1.0 STATEMENT OF PROBLEM

The purpose of this calculation is to evaluate the McGuire Unit 2 Reactor Vessel flaw at the lower head to ring segments girth weld, as identified during the 10 year In Service Inspection during refueling outage 2-EOC-8. The indication being evaluated has been identified and documented in the Problem Investigation Program (PIP-2-M93-0717). This calculation is performed to satisfy the requirements of ASME B&PV Code, Section XI, subsection IWB-3600 "Analytical Evaluation of Flaws".

2.0 QA CONDITION

QA Condition 1 - Nuclear Safety Related

The reactor vessel is an ASME Section III, Class 1 pressure boundary.

3.0 DESIGN METHOD USED

The flaw is characterized and evaluated using Linear Elastic Fracture Mechanics methods. The nil-ductility (RT_{ndt}) temperature of the limiting material is determined based on actual material tests and USNRC Standard Review Plan, Branch Technical Position 5-2. The loads are based on conservative boundings of all Normal and Upset loads. Faulted loads and Hydrostatic Test load cases are also addressed. The formulas of ASME Section XI, Appendix A are used to calculate the stress intensities.

4.0 APPLICABLE CODES AND STANDARDS

ASME Boiler and Pressure Vessel Code, Section III, Subsection NB (Class 1 Vessels) 1971 Edition, including addenda thru the Winter 1971.

ASME Boiler and Pressure Vessel Code, Section XI, Subsections IWA, IWB (Class 1 Vessels) and Appendix A , 1980 Edition, including addenda thru the Winter 1980.

5.0 OTHER DESIGN CRITERIA

Reg. Guide 1.99, "Radiation Embrittlement of Reactor Pressure Vessels", Rev. 2 dated May 1988

US NRC Standard Review Plan, Section 5.3.2 (Pressure- Temperature Limits), and Branch Technical position MTEB 5-2 (Fracture Toughness Requirements)

9308260321 930818
PDR ADOCK 05000370
P PDR

6.0 APPLICABLE DESIGN INPUTS

The following are the applicable design criteria used in this analysis. The criteria of ANSI N45.2.11 have been reviewed and included as applicable to this work.

Function: The reactor vessel provides a class 1 reactor coolant pressure boundary.

Design Conditions: Design life is defined as 32 effective full power years (40 years * 0.8 availability).

Environmental Conditions: The vessel lower head does not see a significant neutron flux, and embrittlement of the ferritic steels is considered unlikely. To ensure conservatism, the radiation shift of the limiting material was calculated and shown to be negligible.

Structural Requirements: The reactor vessel structural integrity is required for plant operating modes 1 through 6.

Material Properties: The mechanical and chemistry values used as the basis of this calculation are from the original Rotterdam Material test reports.

7.0 INITIAL / FINAL CONDITIONS

Not Applicable

8.0 CRITERIA CITED IN THE FSAR

Sections:

5.2.4 "Fracture Toughness"
5.4.3.7 "Reactor Vessel Material Surveillance Program Requirements"

9.0 CRITERIA CITED IN THE TECHNICAL SPECIFICATIONS

3.4.9.1 "Reactor Coolant System, Pressure/ Temperature Limits"
3.4.10 "Reactor Coolant System, Structural Integrity"

10.0 ASSUMPTIONS

As stated.

11.0 REFERENCES

11-1 WCAP-11029, Analysis of Capsule V from the Duke Power Company McGuire Unit 2 Reactor Vessel Radiation Surveillance Program, January 1986

11-2 WCAP-13516, Analysis of Capsule U from the Duke Power Company McGuire Unit 2 Reactor Vessel Radiation Surveillance Program, October 1992

11-3 Westinghouse Electric Corporation Equipment Specification No. 676413, rev 2, "Reactor Vessel"

11-4 Westinghouse Electric Corporation Equipment Specification No. 952564, rev 1, "Addendum to Equipment Specification 676413, rev. 2, Standard Four Loop Plant, McGuire II & Catawba I Reactor Vessels", MCM 2201.21-0001

12.0 ATTACHED REFERENCES

12-1 Rotterdam Dockyard Drawing "Location, Identification and Thermal History of Vessel Parts"

12-2 Certified Material Test Reports, Rotterdam Dockyard Vessel 30664

12-3 Rotterdam Dockyard Drawing "173 Inch PWR Vessel 'Westinghouse' General Arrangement", Drawing No. 30738-1510 sheet 1 of 2, rev. D

12-4 Ultrasonic Examination Results of the Lower Head-to-Bottom Head Weld (2RRV-W01) for the McGuire Unit II July 1993 Reactor Pressure Vessel Examination, BWNT

13.0 EVALUATION

13.1 Determination of Reference Transition/ Nil Ductility Temperature (RT_{ndt}) for the McGuire Unit 2 Reactor Vessel Lower Head Girth Weld Regions:

The lower head consists of a bottom dome (Item 01) welded to a ring segment (Item 02). The girth weld is identified as seam (W01). The location and identification of the materials used in these materials are shown in the attached Rotterdam drawing "Location, Identification and Thermal History of Vessel Parts, Weld and Surveillance Material" and Weld Material Qualification reports.

Weld Seam W01:

The following defines the method of determining the weld seam RT_{ndt}.

The nil ductility temperature is based on Charpy V-notch tests performed at a single temperature, and USNRC Branch Technical Position 5-2. Radiation shift is verified to be negligible for the limiting material (Weld seam W01).

Material:

Heat Number: 899680
Flux: Grau L.O. (LW 320) Lot P.23

Test Reports:

Rotterdam Lab No. P710 dated July 1972

Charpy V-Notch results (conducted at -12°C, or 10°F):
(acceptance criteria was 5.2 Kgm/cm² or 30 ft-lbs)

Impact Toughness		Lat. Expansion	% Shear
10.0 Kgm/cm²	(57.8 ft-lbs)	0.043 in LE	47% shear
7.5 Kgm/cm²	(43.4 ft-lbs)	0.039 in LE	47% shear
6.8 Kgm/cm²	(39.3 ft-lbs)	0.055 in LE	55% shear

Weld History:

The weld Seam W01 was weld repaired using three different combinations of heats of weld wire. The combinations, and test report references are as follows:

Heat	Test Report No.
7011/ 6143	L747
7565/ 7158	O726
7359/ 6708	N750

The test reports show that in all cases the base weld (Heat 899680, test report P710) is limiting in terms of material toughness. The vessel was post weld heat treated following each weld repair.

RT_{ndt} Determination:

USNRC Branch Technical Position 5-2 (Fracture Toughness Requirements) is used as guidance in determining RT_{ndt}. Based on section B1.1(4),

"If limited Charpy V-Notch tests were performed at a single temperature to confirm that at least 30 ft-lbs was obtained, that temperature may be used as an estimate of the RT_{ndt} provided at least 45 ft-lbs was obtained if the specimens were longitudinally oriented..."

The test temperature of -12°C (10°F) can be used as an estimate of RT_{ndt}, since a minimum of 39.3 ft-lbs was obtained. Note that in this case the specimen is a weld, and there is no longitudinal (weak) direction.

Therefore: RT_{ndt}(initial) = -12°C (10°F)

The radiation shift for this material in this region of the vessel is shown to be insignificant, as follows:

Weld Seam (W01) is located approximately 200 inches (520 cm) below the core midplane (refer to Rotterdam Drawing 30738-1510, sheet 1 of 2). The axial variation in fast neutron (>1.0 MeV) fluence is provided by Westinghouse WCAP 11029, figure 6-5. At approximately 280 cm below the core midplane the (relative) fluence is noted to be 0.001 (0.1%) of the peak. The latest surveillance capsule results (Capsule U, WCAP-13516) show the peak neutron fluence (>1.0MeV) to be 2.04E19 n/cm². Thus, the fluence at 280 cm below core midplane would be approximately 2E16 n/cm² (0.001 * 2E19 = 2E16). This fluence is considerably below the threshold (1E17 n/cm²) for consideration of neutron embrittlement. The fluence at the weld seam W01 (500 cm below the core midplane) would be considerably lower.

