MT-SMT-093

DEVELOPMENT OF PRESSURE-TEMPERATURE LIMIT CURVES FOR A LOOP ISOLATED FROM THE REACTOR VESSEL: BEAVER VALLEY UNITS 1 AND 2

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1.0 INTRODUCTION

Because the Beaver Valley Units 1 and 2 have loop isolation valves, the possibility exists that a loop may be pressurized, with the reactor vessel not included. In this case, the pressure-temperature limit curves which are contained in the plant technical specification will be extremely conservative, because these curves are based on the most limiting material in the entire primary system, the irradiated beltline region of the reactor vessel which would not be pressurized.

This report has been prepared to provide pressure temperature limit curves which would apply to any of the main coolant loops, in the case where the reactor vessel is not connected to it. It will be shown that the allowable pressure at any given temperature is significantly higher for this case than the pressure allowed by the technical specification heatup and cooldown curves.

This report has been prepared to document the material properties and analysis procedures used to develop these pressure-temperature limit curves.

2.0 ANALYSIS METHODS AND MATERIAL PROPERTIES

In order to develop pressure-temperature limit curves for the loop without the reactor vessel, it is first necessary to determine the most governing location in the loop. The loop is shown schematically in Figure 2-1. Only the ferritic steel portions of the loop need to be considered, which eliminates the piping and leaves the primary side of the steam generator, and the pressurizer as candidates.

A detailed review of these two components resulted in the channel head to tubesheet region of the steam generator being chosen as the governing location. This region is shown in cross section in Figure 2-2.

The next step is to calculate the allowable pressure at each temperature, to provide a complete curve of pressure vs. temperature for the isolated loop. The requirements of Section III, Appendix G of the ASME Code[1] must be followed. The requirement here is to postulate a semi-elliptic surface flaw with aspect ratio (length/depth) equal to 6:1, and show that the total applied stress intensity factor for the postulated flaw (with a factor of safety of 2.0 on the pressure) does not exceed the reference fracture toughness, K_{IR}, at the temperature or concern. To accomplish this calculation, both material properties and stress intensity factor calculation methods must be documented.

2.1 STRESS INTENSITY FACTOR DETERMINATION

The stress intensity factor K_I for this case can be calculated using the actual stress profile through the wall. The stress distribution through the wall thickness is represented by a third order polynomial:

$$\sigma = \sum_{j=0}^{3} A_j x^j$$

The stress intensity factors for various aspect ratios, a/c, (a: semi-minor axis, c: semi-major axis), for various locations along the crack front (ϕ), for inside and outside surface flaws of a cylinder, and for various ratios of thickness to inside radius, t/R were obtained by Raju and Newman (Reference 2). Magnification factors for various locations can be obtained by using an interpolation or extrapolation method. Stress intensity factors can be expressed by the general form:

$$K_I = \left[\frac{\pi a}{Q}\right]^{0.5} \sum_{j=0}^{3} G_j\,(a/c,\ a/t,\ t/R,\ \phi)\ A_j\ a^j$$

where a/c: Aspect Ratio

a/t: Ratio of crack depth to thickness of a cylinder

t/R: Ratio of thickness to inside radius

ϕ: Crack front location

$$Q^{1/2} = \int_0^{\pi/2} \left(\cos^2\phi + \frac{a^2}{c^2}\sin^2\phi\right)^{1/2} d\phi$$

2.2 FRACTURE TOUGHNESS

The fracture toughness for ferritic steels has been taken directly from the reference curves of Appendix G, Section III (Reference 1) as reproduced here in Figure 2-3. In the transition temperature region, these curves can be represented by the following equation:

$$K_{IR} = -\,26.8 + 1.233 \exp\,[0.0145\,(T - RT_{NDT} + 160°F)]$$

where K_{IR} is in ksi$\sqrt{\text{in}}$.

The fracture toughness of steam generator materials has been examined in recent years relative to the reference toughness curves of the ASME code. Dynamic fracture toughness tests were conducted on base metal, weldments, and heat-affected zones, and were all found to be bounded by the ASME K_{IR}

curve. Behavior was found to be very similar to that of the reactor vessel steels and weldments for which the K_{IR} curve was developed. Thus, even though the minimum specified yield strength of these materials can be in excess of the 50 ksi value specified for the ASME reference K_{IR} curve, these results show that these materials should also be covered. Further discussion and details are found in References 3-6.

The value of K_{IR} to be used in the analysis is developed from the relationship of the service temperature with RT_{NDT}, which is a parameter determined from Charpy V-notch and drop weight tests. The Beaver Valley Steam Generators were purchased to an RT_{NDT} value of 60°F. This value applies throughout the operating life of the plant, because regions other than the reactor vessel are not irradiated.

2.3 CALCULATION OF PRESSURE-TEMPERATURE CURVES

The allowable pressure at a given temperature was determined by first calculating the fracture toughness at that temperature, using the expression of Section 2.2.

Next the stress intensity factor as a function of pressure was determined for a postulated flaw in the tubesheet to channel head junction region, using the stress distribution determined from detailed finite element analysis of the region, and the stress intensity factor expression of Section 2.3. The axial stress distribution through the cross section is given in Table 2-1. The axial stresses are much higher than the circumferential stresses in this region, and thus will govern the determination of the curves. The only loading considered in the isolated loop is pressure, because the likelihood of significant thermal transients in the isolated loop is small.

The stress intensity factor was determined for a postulated flaw depth of 1.0 inch, and length equal to 6.0 inches. This flaw is slightly smaller than the one-quarter thickness flaw required by Section III, Appendix G, for areas remote from discontinuities, but this region is clearly a discontinuity region. Smaller reference flaws may be used in discontinuity regions,

provided it can be assured that such flaws can be found by inservice inspection methods. A flaw one inch deep and six inches long would clearly be detectable by inservice inspection methods, so its use is justified.

