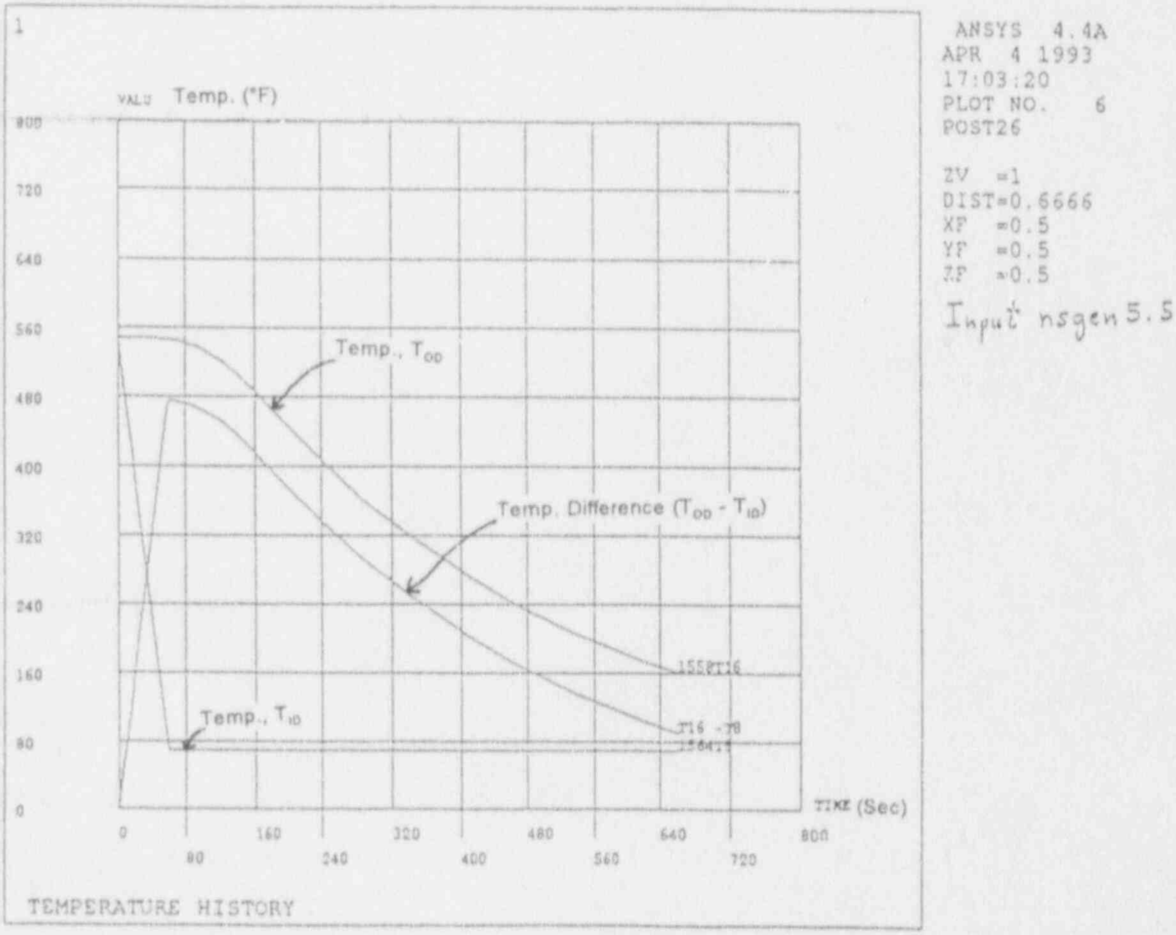



Figure 6-37. Auxiliary Feedwater Cycling, Axial Stress Contributions, t = 275 sec.




Input nsgen 5.5

Figure 6-38. Bounding Faulted Event, Temperature Transient

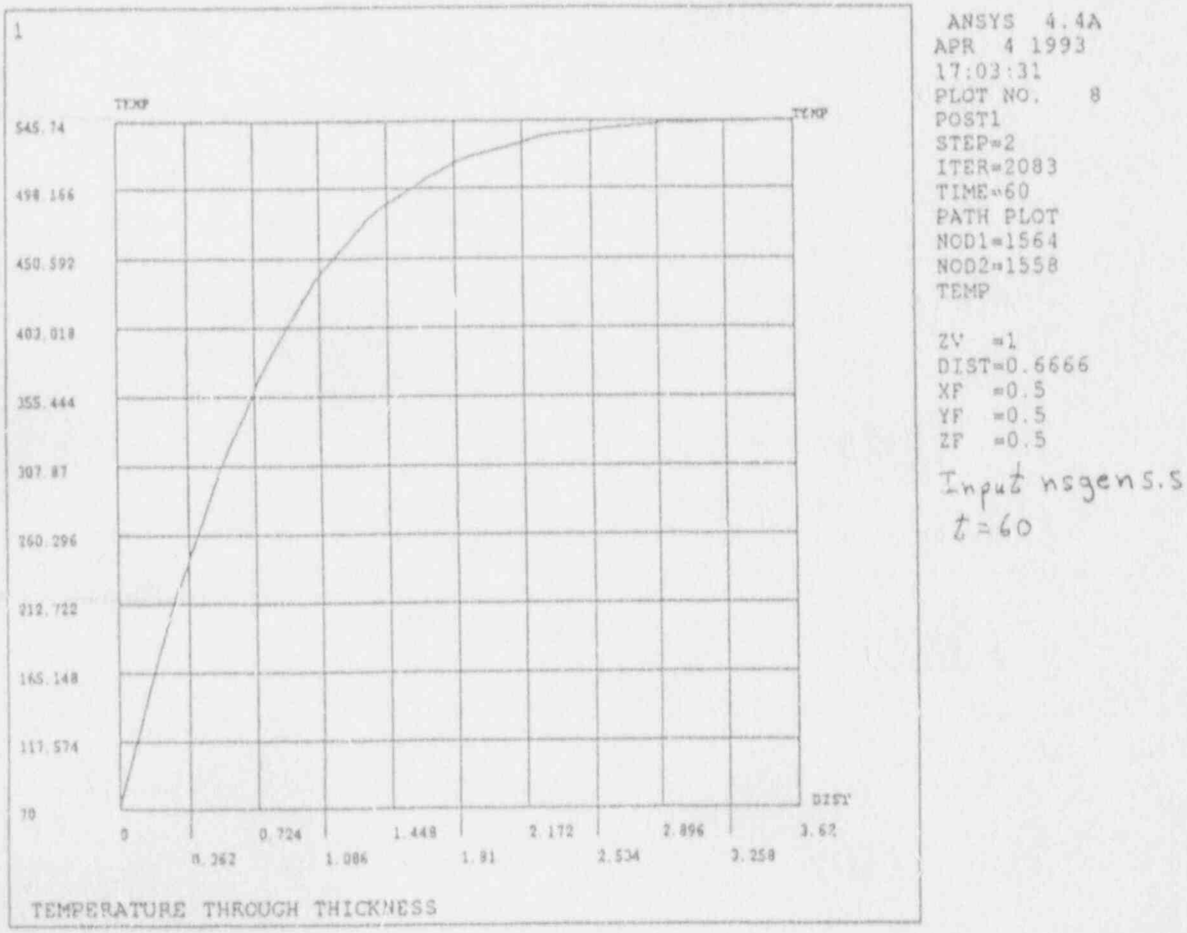



Figure 6-39. Bounding Faulted Event, Temperature Profile, t = 60 sec.

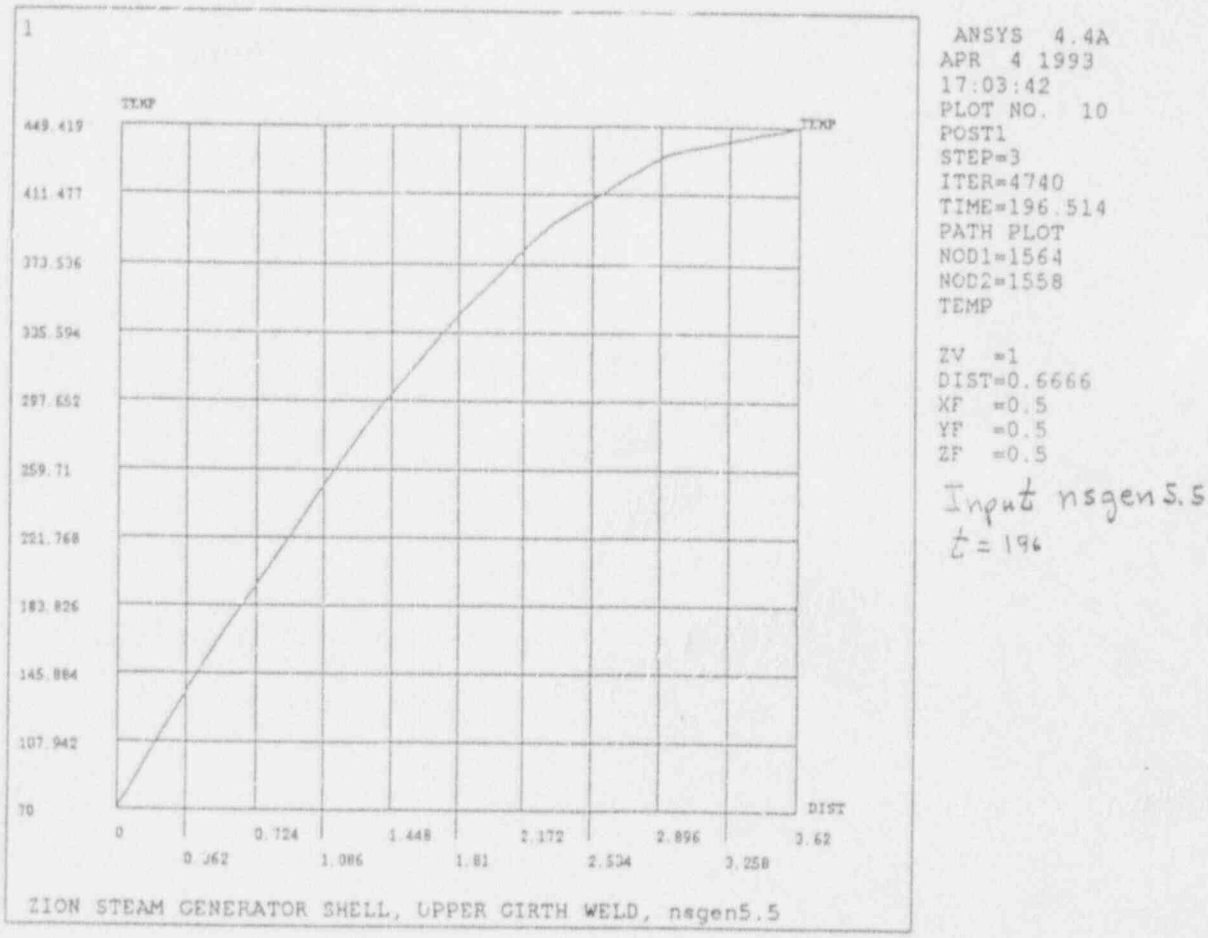



Figure 6-40. Bounding Faulted Event, Temperature Profile, t = 197 sec.

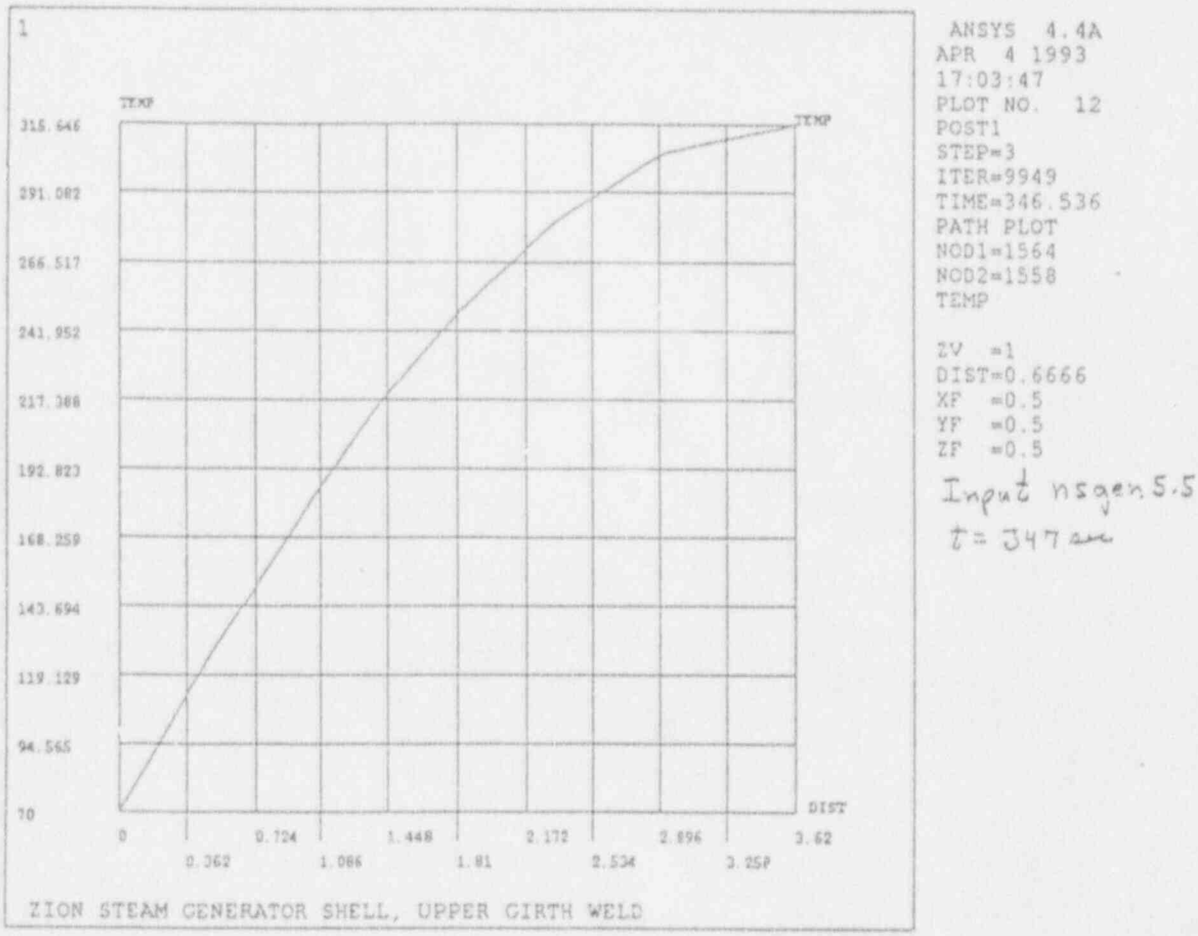



Figure 6-41. Bounding Faulted Event, Temperature Profile, t = 347 sec.

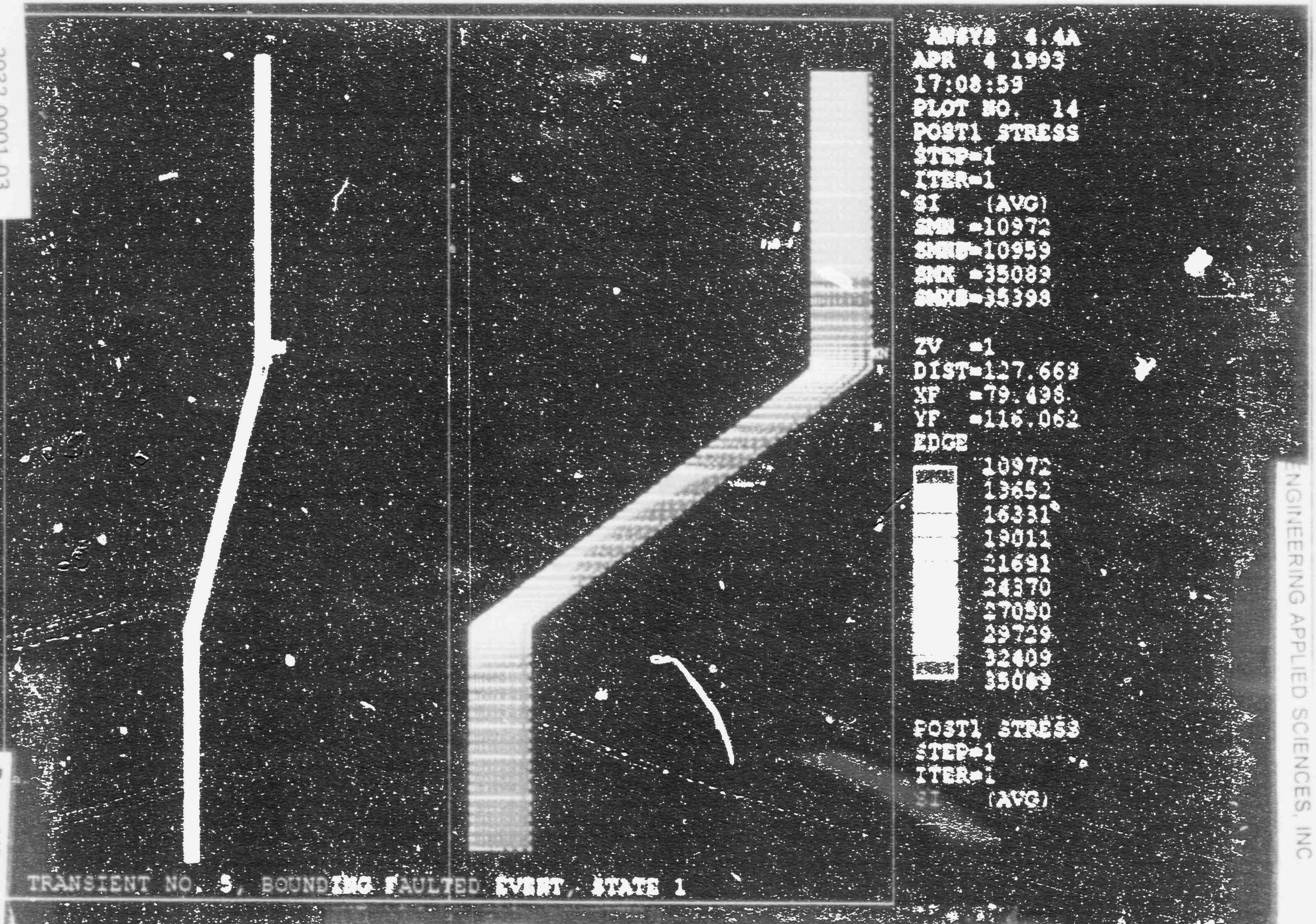



Figure 6-42. Bounding Faulted Event, Stress Intensity, Steady State, t = 0 sec

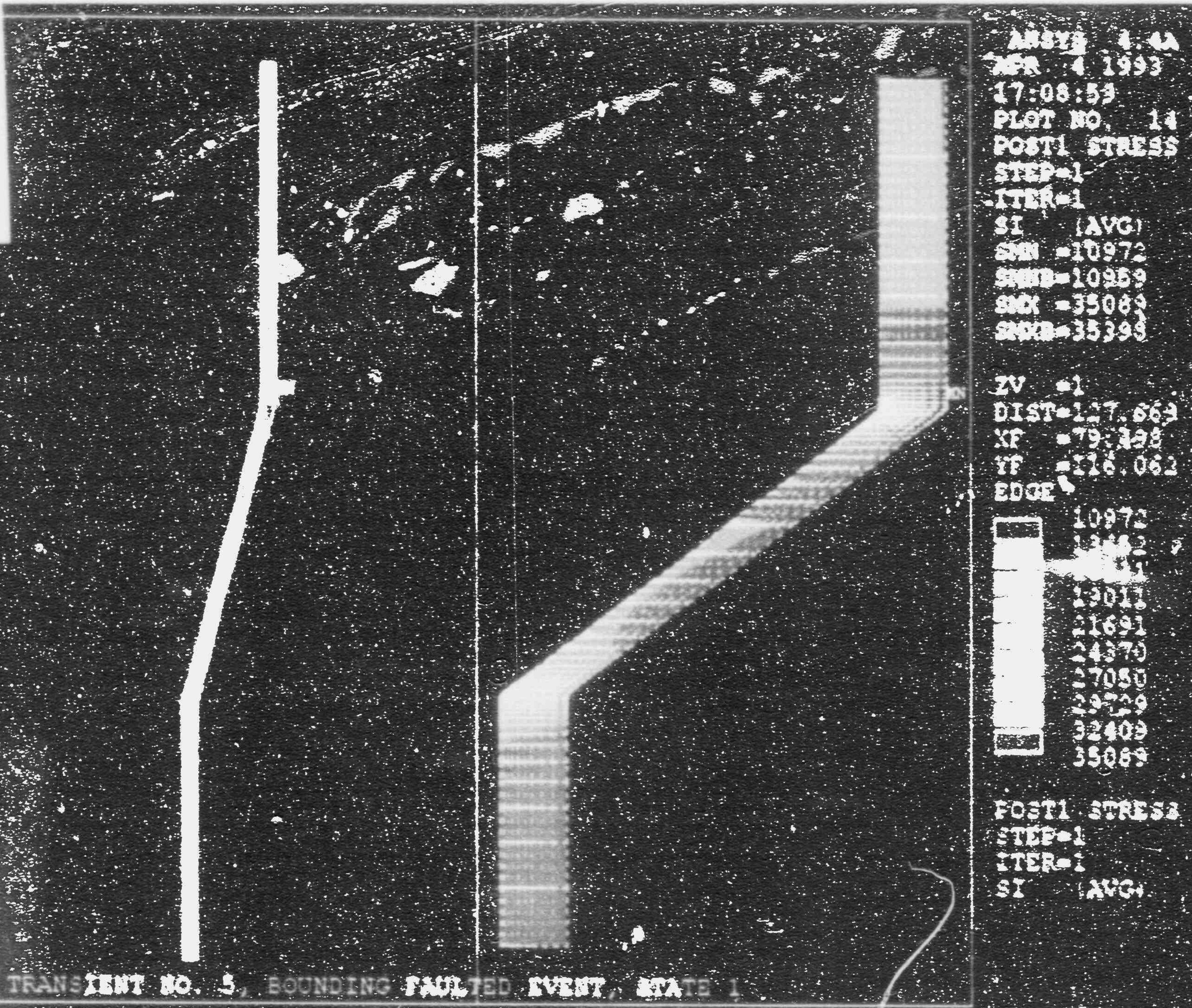
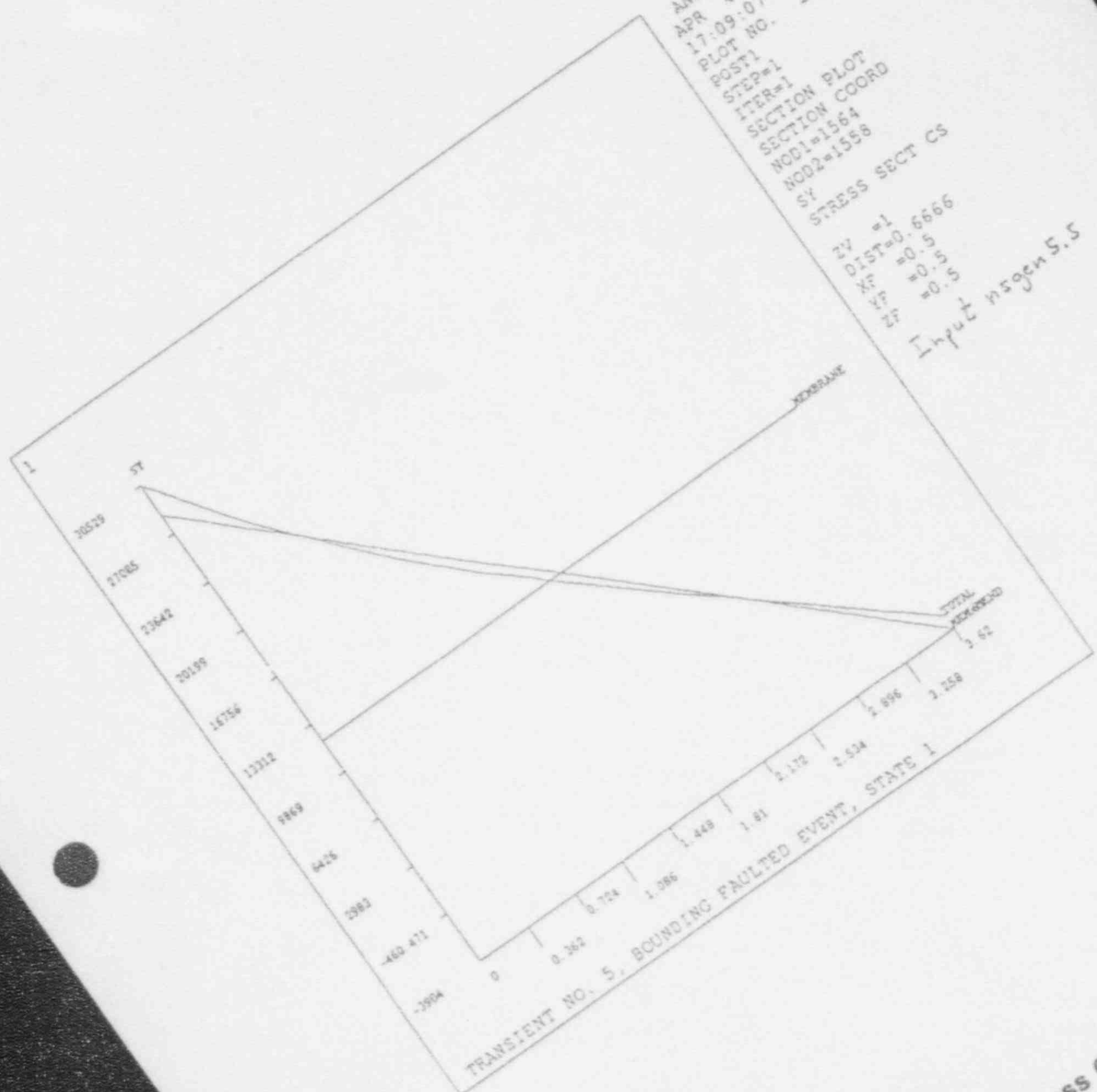



Figure 6-42. Bounding Faulted Event, Stress Intensity, Steady State, t = 0 sec

ENGINEERI




Faulted Event, Axial Stress Contributions, Steady State, t = 0 sec.

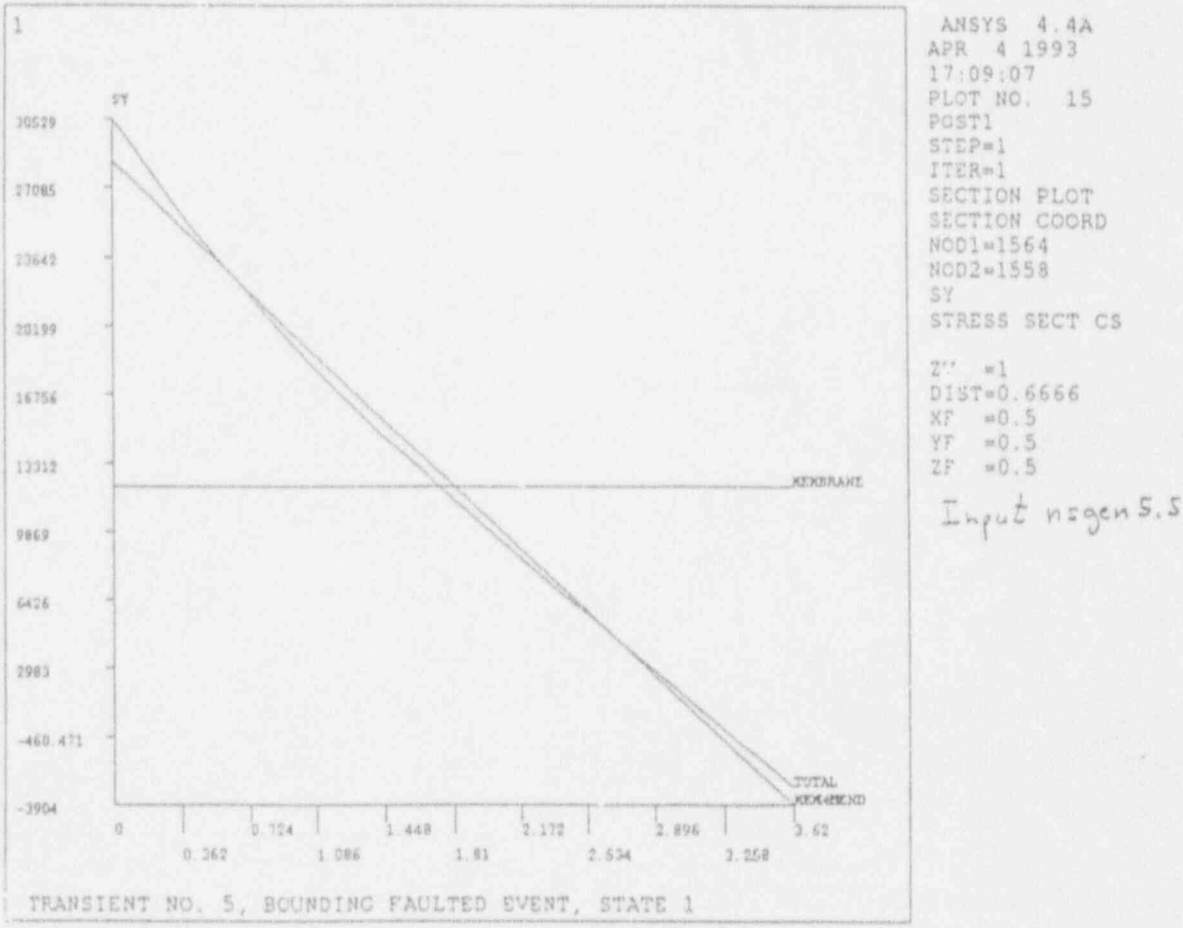



Figure 6-43. Bounding Faulted Event, Axial Stress Contributions, Steady State, t = 0 sec.

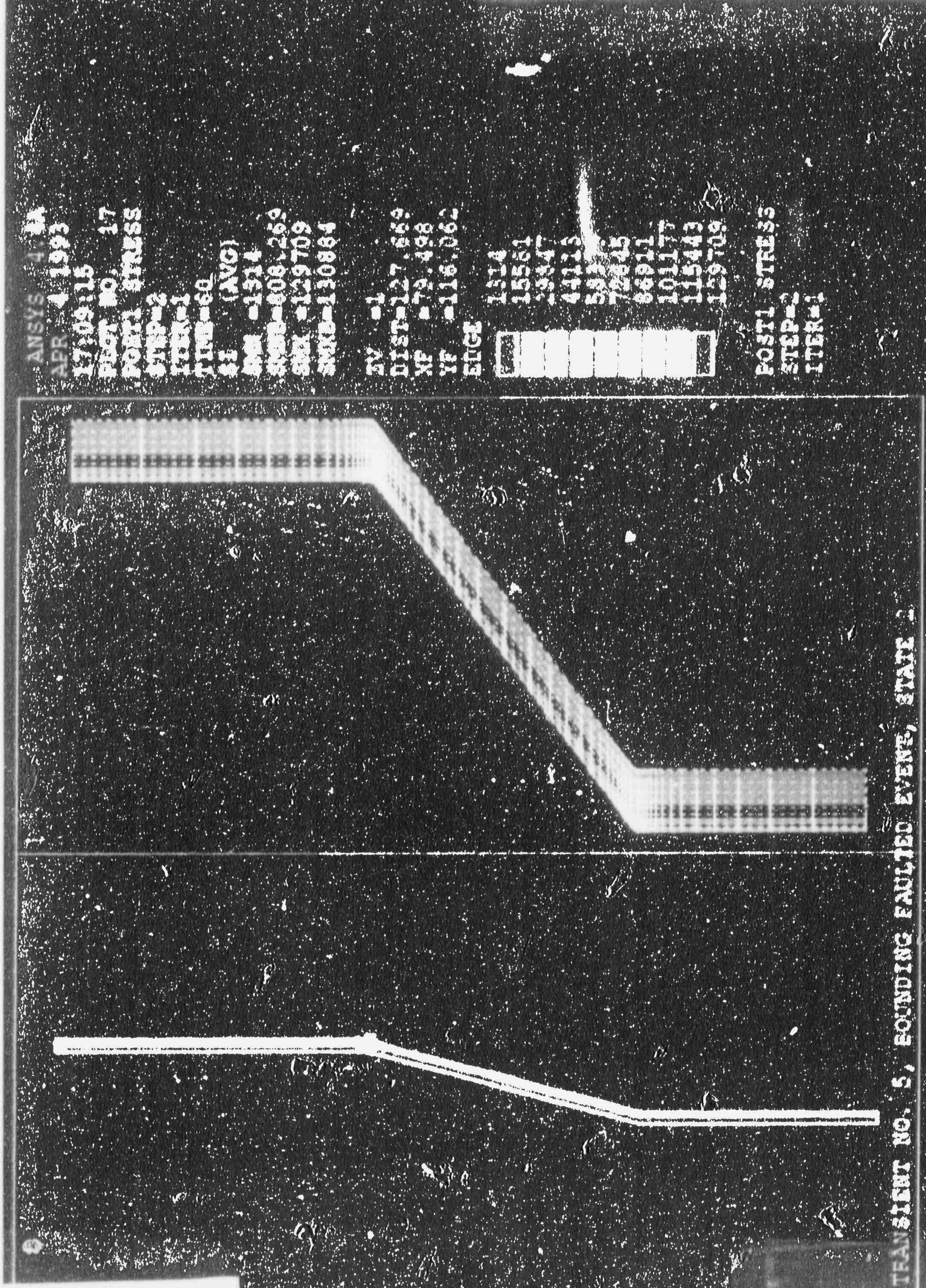



Figure 6-44 Bounding Faulted Event, Stress Intensity, t=60 sec

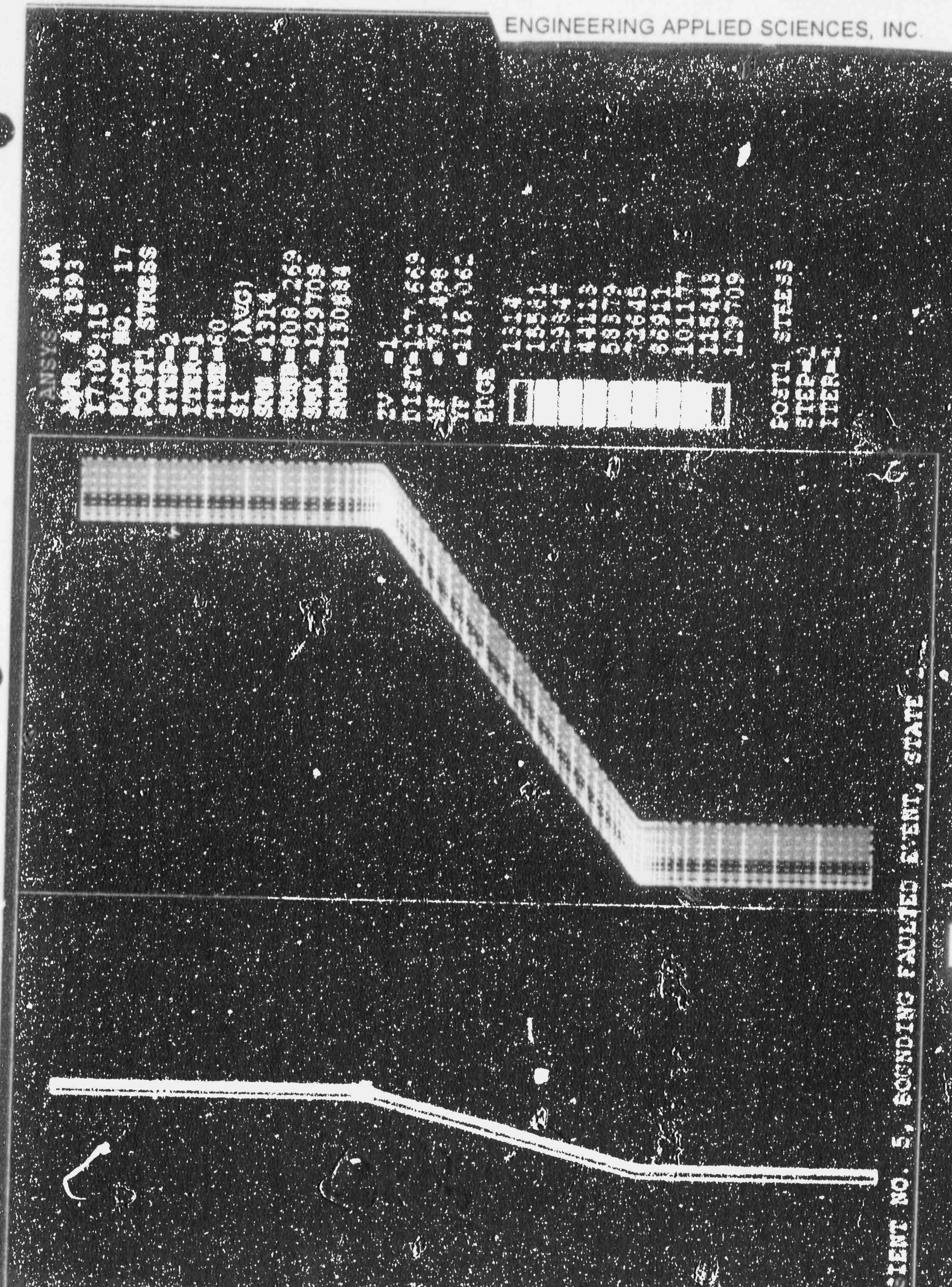



Figure 6-44 Bounding Faulted Event, Stress Intensity, t=60 sec

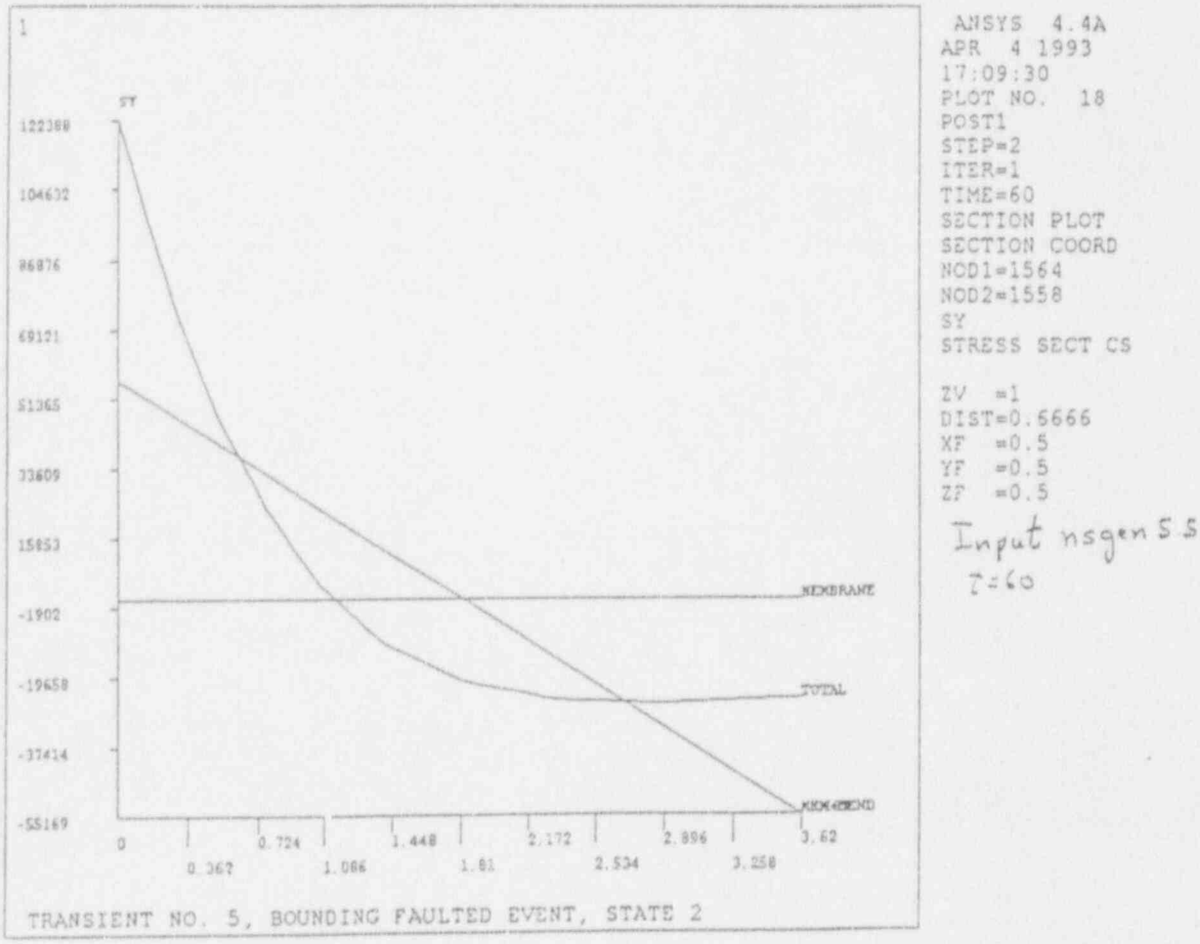



Figure 6-45. Bounding Faulted Event, Axial Stress Contributions, t = 60 sec.

