EXECUTIVE SUMMARY

Background and Purpose

The reactor pressure vessel (RPV) at the Pilgrim Nuclear Station was designed in the late 1960's. Calculations for vessel life were based on fatigue analyses that were then performed by hand, using estimated numbers of cycles that were developed without the benefit of operating experience. The fatigue life of the vessel can now be calculated much more accurately by using modern analysis techniques and actual operating experience.

In recent years, it has become apparent that some of the original estimates for operating cycles that were used in the vessel design were low and in some instances would be exceeded prior to the 40 year design life. This project was undertaken to account for these increased cycle projections. Its primary purpose is to supplement the original analysis, remove unnecessary conservatism, and produce a more accurate calculation of vessel fatigue life using current analytical methods and current estimates for cyclic loading due to thermal, pressure and mechanical loads.

A second objective of this project was to review and update the existing analysis of the feedwater inlet sparger. The original sparger analysis illustrated that the sparger may have to be inspected six times during the remaining plant life because possible leaking and deterioration of the sparger seals may lead to high fatigue stresses in the feedwater nozzle. This project included a review and revision of the sparger analysis to extend its useful life.

In addition to these primary tasks, the project included a related study to determine the effects of reducing feedwater inlet temperature on the fatigue life of the feedwater nozzles, ASME Section XI computer models, and preliminary screening criteria. The results of these studies are not included in this summary.

Critical Points for Fatigue Evaluations

Since fatigue stresses are highest at points of structural discontinuity, the important locations for evaluation are easily identified. In the original analysis, the following locations were evaluated:

1. Closure region
2. Bottom head and support skirt
3. Feedwater nozzle (revised in 1982 to include rapid cycling)
4. Steam outlet nozzles
5. Recirculation inlet nozzles
6. Recirculation outlet nozzles
7. Core spray nozzle
8. Vessel shell
9. 4" vent nozzle
10. 2" instrument nozzles

11. 6" instrument spray nozzles
12. Drain nozzle
13. CRD nozzle
14. Jet pump instrument nozzles
15. Miscellaneous internals and attachments

A detailed review of the original analysis confirmed that the assumptions and results for Items 11 through 15, although conservative, were acceptable; therefore these were not reevaluated in this project. Reanalysis of the vessel was performed for locations 1 - 11 above, which are shown in Figure 1.

Reanalysis for the feedwater nozzle (Item 3) was done primarily for rapid thermal cycling. The system transient analysis had been redone in 1979 and was acceptable; however, as part of this program, the feedwater sparger and nozzle was re-analyzed to include the more accurate cycle-count data that is now available.

Improvements to Original Analysis

The original analysis was supplemented and revised to include the following three improvements.

1. Method of Analysis

   The original structural analysis was done by hand using interaction and seal-shell analysis. This type of analysis usually produces accurate results for stress near a discontinuity, but cannot predict the localized peak stresses that are necessary to calculate fatigue life. As a result, stress concentration factors were multiplied by the calculated stresses to produce the peak stresses for the fatigue analysis. Good engineering practice required that the stress concentration factors be conservative, and these conservatisms were reflected directly into increased fatigue stress and consequent decrease in predicted fatigue life.

   In addition, the original analysis could not predict stress gradients near structural discontinuities. This limitation required that any flaw analysis that might be required in these areas be based on maximum stress, rather than actual stress at the location of the flaw. (Flaw evaluation is not covered in this report, but related tasks involving flaw analysis were done as part of this overall program and are reported in Altran Technical Report No. 93177-TR-04).

   The method used for the revised analysis of the RPV uses finite element computer models to calculate peak stress directly and thereby eliminates the previous conservatism related to the use of stress concentration factors (although Code allowable stress concentration factors were applied selectively to compensate for specific analysis uncertainties). It also provides accurate stress values in areas of rapid stress change, so that evaluation of ASME Section XI flaws can be done more accurately, if required.

