Attachment 2

FRACTURE AND NDE EVALUATIONS FOR THE CLOSURE FLANGE REGIONS OF COMANCHE PEAK UNITS 1 AND 2

W. T. Kaiser
D. C. Adamonis
D. E. Prager

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APPROVED:
J. N. Chirigos, Manager
Structural Materials
Engineering

APPROVED: T.R. Mager
T. R. Mager, Manager
Metallurgical and NDE Analysis

MT-SME 3362

PREFACE

This report has been reviewed and checked.

John C. Schmertz
J. C. Schmertz

R. D. Rishel
R. D. Rishel

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1.0 INTRODUCTION

This report provides the information requested by Reference 1 on the Westinghouse analysis which showed the closure flange regions of Comanche Peak Units 1 and 2 are less limiting than the beltline regions. As a result of this analysis, Westinghouse has shown that the Comanche Peak Units 1 and 2 heatup and cooldown curves are not impacted by the new 10CFR50[2] rule.

The new 10CFR50 rule states that when the pressure exceeds 20 percent of the preservice hydrostatic test pressure the temperature of the closure head and vessel flange regions must exceed the material RT_{NDT} by at least 120°F for normal operation and by 90°F for hydrostatic pressure tests and leak tests. For the Comanche Peak plants, 20 percent of the preservice hydrostatic test pressure is 621 psig. In addition, 10CFR50 states that exceptions to the new 10CFR50 rule can be made provided the NRC is in agreement with the analysis techniques used. As a result, Westinghouse has used a finite element model to show that the Comanche Peak closure flange regions do not actually impact the heatup and cooldown curves. Details of the analysis are given in this report. The specific information provided is listed as follows:

1) A description of the finite element analysis used to determine the stresses within the closure flange regions.

2) The bolt-up, pressure and thermal stresses determined by the finite element analysis at the inside and outside surface locations of the flange to head and flange to shell junctions.

3) How the bolt-up, pressure and thermal stresses were combined to determine the applied stress intensity factors.

4) The flaw geometry used to calculate the applied stress intensity factors.

5) The applied stress intensity factors for the flange to head and flange to shell junctions.

6) The Technical Specification pressure-temperature limit that will be used to pressurize the reactor vessel from 400 psig to leak test and hydrotest pressure prior to the leak test and hydrotest.

7) The non-destructive examination methods that are currently specified for inservice examinations of head flange-to-dome welds and flange-to-vessel welds.

8) A qualitative assessment of the flaw detection and sizing capabilities of the non-destructive examination methods described in Item 7.

2.0 FINITE ELEMENT MODEL

A two dimensional finite element model for a typical 4-loop reactor vessel closure head flange and vessel flange geometry was used in the analysis. The WECAN[3] finite element program was used to develop the model. The critical dimensions in this model are within 4 percent of the geometry for Comanche Peak Units 1 and 2. The finite element model was used to obtain temperature and stress gradients caused by the heatup and cooldown transients. Separate analyses were performed to determine the boltup, pressure, and thermal stresses. Figure 1 shows the cross sections analyzed.

Two-dimensional axisymmetric elements were used to model the closure flange regions of the reactor vessel. The bulk of the model is comprised of isotropic elements. constant strain elements were used for all the orthotropic elements as well as for any three node isotropic elements. Four node isoparametric elements were used for all the four node isotropic elements. Orthotropic elements were used to model the nuts, bolts, and the flange material between the bolt holes. These elements were given a very low stiffness value in the hoop direction to account for the absence of any circumferential loads between adjacent members. The stainless steel clad, which covers the internal surfaces of the vessel, was considered to be non-structural and was not included as part of the finite element model. The insulating effect of the clad on model temperatures was included.

2.1 MECHANICAL BOUNDARY CONDITIONS

Physically, the reactor vessel shell will displace laterally, and the crown of the head does not displace laterally. To approximate this behavior, the bottom surface of the model in the shell region and the vertical surface of the model at the vessel crown were both assumed to be resting on rollers. This arrangement of restraint is assumed to correspond to the actual behavior of the vessel and prevents any rigid body motion of the model. Figure 2 shows this arrangement.

The initial bolt preload tensioning is designed to be so large that the mating flanges of the closure head and shell will never be separated by the contained coolant pressure. Because of this design, only bearing stresses can exist at the interface between the mating flanges of the head and shell. When the contained coolant pressure is zero, these bearing stresses exactly balance the bolt preload. As the coolant pressure increases, the flange bearing stresses diminish since the coolant pressure is now helping the flange bearing stresses in opposing the initial bolt preload.

2.2 THERMAL BOUNDARY CONDITIONS

For thermal analysis, all exterior surfaces of the model were assumed to be perfectly insulated and, therefore, adiabatic. Figure 3 shows the thermal boundary conditions. When the inside surface of the vessel is subjected to thermal transients, the primary mechanism of heat transfer is forced convection. The thermal properties of the metal are computed as linear functions of temperature. A uniform film coefficient was assumed for the entire inside surface of the vessel. Since the thermal resistance across the flange mating surfaces will not be significant, al the nodes on the flange mating surfaces were thermally coupled on the finite element model.

3.0 BOLTUP, PRESSURE AND THERMAL STRESSES

The boltup, pressure and thermal stresses for the heatup and cooldown transients are determined for the temperature range where the new 10CFR50 rule impacts the Comanche Peak Units 1 and 2 heatup and cooldown curves. The minimum temperature of the Comanche Peak closure flange regions is 160°F since the limiting RT_{NDT} is 40°F, and it occurs in the closure head flange region of both units. Figures 4 and 5 show that the 10CFR50 rule (without this special stress analysis) impacts the curves in the temperature range from 120°F to 160°F.

The thermal stresses used conservatively cover this temperature range for both the heatup and cooldown transients. For the heatup transient analysis, the thermal stresses near the middle of the 100°F/hour heatup transient are used. These stresses are obtained for a coolant temperature which is greater than the 120° to 160°F temperature range of interest. For the cooldown transient analysis, the thermal stresses at the end of 100°F/hour cooldown are used. These thermal stresses can be applied to the analysis which shows the new 10CFR50 rule does not impact the Comanche Peak heatup and cooldown curves.

The pressure stresses used in the analysis are based on an internal pressure of 776 psig since this is the maximum allowable pressure on Figures 4 and 5 in the temperature range from 120°F to 160°F.

Tables 1 through 4 contain the boltup, pressure, and thermal stresses for cross sections 1, 2, and 3. Table 1 contains the stresses in the longitudinal direction for the heatup transient, and Table 2 lists the heatup transient circumferential stresses. For the cooldown transient, Tables 3 and 4 contain the longitudinal and circumferential stresses, respectively.

4.0 FRACTURE MECHANICS ANALYSIS

The methods of the ASME Code Section XI, Appendix A[4] are used to generate the fracture analysis results. The flaw assumed in the analysis is a 0.625 inch deep surface flaw with an aspect ratio of 1:6. A safety factor of 2.0 is applied to the stress intensity factor due to the primary stresses (boltup and pressure stresses) as required by the ASME Code Section III, Appendix G [5]. Therefore, the primary and secondary (thermal) stress intensity factors (K_I) were combined in the following manner:

$$(K_I)_{Total} = 2\,(K_I)_{primary} + (K_I)_{secondary} \qquad (1)$$

In this report, the computed values of K_I which are negative are considered to be zero.

The NRC used the same fracture analysis techniques to develop the new 10CFR50 rule. The only difference is that Westinghouse used a finite element model to obtain stresses which are more accurate and less than the bending stress of 40 ksi conservatively assumed by the NRC.

5.0 FRACTURE MECHANICS RESULTS

The resultant primary, secondary, and total stress intensity factors for the heatup and cooldown transients are listed in Tables 5 through 12. For the heatup transient, Tables 5 and 6 contain the K_I values for inside and outside surface circumferential flaws, respectively. Tables 7 and 8 present the K_I values for inside and outside surface longitudinal flaws subjected to the heatup transient. For the cooldown transient, Tables 9 and 10 list the K_I values for inside and outside surface circumferential flaws, respectively. Tables 11 and 12 contain the K_I values for inside and outside surface longitudinal flaws subjected to the cooldown transient.