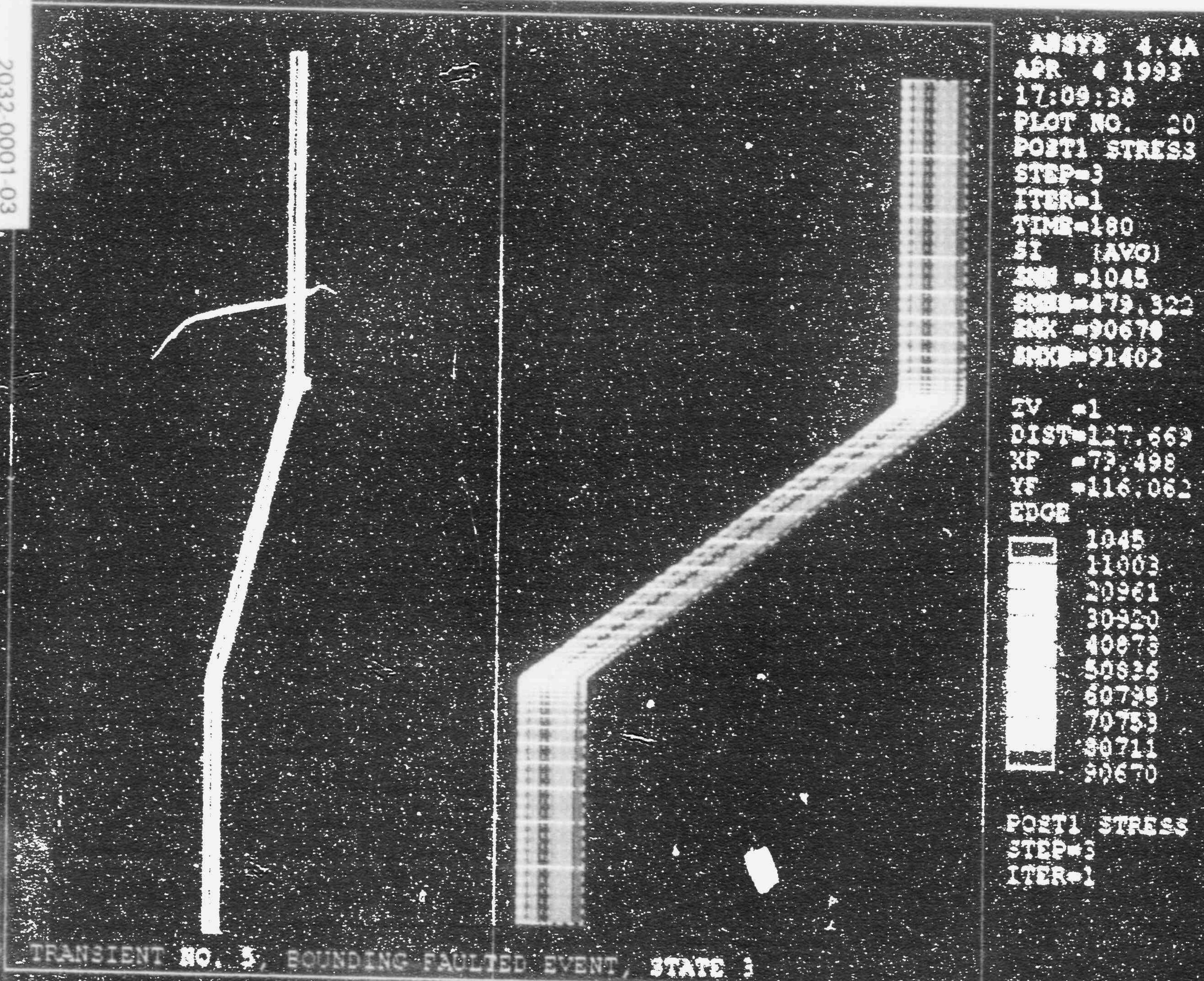



Figure 6-46 Bounding Faulted Event, Stress Intensity, t=197 sec

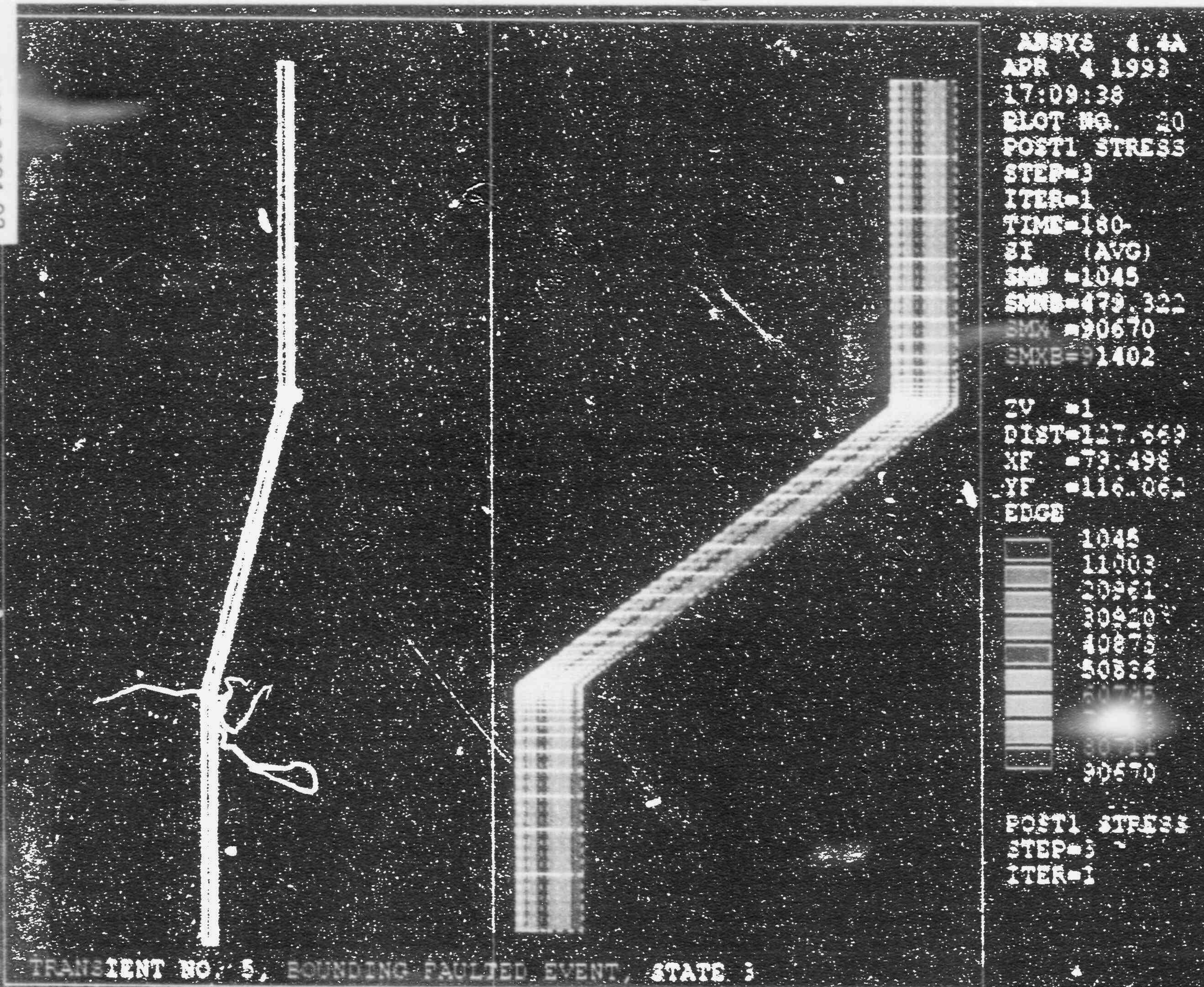



Figure 6-46 Bounding Faulted Event, Stress Intensity, t=197 sec

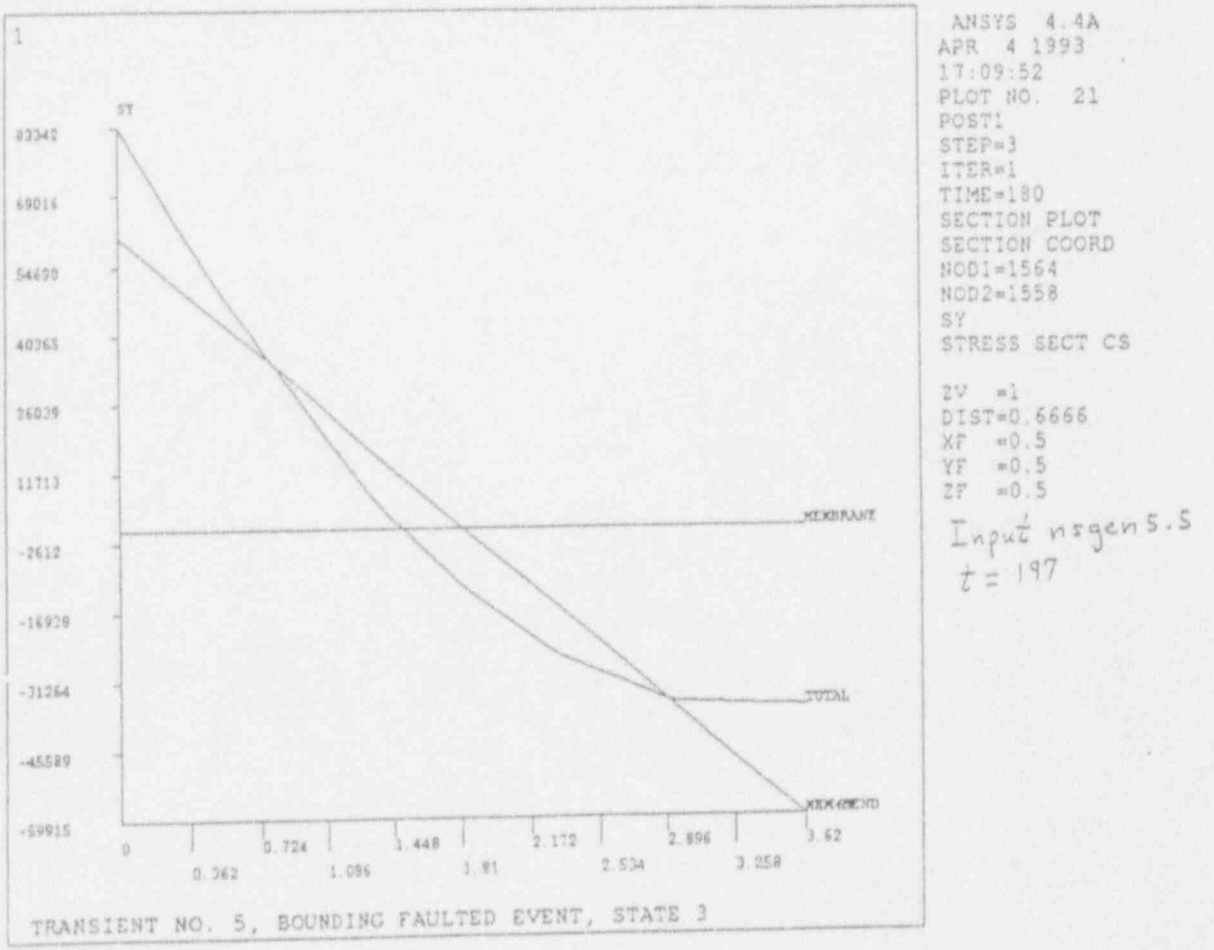



Figure 6-47. Bounding Faulted Event, Axial Stress Contributions, t = 197 sec.

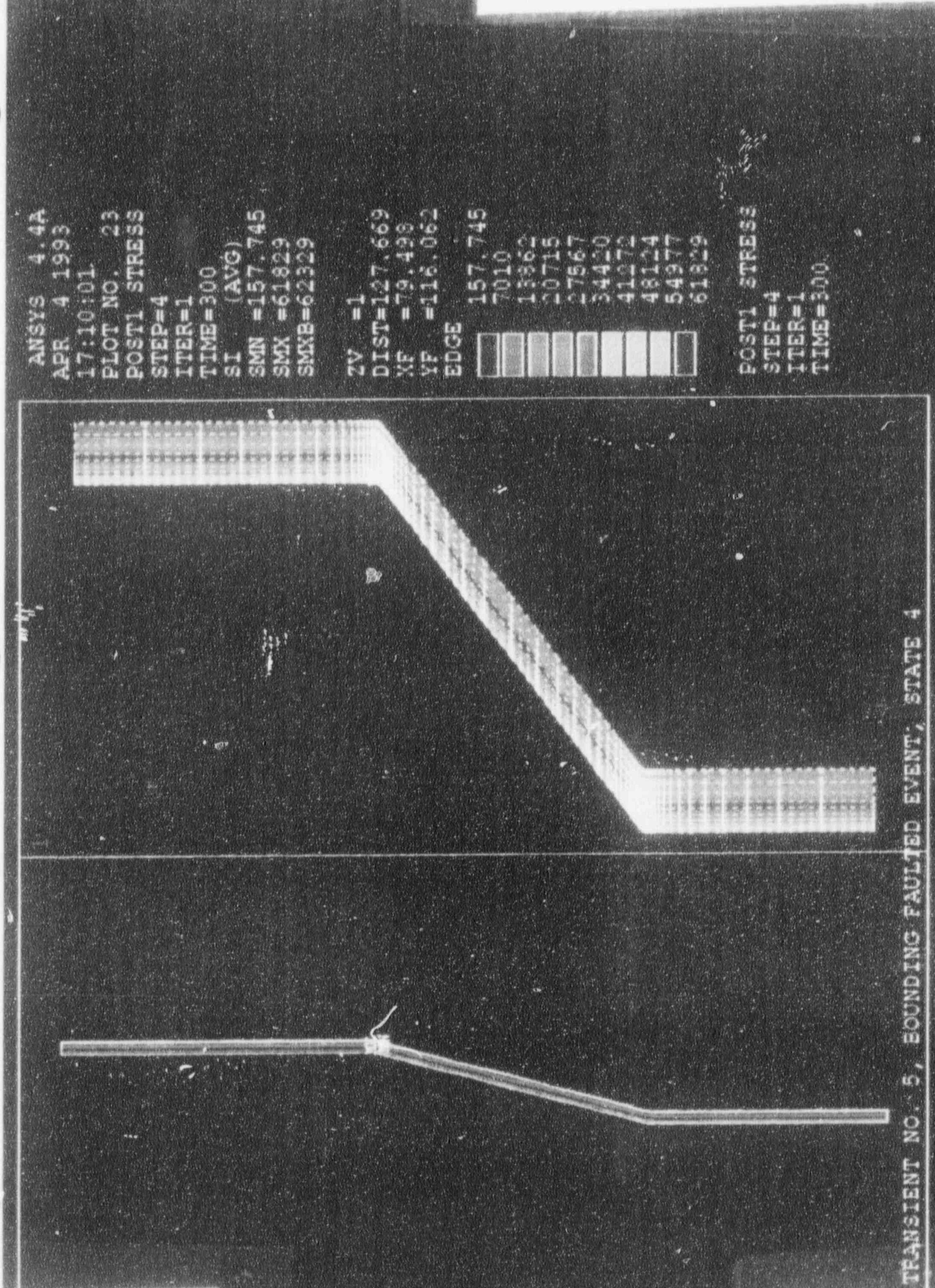



Figure 6-48 Bounding Faulted Event, Stress Intensity, t=347 sec

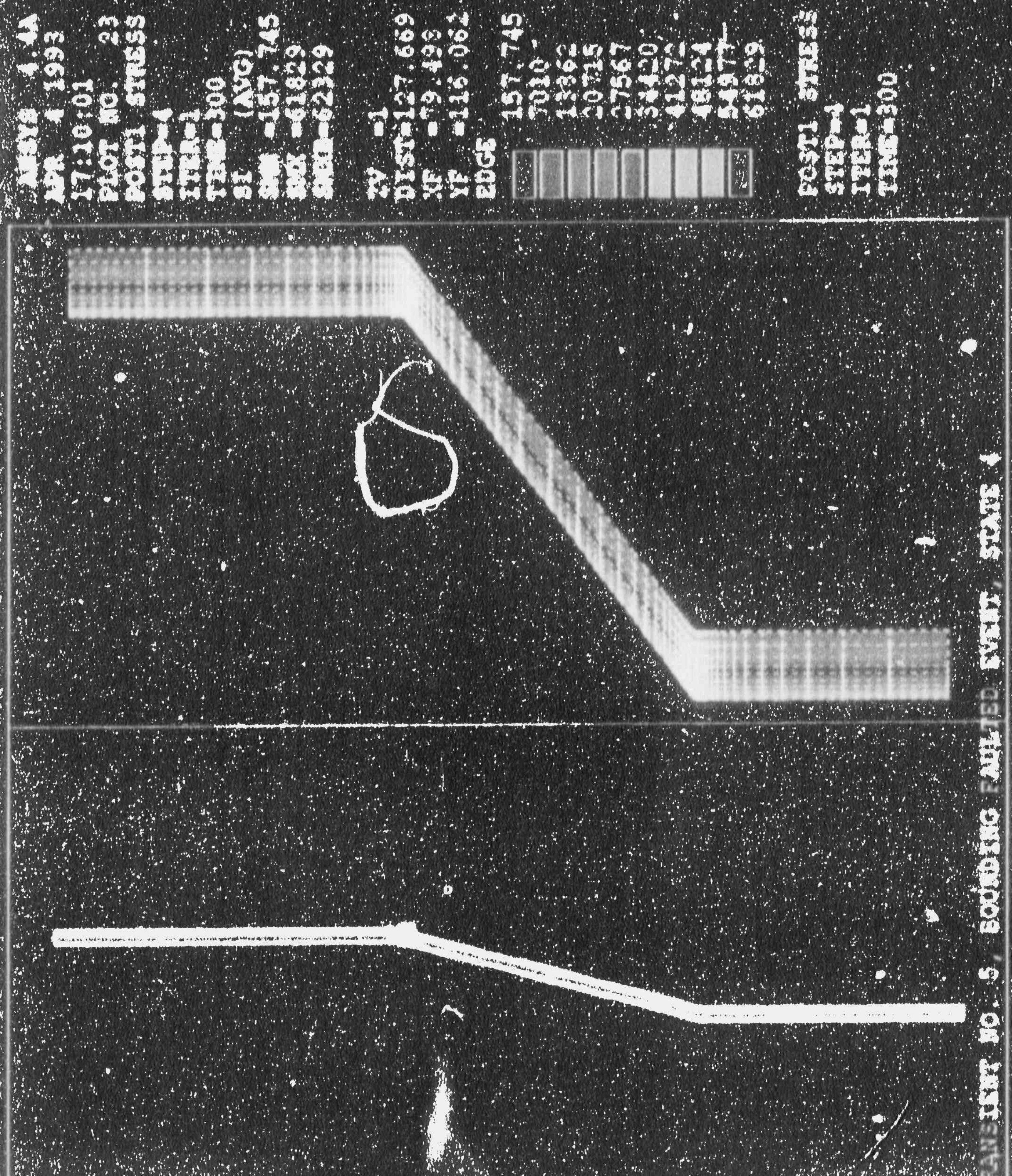



Figure 6-48 Bounding Faulted Event, Stress Intensity, t=347 sec

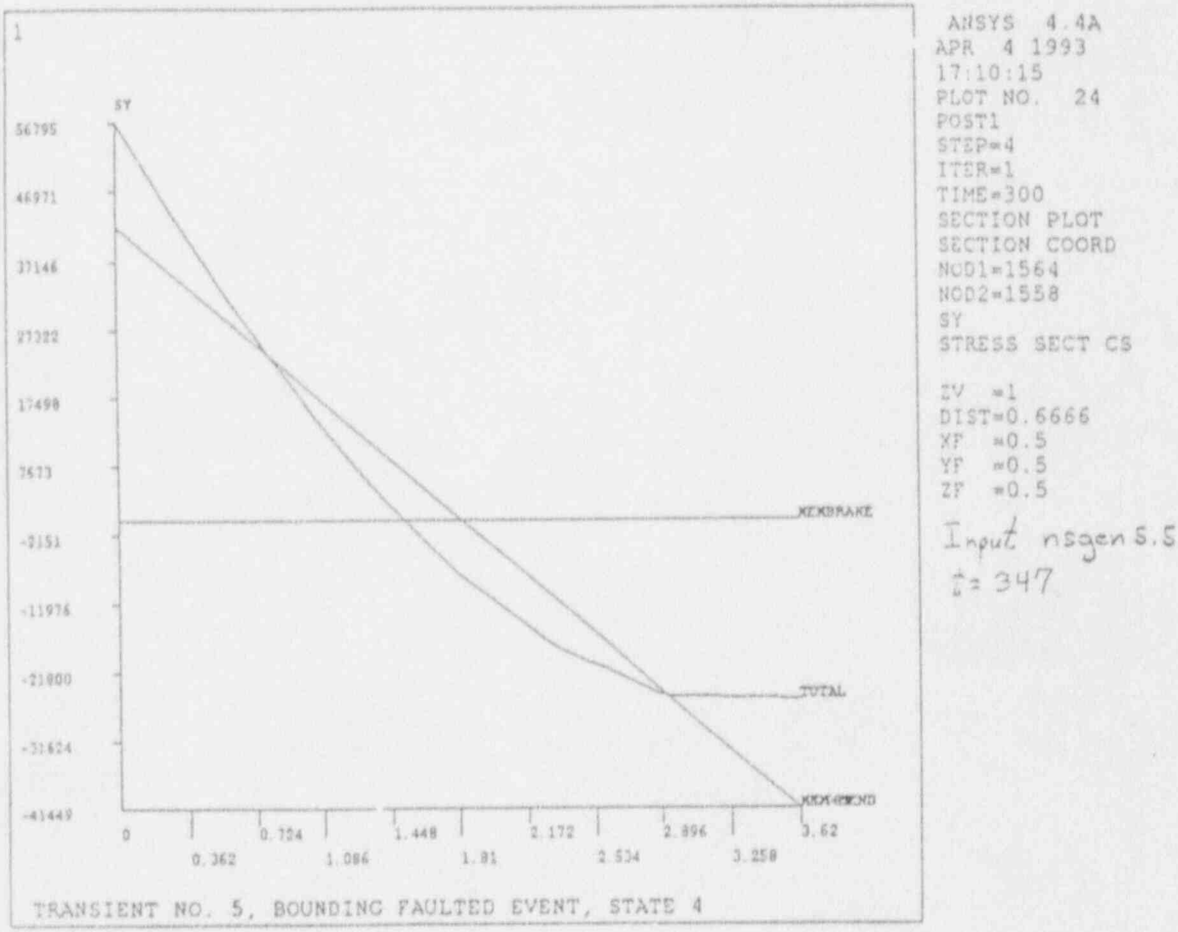



**Figure 6-49. Bounding Faulted Event, Axial Stress Contributions, t = 347 sec.**

# 7.0 FLAW EVALUATION BY FRACTURE MECHANICS

## 7.1 GENERAL APPROACH

The general approach for flaw evaluation has been described in Section 3. Flaws whose dimensions exceed the acceptance by examination standards of IWC-3510-1 may be accepted if they meet the analytical evaluation criteria of article IWC-3600. In the following parts of this section, the fracture mechanics flaw evaluation criteria are described and then applied to two cases of (1) a subsurface girth weld flaw and (2) a surface girth weld flaw. Stress analysis results of Section 6 are used in the evaluation. A range of normal and upset conditions are considered and a bounding analysis is used for the limiting emergency/faulted condition.

## 7.2 FLAW ACCEPTANCE BY ANALYSIS CRITERIA

Flaw acceptance by analysis criteria are taken from Section XI, article IWC-3600 of the ASME B&PV Code, 1992 Edition. Analysis procedures and material property data follow Appendix A. Flaw acceptance criteria and analysis procedures are as follows.

For the purposes of these conservative analyses, a bounding case has been assumed that all flaws lie in a plane perpendicular to the hoop stress component. Fracture evaluation acceptance criteria may be based on allowable flaw size or applied stress intensity factor. In the former case, flaws are considered acceptable by Code if:

$a_f < 0.1\ a_c$

$a_f < 0.5\ a_i$

where $a_f$ = the maximum size to which the detected flaw is calculated to grow in a specified time period, which can be the next scheduled inspection of the component or until the end of vessel design lifetime.

$a_c$ = the minimum critical flaw size of the flaw under normal operating conditions.

$a_i$ = the minimum critical flaw size of the flaw for initiation of nonarresting growth under postulated emergency and faulted conditions.

These criteria interject a safety factor of ten (10) on critical crack length for instability (normal/upset) and a factor of two (2) on the critical crack length for initiation (emergency/faulted). Another way of evaluating these same criteria is through critical stress intensity factors for initiation and for arrest. Flaws may be shown to be acceptable on the basis of applied stress intensity factor if the applied stress intensity factor and/or the flaw size "a"$_f$ satisfy the following criteria.

(a) For normal conditions:

$$K_I < \frac{K_{Ia}}{\sqrt{10}}$$

where $K_I$ = the maximum applied stress intensity factor for normal (including upset and test) conditions for the flaw size $a_f$ (defined in IWB-3611)

$K_{Ia}$ = the available fracture toughness based on crack arrest for the corresponding crack tip temperature.

(b) For emergency and faulted conditions:

$$K_I < \frac{K_{Ic}}{\sqrt{2}}$$

where $K_I$ = the maximum applied stress intensity factor for the flaw size $a_f$ under emergency and faulted condition

$K_{Ic}$ = the available fracture toughness based on fracture initiation for the corresponding crack tip temperature.

Demonstration of flaw acceptability by analysis is perhaps simplest using the stress intensity factor approach. The applied stress intensity factor need only be compared to acceptable levels based on initiation or arrest toughness values. If the flaw size is such that a more refined approach is needed, then advantage can be taken of the fact that for emergency or faulted conditions, a crack which initiates growth but arrests before penetrating 75% of the vessel wall is acceptable. The allowable flaw size approach allows for this circumstance.

The stress intensity factor criteria simply prevents the onset of fracture and thus crack arrest is not evaluated. The stress intensity factor criteria will be used in general. The flaw size criteria will be used in the event of a flaw which fails the emergency/faulted stress intensity factor criteria.

## 7.3 COMPUTATION OF APPLIED STRESS INTENSITY FACTORS

The applied stress intensity factor can be determined by the K formula given in Article A-3000, Section XI, ASME B&PV Code, 1992 Edition.

$$K_I = \sigma_m M_m \sqrt{\pi} \frac{\sqrt{a}}{Q} + \sigma_b M_b \sqrt{\pi} \sqrt{\frac{a}{Q}}$$

where $\sigma_m$ = Linearized bending stress distribution through the vessel wall thickness

$a$ = minor half diameter, inches, of subsurface flaw or depth of a surface flaw

$Q$ = flaw shape parameter to be determined from Figure A-3300-1 using $(\sigma_m + \sigma_b)/\sigma_{ys}$ and the flaw geometry.

$M_m$ = correction factor for membrane stress from Figure A-3300-2

$M_b$ = correction factor for bending stress from Figure A-3300-5

The linearization of actual stress profiles across the wall thickness is accomplished by the procedure depicted in Figure 7-1.

In some cases, more sophisticated formulations for stress intensity factors can make the difference between flaw acceptance or rejection. In cases where conservative bounding calculations are not appropriate then more sophisticated approaches will be utilized. For example, the stress distribution across the wall thickness can be modeled as a third order polynomial rather than by a straight line. It is sometimes convenient to select a bounding case crack length as a continuous 360° surface flaw. When this is not appropriate, the finite length of the actual indication will be considered. Also possible crack shape changes during fatigue crack growth are typically not considered.

## 7.4 SELECTED FLAW GEOMETRIES

The subsurface flaw geometry selected for analysis is one which was indicated to be in the upper shell to transition cone girth weld of steam generator D, Zion Unit 2, during the 1990 spring refueling outage. The subsurface flaw is in a circumferential orientation with a total length, l, of 3.20 inches and a total depth, 2a, of 1.01 inches. An elliptical shape is assumed. The distance of closest approach to the shell ID is 0.27 inches. The depth and length of the flaw leads to an aspect ratio, a/l, of 0.158.

The surface flaw geometry selected for analysis is a flaw open to the ID of the steam generator shell with a depth of 0.30 inches and a length of 1.90 inches. This leads to the same aspect ratio, a/l, as the surface flaw. As in the subsurface flaw case, a circumferential orientation and elliptical flaw shape is assumed.

## 7.5 LOADING CONDITIONS

Finite element stress analysis results are presented in Section 6 for a number of specified transients and conditions. Normal and upset transients are heat up, cool down, large step load decrease, auxiliary feedwater cycling at hot standby and reactor trip. Specific conditions of interest during these transients are the initial condition for the cool down transient which is 547°F at 1020 psi, termed here hot standby, and the initial condition for the large step load decrease, 506°F at 720 psi, which is the steady state 100% power condition.

The above transients and conditions combine together to create cyclic loading conditions. For example, the heat up and cool down transients produce a heat up/cool down cycle and the transition from hot standby to 100% power produces the loading and unloading to 100% power fatigue cycle.

At hot standby, auxiliary feedwater cycling maintains a reasonably constant secondary side water level. This auxiliary feedwater cycling occurs about 10 minutes every two hours leading to cyclic thermal stresses. Using the thermal hydraulic boundary conditions from Reference 7, stresses developed during this transient condition were analyzed, with the results presented in Section 6. At hot standby, five cycles of thermal stresses occur about every two hours. For fatigue crack growth calculations the cyclic stress range for all five cycles was conservatively set equal to the maximum range.

Fatigue cycles considered in this analysis are tabulated in Table 7-1. The design allowable occurrences are taken from Reference 5. Present conservative estimates of occurrences per fuel cycle are also listed. The total of 540 cycles for loading and unloading to 100% power is an occurrence rate of about once a day for 18 months. The total of 1250 cycles for auxiliary feedwater cycling is based on a conservative estimate of 500 hours of hot standby per fuel cycle with an average of 2.5 cycles per hour. The total of 1250 cycles is considered to umbrella other less severe transients involving auxiliary feedwater cycling. Figure 7-2 is a schematic illustration of fatigue cycles included in the present analysis.

A bounding faulted event had to be assumed since previous documentation regarding the limiting faulted event was unavailable. Reference 6 refers to a transient involving water ingress to a hot, dry steam generator shell. This thermal shock event was selected as the bounding faulted transient. For convenience in analysis, the ID metal temperature of the shell was ramped from 547°F to 70°F in one minute. This is more severe than can occur in practice but serves as a bounding event. No internal pressure was applied during the thermal shock.

**Table 7-1. Fatigue Design Allowables**

| Fatigue Cycle | Total Design Allowable Occurrences | Estimated Occurrence Per Fuel Cycle |
|---|---|---|
| Heat up & cool down | 200 | 20 |
| Loading & unloading to 100% power | 18,300 | 540 |
| Large step load decrease | 200 | 20 |
| Reactor (turbine) trip | 400 | 40 |
| Auxiliary feedwater cycling during hot standby | 18,300 | 1250 |

## 7.6 FATIGUE CRACK GROWTH ANALYSIS

From the finite element stress analyses of Section 6 and the fatigue cycle list of Table 7-1, six loading conditions are of interest. These are hot standby, which is 547°F at 120 psi, steady state 100% power, which is 506°F at 720 psi, large step load decrease, auxiliary feedwater cycling reactor trip. From consideration of fatigue cycling, the time of interest for the large step load decrease transient is 1200 seconds and for the reactor trip transient, 685 seconds. During auxiliary feedwater cycling the largest stress range occurs between 450 seconds and 560 seconds into the 600 second total duration of the transient. Axial stress distributions across the wall thickness for these conditions are shown in Figure 7-2. Linearized membrane and bending stresses according to Figure 7-1 are listed in Table 7-2 for the subsurface flow case and in Table 7-3 for the surface flaw case.

**Table 7-2. Subsurface Flaw Case**

| Condition | Linearized Membrane Stress (ksi) | Linearized Bending Stress (ksi) | Stress Intensity Factor (ksi√in) |
|---|---|---|---|
| Hot Standby | 10.56 | 19.32 | 29.84 |
| 100% Power | 7.46 | 13.64 | 21.06 |
| Large Step Load Decrease (t = 1200 seconds) | 10.39 | 14.72 | 25.16 |
| Reactor Trip (t = 685 seconds) | -0.71 | 10.29 | 7.72 |
| Auxiliary Feedwater Cycling | | | |
| (t = 450 seconds) | 10.23 | 15.75 | 26.43 |
| (t = 560 seconds) | 7.80 | 34.02 | 32.19 |

**Table 7-3. Surface Flaw Case**

| Condition | Linearized Membrane Stress (ksi) | Linearized Bending Stress (ksi) | Stress Intensity Factor (ksi√in) |
|---|---|---|---|
| Hot Standby | 6.98 | 23.55 | 28.98 |
| 100% Power | 4.92 | 16.63 | 20.46 |
| Large Step Load Decrease (t = 1200 seconds) | 7.90 | 17.67 | 24.57 |
| Reactor Trip (t = 685 seconds) | -3.80 | 13.93 | 8.73 |
| Auxiliary Feedwater Cycling | | | |
| (t = 450 seconds) | 17.10 | 7.64 | 25.15 |
| (t = 560 seconds) | -10.17 | 49.30 | 34.39 |

Fatigue cycling between the conditions listed in Tables 7-2 and 7-3 is illustrated schematically in Figure 7-2. The estimated number of transients per fuel cycle is also shown. The initial stress intensity factor ranges associated with these fatigue cycles are summarized in Tables 7-4 and 7-5 along with the R ratio, that is the ratio of minimum to maximum stress intensity factor during the fatigue cycle.