2. Cycle Counts Based on Operating Experience

The cycle counts used in the original analysis were estimates made with very limited operating experience. The revised analysis uses cycle counts based on 21 years of PNPS experience, extrapolated to the 40-year design life of the plant. The extrapolation is based on a linear regression analysis plus three standard deviations to account for the data spread in the operating experience. A comparison of the original and new cycle counts follows.

Cycle Counts

Event	Original Analysis	Revised Analysis
Boltup	123	22
Hydro	130	22
Cold Startup	120	212
Hot Standby Startup	120	337
50% PWR Reduction	14,600	379
Loss of FW Heaters	80	10
Loss of FW Pumps	10	26
Turbine Generator Trips	40	27
Other Scrams	147	132
Full PWR Recirc S/U	5	16
PWR Reduction to Hot Standby	118	176
Shutdowns	118	145
Safety Valve Blowdown S/D	2	47
Refueling Floodup S/D	118	20
Unbolt	123	22

3. Stress Range for Each Event

In most cases, the original analysis made the very conservative assumption that every design cycle produced the maximum range of stress, regardless of the event. In fact, most events produce a stress range well below the maximum.

The revised analysis accurately accounts for the actual stress range for each event, then uses that stress with the cycle count for that same event to determine its incremental contribution to total fatigue.

Results

The revised fatigue analysis showed substantial increases in fatigue life when compared to the original analysis. All sections of the vessel are acceptable for the full 40-year design life of the RPV, including the feedwater nozzle and sparger. Fatigue Usage Factors that include the increased cycle counts are all well below the limiting value of 1.0 as follows:

Fatigue Usage Factors

Component	Original Analysis	Revised Analysis
Closure Region	.77	.049
Closure Studs	.79	.07
Bottom Head and Supt. Skirt	.309	.044
Feedwater Nozzle		
System Transients	.545[1]	.637
Combined (Rapid and System)	.678[1][3]	<.8[4]
Steam Outlet Nozzle	[2]	[2]
Recirculation Inlet Nozzle	.97	.037
Recirculation Outlet Nozzle	.751	[2]
Core Spray Nozzle	.437	.01
Vessel Shell	.435	.012
Vent Nozzle	[2]	[2]
Instrument Nozzle	[2]	[2]

(1) From 1979 analysis, using finite elements

(2) Meets exclusion rules for ASME Code - fatigue analysis not required

(3) This usage factor requires that the sparger be refurbished six times during remaining plant life.

(4) Based on no refurbishment.

The large reductions in most of the fatigue factors are primarily the result of two factors: a substantial reduction in peak stress, and an accurate representation of the actual stress range of each event. The revised cycle counts show that both of the most severe transients (cold startups and loss of feedwater pumps) increased from the number projected in original analysis, but these increases were offset by the stress and stress range reductions resulting from this analysis.

The increase in feedwater nozzle life is a result of eliminating several conservatisms contained in the original analysis. Improvements in the revised analysis (relative to the original analysis) included use of more accurate values for loss coefficients at the feedwater sparger seals and gaps, coefficient of flow friction, coefficient of thermal expansion, and material corrosion rates. In addition, many different evaluations were performed to account for possible variations in the positions of the feedwater sparger.

The low fatigue usage factors resulting from the revised analysis show clearly the reactor vessel at PNPS can be operated safely for its full 40-year design life, and still maintain a substantial capacity beyond the 40 year design life, without refurbishment of the feedwater inlet sparger. The maximum usage factor for the vessel is calculated at the feedwater nozzle and is <0.8.

The revised analysis also provided valuable information regarding stress gradients in the maximum stress regions. This information will be useful if ASME Section XI flaw evaluations are required in the future. Selected plots showing these stress and thermal gradients are presented in Figures 2 through 6.