The RT_{ndt} radiation shift at this fluence level can be predicted using the formulas of Reg. Guide 1.99, Rev. 2, as follows:

$\Delta RT_{ndt} = CF * f^{(0.28 - 0.10 \log f)}$
(Where all values are defined and obtained using RG 1.99, Rev. 2)
CF = 41 (Ni = 0.75, Cu = 0.03)
f = 0.002E19 n/cm² (EOL = 32 EFPY, assuming no attenuation thru wall, assuming axial location approx. half actual distance of W01 from core midplane)

ΔRT_{ndt} = 1.3 °F (considering conservatisms - insignificant)

Since this RT_{ndt}(initial) is based on actual material test results, and the lowest impact toughness (39 ft-lbs) was greater than the limit (30 ft-lbs) by more than the accuracy of the test method (ASTM E23; calabration to ± 5% = 1.5 - 2.0 ft-lbs) there is no need to apply margin to the initial values. Additionally, since there is no significant radiation shift, there is no need to apply a radiation shift margin.

RT_{ndt} = 10°F

Bottom Head Dome, Item 01:

The following defines the method of determining the bottom head dome RT_{ndt}.

The nil ductility temperature is based on drop weight test results, a series of Charpy V-notch tests at various temperatures and USNRC Branch Technical Position 5-2.

Material:

SA-533 Gr. B, Cl. 1
Heat Number: 55292-3

Test Reports:

Rotterdam Lab No. L573
N.D.T. Temperature (Drop Weight Tests: ASTM E208) = -40C (-40°F)
Charpy V-Notch results (conducted at +4.4C, or 40°F):
(acceptance criteria was 5.2 Kgm/cm² or 30 ft-lbs)

Impact Toughness		Lat. Expansion	% Shear
23.8 Kgm/cm²	(137 ft-lbs)	0.087 in LE	95% shear
16.6 Kgm/cm²	(96 ft-lbs)	0.071 in LE	82% shear
15.5 Kgm/cm²	(89 ft-lbs)	0.071 in LE	72% shear

Additional CVN Tests:

Temperature (°C)	Temperature (°F)	Impact (Kgm/cm²)	(Ft-Lbs)	Lateral Exp. (in)
-90	-130	1.4	8.1	0.008
-77	-107	2.1	12.1	0.008
-70	-94	6.5	37.6	0.032
-60	-76	6.4	37.0	0.028
-50	-58	5.9	34.1	0.028
-40	-40	6.3	36.4	0.028
-30	-22	8.6	49.7	0.039
-20	-4	10.3	59.6	0.047
-10	14	12.3	71.1	0.055
0	32	12.8	74.0	0.059
10	50	15.6	90.2	0.067
20	68	16.1	93.1	0.071
30	86	18.5	107	0.083
40	104	20.5	118	0.087
50	122	21.6	125	0.087
60	140	24.0	138	0.091

At T_{ndt} + 60°F= 20°F (-40°F + 60°F = 20°F), the Charpy V-Notch tests are all greater than 71 ft-lbs impact energy (required to be greater than 50 ft-lbs) and greater than 55 mils lateral expansion (required to be greater than 35 mils), and therefore the T_{ndt} may be used as the RT_{ndt}.

RT_{ndt} = -40°F

Ring Segment Item 02-03:

The following defines the method of determining the ring segment 02-03 RT_{ndt}.

The nil ductility temperature is based on drop weight test results, a series of Charpy V-notch tests at various temperatures and USNRC Branch Technical Position 5-2.

Material:
SA-533 Gr. B, Cl. 1
Heat Number: 55126-2-1

Test Reports:
Rotterdam Lab No. L589
N.D.T. Temperature (Drop Weight Tests: ASTM E208) = -40C (-40°F)
Charpy V-Notch results (conducted at +4.4C, or 40°F):
(acceptance criteria was 5.2 Kgm/cm² or 30 ft-lbs)

Impact Toughness		Lat. Expansion	% Shear
18.6 Kgm/cm²	(107 ft-lbs)	0.075 in LE	67% shear
19.3 Kgm/cm²	(111 ft-lbs)	0.083 in LE	72% shear
15.8 Kgm/cm²	(91.4 ft-lbs)	0.067 in LE	67% shear

Additional CVN Tests:

Temperature (°C)	Temperature (°F)	Impact (Kgm/cm²)	(Ft-Lbs)	Lateral Exp. (in)
-100	-148	1.1	6.[illegible]	0.004
-90	-130	1.8	10.4	0.008
-80	-112	1.5	8.6	0.008
-70	-94	4.6	26.6	0.024
-60	-76	5.3	30.6	0.028
-50	-58	6.8	39.3	0.032
-40	-40	8.5	49.1	0.039
-30	-22	9.1	52.6	0.039
-20	-4	13.8	79	0.063
-10	14	14.9	86	0.063
0	32	18.3	105	0.075
0	32	16.9	97	0.071
10	50	25.1	145	0.091
20	68	24.6	142	0.094
30	86	20.5	118	0.087
40	104	21.4	123	0.087
50	122	21.9	126	0.087
60	140	23.3	134	0.099

At T_{ndt} + 60°F = 20°F (-40°F + 60°F = 20°F), the Charpy V-Notch tests are all greater than 86 ft-lbs (required to be greater than 50 ft-lbs) and greater than 63 mils lateral expansion (required to be greater than 35 mils), and therefore the T_{ndt} may be used as the RT_{ndt}.

RT_{ndt} = -40°F

13.2 Characterization of Flaw

The indication is located at 129 to 130 degrees on the lower hemisphere circumferential weld at the surface of the vessel outer diameter. The indication has been determined by B&W Nuclear Services to be planar, oriented transverse to the weld, .5 inch deep, and 2.4 inches in length. A complete report from B&W Nuclear Services describing flaw determination and sizing methods is included as Attachment 4.

13.3 General Discussion of Loads

Applicable load cases for consideration are Gravity, Seismic, Pressure, and Thermal Transients.

By inspection, stresses due to Gravity and Seismic are negligible.

Pressure and Thermal Transients conditions are defined in references [11-3], [11-4] and the Technical Specification.

Thermal Transient descriptions and numbers of cycles are given in Table 13.3-1.

Appropriate combinations of Pressure and Temperature stress fields are evaluated for crack stability and growth in sections 13.4 through 13.7. Details of methods and references are provided there.

Additional residual stresses are considered in combination with stresses produced by loads. Residual stresses are conservatively estimated in accordance with ASME Section XI, Appendix E, Table E-2, 1986 edition; that is +/- 10 ksi. Tension is assumed on the exterior surface since the last welding passes were done there.

Table 13.3-1

Thermal Transients

Reference Westinghouse Equipment Specification 952564 Rev. 1

Figure	Description	Cycles	Condition
1	Plant Heatup 100°F/hr	200	Normal
1	Plant Cooldown 100°F/hr	200	Normal
2	Plant Loading 5%/minute	18300	Normal
2	Plant Unloading 5%/minute	18300	Normal
3	10% Step Load Increase	2000	Normal
3	10% Step Load Decrease	2000	Normal
4	Large Step Load Decrease	200	Normal
13	Turbine Roll Test	10	Normal
14	Hydro Before Startup	5	Normal
15	Hydro Test @ 2485 psig	50	Normal
5	Loss of Load	80	Upset
6	Loss of Power	40	Upset
7,8,9	Loss of Flow in 1 Loop	80	Upset
10	Reactor Trip From Full Power	400	Upset
11	Reactor Coolant Pipe Break	1	Faulted
12	Steam Line Break From No Load	1	Faulted
	Total	41867	
	Total w/o Loading & Unloading @ 5%/minute	5267	

13.4 Evaluation 1: Heatup, Leak Test, Hydro, and Cooldown

This evaluation considers conditions of Normal Heatup, Leak Test, Hydro, and Cooldown.

Tables 13.4-1 and 13.4-2 and their notes describe, in summary form, the results of this evaluation. Further discussion is given here.

In this evaluation stresses of combined cases of Pressure and Thermal Transient temperature fields (and residual) are used to calculate K_I values.