**Table 7-4. Subsurface Flaw Case**

| Fatigue Cycle | Stress Intensity Factor Range | R Ratio |
|---|---|---|
| Large step load decrease | 4.10 | 0.84 |
| Standby to 100% power | 8.78 | 0.71 |
| Reactor trip | 22.12 | 0.26 |
| Heat up & cool down | 29.84 | 0.00 |
| Auxiliary feedwater cycling | 5.76 | 0.82 |

**Table 7-5. Subsurface Flaw Case**

| Fatigue Cycle | Initial Stress Intensity Factor Range ($\Delta K$, ksi$\sqrt{in}$) | R Ratio |
|---|---|---|
| Large step load decrease | 4.11 | 0.83 |
| Hot standby to 100% power | 8.52 | 0.71 |
| Reactor trip | 20.25 | 0.30 |
| Heat up & cool down | 28.98 | 0.00 |
| Auxiliary feedwater cycling | 9.24 | 0.73 |

Fatigue crack growth is computed via the equation:

$$da/dN = C_0 \, \Delta K^n$$

where $\Delta K$ is the stress intensity factor range. The parameters $C_0$ and n are found in Article A-4000 Section XI of the ASME B&PV Code. The air reference properties are used for the subsurface flaw since the crack is not exposed to an aqueous environment. For the surface flaw case exposure of the crack tip to the aqueous environment increases the fatigue crack growth rate and the $C_0$ and n parameters are adjusted accordingly. Integration of the above equation leads to the crack size, a, as a function of the number of cycles, N. In general, the stress intensity factor range varies with location along the crack front and crack shape changes can occur during fatigue crack growth. For the present, the common assumption of self similar growth is applied. With this assumption and the further assumption that variations in $M_m$ and $M_b$ with crack size, a, are small, fatigue crack growth was computed for one fuel cycle.

For the subsurface flaw, the crack size, a, increased from 0.505 to 0.5055 inches over one fuel cycle. In this case fatigue crack growth is virtually non existent. For the surface crack case, where the starting crack depth was 0.302 inches, increased fatigue crack growth rates to account for the effect of exposure to a water environment led to a small amount of predicted crack growth. After one fuel cycle, an ASME Code analysis predicts an increase in crack depth from 0.302 to 0.343 inches. This amount of growth is small and is consistent with the computational assumptions. The computed crack growth is somewhat of an overestimate since upper bound growth rates were used rather than changing the "$C_0$" and "n" parameters for low $\Delta K$ levels. In some cases, girth weld cracks in steam generators have grown faster than ASME Code analyses would predict. Historical observations of cracking at Zion Units 1 and 2 are discussed in the next section along with additional crack growth considerations.

## 7.7 CRACK GROWTH CONSIDERATIONS

Environmentally enhanced crack growth has been observed in low alloy steels tested in high temperature water. This is reflected in the fact that the ASME Code fatigue crack growth rate curve for aqueous environments lies above the line for air environments. Factors which promote environmentally enhanced crack growth rates are low flow past the crack mouth, high crack tip strain rates, buildup of sulfur anions near the crack tip and oxidizing conditions. With sufficiently high levels of loading, water with high oxygen levels can lead to crack growth under constant rather than cyclic loading.

Crack depth observations at Zion Units 1 and 2 were discussed in Section 3. Crack depths as measured by ultrasonic testing were compared to crack depths revealed by repeated grinding and MT testing. Ultrasonic testing indicated the presence of much deeper surface cracks than the more reliable MT/grindout process. See Figure 3-3. Part of the disparity in results may be due to the surface proximity rules used to judge if a UT indication must be treated as surface connected. Using the MT/grindout process as the most accurate indicator of crack depth, the maximum crack depth observed after about 10 cycles of operation was 0.58 inches. After removal of all indications, subsequent operation for one additional cycle led to a maximum observed MT/grindout depth of 0.32 inches. This historical performance sets the scale for expected observations of crack depth after several cycles of operation. Crack growth predictions of the previous section from an ASME Code corrosion fatigue perspective essentially underestimate expected crack depths.

Based on the above information and the service performance of similar steam generator units, Reference 8-17, it is argued that periodic exposure to water with elevated oxygen levels has led to environmentally enhanced crack growth under the combined action of static and cyclic loads. The extent of crack growth appears to be greater than a pure corrosion fatigue process would predict. Auxiliary feedwater cycling provides periodic injections of water with elevated oxygen levels. These elevated oxygen levels are transient as diffusion occurs and elevated temperatures lead to more efficient oxygen scavenging by hydrazine in the auxiliary feedwater cycling. Associated cyclic thermal stressing is considered important from a corrosion fatigue standpoint but, perhaps more importantly, periodic active straining of crack tips can serve to stabilize crack growth under longer periods of static loading. With this viewpoint crack growth is principally related to periods of auxiliary feedwater cycling.

Measured crack growth rates in high temperature oxygenated water under static and slowly varying loads are shown in Figure 7-4 and 7-5, Reference 8. At very high oxygen levels the maximum observed crack growth rate is about 4x10-3 inches/hour, while at more moderate oxygen levels this rate is on the order to 10-4 inches/hour. During one fuel cycle, auxiliary feedwater cycling may occur over an estimated 500 hours total. In this time period an unrealistically high oxygen level of 8 ppm could lead to about 2 inches of crack growth. A more realistic oxygen level would lead to an estimate of about 0.05 inches of crack growth. These growth estimates bound the historical observations of crack depths at Zion Units 1 and 2. The most reasonable approach to crack depth projections is to use the historical data.

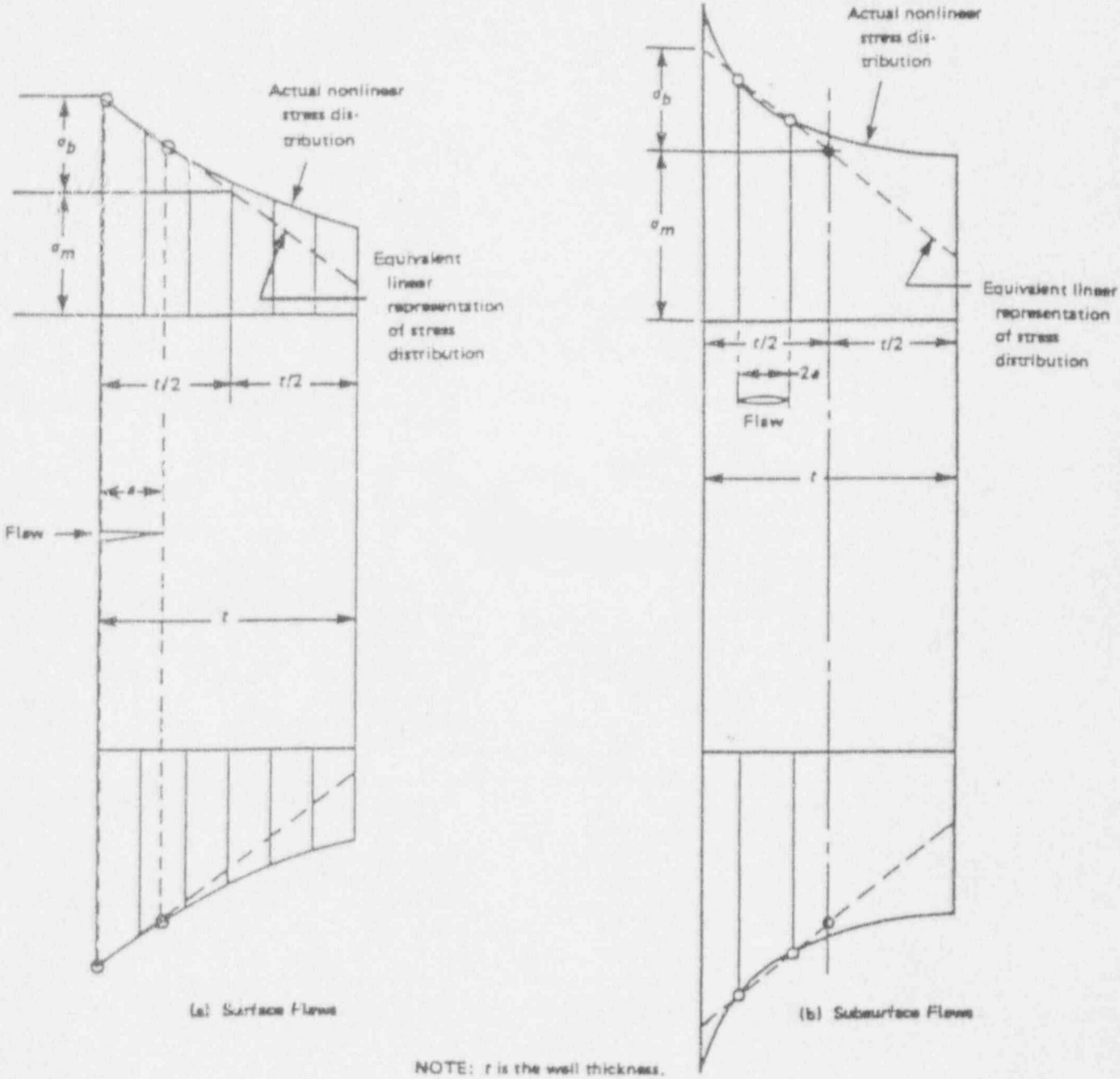
A reasonable yet conservative use of historical crack depth information is to select a crack growth increment for one cycle of operation equal to the largest, new, one cycle, crack depth that has appeared in the past, 0.32 inches. For the presently selected, beginning of cycle, surface crack depth of 0.30 inches, this would lead to an end of cycle crack depth of 0.64 inches. As a check of the reasonableness of this projection recall that the maximum observed crack depth after 10 cycles is 0.58 inches. The cumulative probability plot of Figure 3-2 for 10 cycles of operation indicates about a 1% probability of occurrence of a crack depth of 0.64 inches or larger. The case of interest here is a projection for 2 cycles of operation, the past cycle and the next cycle. An end of cycle projected crack depth of 0.64 inches is conservative.

### 7.8 APPLICATION OF FRACTURE EVALUATION ACCEPTANCE CRITERIA

For normal and upset conditions the allowable stress intensity factor is $K_{Ia}/\sqrt{10}$. A good limiting case, $RT_{NDT}$, assuming cracks to be in the weld region, is 10°F. If cracks in the base metal are of interest, then a limiting $RT_{NDT}$ of 30°F would be appropriate. In either case, temperatures at normal and upset conditions lead to the consideration of upper shelf toughness levels rather than transition range values. The $K_{Ia}$ toughness from Article A4000 is expected to be in excess of 200ksi√in at a temperature near 220°F. Measurement of upper shelf toughness would require massive specimens for a linear elastic fracture mechanics approach to the materials of interest. Upper shelf toughness levels expressed in terms of K are more typically inferred from elastic plastic tests and the trending of results from lower temperatures. A value of 200ksi√in to characterize the appropriate upper shelf toughness is conservative. This value is selected as limiting. The allowable stress intensity factor is then 63.3 ksi√in. The maximum applied stress intensity factor for the specified subsurface and surface flaws is comfortably less than this value. The stress intensity factor criteria for normal and upset conditions is met. It is met at both hot standby, conditions, 547°F and 1020 psi and the design temperature and pressure of 600°F and 1085 psi.

For emergency and faulted conditions, the limiting transient is selected as a thermal shock from 547°F to 70°F without internal pressure. In this case, the stresses are taken from a transient thermal stress analysis as presented in Section 6. The stress and temperature distributions were available at 60 and 660 seconds into the transient. Over the crack lengths of interest, the stress and temperature distributions were essentially linear. Temperatures and stresses were interpolated for other times. The temperature at the crack tip determines the allowable stress intensity factor. As time into the transient increases, the temperature at the crack tip drops and thus the allowable stress intensity factor, $K_{IC}/\sqrt{2}$, also decreases. However, as time increases, the thermal stresses decrease and this decreases the applied stress intensity. The applied and allowable stress intensity factors were plotted as a function of time during the faulted transient. The applied stress intensity factor was always substantially less than the allowable value with the worst case condition at one minute into the transient. Even with a bounding faulted transient event, the faulted transient allowable stress intensity factor criteria were easily met.

The ASME Code fatigue analysis indicated minimal crack growth over one cycle of operation for both the subsurface and surface cracks. From historical observations of girth weld cracks at Zion Units 1 and 2, the performance of similar plants and crack growth rate data is the literature, crack growth for surface cracks is expected to be larger than the standard ASME Code corrosion fatigue analysis. In the previous section a conservative growth allowance of 0.32 inches for one cycle of operation was discussed. Increase of the crack depth by this amount while assuming a constant a/l ratio is a reasonable, conservative approach to arrive at a projected end of cycle crack depth and shape. From previous analysis, the allowable end of cycle crack size is limited by the stress intensity factor criteria for normal and upset conditions. The limiting condition is auxiliary feedwater cycling at 275 seconds into this transient. Figure 7-6 shows a plot of stress intensity factor versus surface crack depth under this loading. Curves are shown for several crack shapes, as specified by the a/l ratio. The allowable stress intensity level is indicated by a dotted line. Figure 7-6 thus specifies the allowable end of cycle allowable crack shapes and sizes and may be used with the above mentioned growth allowance to evaluate the acceptability of NDE crack indications at girth welds.




From Fig. A-3200=1
Figure 7-1. Linearized Representation of Stresses

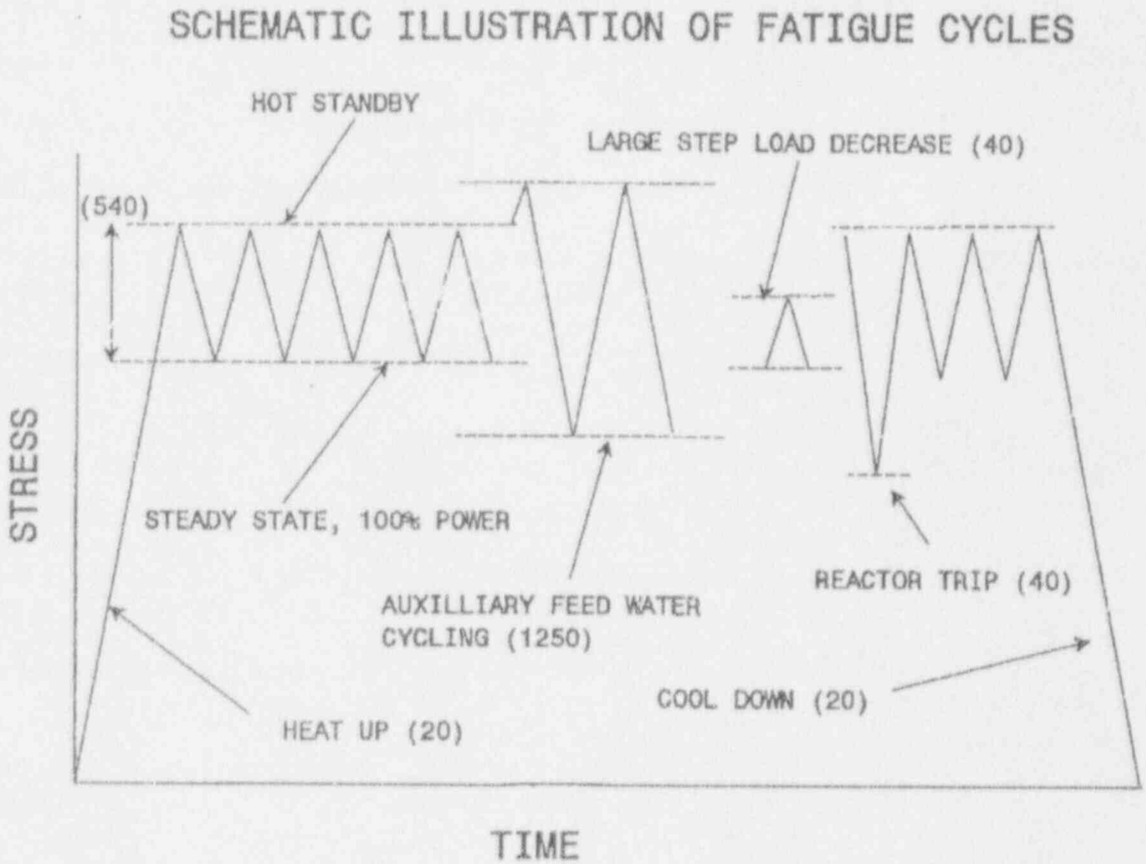



Figure 7-2. Schematic Stress Time Plot to Identify Fatigue Cycles

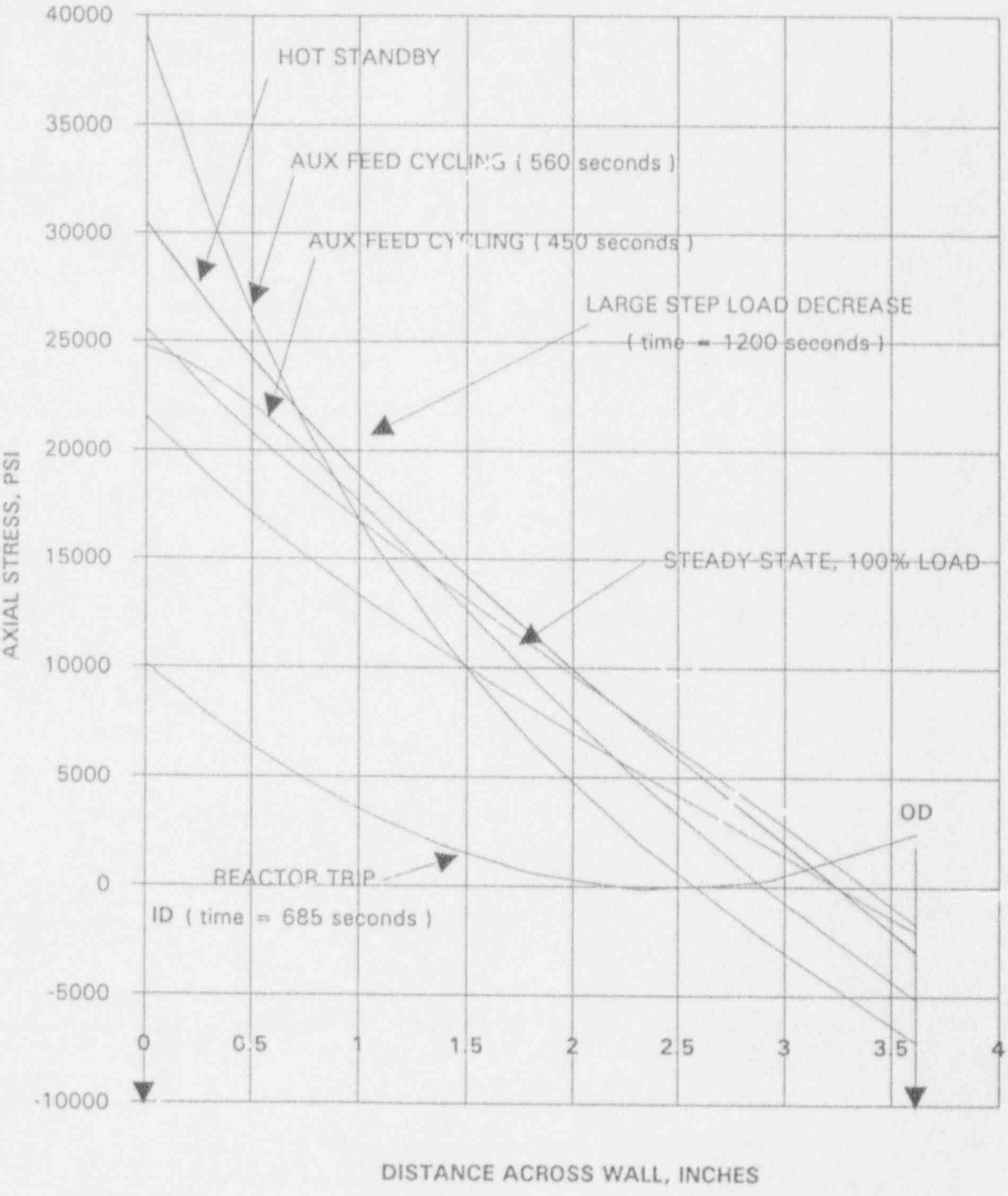
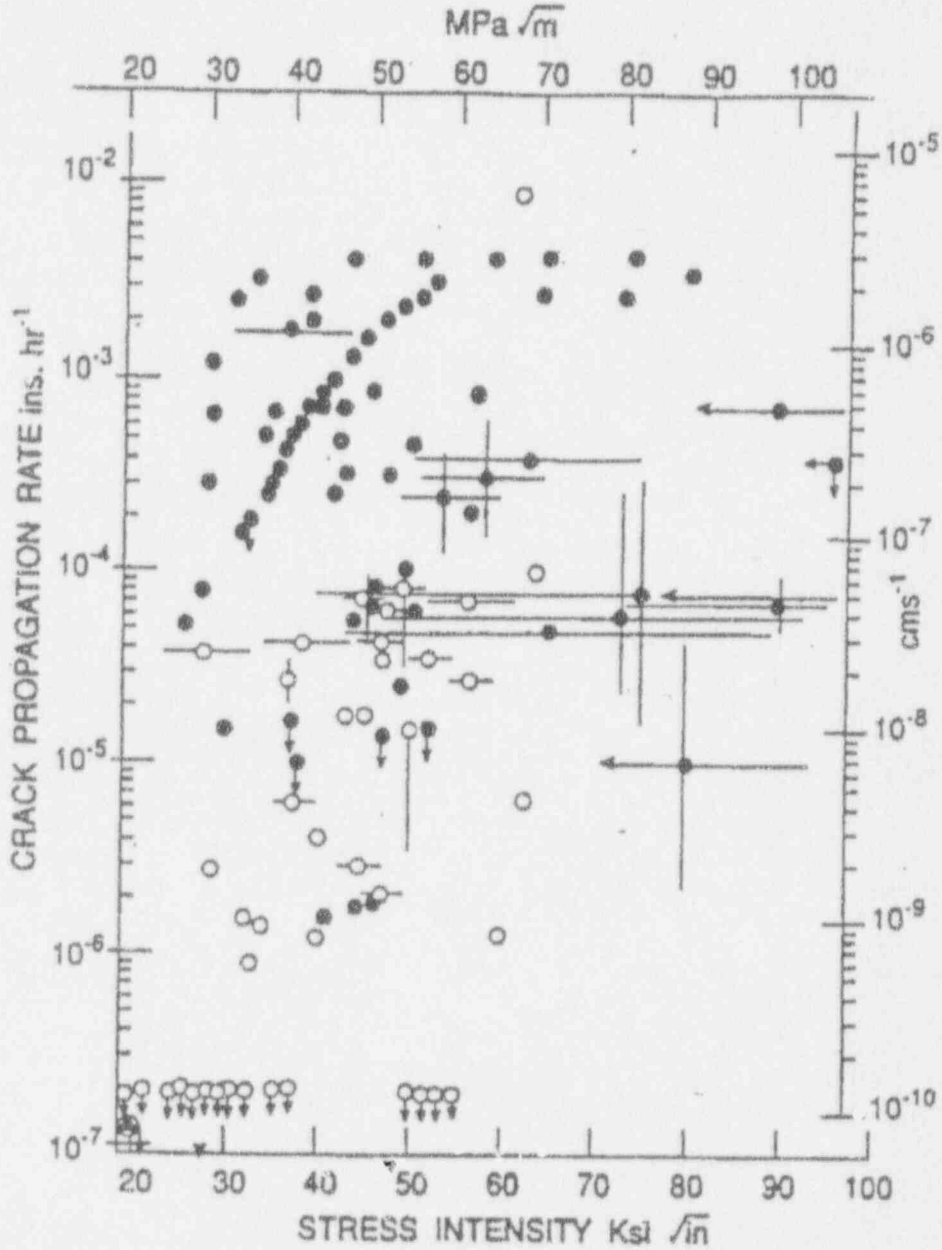
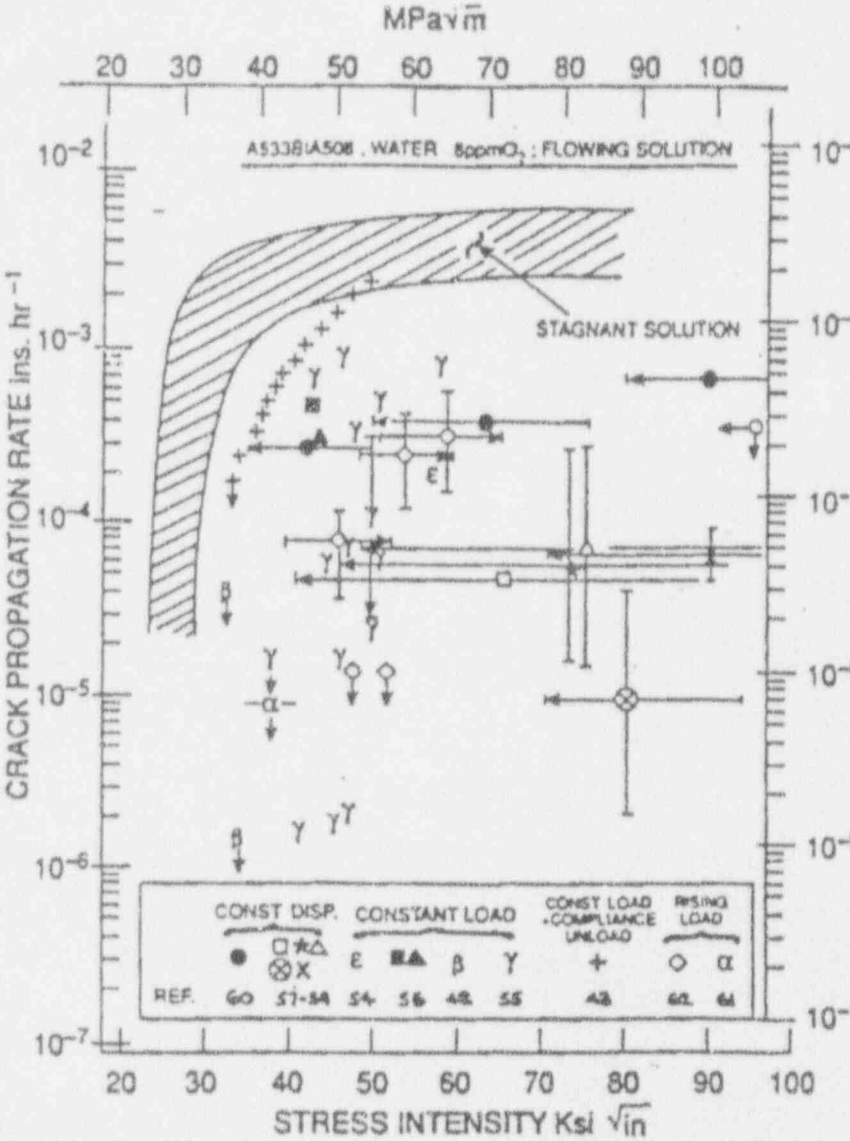



**Figure 7-3. Axial Stress Distribution Across Wall Thickness**




Summary of transgranular stress corrosion data for A533B, A508, SA333, and SA106 steels in oxygenated water at 288°C. The origin of these data will be referenced later, but essentially all those marked (●) were obtained in 8 ppm $O_2$ water, and those marked (O) were obtained in 200 ppb $O_2$ water. See Reference 8.

**Figure 7-4. Crack Growth of Low Alloy Steels in High Temperature Oxygenated Water**




Crack propagation rate/stress intensity data obtained in 8 ppm oxygenated, flowing water at 288°C for constant load, constant load with periodic unloading and constant displacement and rising load conditions. See Reference 8.

**Figure 7-5. Crack Growth of Low Alloy Steels in High Temperature Oxygenated Water**

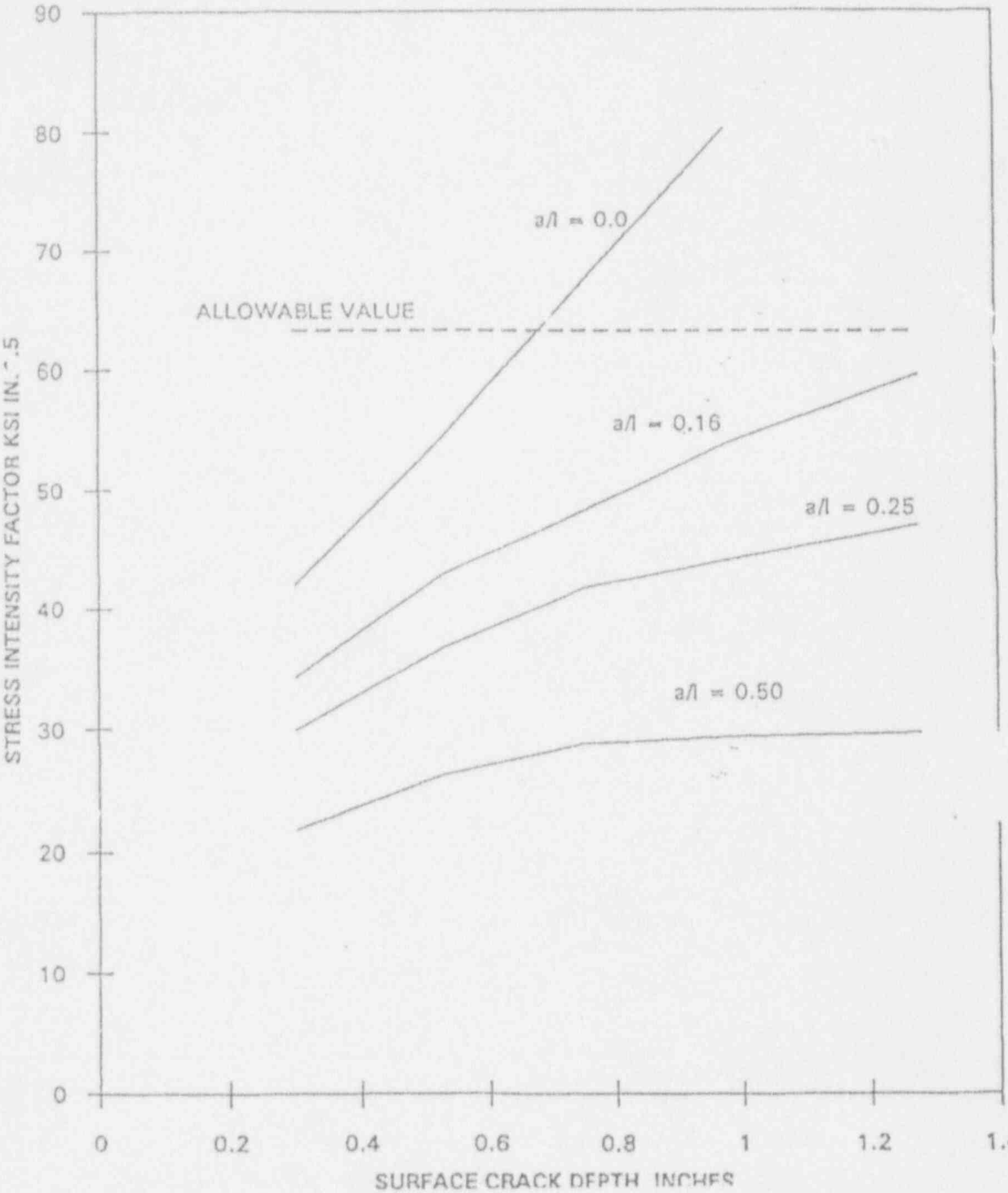



**Figure 7-6. Stress Intensity Factor Versus Surface Crack Depth During Maximum Normal/Upset Condition Loading**

## 8.0 REFERENCES


1. "ASME Boiler and Pressure Vessel Code," 1989 Code (no addenda) and the 1992 Edition was used for additional technical guidance, American Society of Mechanical Engineers, New York, NY.

2. Report, "Zion Steam Generator Girth Weld Flaw Evaluation," Engineering Applied Sciences Inc., No. 2011-024, dated February 3, 1993.

3. "ANSYS Engineering Analysis System User's Manual," For ANSYS Revision 4.4A, Gabe DeSalvo and Robert Gorman, Swanson Analysis Systems Inc., Houston, PA.

4. Roark, R.J., and W.C. Young, "Formulas for Stress and Strain," McGraw Hill Book Company, New York, NY, 1982.

5. Letter, R. Smith (EASI) to R. Mallett (MSTI), "Steam Generator Flaw Evaluation -Job No. 2017, dated March 17, 1993. MSTI Log. No. 2017-M018.

6. Bamford, W.H., et alii, "Background and Technical Basis: Handbook on Flaw Evaluation for the Zion, Byron and Braidwood Units 1 & 2 Main Coolant System and Components," Westinghouse Electric Corporation #WCAP-12446, Revision 1, dated December 1991.

7. Report, "Zion Unit 1 Steam Generator Girth Weld Repair Report Fall 1989, and Zion Unit 2 Steam Generator Girth Weld Repair Report Spring 1990," Westinghouse Electric Corporation Report WCAP-12489, June 1991.

8. Ford, F.P., Andresen, P.L., Weinstein, D., Ranganath, S., and Pathania, R., "Stress Corrosion Cracking of Low-allow Steels in High Temperature Water", Proceedings of the Fifth International Symposium on Environmental Degradation of Materials in Nuclear Power Systems - Water Reactors, ANS, 1992.

9. Van Der Sluys, W.A. and Pathania, R., "Studies of Stress Corrosion Cracking in Steels Used for Reactor Pressure Vessels", Proceedings of the Fifth International Symposium on Environmental Degradation of Materials in Nuclear Power Systems - Water Reactors, ANS, 1992.

10. Lenz, E. Wieling, N. and Munster, H., "Influence of Variation of Flow Rates and Temperature on the Cyclic Crack Growth Rate under BWR Conditions", Proceedings of the Third International Symposium on Environmental Degradation of Materials in Nuclear Power Systems - Water Reactors, TMS, 1988.

11. Thomas, C., Bamford, W.H., Kurak, D. and Rao, G.V., "Steam Generator Shell Cracking: Is It Service Degradation?", 1991 ASME Pressure Vessels and Piping Conference, Service Experience in Operating Plants, ASME PVP - Vol. 240, 1992.

12. Zajowski, C.J., "Evaluation of the Transgranular Cracking Phenomenon on the Indian Point Unit Three Steam Generator Vessels," Int. Jrnl. Press. Vessels and Piping, Vol. 6, No. 2, 1986.

13. Bamford, W.J., Smith, L.C. and Thurman, A.L., "Integrity Issues in PWR Steam Generators and Feedwater Systems," in Performance and Evaluation of light Water Reactor Pressure Vessels, ASME publication PVP-Vol. 119, 1987.

14. Rao, G.V., "Investigation and Resolution of Steam Generator Girth Weld Cracking Incidents in Pressurized Water Reactors," in Proceedings, International Symposium at Fontevraud II September 1990.

15. Bamford, W.H., Rao, G.V. and Houtman, J.I., "Investigation of Service-Induced Degradation of Steam Generator Shell Materials," in Proceedings of the Fifth International Symposium on Environmental Degradation of Materials in Nuclear Power Systems, - Water Reactors, August 1991. American Nuclear Society, April 1992.

16. Durkin, C.J. Jr., Sinka, S.K., Esselman, T.C. and Madia, J., "Characteristics of Steam Generator Girth Weld Cracking," 1991 ASME Pressure Vessels and Piping Conference, San Diego, CA, in Service Experience in Operating Plants: 1991, ASME Publication PVP-Vol. 221, 1991.

17. Skabowski, R.A. and Sinka, S.K., "A Statistical Model of Pitting and Cracking Phenomena in Steam Generator Girth Welds," 1991 Pressure Vessels and Piping Conference, San Diego, CA, in Service Experience in Operating Plants: 1991, ASME Publication PVP-Vol. 221, 1991.