These results indicate that the maximum total K_I of 64.74 ksi$\sqrt{in}$ occurs for an outside surface circumferential flaw at cross section 3 during cooldown (Table 10). This K_I is relatively small, and all the other K_I values in Tables 5 through 12 are smaller. Therefore, the Westinghouse analysis shows that the closure flange regions are less limiting than the Comanche Peak Units 1 and 2 heatup and cooldown curves in Figures 6 and 7.

6.0 TECHNICAL SPECIFICATION PRESSURE-TEMPERATURE LIMIT

This section describes the pressure-temperature limit that will be used to pressurize the reactor vessel from 400 psig to the leak test or hydrotest pressure. To reach the test pressure, follow the normal heatup curve in Figure 6 up to the minimum temperature required for the test. Then follow a vertical line (dashed in Figure 6) up to the desired test pressure.

7.0 NDE METHODS

Nondestructive examinations currently specified for inservice inspection of the reactor vessel flange-to-upper shell weld and the vessel head flange-to-dome weld are in accordance with Section XI of the ASME Boiler and Pressure Vessel Code[6] Table IWB-2500-1 requires volumetric examination of flange-to-shell welds and volumetric and surface examinations of head flange-to-dome welds. The 1980 Edition of Section XI specifies the boundaries for volumetric examination include the weld and adjacent base material for a distance equal to one-half the weld thickness on both sides of the weld, Figures 8 and 9. The area specified for surface examination is the radiused or transition section of the flange on the outside surface as shown in Figure 9 between locations C and E.

Volumetric coverage of the reactor vessel flange-to-upper shell weld and specified adjacent base material is accomplished by two ultrasonic scan routines. Coverage from the flange side of the weld involves use of angled longitudinal waves from the flange seal surface. Beam angles are selected based on their ability to provide coverage of the weld and specified adjacent base material and provide near normal incidence to the plane of the weld. Refracted beam angles in the range 0° to 16° are typically used for these examinations. Examinations from the shell side of the weld involve 0°, 45°, and 60° refracted angle beam coverage from the vessel inside diameter surface. Angle beam scanning is performed in two directions parallel to the weld and perpendicular to the weld from the shell side. Access for the shell side examinations is limited to outages when the core barrel is removed from the reactor vessel.

Volumetric examination of the reactor vessel closure head flange-to-dome weld and specified adjacent base material is accomplished by 0°, 45° and 60° refracted angle coverage from the head outside surface. Angle beam scanning is performed in two directions parallel to the weld and perpendicular to the weld from the dome side. Surface examinations of the radiused or transition section of the head flange outside surface are conducted by a magnetic particle technique.

8.0 DETECTION AND SIZING ASSESSMENT

No quantitative information concerning detection and sizing capabilities of the techniques currently applied during examinations of closure flange junctions has been developed based upon qualification demonstrations, nor are such demonstrations specifically required by existing codes and standards. However, certain salient features of the examinations may be considered to establish that flaws of the type postulated in this analysis which fall within the volumes subject to examination are likely to be detected.

Flaws assumed for this analysis are 0.625 inch deep planar surface flaws with 1:6 aspect ratios. They may be oriented circumferentially or axially with respect to the vessel or head and may lie on the OD or ID surface.

The fact that the postulated flaws are surface related is significant from a detection probability point of view. Incipient cracks starting at right angles to a given surface (OD or ID) provide favorable conditions for detection via ASME Code specified 45° shear wave ultrasonic examinations from the opposite surface. Circumferential flaws are oriented favorably for detection during axial scanning. Axial flaws are oriented favorably for detection during circumferential scans. Circumferentially oriented flaws in the vessel flange weld region also provide favorable conditions for detection during ultrasonic examinations from the flange seal surface. Beam angles selected for these particular scans provide near normal incidence to the anticipated flaw plane thereby enhancing the probability of detection. Application of near surface examination methods in the form of full node 45° or shallow angle techniques significantly increases the probability of detecting flaws at the examination surface, i.e., the vessel inside and the head outside. Finally, the probability of detecting flaws which intersect the OD surface in areas of the vessel head subject to surface examination should be high.

While the qualitative assessment indicates that detection probabilities are reasonably good for flaws postulated in this analysis, certain unknown factors such as clad effects, defect roughness, orientation, and transparency due to high compressive stresses influence the ability to detect and ultimately provide a realistic estimate of the size with current techniques. Defect sizing by ultrasonic methods has been the subject of several recent studies. To date, no single method has been identified which consistently provides precise sizing data. Typically several different methods must be applied and the most conservative results used in any analysis that might be necessary.

The state-of-the-art of reactor vessel examination has improved over the past several years. Enhanced near surface detection capabilities, trends toward lower recording levels, and tip-diffraction sizing methods are examples. Continued emphasis on NDE technique development promises to provide further improvements and more quantitative data concerning detection and sizing accuracies.

9.0 REFERENCES

1. Youngblood, B. J., "Heatup and Cooldown Curves for use in the Comanche Peak Technical Specifications", U.S. Nuclear Regulatory Commission, Washington, D.C., December 9, 1983.
2. Code of Federal Regulations, 10CFR50, Appendix G, "Fracture Toughness Requirements", U.S. Nuclear Regulatory Commission, Washington, D.C., Amended May 17, 1983 (48 Federal Register 24010).
3. WECAN Westinghouse Electric Computer Analysis User's Manual, Westinghouse R&D Center, Pittsburgh, Pennsylvania, September 17, 1979.
4. ASME Boiler and Pressure Vessel Code, Section XI, Division 1 - Appendix A, "Analysis of Flaw Indications", 1983 Edition.
5. ASME Boiler and Pressure Vessel Code, Section III, Division 1 - Appendix G, "Protection Against Nonductile Failure", 1983 Edition.
6. ASME Boiler and Pressure Vessel Code, Section XI, Division 1 - Subsection IWB, "Requirements for Class 1 Components of Light-Water Cooled Power Plants", 1980 Edition.