Once the stress intensity factor was calculated for a given pressure, a factor of two was added, so that the following relationship was satisfied, in accordance with the ASME Code requirements of Section III, Appendix G.

$$2K_I < K_{IR}$$

This procedure was repeated at a series of temperatures, and the resulting curve is shown in Figure 2-4.

TABLE 2-1

STRESS DISTRIBUTION FOR A PRESSURE OF 1000 PSI
IN THE TUBESHEET TO CHANNEL HEAD REGION:
BEAVER VALLEY UNITS 1 AND 2

Location (measured from inside surface)	Axial Stress
0.0	21.61
0.17	20.70
0.33	19.57
0.96	15.50
1.58	11.99
2.21	7.75
2.84	4.01
3.38	0.90
3.93	-2.14
4.47	-8.43
5.02	

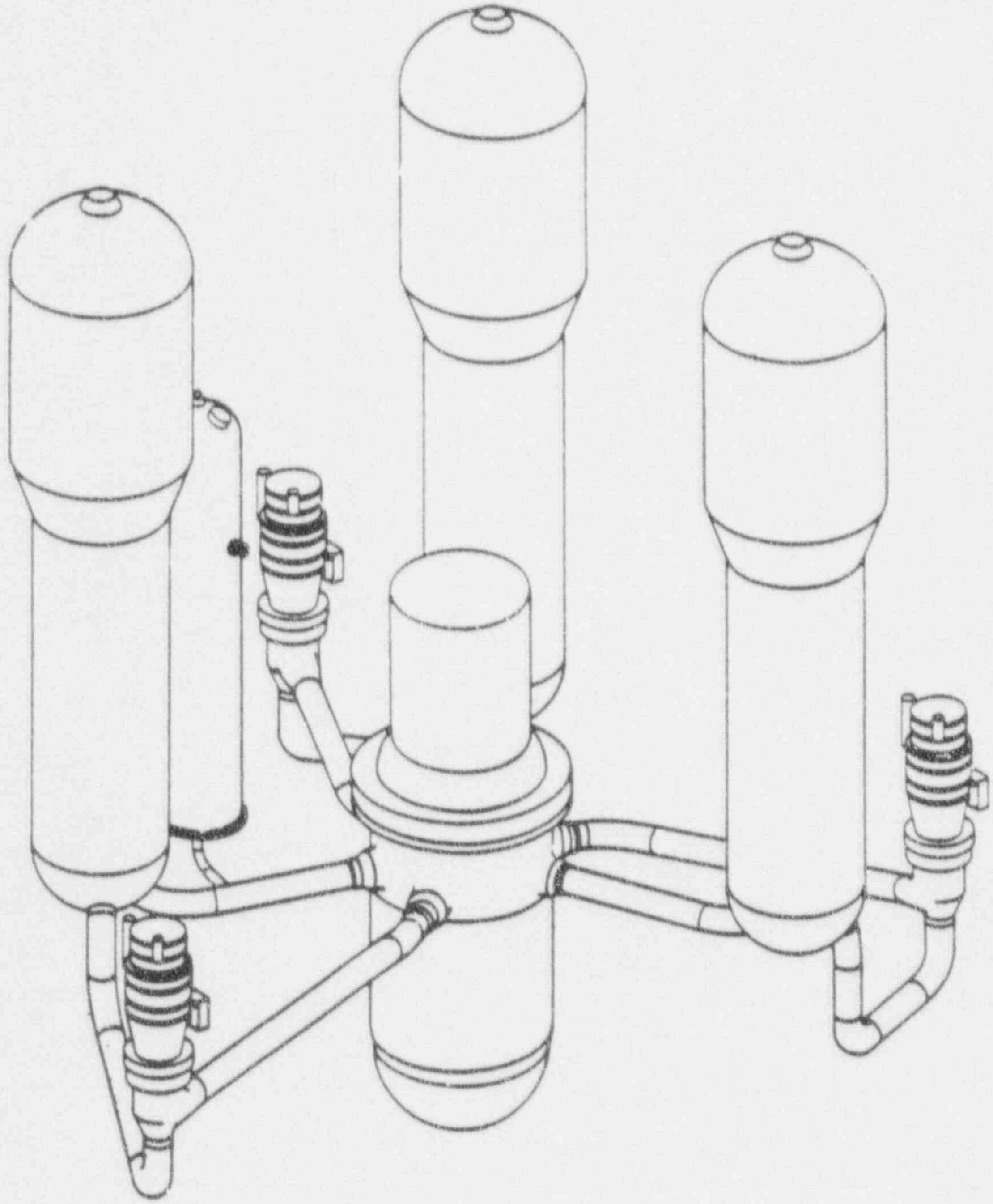

FIGURE 2-1

SCHEMATIC OF BEAVER VALLEY PRIMARY LOOP

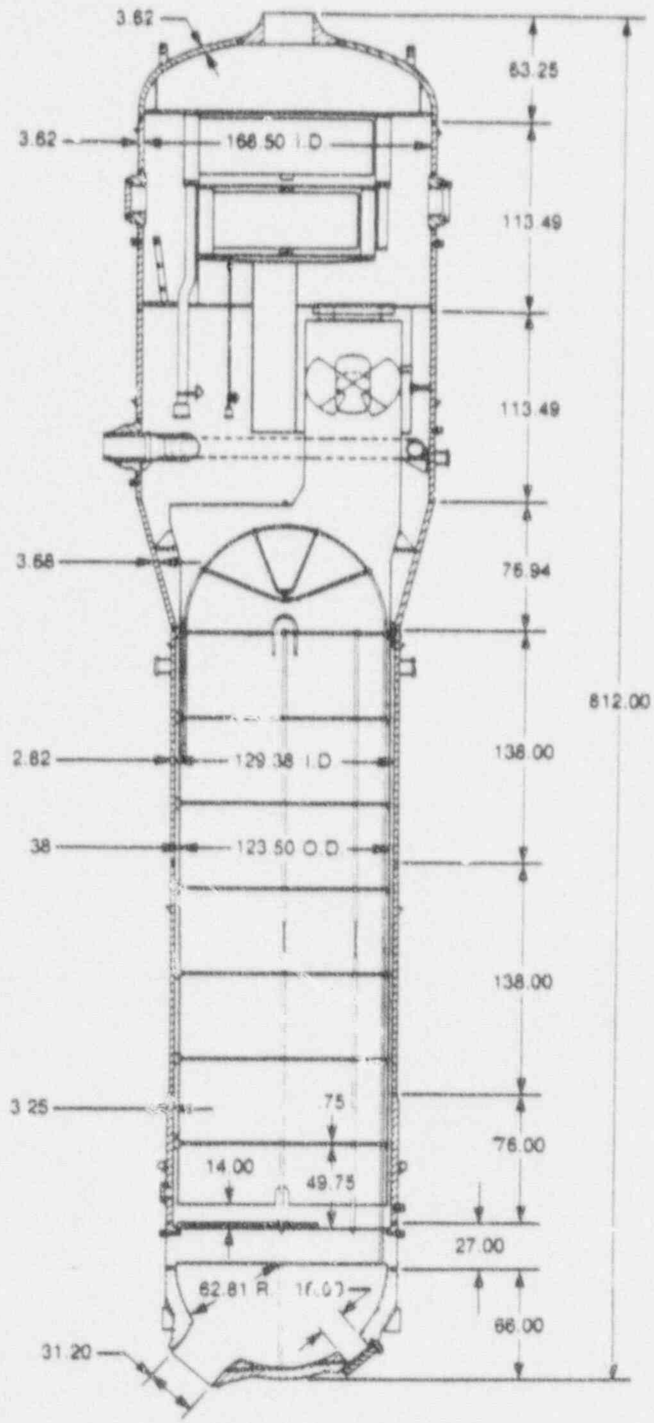