PRESSURE and TEMPERATURE STRESS FIELD and METAL TEMPERATURE DETERMINATION

Since K_{Ia} and K_{Ic} material values are a function of material temperature, and K_I values are a function of pressure, it is necessary that the appropriate pairings of pressure and temperature are evaluated.

Pressure and temperature combinations for Plant Heatup, Leak Test and Cooldown are defined by Figures 3.4-3 and 3.4-5 and discussed on page 3/4 4-30 of the Technical Specification. (Figures and text are reproduced here as Enclosures 13.4-1, 13.4-2, and 13.4-3.)

Figure 13.4-1 shows these curves labeled as "Envelope of Tech Spec Limits for Normal Heatup & Leak Test" and "Envelope of Tech Spec Limits for Normal Cooldown".

Hydro Tests (described as figures 14 and 15 of Table 13.3-1) are not performed for McGuire 2. Instead, pressures and temperatures as defined by ASME Section XI, Table IWB-5222-1, 1980 edition are used. Figure 13.4-1 also shows these combinations. Since only those beneath the Tech Spec limitations are valid for use, and these are enveloped by the Tech Spec conditions, no specific pressure temperature combinations for Hydro are evaluated.

This evaluation is performed for temperatures beginning at 85 °F and increasing to 557 °F. Pressure values for each temperature are the envelope of Heatup, Leak Test, and Cooldown.

Pressure Stress is computed using thin wall theory.

This location is sufficiently remote from significant structural discontinuities to preclude the necessity for stress multipliers.

The effects of uneven heating through the vessel wall must be included in the evaluation. These effects increase in severity with the rate of heating or cooling, and since it is heating that will cause tensile stress on the exterior surface (additive with pressure stress), heating is evaluated. Table 13.4-3 shows the temperature changes and rates for Hydro and Heatup, and shows that Heatup will be used. (Reference [11-4] specifies that the Heatup rate is 100 °F/ hr, whereas the Tech Spec limits this rate to 60 °F/hr as used here. Reference [11-4] also begins a heatup at 70 °F, but this evaluation will begin pressure application and heatup from isothermal conditions at 85 °F., in line with the curves presented in the Tech Spec.)

The stress effects of this heatup were determined using the computer program TRANS2A, described in section 14.0. The following summarizes the input.

Section Properties:

SECTION NUMBER	SECTION NAME	MATERIAL TYPE	INSIDE (DIAMETER (IN)	WALL THICKNESS (IN)	AMBIENT TEMPERATURE (F)	WALL DIVISIONS
1	LOWRHEAD	CMS	176.000	5.690	70.000	20

The effects of not considering the cladding are judged negligible.

The input boundary conditions specified a ramped temperature function at the inside surface beginning at 85 °F at time zero and ending at 557 °F at 28320 seconds (60 °F/hour).

The solution was numerically determined using one time step for each degree of temperature rise, or about every 37 seconds.

The computer program internally computes a heat transfer coefficient based on temperatures, geometries, and flows as for the inside of a pipe. Having a high heat transfer coefficient would be conservative for determining a through wall stress gradient, but a low value would be proper for bounding the temperature lag for the metal and hence the K_{Ia} and K_{Ic}.

The flow in this case was set equivalent to full design flow of 144.4×10^6 lbm/hr [ref. FSAR Chapter 4, Appendix 4, Table 4-1], or 378000 gpm at 557 °F and 2500 psia. Note that the program assumes this is flowing inside a pipe 176 inches inside diameter, thus the heat transfer coefficient is lower bound. The resulting heat transfer coefficient ranged from approximately 300 to 750 BTU/sf/hr/°F.

Figure 13.4-2 and its lower range, Figure 13.4-3, show the water temperature and the inside, average, and outside temperature responses vs. time. From these it is seen that the heat transfer coefficient is also sufficiently high to determine the stresses due to uneven heating since the maximum temperature difference between the fluid and the inner wall is less than five degrees.

Figure 13.4-4 shows the outer wall temperature as a function of the water temperature for water temperatures less than 105°F. In the determination of K_{Ia} and K_{IC}, the metal temperature shown here is used at these water temperatures. For water temperatures at or above 105 °F, a metal temperature 18 degrees less than the water temperature is used. This reflects the maximum difference from Figure 13.4-2.

Since no rotation takes place in the vessel wall, the resulting stress due to uneven heating at any point at any time is E * alpha * ΔT / (1-nu) where E is Young's modulus, alpha is the linear coefficient of thermal expansion, ΔT is the difference between the temperature at the point and the average through wall temperature at that time, and nu is Poisson's ratio.

To find this stress, Figure 13.4-5 shows a plot of the subject ΔT at the exterior surface as a function of the water temperature for water temperatures less than 105 °F. In the determination of this stress, the ΔT values shown here are used at these water temperatures. For water temperatures at or above 105 °F, the maximum ΔT for the transient, 5 °F, is used.

The resulting stress is conservatively assumed to be all membrane in calculating K_I.

Figure 13.4-6 shows the profile of stress through the section at the end of the transient. (Note the near flat slope of the profile near the exterior surface, reinforcing the decision to characterize this stress as all membrane in accordance with ASME Section XI Figure A-3200-1.)

RESIDUAL STRESS

The 10 ksi residual stress (as discussed in section 13.3) is applied as bending stress in accordance with ASME Section XI Figure A-3200-1.

K_I DETERMINATION

Calculation of K_I and comparison to allowables for the appropriate combinations of stresses are shown in summary form in Tables 13.4-1 and 13.4-2.

SUMMARY

Tables 13.4-1 & 13.4-2 show that the worst comparison of calculated K_I to allowable is 86%, even with all the conservatisms employed.

Table 13.4-1

1980 ASME Section XI Appendix A Analysis of Flaw Indications

Normal Heatup & Cooldown Conditions for Temperatures ≤ 100°F

Units inch, kip, °F

	Notes				
Water Temp	(1)	85.00	90.00	95.00	100.00
Metal Temp	(2)	85.00	90.00	95.00	100.00
Press	(1)	568.00	58[illegible] 00	594.00	609.00
a	(3)	0.50	0.50	0.50	0.50
l	(3)	2.40	2.40	2.40	2.40
t	(3)	5.69	5.69	5.69	5.69
a/t		0.09	0.09	0.09	0.09
a/l		0.21	0.21	0.21	0.21
RT_{NDT}	(4)	10.00	10.00	10.00	10.00
$T-RT_{NDT}$		75.00	80.00	85.00	90.00
K_{Ia}	(5)	64.02	66.82	69.83	73.07
K_{Ic}	(5)	126.12	135.89	146.70	158.63
σ_m pres	(6)	4.41	4.51	4.61	4.73
ΔT memb	(7)	0	0.84	1.78	2.45
σ_m ΔT	(7)	0	0.26	0.54	0.75
σ_m resid	(8)	0	0	0	0
σ_m	(9)	4.41	4.77	5.15	5.47
σ_b pres	(6)	0	0	0	0
ΔT bend	(7)	0	0	0	0
σ_b ΔT	(7)	0	0	0	0
σ_b resid	(8)	10.00	10.00	10.00	10.00
σ_b	(9)	10.00	10.00	10.00	10.00
M_m	(10)	1.10	1.10	1.10	1.10
M_b	(10)	0.92	0.92	0.92	0.92
σ_{ys}	(11)	50.00	50.00	50.00	50.00
Q	(12)	1.33	1.33	1.33	1.32
K_I	(13)	15.29	15.72	16.19	16.57
$\sqrt{2}K_I/K_{Ic}$	(14)	0.17	0.16	0.16	0.15
$\sqrt{10}K_I/K_{Ia}$	(14)	0.75	0.74	0.73	0.72

Notes:

(1) Reactor coolant temperature & pressure for Normal Heatup ≤ 100°F, Leak Test, Hydro requirements (IWB-5222-1). Reference Enclosures 13.4-2 & -3

(2) Reactor wall outside metal temperature. Outside metal temperature lags behind the fluid temperature, see Figure 13.4-4

(3) Crack depth, length & vessel wall thickness, Reference 12-4 & "Characterization of Flaw" section 13.2

(4) Determination of Reference Transition/Nil Ductility Temperature, reference section 13.1

(5) Available fracture toughness based on crack arrest & fracture initiation, respectively, for the corresponding crack tip temperature (ksi√in) as defined in ASME Section XI, Appendix A, Figure A-4200-1 (reference section 4.0).