FIGURE 1

CRITICAL CROSS SECTIONS

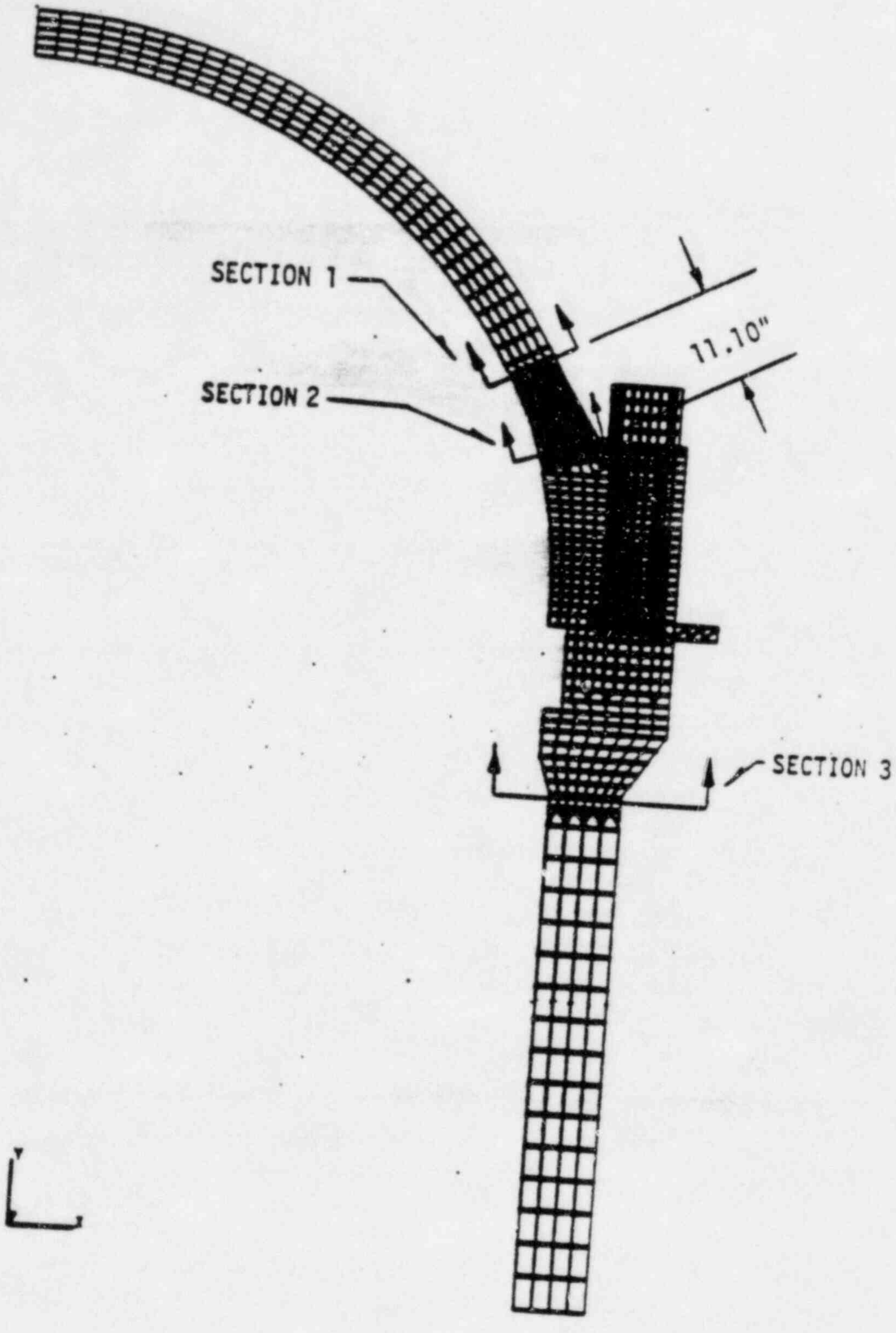


FIGURE 2
MECHANICAL BOUNDARY CONDITIONS

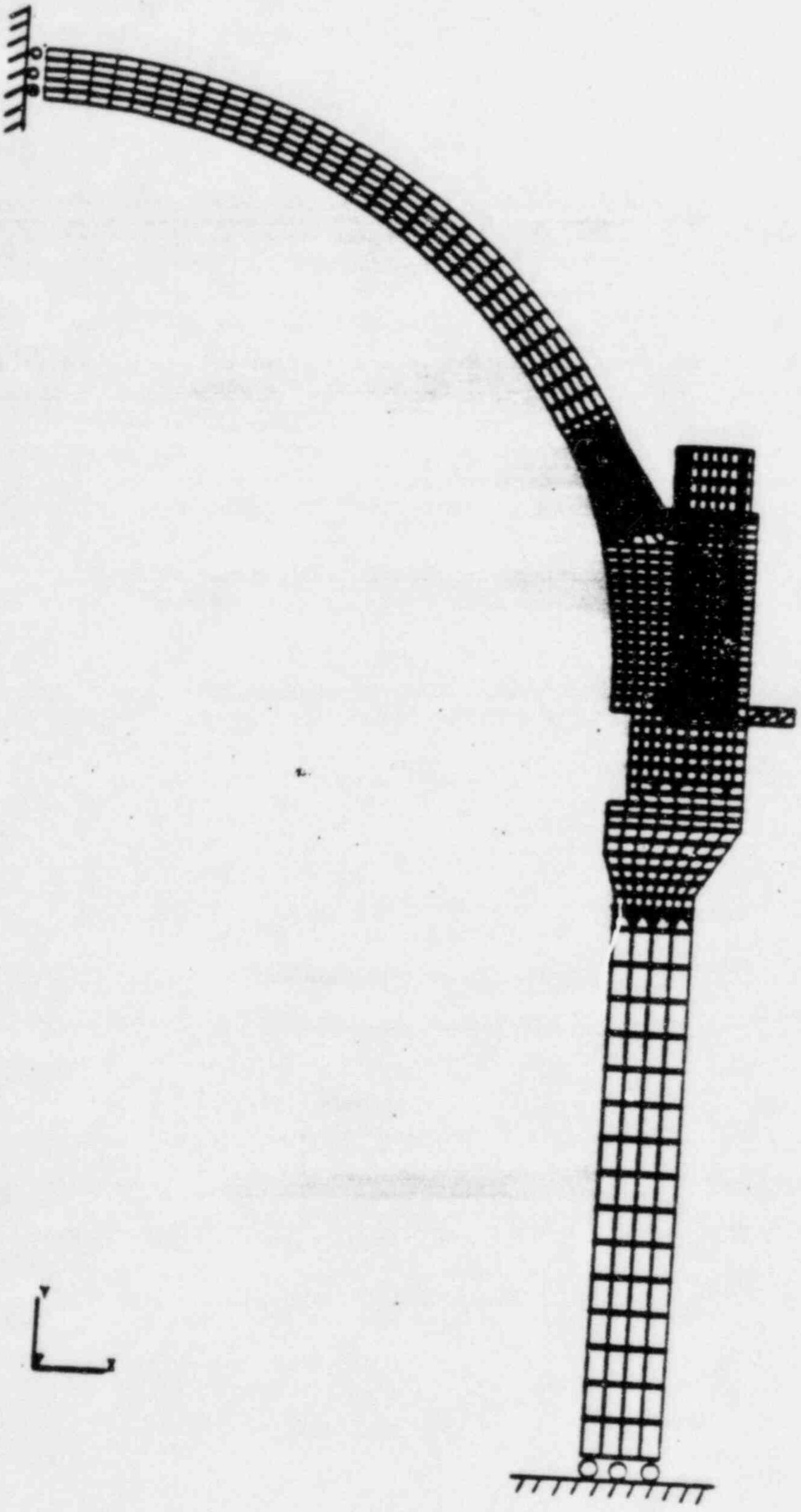
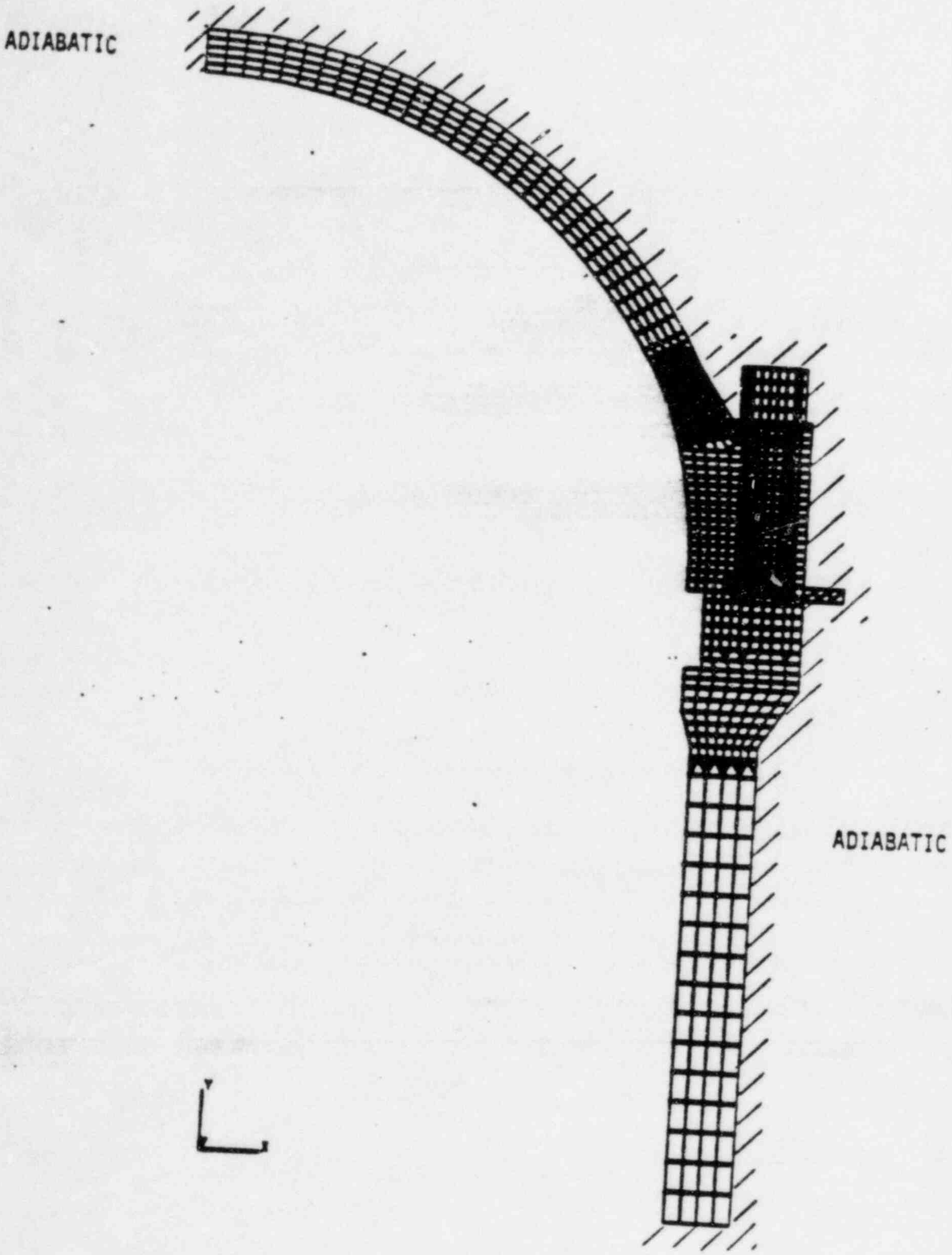