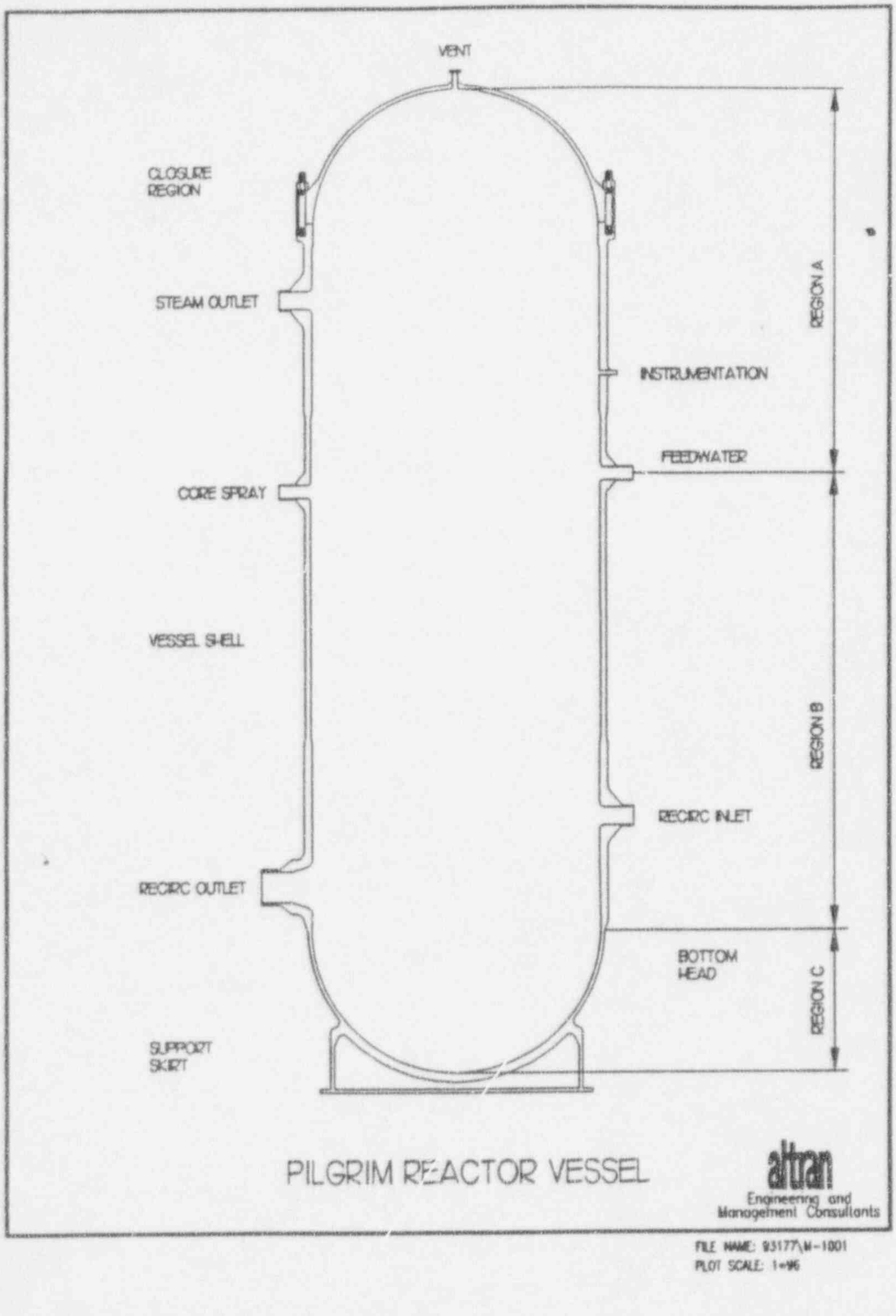

Figure 1

Re-analyzed Pressure Boundary Components of the Pilgrim Reactor Vessel