FIGURE 2-2

CROSS SECTIONAL VIEW OF THE BEAVER VALLEY STEAM GENERATORS

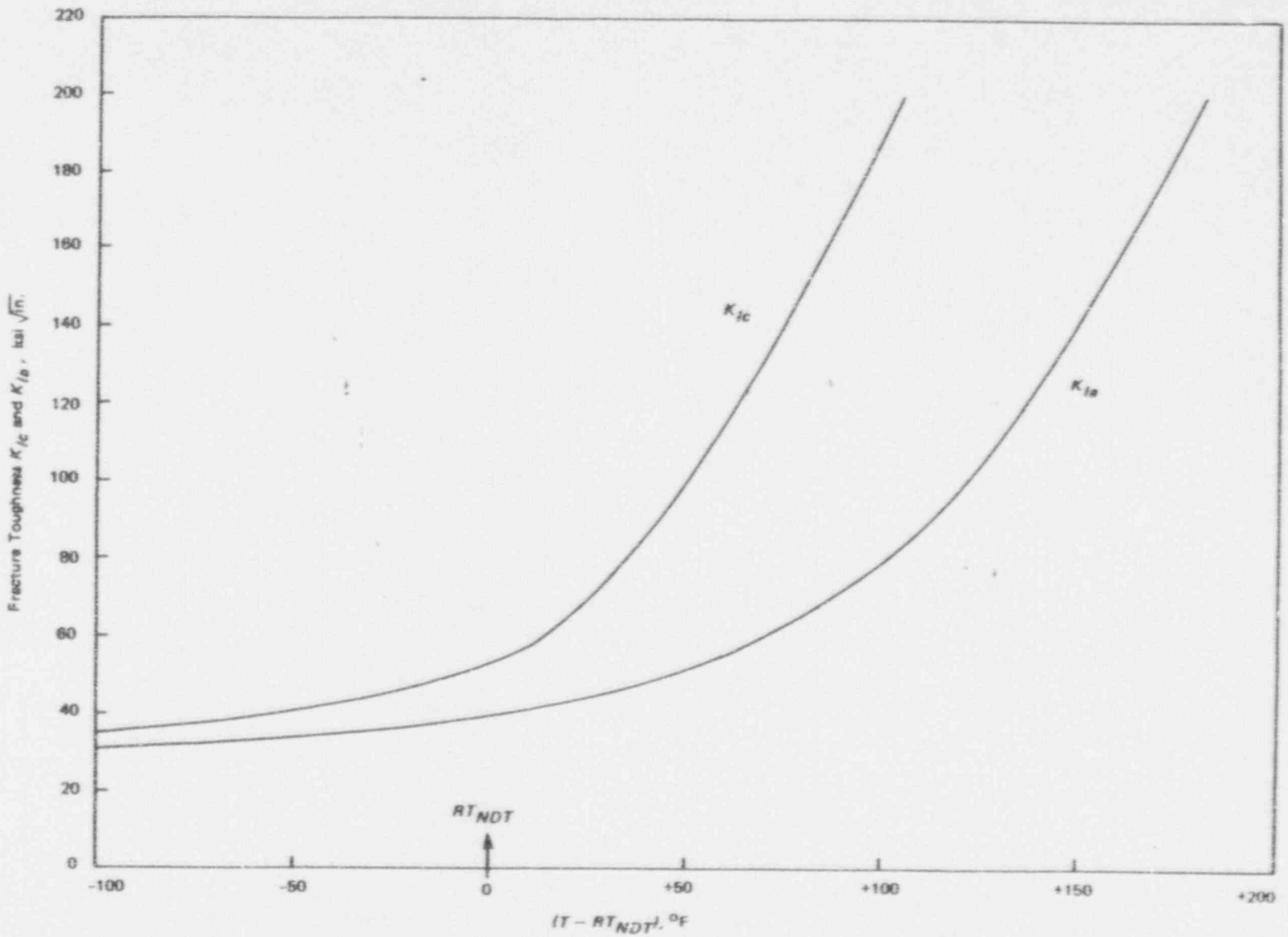

FIGURE 2-3

ASME SECTION III, APPENDIX G REFERENCE TOUGHNESS CURVE

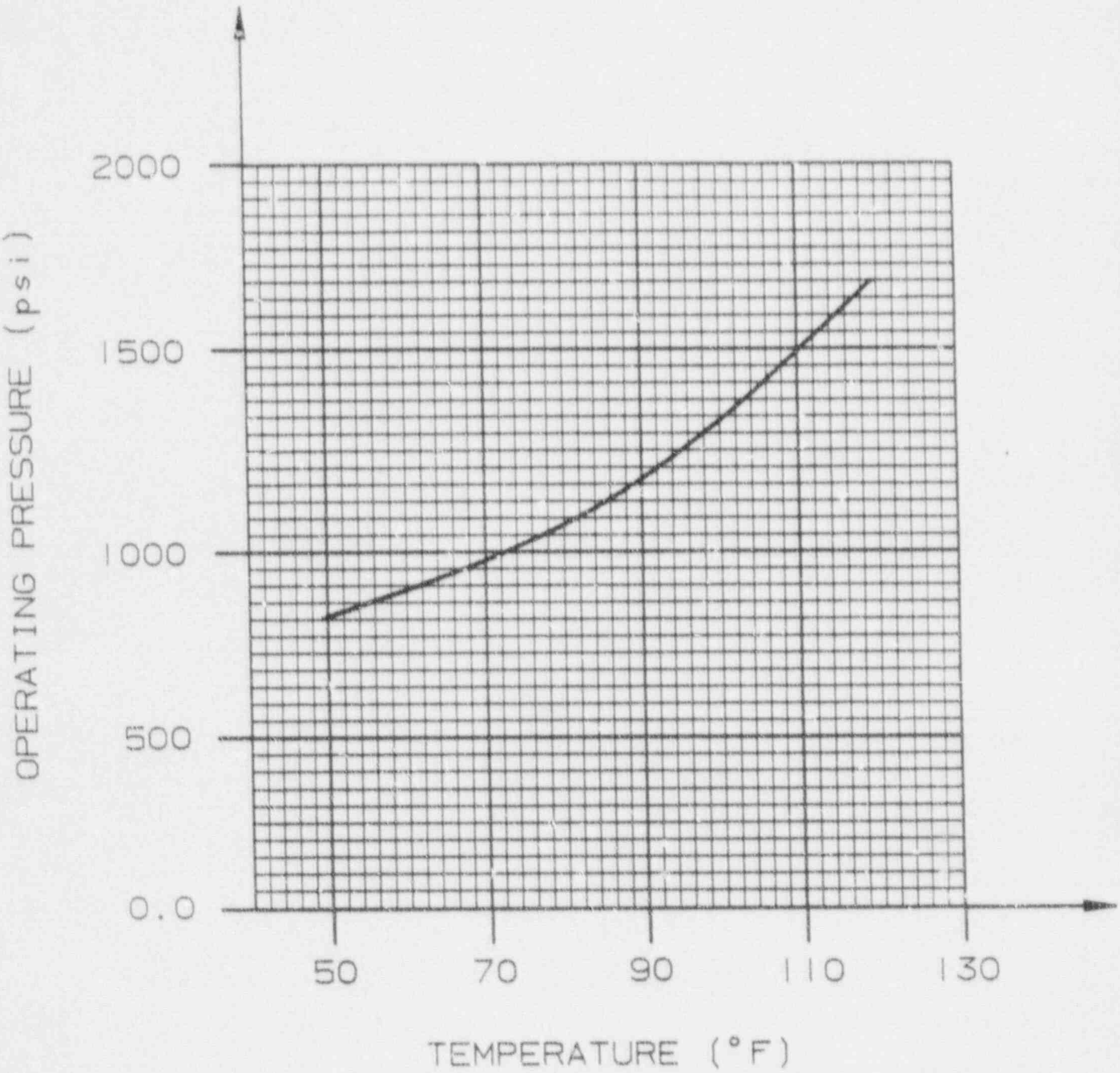

FIGURE 2-4

ALLOWABLE PRESSURE-TEMPERATURE CURVE FOR
AN ISOLATED LOOP - BEAVER VALLEY UNITS 1 AND 2

3.0 SUMMARY AND DISCUSSION

A pressure-temperature limit curve has been developed for the case of an isolated loop for the Beaver Valley Units 1 and 2 and is shown in Figure 3-1. The technical specification limit curves from heatup and cooldown are shown for comparison in Figures 3-2 and 3-3 for Beaver Valley Unit 1, and in Figures 3-4 and 3-5 for Unit 2.

It is clear from comparing the isolated loop pressure-temperature curves with the technical specification curves that the isolated loop curves developed here allow much higher pressures at a given temperature. For example, at room temperature the allowable pressure for the isolated lop is more than double the allowable pressure from the technical specification.

Also shown in Figure 3-1 are curves developed using a safety factor of 1.0, and 1.5 on the pressure. In this figure it can be seen that the allowable pressure with the safety factor = 2.0 is nearly 1000 psi at room temperature, and much higher with the smaller safety factor. Actual failure pressure at room temperature is in excess of 2000 psi, when account is taken of the lower bound fractu.e toughness and the large postulated flaw used for the development of the isolated loop curve.