FIGURE 3

THERMAL BOUNDARY CONDITIONS



COPPER CONTENT : CONSERVATIVELY ASSUMED TO BE 0.10 WT%

RT_{NDT} INITIAL : CONSERVATIVELY ASSUMED TO BE 40°F

RT_{NDT} AFTER 16 EFPY : 1/4T, 110°F
3/4T, 87°F

CURVE APPLICABLE FOR HEATUP RATES UP TO 60°F/HR FOR THE SERVICE PERIOD UP TO 16 EFPY AND CONTAINS MARGINS OF 10°F AND 60 PSIG FOR POSSIBLE INSTRUMENT ERRORS

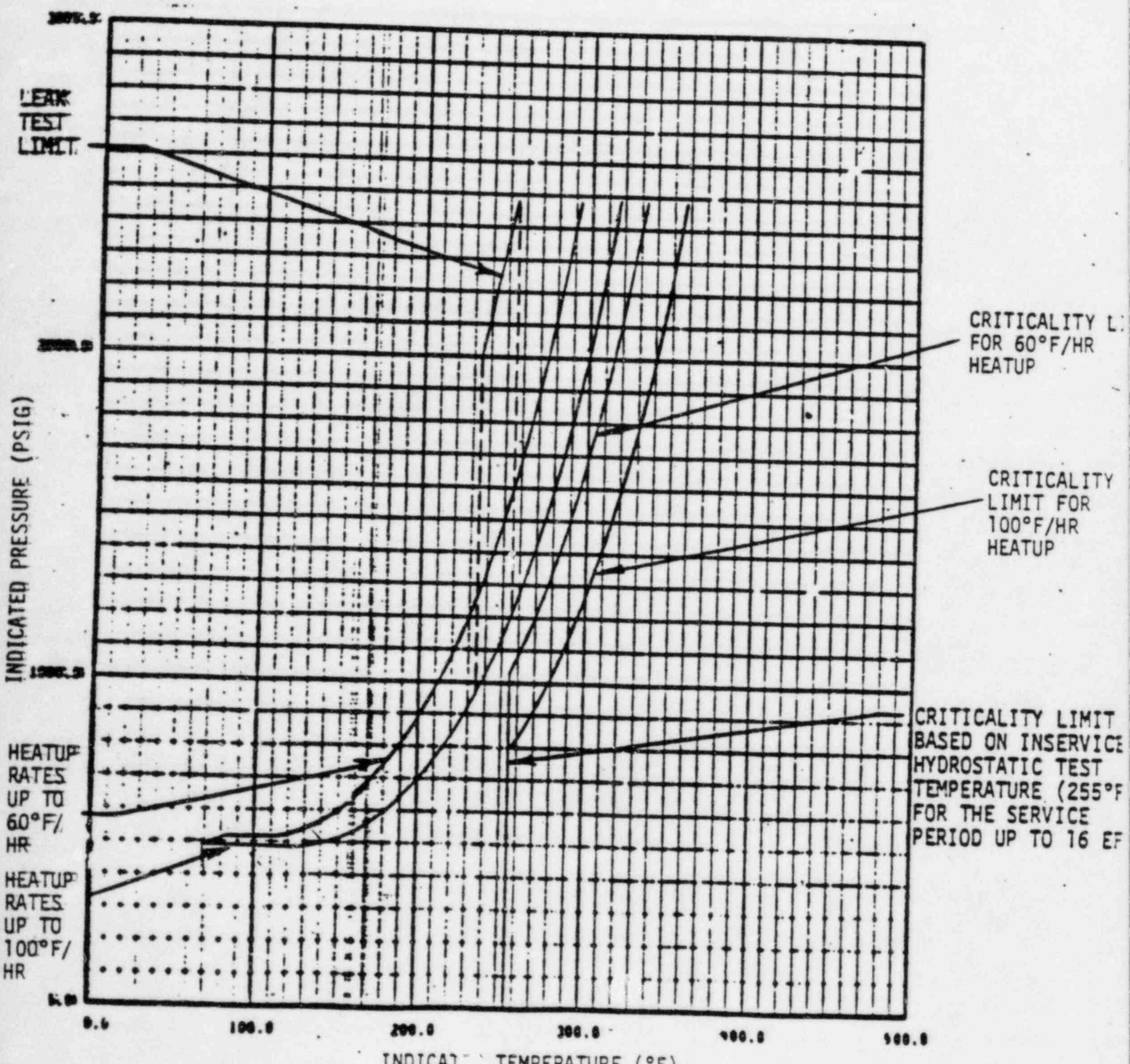


Figure 4 IMPACT OF NEW 10CFR50 RULE (WITHOUT SPECIAL STRESS ANALYSIS) ON COMANCHE PEAK UNITS 1 AND 2 REACTOR COOLANT SYSTEM HEATUP LIMITATIONS APPLICABLE UP TO 16 EFPY

COPPER CONTENT : CONSERVATIVELY ASSUMED TO BE 0.10 WT%

RT_{NDT} INITIAL : CONSERVATIVELY ASSUMED TO BE 40°F

RT_{NDT} AFTER 16 EFPY : 1/4T, 110°F
3/4T, 87°F

CURVE APPLICABLE FOR COOLDOWN RATES UP TO 100°F/HR FOR THE SERVICE PERIOD UP TO 16 EFPY AND CONTAINS MARGINS OF 10°F AND 60 PSIG FOR POSSIBLE INSTRUMENT ERRORS