# APPENDIX A

# INPUT DATA LISTINGS

```
!, File = veri.5
/SHOW,file33,dat

/PREP7
/TITLE, PRESSURE LOAD VERIFICATION
!, PARAMETERS  ********************
PB=87.875
PA=PB+3.62
PP=1065
PE=30E6
PNU=0.3
PAL=6E-6
PDEN=490
PK=25
PC=0.11

PDEN=PDEN/1728
PK=PK/(3600*12)
PD=PK/(PDEN*PC)

!, SOLID MODEL  ************
K,1,PB
K,2,PA
K,3,PA,1
K,4,PB,1
L,1,4,1
L,4,3,10,5
L,1,2,10,5
A,1,2,3,4

!, NODES & ELEMENTS  *******
ET,1,82
KEYOPT,1,3,1

MP,C,1,PC
MP,KXX,1,PK
MP,EX,1,PE
MP,NUXY,1,PNU
MP,ALPX,1,PAL
MP,DENS,1,PDEN

ELSIZE,,,2
AMESH,ALL

!, BOUNDARY CONDITIONS  ****
NSEL,Y,0
D,ALL,UY

!, COUPLING AT TOP BOUNDARY  ********
CPSIZE,22
KPSEL,,3,4
LSKP,1
NLINE,1
*GET,N1,NDMN
NJ=N1
:P1
*GET,NJ,NDMN,NJ
*IF,NJ,EQ,0,:P2
CP,1,UY,N1,NJ
*GO,:P1
:P2

NALL

!, INTERNAL PRESSURE, INSIDE SURF
KPSEL,,1,4,3
```

```
LSKP,1
NLINE,1
PSF,ALL,,,PP
NALL
!, END SURF
FAX=((PB**2)*PP)/2      !, AXIAL FORCE PER RADIAN
F,N1,FY,FAX

KPSEL,,1
NKPOI
*GET,N1,NDMX
KPSEL,,2
NKPOI
*GET,N2,NDMX
NALL

AFWRITE
FINISH

/INPUT,27
FINISH

/POST1
SET
/DSCALE,,OFF
/PLOFF,,,2
/SHOW,,,1
/NUM,2
/WINDOW,,TOP
PLNSTR,SX
!, PLNSTR,SY
/NOERASE
/WINDOW,,BOT
PLNSTR,SZ
/ERASE
/WINDOW,,FULL

/WINDOW,,TOP
/SHOW,,,1
/NUM,2
PLPATH,N1,N2,SX
!, PLPATH,N1,N2,SY
/NOERASE
/WINDOW,,BOT
PLPATH,N1,N2,SZ

PRPATH,N1,N2,SX
PRPATH,N1,N2,SY
PRPATH,N1,N2,SZ

!, ROARK FORMULAS  ***********
C1=(PA**2)-(PB**2)
RX=PA
C2=(PA**2)+(RX**2)
C3=(RX**2)*C1
SHO=(PP*(PB**2)*C2)/C3
C4=(PA**2)-(RX**2)
SRO=-(PP*(PB**2)*C4)/C3
SAO=(PP*(PB**2))/C1

RX=PB
C2=(PA**2)+(RX**2)
C3=(RX**2)*C1
SHI=(PP*(PB**2)*C2)/C3
C4=(PA**2)-(RX**2)
SRI=-(PP*(PB**2)*C4)/C3
```

```
SAI=(PP*(PB**2))/C1

FINISH
/EOF

  PRESSURE LOAD VERIFICATION
   SX   IN GLOBAL COORDINATES
   DISTANCE                 SX
      0.              -1065.0
      3.6200               0.38782

   SY   IN GLOBAL COORDINATES
   DISTANCE                 SY
     0.                12665.
     3.6200            12665.

   SZ   IN GLOBAL COORDINATES
   DISTANCE                 SZ
      0.                26396.
      3.6200            25331.
     1  *SET,PB  ,  87.8750000
     2  *SET,PA  ,  91.4950000
     3  *SET,PP  ,  1065.00000
     4  *SET,PE  ,  30000000.0
     5  *SET,PNU , 0.300000000
     6  *SET,PAL , 0.600000000E-05
     7  *SET,PDEN, 0.283564815
     8  *SET,PK  , 0.578703704E-03
     9  *SET,PC  , 0.110000000
    10  *SET,PD  , 0.185528757E-01
    11  *SET,N1  ,  1.00000000
    12  *SET,NJ  ,          0.
    13  *SET,FAX ,  4111973.32
    14  *SET,N2  ,  2.00000000
    15  *SET,C1  ,  649.319400
    16  *SET,RX  ,  87.8750000
    17  *SET,C2  ,  16093.3506
    18  *SET,C3  ,  5014054.55
    19  *SET,SHO ,  25330.9747
    20  *SET,C4  ,  649.319400
    21  *SET,SRO ,          0.
    22  *SET,SAO ,  12665.4873
    23  *SET,SHI ,  26395.9747
    24  *SET,SRI , -1065.00000
    25  *SET,SAI ,  12665.4873
```

```
!, File = ver2.5
/SHOW,file33,dat

/PREP7
/TITLE, PRESSURE LOAD VERIFICATION
!, PARAMETERS  ********************
PB=87.875
PA=PB+3.62
PP=1065
PE=30E6
PNU=0.3
PAL=6E-6
PDEN=490
PK=25
PC=0.11

D1=10
B1=5

PDEN=PDEN/1728
PK=PK/(3600*12)
PD=PK/(PDEN*PC)

!, SOLID MODEL  ************
K,1,PB
K,2,PA
K,3,PA,1
K,4,PB,1
L,1,4,1
L,1,2,D1,B1
L,4,3,D1,B1
A,1,2,3,4

!, NODES & ELEMENTS  *******
KAN,-1
ET,1,77
KEYOPT,1,3,1

MP,C,1,PC
MP,KXX,1,PK
MP,EX,1,PE
MP,NUXY,1,PNU
MP,ALPX,1,PAL
MP,DENS,1,PDEN

ELSIZE,,,2
AMESH,ALL

!, STEP SIZE  ******************************
DT=((PA-PB)/(D1*B1))**2
DT=DT/(10*PD)

!, BUNDARY CONDITIONS  **********************
TREF=70

!, TRANSIENT NO. 1,  ***********
:S1
TIM=0
TIME,TIM
KPSEL,,2,3
LSKP,1
NLINE,1
NT,ALL,TEMP,70
ITER,-10,,10
KBC,1
NALL
```

```
LWRITE

DTIM=20*60
TIM=TIM+DTIM
NSTP=DTIM/DT
TIME,TIM
KPSEL,,2,3
LSKP,1
NLINE,1
NT,ALL,TEMP,600
KBC,0
ITER,-NSTP,,1
NALL
LWRITE

KPSEL,,1
NKPOI
*GET,N1,NDMX
KPSEL,,2
NKPOI
*GET,N2,NDMX
NALL

SAVE
AFWRITE
FINISH

/INPUT,27
FINISH

/POST26
NUMVAR,20
DISP,2,N1,TEMP,T1
DISP,3,N2,TEMP,T2
ADD,4,3,2,,T2  ,-T1 ,,1.0,-1.0
EXTREME,1,2,1
/GRAPH,GRID,1
/SHOW,,,1
/NUM,2
PLVAR,2,3,4
/SHOW
/NUM
PRVAR,2,3,4
FINISH

/POST1
SET,,,,,1200
/GRAPH,GRID,1
PLNSTR,TEMP
PLPATH,N1,N2,TEMP
FINISH

/PREP7
RESUME
EALL
NALL
NTDELE,ALL

TREF,70
TUNIF,70

ITER,1,,1
KAN,0

!, BOUNDARY CONDITIONS  ****
NSEL,Y,0
```

```
D,ALL,UY

!, COUPLING AT TOP BOUNDARY  ********
CPSIZE,22
KPSEL,,3,4
LSKP,1
NLINE,1
*GET,NN1,NDMN
NJ=NN1
:P1
*GET,NJ,NDMN,NJ
*IF,NJ,EQ,0,:P2
CP,1,UY,NN1,NJ
*GO,:P1
:P2

NALL

WSORT

TIME,1200
KTEMP,,,1200
LWRITE

AFWRITE
FINISH

/INPUT,27
FINISH

/POST1
SET
/PLOFF,,,2
/SHOW,,,1
/NUM,2
/WINDOW,,TOP
!, PLNSTR,SX
PLNSTR,SY
/NOERASE
/WINDOW,,BOT
PLNSTR,SZ
/ERASE
/WINDOW,,FULL
/SHOW
/NUM

PLPATH,N1,N2,SX
PLPATH,N1,N2,SY
PLPATH,N1,N2,SZ

PRPATH,N1,N2,SX
PRPATH,N1,N2,SY
PRPATH,N1,N2,SZ


!, ROARK FORMULAS  ***********
C1=PE*PAL*((600-70)/1200)
C2=8*PD*(1-PNU)
C3=(3*(PB**2))-(PA**2)
D1=4*(PB**4)
D2=(PA**2)-(PB**2)
D3=LOG(PA/PB)
PHO=(C1/C2)*(C3-((D1/D2)*D3))

C3=(PB**2)+(PA**2)
D1=4*(PB**2)*(PA**2)
```

```
PHI=(C1/C2)*(C3-((D1/D2)*D3))

FINISH

/EOF

   SY   IN GLOBAL COORDINATES
   DISTANCE               SY
     0.                13282.
     3.6200           -25792.

   SZ   IN GLOBAL COORDINATES
   DISTANCE               SZ
     0.                13282.
     3.6200           -25801.

    41   *SET,PHO , -26206.3259
    42   *SET,PHI ,  13368.6749

     1   *SET,PB  ,  87.8750000
     2   *SET,PA  ,  91.4950000
     3   *SET,PP  ,  1065.00000
     4   *SET,PE  ,  30000000.0
     5   *SET,PNU , 0.300000000
     6   *SET,PAL , 0.600000000E-05
     7   *SET,PDEN, 0.283564815
     8   *SET,PK  , 0.578703704E-03
     9   *SET,PC  , 0.110000000
    10   *SET,PD  , 0.185528757E-01
    11   *SET,N1  ,  1.00000000
    12   *SET,NJ  ,          0.
    13   *SET,FAX ,  4111973.32
    14   *SET,N2  ,  2.00000000
    15   *SET,C1  ,  79.5000000
    16   *SET,RX  ,  87.8750000
    17   *SET,C2  , 0.103896104
    18   *SET,C3  ,  16093.3506
    19   *SET,SH  ,  25330.9747
    20   *SET,SR  , -1.51295908
    21   *SET,SA  ,  12665.4873
    22   *SET,SHO ,  25330.9747
    23   *SET,C4  ,  649.319400
    24   *SET,SRO ,          0.
    25   *SET,SAO ,  12665.4873
    26   *SET,SHI ,  26395.9747
    27   *SET,SRI , -1065.00000
    28   *SET,SAI ,  12665.4873
    29   *SET,D1  ,  258574319.
    30   *SET,B1  ,  5.00000000
    31   *SET,DT  , 0.282530864E-01
    32   *SET,TREF,  70.0000000
    33   *SET,TIM ,  1200.00000
    34   *SET,DTIM,  1200.00000
    35   *SET,NSTP,  42473.2358
    36   *SET,E1  ,  1.00000000
    37   *SET,E2  ,  10.0000000
    38   *SET,J   ,  100.000000
    39   *SET,D2  ,  649.319400
    40   *SET,D3  , 0.403689758E-01
    41   *SET,PHO , -26206.3259
    42   *SET,PHI ,  13368.6749
    43   *SET,NN1 ,  22.0000000
```

```
!, File = nsgen5.5
/SHOW,file33,dat

/PREP7
/TITLE, ZION STEAM GENERATOR SHELL, UPPER GIRTH WELD, nsgen5.5
!, PARAMETERS  ************************************
R1=67.50      !, INSIDE RADIUS, LOWER SHELL
R2=87.875     !, INSIDE RADIUS, UPER SHELL
HT=76.75      !, HEIGHT OF TRANSITION
TW=3.62       !, THICKNESS OF WALL
RF=2*TW       !, RADIUS OF FILLETS

D1=10         !, THRU THICKNESS
D2=15         !, LOWER SHELL
D3=30         !, CONE
D4=15         !, UPPER SHELL

B1=5          !, BIAS THRU THICKNESS
B2=1/40       !, BIAS UP BOT SHELL
B3=-20        !, BIAS ON CONE
B4=40         !, BIAS ON UPPER SHELL

!, KEYPOINTS  **************************************
K,1,R1
K,2,R1,R1
K,3,R2,(R1+HT)
K,4,R2,(R1+HT+R2)
KGEN,2,1,4,1,TW,,,10

!, LINES  ******************************************
L,1,2
L,2,3
L,3,4
LFILLT,1,2,RF
LDVS,4,,3
LFILLT,2,3,RF
LDVS,5,,3
L,11,12
L,12,13
L,13,14
LFILLT,6,7,RF
LDVS,9,,3
LFILLT,7,8,RF
LDVS,10,,3
L,1,11,D1,B1
L,5,9,D1,B1
L,6,10,D1,B1
L,7,15,D1,B1
L,8,16,D1,B1
L,4,14,D1,B1
L,1,5,D2,B2
L,11,9,D2,B2
L,6,7,D3,B3
L,10,15,D3,B3
L,8,4,D4,B4
L,16,14,D4,B4

!, AREAS  *******************
A,1,11,9,5
A,5,9,10,6
A,6,10,15,7
A,7,15,16,8
A,8,16,14,4

!, TYPE, MAT, REAL  ********************
KAN,-1
```

```
ET,1,77    !, 2ND ORDER QUADRATIC THERMAL ELEMENT
KEYOPT,1,3,1

!, DENSITY  ************************************
DEN=490       !, DENSITY (lb/ft**3)
MP,DENS,1,DEN/1728   !, DENSITY (lb/in**3)

!, HEAT CAPACITY & CONDUCTIVITY  ***************
MPTEMP,1,70,100,150,200,250,300
MPTEMP,7,350,400,450,500,550,600
TK=23.3               !, T=70 CONDUCTIVITY (Btu/hr-ft-degF)
TD=0.455              !, T=70 DIFFUSIVITY  (ft**2/hr)
TDR=TD*(144/3600)  !, DIFF REF (in**2/sec)
TC=TK/(DEN*TD)      !, SPECIFIC HEAT (Btu/lb-degF)
MPDATA,C,1,1,TC
C1=3600*12          !,
MPDATA,KXX,1,1,TK/C1

TK=23.6 $ TD=0.451     !, T=100
TC=TK/(DEN*TD)  !, SPECIFIC HEAT (Btu/lb-degF)
MPDATA,C,1,2,TC $ MPDATA,KXX,1,2,TK/C1

TK=24.1 $ TD=0.444     !, T=150
TC=TK/(DEN*TD)  !, SPECIFIC HEAT (Btu/lb-degF)
MPDATA,C,1,3,TC $ MPDATA,KXX,1,3,TK/C1

TK=24.4 $ TD=0.437     !, T=200
TC=TK/(DEN*TD)  !, SPECIFIC HEAT (Btu/lb-degF)
MPDATA,C,1,4,TC $ MPDATA,KXX,1,4,TK/C1

TK=24.6 $ TD=0.429     !, T=250
TC=TK/(DEN*TD)  !, SPECIFIC HEAT (Btu/lb-degF)
MPDATA,C,1,5,TC $ MPDATA,KXX,1,5,TK/C1

TK=24.7 $ TD=0.420     !, T=300
TC=TK/(DEN*TD)  !, SPECIFIC HEAT (Btu/lb-degF)
MPDATA,C,1,6,TC $ MPDATA,KXX,1,6,TK/C1

TK=24.7 $ TD=0.409     !, T=350
TC=TK/(DEN*TD)  !, SPECIFIC HEAT (Btu/lb-degF)
MPDATA,C,1,7,TC $ MPDATA,KXX,1,7,TK/C1

TK=24.6 $ TD=0.398     !, T=400
TC=TK/(DEN*TD)  !, SPECIFIC HEAT (Btu/lb-degF)
MPDATA,C,1,8,TC $ MPDATA,KXX,1,8,TK/C1

TK=24.4 $ TD=0.388     !, T=450
TC=TK/(DEN*TD)  !, SPECIFIC HEAT (Btu/lb-degF)
MPDATA,C,1,9,TC $ MPDATA,KXX,1,9,TK/C1

TK=24.2 $ TD=0.377     !, T=500
TC=TK/(DEN*TD)  !, SPECIFIC HEAT (Btu/lb-degF)
MPDATA,C,1,10,TC $ MPDATA,KXX,1,10,TK/C1

TK=23.9 $ TD=0.364     !, T=550
TC=TK/(DEN*TD)  !, SPECIFIC HEAT (Btu/lb-degF)
MPDATA,C,1,11,TC $ MPDATA,KXX,1,11,TK/C1

TK=23.5 $ TD=0.353     !, T=600
TC=TK/(DEN*TD)  !, SPECIFIC HEAT (Btu/lb-degF)
MPDATA,C,1,12,TC $ MPDATA,KXX,1,12,TK/C1

!, ELASTIC MODULUS & POISSON RATIO  ***********
MPTEMP
MPTEMP,1,70,200,300,400,500,600
MPDATA,EX,1,1,29.2E6,28.5E6,28.0E6,27.4E6,27.0E6,26.4E6
```

```
MPTEMP
MP,NUXY,1,0.29

!, THERMAL EXPANSION COEFICIENT  **************
MPTEMP,1,70,100,150,200,250,300
MPTEMP,7,350,400,450,500,550,600
MPDATA,ALPX,1,1,7.02E-6,7.06E-6,7.16E-6,7.25E-6,7.34E-6,7.43E-6
MPDATA,ALPX,1,7,7.50E-6,7.58E-6,7.63E-6,7.70E-6,7.77E-6,7.83E-6

/SHOW,,,1
/NUM,2
!, /WINDOW,,LTOP
/TITLE, ZION STEAM GENERATOR SHELL, HEAT CAPACITY Btu/lb-degF
MPPLOT,C,1
!, /NOERASE
!, /WINDOW,,RTOP
/TITLE, ZION STEAM GENERATOR SHELL, THERMAL CONDUCTIVITY Btu/ln-sec-degF
MPPLOT,KXX,1
!, /WINDOW,,LBOT
/TITLE, ZION STEAM GENERATOR SHELL, ELASTIC MODULUS lb/in**2
MPPLOT,EX,1
!, /WINDOW,,RBOT
/TITLE, ZION STEAM GENERATOR SHELL, THERMAL EXPANSION COEFFICIENT in/in-degF
MPPLOT,ALPX,1
/TITLE, ZION STEAM GENERATOR SHELL, UPPER GIRTH WELD, nsgen5.5
/ERASE
/WINDOW,,FULL
/SHOW
/NUM

R,1

!, NODES & ELEMENTS  ************************
ELSIZE,,,2
AMESH,ALL
WSORT

!, !, STEP SIZE  ******************************
DT=(TW/(D1*B1))**2
DT=DT/(10*TDR)

!, BOUNDARY CONDITIONS  **********************
TREF=70

!, *GO,:S2
!, *GO,:S3
!, *GO,:S4
*GO,:S5
!, TRANSIENT NO. 1, HEATUP @ 100degF/hr  ***********
/TITLE, TRANSIENT NO. 1, HEATUP @ 100degF/hr
:S1
TIM=0
TIME,TIM
LSSEL,,1,5
NLINE,1
NT,ALL,TEMP,70
ITER,-10,,10
KBC,1
NALL
LWRITE

DTIM=5*3600
TIM=TIM+DTIM
NSTP=DTIM/DT
TIME,TIM
```

```
LSSEL,,1,5
NLINE,1
NT,ALL,TEMP,547
KBC,0
ITER,-NSTP,,1
NALL
LWRITE

DTIM=10*60
TIM=TIM+DTIM
NSTP=DTIM/DT
TIME,TIM
LSSEL,,1,5
NLINE,1
NT,ALL,TEMP,547
ITER,-NSTP,,1
NALL
LWRITE
*GO,:EX1

!, TRANSIENT NO. 2, COOLDOWN @ 100degF/hr  *********
/TITLE, TRANSIENT NO. 2, COOLDOWN @ 100degF/hr
:S2
TIM=0
TIME,TIM
LSSEL,,1,5
NLINE,1
NT,ALL,TEMP,547
ITER,-10,,10
KBC,1
NALL
LWRITE

DTIM=5*3600
TIM=TIM+DTIM
NSTP=DTIM/DT

TIME,TIM
LSSEL,,1,5
NLINE,1
NT,ALL,TEMP,70
KBC,0
ITER,-NSTP,,1
NALL
LWRITE

DTIM=10*60
TIM=TIM+DTIM
NSTP=DTIM/DT
TIME,TIM
LSSEL,,1,5
NLINE,1
NT,ALL,TEMP,70
ITER,-NSTP,,1
NALL
LWRITE
*GO,:EX1

!, TRANSIENT NO. 3, LARGE STEP LOAD DECREASE  *****
/TITLE, TRANSIENT NO. 3, LARGE STEP LOAD DECREASE
:S3
TIM=0
TIME,TIM
LSSEL,,1,5
NLINE,1
NT,ALL,TEMP,506
```

```
ITER,-10,,10
KBC,1
NALL
LWRITE

DTIM=60
TIM=TIM+DTIM
NSTP=DTIM/DT
TIME,TIM
LSSEL,,1,5
NLINE,1
NT,ALL,TEMP,546
KBC,0
ITER,-NSTP,,1
NALL
LWRITE

DTIM=120
TIM=TIM+DTIM
NSTP=DTIM/DT
TIME,TIM
LSSEL,,1,5
NLINE,1
NT,ALL,TEMP,510
ITER,-NSTP,,1
NALL
LWRITE

DTIM=(20*60)-TIM
TIM=TIM+DTIM
TIME,TIM
LSSEL,,1,5
NLINE,1
NT,ALL,TEMP,537
ITER,-NSTP,,1
NALL
LWRITE

DTIM=10*60
TIM=TIM+DTIM
TIME,TIM
LSSEL,,1,5
NLINE,1
NT,ALL,TEMP,537
ITER,-NSTP,,1
NALL
LWRITE
*GO,:EX1

!, TRANSIENT NO. 4, REACTOR TRIP  *****************
/TITLE, TRANSIENT NO. 4, REACTOR TRIP
:S4
TIM=0
TIME,TIM
LSSEL,,1,5
NLINE,1
NT,ALL,TEMP,546.99
ITER,-10,,10
KBC,1
NALL
LWRITE

DTIM=11.5*60
TIM=TIM+DTIM
NSTP=DTIM/DT
TIME,TIM
```

```
LSSEL,,1,5
NLINE,1
NT,ALL,TEMP,389.86
KBC,0
ITER,-NSTP,,1
NALL
LWRITE

DTIM=10*60
TIM=TIM+DTIM
NSTP=DTIM/DT
TIME,TIM
LSSEL,,1,5
NLINE,1
NT,ALL,TEMP,389.86
KBC,0
ITER,-NSTP,,1
NALL
LWRITE

!, TRANSIENT NO. 5, BOUNDING FAULTED EVENT  *******
/TITLE, TRANSIENT NO. 5, BOUNDING FAULTED EVENT, STATE 1
:S5
TIM=0
TIME,TIM
LSSEL,,1,5
NLINE,1
NT,ALL,TEMP,547
ITER,-10,,10
KBC,1
NALL
LWRITE

DTIM=60
TIM=TIM+DTIM
NSTP=DTIM/DT
TIME,TIM
LSSEL,,1,5
NLINE,1
NT,ALL,TEMP,70
KBC,0
ITER,-NSTP,,1
NALL
LWRITE

DTIM=10*60
TIM=TIM+DTIM
NSTP=DTIM/DT
TIME,TIM
LSSEL,,1,5
NLINE,1
NT,ALL,TEMP,70
KBC,0
ITER,-NSTP,,1
NALL
LWRITE
!, END TRANSIENTS  ***************************

:EX1
!, MAKE SOME PLOTS  *********
/SHOW,,,1
/NUM,2
/ERASE
/WINDOW,,LEFT
/PBC,ALL,1
NPLOT
```

```
/NOERASE
/WINDOW,,RIGH
/PBC,ALL,0
EPLOT
/ERASE
/WINDOW,,FULL
/SHOW
/NUM

KPSEL,,5  $ NKPOI $ *GET,N5,NDMN
KPSEL,,9  $ NKPOI $ *GET,N9,NDMN
KPSEL,,6  $ NKPOI $ *GET,N6,NDMN
KPSEL,,10 $ NKPOI $ *GET,N10,NDMN
KPSEL,,7  $ NKPOI $ *GET,N7,NDMN
KPSEL,,15 $ NKPOI $ *GET,N15,NDMN
KPSEL,,8  $ NKPOI $ *GET,N8,NDMN
KPSEL,,16 $ NKPOI $ *GET,N16,NDMN

NALL
SAVE
AFWRITE
FINISH

/INPUT,27
FINISH

/POST26
NUMVAR,20
DISP,2,N5,TEMP,T5
DISP,3,N9,TEMP,T9
DISP,4,N6,TEMP,T6
DISP,5,N10,TEMP,T10
DISP,6,N7,TEMP,T7
DISP,7,N15,TEMP,T15
DISP,8,N8,TEMP,T8
DISP,9,N16,TEMP,T16

ADD,10,3,2,,T9  ,-T5 ,,1.0,-1.0
ADD,11,5,4,,T10 ,-T6 ,,1.0,-1.0
ADD,12,7,6,,T15 ,-T7 ,,1.0,-1.0
ADD,13,9,8,,T16 ,-T8 ,,1.0,-1.0
EXTREME,10,13,1
/GRAPH,GRID,1

/SHOW,,,1
/NUM,2
!, /WINDOW,,LTOP
!, PRVAR,2,3,10
!, PLVAR,2,3,10
!, /NOERASE
!, /WINDOW,,RTOP
!, PRVAR,4,5,11
!, PLVAR,4,5,11
!, /WINDOW,,LBOT
!, PRVAR,6,7,12
!, PLVAR,6,7,12
!, /WINDOW,,RBOT
/TITLE, TEMPERATURE HISTORY
PRVAR,8,9,13
PLVAR,8,9,13
/TITLE, ZION STEAM GENERATOR SHELL, UPPER GIRTH WELD
/ERASE
/WINDOW,,FULL
/SHOW
/NUM
```

```
FINISH

/POST1
!, SET,,,,,5*3600
SET,,,,,60
!, SET,,,,,11.5*60
/RATIO,,5
PLNSTR,TEMP
/RATIO
/GRAPH,GRID,1
/SHOW,,,1
/NUM,2
!, /WINDOW,,LTOP
!, PLPATH,N5,N9,TEMP
!, /NOERASE
!, /WINDOW,,RTOP
!, PLPATH,N6,N10,TEMP
!, /WINDOW,,LBOT
!, PLPATH,N7,N15,TEMP
!, /WINDOW,,RBOT
/TITLE, TEMPERATURE THROUGH THICKNESS
PLPATH,N8,N16,TEMP
PRPATH,N8,N16,TEMP
/ERASE
/WINDOW,,FULL
/SHOW
/NUM

!, SET,,,,,4200
!, SET,,,,,600
SET,,,,,180
!, SET,,,,,((11.5*60)+600)
/RATIO,,5
PLNSTR,TEMP
/RATIO
/GRAPH,GRID,1
/SHOW,,,1
/NUM,2
!, /WINDOW,,LTOP
!, PLPATH,N5,N9,TEMP
!, /NOERASE
!, /WINDOW,,RTOP
!, PLPATH,N6,N10,TEMP
!, /WINDOW,,LBOT
!, PLPATH,N7,N15,TEMP
!, /WINDOW,,RBOT
PLPATH,N8,N16,TEMP
PRPATH,N8,N16,TEMP
/TITLE, ZION STEAM GENERATOR SHELL, UPPER GIRTH WELD
/ERASE
/WINDOW,,FULL
/SHOW
/NUM

SET,,,,,300
/RATIO,,5
PLNSTR,TEMP
/RATIO
/GRAPH,GRID,1
/SHOW,,,1
/NUM,2
!, /WINDOW,,LTOP
!, PLPATH,N5,N9,TEMP
!, /NOERASE
!, /WINDOW,,RTOP
!, PLPATH,N6,N10,TEMP
```

```
!, /WINDOW,,LBOT
!, PLPATH,N7,N15,TEMP
!, /WINDOW,,RBOT
PLPATH,N8,N16,TEMP
PRPATH,N8,N16,TEMP
/TITLE, ZION STEAM GENERATOR SHELL, UPPER GIRTH WELD
/ERASE
/WINDOW,,FULL
/SHOW
/NUM
FINISH

/PREP7
RESUME
EALL
NALL
NTDELE,ALL

TREF,70
TUNIF,70

ITER,1,,1
KAN,0

!, BOUNDARY CONDITIONS  *************
NSEL,Y,0
D,ALL,UY,0.0
NALL

!, COUPLING AT TOP BOUNDARY  ********
CPSIZE,(D1+1)*2
KPSEL,,4,14,10
LSKP,1
NLINE,1
*GET,N1,NDMN
NJ=N1
:P1
*GET,NJ,NDMN,NJ
*IF,NJ,EQ,0,:P2
CP,1,UY,N1,NJ
*GO,:P1
:P2
NALL

*CREATE,LMAC
!, *USE,LMAC,TIM,PR
!, INTERNAL PRESSURE, INSIDE SURF
LSSEL,,1,5
NLINE,1
PSF,ALL,,,ARG2
NALL
!, END SURF
FAR=((R2**2)*ARG2 )/2     !, AXIAL FORCE PER RADIAN
F,N1,FY,FAR
!, THERMAL LOAD  ***********
TIME,ARG1
KTEMP,,,ARG1
LWRITE
*END,LMAC

!, *GO,:L2
!, *GO,:L3
!, *GO,:L4
*GO,:L5
!, TRANSIENT NO. 1, HEATUP @ 100deg/hour
*USE,LMAC,0,0
```

```
*USE,LMAC,5*3600,1020
*GO,:EX2

!, TRANSIENT NO. 2, COOLDOWN @ 100deg/hour
:L2
*USE,LMAC,0,1020
*USE,LMAC,5*3600,0
*GO,:EX2

!, TRANSIENT NO. 3, LARGE LOAD STEP DECREASE  *********
:L3
*USE,LMAC,0,720
*USE,LMAC,60,1091
*USE,LMAC,180,802
*USE,LMAC,20*60,938
*GO,:EX2

!, TRANSIENT NO. 4, REACTOR TRIP  ********************
:L4
*USE,LMAC,0,1020
*USE,LMAC,11.5*60,220

!, TRANSIENT NO. 5, BOUNDING FAULTED EVENT *********
:L5
*USE,LMAC,0,1020
*USE,LMAC,60,0
*USE,LMAC,180,0
*USE,LMAC,300,0
*USE,LMAC,600,0

:EX2
!, MAKE SOME PLOTS  *********
/SHOW,,,1
/ERASE
/WINDOW,,LEFT
/PBC,ALL,1
NPLOT
/NOERASE
/WINDOW,,RIGH
/PBC,ALL,0
EPLOT
/ERASE
/WINDOW,,FULL
/SHOW

AFWRITE
FINISH

/INPUT,27
FINISH

:RES
/POST1
STRESS,TMP,82,88  !, TEMPERATURE
/DSCALE,,OFF

*CREATE,CMAC
/RATIO
/WINDOW,,LEFT
/EDGE,,1
PLNSTR,SI
/NOERASE
/RATIO,,5
/WINDOW,,RIGH
/EDGE
PLNSTR,SI
```

```
/RATIO
/WINDOW,,FULL
/ERASE
*END,CMAC

*CREATE,SMAC
/SHOW,,,1
/NUM,2
!, /WINDOW,,LTOP
!, PLSECT,N5,N9,-1,SI
!, PRSECT,N5,N9,-1,SI
!, /NOERASE
!, /WINDOW,,RTOP
!, PLSECT,N6,N10,-1,SI
!, PRSECT,N6,N10,-1,SI
!, /WINDOW,,LBOT
!, PLSECT,N7,N15,-1,SI
!, PRSECT,N7,N15,-1,SI
!, /WINDOW,,RBOT
PLSECT,N8,N16,-1,SI
PRSECT,N8,N16,-1,SI
/ERASE
/WINDOW,,FULL
/SHOW
/NUM
*END,SMAC

*CREATE,AMAC
/SHOW,,,1
/NUM,2
!, /WINDOW,,LTOP
!, PLSECT,N5,N9,-1,SY
!, PRSECT,N5,N9,-1,SY
!, /NOERASE
!, /WINDOW,,RTOP
!, PLSECT,N6,N10,-1,SY
!, PRSECT,N6,N10,-1,SY
!, /WINDOW,,LBOT
!, PLSECT,N7,N15,-1,SY
!, PRSECT,N7,N15,-1,SY
!, /WINDOW,,RBOT
PLSECT,N8,N16,-1,SY
PRSECT,N8,N16,-1,SY
/ERASE
/WINDOW,,FULL
/SHOW
/NUM
*END,AMAC

*CREATE,PMAC
/SHOW,,,1
/NUM,2
!, /WINDOW,,LTOP
!, PLPATH,N5,N9,SY
!, PRPATH,N5,N9,SY
!, /NOERASE
!, /WINDOW,,RTOP
!, PLPATH,N6,N10,SY
!, PRPATH,N6,N10,SY
!, /WINDOW,,LBOT
!, PLPATH,N7,N15,SY
!, PRPATH,N7,N15,SY
!, /WINDOW,,RBOT
PLPATH,N8,N16,SY
PRPATH,N8,N16,SY
/ERASE
```

```
/WINDOW,,FULL
/SHOW
/NUM
*END,PMAC

SET,1
!, /TITLE, TRANSIENT NO. 1, HEATUP  @ 100deg/hour, STATE 1
!, /TITLE, TRANSIENT NO. 2, COOLDOWN @ 100deg/hour, STATE 1
!, /TITLE, TRANSIENT NO. 3, LARGE STEP LOAD DECREASE STATE 1
!, /TITLE, TRANSIENT NO. 4, REACTOR TRIP  STATE 1
/TITLE, TRANSIENT NO. 5, BOUNDING FAULTED EVENT, STATE 1
*USE,CMAC
!, *USE,SMAC
*USE,AMAC
*USE,PMAC
PRRFOR

SET,2
!, /TITLE, TRANSIENT NO. 1, HEATUP  @ 100deg/hour, STATE 2
!, /TITLE, TRANSIENT NO. 2, COOLDOWN @ 100deg/hour, STATE 2
!, /TITLE, TRANSIENT NO. 3, LARGE STEP LOAD DECREASE STATE 2
!, /TITLE, TRANSIENT NO. 4, REACTOR TRIP  STATE 2
/TITLE, TRANSIENT NO. 5, BOUNDING FAULTED EVENT, STATE 2
*USE,CMAC
!, *USE,SMAC
*USE,AMAC
*USE,PMAC
PRRFOR

!, *GO,:EX3

SET,3
!, /TITLE, TRANSIENT NO. 3, LARGE STEP LOAD DECREASE STATE 3
/TITLE, TRANSIENT NO. 5, BOUNDING FAULTED EVENT, STATE 3
*USE,CMAC
!, *USE,SMAC
*USE,AMAC
*USE,PMAC
PRRFOR

SET,4
!, /TITLE, TRANSIENT NO. 3, LARGE STEP LOAD DECREASE STATE 4
/TITLE, TRANSIENT NO. 5, BOUNDING FAULTED EVENT, STATE 4
*USE,CMAC
!, *USE,SMAC
*USE,AMAC
*USE,PMAC
PRRFOR

:EX3
*STATUS
FINISH

/EOF
```

# APPENDIX B

## INPUT DATA LISTINGS

File = fwcycle1.rpt

*** PREP7 GLOBAL STATUS ***
TITLE= ZION STEAM GENERATOR SHELL, UPPER GIRTH WELD, fwcyc1.5
ANALYSIS TYPE= -1
NUMBER OF ELEMENT TYPES= 1
770 ELEMENTS CURRENTLY SELECTED. MAX ELEMENT NUMBER = 770
2485 NODES CURRENTLY SELECTED. MAX NODE NUMBER = 2485
1 KEYPOINTS CURRENTLY SELECTED. MAX KEYPOINT NUMBER = 28
10 LINE SEG CURRENTLY SELECTED. MAX LINE SEG NUMBER = 34
11 AREAS CURRENTLY SELECTED. MAX AREA NUMBER = 11
MAXIMUM LINEAR PROPERTY NUMBER= 1
MAXIMUM REAL CONSTANT SET NUMBER= 1
ACTIVE COORDINATE SYSTEM= 0 (CARTESIAN)
NUMBER OF ELEMENT CONVECTIONS= 77

SUMMARY OF VARIABLES STORED THIS STEP AND EXTREME VALUES

| VARI | TYPE | IDENTIFIERS | | NAME | MINIMUM | AT TIME | MAXIMUM | AT TIME |
|---|---|---|---|---|---|---|---|---|
| 2 | DISP | 1414 | TEMP | 1414TK23 | 453.9 | 562.4 | 547.0 | 0. |
| 3 | DISP | 1398 | TEMP | 1398TK27 | 514.0 | 600.0 | 547.0 | 0. |
| 4 | DISP | 1660 | TEMP | 1660TK24 | 453.9 | 562.4 | 547.0 | 0. |
| 5 | DISP | 1654 | TEMP | 1654TK28 | 514.0 | 600.0 | 547.0 | 0.1441 |
| 6 | DISP | 1766 | TEMP | 1766TK9 | 489.1 | 569.1 | 547.0 | 0. |
| 7 | DISP | 1750 | TEMP | 1750TK19 | 525.4 | 600.0 | 547.0 | 0.6052 |
| 10 | OPER | 10 | ADD | TK27TK23 | -0.2046E-11 | 0. | 62.89 | 562.4 |
| 11 | OPER | 11 | ADD | TK28TK24 | 0.1307E-10 | 0. | 62.88 | 562.4 |
| 12 | OPER | 12 | ADD | TK19TK9 | -0.9550E-11 | 0. | 37.91 | 569.1 |