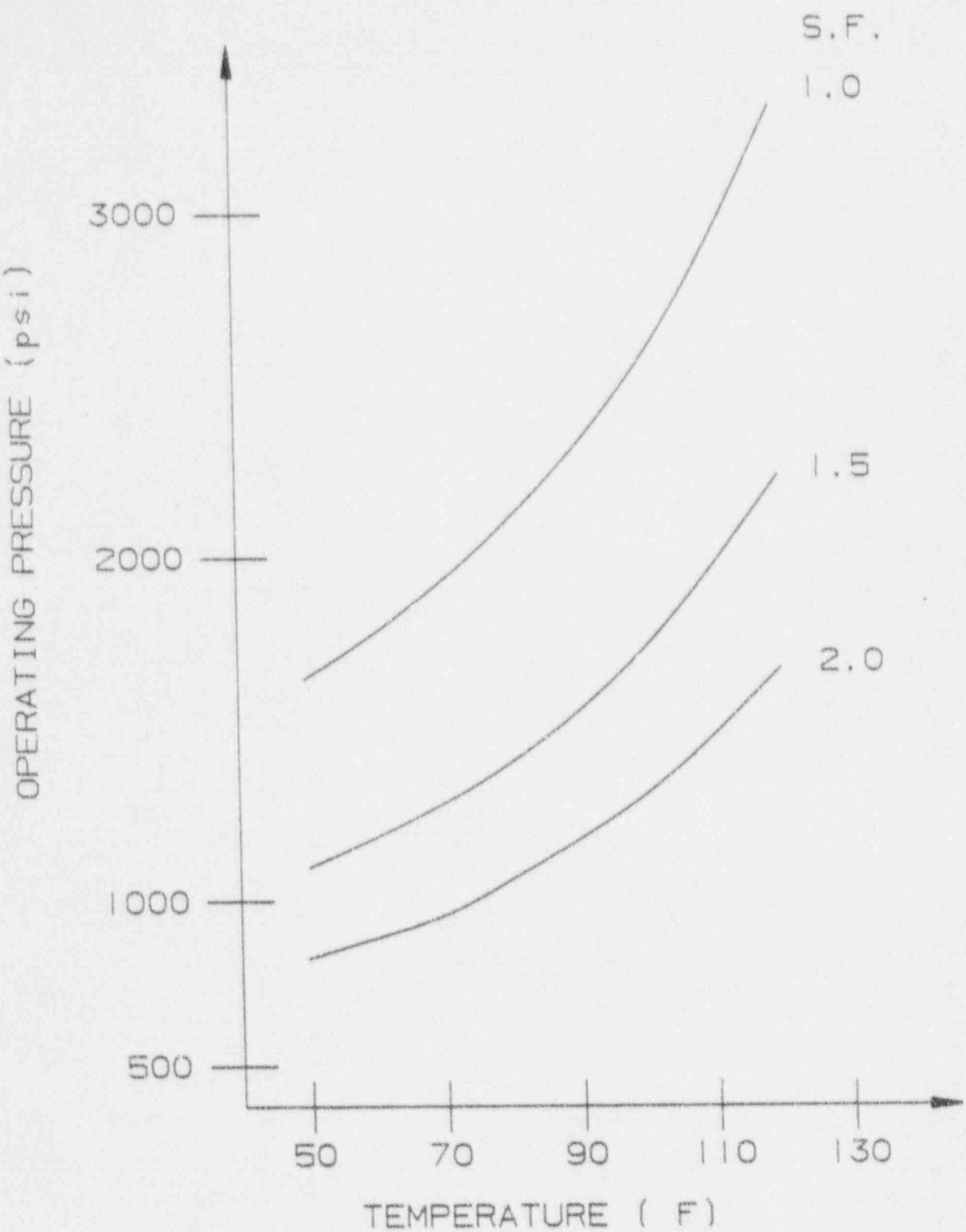

FIGURE 3-1

PRESSURE-TEMPERATURE LIMIT CURVES FOR AN ISOLATED LOOP
BEAVER VALLEY UNITS 1 AND 2, SHOWN WITH CURVES
INCORPORATING LOWER SAFETY FACTORS FOR COMPARISON

MATERIAL PROPERTY BASIS

CONTROLLING MATERIAL: WELD METAL
COPPER CONTENT: 0.31 WT%
PHOSPHORUS CONTENT: 0.015 WT%
RT_{NDT} INITIAL: 0°F
RT_{NDT} AFTER 9.5 EFPY: 1/4T, 274°F
: 3/4T, 137°F

CURVE APPLICABLE FOR HEATUP RATES UP TO 60°F/HR FOR THE SERVICE PERIOD UP TO 9.5 EFPY AND CONTAINS MARGINS OF 28°F AND 71 PSIG FOR POSSIBLE INSTRUMENT ERRORS