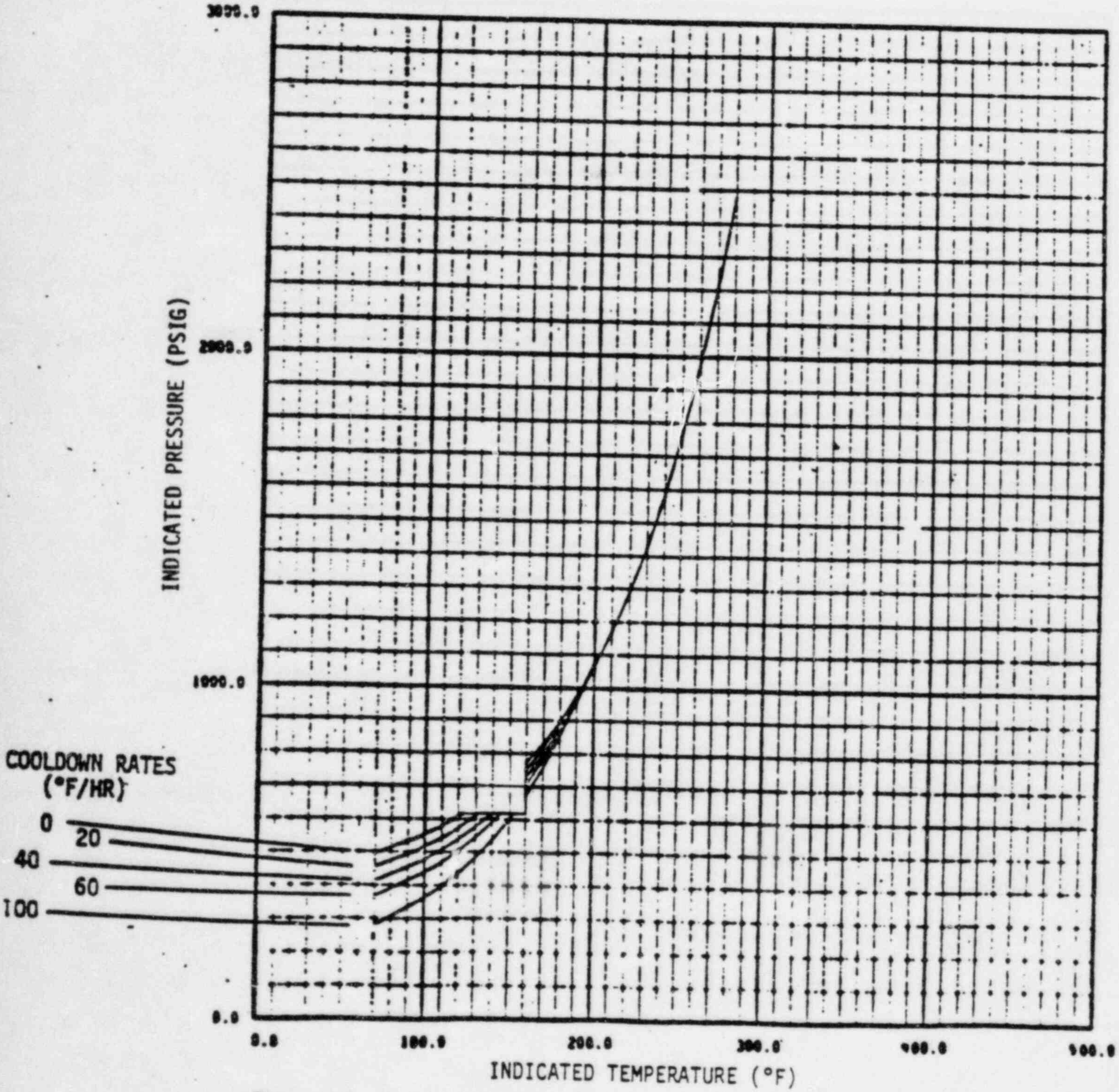


Figure 5 IMPACT OF NEW 10CFR50 RULE (WITHOUT SPECIAL STRESS ANALYSIS) ON COMANCHE PEAK UNITS 1 AND 2 REACTOR COOLANT SYSTEM COOLDOWN LIMITATIONS APPLICABLE UP TO 16 EFPY

COPPER CONTENT : CONSERVATIVELY ASSUMED TO BE 0.10 WT%

RT_{NDT} INITIAL : CONSERVATIVELY ASSUMED TO BE 40°F

RT_{NDT} AFTER 16 EFPY : 1/4T, 110°F
3/4T, 87°F

CURVE APPLICABLE FOR HEATUP RATES UP TO 60°F/HR FOR THE SERVICE PERIOD UP TO 16 EFPY AND CONTAINS MARGINS OF 10°F AND 60 PSIG FOR POSSIBLE INSTRUMENT ERRORS

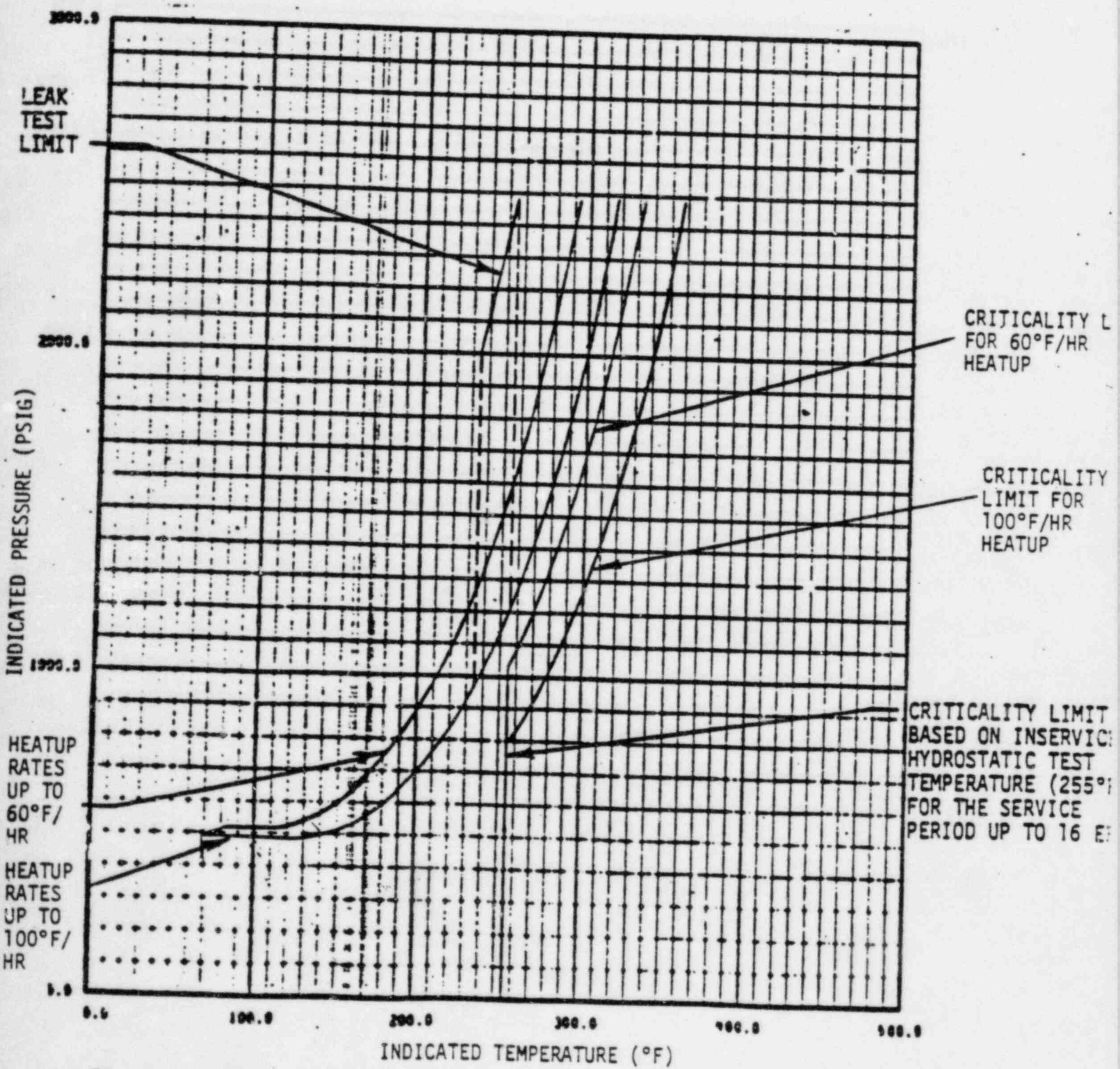


Figure 6 COMANCHE PEAK UNITS 1 AND 2 REACTOR COOLANT SYSTEM HEATUP LIMITATIONS APPLICABLE UP TO 15 EFPY

MATERIAL PROPERTY BASIS

COPPER CONTENT : CONSERVATIVELY ASSUMED TO BE 0.10 WT%

RT_{NDT} INITIAL : CONSERVATIVELY ASSUMED TO BE 40°F

RT_{NDT} AFTER 16 EFPY : 1/4T, 110°F
3/4T, 87°F

CURVE APPLICABLE FOR COOLDOWN RATES UP TO 100°F/HR FOR THE SERVICE PERIOD UP TO 16 EFPY AND CONTAINS MARGINS OF 10°F AND 60 PSIG FOR POSSIBLE INSTRUMENT ERRORS