ANSYS POST26 VARIABLE LISTING

| TIME | DISP1660 TEMP 1660TK24 | DISP1654 TEMP 1654TK28 | OPER 11 ADD TK28TK24 |
|---|---|---|---|
| 0. | 547.000 | 547.000 | 0.130740E-10 |
| 0.28818E-01 | 547.000 | 547.000 | 0.841455E-04 |
| 0.14409 | 546.999 | 547.000 | 0.111900E-02 |
| 0.60519 | 546.989 | 547.000 | 0.113568E-01 |
| 2.4496 | 546.869 | 547.000 | 0.130580 |
| 9.8271 | 545.030 | 547.000 | 1.96994 |
| 10.000 | 544.962 | 547.000 | 2.03832 |
| 10.029 | 544.950 | 547.000 | 2.04957 |
| 10.144 | 544.907 | 547.000 | 2.09338 |
| 10.605 | 544.738 | 547.000 | 2.26179 |
| 12.450 | 544.079 | 547.000 | 2.92113 |
| 19.827 | 541.187 | 547.000 | 5.81289 |
| 20.000 | 541.114 | 547.000 | 5.88574 |
| 20.029 | 541.102 | 547.000 | 5.89794 |
| 20.144 | 541.053 | 547.000 | 5.94708 |
| 20.605 | 540.853 | 547.000 | 6.14713 |
| 22.447 | 540.018 | 547.000 | 6.98197 |
| 29.818 | 536.315 | 547.000 | 10.6849 |
| 50.000 | 524.114 | 546.979 | 22.8646 |
| 50.029 | 524.095 | 546.979 | 22.8842 |
| 50.144 | 524.014 | 546.979 | 22.9648 |
| 50.605 | 523.683 | 546.978 | 23.2951 |
| 52.448 | 522.478 | 546.974 | 24.4966 |
| 59.821 | 521.461 | 546.953 | 25.4921 |

| | | | |
|---|---|---|---|
| 69.153 | 526.875 | 546.903 | 20.0286 |
| 75.000 | 532.415 | 546.856 | 14.4408 |
| 75.029 | 532.440 | 546.855 | 14.4158 |
| 75.144 | 532.510 | 546.854 | 14.3445 |
| 75.605 | 532.628 | 546.850 | 14.2225 |
| 77.447 | 532.437 | 546.832 | 14.3948 |
| 82.457 | 530.947 | 546.773 | 15.8255 |
| 90.000 | 530.067 | 546.657 | 16.5902 |
| 90.029 | 530.066 | 546.657 | 16.5911 |
| 90.144 | 530.055 | 546.655 | 16.6003 |
| 90.605 | 529.974 | 546.647 | 16.6725 |
| 92.450 | 529.473 | 546.613 | 17.1394 |
| 99.827 | 526.567 | 546.458 | 19.8910 |
| 110.00 | 521.332 | 546.202 | 24.8698 |
| 110.03 | 521.316 | 546.201 | 24.8856 |
| 110.14 | 521.249 | 546.198 | 24.9492 |
| 110.60 | 520.982 | 546.185 | 25.2031 |
| 112.45 | 519.913 | 546.133 | 26.2199 |
| 119.82 | 515.494 | 545.915 | 30.4216 |
| 149.31 | 495.584 | 544.878 | 49.2941 |
| 150.00 | 495.078 | 544.851 | 49.7729 |
| 150.03 | 495.057 | 544.849 | 49.7921 |
| 150.14 | 494.981 | 544.845 | 49.8642 |
| 150.60 | 494.714 | 544.826 | 50.1121 |
| 152.45 | 494.117 | 544.752 | 50.6349 |
| 158.99 | 497.215 | 544.477 | 47.2620 |
| 166.13 | 507.206 | 544.151 | 36.9452 |
| 174.63 | 523.936 | 543.723 | 19.7864 |
| 175.00 | 524.773 | 543.703 | 18.9300 |
| 175.03 | 524.826 | 543.701 | 18.8749 |
| 175.14 | 524.990 | 543.695 | 18.7049 |
| 175.60 | 525.362 | 543.670 | 18.3087 |
| 177.45 | 525.668 | 543.570 | 17.9022 |
| 181.22 | 524.763 | 543.357 | 18.5936 |
| 187.50 | 522.832 | 542.978 | 20.1453 |
| 190.00 | 522.349 | 542.819 | 20.4694 |
| 190.03 | 522.344 | 542.817 | 20.4729 |
| 190.14 | 522.319 | 542.809 | 20.4898 |
| 190.60 | 522.203 | 542.779 | 20.5766 |
| 192.45 | 521.647 | 542.659 | 21.0115 |
| 199.82 | 518.898 | 542.159 | 23.2611 |
| 220.00 | 508.438 | 540.755 | 32.3169 |
| 220.03 | 508.420 | 540.753 | 32.3322 |
| 220.14 | 508.352 | 540.744 | 32.3927 |
| 220.60 | 508.084 | 540.712 | 32.6276 |
| 222.45 | 507.064 | 540.582 | 33.5182 |
| 229.82 | 503.178 | 540.076 | 36.8982 |
| 259.31 | 487.432 | 538.164 | 50.7319 |
| 275.00 | 478.651 | 537.143 | 58.4919 |
| 275.03 | 478.636 | 537.141 | 58.5052 |
| 275.14 | 478.581 | 537.134 | 58.5523 |
| 275.60 | 478.414 | 537.104 | 58.6897 |
| 277.45 | 478.282 | 536.983 | 58.7002 |
| 283.53 | 482.739 | 536.573 | 53.8339 |
| 290.44 | 494.216 | 536.081 | 41.8648 |

| | | | |
|---|---|---|---|
| 298.70 | 512.841 | 535.453 | 22.6123 |
| 300.00 | 516.101 | 535.350 | 19.2490 |
| 300.03 | 516.163 | 535.348 | 19.1855 |
| 300.14 | 516.355 | 535.339 | 18.9841 |
| 300.60 | 516.817 | 535.302 | 18.4851 |
| 302.45 | 517.345 | 535.153 | 17.8081 |
| 306.05 | 516.581 | 534.856 | 18.2744 |
| 311.89 | 514.018 | 534.354 | 20.3357 |
| 321.10 | 509.703 | 533.527 | 23.8241 |
| 330.00 | 507.056 | 532.712 | 25.6558 |
| 330.03 | 507.049 | 532.709 | 25.6600 |
| 330.14 | 507.019 | 532.699 | 25.6798 |
| 330.60 | 506.876 | 532.656 | 25.7800 |
| 332.45 | 506.190 | 532.485 | 26.2959 |
| 339.82 | 502.873 | 531.816 | 28.9434 |
| 360.85 | 491.363 | 530.071 | 38.7076 |
| 375.00 | 482.460 | 529.024 | 46.5634 |
| 375.03 | 482.442 | 529.022 | 46.5794 |
| 375.14 | 482.374 | 529.013 | 46.6390 |
| 375.60 | 482.137 | 528.981 | 46.8442 |
| 377.45 | 481.428 | 528.853 | 47.4249 |
| 384.82 | 480.523 | 528.347 | 47.8240 |
| 397.81 | 483.373 | 527.458 | 44.0860 |
| 414.83 | 491.799 | 526.237 | 34.4381 |
| 437.59 | 506.893 | 524.474 | 17.5813 |
| 450.00 | 516.065 | 523.471 | 7.40575 |
| 450.03 | 516.082 | 523.469 | 7.38681 |
| 450.14 | 516.125 | 523.459 | 7.33460 |
| 450.60 | 516.158 | 523.421 | 7.26381 |
| 452.45 | 515.692 | 523.270 | 7.57825 |
| 457.77 | 513.075 | 522.836 | 9.76067 |
| 467.07 | 507.850 | 522.098 | 14.2482 |
| 480.00 | 502.983 | 521.149 | 18.1654 |
| 480.03 | 502.975 | 521.146 | 18.1719 |
| 480.14 | 502.938 | 521.138 | 18.2005 |
| 480.60 | 502.771 | 521.106 | 18.3350 |
| 482.45 | 501.997 | 520.980 | 18.9827 |
| 489.82 | 498.386 | 520.500 | 22.1142 |
| 511.85 | 485.708 | 519.283 | 33.5756 |
| 530.00 | 473.866 | 518.420 | 44.5537 |
| 530.03 | 473.846 | 518.418 | 44.5720 |
| 530.14 | 473.769 | 518.413 | 44.6446 |
| 530.60 | 473.461 | 518.393 | 44.9320 |
| 532.45 | 472.253 | 518.312 | 46.0590 |
| 539.82 | 467.511 | 517.980 | 50.4699 |
| 560.00 | 454.495 | 516.949 | 62.4540 |
| 560.03 | 454.478 | 516.947 | 62.4695 |
| 560.14 | 454.417 | 516.941 | 62.5242 |
| 560.60 | 454.229 | 516.915 | 62.6865 |
| 562.45 | 453.928 | 516.811 | 62.8825 |
| 569.10 | 456.565 | 516.410 | 59.8444 |
| 577.65 | 465.698 | 515.836 | 50.1375 |
| 588.19 | 482.036 | 515.033 | 32.9964 |
| 600.00 | 503.733 | 514.014 | 10.2809 |

FOR LOAD STEP= 12 ITERATION= 1910 SECTION= 1
TIME= 275.000 LOAD CASE= 1

| DISTANCE | TEMP |
|---|---|
| 0. | 478.65 |
| 0.75417E-01 | 482.46 |
| 0.15083 | 486.23 |
| 0.22625 | 489.60 |
| 0.30167 | 492.97 |
| 0.37708 | 495.94 |
| 0.45250 | 498.84 |
| 0.52792 | 501.66 |
| 0.60333 | 504.07 |
| 0.67875 | 506.48 |
| 0.75417 | 508.89 |
| 0.82958 | 510.84 |
| 0.90500 | 512.76 |
| 0.98042 | 514.68 |
| 1.0558 | 516.56 |
| 1.1313 | 518.01 |
| 1.2067 | 519.45 |
| 1.2821 | 520.89 |
| 1.3575 | 522.34 |
| 1.4329 | 523.59 |
| 1.5083 | 524.61 |
| 1.5838 | 525.62 |
| 1.6592 | 526.64 |
| 1.7346 | 527.66 |
| 1.8100 | 528.67 |
| 1.8854 | 529.36 |
| 1.9608 | 530.02 |
| 2.0363 | 530.68 |
| 2.1117 | 531.33 |
| 2.1871 | 531.99 |
| 2.2625 | 532.65 |
| 2.3379 | 533.21 |
| 2.4133 | 533.58 |
| 2.4888 | 533.95 |
| 2.5642 | 534.32 |
| 2.6396 | 534.69 |
| 2.7150 | 535.06 |
| 2.7904 | 535.43 |
| 2.8658 | 535.80 |
| 2.9413 | 536.06 |
| 3.0167 | 536.18 |
| 3.0921 | 536.30 |
| 3.1675 | 536.42 |
| 3.2429 | 536.54 |
| 3.3183 | 536.66 |
| 3.3938 | 536.78 |
| 3.4692 | 536.90 |
| 3.5446 | 537.02 |
| 3.6200 | 537.14 |

PLOT VALUE ALONG PATH FROM NODE 1766 TO NODE 1750 OF TEMP DSYS= 0

| DISTANCE | TEMP |
|---|---|

| | |
|---|---|
| 0. | 508.56 |
| 0.75417E-01 | 510.31 |
| 0.15083 | 512.06 |
| 0.22625 | 513.77 |
| 0.30167 | 515.48 |
| 0.37708 | 517.06 |
| 0.45250 | 518.62 |
| 0.52792 | 520.15 |
| 0.60333 | 521.50 |
| 0.67875 | 522.85 |
| 0.75417 | 524.20 |
| 0.82958 | 525.32 |
| 0.90500 | 526.42 |
| 0.98042 | 527.52 |
| 1.0558 | 528.60 |
| 1.1313 | 529.45 |
| 1.2067 | 530.30 |
| 1.2821 | 531.14 |
| 1.3575 | 531.99 |
| 1.4329 | 532.73 |
| 1.5083 | 533.34 |
| 1.5838 | 533.95 |
| 1.6592 | 534.55 |
| 1.7346 | 535.16 |
| 1.8100 | 535.77 |
| 1.8854 | 536.19 |
| 1.9608 | 536.59 |
| 2.0363 | 537.00 |
| 2.1117 | 537.40 |
| 2.1871 | 537.80 |
| 2.2625 | 538.21 |
| 2.3379 | 538.55 |
| 2.4133 | 538.79 |
| 2.4888 | 539.02 |
| 2.5642 | 539.25 |
| 2.6396 | 539.48 |
| 2.7150 | 539.71 |
| 2.7904 | 539.95 |
| 2.8658 | 540.18 |
| 2.9413 | 540.34 |
| 3.0167 | 540.42 |
| 3.0921 | 540.49 |
| 3.1675 | 540.57 |
| 3.2429 | 540.65 |
| 3.3183 | 540.73 |
| 3.3938 | 540.80 |
| 3.4692 | 540.88 |
| 3.5446 | 540.96 |
| 3.6200 | 541.03 |

FOR LOAD STEP= 19 ITERATION= 1042 SECTION= 1
TIME= 560.000 LOAD CASE= 1
PLOT VALUE ALONG PATH FROM NODE 1660 TO NODE 1654 OF TEMP DSYS= 0

| DISTANCE | TEMP |
|---|---|
| 0. | 454.50 |

| | |
|---|---|
| 0.75417E-01 | 458.75 |
| 0.15083 | 462.95 |
| 0.22625 | 466.70 |
| 0.30167 | 470.46 |
| 0.37708 | 473.75 |
| 0.45250 | 476.97 |
| 0.52792 | 480.10 |
| 0.60333 | 482.75 |
| 0.67875 | 485.41 |
| 0.75417 | 488.06 |
| 0.82958 | 490.18 |
| 0.90500 | 492.26 |
| 0.98042 | 494.34 |
| 1.0558 | 496.38 |
| 1.1313 | 497.91 |
| 1.2067 | 499.44 |
| 1.2821 | 500.98 |
| 1.3575 | 502.51 |
| 1.4329 | 503.82 |
| 1.5083 | 504.86 |
| 1.5838 | 505.90 |
| 1.6592 | 506.95 |
| 1.7346 | 507.99 |
| 1.8100 | 509.03 |
| 1.8854 | 509.70 |
| 1.9608 | 510.34 |
| 2.0363 | 510.98 |
| 2.1117 | 511.63 |
| 2.1871 | 512.27 |
| 2.2625 | 512.91 |
| 2.3379 | 513.45 |
| 2.4133 | 513.78 |
| 2.4888 | 514.12 |
| 2.5642 | 514.46 |
| 2.6396 | 514.79 |
| 2.7150 | 515.13 |
| 2.7904 | 515.46 |
| 2.8658 | 515.80 |
| 2.9413 | 516.03 |
| 3.0167 | 516.13 |
| 3.0921 | 516.23 |
| 3.1675 | 516.34 |
| 3.2429 | 516.44 |
| 3.3183 | 516.54 |
| 3.3938 | 516.64 |
| 3.4692 | 516.74 |
| 3.5446 | 516.85 |
| 3.6200 | 516.95 |

PLOT VALUE ALONG PATH FROM NODE 1766 TO NODE 1750 OF TEMP DSYS= 0

| DISTANCE | TEMP |
|---|---|
| 0. | 490.78 |
| 0.75417E-01 | 492.76 |
| 0.15083 | 494.73 |
| 0.22625 | 496.68 |

| | |
|---|---|
| 0.30167 | 498.63 |
| 0.37708 | 500.44 |
| 0.45250 | 502.23 |
| 0.52792 | 503.98 |
| 0.60333 | 505.53 |
| 0.67875 | 507.07 |
| 0.75417 | 508.62 |
| 0.82958 | 509.90 |
| 0.90500 | 511.16 |
| 0.98042 | 512.42 |
| 1.0558 | 513.66 |
| 1.1313 | 514.62 |
| 1.2067 | 515.58 |
| 1.2821 | 516.54 |
| 1.3575 | 517.51 |
| 1.4329 | 518.34 |
| 1.5083 | 519.03 |
| 1.5838 | 519.71 |
| 1.6592 | 520.40 |
| 1.7346 | 521.08 |
| 1.8100 | 521.77 |
| 1.8854 | 522.23 |
| 1.9608 | 522.67 |
| 2.0363 | 523.12 |
| 2.1117 | 523.56 |
| 2.1871 | 524.01 |
| 2.2625 | 524.45 |
| 2.3379 | 524.83 |
| 2.4133 | 525.08 |
| 2.4888 | 525.32 |
| 2.5642 | 525.57 |
| 2.6396 | 525.82 |
| 2.7150 | 526.07 |
| 2.7904 | 526.31 |
| 2.8658 | 526.56 |
| 2.9413 | 526.74 |
| 3.0167 | 526.82 |
| 3.0921 | 526.89 |
| 3.1675 | 526.97 |
| 3.2429 | 527.05 |
| 3.3183 | 527.13 |
| 3.3938 | 527.21 |
| 3.4692 | 527.29 |
| 3.5446 | 527.37 |
| 3.6200 | 527.45 |

SUMMARY OF VARIABLES STORED THIS STEP AND EXTREME VALUES

| VARI | TYPE | IDENTIFIERS | | NAME | MINIMUM | AT TIME | MAXIMUM | AT TIME |
|---|---|---|---|---|---|---|---|---|
| 2 | ESTR | 531 | 16 | 531 SY24 | 0.2433E+05 | 600.0 | 0.4056E+05 | 275.0 |
| 3 | ESTR | 611 | 16 | 611 SY9 | 9183. | 600.0 | 0.1705E+05 | 560.0 |
| 4 | ESTR | 531 | 18 | 531 SZ24 | 0.1686E+05 | 600.0 | 0.3290E+05 | 275.0 |
| 5 | ESTR | 611 | 18 | 611 SZ9 | 0.1707E+05 | 600.0 | 0.2661E+05 | 275.0 |
| 6 | ESTR | 531 | 51 | 531 SI24 | 0.2495E+05 | 600.0 | 0.4118E+05 | 275.0 |
| 7 | ESTR | 611 | 51 | 611 SI9 | 0.1797E+05 | 600.0 | 0.2710E+05 | 275.0 |

TIME ESTR 531 16 ESTR 611 16 ESTR 531 18 ESTR 611 18 ESTR

531 51 ESTR 611 51

| | 531 SY24 | 611 SY9 | 531 SZ24 | 611 SZ9 | 531 SI24 | 611 SI9 |
|---|---|---|---|---|---|---|
| 0. | 28249.2 | 10244.1 | 19355.9 | 18514.8 | 29062.1 | 19534.9 |
| 10.000 | 28732.0 | 10501.1 | 19881.4 | 18744.4 | 29537.9 | 19758.5 |
| 20.000 | 29728.6 | 10918.9 | 20936.1 | 19210.2 | 30523.2 | 20280.1 |
| 50.000 | 34087.0 | 13347.2 | 25530.9 | 22349.9 | 34839.9 | 23122.1 |
| 75.000 | 30751.9 | 11665.9 | 22341.7 | 20482.4 | 31511.0 | 21471.3 |
| 90.000 | 31280.6 | 11967.4 | 22848.2 | 20661.2 | 32037.4 | 21556.1 |
| 110.00 | 33407.2 | 13154.4 | 25071.5 | 21988.8 | 34140.6 | 22765.0 |
| 150.00 | 39609.0 | 16306.9 | 31630.5 | 25967.1 | 40279.8 | 26537.6 |
| 175.00 | 29894.6 | 11314.2 | 21851.4 | 20168.5 | 30622.5 | 21221.9 |
| 190.00 | 30509.6 | 11765.4 | 22376.9 | 20301.5 | 31232.4 | 21162.1 |
| 220.00 | 34127.5 | 13731.5 | 26047.1 | 22528.0 | 34816.0 | 23208.6 |
| 275.00 | 40560.3 | 16936.0 | 32899.0 | 26614.2 | 41178.2 | 27097.1 |
| 300.00 | 28461.5 | 10816.8 | 20685.5 | 19456.2 | 29147.9 | 20471.0 |
| 330.00 | 31174.3 | 12333.4 | 23209.7 | 20820.5 | 31844.1 | 21546.0 |
| 375.00 | 37021.0 | 15375.8 | 29314.4 | 24431.9 | 37631.3 | 24926.3 |
| 450.00 | 25374.0 | 9691.47 | 17445.0 | 17593.9 | 26046.5 | 18469.1 |
| 480.00 | 29047.2 | 11553.5 | 21136.0 | 19542.6 | 29685.0 | 20221.9 |
| 530.00 | 35888.7 | 15084.5 | 28406.6 | 23790.8 | 36455.9 | 24218.0 |
| 560.00 | 40014.2 | 17054.5 | 32836.4 | 26354.7 | 40541.0 | 26663.4 |
| 600.00 | 24328.0 | 9183.44 | 16863.9 | 17065.5 | 24954.4 | 17974.0 |

***** POST1 LINEARIZED STRESS LISTING *****

INSIDE NODE = 1660 OUTSIDE NODE = 1654

LOAD STEP 12 ITERATION= 1 SECTION= 1

TIME= 275.00 LOAD CASE= 1

** AXISYMMETRIC OPTION ** RHO = 0.67980E+13

THE FOLLOWING X,Y,Z STRESSES ARE IN SECTION COORDINATES.

** MEMBRANE **

| SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|
| 422.2 | 0.1049E+05 | 0.1425E+05 | 1317. | 0. | 0. |

| SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|
| 0.1425E+05 | 0.1066E+05 | 252.6 | 0.1399E+05 | 0.1259E+05 |

** BENDING ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -1252. | 0.2140E+05 | 0.1230E+05 | 0. | 0. | 0. |
| C | -835.0 | 149.0 | 0. | 0. | 0. | 0. |
| O | -417.7 | -0.2110E+05 | -0.1230E+05 | 0. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 0.2140E+05 | 0.1230E+05 | -1252. | 0.2265E+05 | 0.1975E+05 |
| C | 149.0 | 0. | -835.0 | 984.0 | 918.6 |
| O | -417.7 | -0.1230E+05 | -0.2110E+05 | 0.2069E+05 | 0.1798E+05 |

** MEMBRANE PLUS BENDING ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -830.1 | 0.3189E+05 | 0.2655E+05 | 1317. | 0. | 0. |
| C | -412.8 | 0.1063E+05 | 0.1425E+05 | 1317. | 0. | 0. |
| O | 4.487 | -0.1062E+05 | 1949. | 1317. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 0.3194E+05 | 0.2655E+05 | -883.1 | 0.3282E+05 | 0.3049E+05 |
| C | 0.1425E+05 | 0.1079E+05 | -567.7 | 0.1481E+05 | 0.1342E+05 |
| O | 1949. | 165.4 | -0.1078E+05 | 0.1273E+05 | 0.1194E+05 |

** PEAK ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -0.1137E-12 | 7773. | 6051. | -1219. | 0. | 0. |
| C | 1231. | -2827. | -2267. | 337.6 | 0. | 0. |
| O | -0.6217E-14 | 4127. | 3513. | -1353. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 7959. | 6051. | -186.7 | 8146. | 7379. |
| C | 1258. | -2267. | -2855. | 4114. | 3853. |
| O | 4531. | 3513. | -403.7 | 4935. | 4513. |

** TOTAL ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -830.1 | 0.3966E+05 | 0.3260E+05 | 98.32 | 0. | 0. |
| C | 817.8 | 7808. | 0.1198E+05 | 1655. | 0. | 0. |
| O | 4.487 | -6491. | 5462. | -35.05 | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE | TEMP |
|---|---|---|---|---|---|---|
| I | 0.3966E+05 | 0.3260E+05 | -830.4 | 0.4049E+05 | 0.3746E+05 | 478.7 |
| C | 0.1198E+05 | 8180. | 445.2 | 0.1153E+05 | 0.1019E+05 | |
| O | 5462. | 4.712 | -6491. | 0.1195E+05 | 0.1037E+05 | 537.1 |

PLOT VALUE ALONG PATH FROM NODE 1660 TO NODE 1654 OF SY DSYS= 0

SY IN GLOBAL COORDINATES

| DISTANCE | SY |
|---|---|
| 0. | 39661. |
| 0.75417E-01 | 37619. |
| 0.15083 | 35594. |
| 0.22625 | 33705. |
| 0.30167 | 31815. |
| 0.37708 | 30088. |
| 0.45250 | 28388. |
| 0.52792 | 26721. |
| 0.60333 | 25236. |

| | |
|---|---|
| 0.67875 | 23751. |
| 0.75417 | 22265. |
| 0.82958 | 20988. |
| 0.90500 | 19727. |
| 0.98042 | 18466. |
| 1.0558 | 17219. |
| 1.1313 | 16174. |
| 1.2067 | 15129. |
| 1.2821 | 14084. |
| 1.3575 | 13039. |
| 1.4329 | 12080. |
| 1.5083 | 11225. |
| 1.5838 | 10371. |
| 1.6592 | 9516.4 |
| 1.7346 | 8662.0 |
| 1.8100 | 7807.6 |
| 1.8854 | 7096.2 |
| 1.9608 | 6395.2 |
| 2.0363 | 5694.2 |
| 2.1117 | 4993.1 |
| 2.1871 | 4292.1 |
| 2.2625 | 3591.1 |
| 2.3379 | 2927.2 |
| 2.4133 | 2338.1 |
| 2.4888 | 1749.0 |
| 2.5642 | 1159.9 |
| 2.6396 | 570.87 |
| 2.7150 | -18.216 |
| 2.7904 | -607.30 |
| 2.8658 | -1196.4 |
| 2.9413 | -1757.8 |
| 3.0167 | -2283.7 |
| 3.0921 | -2809.6 |
| 3.1675 | -3335.5 |
| 3.2429 | -3861.5 |
| 3.3183 | -4387.4 |
| 3.3938 | -4913.3 |
| 3.4692 | -5439.2 |
| 3.5446 | -5965.2 |
| 3.6200 | -6491.1 |

***** POST1 LINEARIZED STRESS LISTING *****
INSIDE NODE = 1660 OUTSIDE NODE = 1654

LOAD STEP 19 ITERATION= 1 SECTION= 1
TIME= 560.00 LOAD CASE= 1

** AXISYMMETRIC OPTION ** RHO = 0.67980E+13
THE FOLLOWING X,Y,Z STRESSES ARE IN SECTION COORDINATES.

** MEMBRANE **

| SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|
| 455.0 | 9415. | 0.1326E+05 | 1181. | 0. | 0. |

| SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|
| 0.1326E+05 | 9568. | 302.0 | 0.1296E+05 | 0.1157E+05 |

** BENDING ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -1192. | 0.2126E+05 | 0.1249E+05 | 0. | 0. | 0. |
| C | -820.2 | 148.0 | 0. | 0. | 0. | 0. |
| O | -448.4 | -0.2096E+05 | -0.1249E+05 | 0. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 0.2126E+05 | 0.1249E+05 | -1192. | 0.2245E+05 | 0.1960E+05 |
| C | 148.0 | 0. | -820.2 | 968.2 | 903.4 |
| O | -448.4 | -0.1249E+05 | -0.2096E+05 | 0.2052E+05 | 0.1786E+05 |

** MEMBRANE PLUS BENDING ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -737.0 | 0.3068E+05 | 0.2575E+05 | 1181. | 0. | 0. |
| C | -365.2 | 9563. | 0.1326E+05 | 1181. | 0. | 0. |
| O | 6.614 | -0.1155E+05 | 778.8 | 1181. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 0.3072E+05 | 0.2575E+05 | -781.4 | 0.3150E+05 | 0.2933E+05 |
| C | 0.1326E+05 | 9702. | -503.7 | 0.1377E+05 | 0.1238E+05 |
| O | 778.8 | 126.0 | -0.1167E+05 | 0.1245E+05 | 0.1213E+05 |

** PEAK ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | 0. | 8462. | 6791. | -1084. | 0. | 0. |
| C | 1206. | -3051. | -2509. | 281.0 | 0. | 0. |
| O | 0.2665E-14 | 4409. | 3808. | -1224. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 8598. | 6791. | -136.7 | 8735. | 7986. |
| C | 1224. | -2509. | -3070. | 4294. | 4042. |
| O | 4726. | 3808. | -317.0 | 5043. | 4652. |

** TOTAL ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -737.0 | 0.3914E+05 | 0.3254E+05 | 96.59 | 0. | 0. |
| C | 840.3 | 6512. | 0.1076E+05 | 1462. | 0. | 0. |
| O | 6.614 | -7140. | 4587. | -43.10 | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE | TEMP |
|---|---|---|---|---|---|---|
| I | 0.3914E+05 | 0.3254E+05 | -737.3 | 0.3987E+05 | 0.3702E+05 | 454.5 |
| C | 0.1076E+05 | 6867. | 485.1 | 0.1027E+05 | 8986. | |
| O | 4587. | 6.908 | -7141. | 0.1173E+05 | 0.1024E+05 | 516.9 |

SY IN GLOBAL COORDINATES

| DISTANCE | SY |
|---|---|
| 0. | 39137. |
| 0.75417E-01 | 36993. |
| 0.15083 | 34867. |
| 0.22625 | 32889. |
| 0.30167 | 30911. |
| 0.37708 | 29112. |
| 0.45250 | 27344. |
| 0.52792 | 25613. |
| 0.60333 | 24083. |
| 0.67875 | 22553. |
| 0.75417 | 21023. |

| | |
|---|---|
| 0.82958 | 19720. |
| 0.90500 | 18435. |
| 0.98042 | 17150. |
| 1.0558 | 15881. |
| 1.1313 | 14831. |
| 1.2067 | 13781. |
| 1.2821 | 12731. |
| 1.3575 | 11681. |
| 1.4329 | 10725. |
| 1.5083 | 9882.1 |
| 1.5838 | 9039.6 |
| 1.6592 | 8197.0 |
| 1.7346 | 7354.5 |
| 1.8100 | 6512.0 |
| 1.8854 | 5823.9 |
| 1.9608 | 5147.1 |
| 2.0363 | 4470.2 |
| 2.1117 | 3793.4 |
| 2.1871 | 3116.6 |
| 2.2625 | 2439.7 |
| 2.3379 | 1801.8 |
| 2.4133 | 1242.3 |
| 2.4888 | 682.80 |
| 2.5642 | 123.29 |
| 2.6396 | -436.22 |
| 2.7150 | -995.73 |
| 2.7904 | -1555.2 |
| 2.8658 | -2114.7 |
| 2.9413 | -2647.8 |
| 3.0167 | -3147.0 |
| 3.0921 | -3646.1 |
| 3.1675 | -4145.3 |
| 3.2429 | -4644.5 |
| 3.3183 | -5143.6 |
| 3.3938 | -5642.8 |
| 3.4692 | -6142.0 |
| 3.5446 | -6641.2 |
| 3.6200 | -7140.3 |

PRINT LINEARIZED STRESS THROUGH A SECTION
INSIDE NODE = 1660 OUTSIDE NODE = 1654

***** POST1 LINEARIZED STRESS LISTING *****
INSIDE NODE = 1660 OUTSIDE NODE = 1654

LOAD STEP 20 ITERATION= 1 SECTION= 1
TIME= 600.00 LOAD CASE= 1

** AXISYMMETRIC OPTION ** RHO = 0.67980E+13
THE FOLLOWING X,Y,Z STRESSES ARE IN SECTION COORDINATES.

** MEMBRANE **

| SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|
| 297.4 | 9251. | 0.1260E+05 | 1107. | 0. | 0. |
| SIG1 | SIG2 | SIG3 | SI | SIGE | |

0.1260E+05 9386. 162.5 0.1243E+05 0.1118E+05

** BENDING ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -1055. | 0.1761E+05 | 8593. | 0. | 0. | 0. |
| C | -672.3 | 122.6 | 0. | 0. | 0. | 0. |
| O | -289.6 | -0.1736E+05 | -8593. | 0. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 0.1761E+05 | 8593. | -1055. | 0.1866E+05 | 0.1616E+05 |
| C | 122.6 | 0. | -672.3 | 794.8 | 741.2 |
| O | -289.6 | -8593. | -0.1736E+05 | 0.1707E+05 | 0.1479E+05 |

** MEMBRANE PLUS BENDING ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -757.5 | 0.2686E+05 | 0.2119E+05 | 1107. | 0. | 0. |
| C | -374.9 | 9374. | 0.1260E+05 | 1107. | 0. | 0. |
| O | 7.808 | -8111. | 4004. | 1107. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 0.2690E+05 | 0.2119E+05 | -801.9 | 0.2770E+05 | 0.2534E+05 |
| C | 0.1260E+05 | 9498. | -499.1 | 0.1310E+05 | 0.1185E+05 |
| O | 4004. | 156.2 | -8259. | 0.1226E+05 | 0.1086E+05 |

** PEAK ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | 0.1137E-12 | -3165. | -4552. | -1045. | 0. | 0. |
| C | 1038. | -812.2 | -287.3 | 304.5 | 0. | 0. |
| O | -0.6040E-13 | 1568. | 928.1 | -1151. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 314.0 | -3479. | -4552. | 4866. | 4428. |
| C | 1087. | -287.3 | -861.0 | 1948. | 1734. |
| O | 2176. | 928.1 | -608.4 | 2785. | 2416. |

SY IN GLOBAL COORDINATES

| DISTANCE | SY |
|---|---|
| 0. | 23693. |
| 0.75417E-01 | 24004. |
| 0.15083 | 24278. |
| 0.22625 | 24252. |
| 0.30167 | 24227. |
| 0.37708 | 23872. |
| 0.45250 | 23462. |
| 0.52792 | 23009. |
| 0.60333 | 22327. |
| 0.67875 | 21645. |
| 0.75417 | 20963. |
| 0.82958 | 20123. |
| 0.90500 | 19270. |
| 0.98042 | 18417. |
| 1.0558 | 17559. |
| 1.1313 | 16635. |
| 1.2067 | 15710. |
| 1.2821 | 14786. |
| 1.3575 | 13861. |
| 1.4329 | 12957. |
| 1.5083 | 12078. |

| | |
|---|---|
| 1.5838 | 11199. |
| 1.6592 | 10320. |
| 1.7346 | 9440.6 |
| 1.8100 | 8561.4 |
| 1.8854 | 7788.4 |
| 1.9608 | 7023.2 |
| 2.0363 | 6258.0 |
| 2.1117 | 5492.7 |
| 2.1871 | 4727.5 |
| 2.2625 | 3962.2 |
| 2.3379 | 3240.9 |
| 2.4133 | 2608.1 |
| 2.4888 | 1975.2 |
| 2.5642 | 1342.4 |
| 2.6396 | 709.58 |
| 2.7150 | 76.749 |
| 2.7904 | -556.08 |
| 2.8658 | -1188.9 |
| 2.9413 | -1776.5 |
| 3.0167 | -2306.1 |
| 3.0921 | -2835.7 |
| 3.1675 | -3365.3 |
| 3.2429 | -3894.9 |
| 3.3183 | -4424.5 |
| 3.3938 | -4954.1 |
| 3.4692 | -5483.7 |
| 3.5446 | -6013.3 |
| 3.6200 | -6543.0 |

!, ****************************************************************
!, ****************************************************************
Additional files of through-thickness profiles;
all peaks and valleys.

TIME= 60.000 LOAD CASE= 1
THE FOLLOWING X,Y,Z STRESSES ARE IN SECTION COORDINATES.

** MEMBRANE **

| SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|
| 209.4 | 0.1137E+05 | 0.1450E+05 | 1378. | 0. | 0. |

| SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|
| 0.1450E+05 | 0.1154E+05 | 41.85 | 0.1446E+05 | 0.1323E+05 |

** BENDING ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -1131. | 0.1698E+05 | 7444. | 0. | 0. | 0. |
| C | -671.2 | 118.2 | 0. | 0. | 0. | 0. |
| O | -211.9 | -0.1674E+05 | -7444. | 0. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 0.1698E+05 | 7444. | -1131. | 0.1811E+05 | 0.1569E+05 |
| C | 118.2 | 0. | -671.2 | 789.4 | 737.5 |
| O | -211.9 | -7444. | -0.1674E+05 | 0.1653E+05 | 0.1435E+05 |

** MEMBRANE PLUS BENDING ** I=INSIDE C=CENTER O=OUTSIDE

SX SY SZ SXY SYZ SXZ

| | | | | | | |
|---|---|---|---|---|---|---|
| I | -921.1 | 0.2835E+05 | 0.2194E+05 | 1378. | 0. | 0. |
| C | -461.8 | 0.1149E+05 | 0.1450E+05 | 1378. | 0. | 0. |
| O | -2.459 | -5372. | 7056. | 1378. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 0.2841E+05 | 0.2194E+05 | -985.9 | 0.2940E+05 | 0.2676E+05 |
| C | 0.1450E+05 | 0.1164E+05 | -618.6 | 0.1512E+05 | 0.1391E+05 |
| O | 7056. | 330.5 | -5705. | 0.1276E+05 | 0.1106E+05 |

** PEAK ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -0.1137E-12 | 5372. | 3834. | -1294. | 0. | 0. |
| C | 983.6 | -1756. | -1264. | 402.6 | 0. | 0. |
| O | -0.1821E-13 | 2286. | 1753. | -1381. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 5667. | 3834. | -295.3 | 5962. | 5290. |
| C | 1042. | -1264. | -1814. | 2855. | 2624. |
| O | 2936. | 1753. | -649.5 | 3585. | 3164. |

** TOTAL ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -921.1 | 0.3372E+05 | 0.2578E+05 | 84.18 | 0. | 0. |
| C | 521.8 | 9732. | 0.1324E+05 | 1781. | 0. | 0. |
| O | -2.459 | -3086. | 8809. | -2.944 | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE | TEMP |
|---|---|---|---|---|---|---|
| I | 0.3372E+05 | 0.2578E+05 | -921.4 | 0.3464E+05 | 0.3143E+05 | 521.5 |
| C | 0.1324E+05 | 0.1006E+05 | 189.4 | 0.1305E+05 | 0.1179E+05 | |
| O | 8809. | -2.422 | -3086. | 0.1189E+05 | 0.1069E+05 | 547.0 |

SY IN GLOBAL COORDINATES

| DISTANCE | SY |
|---|---|
| 0. | 33720. |
| 0.75417E-01 | 32240. |
| 0.15083 | 30765. |
| 0.22625 | 29335. |
| 0.30167 | 27905. |
| 0.37708 | 26579. |
| 0.45250 | 25271. |
| 0.52792 | 23990. |
| 0.60333 | 22855. |
| 0.67875 | 21721. |
| 0.75417 | 20586. |
| 0.82958 | 19625. |
| 0.90500 | 18677. |
| 0.98042 | 17730. |
| 1.0558 | 16794. |
| 1.1313 | 16015. |
| 1.2067 | 15237. |
| 1.2821 | 14459. |
| 1.3575 | 13681. |
| 1.4329 | 12963. |
| 1.5083 | 12317. |
| 1.5838 | 11671. |
| 1.6592 | 11024. |
| 1.7346 | 10378. |
| 1.8100 | 9732.1 |

| | |
|---|---|
| 1.8854 | 9165.9 |
| 1.9608 | 8605.5 |
| 2.0363 | 8045.1 |
| 2.1117 | 7484.7 |
| 2.1871 | 6924.3 |
| 2.2625 | 6364.0 |
| 2.3379 | 5817.4 |
| 2.4133 | 5298.5 |
| 2.4888 | 4779.7 |
| 2.5642 | 4260.8 |
| 2.6396 | 3742.0 |
| 2.7150 | 3223.1 |
| 2.7904 | 2704.3 |
| 2.8658 | 2185.4 |
| 2.9413 | 1662.7 |
| 3.0167 | 1135.1 |
| 3.0921 | 607.56 |
| 3.1675 | 79.977 |
| 3.2429 | -447.61 |
| 3.3183 | -975.19 |
| 3.3938 | -1502.8 |
| 3.4692 | -2030.4 |
| 3.5446 | -2558.0 |
| 3.6200 | -3085.5 |

TIME= 75.000 LOAD CASE= 1
THE FOLLOWING X,Y,Z STRESSES ARE IN SECTION COORDINATES.