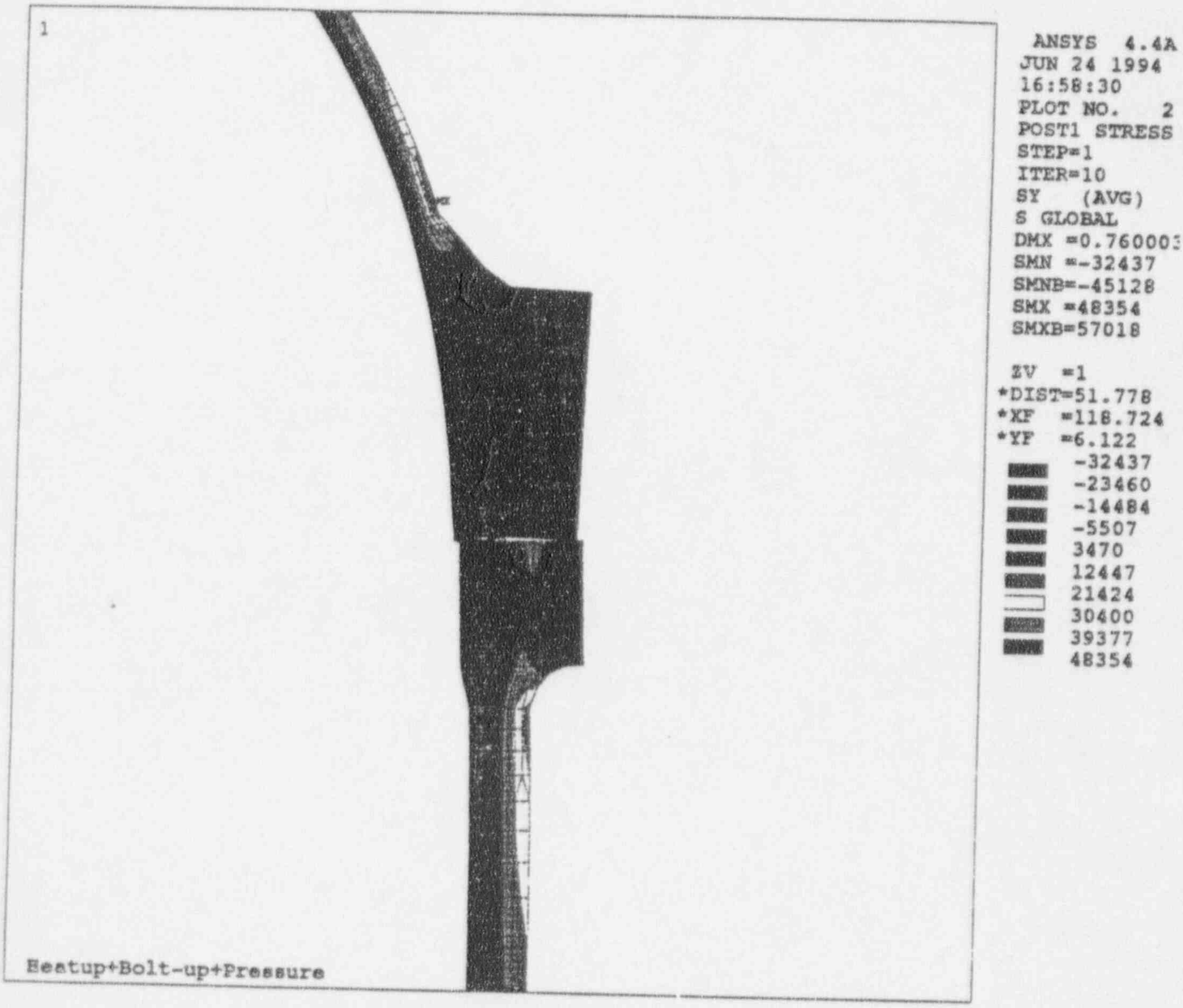

Figure 2

Closure Region - Displaced Geometry
and Sy Stresses for End of Heatup