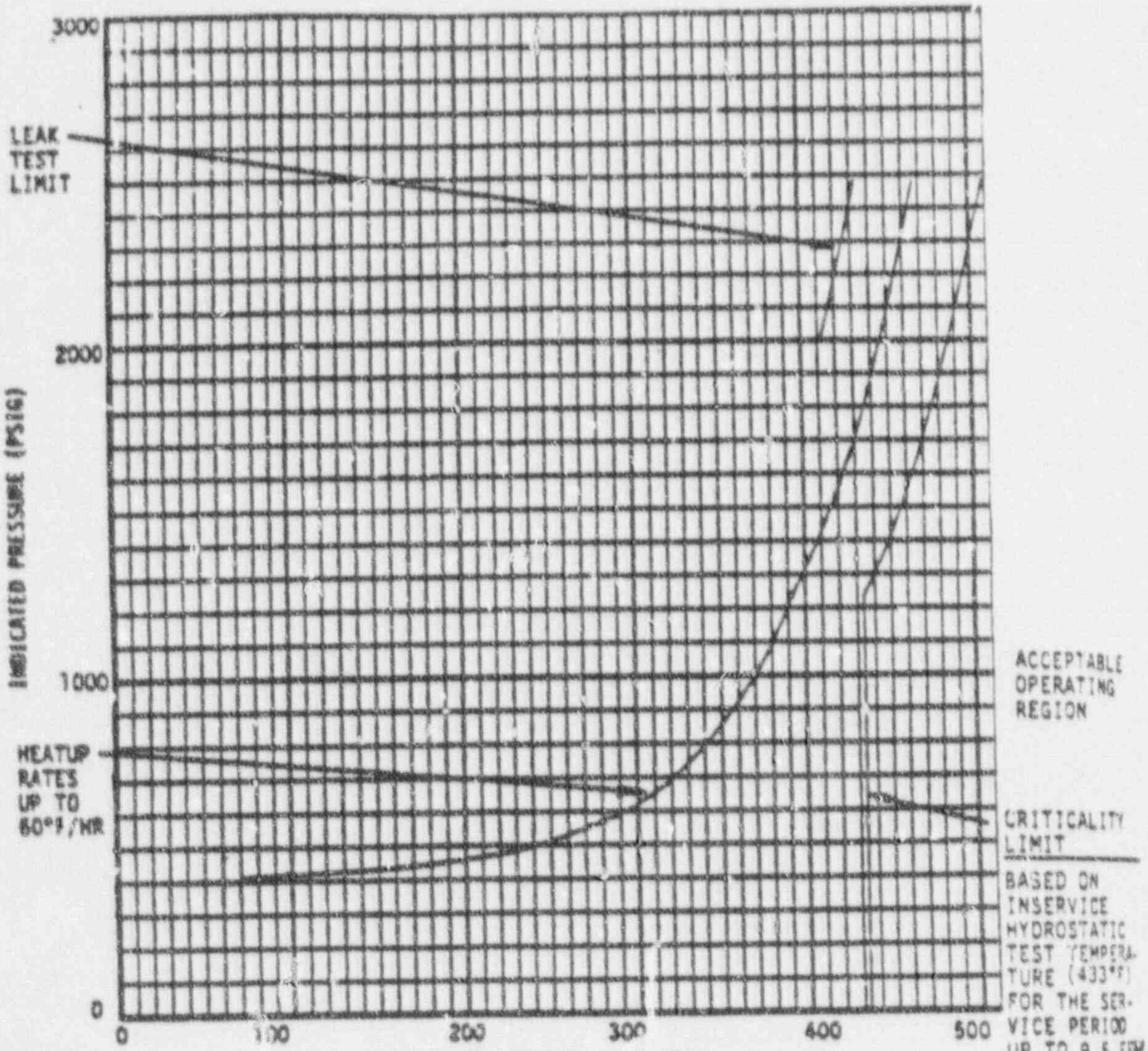

FIGURE 3-2

TECHNICAL SPECIFICATION HEATUP LIMITS FOR BEAVER VALLEY UNIT 1

MATERIAL PROPERTY BASIS

CONTROLLING MATERIAL: WELD METAL
COPPER CONTENT: 0.31 WT%
PHOSPHORUS CONTENT: 0.015 WT%
RT_{NDT} INITIAL: 0°F
RT_{NDT} AFTER 9.5 EFPY: 1/4T, 274°F
3/4T, 137°F

CURVE APPLICABLE FOR COOLDOWN RATES UP TO 100°F/HR FOR THE SERVICE PERIOD UP TO 9.5 EFPY AND CONTAINS MARGINS OF 28°F AND 71 PSIG FOR POSSIBLE INSTRUMENT ERRORS