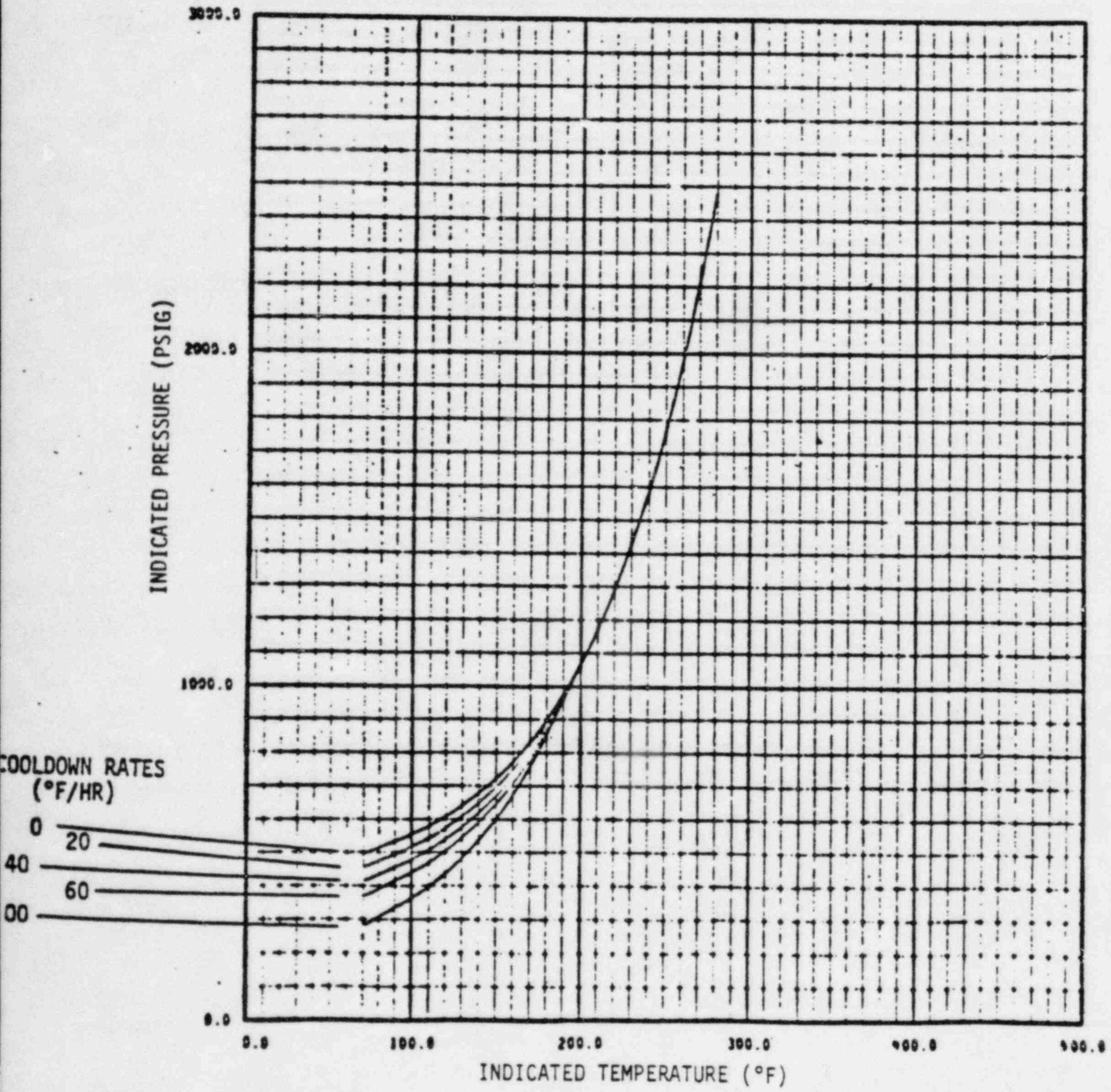


Figure 7 COMANCHE PEAK UNITS 1 AND 2 REACTOR COOLANT SYSTEM COOLDOWN LIMITATIONS APPLICABLE UP TO 16 EFPY

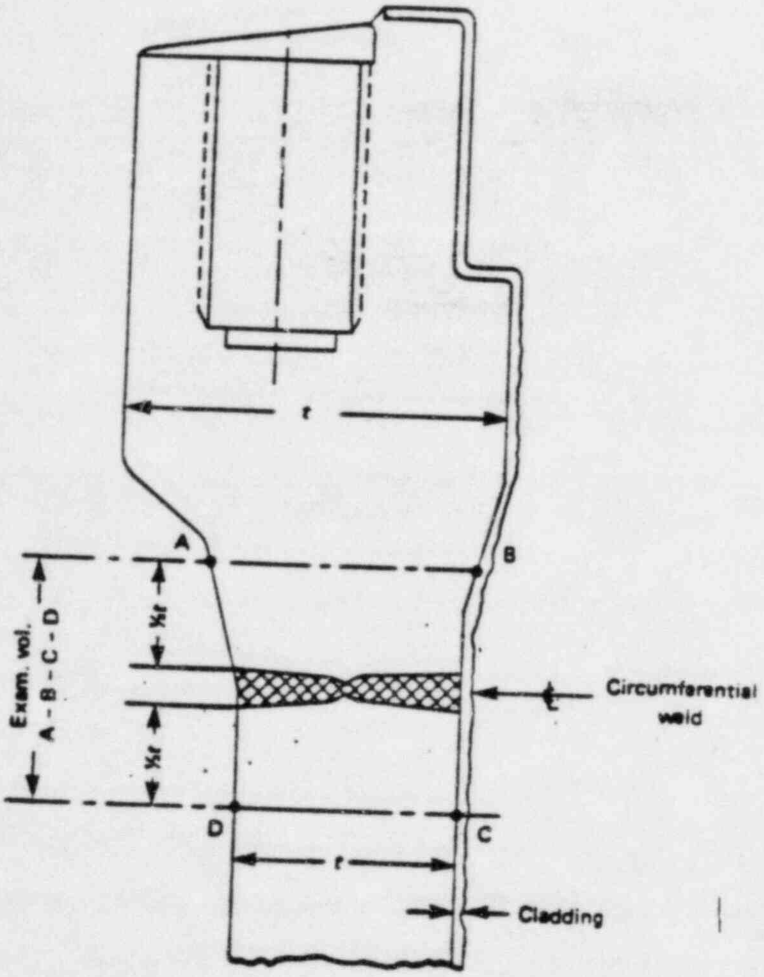


FIGURE 8: SHELL-TO-FLANGE WELD JOINT

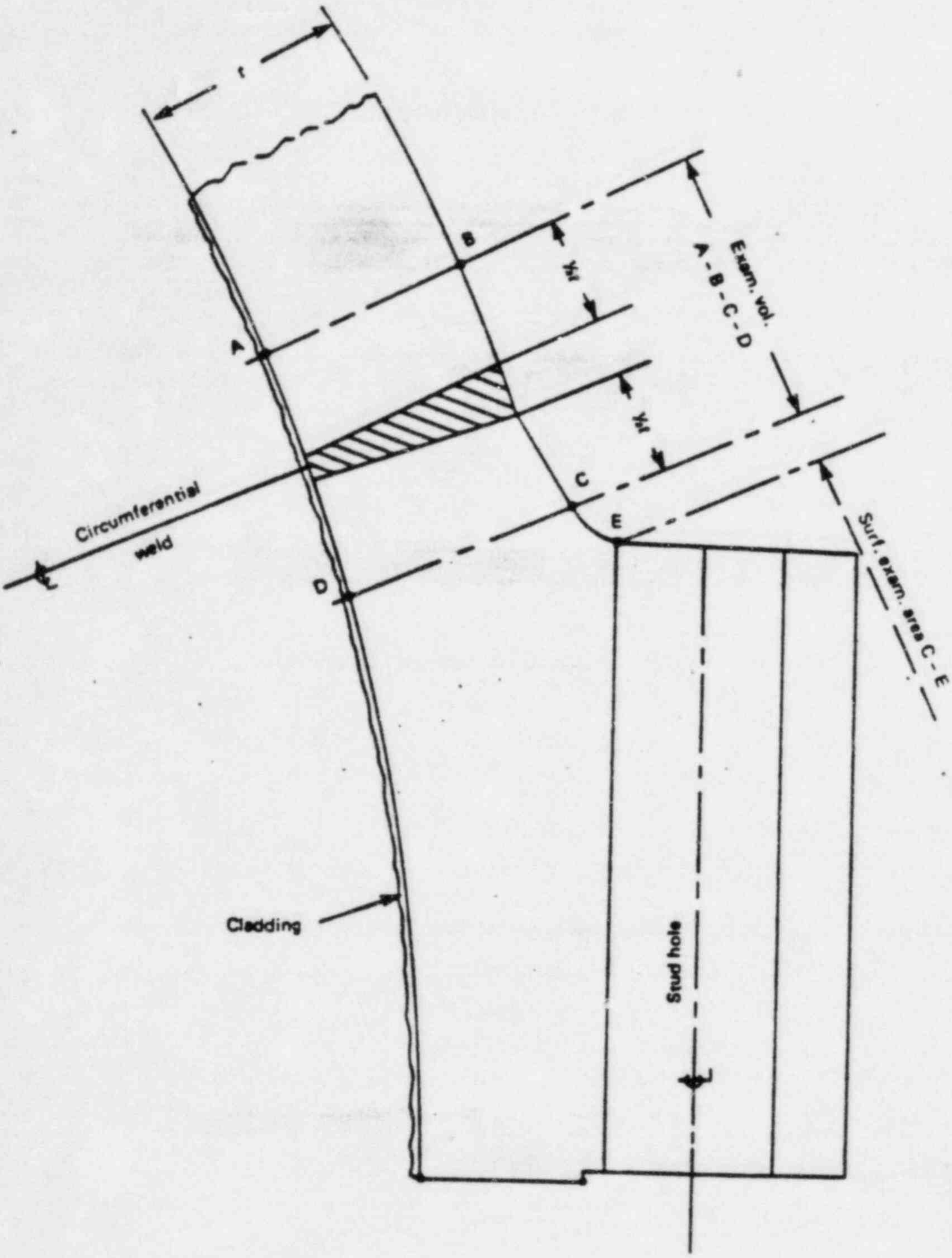


FIGURE 9: HEAD-TO-FLANGE WELD JOINT

TABLE 1

HEATUP TRANSIENT LONGITUDINAL STRESSES FOR CROSS SECTIONS 1, 2 AND 3

Cross Section	Location	Boltup Stress (ksi)	Pressure Stress (ksi)	Thermal Stress (ksi)	Total Stress (ksi)
1	Inside	-8.60	5.48	-12.32	-15.44
1	Outside	0.66	7.41	10.38	18.45
2	Inside	-10.78	4.71	-6.84	-12.91
2	Outside	8.37	2.70	3.34	14.41
3	Inside	-14.24	2.19	-8.96	-21.01
3	Outside	15.61	5.59	3.70	24.90

TABLE 2

HEATUP TRANSIENT CIRCUMFERENTIAL STRESSES FOR CROSS SECTIONS 1, 2 AND 3

Cross Section	Location	Boltup Stress (ksi)	Pressure Stress (ksi)	Thermal Stress (ksi)	Total Stress (ksi)
1	Inside	4.14	4.96	-14.57	-5.47
1	Outside	-5.33	5.29	5.91	5.87
2	Inside	3.74	4.39	-14.14	-6.01
2	Outside	-8.42	3.62	9.48	4.68
3	Inside	0.38	5.58	-15.89	-9.93
3	Outside	1.52	5.89	11.59	19.00

TABLE 3

COOLDOWN TRANSIENT LONGITUDINAL STRESSES FOR CROSS SECTIONS 1, 2 AND 3

Cross Section	Location	Boltup Stress (ksi)	Pressure Stress (ksi)	Thermal Stress (ksi)	Total Stress (ksi)
1	Inside	-8.60	5.48	17.65	14.53
1	Outside	0.66	7.41	-15.66	-7.59
2	Inside	-10.78	4.71	11.13	5.06
2	Outside	8.37	2.70	-3.37	7.70
3	Inside	-14.24	2.19	20.26	8.21
3	Outside	15.61	5.59	-7.79	13.41

TABLE 4

COOLDOWN TRANSIENT CIRCUMFERENTIAL STRESSES FOR CROSSS SECTIONS 1, 2 AND 3

Cross Section	Location	Boltup Stress (ksi)	Pressure Stress (ksi)	Thermal Stress (ksi)	Total Stress (ksi)
1	Inside	4.14	4.96	19.98	29.08
1	Outside	-5.33	5.29	-4.11	-4.15
2	Inside	3.74	4.39	23.40	31.53
2	Outside	-8.42	3.62	-2.61	-7.41
3	Inside	0.38	5.58	25.34	31.30
3	Outside	1.52	5.89	-10.13	-2.72

TABLE 5

HEATUP TRANSIENT STRESS INTENSITY FACTORS (K_I) FOR INSIDE SURFACE CIRCUMFERENTIAL FLAWS