COLOR PLOT

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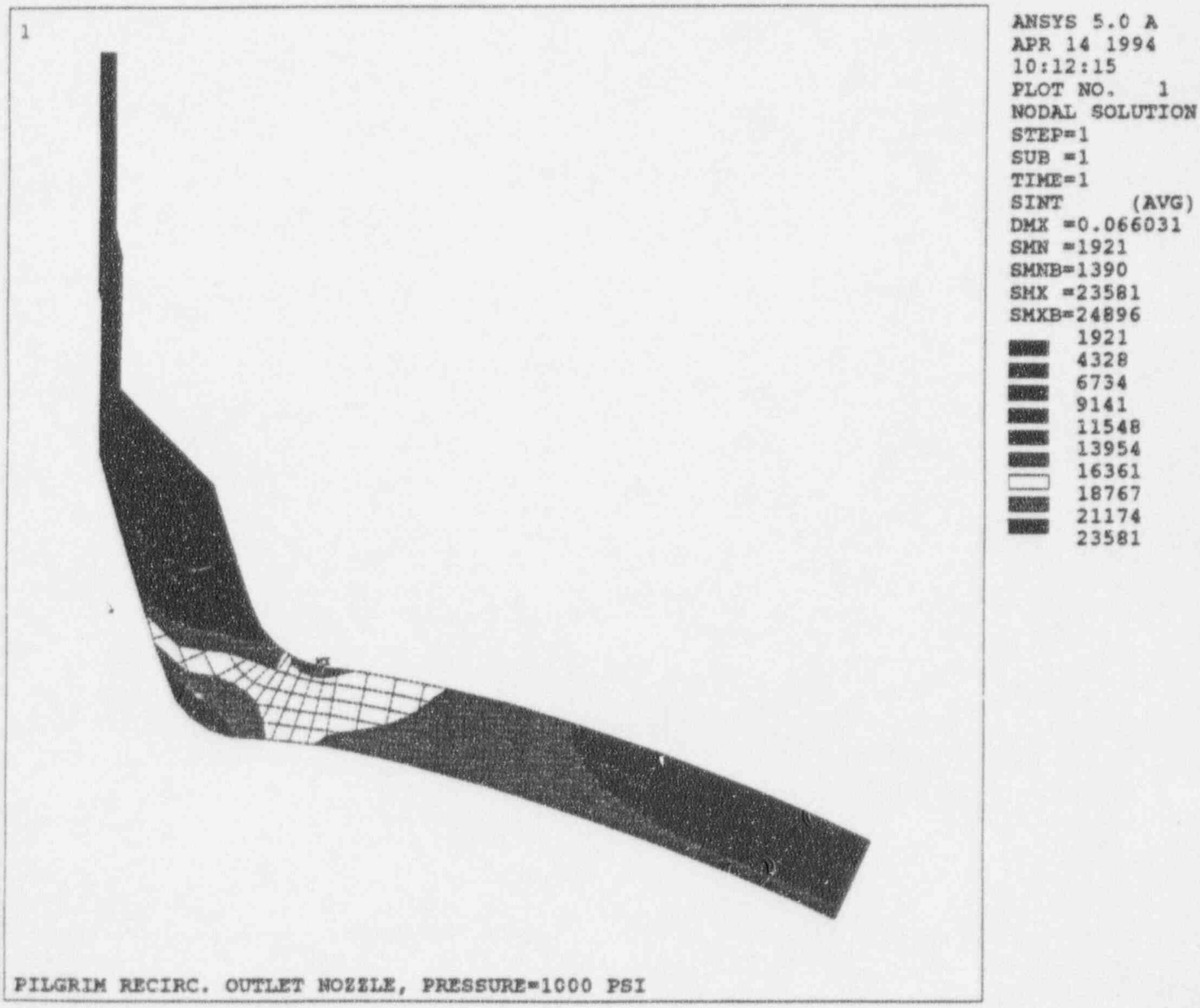