(6) Membrane pressure stress = PD/4t (thin wall theory hoop stress in a spherical shell) where D = 176.75". Bending component of pressure stress = 0.

(7) Average minus outside temperature from TRANS2A analysis (microfiche attachment M1 & Fig. 13.4-5), used to calculate σ_m $(E\alpha\Delta T/(1-\mu)$ where E = 29.9E3, α = 7.12E-6 in/in/°F, μ = 0.3). Conservatively define all transient stress to be membrane (M_m is larger than M_b in K_I computation, reference ASME Section XI Appendix A, article A-3300).

(8) Residual stress is conservatively assumed to be 10 ksi bending per the 1986 edition of the ASME Section XI Appendix E, Table E-2.

(9) Total membrane/bending stress to be used in K_I determination. Sum of pressure, transient & residual stresses.

(10) Correction factors for membrane & bending stress as defined in ASME Section XI, Appendix A, article A-3300. See Figures A-3300-3 & A-3300-5 (M_m = 1.1 & M_b = 0.9).

(11) Yield stress of material @ temperature. Reference Figure 13.4-7 & ASME Section III, Appendix I, 1977.

(12) Shape factor for flaw as defined in Figure A-3300-1 of ASME Section XI Appendix A.

(13) Stress intensity factor as defined in ASME Section XI Appendix A, article A-3300. $K_I = \sigma_m M_m \sqrt{\pi}\sqrt{(a/Q)} + \sigma_b M_b \sqrt{\pi}\sqrt{(a/Q)}$

(14) Ratio to allowables; $K_I < K_{Ia}/\sqrt{10}$ for normal conditions and $K_I < K_{Ic}/\sqrt{2}$ for emergency & faulted conditions, are required by ASME Section XI article IWB-3612.

Table 13.4-2

1980 ASME Section XI Appendix A Analysis of Flaw Indications

Normal Heatup & Cooldown & Leak Test Conditions for Temperatures > 100°F

Units inch, kip, °F

	Note								
Water Temp	(1)	105.000	130.000	150.000	175.000	200.000	215.000	230.000	235.000
Metal Temp	(2)	86.890	111.890	131.890	156.890	181.890	196.890	211.890	216.890
Press	(1)	621.000	724.000	832.000	1021.000	1291.000	2000.000	2363.750	2485.000
a	(3)	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
l	(3)	2.400	2.400	2.400	2.400	2.400	2.400	2.400	2.400
t	(3)	5.690	5.690	5.690	5.690	5.690	5.690	5.690	5.690
a/t		0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088
a/l		0.208	0.208	0.208	0.208	0.208	0.208	0.208	0.208
RT_{NDT}	(4)	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000
$T-RT_{NDT}$		76.890	101.890	121.890	146.890	171.890	186.890	201.890	206.890
K_{Ia}	(5)	65.058	81.774	100.268	132.368	178.492	200.000	200.000	200.000
K_{Ic}	(5)	129.702	192.304	200.000	200.000	200.000	200.000	200.000	200.000
σ_m pres	(6)	4.823	5.622	6.461	7.929	10.026	15.532	18.356	19.298
ΔT memb	(7)	5.170	5.170	5.170	5.170	5.170	5.170	5.170	5.170
σ_m ΔT	(7)	1.572	1.572	1.572	1.572	1.572	1.572	1.572	1.572
σ_m resid	(8)	0	0	0	0	0	0	0	0
σ_m	(9)	6.395	7.195	8.033	9.501	11.598	17.104	19.929	20.870
σ_b pres	(6)	0	0	0	0	0	0	0	0
σ_b ΔT	(7)	0	0	0	0	0	0	0	0
ΔT memb	(7)	0	0	0	0	0	0	0	0
σ_b resid	(8)	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000
σ_b	(9)	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000
M_m	(10)	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100
M_b	(10)	0.920	0.920	0.920	0.920	0.920	0.920	0.920	0.920
σ_{ys}	(11)	50.000	49.855	49.130	48.550	47.825	47.825	47.100	46.815
Q	(12)	1.322	1.320	1.317	1.311	1.302	1.277	1.260	1.253
K_I	(13)	17.694	18.670	19.701	21.511	24.119	31.069	34.754	36.005
$\sqrt{2}K_I/K_{Ic}$	(14)	0.193	0.137	0.139	0.152	0.171	0.220	0.246	0.255
$\sqrt{10}K_I/K_{Ia}$	(14)	0.860	0.722	0.621	0.514	0.427	0.491	0.550	0.569

Notes:

(1) Reactor coolant temperature & pressure for Normal Heatup > 100°F, Leak Test, Hydro requirements (IWB-5222-1). Reference Figure 13.4-1

(2) Reactor wall outside metal temperature. Outside metal temperature lags behind the fluid temperature by a maximum of 18.1 °F. See Figure 13.4-2

(3) Crack depth, length & vessel wall thickness, Reference 12-4 & "Characterization of Flaw" section 13.2

(4) Determination of Reference Transition/Nil Ductility Temperature, reference section 13.1

(5) Available fracture toughness based on crack arrest & fracture initiation, respectively, for the corresponding crack tip temperature ($ksi\sqrt{in}$) as defined in ASME Section XI, Appendix A, Figure A-4200-1 (reference section 4.0).

(6) Membrane pressure stress = PD/4t (thin wall theory hoop stress in a spherical shell) where D = 176.75". Bending component of pressure stress = 0.

(7) Maximum of average minus outside temperature from TRANS2A analysis (microfiche attachment M1 & Figure 13.4-6), used to calculate σm ($E\alpha\Delta T/(1-\mu)$ where E = 29.9E3, α = 7.12E-6 in/in/°F, μ = 0.3). Conservatively define all transient stress to be membrane (M_m is larger than M_b in K_I computation, reference ASME Section XI Appendix A, article A-3300).

(8) Residual stress is conservatively assumed to be 10 ksi bending per the 1986 edition of the ASME Section XI Appendix E, Table E-2.

(9) Total membrane/bending stress to be used in K_I determination. Sum of pressure, transient & residual stresses.

(10) Correction factors for membrane & bending stress as defined in ASME Section XI, Appendix A, article A-3300. See Figures A-3300-3 & A-3300-5 (M_m = 1.1 & M_b = 0.9).

(11) Yield stress of material @ temperature. Reference Figure 13.4-7 & ASME Section III, Appendix I, 1977.

(12) Shape factor for flaw as defined in Figure A-3300-1 of ASME Section XI Appendix A.

(13) Stress intensity factor as defined in ASME Section XI Appendix A, article A-3300. $K_I = \sigma_m M_m \sqrt{\pi}\sqrt{(a/Q)} + \sigma_b M_b \sqrt{\pi}\sqrt{(a/Q)}$

(14) Ratio to allowables; $K_I < K_{Ia}/\sqrt{10}$ for normal conditions and $K_I < K_{Ic}/\sqrt{2}$ for emergency & faulted conditions, are required by ASME Section XI article IWB-3612.