** MEMBRANE **

| SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|
| 194.7 | 0.1128E+05 | 0.1434E+05 | 1361. | 0. | 0. |

| SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|
| 0.1434E+05 | 0.1144E+05 | 29.98 | 0.1431E+05 | 0.1311E+05 |

** BENDING ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -1116. | 0.1660E+05 | 7077. | 0. | 0. | 0. |
| C | -656.2 | 115.5 | 0. | 0. | 0. | 0. |
| O | -196.6 | -0.1636E+05 | -7077. | 0. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 0.1660E+05 | 7077. | -1116. | 0.1771E+05 | 0.1535E+05 |
| C | 115.5 | 0. | -656.2 | 771.7 | 720.9 |
| O | -196.6 | -7077. | -0.1636E+05 | 0.1617E+05 | 0.1405E+05 |

** MEMBRANE PLUS BENDING ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -921.1 | 0.2787E+05 | 0.2142E+05 | 1361. | 0. | 0. |
| C | -461.6 | 0.1139E+05 | 0.1434E+05 | 1361. | 0. | 0. |
| O | -1.956 | -5087. | 7266. | 1361. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 0.2794E+05 | 0.2142E+05 | -985.3 | 0.2892E+05 | 0.2628E+05 |
| C | 0.1434E+05 | 0.1155E+05 | -615.8 | 0.1496E+05 | 0.1378E+05 |
| O | 7266. | 339.4 | -5428. | 0.1269E+05 | 0.1101E+05 |

** PEAK ** I=INSIDE C=CENTER O=OUTSIDE

| SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| I | 0.1137E-12 | 2145. | 661.2 | -1284. | 0. | 0. |
| C | 975.7 | -1473. | -977.8 | 397.4 | 0. | 0. |
| O | 0.2043E-13 | 1893. | 1346. | -1366. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 2746. | 661.2 | -600.8 | 3347. | 2928. |
| C | 1039. | -977.8 | -1535. | 2574. | 2346. |
| O | 2608. | 1346. | -715.1 | 3323. | 2906. |

** TOTAL ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -921.1 | 0.3002E+05 | 0.2208E+05 | 76.48 | 0. | 0. |
| C | 514.2 | 9921. | 0.1337E+05 | 1758. | 0. | 0. |
| O | -1.956 | -3193. | 8612. | -4.733 | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE | TEMP |
|---|---|---|---|---|---|---|
| I | 0.3002E+05 | 0.2208E+05 | -921.4 | 0.3094E+05 | 0.2784E+05 | 532.4 |
| C | 0.1337E+05 | 0.1024E+05 | 196.1 | 0.1317E+05 | 0.1192E+05 | |
| O | 8612. | -1.915 | -3193. | 0.1181E+05 | 0.1058E+05 | 546.9 |

| DISTANCE | SY |
|---|---|
| 0. | 30019. |
| 0.75417E-01 | 2[illegible]310. |
| 0.15083 | 28585. |
| 0.22625 | 27733. |
| 0.30167 | 26881. |
| 0.37708 | 25934. |
| 0.45250 | 24970. |
| 0.52792 | 24004. |
| 0.60333 | 23021. |
| 0.67875 | 22037. |
| 0.75417 | 21054. |
| 0.82958 | 20127. |
| 0.90500 | 19204. |
| 0.98042 | 18281. |
| 1.0558 | 17365. |
| 1.1313 | 16554. |
| 1.2067 | 15742. |
| 1.2821 | 14931. |
| 1.3575 | 14120. |
| 1.4329 | 13364. |
| 1.5083 | 12675. |
| 1.5838 | 11986. |
| 1.6592 | 11298. |
| 1.7346 | 10609. |
| 1.8100 | 9920.7 |
| 1.8854 | 9324.9 |
| 1.9608 | 8735.8 |
| 2.0363 | 8146.8 |
| 2.1117 | 7557.7 |
| 2.1871 | 6968.7 |
| 2.2625 | 6379.6 |
| 2.3379 | 5809.8 |
| 2.4133 | 5278.8 |
| 2.4888 | 4747.9 |
| 2.5642 | 4216.9 |
| 2.6396 | 3685.9 |

| | |
|---|---|
| 2.7150 | 3154.9 |
| 2.7904 | 2623.9 |
| 2.8658 | 2093.0 |
| 2.9413 | 1563.1 |
| 3.0167 | 1034.6 |
| 3.0921 | 506.11 |
| 3.1675 | -22.368 |
| 3.2429 | -550.85 |
| 3.3183 | -1079.3 |
| 3.3938 | -1607.8 |
| 3.4692 | -2136.3 |
| 3.5446 | -2664.8 |
| 3.6200 | -3193.2 |

TIME= 150.00 LOAD CASE= 1

THE FOLLOWING X,Y,Z STRESSES ARE IN SECTION COORDINATES.

** MEMBRANE **

| SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|
| 347.0 | 0.1099E+05 | 0.1452E+05 | 1367. | 0. | 0. |

| SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|
| 0.1452E+05 | 0.1116E+05 | 174.2 | 0.1434E+05 | 0.1299E+05 |

** BENDING ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -1224. | 0.1995E+05 | 0.1070E+05 | 0. | 0. | 0. |
| C | -784.6 | 138.9 | 0. | 0. | 0. | 0. |
| O | -345.7 | -0.1968E+05 | -0.1070E+05 | 0. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 0.1995E+05 | 0.1070E+05 | -1224. | 0.2118E+05 | 0.1839E+05 |
| C | 138.9 | 0. | -784.6 | 923.5 | 862.5 |
| O | -345.7 | -0.1070E+05 | -0.1968E+05 | 0.1933E+05 | 0.1675E+05 |

** MEMBRANE PLUS BENDING ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -876.6 | 0.3094E+05 | 0.2522E+05 | 1367. | 0. | 0. |
| C | -437.7 | 0.1112E+05 | 0.1452E+05 | 1367. | 0. | 0. |
| O | 1.251 | -8690. | 3813. | 1367. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 0.3100E+05 | 0.2522E+05 | -935.2 | 0.3193E+05 | 0.2947E+05 |
| C | 0.1452E+05 | 0.1128E+05 | -597.0 | 0.1511E+05 | 0.1378E+05 |
| O | 3813. | 211.1 | -8900. | 0.1271E+05 | 0.1135E+05 |

** PEAK ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -0.1137E-12 | 7794. | 6116. | -1271. | 0. | 0. |
| C | 1151. | -2544. | -2009. | 369.7 | 0. | 0. |
| O | -0.1354E-13 | 3594. | 3017. | -1387. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 7996. | 6116. | -202.0 | 8198. | 7438. |
| C | 1187. | -2009. | -2581. | 3768. | 3517. |
| O | 4067. | 3017. | -473.3 | 4541. | 4117. |

** TOTAL ** I=INSIDE C=CENTER O=OUTSIDE

| SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| I | -876.6 | 0.3873E+05 | 0.3133E+05 | 95.95 | 0. | 0. |
| C | 713.0 | 8581. | 0.1251E+05 | 1736. | 0. | 0. |
| O | 1.251 | -5096. | 6830. | -20.64 | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE | TEMP |
|---|---|---|---|---|---|---|
| I | 0.3873E+05 | 0.3133E+05 | -876.9 | 0.3961E+05 | 0.3648E+05 | 495.1 |
| C | 0.1251E+05 | 8947. | 346.4 | 0.1216E+05 | 0.1083E+05 | |
| O | 6830. | 1.368 | -5096. | 0.1193E+05 | 0.1036E+05 | 544.9 |

| DISTANCE | SY |
|---|---|
| 0. | 38734. |
| 0.75417E-01 | 36674. |
| 0.15083 | 34635. |
| 0.22625 | 32760. |
| 0.30167 | 30884. |
| 0.37708 | 29203. |
| 0.45250 | 27555. |
| 0.52792 | 25945. |
| 0.60333 | 24543. |
| 0.67875 | 23141. |
| 0.75417 | 21738. |
| 0.82958 | 20559. |
| 0.90500 | 19397. |
| 0.98042 | 18234. |
| 1.0558 | 17087. |
| 1.1313 | 16140. |
| 1.2067 | 15194. |
| 1.2821 | 14248. |
| 1.3575 | 13301. |
| 1.4329 | 12434. |
| 1.5083 | 11663. |
| 1.5838 | 10893. |
| 1.6592 | 10122. |
| 1.7346 | 9351.3 |
| 1.8100 | 8580.6 |
| 1.8854 | 7929.3 |
| 1.9608 | 7286.7 |
| 2.0363 | 6644.2 |
| 2.1117 | 6001.6 |
| 2.1871 | 5359.0 |
| 2.2625 | 4716.4 |
| 2.3379 | 4101.4 |
| 2.4133 | 3541.9 |
| 2.4888 | 2982.5 |
| 2.5642 | 2423.0 |
| 2.6396 | 1863.6 |
| 2.7150 | 1304.1 |
| 2.7904 | 744.70 |
| 2.8658 | 185.25 |
| 2.9413 | -359.65 |
| 3.0167 | -885.92 |
| 3.0921 | -1412.2 |
| 3.1675 | -1938.5 |
| 3.2429 | -2464.7 |
| 3.3183 | -2991.0 |
| 3.3938 | -3517.3 |

```
 3.4692          -4043.6
 3.5446          -4569.8
 3.6200          -5096.1

 TIME=   175.00        LOAD CASE=  1
THE FOLLOWING X,Y,Z STRESSES ARE IN SECTION COORDINATES.

          ** MEMBRANE **
    SX          SY          SZ          SXY         SYZ         SXZ
  288.4     0.1088E+05  0.1422E+05   1332.          0.          0.
   SIG1        SIG2        SIG3         SI         SIGE
 0.1422E+05  0.1105E+05   123.4     0.1409E+05  0.1281E+05

          ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
    SX          SY          SZ          SXY         SYZ         SXZ
I -1176.     0.1861E+05   9254.          0.          0.          0.
C  -731.1      129.6        0.           0.          0.          0.
O  -286.2   -0.1835E+05  -9254.          0.          0.          0.
   SIG1        SIG2        SIG3         SI         SIGE
I 0.1861E+05   9254.      -1176.     0.1979E+05  0.1715E+05
C   129.6        0.        -731.1      860.7       803.8
O  -286.2     -9254.    -0.1835E+05  0.1807E+05  0.1565E+05

          ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
    SX          SY          SZ          SXY         SYZ         SXZ
I  -887.6    0.2949E+05  0.2347E+05   1332.          0.          0.
C  -442.7    0.1101E+05  0.1422E+05   1332.          0.          0.
O   2.199     -7474.      4964.       1332.          0.          0.
   SIG1        SIG2        SIG3         SI         SIGE
I 0.2955E+05  0.2347E+05  -945.9     0.3050E+05  0.2796E+05
C 0.1422E+05  0.1116E+05  -595.7     0.1481E+05  0.1355E+05
O  4964.       232.6      -7704.     0.1267E+05  0.1109E+05

          ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
    SX          SY          SZ          SXY         SYZ         SXZ
I -0.2274E-12  -346.4      -1885.      -1257.         0.          0.
C  1106.      -1638.      -1098.       368.4         0.          0.
O 0.2709E-13   2357.       1744.      -1356.         0.          0.
   SIG1        SIG2        SIG3         SI         SIGE
I  1096.      -1442.      -1885.       2981.       2786.
C  1155.      -1098.      -1687.       2842.       2598.
O  2975.       1744.      -617.9       3592.       3162.

          ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
    SX          SY          SZ          SXY         SYZ         SXZ
I  -887.6    0.2915E+05  0.2159E+05   75.59          0.          0.
C   663.6      9372.     0.1312E+05   1701.          0.          0.
O   2.199     -5117.      6708.      -23.28          0.          0.
   SIG1        SIG2        SIG3         SI         SIGE        TEMP
I 0.2915E+05  0.2159E+05  -887.8     0.3004E+05  0.2706E+05   524.8
C 0.1312E+05   9692.       342.9     0.1278E+05  0.1146E+05
O  6708.       2.337      -5117.     0.1183E+05  0.1027E+05   543.7

  DISTANCE          SY
     0.           29147.
```

| | |
|---|---|
| 0.75417E-01 | 29061. |
| 0.15083 | 28932. |
| 0.22625 | 28464. |
| 0.30167 | 27995. |
| 0.37708 | 27249. |
| 0.45250 | 26455. |
| 0.52792 | 25632. |
| 0.60333 | 24648. |
| 0.67875 | 23665. |
| 0.75417 | 22681. |
| 0.82958 | 21635. |
| 0.90500 | 20585. |
| 0.98042 | 19534. |
| 1.0558 | 18488. |
| 1.1313 | 17504. |
| 1.2067 | 16519. |
| 1.2821 | 15535. |
| 1.3575 | 14550. |
| 1.4329 | 13626. |
| 1.5083 | 12775. |
| 1.5838 | 11924. |
| 1.6592 | 11073. |
| 1.7346 | 10223. |
| 1.8100 | 9371.7 |
| 1.8854 | 8654.4 |
| 1.9608 | 7946.7 |
| 2.0363 | 7239.1 |
| 2.1117 | 6531.4 |
| 2.1871 | 5823.8 |
| 2.2625 | 5116.1 |
| 2.3379 | 4446.0 |
| 2.4133 | 3851.4 |
| 2.4888 | 3256.9 |
| 2.5642 | 2662.3 |
| 2.6396 | 2067.8 |
| 2.7150 | 1473.2 |
| 2.7904 | 878.67 |
| 2.8658 | 284.12 |
| 2.9413 | -285.14 |
| 3.0167 | -822.01 |
| 3.0921 | -1358.9 |
| 3.1675 | -1895.7 |
| 3.2429 | -2432.6 |
| 3.3183 | -2969.5 |
| 3.3938 | -3506.3 |
| 3.4692 | -4043.2 |
| 3.5446 | -4580.1 |
| 3.6200 | -5116.9 |

TIME= 275.00 LOAD CASE= 1
THE FOLLOWING X,Y,Z STRESSES ARE IN SECTION COORDINATES.

** MEMBRANE **

| SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|
| 422.2 | 0.1049E+05 | 0.1425E+05 | 1317. | 0. | 0. |

| SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|
| 0.1425E+05 | 0.1066E+05 | 252.6 | 0.1399E+05 | 0.1259E+05 |

** BENDING ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -1252. | 0.2140E+05 | 0.1230E+05 | 0. | 0. | 0. |
| C | -835.0 | 149.0 | 0. | 0. | 0. | 0. |
| O | -417.7 | -0.2110E+05 | -0.1230E+05 | 0. | 0. | C. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 0.2140E+05 | 0.1230E+05 | -1252. | 0.2265E+05 | 0.1975E+05 |
| C | 149.0 | 0. | -835.0 | 984.0 | 918.6 |
| O | -417.7 | -0.1230E+05 | -0.2110E+05 | 0.2069E+05 | 0.1798E+05 |

** MEMBRANE PLUS BENDING ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -830.1 | 0.3189E+05 | 0.2655E+05 | 1317. | 0. | 0. |
| C | -412.8 | 0.1063E+05 | 0.1425E+05 | 1317. | 0. | 0. |
| O | 4.487 | -0.1062E+05 | 1949. | 1317. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 0.3194E+05 | 0.2655E+05 | -883.1 | 0.3282E+05 | 0.3049E+05 |
| C | 0.1425E+05 | 0.1079E+05 | -567.7 | 0.1481E+05 | 0.1342E+05 |
| O | 1949. | 165.4 | -0.1078E+05 | 0.1273E+05 | 0.1194E+05 |

** PEAK ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -0.1137E-12 | 7773. | 6051. | -1219. | 0. | 0. |
| C | 1231. | -2827. | -2267. | 337.6 | 0. | 0. |
| O | -0.6217E-14 | 4127. | 3513. | -1353. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 7959. | 6051. | -186.7 | 8146. | 7379. |
| C | 1258. | -2267. | -2855. | 4114. | 3853. |
| O | 4531. | 3513. | -403.7 | 4935. | 4513. |

** TOTAL ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -830.1 | 0.3966E+05 | 0.3260E+05 | 98.32 | 0. | 0. |
| C | 817.8 | 7808. | 0.1198E+05 | 1655. | 0. | 0. |
| O | 4.487 | -6491. | 5462. | -35.05 | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE | TEMP |
|---|---|---|---|---|---|---|
| I | 0.3966E+05 | 0.3260E+05 | -830.4 | 0.4049E+05 | 0.3746E+05 | 478.7 |
| C | 0.1198E+05 | 8180. | 445.2 | 0.1153E+05 | 0.1019E+05 | |
| O | 5462. | 4.712 | -6491. | 0.1195E+05 | 0.1037E+05 | 537.1 |

| DISTANCE | SY |
|---|---|
| 0. | 39661. |
| 0.75417E-01 | 37619. |
| 0.15083 | 35594. |
| 0.22625 | 33705. |
| 0.30167 | 31815. |
| 0.37708 | 30088. |
| 0.45250 | 28388. |
| 0.52792 | 26721. |
| 0.60333 | 25236. |
| 0.67875 | 23751. |
| 0.75417 | 22265. |

| | |
|---|---|
| 0.82958 | 20988. |
| 0.90500 | 19727. |
| 0.98042 | 18466. |
| 1.0558 | 17219. |
| 1.1313 | 16174. |
| 1.2067 | 15129. |
| 1.2821 | 14084. |
| 1.3575 | 13039. |
| 1.4329 | 12080. |
| 1.5083 | 11225. |
| 1.5838 | 10371. |
| 1.6592 | 9516.4 |
| 1.7346 | 8662.0 |
| 1.8100 | 7807.6 |
| 1.8854 | 7096.2 |
| 1.9608 | 6395.2 |
| 2.0363 | 5694.2 |
| 2.1117 | 4993.1 |
| 2.1871 | 4292.1 |
| 2.2625 | 3591.1 |
| 2.3379 | 2927.2 |
| 2.4133 | 2338.1 |
| 2.4888 | 1749.0 |
| 2.5642 | 1159.9 |
| 2.6396 | 570.87 |
| 2.7150 | -18.216 |
| 2.7904 | -607.30 |
| 2.8658 | -1196.4 |
| 2.9413 | -1757.8 |
| 3.0167 | -2283.7 |
| 3.0921 | -2809.6 |
| 3.1675 | -3335.5 |
| 3.2429 | -3861.5 |
| 3.3183 | -4387.4 |
| 3.3938 | -4913.3 |
| 3.4692 | -5439.2 |
| 3.5446 | -5965.2 |
| 3.6200 | -6491.1 |

TIME= 300.00 LOAD CASE= 1

THE FOLLOWING X,Y,Z STRESSES ARE IN SECTION COORDINATES.

** MEMBRANE **

| SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|
| 324.3 | 0.1030E+05 | 0.1373E+05 | 1261. | 0. | 0. |

| SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|
| 0.1373E+05 | 0.1046E+05 | 167.3 | 0.1356E+05 | 0.1226E+05 |

** BENDING ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -1164. | 0.1907E+05 | 9858. | 0. | 0. | 0. |
| C | -741.5 | 132.7 | 0. | 0. | 0. | 0. |
| O | -319.1 | -0.1880E+05 | -9858. | 0. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 0.1907E+05 | 9858. | -1164. | 0.2023E+05 | 0.1754E+05 |

```
C   132.7        0.      -741.5      874.3      816.0
O  -319.1     -9858.    -0.1880E+05  0.1848E+05  0.1601E+05

        ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY           SZ          SXY        SYZ       SXZ
I -839.6     0.2937E+05  0.2359E+05    1261.         0.         0.
C -417.2     0.1043E+05  0.1373E+05    1261.         0.         0.
O  5.208     -8502.       3870.        1261.         0.         0.
   SIG1        SIG2        SIG3          SI         SIGE
I 0.2942E+05  0.2359E+05  -892.2     0.3031E+05  0.2786E+05
C 0.1373E+05  0.1058E+05  -561.9     0.1429E+05  0.1300E+05
O  3870.       188.3      -8685.     0.1255E+05  0.1118E+05

        ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY           SZ          SXY        SYZ       SXZ
I     0.       -1633.       -3159.      -1189.        0.        0.
C   1132.      -1511.       -958.1       341.3        0.        0.
O -0.2665E-13   2351.        1706.      -1297.        0.        0.
   SIG1        SIG2        SIG3          SI         SIGE
I  626.2       -2259.      -3159.       3785.       3425.
C  1175.       -958.1      -1555.       2730.       2486.
O  2925.        1706.      -574.8       3500.       3077.

        ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY           SZ          SXY        SYZ       SXZ
I -839.6     0.2773E+05  0.2043E+05    72.10         0.        0.
C  714.8       8921.     0.1277E+05    1603.         0.        0.
O  5.208      -6151.       5575.      -35.37         0.        0.
   SIG1        SIG2        SIG3          SI         SIGE        TEMP
I 0.2773E+05  0.2043E+05  -839.9     0.2857E+05  0.2571E+05   516.1
C 0.1277E+05   9224.       412.5     0.1236E+05  0.1102E+05
O  5575.        5.445     -6152.     0.1173E+05  0.1016E+05   535.4


    DISTANCE          SY
       0.           27735.
   0.75417E-01      27905.
   0.15083          28025.
   0.22625          27751.
   0.30167          27477.
   0.37708          26865.
   0.45250          26197.
   0.52792          25488.
   0.60333          24562.
   0.67875          23637.
   0.75417          22711.
   0.82958          21669.
   0.90500          20618.
   0.98042          19567.
    1.0558          18518.
    1.1313          17494.
    1.2067          16471.
    1.2821          15447.
    1.3575          14423.
    1.4329          13453.
```

| | |
|---|---|
| 1.5083 | 12546. |
| 1.5838 | 11640. |
| 1.6592 | 10734. |
| 1.7346 | 9827.5 |
| 1.8100 | 8921.3 |
| 1.8854 | 8152.8 |
| 1.9608 | 7394.4 |
| 2.0363 | 6636.0 |
| 2.1117 | 5877.6 |
| 2.1871 | 5119.1 |
| 2.2625 | 4360.7 |
| 2.3379 | 3646.5 |
| 2.4133 | 3021.5 |
| 2.4888 | 2396.4 |
| 2.5642 | 1771.3 |
| 2.6396 | 1146.2 |
| 2.7150 | 521.15 |
| 2.7904 | -103.92 |
| 2.8658 | -728.99 |
| 2.9413 | -1315.6 |
| 3.0167 | -1852.9 |
| 3.0921 | -2390.2 |
| 3.1675 | -2927.6 |
| 3.2429 | -3464.9 |
| 3.3183 | -4002.2 |
| 3.3938 | -4539.5 |
| 3.4692 | -5076.8 |
| 3.5446 | -5614.2 |
| 3.6200 | -6151.5 |

TIME= 385.00 LOAD CASE= 1
THE FOLLOWING X,Y,Z STRESSES ARE IN SECTION COORDINATES.

** MEMBRANE **

| SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|
| 378.7 | 0.1007E+05 | 0.1369E+05 | 1245. | 0. | 0. |

| SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|
| 0.1369E+05 | 0.1023E+05 | 221.4 | 0.1347E+05 | 0.1212E+05 |

** BENDING ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -1180. | 0.2006E+05 | 0.1097E+05 | 0. | 0. | 0. |
| C | -776.6 | 139.6 | 0. | 0. | 0. | 0. |
| O | -373.5 | -0.1978E+05 | -0.1097E+05 | 0. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 0.2006E+05 | 0.1097E+05 | -1180. | 0.2124E+05 | 0.1846E+05 |
| C | 139.6 | 0. | -776.6 | 916.2 | 855.0 |
| O | -373.5 | -0.1097E+05 | -0.1978E+05 | 0.1941E+05 | 0.1683E+05 |

** MEMBRANE PLUS BENDING ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -801.0 | 0.3013E+05 | 0.2466E+05 | 1245. | 0. | 0. |
| C | -398.0 | 0.1021E+05 | 0.1369E+05 | 1245. | 0. | 0. |
| O | 5.126 | -9704. | 2722. | 1245. | 0. | 0. |

SIG1 SIG2 SIG3 SI SIGE

| | | | | | |
|---|---|---|---|---|---|
| I | 0.3018E+05 | 0.2466E+05 | -851.0 | 0.3103E+05 | 0.2867E+05 |
| C | 0.1369E+05 | 0.1036E+05 | -542.0 | 0.1423E+05 | 0.1289E+05 |
| O | 2722. | 162.2 | -9861. | 0.1258E+05 | 0.1152E+05 |

** PEAK ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | 0. | 6244. | 4613. | -1154. | 0. | 0. |
| C | 1147. | -2359. | -1820. | 327.0 | 0. | 0. |
| O | 0.5862E-13 | 3473. | 2866. | -1280. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 6450. | 4613. | -206.6 | 6657. | 5955. |
| C | 1177. | -1820. | -2389. | 3566. | 3318. |
| O | 3894. | 2866. | -421.1 | 4315. | 3904. |

** TOTAL ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -801.0 | 0.3638E+05 | 0.2927E+05 | 90.50 | 0. | 0. |
| C | 748.6 | 7856. | 0.1187E+05 | 1572. | 0. | 0. |
| O | 5.126 | -6232. | 5588. | -35.70 | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE | TEMP |
|---|---|---|---|---|---|---|
| I | 0.3638E+05 | 0.2927E+05 | -801.3 | 0.3718E+05 | 0.3419E+05 | 480.5 |
| C | 0.1187E+05 | 8188. | 416.2 | 0.1145E+05 | 0.1013E+05 | |
| O | 5588. | 5.366 | -6232. | 0.1182E+05 | 0.1024E+05 | 528.3 |

| DISTANCE | SY |
|---|---|
| 0. | 36376. |
| 0.75417E-01 | 34699. |
| 0.15083 | 33028. |
| 0.22625 | 31404. |
| 0.30167 | 29779. |
| 0.37708 | 28250. |
| 0.45250 | 26736. |
| 0.52792 | 25249. |
| 0.60333 | 23904. |
| 0.67875 | 22558. |
| 0.75417 | 21212. |
| 0.82958 | 20046. |
| 0.90500 | 18894. |
| 0.98042 | 17742. |
| 1.0558 | 16602. |
| 1.1313 | 15639. |
| 1.2067 | 14677. |
| 1.2821 | 13714. |
| 1.3575 | 12751. |
| 1.4329 | 11861. |
| 1.5083 | 11060. |
| 1.5838 | 10259. |
| 1.6592 | 9457.9 |
| 1.7346 | 8656.7 |
| 1.8100 | 7855.5 |
| 1.8854 | 7170.5 |
| 1.9608 | 6493.9 |
| 2.0363 | 5817.4 |
| 2.1117 | 5140.8 |
| 2.1871 | 4464.2 |

| | |
|---|---|
| 2.2625 | 3787.6 |
| 2.3379 | 3141.6 |
| 2.4133 | 2557.3 |
| 2.4888 | 1973.0 |
| 2.5642 | 1388.6 |
| 2.6396 | 804.30 |
| 2.7150 | 219.97 |
| 2.7904 | -364.37 |
| 2.8658 | -948.70 |
| 2.9413 | -1507.0 |
| 3.0167 | -2031.9 |
| 3.0921 | -2556.9 |
| 3.1675 | -3081.9 |
| 3.2429 | -3606.8 |
| 3.3183 | -4131.8 |
| 3.3938 | -4656.7 |
| 3.4692 | -5181.7 |
| 3.5446 | -5706.6 |
| 3.6200 | -6231.6 |

TIME= 450.00 LOAD CASE= 1
THE FOLLOWING X,Y,Z STRESSES ARE IN SECTION COORDINATES.

** MEMBRANE **

| SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|
| 220.0 | 9820. | 0.1290E+05 | 1158. | 0. | 0. |

| SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|
| 0.1290E+05 | 9958. | 82.19 | 0.1282E+05 | 0.1163E+05 |

** BENDING ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -1026. | 0.1621E+05 | 6969. | 0. | 0. | 0. |
| C | -620.4 | 112.9 | 0. | 0. | 0. | 0. |
| O | -214.8 | -0.1599E+05 | -6969. | 0. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 0.1621E+05 | 6969. | -1026. | 0.1724E+05 | 0.1494E+05 |
| C | 112.9 | 0. | -620.4 | 733.3 | 683.9 |
| O | -214.8 | -6969. | -0.1599E+05 | 0.1577E+05 | 0.1371E+05 |

** MEMBRANE PLUS BENDING ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -806.0 | 0.2603E+05 | 0.1987E+05 | 1158. | 0. | 0. |
| C | -400.4 | 9933. | 0.1290E+05 | 1158. | 0. | 0. |
| O | 5.248 | -6169. | 5930. | 1158. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 0.2608E+05 | 0.1987E+05 | -855.9 | 0.2694E+05 | 0.2443E+05 |
| C | 0.1290E+05 | 0.1006E+05 | -528.7 | 0.1343E+05 | 0.1226E+05 |
| O | 5930. | 215.5 | -6379. | 0.1231E+05 | 0.1067E+05 |

** PEAK ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -0.1137E-12 | -1290. | -2649. | -1095. | 0. | 0. |
| C | 947.6 | -420.3 | 79.98 | 346.8 | 0. | 0. |
| O | 0.1776E-14 | 992.7 | 384.1 | -1190. | 0. | 0. |

SIG1 SIG2 SIG3 SI SIGE

| | | | | | |
|---|---|---|---|---|---|
| I | 626.2 | -1916. | -2649. | 3275. | 2977. |
| C | 1030. | 79.98 | -503.2 | 1534. | 1341. |
| O | 1785. | 384.1 | -792.6 | 2578. | 2235. |

** TOTAL ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -806.0 | 0.2475E+05 | 0.1722E+05 | 63.25 | 0. | 0. |
| C | 547.2 | 9513. | 0.1298E+05 | 1505. | 0. | 0. |
| O | 5.248 | -5176. | 6314. | -31.09 | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE | TEMP |
|---|---|---|---|---|---|---|
| I | 0.2475E+05 | 0.1722E+05 | -806.2 | 0.2555E+05 | 0.2274E+05 | 516.1 |
| C | 0.1298E+05 | 9759. | 301.1 | 0.1268E+05 | 0.1142E+05 | |
| O | 6314. | 5.468 | -5176. | 0.1149E+05 | 9967. | 523.5 |

| DISTANCE | SY |
|---|---|
| 0. | 24745. |
| 0.75417E-01 | 24484. |
| 0.15083 | 24211. |
| 0.22625 | 23840. |
| 0.30167 | 23470. |
| 0.37708 | 22973. |
| 0.45250 | 22454. |
| 0.52792 | 21917. |
| 0.60333 | 21279. |
| 0.67875 | 20640. |
| 0.75417 | 20002. |
| 0.82958 | 19285. |
| 0.90500 | 18561. |
| 0.98042 | 17838. |
| 1.0558 | 17112. |
| 1.1313 | 16347. |
| 1.2067 | 15582. |
| 1.2821 | 14818. |
| 1.3575 | 14053. |
| 1.4329 | 13293. |
| 1.5083 | 12537. |
| 1.5838 | 11781. |
| 1.6592 | 11025. |
| 1.7346 | 10269. |
| 1.8100 | 9512.7 |
| 1.8854 | 8806.9 |
| 1.9608 | 8104.7 |
| 2.0363 | 7402.6 |
| 2.1117 | 6700.4 |
| 2.1871 | 5998.3 |
| 2.2625 | 5296.1 |
| 2.3379 | 4621.4 |
| 2.4133 | 4001.7 |
| 2.4888 | 3382.1 |
| 2.5642 | 2762.5 |
| 2.6396 | 2142.9 |
| 2.7150 | 1523.3 |
| 2.7904 | 903.71 |
| 2.8658 | 284.10 |
| 2.9413 | -301.31 |

| | |
|---|---|
| 3.0167 | -842.94 |
| 3.0921 | -1384.6 |
| 3.1675 | -1926.2 |
| 3.2429 | -2467.8 |
| 3.3183 | -3009.5 |
| 3.3938 | -3551.1 |
| 3.4692 | -4092.7 |
| 3.5446 | -4634.4 |
| 3.6200 | -5176.0 |

TIME= 560.00 LOAD CASE= 1

THE FOLLOWING X,Y,Z STRESSES ARE IN SECTION COORDINATES.

** MEMBRANE **

| SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|
| 455.0 | 9415. | 0.1326E+05 | 1181. | 0. | 0. |

| SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|
| 0.1326E+05 | 9568. | 302.0 | 0.1296E+05 | 0.1157E+05 |

** BENDING ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -1192. | 0.2126E+05 | 0.1249E+05 | 0. | 0. | 0. |
| C | -820.2 | 148.0 | 0. | 0. | 0. | 0. |
| O | -448.4 | -0.2096E+05 | -0.1249E+05 | 0. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 0.2126E+05 | 0.1249E+05 | -1192. | 0.2245E+05 | 0.1960E+05 |
| C | 148.0 | 0. | -820.2 | 968.2 | 903.4 |
| O | -448.4 | -0.1249E+05 | -0.2096E+05 | 0.2052E+05 | 0.1786E+05 |

** MEMBRANE PLUS BENDING ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | S[illegible] | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -737.0 | 0.3[illegible]05 | 0.2575E+05 | 1181. | 0. | 0. |
| C | -365.2 | 95[illegible] | 0.1326E+05 | 1181. | 0. | 0. |
| O | 6.614 | -0.1155E+05 | 778.8 | 1181. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 0.3072E+05 | 0.2575E+05 | -781.4 | 0.3150E+05 | 0.2933E+05 |
| C | 0.1326E+05 | 9702. | -503.7 | 0.1377E+05 | 0.1238E+05 |
| O | 778.8 | 126.0 | -0.1167E+05 | 0.1245E+05 | 0.1213E+05 |

** PEAK ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | 0. | 8462. | 6791. | -1084. | 0. | 0. |
| C | 1206. | -3051. | -2509. | 281.0 | 0. | 0. |
| O | 0.2665E-14 | 4409. | 3808. | -1224. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 8598. | 6791. | -136.7 | 8735. | 7986. |
| C | 1224. | -2509. | -3070. | 4294. | 4042. |
| O | 4726. | 3808. | -317.0 | 5043. | 4652. |

** TOTAL ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -737.0 | 0.3914E+05 | 0.3254E+05 | 96.59 | 0. | 0. |
| C | 840.3 | 6512. | 0.1076E+05 | 1462. | 0. | 0. |
| O | 6.614 | -7140. | 4587. | -43.10 | 0. | 0. |

SIG1 SIG2 SIG3 SI SIGE TEMP

| | | | | | | |
|---|---|---|---|---|---|---|
| I | 0.3914E+05 | 0.3254E+05 | -737.3 | 0.3987E+05 | 0.3702E+05 | 454.5 |
| C | 0.1076E+05 | 6867. | 485.1 | 0.1027E+05 | 8986. | |
| O | 4587. | 6.908 | -7141. | 0.1173E+05 | 0.1024E+05 | 516.9 |

| DISTANCE | SY |
|---|---|
| 0. | 39137. |
| 0.75417E-01 | 36993. |
| 0.15083 | 34867. |
| 0.22625 | 32889. |
| 0.30167 | 30911. |
| 0.37708 | 29112. |
| 0.45250 | 27344. |
| 0.52792 | 25613. |
| 0.60333 | 24083. |
| 0.67875 | 22553. |
| 0.75417 | 21023. |
| 0.82958 | 19720. |
| 0.90500 | 18435. |
| 0.98042 | 17150. |
| 1.0558 | 15881. |
| 1.1313 | 14831. |
| 1.2067 | 13781. |
| 1.2821 | 12731. |
| 1.3575 | 11681. |
| 1.4329 | 10725. |
| 1.5083 | 9882.1 |
| 1.5838 | 9039.6 |
| 1.6592 | 8197.0 |
| 1.7346 | 7354.5 |
| 1.8100 | 6512.0 |
| 1.8854 | 5823.9 |
| 1.9608 | 5147.1 |
| 2.0363 | 4470.2 |
| 2.1117 | 3793.4 |
| 2.1871 | 3116.6 |
| 2.2625 | 2439.7 |
| 2.3379 | 1801.8 |
| 2.4133 | 1242.3 |
| 2.4888 | 682.80 |
| 2.5642 | 123.29 |
| 2.6396 | -436.22 |
| 2.7150 | -995.73 |
| 2.7904 | -1555.2 |
| 2.8658 | -2114.7 |
| 2.9413 | -2647.8 |
| 3.0167 | -3147.0 |
| 3.0921 | -3646.1 |
| 3.1675 | -4145.3 |
| 3.2429 | -4644.5 |
| 3.3183 | -5143.6 |
| 3.3938 | -5642.8 |
| 3.4692 | -6142.0 |
| 3.5446 | -6641.2 |
| 3.6200 | -7140.3 |

TIME= 600.00 LOAD CASE= 1

THE FOLLOWING X,Y,Z STRESSES ARE IN SECTION COORDINATES.