Figure 3 COLOR PLOT

Recirculation Outlet Nozzle - Stress Intensity for 1000 psi Pressure Lead

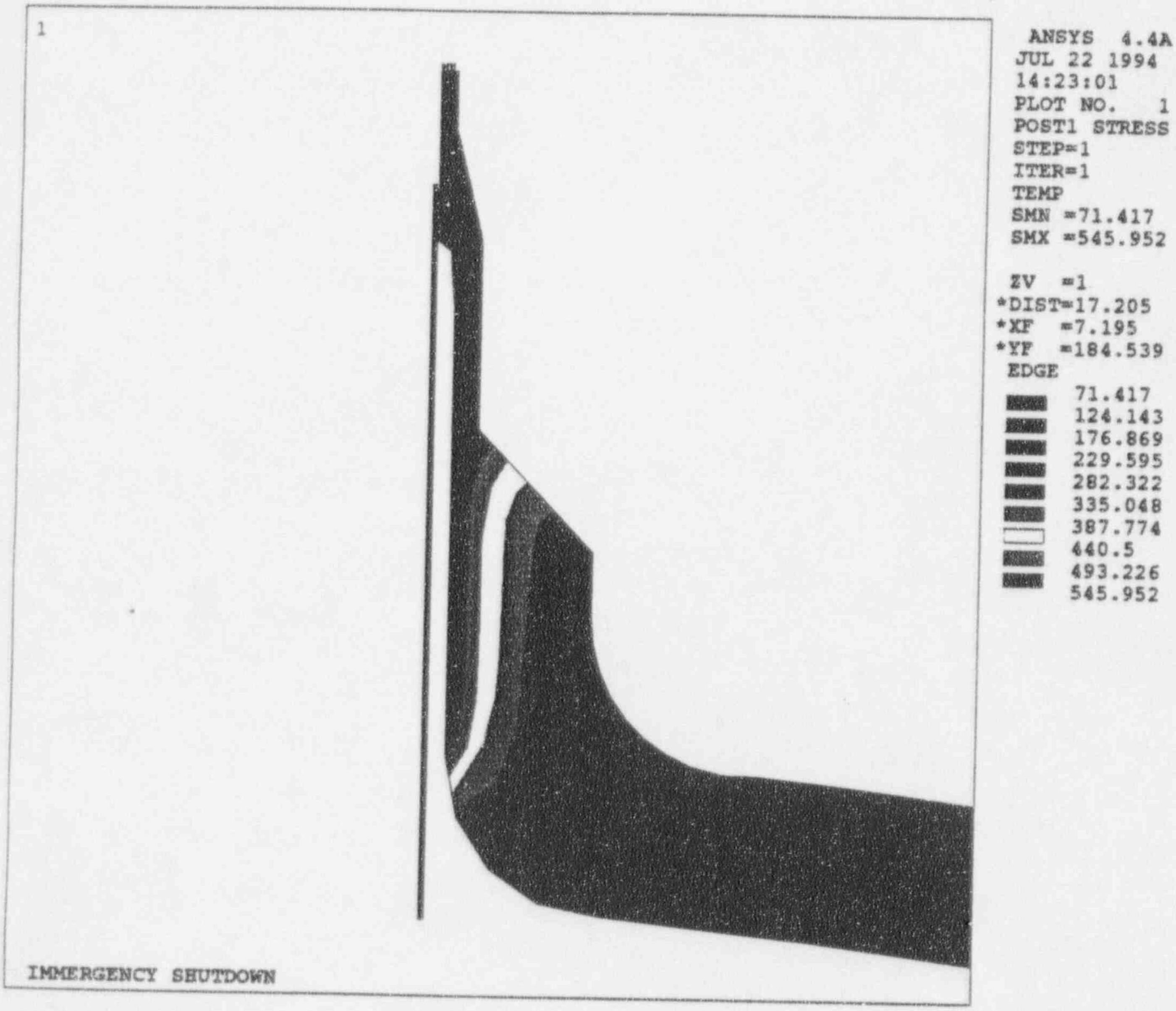

Figure 4 COLOR PLOT

Core Spray Nozzle - Emergency