Table 13.4-3

Thermal Transients with Tcold Increasing

Reference Westinghouse Equipment Specification 952564 Rev. 1

Transient Envelope 1: Startup & Hydro

Figure	Description	Tc Rise (°F)	Δtime (sec)
1	Plant Heat Up 100°F/hr	487	17532
15	Hydro Test @ 2485 psig	300	10800
(use Plant Heatup @ 60 °F/hr from 85 °F to 557 °F, 472°F in 28320 sec in accordance with Tech Spec)		472 °F	28320 sec

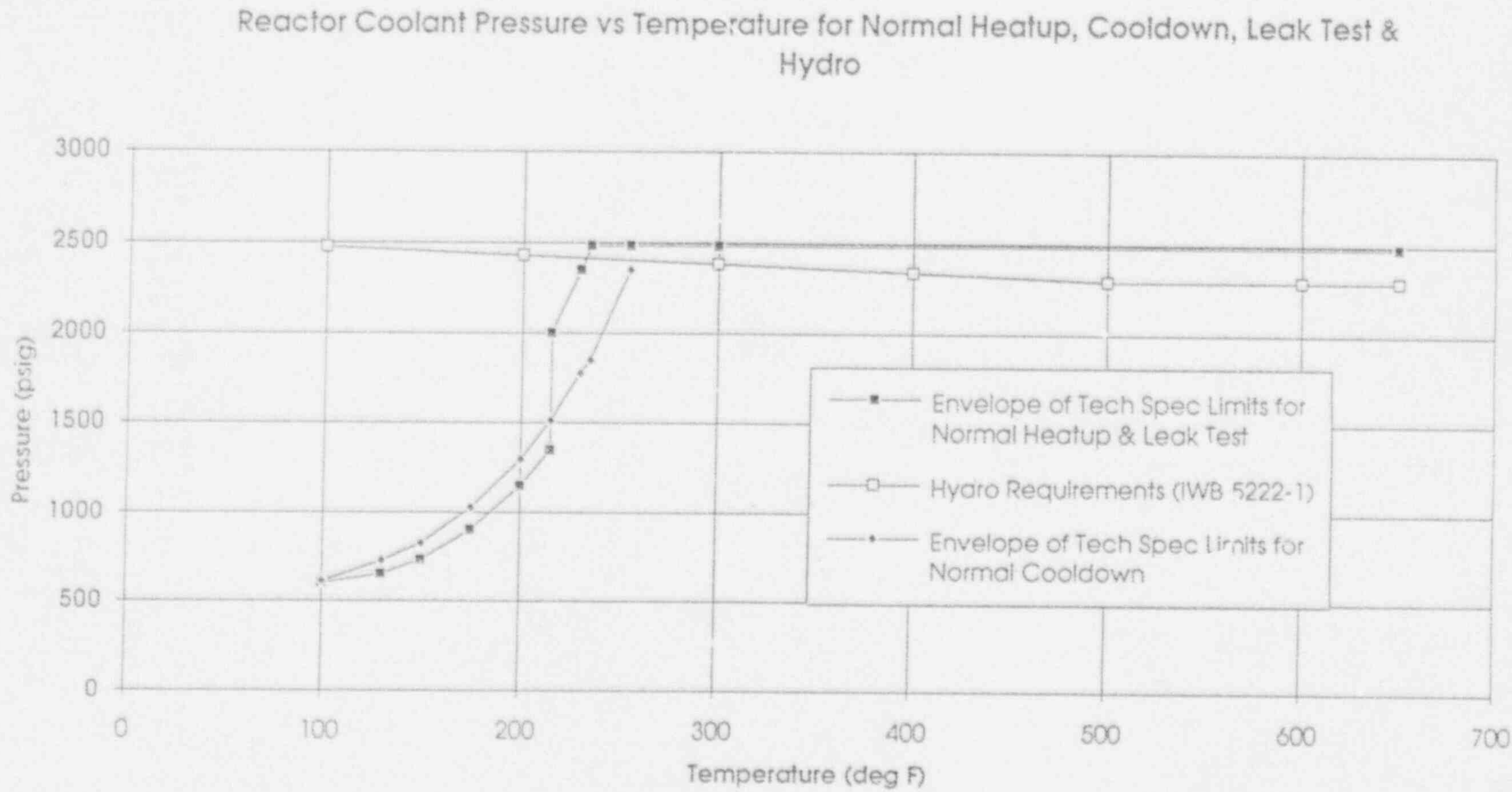
Reactor Coolant Pressure vs Temperature for Normal Heatup, Cooldown, Leak Test & Hydro
3000
2500
2000
1500
1000
500
0
Pressure (psig)
0
100
200
300
400
500
600
700
Temperature (deg F)
Envelope of Tech Spec Limits for Normal Heatup & Leak Test
Hydro Requirements (IWB 5222-1)
Envelope of Tech Spec Limits for Normal Cooldown

Figure 13.4-1

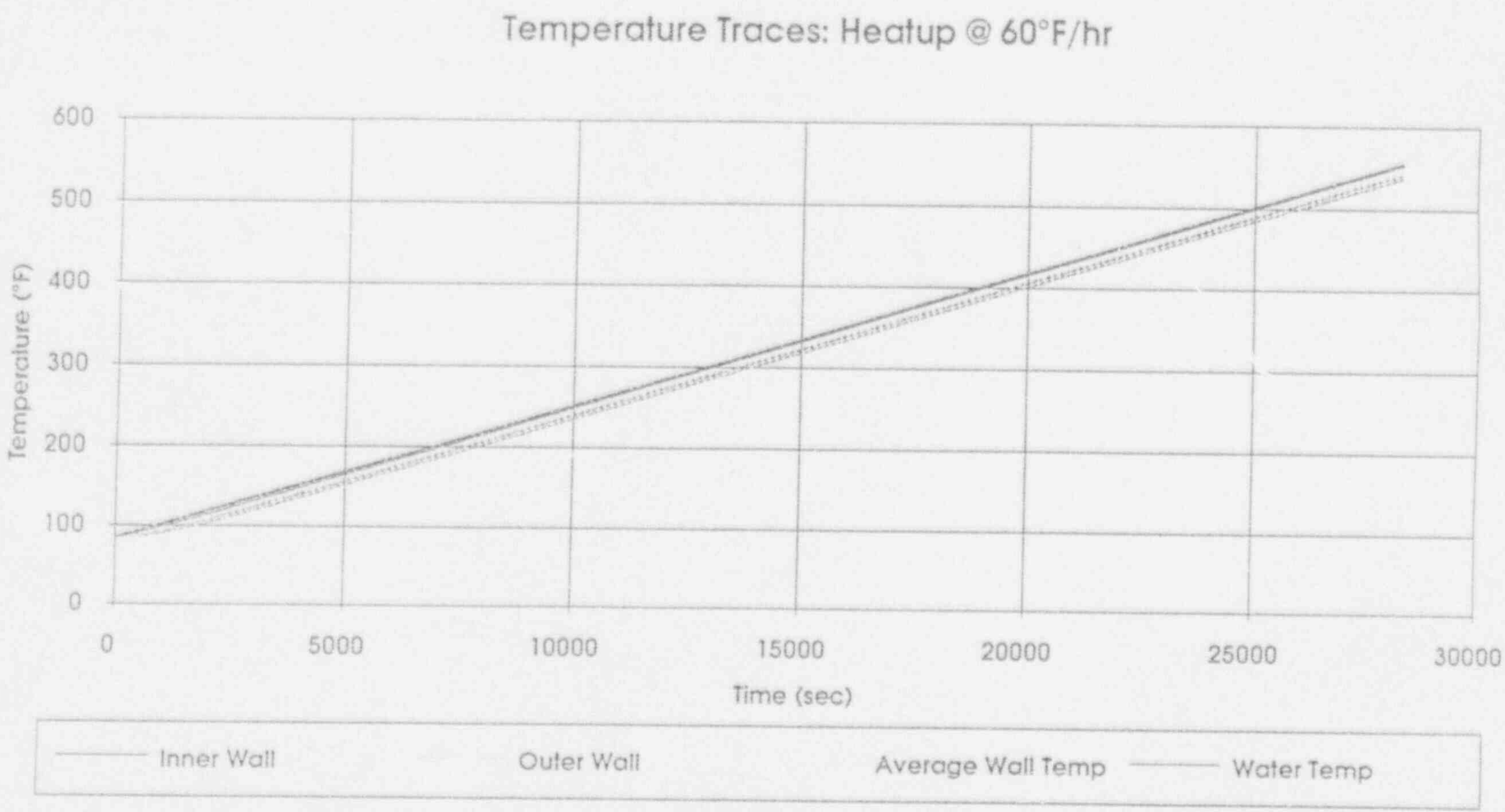
Temperature Traces: Heatup @ 60°F/hr
Temperature (°F)
600
500
400
300
200
100
0
0
5000
10000
15000
20000
25000
30000
Time (sec)
Inner Wall
Outer Wall
Average Wall Temp
Water Temp