CROSS SECTION	PRIMARY K_I (ksi$\sqrt{in}$)	SECONDARY K_I (ksi$\sqrt{in}$)	TOTAL K_I (ksi$\sqrt{in}$)
1	3.51	0.00	7.02
2	3.48	0.00	6.96
3	6.48	0.00	12.96

TABLE 6

HEATUP TRANSIENT STRESS INTENSITY FACTORS (K_I) FOR OUTSIDE SURFACE CIRCUMFERENTIAL FLAWS

CROSS SECTION	PRIMARY K_I (ksi$\sqrt{in}$)	SECONDARY K_I (ksi$\sqrt{in}$)	TOTAL K_I (ksi$\sqrt{in}$)
1	10.43	14.04	34.90
2	14.16	6.34	34.66
3	27.95	8.17	64.07

TABLE 7

HEATUP TRANSIENT STRESS INTENSITY FACTORS (K_I) FOR INSIDE SURFACE LONGITUDINAL FLAWS

CROSS SECTION	PRIMARY K_I (ksi$\sqrt{in}$)	SECONDARY K_I (ksi$\sqrt{in}$)	TOTAL K_I (ksi$\sqrt{in}$)
1	12.26	0.00	24.52
2	10.63	0.00	21.26
3	9.58	0.00	19.16

TABLE 8

HEATUP TRANSIENT STRESS INTENSITY FACTORS (K_I) FOR OUTSIDE SURFACE LONGITUDINAL FLAWS

CROSS SECTION	PRIMARY K_I (ksi$\sqrt{in}$)	SECONDARY K_I (ksi$\sqrt{in}$)	TOTAL K_I (ksi$\sqrt{in}$)
1	6.37	12.59	25.33
2	2.31	14.65	19.27
3	10.33	17.55	38.21

TABLE 9

COOLDOWN TRANSIENT STRESS INTENSITY FACTORS (K_I) FOR INSIDE SURFACE CIRCUMFERENTIAL FLAWS

CROSS SECTION	PRIMARY K_I $(ksi\sqrt{in})$	SECONDARY K_I $(ksi\sqrt{in})$	TOTAL K_I $(ksi\sqrt{in})$
1	3.51	22.02	29.04
2	3.48	14.40	21.36
3	6.48	26.83	39.79

TABLE 10

COOLDOWN TRANSIENT STRESS INTENSITY FACTORS (K_I) FOR OUTSIDE SURFACE CIRCUMFERENTIAL FLAWS

CROSS SECTION	PRIMARY K_I $(ksi\sqrt{in})$	SECONDARY K_I $(ksi\sqrt{in})$	TOTAL K_I $(ksi\sqrt{in})$
1	10.43	1.40	22.26
2	14.16	5.41	33.73
3	27.95	8.84	64.74

TABLE 11

COOLDOWN TRANSIENT STRESS INTENSITY FACTORS (K_I) FOR INSIDE SURFACE LONGITUDINAL FLAWS

CROSS SECTION	PRIMARY K_I ($ksi\sqrt{in}$)	SECONDARY K_I ($ksi\sqrt{in}$)	TOTAL K_I ($ksi\sqrt{in}$)
1	12.26	26.56	51.08
2	10.63	31.53	52.79
3	9.58	34.04	53.20

TABLE 12

COOLDOWN TRANSIENT STRESS INTENSITY FACTORS (K_I) FOR OUTSIDE SURFACE LONGITUDINAL FLAWS

CROSS SECTION	PRIMARY K_I ($ksi\sqrt{in}$)	SECONDARY K_I ($ksi\sqrt{in}$)	TOTAL K_I ($ksi\sqrt{in}$)
1	6.37	11.15	23.89
2	2.31	14.47	19.09
3	10.33	10.60	31.26