** MEMBRANE **

| SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|
| 297.4 | 9251. | 0.1260E+05 | 1107. | 0. | 0. |

| SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|
| 0.1260E+05 | 9386. | 162.5 | 0.1243E+05 | 0.1118E+05 |

** BENDING ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -1055. | 0.1761E+05 | 8593. | 0. | 0. | 0. |
| C | -672.3 | 122.6 | 0. | 0. | 0. | 0. |
| O | -289.6 | -0.1736E+05 | -8593. | 0. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 0.1761E+05 | 8593. | -1055. | 0.1866E+05 | 0.1616E+05 |
| C | 122.6 | 0. | -672.3 | 794.8 | 741.2 |
| O | -289.6 | -8593. | -0.1736E+05 | 0.1707E+05 | 0.1479E+05 |

** MEMBRANE PLUS BENDING ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -757.5 | 0.2686E+05 | 0.2119E+05 | 1107. | 0. | 0. |
| C | -374.9 | 9374. | 0.1260E+05 | 1107. | 0. | 0. |
| O | 7.808 | -8111. | 4004. | 1107. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 0.2690E+05 | 0.2119E+05 | -801.9 | 0.2770E+05 | 0.2534E+05 |
| C | 0.1260E+05 | 9498. | -499.1 | 0.1310E+05 | 0.1185E+05 |
| O | 4004. | 156.2 | -8259. | 0.1226E+05 | 0.1086E+05 |

** PEAK ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | 0.1137E-12 | -3165. | -4552. | -1045. | 0. | 0. |
| C | 1038. | -812.2 | -287.3 | 304.5 | 0. | 0. |
| O | -0.6040E-13 | 1568. | 928.1 | -1151. | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE |
|---|---|---|---|---|---|
| I | 314.0 | -3479. | -4552. | 4866. | 4428. |
| C | 1087. | -287.3 | -861.0 | 1948. | 1734. |
| O | 2176. | 928.1 | -608.4 | 2785. | 2416. |

** TOTAL ** I=INSIDE C=CENTER O=OUTSIDE

| | SX | SY | SZ | SXY | SYZ | SXZ |
|---|---|---|---|---|---|---|
| I | -757.5 | 0.2369E+05 | 0.1664E+05 | 62.19 | 0. | 0. |
| C | 663.2 | 8561. | 0.1231E+05 | 1412. | 0. | 0. |
| O | 7.808 | -6543. | 4932. | -43.21 | 0. | 0. |

| | SIG1 | SIG2 | SIG3 | SI | SIGE | TEMP |
|---|---|---|---|---|---|---|
| I | 0.2369E+05 | 0.1664E+05 | -757.7 | 0.2445E+05 | 0.2180E+05 | 503.7 |
| C | 0.1231E+05 | 8806. | 418.2 | 0.1189E+05 | 0.1059E+05 | |
| O | 4932. | 8.125 | -6543. | 0.1148E+05 | 9971. | 514.0 |

| DISTANCE | SY |
|---|---|
| 0. | 23693. |
| 0.75417E-01 | 24004. |
| 0.15083 | 24278. |
| 0.22625 | 24252. |
| 0.30167 | 24227. |

| | |
|---|---|
| 0.37708 | 23872. |
| 0.45250 | 23462. |
| 0.52792 | 23009. |
| 0.60333 | 22327. |
| 0.67875 | 21645. |
| 0.75417 | 20963. |
| 0.82958 | 20123. |
| 0.90500 | 19270. |
| 0.98042 | 18417. |
| 1.0558 | 17559. |
| 1.1313 | 16635. |
| 1.2067 | 15710. |
| 1.2821 | 14786. |
| 1.3575 | 13861. |
| 1.4329 | 12957. |
| 1.5083 | 12078. |
| 1.5838 | 11199. |
| 1.6592 | 10320. |
| 1.7346 | 9440.6 |
| 1.8100 | 8561.4 |
| 1.8854 | 7788.4 |
| 1.9608 | 7023.2 |
| 2.0363 | 6258.0 |
| 2.1117 | 5492.7 |
| 2.1871 | 4727.5 |
| 2.2625 | 3962.2 |
| 2.3379 | 3240.9 |
| 2.4133 | 2608.1 |
| 2.4888 | 1975.2 |
| 2.5642 | 1342.4 |
| 2.6396 | 709.58 |
| 2.7150 | 76.749 |
| 2.7904 | -556.08 |
| 2.8658 | -1188.9 |
| 2.9413 | -1776.5 |
| 3.0167 | -2306.1 |
| 3.0921 | -2835.7 |
| 3.1675 | -3365.3 |
| 3.2429 | -3894.9 |
| 3.3183 | -4424.5 |
| 3.3938 | -4954.1 |
| 3.4692 | -5483.7 |
| 3.5446 | -6013.3 |
| 3.6200 | -6543.0 |

# APPENDIX C

# INPUT DATA LISTINGS

```
, File = fwcycle1.5 from rtrp1.5
/SHOW,file33,dat

/INPUT,fileparm,dat
*GO,:RES

/PREP7
/TITLE, ZION STEAM GENERATOR SHELL, UPPER GIRTH WELD, fwcyc1.5
!, PARAMETERS  ************************************
R1=64.69     !, INSIDE RADIUS, LOWER SHELL
R2=84.255    !, INSIDE RADIUS, UPER SHELL
TW=3.62      !, THICKNESS OF WALL
RF=2*TW      !, RADIUS OF FILLETS  (EST.)

Y2=15.67     !, REGION 4/5
Y3=32.00     !, LOWER WELD
Y4=51.38     !, REGION 3/4
Y5=75.32     !, REGION 2/3
Y6=84.47     !, REGION 1/2
Y7=94.26     !, REGION 0/1
Y8=108.75    !, UPPER WELD
Y9=121.13    !, REGION 1A/2A
Y10=155.00   !, TOP

!, EXTEND MODEL LENGTH  ***
Y1=Y3-63
Y10=Y8+71

ANGR=ATAN((Y8-Y3)/(R2-R1))
PI=ACOS(-1)
ANGR=(PI/2)-ANGR
ANGD=ANGR*(180/PI)

HU=3600*144 !, HF UNIT CONVERSION

D1=10        !, THRU THICKNESS
D2=8         !, LOWER SHELL
D3=6         !, CONE
D4=10        !, UPPER SHELL
D5=8
D6=4
D7=4
D8=8
D9=8
D10=15
DF=3         !, DIV IN FILLET

B1=5         !, BIAS THRU THICKNESS
B10=4

!, COORDINATE SYSTEMS  *********************
LOCAL,11,0,R1,Y3,,-ANGD
LOCAL,12,0,R1,Y3,,-(ANGD/2)
LOCAL,13,0,R2,Y8,,-(ANGD/2)
CSYS
```

```
!, KEYPOINTS ***************************************
K,1,R1,Y1
K,2,R1,Y2
K,3,R1,Y3
K,4,R1,Y4
KMOVE,4,0,999,Y4,0,11,0.0,999,999
K,5,R1,Y5
KMOVE,5,0,999,Y5,0,11,0.0,999,999
K,6,R1,Y6
KMOVE,6,0,999,Y6,0,11,0.0,999,999
K,7,R1,Y7
KMOVE,7,0,999,Y7,0,11,0.0,999,999
K,8,R2,Y8
K,9,R2,Y9
K,10,R2,Y10

K,11,(R1+TW),Y1
K,12,(R1+TW),Y2
CSYS,12
K,13,(TW/COS(ANGR/2))
CSYS,11
*GET,YC,KY,4
K,14,TW,YC
*GET,YC,KY,5
K,15,TW,YC
*GET,YC,KY,6
K,16,TW,YC
*GET,YC,KY,7
K,17,TW,YC
CSYS,13
K,18,(TW/COS(ANGR/2))
CSYS
K,19,(R2+TW),Y9
K,20,(R2+TW),Y10
SAVE

!, LINES ****************************
L,1,11,D1,B1
L,1,2,D2
L,2,3,D3
L,3,4,D4
LFILLT,3,4,(RF+TW)
LDVS,3,,D3
LDVS,4,,D4
LDVS,5,,DF
L,4,5,D5
L,5,6,D6
L,6,7,D7
L,7,8,D8
L,8,9,D9
LFILLT,9,10,RF
LDVS,9,,D8
LDVS,10,,D9
LDVS,11,,DF
L,9,10,D10,B10
```

```
*GET,LL1,LSMX

L,11,12,D2
L,12,13,D3
L,13,14,D4
LFILLT,14,15,RF
LDVS,14,,D3
LDVS,15,,D4
LDVS,16,,DF
L,14,15,D5
L,15,16,D6
L,16,17,D7
L,17,18,D8
L,18,19,D9
LFILLT,20,21,(RF+TW)
LDVS,20,,D8
LDVS,21,,D9
LDVS,22,,DF
L,19,20,D10,B10

L,2,12,D1,B1
L,21,25,D1,B1
L,22,26,D1,B1
L,4,14,D1,B1
L,5,15,D1,B1
L,6,16,D1,B1
L,7,17,D1,B1
L,23,27,D1,B1
L,24,28,D1,B1
L,9,19,D1,B1
L,10,20,D1,B1
SAVE

!, AREAS ********************
A,1,11,12,2
A,2,12,25,21
A,21,25,26,22
A,22,26,14,4
A,4,14,15,5
A,5,15,16,6
A,6,16,17,7
A,7,17,27,23
A,23,27,28,24
A,24,28,19,9
A,9,19,20,10
SAVE

!, TYPE, MAT, REAL ********************
KAN,-1
ET,1,77    !, 2ND ORDER QUADRATIC THERMAL ELEMENT
KEYOPT,1,3,1

!, DENSITY **********************************
DEN=490        !, DENSITY (lb/ft**3)
MP,DENS,1,DEN/1728    !, DENSITY (lb/in**3)
```

```
!, ELASTIC MODULUS & POISSON RATIO ***********
MPTEMP
MPTEMP,1,70,200,300,400,500,600
MPDATA,EX,1,1,29.2E6,28.5E6,28.0E6,27.4E6,27.0E6,26.4E6

MPTEMP
MP,NUXY,1,0.29

!, THERMAL EXPANSION COEFICIENT **************
MPTEMP,1,70,100,150,200,250,300
MPTEMP,7,350,400,450,500,550,600
MPDATA,ALPX,1,1,7.02E-6,7.06E-6,7.16E-6,7.25E-6,7.34E-6,7.43E-6
MPDATA,ALPX,1,7,7.50E-6,7.58E-6,7.63E-6,7.70E-6,7.77E-6,7.83E-6

/SHOW,,,1
/GRAPH,GRID,1
/NUM,2
!, /WINDOW,,LTOP
/TITLE, ZION STEAM GENERATOR SHELL, HEAT CAPACITY Btu/lb-degF
MPPLOT,C,1
!, /NOERASE
!, /WINDOW,,RTOP
/TITLE, ZION STEAM GENERATOR SHELL, THERMAL CONDUCTIVITY Btu/1n-sec-degF
MPPLOT,KXX,1
!, /WINDOW,,LBOT
/TITLE, ZION STEAM GENERATOR SHELL, ELASTIC MODULUS lb/in**2
MPPLOT,EX,1
!, /WINDOW,,RBOT
/TITLE, ZION STEAM GENERATOR SHELL, THERMAL EXPANSION COEFFICIENT in/in-degF
MPPLOT,ALPX,1
/TITLE, ZION STEAM GENERATOR SHELL, UPPER GIRTH WELD, fwcyc1.5
/ERASE
/WINDOW,,FULL
/SHOW
/NUM

R,1

!, NODES & ELEMENTS ************************
ELSIZE,,,?
AMESH   !
WSORT

!, !, STEP SIZE ******************************
DT=(TW/(D1*B1))**2
DT=DT/(10*TDR)

!, BOUNDARY CONDITIONS **********************
TREF,70

!, *GO,:S2
!, *GO,:S3
!, *GO,:S4
!, *GO,:S5
*GO,:S6
```

```
!, TRANSIENT NO. 1, HEATUP @ 100degF/hr  ***********
/TITLE, TRANSIENT NO. 1, HEATUP @ 100degF/hr
:S1
TIM=0
TIME,TIM
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,70
ITER,-10,,10
KBC,1
NALL
LWRITE

DTIM=5*3600
TIM=TIM+DTIM
NSTP=DTIM/DT
TIME,TIM
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,547
ITER,-NSTP,,1
KBC,0
NALL
LWRITE

DTIM=10*60
TIM=TIM+DTIM
NSTP=DTIM/DT
TIME,TIM
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,547
ITER,-NSTP,,1
NALL
LWRITE
*GO,:EX1

!, TRANSIENT NO. 2, COOLDOWN @ 100degF/hr  *********
/TITLE, TRANSIENT NO. 2, COOLDOWN @ 100degF/hr
:S2
TIM=0
TIME,TIM
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,547
ITER,-10,,10
KBC,1
NALL
LWRITE

DTIM=5*3600
TIM=TIM+DTIM
NSTP=DTIM/DT

TIME,TIM
```

```
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,70
KBC,0
ITER,-NSTP,,1
NALL
LWRITE

DTIM=10*60
TIM=TIM+DTIM
NSTP=DTIM/DT
TIME,TIM
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,70
ITER,-NSTP,,1
NALL
LWRITE
*GO,:EX1

!, TRANSIENT NO. 3, LARGE STEP LOAD DECREASE *****
/TITLE, TRANSIENT NO. 3, LARGE STEP LOAD DECREASE
:S3
TIM=0
TIME,TIM
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,506
ITER,-10,,10
KBC,1
NALL
LWRITE

DTIM=60
TIM=TIM+DTIM
NSTP=DTIM/DT
TIME,TIM
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,546
KBC,0
ITER,-NSTP,,1
NALL
LWRITE

DTIM=120
TIM=TIM+DTIM
NSTP=DTIM/DT
TIME,TIM
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,510
ITER,-NSTP,,1
NALL
LWRITE
```

```
DTIM=(20*60)-TIM
TIM=TIM+DTIM
TIME,TIM
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,537
ITER,-NSTP,,1
NALL
LWRITE

DTIM=10*60
TIM=TIM+DTIM
TIME,TIM
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,537
ITER,-NSTP,,1
NALL
LWRITE
*GO,:EX1

!, TRANSIENT NO. 4, REACTOR TRIP  *****************
/TITLE, TRANSIENT NO. 4, REACTOR TRIP
:S4
TIM=0
TIME,TIM
LSSEL,,2      $ NLINE,1   !, REGION 5
CVSF,ALL,,,1208/HU,547
LSSEL,,3,5    $ NLINE,1   !, REGION 4
CVSF,ALL,,,1208/HU,547
LSSEL,,6      $ NLINE,1   !, REGION 3
CVSF,ALL,,,1208/HU,547
LSSEL,,7      $ NLINE,1   !, REGION 2
CVSF,ALL,,,1208/HU,547
LSSEL,,8      $ NLINE,1   !, REGION 1
CVSF,ALL,,,5000/HU,547
LSSEL,,9,12   $ NLINE,1   !, REGION 0
CVSF,ALL,,,10000/HU,547
ITER,-10,,10
KBC,1
NALL
LWRITE

*CREATE,HMAC
!, 1=T0 2=T2 3=H2 4=T3 5=H3 6=T4 7=H4 8=T5 9=H5
LSSEL,,2      $ NLINE,1   !, REGION 5
CVSF,ALL,,,ARG9/HU,ARG8
LSSEL,,3,5    $ NLINE,1   !, REGION 4
CVSF,ALL,,,ARG7/HU,ARG6
LSSEL,,6      $ NLINE,1   !, REGION 3
CVSF,ALL,,,ARG5/HU,ARG4
LSSEL,,7      $ NLINE,1   !, REGION 2
CVSF,ALL,,,ARG3/HU,ARG2
LSSEL,,8      $ NLINE,1   !, REGION 1
```

```
CVSF,ALL,,,5000/HU,160
LSSEL,,9,12  $ NLINE,1   !, REGION 0
CVSF,ALL,,,10000/HU,ARG1
KBC,0
NALL
LWRITE
*END,HMAC


DTIM=1.0     !, 1.0
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
!,      1=T0 2=T2 3=H2 4=T3 5=H3 6=T4 7=H4 8=T5 9=H5
*USE,HMAC,547, 547,1208, 547,1208, 547,1208, 547,1208

DTIM=0.1    !, 1.1
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
!,      1=T0 2=T2 3=H2 4=T3 5=H3 6=T4 7=H4 8=T5 9=H5
*USE,HMAC,547, 200,1208, 547,1208, 547,1208, 547,1208

DTIM=1.0   !, 2.1
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
!,      1=T0 2=T2 3=H2 4=T3 5=H3 6=T4 7=H4 8=T5 9=H5
*USE,HMAC,547, 200,1208, 234,1208, 547,1208, 547,1208

DTIM=1.1   !, 3.2
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
!,      1=T0 2=T2 3=H2 4=T3 5=H3 6=T4 7=H4 8=T5 9=H5
*USE,HMAC,547, 200,1208, 234,1208, 292,1208, 547,1208

DTIM=2.2   !, 5.4
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
!,      1=T0 2=T2 3=H2 4=T3 5=H3 6=T4 7=H4 8=T5 9=H5
*USE,HMAC,546, 200,1208, 234,1208, 292,1208, 370,1208

DTIM=5.0   !, 10.4
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
!,      1=T0 2=T2 3=H2 4=T3 5=H3 6=T4 7=H4 8=T5 9=H5
```

```
*USE,HMAC,546, 200,1208, 234,1208, 292,1208, 370,1208

DTIM=0.6   !, 11.0
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
!,      1=T0 2=T2 3=H2 4=T3 5=H3 6=T4 7=H4 8=T5 9=H5
*USE,HMAC,545, 226, 761, 258, 662, 402, 578, 357, 502

DTIM=114   !, 125.0
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
!,      1=T0 2=T2 3=H2 4=T3 5=H3 6=T4 7=H4 8=T5 9=H5
*USE,HMAC,525, 221, 761, 250, 662, 290, 578, 341, 502

DTIM=105   !, 230.0
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
!,      1=T0 2=T2 3=H2 4=T3 5=H3 6=T4 7=H4 8=T5 9=H5
*USE,HMAC,500, 216, 761, 243, 662, 280, 578, 326, 502

DTIM=225   !, 455.0
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
!,      1=T0 2=T2 3=H2 4=T3 5=H3 6=T4 7=H4 8=T5 9=H5
*USE,HMAC,425, 206, 761, 227, 662, 257, 578, 295, 502

DTIM=105   !, 560.0
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
!,      1=T0 2=T2 3=H2 4=T3 5=H3 6=T4 7=H4 8=T5 9=H5
*USE,HMAC,400, 201, 761, 220, 662, 247, 578, 280, 502

DTIM=125   !, 685.0
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
!,      1=T0 2=T2 3=H2 4=T3 5=H3 6=T4 7=H4 8=T5 9=H5
*USE,HMAC,390, 195, 761, 211, 662, 234, 578, 263, 502

*GO,:EX1

!, TRANSIENT NO. 5, BOUNDING FAULTED EVENT  *******
!, /TITLE, TRANSIENT NO. 5, BOUNDING FAULTED EVENT, STATE 1
:S5
```

```
TIM=0
TIME,TIM
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,547
ITER,-10,,10
KBC,1
NALL
LWRITE

DTIM=60
TIM=TIM+DTIM
NSTP=DTIM/DT
TIME,TIM
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,70
KBC,0
ITER,-NSTP,,1
NALL
LWRITE

DTIM=10*60
TIM=TIM+DTIM
NSTP=DTIM/DT
TIME,TIM
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,70
KBC,0
ITER,-NSTP,,1
NALL
LWRITE

!, TRANSIENT NO. 6, FEEDWATER CYCLING EVENT  ******
:S6
TIM=0
TIME,TIM
ITER,-10,,10
KBC,1
LSSEL,,LL1        $ NLINE,1 !, REGION 1A
CVSF,ALL,,,24/HU,547
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,,76/HU,547
NALL
LWRITE

DTIM=10       !, 10
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
KBC,0
LSSEL,,LL1        $ NLINE,1 !, REGION 1A
CVSF,ALL,,,270.9/HU,546.5
```

```
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,,322.9/HU,538
NALL
LWRITE

DTIM=10      !, 20
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1      $ NLINE,1 !, REGION 1A
CVSF,ALL,,,323.9/HU,546
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,,375.9/HU,530
NALL
LWRITE

DTIM=30      !, 50
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1      $ NLINE,1 !, REGION 1A
CVSF,ALL,,,422.4/HU,545
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,,472.4/HU,502
NALL
LWRITE

DTIM=25      !, 75
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1      $ NLINE,1 !, REGION 1A
CVSF,ALL,,,806.2/HU,543.6
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,,2002.2/HU,534
NALL
LWRITE

DTIM=15      !, 90
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1      $ NLINE,1 !, REGION 1A
CVSF,ALL,,,360.6/HU,543
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,, 412.6/HU,522
NALL
LWRITE

DTIM=20      !, 110
TIM=TIM+DTIM
```

```
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1      $ NLINE,1 !, REGION 1A
CVSF,ALL,,,434.2/HU,542
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,, 486.2/HU,504
NALL
LWRITE

DTIM=40       !, 150
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1      $ NLINE,1 !, REGION 1A
CVSF,ALL,,,532.0/HU,540.2
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,, 584.0/HU,468
NALL
LWRITE

DTIM=25       !, 175
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1      $ NLINE,1 !, REGION 1A
CVSF,ALL,,,792.0/HU,539.1
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,,1988.0/HU,531
NALL
LWRITE

DTIM=15       !, 190
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1      $ NLINE,1 !, REGION 1A
CVSF,ALL,,,357.4/HU,538.4
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,, 409.4/HU,518
NALL
LWRITE

DTIM=30       !, 220
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1      $ NLINE,1 !, REGION 1A
CVSF,ALL,,,464.6/HU,537.1
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,, 516.6/HU,490
```

```
NALL
LWRITE

DTIM=55        !, 275
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1        $ NLINE,1 !, REGION 1A
CVSF,ALL,,,553.2/HU,534.6
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,, 605.2/HU,453
NALL
LWRITE

DTIM=25        !, 300
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1        $ NLINE,1 !, REGION 1A
CVSF,ALL,,,805.3/HU,533.5
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,,2001.3/HU,524
NALL
LWRITE

DTIM=30        !, 330
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1        $ NLINE,1 !, REGION 1A
CVSF,ALL,,,423.5/HU,532.1
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,, 475.5/HU,497
NALL
LWRITE

DTIM=45        !, 375
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1        $ NLINE,1 !, REGION 1A
CVSF,ALL,,,529.4/HU,530.1
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,, 581.4/HU,459
NALL
LWRITE

DTIM=75        !, 450
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
```

```
ITER, NSTP,,1
LSSEL,,LL1       $ NLINE,1 !, REGION 1A
CVSF,ALL,,,778.2/HU,526.8
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,,1974.2/HU,520
NALL
LWRITE

DTIM=30       !, 480
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1       $ NLINE,1 !, REGION 1A
CVSF,ALL,,,416.9/HU,525.4
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,, 468.9/HU,492
NALL
LWRITE

DTIM=50       !, 530
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1       $ NLINE,1 !, REGION 1A
CVSF,ALL,,,534.3/HU,523.2
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,, 596.3/HU,450
NALL
LWRITE

DTIM=30       !, 560
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1       $ NLINE,1 !, REGION 1A
CVSF,ALL,,,580.7/HU,522.0
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,, 632.7/HU,427
NALL
LWRITE

DTIM=40       !, 600
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1       $ NLINE,1 !, REGION 1A
CVSF,ALL,,,791.0/HU,520.0
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,,1987.0/HU,512
NALL
LWRITE
```

```
!, END TRANSIENTS **************************

:EX1
!, MAKE SOME PLOTS *********
/SHOW,,,1
/NUM,2
/ERASE
/WINDOW,,LEFT
/PBC,ALL,1
NPLOT
/NOERASE
/WINDOW,,RIGH
/PBC,ALL,0
EPLOT
/ERASE
/WINDOW,,FULL
/SHOW
/NUM

KPSEL,,1  $ NKPOI $ *GET,NK1,NDMN
KPSEL,,21 $ NKPOI $ *GET,NK21,NDMN
KPSEL,,22 $ NKPOI $ *GET,NK22,NDMN
KPSEL,,23 $ NKPOI $ *GET,NK23,NDMN
KPSEL,,24 $ NKPOI $ *GET,NK24,NDMN
KPSEL,,9  $ NKPOI $ *GET,NK9,NDMN
KPSEL,,10 $ NKPOI $ *GET,NK10,NDMN
KPSEL,,27 $ NKPOI $ *GET,NK27,NDMN
KPSEL,,28 $ NKPOI $ *GET,NK28,NDMN
KPSEL,,19 $ NKPOI $ *GET,NK19,NDMN

NSEL,,NK24
ENODE
*GET,EK24,ELMN
NSEL,,NK9
ENODE
*GET,EK9,ELMN
EALL
NALL

SAVE
AFWRITE
FINISH

/INPUT,27
FINISH

!, *******************************************
!, *******************************************
/POST26
NUMVAR,20
DISP,2,NK23,TEMP,TK23
DISP,3,NK27,TEMP,TK27
DISP,4,NK24,TEMP,TK24
DISP,5,NK28,TEMP,TK28
DISP,6,NK9,TEMP,TK9
```

```
DISP,7,NK19,TEMP,TK19

ADD,10,3,2,,TK27,TK23,,1.0,-1.0
ADD,11,5,4,,TK28,TK24,,1.0,-1.0
ADD,12,7,6,,TK19,TK9 ,,1.0,-1.0
EXTREME,10,13,1
/GRAPH,GRID,1

/SHOW,,,1
/NUM,2
!, /WINDOW,,LTOP
!, PRVAR,2,3,10
!, PLVAR,2,3,10
!, /NOERASE
!, /WINDOW,,RTOP
!, PRVAR,4,5,11
!, PLVAR,4,5,11
!, /WINDOW,,LBOT
!, PRVAR,6,7,12
!, PLVAR,6,7,12
!, /WINDOW,,RBOT
!, /TITLE, TEMPERATURE HISTORY, TOP FILLET TOP
PRVAR,4,5,11
PLVAR,4,5,11
!, /TITLE, ZION STEAM GENERATOR SHELL, UPPER GIRTH WELD
/ERASE
/WINDOW,,FULL
/SHOW
/NUM

FINISH

/POST1
SET,,,,,60
/RATIO,,5
PLNSTR,TEMP
/RATIO
/GRAPH,GRID,1
/SHOW,,,1
/NUM,2
!, /TITLE, TEMPERATURE THROUGH THICKNESS
PLPATH,NK24,NK28,TEMP
PRPATH,NK24,NK28,TEMP
PLPATH,NK9,NK19,TEMP
PRPATH,NK9,NK19,TEMP
/ERASE
/WINDOW,,FULL
/SHOW
/NUM

SET,,,,,275
/RATIO,,5
PLNSTR,TEMP
/RATIO
/GRAPH,GRID,1
```

```
/SHOW,,,1
/NUM,2
PLPATH,NK24,NK28,TEMP
PRPATH,NK24,NK28,TEMP
PLPATH,NK9,NK19,TEMP
PRPATH,NK9,NK19,TEMP
!, /TITLE, ZION STEAM GENERATOR SHELL, UPPER GIRTH WELD
/ERASE
/WINDOW,,FULL
/SHOW
/NUM

SET,,,,,560
/RATIO,,5
PLNSTR,TEMP
/RATIO
/GRAPH,GRID,1
/SHOW,,,1
/NUM,2
PLPATH,NK24,NK28,TEMP
PRPATH,NK24,NK28,TEMP
PLPATH,NK9,NK19,TEMP
PRPATH,NK9,NK19,TEMP
!, /TITLE, ZION STEAM GENERATOR SHELL, UPPER GIRTH WELD
/ERASE
/WINDOW,,FULL
/SHOW
/NUM

SET,,,,,600
/RATIO,,5
PLNSTR,TEMP
/RATIO
/GRAPH,GRID,1
/SHOW,,,1
/NUM,2
PLPATH,NK24,NK28,TEMP
PRPATH,NK24,NK28,TEMP
PLPATH,NK9,NK19,TEMP
PRPATH,NK9,NK19,TEMP
!, /TITLE, ZION STEAM GENERATOR SHELL, UPPER GIRTH WELD
/ERASE
/WINDOW,,FULL
/SHOW
/NUM

!, AXIAL PROFILE *****************
SET,,,,,50
LPATH,NK1,NK21,NK22,NK23,NK24,NK10
PDEF,INTR,TID,TEMP
/PBC,PATH,1
NPLOT
/PBC,PATH,0
PVIEW,PLOT,TID
```

```
SET,,,,,560
LPATH,NK1,NK21,NK22,NK23,NK24,NK10
PDEF,INTR,TID,TEMP
/PBC,PATH,1
NPLOT
/PBC,PATH,0
PVIEW,PLOT,TID

FINISH

!, ***********************************************
!, ***********************************************
/PREP7
RESUME
EALL
NALL
CVDELE,ALL
TDELE,ALL

TREF,70
TUNIF,70

ITER,1,,1
KAN,0

!, BOUNDARY CONDITIONS  *************
NSEL,Y,Y1
D,ALL,UY,0.0
NALL

!, COUPLING AT TOP BOUNDARY  ********
CPSIZE,(D1+1)*2
KPSEL,,10,20,10
LSKP,1
NLINE,1
*GET,N1,NDMN
NJ=N1
:P1
*GET,NJ,NDMN,NJ
*IF,NJ,EQ,0,:P2
CP,1,UY,N1,NJ
*GO,:P1
:P2
NALL

*CREATE,LMAC
!, *USE,LMAC,TIM,PR
!, INTERNAL PRESSURE, INSIDE SURF
LSSEL,,2,LL1
NLINE,1
PSF,ALL,,,ARG2
NALL
!, END SURF
FAR=((R2**2)*ARG2 )/2     !, AXIAL FORCE PER RADIAN
F,N1,FY,FAR
```

```
!, THERMAL LOAD ***********
TIME,ARG1
KTEMP,,,ARG1
LWRITE
*END,LMAC

!, *GO,:L2
!, *GO,:L3
!, *GO,:L4
!, *GO,:L5
*GO,:L6
!, TRANSIENT NO. 1, HEATUP @ 100deg/hour
*USE,LMAC,0,0
*USE,LMAC,5*3600,1020
*GO,:EX2

!, TRANSIENT NO. 2, COOLDOWN @ 100deg/hour
:L2
*USE,LMAC,0,1020
*USE,LMAC,5*3600,0
*GO,:EX2

!, TRANSIENT NO. 3, LARGE LOAD STEP DECREASE *********
:L3
*USE,LMAC,0,720
*USE,LMAC,60,1091
*USE,LMAC,180,802
*USE,LMAC,20*60,938
*GO,:EX2

!, TRANSIENT NO. 4, REACTOR TRIP *********************
:L4
*USE,LMAC,0,1020
*USE,LMAC,0.556,1020
*USE,LMAC,1.111,1020
*USE,LMAC,2.222,1020
*USE,LMAC,4.444,1020
*USE,LMAC,6.667,1020
*USE,LMAC,9.420,1020
*USE,LMAC,10,1003
*USE,LMAC,20,987
*USE,LMAC,50,947
*USE,LMAC,125,848
*USE,LMAC,230,681
*USE,LMAC,305,540
*USE,LMAC,385,422
*USE,LMAC,455,326
*USE,LMAC,560,247
*USE,LMAC,685,220
*GO,:EX2

!, TRANSIENT NO. 5, BOUNDING FAULTED EVENT *********
:L5
*USE,LMAC,0,1020
*USE,LMAC,60,0
```

```
*USE,LMAC,180,0
*USE,LMAC,300,0
*USE,LMAC,600,0

!, TRANSIENT NO. 6, FEEDWATER CYCLING ***************
:L6
*USE,LMAC,0,1020
*USE,LMAC,10,1016
*USE,LMAC,20,1012
*USE,LMAC,50,1003
*USE,LMAC,60,998
*USE,LMAC,75,990
*USE,LMAC,90,987
*USE,LMAC,110,979
*USE,LMAC,150,964
*USE,LMAC,175,955
*USE,LMAC,190,948
*USE,LMAC,220,940
*USE,LMAC,275,920
*USE,LMAC,300,904
*USE,LMAC,330,900
*USE,LMAC,375,885
*USE,LMAC,385,884
*USE,LMAC,450,862
*USE,LMAC,480,852
*USE,LMAC,530,834
*USE,LMAC,560,826
*USE,LMAC,600,812

:EX2
!, MAKE SOME PLOTS *********
/SHOW,,,1
/ERASE
/WINDOW,,LEFT
/PBC,ALL,1
NPLOT
/NOERASE
/WINDOW,,RIGH
/PBC,ALL,0
EPLOT
/ERASE
/WINDOW,,FULL
/SHOW

AFWRITE
FINISH
!, ******************************************
!, ******************************************

/INPUT,27
FINISH

!, ******************************************
!, ******************************************
/POST26
```

```
ESTR,2,EK24,16,SY24
ESTR,3,EK9,16,SY9
ESTR,4,EK24,18,SZ24
ESTR,5,EK9,18,SZ9
ESTR,6,EK24,51,SI24
ESTR,7,EK9,51,SI9
/GRAPH,GRID,1
PRVAR,2,3,4,5,6,7
PLVAR,2,4,6
PLVAR,3,5,7

FINISH

:RES
!, ******************************************
!, ******************************************
/POST1
STRESS,TMP,82,88  !, TEMPERATURE
/DSCALE,,OFF

*CREATE,CMAC
/RATIO
/WINDOW,,LEFT
/EDGE,,1
PLNSTR,SI
/NOERASE
/RATIO,,5
/WINDOW,,RIGH
/EDGE
PLNSTR,SI
/RATIO
/WINDOW,,FULL
/ERASE
*END,CMAC

*CREATE,SMAC
/SHOW,,,1
/NUM,2
PLSECT,NK24,NK28,-1,SI
PRSECT,NK24,NK28,-1
/ERASE
/WINDOW,,FULL
/SHOW
/NUM
*END,SMAC

*CREATE,AMAC
/SHOW,,,1
PLSECT,NK24,NK28,-1 SY
PRSECT,NK24,NK28,-1
/ERASE
/WINDOW,,FULL
/SHOW
*END,AMAC
```

```
*CREATE,PMAC
/SHOW,,,1
PLPATH,NK24,NK28,SY
PRPATH,NK24,NK28,SY
/ERASE
/WINDOW,,FULL
/SHOW
*END,PMAC

/TITLE, FEEDWATER CYCLING TRANSIENT
SET,,,,,60  $ *USE,CMAC
*USE,AMAC
*USE,PMAC
SET,,,,,75  $ *USE,CMAC
*USE,AMAC
*USE,PMAC
SET,,,,,150 $ *USE,CMAC
*USE,AMAC
*USE,PMAC
SET,,,,,175 $ *USE,CMAC
*USE,AMAC
*USE,PMAC
SET,,,,,275 $ *USE,CMAC
*USE,AMAC
*USE,PMAC
SET,,,,,300 $ *USE,CMAC
*USE,AMAC
*USE,PMAC
SET,,,,,385 $ *USE,CMAC
*USE,AMAC
*USE,PMAC
SET,,,,,450 $ *USE,CMAC
*USE,AMAC
*USE,PMAC
SET,,,,,560 $ *USE,CMAC
*USE,AMAC
*USE,PMAC
SET,,,,,600 $ *USE,CMAC
*USE,AMAC
*USE,PMAC

FINISH
/EOF

SET,,,,,275
/TITLE, FEEDWATER CYCLING TRANSIENT
*USE,CMAC
!, *USE,SMAC
*USE,AMAC
*USE,PMAC
PRRFOR

SET,,,,,560
*USE,CMAC
!, *USE,SMAC
```

```
*USE,AMAC
*USE,PMAC
PRRFOR

SET,,,,,600
*USE,CMAC
!, *USE,SMAC
*USE,AMAC
*USE,PMAC
PRRFOR

!, AXIAL PROFILE ****************
!, SET,,,,,50
SET,,,,,50
LPATH,NK1,NK21,NK22,NK23,NK24,NK10
PDEF,INTR,SIID,SI
PDEF,INTR,SYID,SY
PDEF,INTR,SZID,SZ
/PBC,PATH,1
NPLOT
/PBC,PATH,0
/GRAPH,GRID,1
PVIEW,PLOT,SYID,SZID,SIID

SET,,,,,275
LPATH,NK1,NK21,NK22,NK23,NK24,NK10
PDEF,INTR,SIID,SI
PDEF,INTR,SYID,SY
PDEF,INTR,SZID,SZ
/PBC,PATH,1
NPLOT
/PBC,PATH,0
/GRAPH,GRID,1
PVIEW,PLOT,SYID,SZID,SIID

SET,,,,,560
LPATH,NK1,NK21,NK22,NK23,NK24,NK10
PDEF,INTR,SIID,SI
PDEF,INTR,SYID,SY
PDEF,INTR,SZID,SZ
/PBC,PATH,1
NPLOT
/PBC,PATH,0
/GRAPH,GRID,1
PVIEW,PLOT,SYID,SZID,SIID

!, SET,,,,,685
SET,,,,,600
LPATH,NK1,NK21,NK22,NK23,NK24,NK10
PDEF,INTR,SIID,SI
PDEF,INTR,SYID,SY
PDEF,INTR,SZID,SZ
/PBC,PATH,1
NPLOT
/PBC,PATH,0
```

```
/GRAPH,GRID,1
PVIEW,PLOT,SYID,SZID,SIID

:EX3
*STATUS
FINISH


/EOF

-rw-r--r--  1 rhm      1128087 Oct 30 19:50 fwcycle1.33
-rw-r--r--  1 rhm      1204146 Nov  8 14:11 fwcycle1.33add
-rw-r--r--  1 rhm       521235 Nov  8 10:31 fwcycle1.33rev
-rw-r--r--  1 rhm        50066 Nov  8 12:04 fwcycle1.5
-rw-r--r--  1 rhm       395136 Oct 30 13:02 fwcycle1.6
-rw-r--r--  1 rhm       397605 Oct 30 19:50 fwcycle1.6a
-rw-r--r--  1 rhm       342994 Nov  8 10:31 fwcycle1.6b
-rw-r--r--  1 rhm       219200 Nov  8 12:08 fwcycle1.6c
-rw-r--r--  1 rhm        74602 Nov  8 15:18 fwcycle1.rpt
-rw-r--r--  1 rhm      1069038 Oct 30 12:32 rtrp1.33
-rw-r--r--  1 rhm       696924 Oct 30 13:46 rtrp1.33post1
-rw-r--r--  1 rhm        52036 Oct 30 16:10 rtrp1.5
-rw-r--r--  1 rhm       405302 Oct 30 12:32 rtrp1.6
-rw-r--r--  1 rhm       197717 Oct 30 12:56 rtrp1.6post
-rw-r--r--  1 rhm        29395 Oct 30 16:16 rtrp1.rpt
-rw-r--r--  1 rhm        42436 Oct 24 14:43 sgenii1.5
-rw-r--r--  1 rhm       247126 Oct 24 14:52 sgenii1.6
```