Figure 13.4-2

CHART 2.XLC

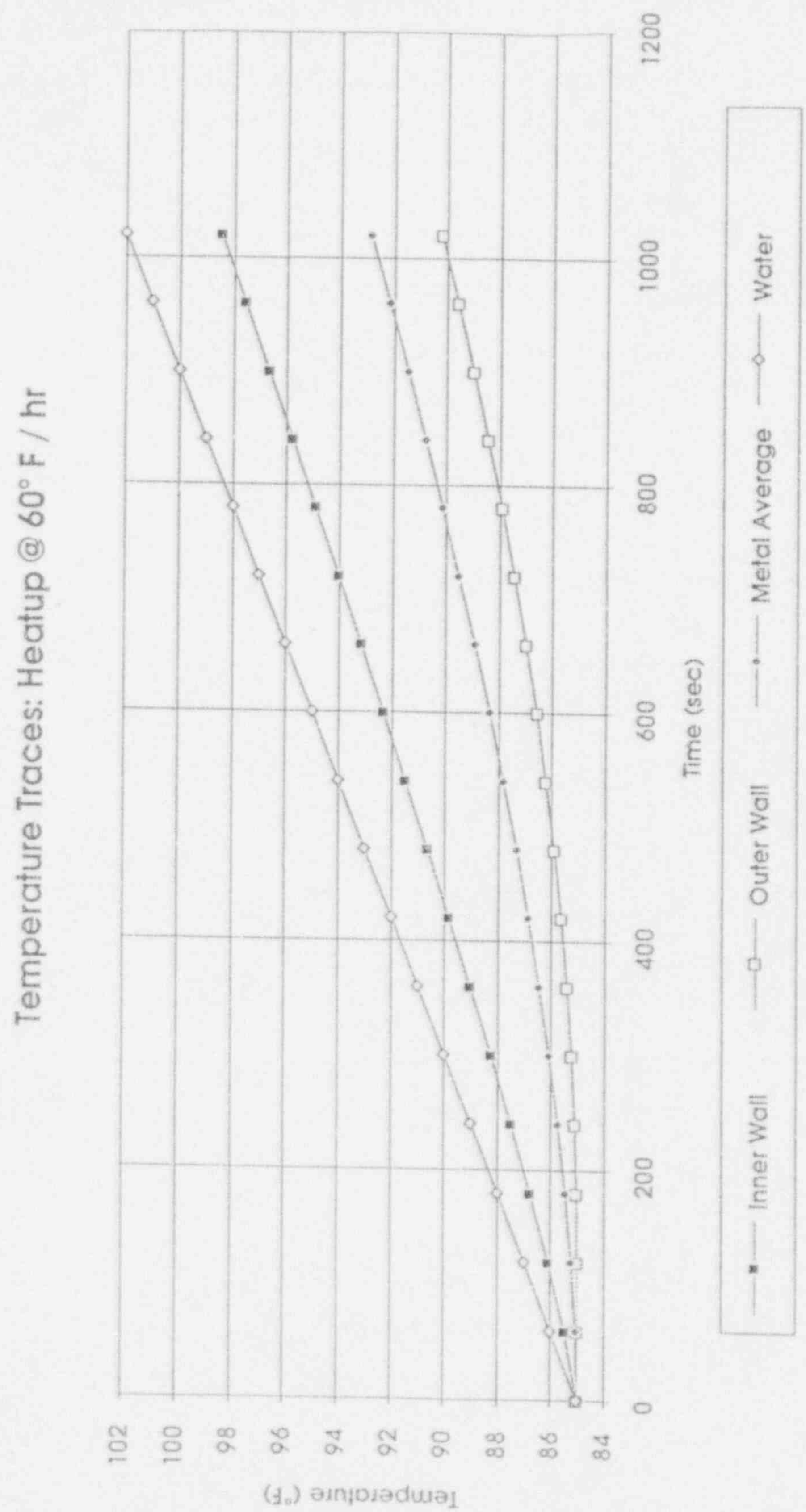

Figure 13.4-3

CHART 4.XLC

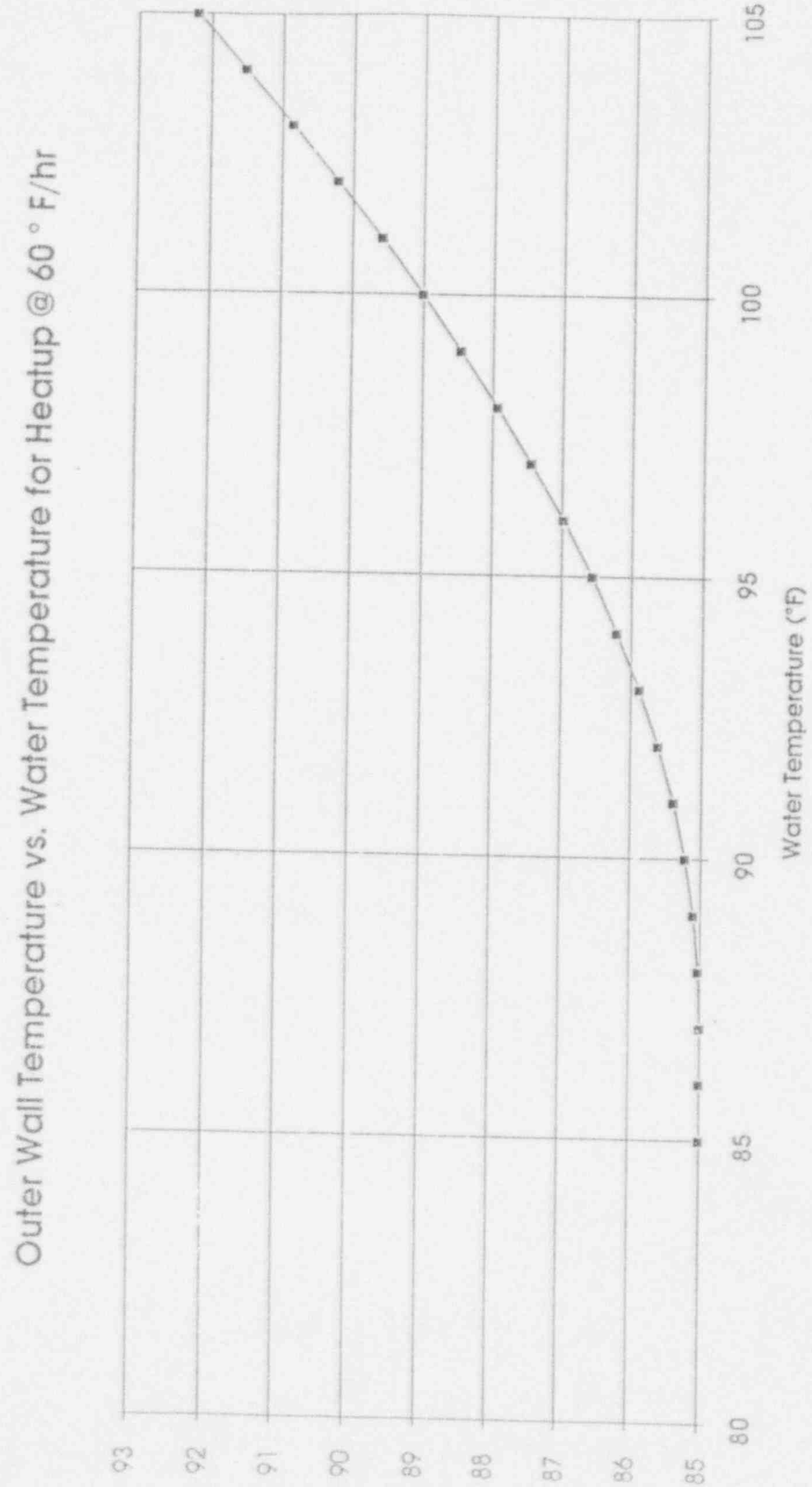

Figure 13.4-4

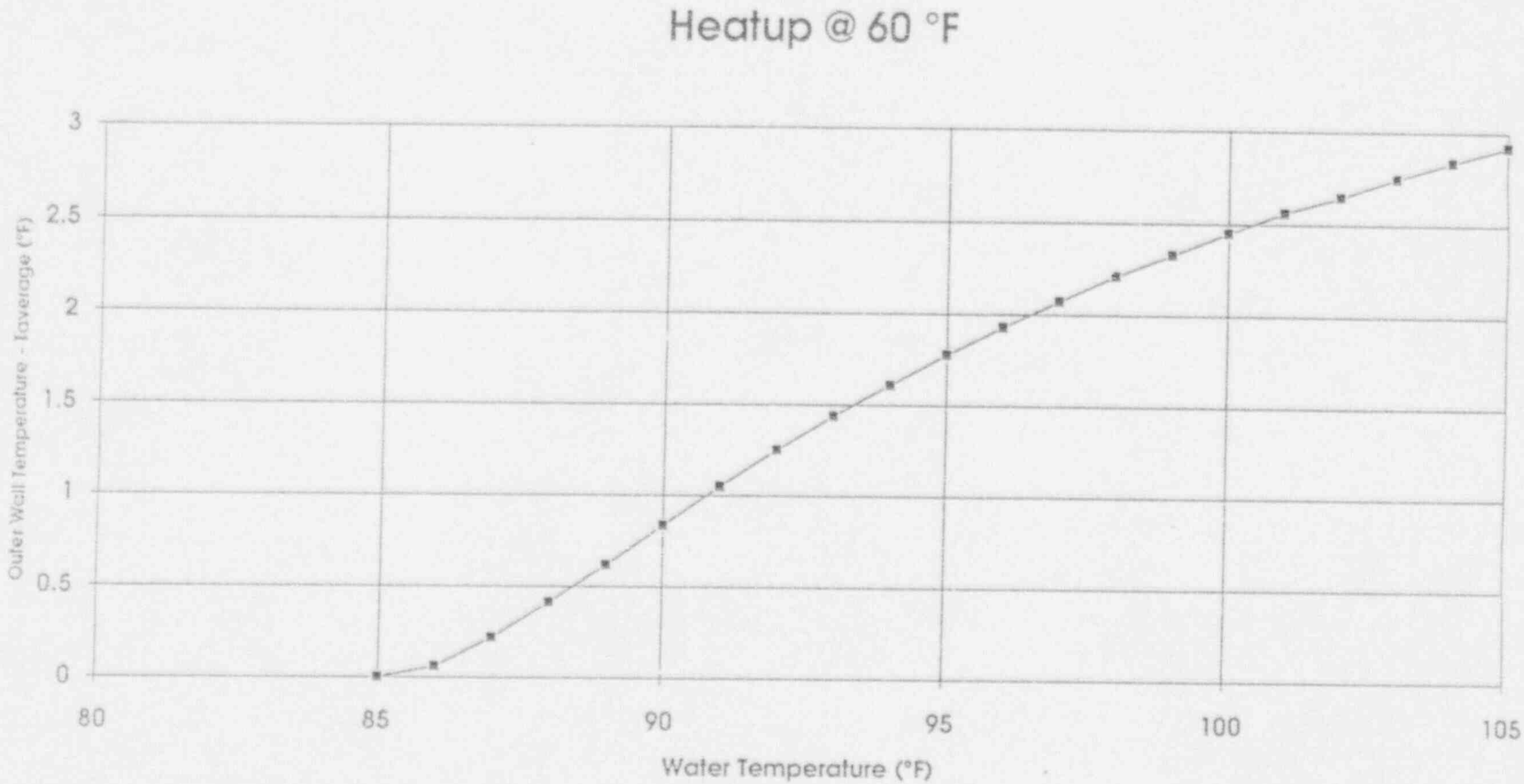
Heatup @ 60 °F
3
2.5
2
1.5
1
0.5
0
Outer Wall Temperature - Taverage (°F)
80
85
90
95
100
105
Water Temperature (°F)

Figure 13.4-5