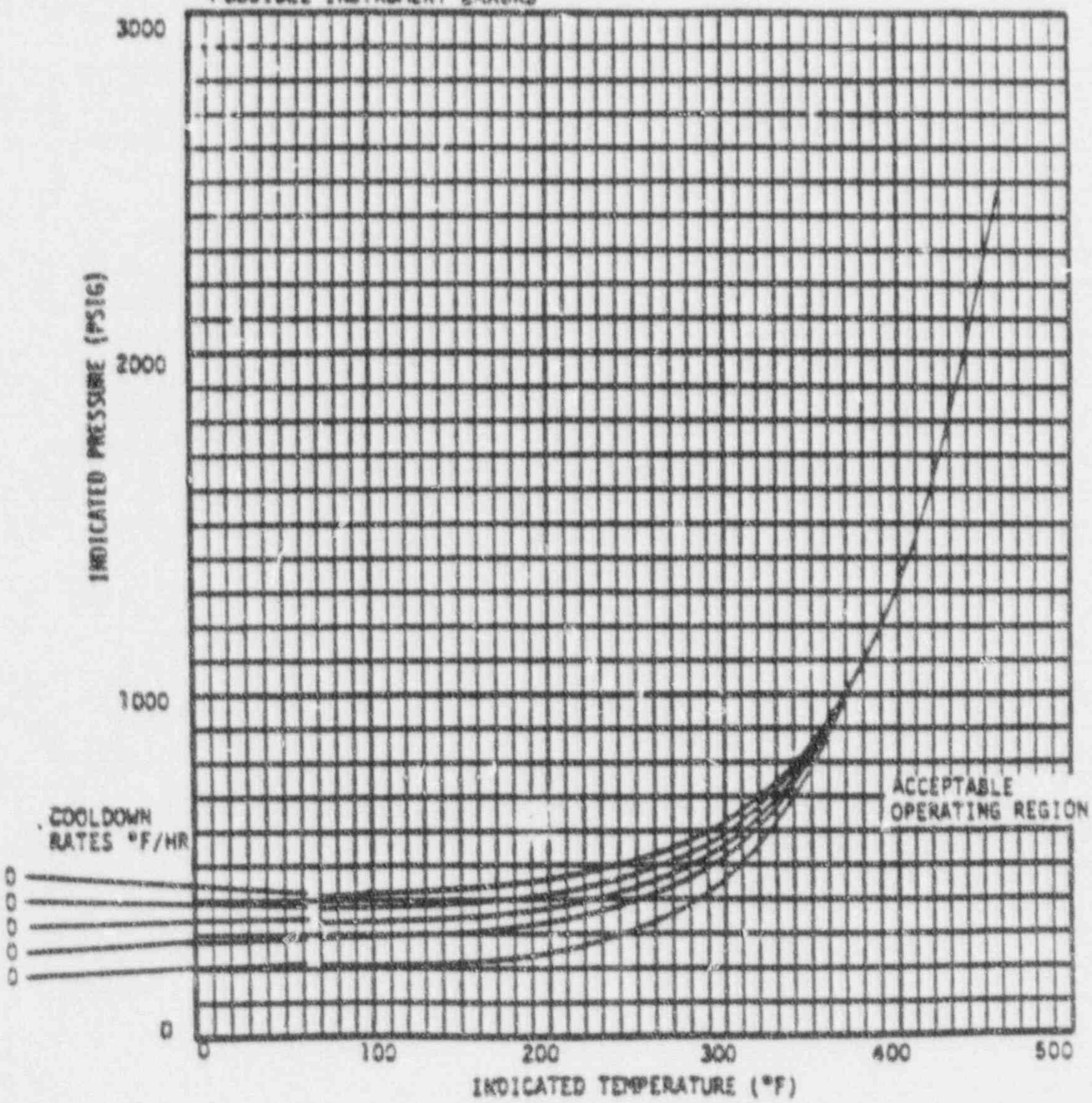

FIGURE 3-3

TECHNICAL SPECIFICATION COOLDOWN LIMITS FOR BEAVER VALLEY UNIT 1

MATERIAL PROPERTY BASIS

CONTROLLING MATERIAL : PLATE METAL
COPPER CONTENT : CONSERVATIVELY ASSUMED TO BE 0.10 WT%
PHOSPHORUS CONTENT : 0.010 WT%
RT_{NDT} INITIAL : 60°F
RT_{NDT} AFTER 10 EFPY : 1/4T, 139°F
3/4T, 114°F