Shutdown Thermal Distribution at 0.05 Hour

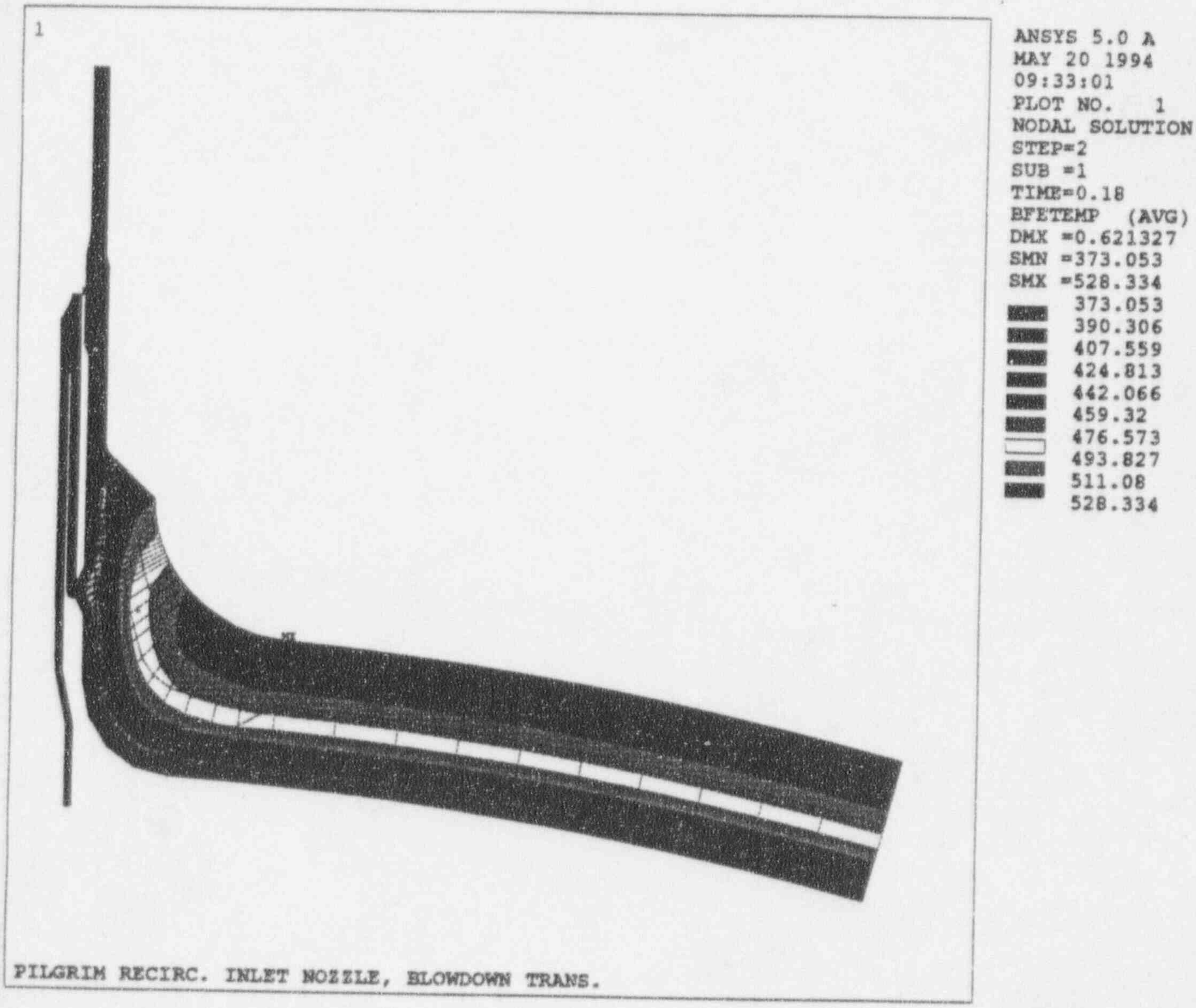

Figure 5 COLOR PLOT

Recirculation Inlet Nozzle -
Blowdown Transient Temperature
Distribution at 0.18 Hour