Thru-Wall Temperature Profile at Water Temperature = 557 °F for Heatup Rate 60°F/hr

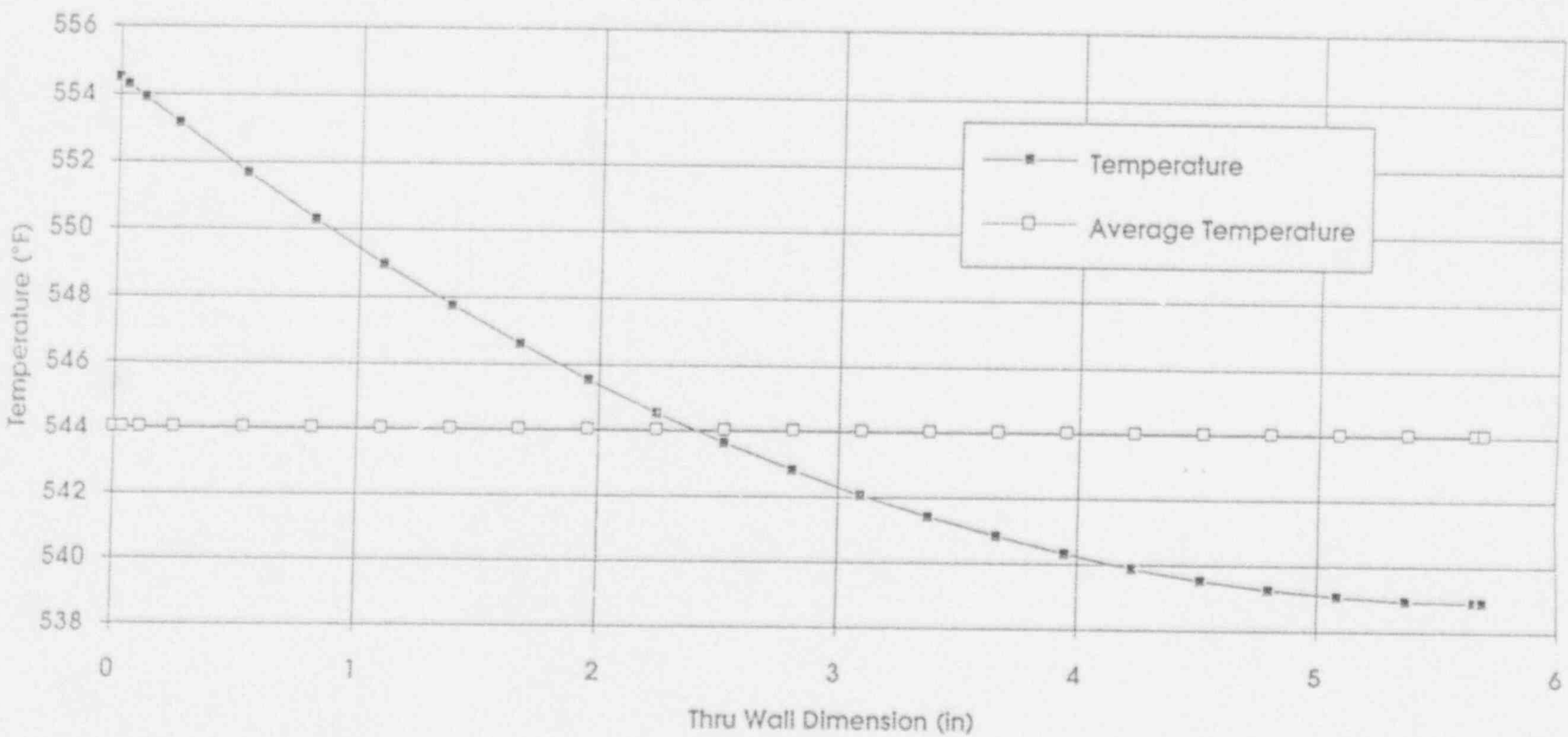

Figure 13.4-6

McGuire Nuclear Station Unit 2 File No: MCC 1201.01-00-0027 Rev. 0
Subject: Evaluation of Reactor Vessel OD Flaw (PIP 2-M93-0717)
Page: 22 By: MFL Date: 8/14/93 Ck: [illegible] Date: 8-16-93