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

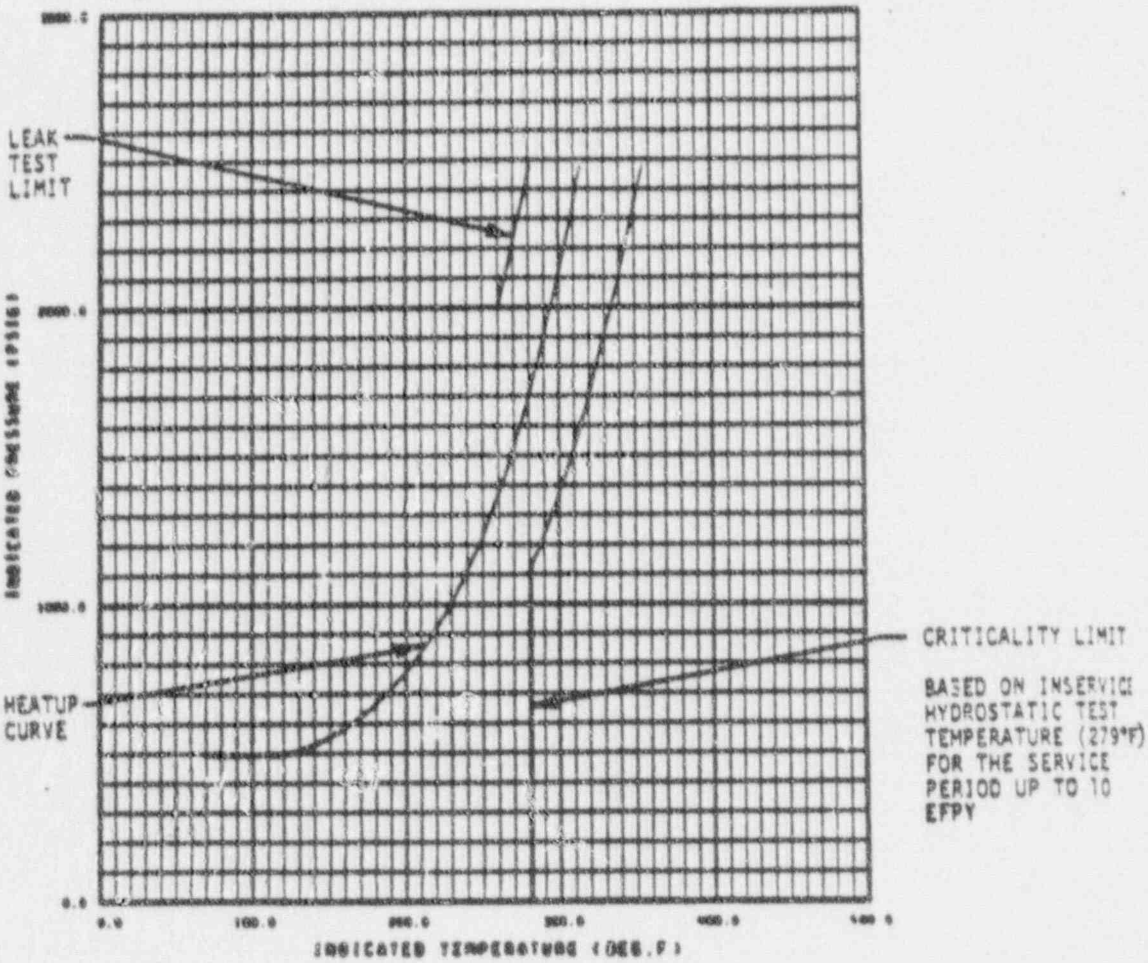

FIGURE 3-4

TECHNICAL SPECIFICATION HEATUP LIMITS FOR BEAVER VALLEY UNIT 2

MATERIAL PROPERTY BASIS

CONTROLLING MATERIAL	:	PLATE METAL
COPPER CONTENT	:	CONSERVATIVELY ASSUMED TO BE 0.10 WT%
PHOSPHORUS CONTENT	:	0.010 WT%
RT_{NDT} INITIAL	:	60°F
RT_{NDT} AFTER 10 EFPY	:	1/4T, 139°F 3/4T, 114°F

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

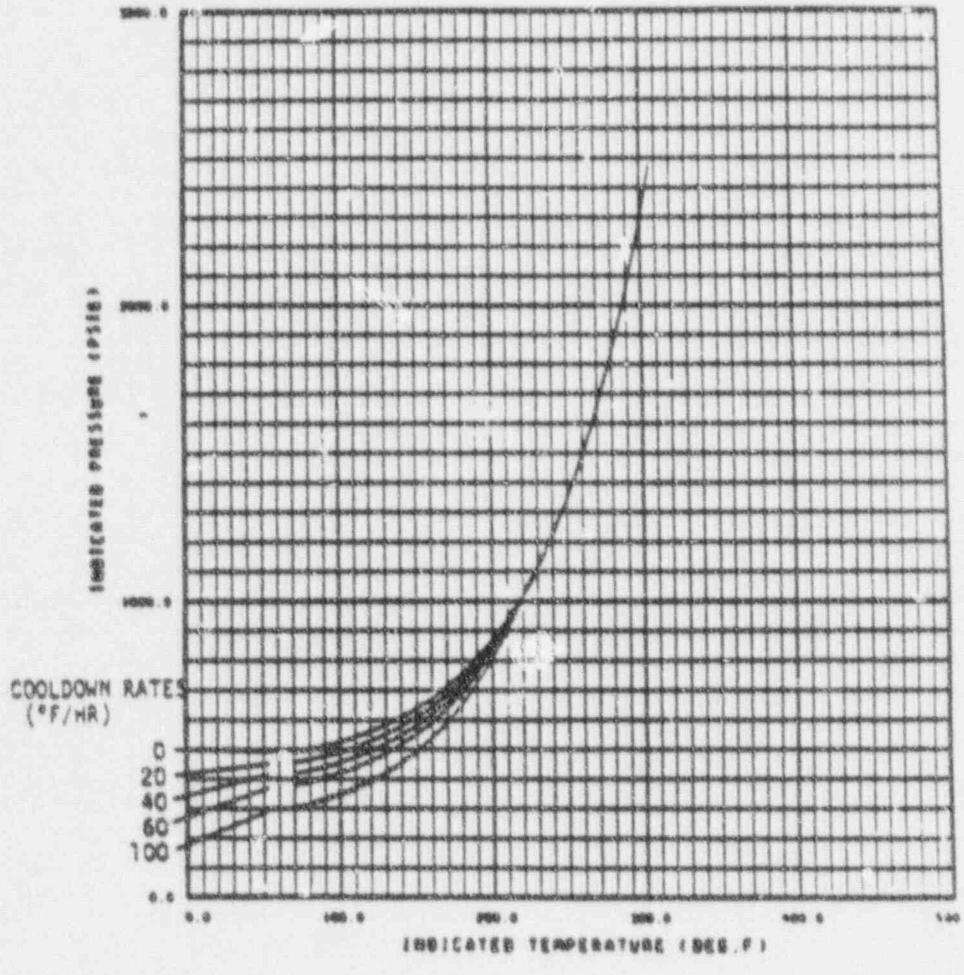

FIGURE 3-5

TECHNICAL SPECIFICATION COOLDOWN LIMITS FOR BEAVER VALLEY UNIT 2

4.0 REFERENCES

1. ASME Code Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," 1989 Edition.

2. Newman, J. C. Jr. and Raju, I. S., "Stress Intensity Factors for Internal Surface Cracks in Cylindrical Pressure Vessels," ASME Trans., Journal of Pressure Vessel Technology, Vol. 102, 1980, pp. 342-346.

3. Logsdon, W. A., "Dynamic Fracture Toughness of ASME SA508 C2a Base and Heat-Affected Zone Material," in Elastic-Plastic Fracture, ASTM STP 668, 1979.

4. Logsdon, W. A., "Dynamic Fracture Toughness of Heavy Section, Narrow Gap Gas Tungsten Arc Weldments," Engineering Fracture Mechanics, Vol. 16, No. 6, 1982.

5. Logsdon, W. A., "Dynamic Fracture Toughness and Fatigue Crack Growth Rate Properties of ASME SA508 Cl.3 and SA508 Cl.3a Base and Heat AFfected Zone Materials," in ASTM Journal of Testing and Evaluation, Vol. 10, July 1981.

6. Logsdon, W. A., and Begley, J. A., "Dynamic Fracture Toughness of SA533 Grade A Class 2 Base Plate and Weldments," in Flaw Growth and Fracture, ASTM STP 631, 1977.