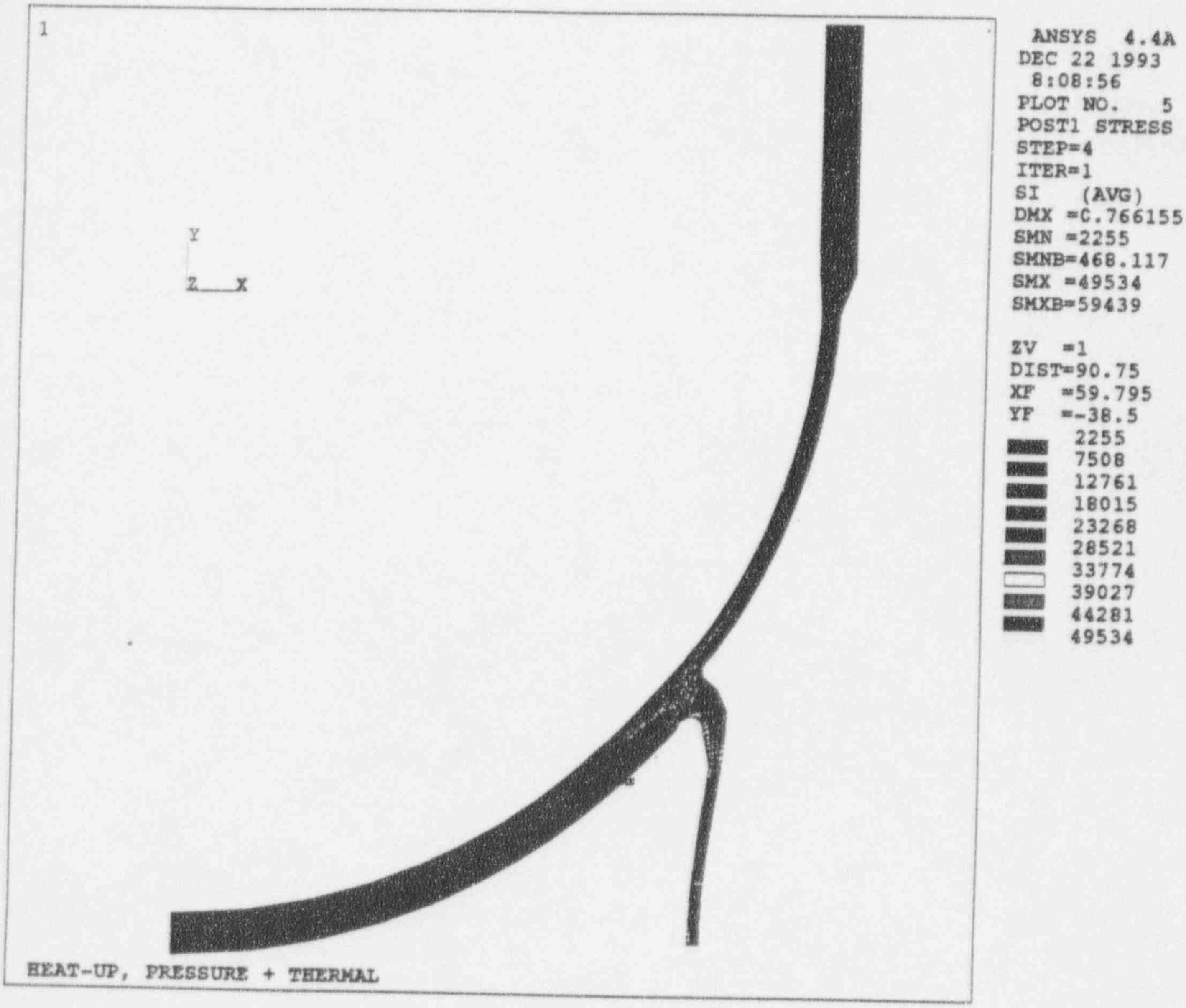

Figure 6 COLOR PLOT

Bottom Head and Support Skirt - Stress Intensity at End of Heat-up