# APPENDIX D

# INPUT DATA LISTINGS

```
!, File = rtrp1.5 copied from sgenii1.5, copied from nsgen5.5
/SHOW,file33,dat

RESUME
/INPUT,fileparm,dat
*GO,:RES

/PREP7
/TITLE, ZION STEAM GENERATOR SHELL, UPPER GIRTH WELD, rtrp1.5
!, PARAMETERS **************************************
R1=64.69    !, INSIDE RADIUS, LOWER SHELL
R2=84.255   !, INSIDE RADIUS, UPER SHELL
TW=3.52     !, THICKNESS OF WALL
RF=2*TW     !, RADIUS OF FILLETS (EST.)

Y2=15.67    !, REGION 4/5
Y3=32.00    !, LOWER WELD
Y4=51.38    !, REGION 3/4
Y5=75.32    !, REGION 2/3
Y6=84.47    !, REGION 1/2
Y7=94.26    !, REGION 0/1
Y8=108.75   !, UPPER WELD
Y9=121.13   !, REGION 1A/2A
Y10=155.00  !, TOP

!, EXTEND MODEL LENGTH ***
Y1=Y3-63
Y10=Y8+71

ANGR=ATAN((Y8-Y3)/(R2-R1))
PI=ACOS(-1)
ANGR=(PI/2)-ANGR
ANGD=ANGR*(180/PI)

HU=3600*144 !, HF UNIT CONVERSION

D1=10       !, THRU THICKNESS
D2=8        !, LOWER SHELL
D3=6        !, CONE
D4=10       !, UPPER SHELL
D5=8
D6=4
D7=4
D8=8
D9=8
D10=15
DF=3        !, DIV IN FILLET

B1=5        !, BIAS THRU THICKNESS
B10=4

!, COORDINATE SYSTEMS **********************
LOCAL,11,0,R1,Y3,,-ANGD
LOCAL,12,0,R1,Y3,,-(ANGD/2)
LOCAL,13,0,R2,Y8,,-(ANGD/2)
```

```
CSYS

!, KEYPOINTS ****************************************
K,1,R1,Y1
K,2,R1,Y2
K,3,R1,Y3
K,4,R1,Y4
KMOVE,4,0,999,Y4,0,11,0.0,999,999
K,5,R1,Y5
KMOVE,5,0,999,Y5,0,11,0.0,999,999
K,6,R1,Y6
KMOVE,6,0,999,Y6,0,11,0.0,999,999
K,7,R1,Y7
KMOVE,7,0,999,Y7,0,11,0.0,999,999
K,8,R2,Y8
K,9,R2,Y9
K,10,R2,Y10

K,11,(R1+TW),Y1
K,12,(R1+TW),Y2
CSYS,12
K,13,(TW/COS(ANGR/2))
CSYS,11
*GET,YC,KY,4
K,14,TW,YC
*GET,YC,KY,5
K,15,TW,YC
*GET,YC,KY,6
K,16,TW,YC
*GET,YC,KY,7
K,17,TW,YC
CSYS,13
K,18,(TW/COS(ANGR/2))
CSYS
K,19,(R2+TW),Y9
K,20,(R2+TW),Y10
SAVE

!, LINES ******************************
L,1,11,D1,B1
L,1,2,D2
L,2,3,D3
L,3,4,D4
LFILLT,3,4,(RF+TW)
LDVS,3,,D3
LDVS,4,,D4
LDVS,5,,DF
L,4,5,D5
L,5,6,D6
L,6,7,D7
L,7,8,D8
L,8,9,D9
LFILLT,9,10,RF
LDVS,9,,D8
LDVS,10,,D9
```

```
LDVS,11,,DF
L,9,10,D10,B10
*GET,,L1,LSMX

L,11,12,D2
L,12,13,D3
L,13,14,D4
LFILLT,14,15,RF
LDVS,14,,D3
LDVS,15,,D4
LDVS,16,,DF
L,14,15,D5
L,15,16,D6
L,16,17,D7
L,17,18,D8
L,18,19,D9
LFILLT,20,21,(RF+TW)
LDVS,20,,D8
LDVS,21,,D9
LDVS,22,,DF
L,19,20,D10,B10

L,2,12,D1,B1
L,21,25,D1,B1
L,22,26,D1,B1
L,4,14,D1,B1
L,5,15,D1,B1
L,6,16,D1,B1
L,7,17,D1,B1
L,23,27,D1,B1
L,24,28,D1,B1
L,9,19,D1,B1
L,10,20,D1,B1
SAVE

!, AREAS ******************
A,1,11,12,2
A,2,12,25,21
A,21,25,26,22
A,22,26,14,4
A,4,14,15,5
A,5,15,16,6
A,6,16,17,7
A,7,17,27,23
A,23,27,28,24
A,24,28,19,9
A,9,19,20,10
SAVE

!, TYPE, MAT, REAL ********************
KAN,-1
ET,1,77    !, 2ND ORDER QUADRATIC THERMAL ELEMENT
KEYOPT,1,3,1

!, DENSITY ********************************
```

```
DEN=490        !, DENSITY (lb/ft**3)
MP,DENS,1,DEN/1728   !, DENSITY (lb/in**3)

!, HEAT CAPACITY & CONDUCTIVITY  ***************
MPTEMP,1,70,100,150,200,250,300
MPTEMP,7,350,400,450,500,550,600
TK=23.3              !, T=70 CONDUCTIVITY (Btu/hr-ft-degF)
TD=0.455             !, T=70 DIFFUSIVITY  (ft**2/hr)
TDR=TD*(144/3600)  !, DIFF REF (in**2/sec)
TC=TK/(DEN*TD)       !, SPECIFIC HEAT (Btu/lb-degF)
MPDATA,C,1,1,TC
C1=3600*12           !,
MPDATA,KXX,1,1,TK/C1

TK=23.6 $ TD=0.451     !, T=100
TC=TK/(DEN*TD)  !, SPECIFIC HEAT (Btu/lb-degF)
MPDATA,C,1,2,TC $ MPDATA,KXX,1,2,TK/C1

TK=24.1 $ TD=0.444     !, T=150
TC=TK/(DEN*TD)  !, SPECIFIC HEAT (Btu/lb-degF)
MPDATA,C,1,3,TC $ MPDATA,KXX,1,3,TK/C1

TK=24.4 $ TD=0.437     !, T=200
TC=TK/(DEN*TD)  !, SPECIFIC HEAT (Btu/lb-degF)
MPDATA,C,1,4,TC $ MPDATA,KXX,1,4,TK/C1

TK=24.6 $ TD=0.429     !, T=250
TC=TK/(DEN*TD)  !, SPECIFIC HEAT (Btu/lb-degF)
MPDATA,C,1,5,TC $ MPDATA,KXX,1,5,TK/C1

TK=24.7 $ TD=0.420     !, T=300
TC=TK/(DEN*TD)  !, SPECIFIC HEAT (Btu/lb-degF)
MPDATA,C,1,6,TC $ MPDATA,KXX,1,6,TK/C1

TK=24.7 $ TD=0.409     !, T=350
TC=TK/(DEN*TD)  !, SPECIFIC HEAT (Btu/lb-degF)
MPDATA,C,1,7,TC $ MPDATA,KXX,1,7,TK/C1

TK=24.6 $ TD=0.398     !, T=400
TC=TK/(DEN*TD)  !, SPECIFIC HEAT (Btu/lb-degF)
MPDATA,C,1,8,TC $ MPDATA,KX[illegible] TK/C1

TK=24.4 $ TD=0.388     !, T=450
TC=TK/(DEN*TD)  !, SPECIFIC HEAT (Btu/lb-degF)
MPDATA,C,1,9,TC $ MPDATA,KXX,1,9,TK/C1

TK=24.2 $ TD=0.377     !, T=500
TC=TK/(DEN*TD)  !, SPECIFIC HEAT (Btu/lb-degF)
MPDATA,C,1,10,TC $ MPDATA,KXX,1,10,TK/C1

TK=23.9 $ TD=0.364     !, T=550
TC=TK/(DEN*TD)  !, SPECIFIC HEAT (Btu/lb-degF)
MPDATA,C,1,11,TC $ MPDATA,KXX,1,11,TK/C1

TK=23.5 $ TD=0.353     !, T=600
```

```
TC=TK/(DEN*TD)  !, SPECIFIC HEAT (Btu/lb-degF)
MPDATA,C,',12,TC $ MPDATA,KXX,1,12,TK/C1

!, ELASTIC MODULUS & POISSON RATIO  ***********
MPTEMP
MPTEMP,1,70,200,300,400,500,600
MPDATA,EX,1,1,29.2E6,28.5E6,28.0E6,27.4E6,27.0E6,26.4E6

MPTEMP
MP,NUXY,1,0.29

!, THERMAL EXPANSION COEFICIENT  **************
MPTEMP,1,70,100,150,200,250,300
MPTEMP,7,350,400,450,500,550,600
MPDATA,ALPX,1,1,7.02E-6,7.06E-6,7.16E-6,7.25E-6,7.34E-6,7.43E-6
MPDATA,ALPX,1,7,7.50E-6,7.58E-6,7.63E-6,7.70E-6,7.77E-6,7.83E-6

/SHOW,,,1
/GRAPH,GRID,1
/NUM,2
!, /WINDOW,,LTOP
/TITLE, ZION STEAM GENERATOR SHELL, HEAT CAPACITY Btu/lb-degF
MPPLOT,C,1
!, /NOERASE
!, /WINDOW,,RTOP
/TITLE, ZION STEAM GENERATOR SHELL, THERMAL CONDUCTIVITY Btu/1n-sec-degF
MPPLOT,KXX,1
!, /WINDOW,,LBOT
/TITLE, ZION STEAM GENERATOR SHELL, ELASTIC MODULUS lb/in**2
MPPLOT,EX,1
!, /WINDOW,,RBOT
/TITLE, ZION STEAM GENERATOR SHELL, THERMAL EXPANSION COEFFICIENT in/in-degF
MPPLOT,ALPX,1
/TITLE, ZION STEAM GENERATOR SHELL, UPPER GIRTH WELD, rtrp1.5
/ERASE
/WINDOW,,FULL
/SHOW
/NUM

R,1

!, NODES & ELEMENTS  ************************
ELSIZE,,,2
AMESH,ALL
WSORT

!, !, STEP SIZE  ******************************
DT=(TW/(D1*B1))**2
DT=DT/(10*TDR)

!, BOUNDARY CONDITIONS  *********************
TREF,70

!, *GO,:S2
!, *GO,:S3
```

```
*GO,:S4
!, *GO,:S5
!, *GO,:S6
!, TRANSIENT NO. 1, HEATUP @ 100degF/hr  ***********
/TITLE, TRANSIENT NO. 1, HEATUP @ 100degF/hr
:S1
TIM=0
TIME,TIM
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,70
ITER,-10,,10
KBC,1
NALL
LWRITE

DTIM=5*3600
TIM=TIM+DTIM
NSTP=DTIM/DT
TIME,TIM
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,547
ITER,-NSTP,,1
KBC,0
NALL
LWRITE

DTIM=10*60
TIM=TIM+DTIM
NSTP=DTIM/DT
TIME,TIM
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,547
ITER,-NSTP,,1
NALL
LWRITE
*GO,:EX1

!, TRANSIENT NO. 2, COOLDOWN @ 100degF/hr  *********
/TITLE, TRANSIENT NO. 2, COOLDOWN @ 100degF/hr
:S2
TIM=0
TIME,TIM
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,547
ITER,-10,,10
KBC,1
NALL
LWRITE

DTIM=5*3600
TIM=TIM+DTIM
```

```
NSTP=DTIM/DT

TIME,TIM
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,70
KBC,0
ITER,-NSTP,,1
NALL
LWRITE

DTIM=10*60
TIM=TIM+DTIM
NSTP=DTIM/DT
TIME,TIM
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,70
ITER,-NSTP,,1
NALL
LWRITE
*GO,:EX1

!, TRANSIENT NO. 3, LARGE STEP LOAD DECREASE  *****
/TITLE, TRANSIENT NO. 3, LARGE STEP LOAD DECREASE
:S3
TIM=0
TIME,TIM
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,506
ITER,-10,,10
KBC,1
NALL
LWRITE

DTIM=60
TIM=TIM+DTIM
NSTP=DTIM/DT
TIME,TIM
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,546
KBC,0
ITER,-NSTP,,1
NALL
LWRITE

DTIM=120
TIM=TIM+DTIM
NSTP=DTIM/DT
TIME,TIM
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,510
```

```
ITER,-NSTP,,1
NALL
LWRITE

DTIM=(20*60)-TIM
TIM=TIM+DTIM
TIME,TIM
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,537
ITER,-NSTP,,1
NALL
LWRITE

DTIM=10*60
TIM=TIM+DTIM
TIME,TIM
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,537
ITER,-NSTP,,1
NALL
LWRITE
*GO,:EX1

!, TRANSIENT NO. 4, REACTOR TRIP *****************
/TITLE, TRANSIENT NO. 4, REACTOR TRIP
:S4
TIM=0
TIME,TIM
LSSEL,,2      $ NLINE,1   !, REGION 5
CVSF,ALL,,,1208/HU,547
LSSEL,,3,5    $ NLINE,1   !, REGION 4
CVSF,ALL,,,1208/HU,547
LSSEL,,6      $ NLINE,1   !, REGION 3
CVSF,ALL,,,1208/HU,547
LSSEL,,7      $ NLINE,1   !, REGION 2
CVSF,ALL,,,1208/HU,547
LSSEL,,8      $ NLINE,1   !, REGION 1
CVSF,ALL,,,5000/HU,547
LSSEL,,9,12  $ NLINE,1   !, REGION 0
CVSF,ALL,,,10000/HU,547
ITER,-10,,10
KBC,1
NALL
LWRITE

*CREATE,HMAC
!, 1=T0 2=T2 3=H2 4=T3 5=H3 6=T4 7=H4 8=T5 9=H5
LSSEL,,2      $ NLINE,1   !, REGION 5
CVSF,ALL,,,ARG9/HU,ARG8
LSSEL,,3,5    $ NLINE,1   !, REGION 4
CVSF,ALL,,,ARG7/HU,ARG6
LSSEL,,6      $ NLINE,1   !, REGION 3
CVSF,ALL,,,ARG5/HU,ARG4
```

```
LSSEL,,7      $ NLINE,1   !, REGION 2
CVSF,ALL,,,ARG3/HU,ARG2
LSSEL,,8      $ NLINE,1   !, REGION 1
CVSF,ALL,,,5000/HU,160
LSSEL,,9,12  $ NLINE,1   !, REGION 0
CVSF,ALL,,,10000/HU,ARG1
KBC,0
NALL
LWRITE
*END,HMAC


DTIM=1.0      !, 1.0
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
!,        1=T0 2=T2 3=H2 4=T3 5=H3 6=T4 7=H4 8=T5 9=H5
*USE,HMAC,547, 547,1208, 547,1208, 547,1208, 547,1208

DTIM=0.1     !, 1.1
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
!,        1=T0 2=T2 3=H2 4=T3 5=H3 6=T4 7=H4 8=T5 9=H5
*USE,HMAC,547, 200,1208, 547,1208, 547,1208, 547,1208

DTIM=1.0   !, 2.1
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
!,        1=T0 2=T2 3=H2 4=T3 5=H3 6=T4 7=H4 8=T5 9=H5
*USE,HMAC,547, 200,1208, 234,1208, 547,1208, 547,1208

DTIM=1.1   !, 3.2
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
!,        1=T0 2=T2 3=H2 4=T3 5=H3 6=T4 7=H4 8=T5 9=H5
*USE,HMAC,547, 200,1208, 234,1208, 292,1208, 547,1208

DTIM=2.2   !, 5.4
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
!,        1=T0 2=T2 3=H2 4=T3 5=H3 6=T4 7=H4 8=T5 9=H5
*USE,HMAC,546, 200,1208, 234,1208, 292,1208, 370,1208

DTIM=5.0   !, 10.4
TIM=TIM+DTIM
TIME,TIM
```

```
NSTP=DTIM/DT
ITER,-NSTP,,1
!,      1=T0 2=T2 3=H2 4=T3 5=H3 6=T4 7=H4 8=T5 9=H5
*USE,HMAC,546, 200,1208, 234,1208, 292,1208, 370,1208

DTIM=0.6   !, 11.0
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
!,      1=T0 2=T2 3=H2 4=T3 5=H3 6=T4 7=H4 8=T5 9=H5
*USE,HMAC,545, 226, 761, 258, 662, 402, 578, 357, 502

DTIM=114   !, 125.0
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
!,      1=T0 2=T2 3=H2 4=T3 5=H3 6=T4 7=H4 8=T5 9=H5
*USE,HMAC,525, 221, 761, 250, 662, 290, 578, 341, 502

DTIM=105   !, 230.0
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
!,      1=T0 2=T2 3=H2 4=T3 5=H3 6=T4 7=H4 8=T5 9=H5
*USE,HMAC,500, 216, 761, 243, 662, 280, 578, 326, 502

DTIM=225   !, 455.0
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
!,      1=T0 2=T2 3=H2 4=T3 5=H3 6=T4 7=H4 8=T5 9=H5
*USE,HMAC,425, 206, 761, 227, 662, 257, 578, 295, 502

DTIM=105   !, 560.0
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
!,      1=T0 2=T2 3=H2 4=T3 5=H3 6=T4 7=H4 8=T5 9=H5
*USE,HMAC,400, 201, 761, 220, 662, 247, 578, 280, 502

DTIM=125   !, 685.0
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
!,      1=T0 2=T2 3=H2 4=T3 5=H3 6=T4 7=H4 8=T5 9=H5
*USE,HMAC,390, 195, 761, 211, 662, 234, 578, 263, 502

*GO,:EX1
```

```
!, TRANSIENT NO. 5, BOUNDING FAULTED EVENT  *******
/TITLE, TRANSIENT NO. 5, BOUNDING FAULTED EVENT, STATE 1
:S5
TIM=0
TIME,TIM
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,547
ITER,-10,,10
KBC,1
NALL
LWRITE

DTIM=60
TIM=TIM+DTIM
NSTP=DTIM/DT
TIME,TIM
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,70
KBC,0
ITER,-NSTP,,1
NALL
LWRITE

DTIM=10*60
TIM=TIM+DTIM
NSTP=DTIM/DT
TIME,TIM
LSSEL,,2,LL1
NLINE,1
NT,ALL,TEMP,70
KBC,0
ITER,-NSTP,,1
NALL
LWRITE

!, TRANSIRNT NO. 6, FEEDWATER CYCLING EVENT  ******
:S6
TIM=0
TIME,TIM
ITER,-10,,10
KBC,1
LSSEL,,LL1        $ NLINE,1 !, REGION 1A
CVSF,ALL,,,24/HU,547
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,,76/HU,547
NALL
LWRITE

DTIM=10        !, 10
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
```

```
KBC,0
LSSEL,,LL1        $ NLINE,1 !, REGION 1A
CVSF,ALL,,,270.9/HU,546.5
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,,322.9/HU,538
NALL
LWRITE

DTIM=10        !, 20
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1        $ NLINE,1 !, REGION 1A
CVSF,ALL,,,323.9/HU,546
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,,375.9/HU,530
NALL
LWRITE

DTIM=30        !, 50
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1        $ NLINE,1 !, REGION 1A
CVSF,ALL,,,422.4/HU,545
LSSEL,,2,(LL1-!) $ NLINE,1 !, REGION 2A
CVSF,ALL,,,472.4/HU,502
NALL
LWRITE

DTIM=25        !, 75
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1        $ NLINE,1 !, REGION 1A
CVSF,ALL,,,806.2/HU,543.6
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,,2002.2/HU,534
NALL
LWRITE

DTIM=15        !, 90
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1        $ NLINE,1 !, REGION 1A
CVSF,ALL,,,360.6/HU,543
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,, 412.6/HU,522
NALL
LWRITE
```

```
DTIM=20        !, 110
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1        $ NLINE,1 !, REGION 1A
CVSF,ALL,,,434.2/HU,542
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,, 486.2/HU,504
NALL
LWRITE

DTIM=40        !, 150
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1        $ NLINE,1 !, REGION 1A
CVSF,ALL,,,532.0/HU,540.2
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,, 584.0/HU,468
NALL
LWRITE

DTIM=25        !, 175
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1        $ NLINE,1 !, REGION 1A
CVSF,ALL,,,792.0/HU,539.1
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,,1988.0/HU,531
NALL
LWRITE

DTIM=15        !, 190
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1        $ NLINE,1 !, REGION 1A
CVSF,ALL,,,357.4/HU,538.4
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,, 409.4/HU,518
NALL
LWRITE

DTIM=30        !, 220
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1        $ NLINE,1 !, REGION 1A
CVSF,ALL,,,464.6/HU,537.1
```

```
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,, 516.6/HU,490
NALL
LWRITE

DTIM=55        !, 275
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1        $ NLINE,1 !, REGION 1A
CVSF,ALL,,,553.2/HU,534.6
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,, 605.2/HU,453
NALL
LWRITE

DTIM=25        !, 300
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1        $ NLINE,1 !, REGION 1A
CVSF,ALL,,,805.3/HU,533.5
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,,2001.3/HU,524
NALL
LWRITE

DTIM=30        !, 330
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1        $ NLINE,1 !, REGION 1A
CVSF,ALL,,,423.5/HU,532.1
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,, 475.5/HU,497
NALL
LWRITE

DTIM=45        !, 375
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1        $ NLINE,1 !, REGION 1A
CVSF,ALL,,,529.4/HU,530.1
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,, 581.4/HU,459
NALL
LWRITE

DTIM=75        !, 450
TIM=TIM+DTIM
```

```
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1        $ NLINE,1 !, REGION 1A
CVSF,ALL,,,778.2/HU,526.8
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,,1974.2/HU,520
NALL
LWRITE

DTIM=30        !, 480
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1        $ NLINE,1 !, REGION 1A
CVSF,ALL,,,416.9/HU,525.4
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,, 468.9/HU,492
NALL
LWRITE

DTIM=50        !, 530
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1        $ NLINE,1 !, REGION 1A
CVSF,ALL,,,534.3/HU,523.2
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,, 596.3/HU,450
NALL
LWRITE

DTIM=30        !, 560
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1        $ NLINE,1 !, REGION 1A
CVSF,ALL,,,580.7/HU,522.0
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,, 632.7/HU,427
NALL
LWRITE

DTIM=40        !, 600
TIM=TIM+DTIM
TIME,TIM
NSTP=DTIM/DT
ITER,-NSTP,,1
LSSEL,,LL1        $ NLINE,1 !, REGION 1A
CVSF,ALL,,,791.0/HU,520.0
LSSEL,,2,(LL1-1) $ NLINE,1 !, REGION 2A
CVSF,ALL,,,1987.0/HU,512
```

```
NALL
LWRITE

!, END TRANSIENTS ****************************

:EX1
!, MAKE SOME PLOTS *********
/SHOW,,,1
/NUM,2
/ERASE
/WINDOW,,LEFT
/PBC,ALL,1
NPLOT
/NOERASE
/WINDOW,,RIGH
/PBC,ALL,0
EPLOT
/ERASE
/WINDOW,,FULL
/SHOW
/NUM

KPSEL,,1  $ NKPOI $ *GET,NK1,NDMN
KPSEL,,21 $ NKPOI $ *GET,NK21,NDMN
KPSEL,,22 $ NKPOI $ *GET,NK22,NDMN
KPSEL,,23 $ NKPOI $ *GET,NK23,NDMN
KPSEL,,24 $ NKPOI $ *GET,NK24,NDMN
KPSEL,,9  $ NKPOI $ *GET,NK9,NDMN
KPSEL,,10 $ NKPOI $ *GET,NK10,NDMN
KPSEL,,27 $ NKPOI $ *GET,NK27,NDMN
KPSEL,,28 $ NKPOI $ *GET,NK28,NDMN
KPSEL,,19 $ NKPOI $ *GET,NK19,NDMN

NSEL,,NK24
ENODE
*GET,EK24,ELMN
NSEL,,NK9
ENODE
*GET,EK9,ELMN
EALL
NALL

SAVE
AFWRITE
FINISH

/INPUT,27
FINISH

!, ********************************************
!, ********************************************
/POST26
NUMVAR,20
DISP 2,NK23,TEMP,TK23
DISP,3,NK27,TEMP,TK27
```

```
DISP,4,NK24,TEMP,TK24
DISP,5,NK28,TEMP,TK28
DISP,6,NK9,TEMP,TK9
DISP,7,NK19,TEMP,TK19

ADD,10,3,2,,TK27,TK23,,1.0,-1.0
ADD,11,5,4,,TK28,TK24,,1.0,-1.0
ADD,12,7,6,,TK19,TK9 ,,1.0,-1.0
EXTREME,10,13,1
/GRAPH,GRID,1

/SHOW,,,1
/NUM,2
!, /WINDOW,,LTOP
!, PRVAR,2,3,10
!, PLVAR,2,3,10
!, /NOERASE
!, /WINDOW,,RTOP
!, PRVAR,4,5,11
!, PLVAR,4,5,11
!, /WINDOW,,LBOT
!, PRVAR,6,7,12
!, PLVAR,6,7.12
!, /WINDOW,,RBOT
/TITLE, TEMPERATURE HISTORY, TOP FILLET TOP
PRVAR,4,5,11
PLVAR,4,5,11
/TITLE, ZION STEAM GENERATOR SHELL, UPPER GIRTH WELD, rtrp1.5
/ERASE
/WINDOW,,FULL
/SHOW
/NUM

FINISH

/POST1
SET,,,,,50
/RATIO,,5
PLNSTR,TEMP
/RATIO
/GRAPH,GRID,1
/SHOW,,,1
/NUM,2
!, /TITLE, TEMPERATURE THROUGH THICKNESS, rtrp1.5 @ 50sec
PLPATH,NK24,NK28,TEMP
PRPATH,NK24,NK28,TEMP
PLPATH,NK9,NK19,TEMP
PRPATH,NK9,NK19,TEMP
/ERASE
/WINDOW,,FULL
/SHOW
/NUM

SET,,,,,180
/RATIO,,5
```

```
PLNSTR,TEMP
/RATIO
/GRAPH,GRID,1
/SHOW,,,1
/NUM,2
PLPATH,NK24,NK28,TEMP
PRPATH,NK24,NK28,TEMP
PLPATH,NK9,NK19,TEMP
PRPATH,NK9,NK19,TEMP
!, /TITLE, ZION STEAM GENERATOR SHELL, UPPER GIRTH WELD
/ERASE
/WINDOW,,FULL
/SHOW
/NUM

SET,,,,,300
/RATIO,,5
PLNSTR,TEMP
/RATIO
/GRAPH,GRID,1
/SHOW,,,1
/NUM,2
PLPATH,NK24,NK28,TEMP
PRPATH,NK24,NK28,TEMP
PLPATH,NK9,NK19,TEMP
PRPATH,NK9,NK19,TEMP
/TITLE, ZION STEAM GENERATOR SHELL, UPPER GIRTH WELD
/ERASE
/WINDOW,,FULL
/SHOW
/NUM

SET,,,,,560
/RATIO,,5
PLNSTR,TEMP
/RATIO
/GRAPH,GRID,1
/SHOW,,,1
/NUM,2
PLPATH,NK24,NK28,TEMP
PRPATH,NK24,NK28,TEMP
PLPATH,NK9,NK19,TEMP
PRPATH,NK9,NK19,TEMP
/TITLE, ZION STEAM GENERATOR SHELL, UPPER GIRTH WELD
/ERASE
/WINDOW,,FULL
/SHOW
/NUM

!, AXIAL PROFILE ****************
SET,,,,,50
LPATH,NK1,NK21,NK22,NK23,NK24,NK10
PDEF,INTR,TID,TEMP
/PBC,PATH,1
NPLOT
```

```
/PBC,PATH,0
PVIEW,PLOT,TID

SET,,,,,560
LPATH,NK1,NK21,NK22,NK23,NK24,NK10
PDEF,INTR,TID,TEMP
/PBC,PATH,1
NPLOT
/PBC,PATH,0
PVIEW,PLOT,TID

FINISH

!, **********************************************
!, **********************************************
/PREP7
RESUME
EALL
NALL
CVDELE,ALL
TDELE,ALL

TREF,70
TUNIF,70

ITER,1,,1
KAN,0

!, BOUNDARY CONDITIONS *************
NSEL,Y,Y1
D,ALL,UY,0.0
NALL

!, COUPLING AT TOP BOUNDARY ********
CPSIZE,(D1+1)*2
KPSEL,,10,20,10
LSKP,1
NLINE,1
*GET,N1,NDMN
NJ=N1
:P1
*GET,NJ,NDMN,NJ
*IF,NJ,EQ,0,:P2
CP,1,UY,N1,NJ
*GO,:P1
:P2
NALL

*CREATE,LMAC
!, *USE,LMAC,TIM,PR
!, INTERNAL PRESSURE, INSIDE SURF
LSSEL,,2,LL1
NLINE,1
PSF,ALL,,,ARG2
NALL
```

```
!, END SURF
FAR=((R2**2)*ARG2 )/2     !, AXIAL FORCE PER RADIAN
F,N1,FY,FAR
!, THERMAL LOAD  ***********
TIME,ARG1
KTEMP,,,ARG1
LWRITE
*END,LMAC

!, *GO,:L2
!, *GO,:L3
*GO,:L4
!, *GO,:L5
!, *GO,:L6
!, TRANSIENT NO. 1, HEATUP @ 100deg/hour
*USE,LMAC,0,0
*USE,LMAC,5*3600,1020
*GO,:EX2

!, TRANSIENT NO. 2, COOLDOWN @ 100deg/hour
:L2
*USE,LMAC,0,1020
*USE,LMAC,5*3600,0
*GO,:EX2

!, TRANSIENT NO. 3, LARGE LOAD STEP DECREASE  *********
:L3
*USE,LMAC,0,720
*USE,LMAC,60,1091
*USE,LMAC,180,802
*USE,LMAC,20*60,938
*GO,:EX2

!, TRANSIENT NO. 4, REACTOR TRIP  *********************
:L4
*USE,LMAC,0,1020
*USE,LMAC,0.556,1020
*USE,LMAC,1.111,1020
*USE,LMAC,2.222,1020
*USE,LMAC,4.444,1020
*USE,LMAC,6.667,1020
*USE,LMAC,9.420,1020
*USE,LMAC,10,1003
*USE,LMAC,20,987
*USE,LMAC,45,955      !, ADDED
*USE,LMAC,50,947
*USE,LMAC,125,848
*USE,LMAC,230,681
*USE,LMAC,305,540
*USE,LMAC,385,422
*USE,LMAC,455,326
*USE,LMAC,560,247
*USE,LMAC,600,235     !, ADDED
*USE,LMAC,685,220
*GO,:EX2
```

```
!, TRANSIENT NO. 5, BOUNDING FAULTED EVENT *********
:L5
*USE,LMAC,0,1020
*USE,LMAC,60,0
*USE,LMAC,180,0
*USE,LMAC,300,0
*USE,LMAC,600,0

!, TRANSIENT NO. 6, FEEDWATER CYCLING ***************
:L6
*USE,LMAC,0,1020
*USE,LMAC,10,1016
*USE,LMAC,20,1012
*USE,LMAC,50,1003
*USE,LMAC,75,990
*USE,LMAC,90,987
*USE,LMAC,110,979
*USE,LMAC,150,964
*USE,LMAC,175,955
*USE,LMAC,190,948
*USE,LMAC,220,940
*USE,LMAC,275,920
*USE,LMAC,300,904
*USE,LMAC,330,900
*USE,LMAC,375,885
*USE,LMAC,450,862
*USE,LMAC,480,852
*USE,LMAC,530,834
*USE,LMAC,560,826
*USE,LMAC,600,812

:EX2
!, MAKE SOME PLOTS *********
/SHOW,,,1
/ERASE
/WINDOW,,LEFT
/PBC,ALL,1
NPLOT
/NOERASE
/WINDOW,,RIGH
/PBC,ALL,0
EPLOT
/ERASE
/WINDOW,,FULL
/SHOW

AFWRITE
FINISH
!, ******************************************
!, ******************************************

/INPUT,27
FINISH

!, ******************************************
```

```
!, ********************************************
/POST26
ESTR,2,EK24,16,SY24
ESTR,3,EK9,16,SY9
ESTR,4,EK24,18,SZ24
ESTR,5,EK9,18,SZ9
ESTR,6,EK24,51,SI24
ESTR,7,EK9,51,SI9
/GRAPH,GRID,1
PRVAR,2,3,4,5,6,7
PLVAR,2,4,6
PLVAR,3,5,7

FINISH

:RES
!, ********************************************
!, ********************************************
/POST1
STRESS,TMP,82,88  !, TEMPERATURE
/DSCALE,,OFF

*CREATE,CMAC
/RATIO
/WINDOW,,LEFT
/EDGE,,1
PLNSTR,SI
/NOERASE
/RATIO,,5
/WINDOW,,RIGH
/EDGE
PLNSTR,SI
/RATIO
/WINDOW,,FULL
/ERASE
*END,CMAC

*CREATE,SMAC
/SHOW,,,1
/NUM,2
PLSECT,NK24,NK28,-1,SI
PRSECT,NK24,NK28,-1
/ERASE
/WINDOW,,FULL
/SHOW
/NUM
*END,SMAC

*CREATE,AMAC
/SHOW,,,1
/NUM,2
PLSECT,NK24,NK28,-1,SY
PRSECT,NK24,NK28,-1
/ERASE
/WINDOW,,FULL
```

```
/SHOW
/NUM
*END,AMAC

*CREATE,PMAC
/SHOW,,,1
/NUM,2
PLPATH,NK24,NK28,SY
PRPATH,NK24,NK28,SY
/ERASE
/WINDOW,,FULL
/SHOW
/NUM
*END,PMAC

SET,1
!, /TITLE, TRANSIENT NO. 1, HEATUP  @ 100deg/hour, STATE 1
!, /TITLE, TRANSIENT NO. 2, COOLDOWN @ 100deg/hour, STATE 1
!, /TITLE, TRANSIENT NO. 3, LARGE STEP LOAD DECREASE STATE 1
/TITLE, TRANSIENT NO. 4, REACTOR TRIP
!, /TITLE, TRANSIENT NO. 5, BOUNDING FAULTED EVENT, STATE 1
*USE,CMAC
!, *USE,SMAC
*USE,AMAC
*USE,PMAC
PRRFOR

SET,2
!, /TITLE, TRANSIENT NO. 1, HEATUP  @ 100deg/hour, STATE 2
!, /TITLE, TRANSIENT NO. 2, COOLDOWN @ 100deg/hour, STATE 2
!, /TITLE, TRANSIENT NO. 3, LARGE STEP LOAD DECREASE STATE 2
/TITLE, TRANSIENT NO. 4, REACTOR TRIP
!, /TITLE, TRANSIENT NO. 5, BOUNDING FAULTED EVENT, STATE 2
*USE,CMAC
!, *USE,SMAC
*USE,AMAC
*USE,PMAC
PRRFOR

!, *GO,:EX3

!, SET,3
SET,,,,,5
!, /TITLE, TRANSIENT NO. 3, LARGE STEP LOAD DECREASE STATE 3
/TITLE, TRANSIENT NO. 4, REACTOR TRIP
!, /TITLE, TRANSIENT NO. 5, BOUNDING FAULTED EVENT, STATE 3
*USE,CMAC
!, *USE,SMAC
*USE,AMAC
*USE,PMAC
PRRFOR

!, SET,4
SET,,,,,560
!, /TITLE, TRANSIENT NO. 3, LARGE STEP LOAD DECREASE STATE 4
```

```
/TITLE, TRANSIENT NO. 4, REACTOR TRIP
!, /TITLE, TRANSIENT NO. 5, BOUNDING FAULTED EVENT, STATE 4
*USE,CMAC
!, *USE,SMAC
*USE,AMAC
*USE,PMAC
PRRFOR
/TITLE, ZION STEAM GENERATOR SHELL, rtrp1.5

SET,,,,,685
!, /TITLE, TRANSIENT NO. 3, LARGE STEP LOAD DECREASE STATE 4
/TITLE, TRANSIENT NO. 4, REACTOR TRIP
!, /TITLE, TRANSIENT NO. 5, BOUNDING FAULTED EVENT, STATE 4
*USE,CMAC
!, *USE,SMAC
*USE,AMAC
*USE,PMAC
PRRFOR
/TITLE, ZION STEAM GENERATOR SHELL, rtrp1.5

!, AXIAL PROFILE  ****************
!, SET,,,,,50
SET,1
LPATH,NK1,NK21,NK22,NK23,NK24,NK10
PDEF,INTR,SIID,SI
PDEF,INTR,SYID,SY
PDEF,INTR,SZID,SZ
/PBC,PATH,1
NPLOT
/PBC,PATH,0
/GRAPH,GRID,1
PVIEW,PLOT,SYID,SZID,SIID
PVIEW,PRIN,SYID,SZID,SIID

SET,,,,,275
LPATH,NK1,NK21,NK22,NK23,NK24,NK10
PDEF,INTR,SIID,SI
PDEF,INTR,SYID,SY
PDEF,INTR,SZID,SZ
/PBC,PATH,1
NPLOT
/PBC,PATH,0
/GRAPH,GRID,1
PVIEW,PLOT,SYID,SZID,SIID

SET,,,,,560
LPATH,NK1,NK21,NK22,NK23,NK24,NK10
PDEF,INTR,SIID,SI
PDEF,INTR,SYID,SY
PDEF,INTR,SZID,SZ
/PBC,PATH,1
NPLOT
/PBC,PATH,0
/GRAPH,GRID,1
PVIEW,PLOT,SYID,SZID,SIID
```

```
SET,,,,,685
!, SET,,,,,600
LPATH,NK1,NK21,NK22,NK23,NK24,NK10
PDEF,INTR,SIID,SI
PDEF,INTR,SYID,SY
PDEF,INTR,SZID,SZ
/PBC,PATH,1
NPLOT
/PBC,PATH,0
/GRAPH,GRID,1
PVIEW,PLOT,SYID,SZID,SIID

:EX3
*STATUS
FINISH


/EOF

*GET,YC23,NY,NK23
*GET,YC9,NY,NK9
NSEL,Y,YC9,YC23
ENODE,1
```