Attachment 3

Farley Unit 2 Proposed
Heat-up and Cooldown Curves

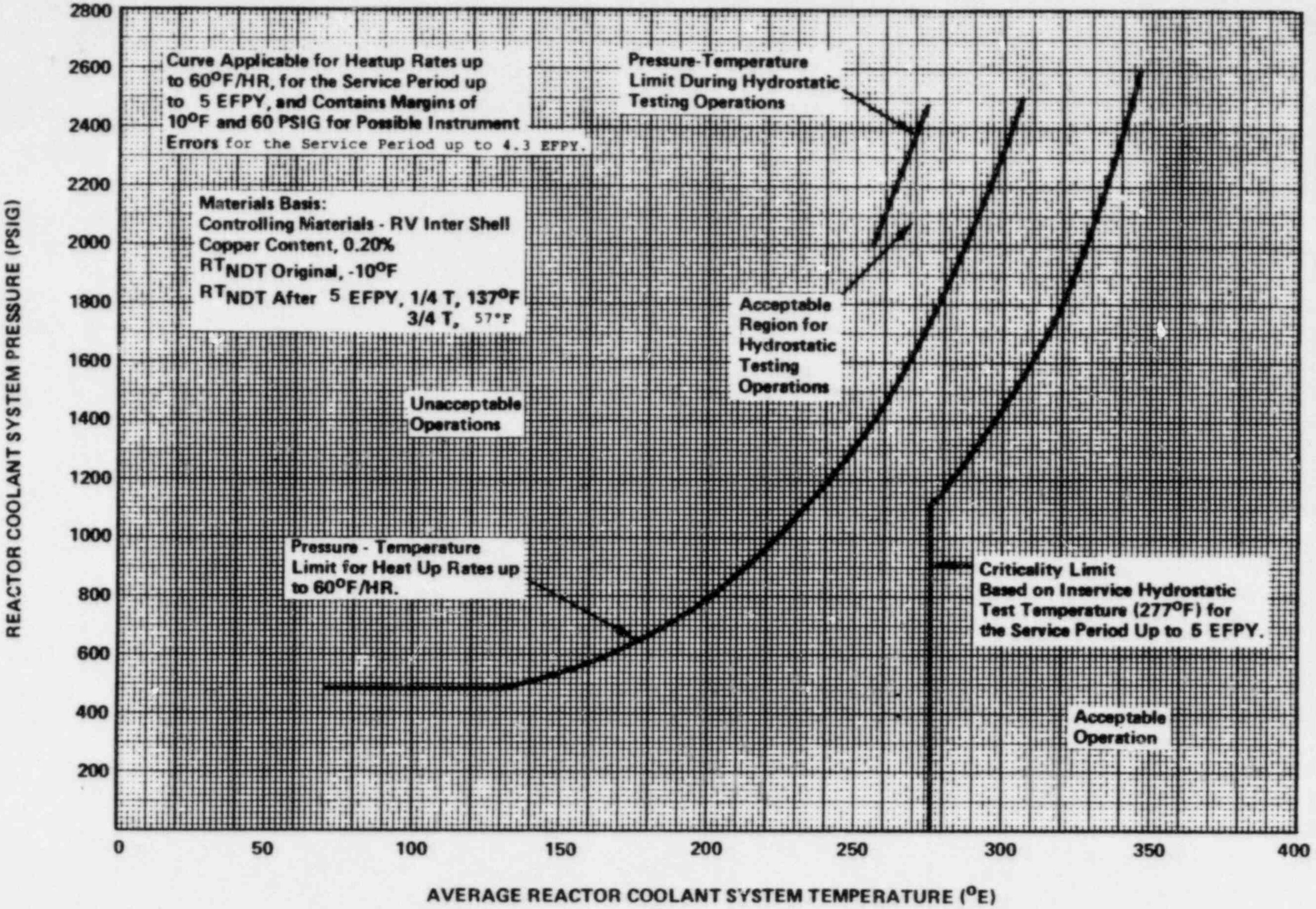


Figure 3.4-2

Reactor Coolant System, Pressure - Temperature Limits Versus 60°F/Hour Heatup Rate
Criticality Limit and Hydrostatic Test Limit

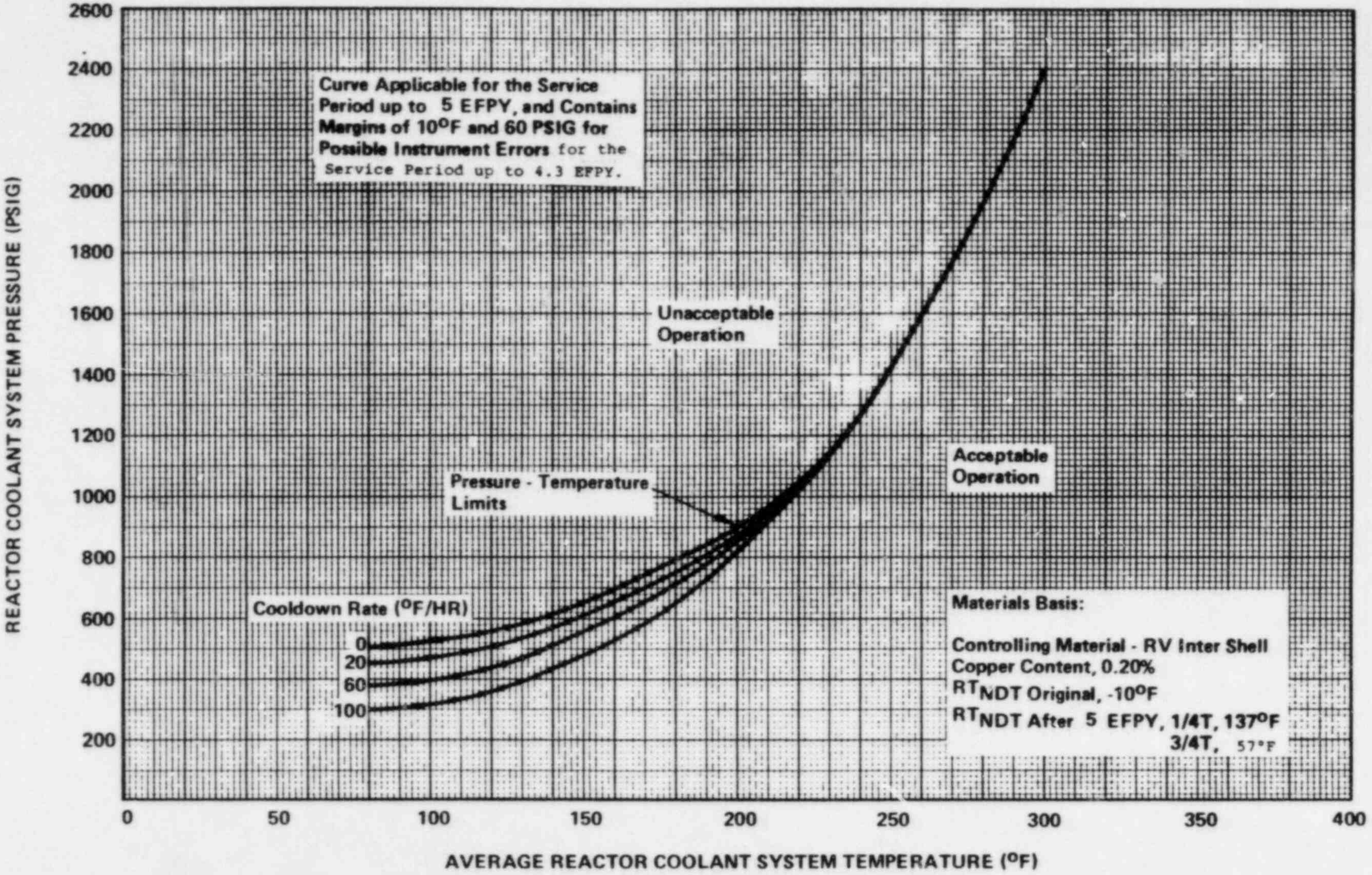


Figure 3.4-3

Reactor Coolant System Pressure - Temperature Limits Versus Cooldown Rates