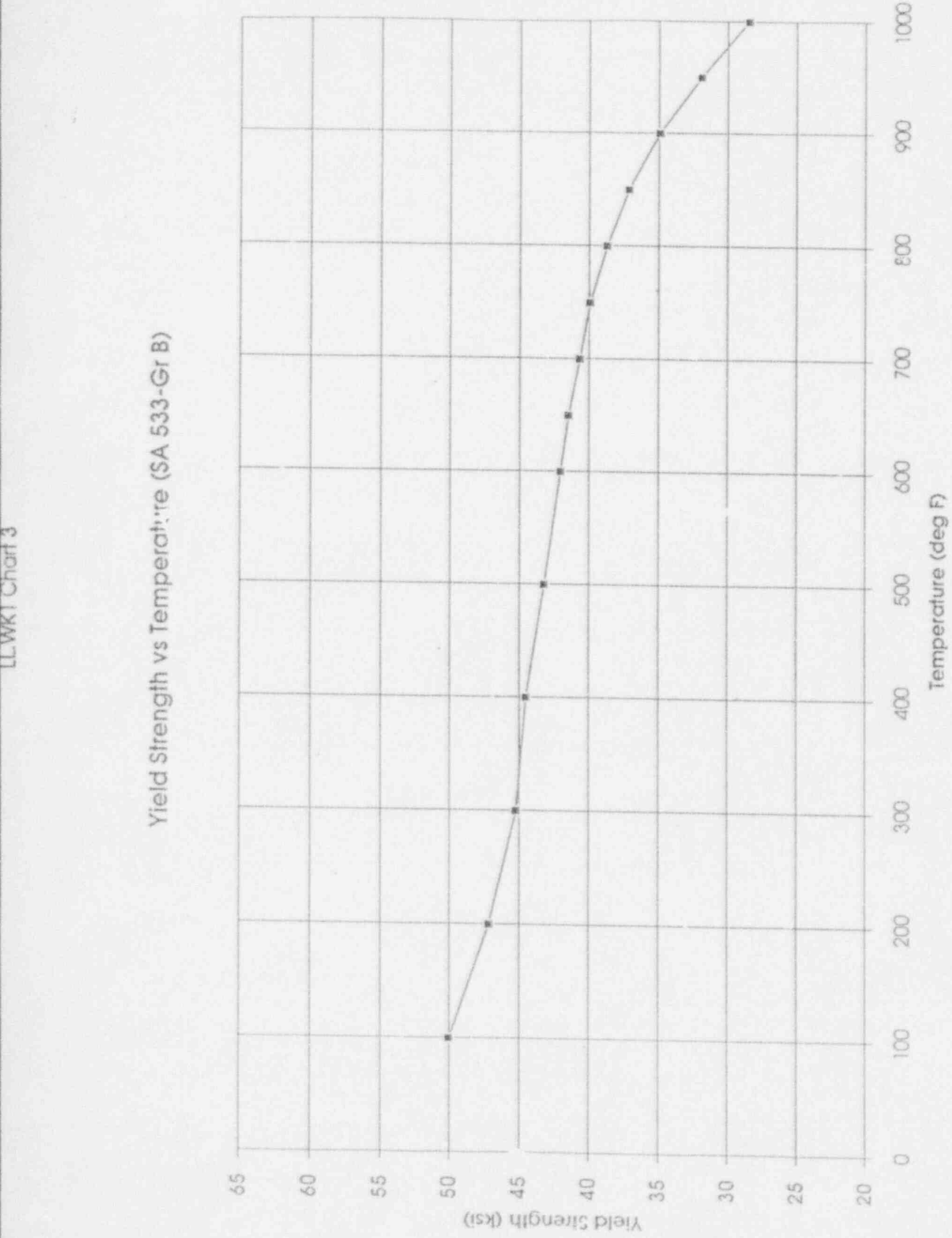

Figure 13.4-7

Table 13.5-2

Thermal Transients with Tcold Increasing

Reference Westinghouse Equipment Specification 952564 Rev. 1

Transient Envelope 2: All except Heatup, Cooldown & Hydro

Figure	Description	Tc Rise (°F)	Δtime (sec)
3	10% Step Load Decrease	14	55
4	Large Step Load Decrease	13	75
5	Loss of Load	34	30
7	Loss of Flow in 1 Loop	44	15
10	Reactor Trip From Full Power	3	8
	Enveloped Heating Transients	44 °F	8 sec

Thru Wall Temperature vs Time for Enveloped Heating Transients

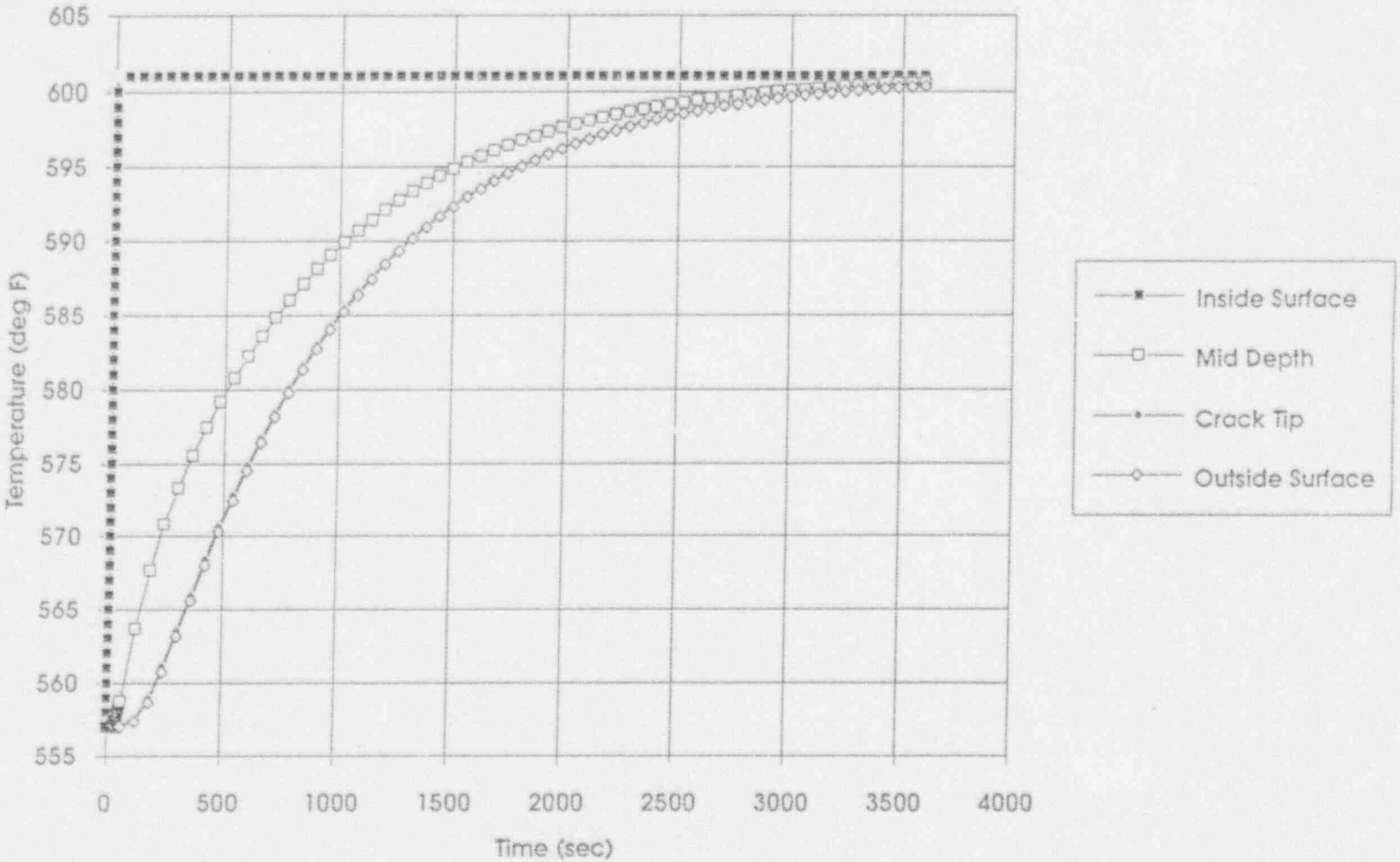

Figure 13.5-1

JMD.WK1 Chart 2

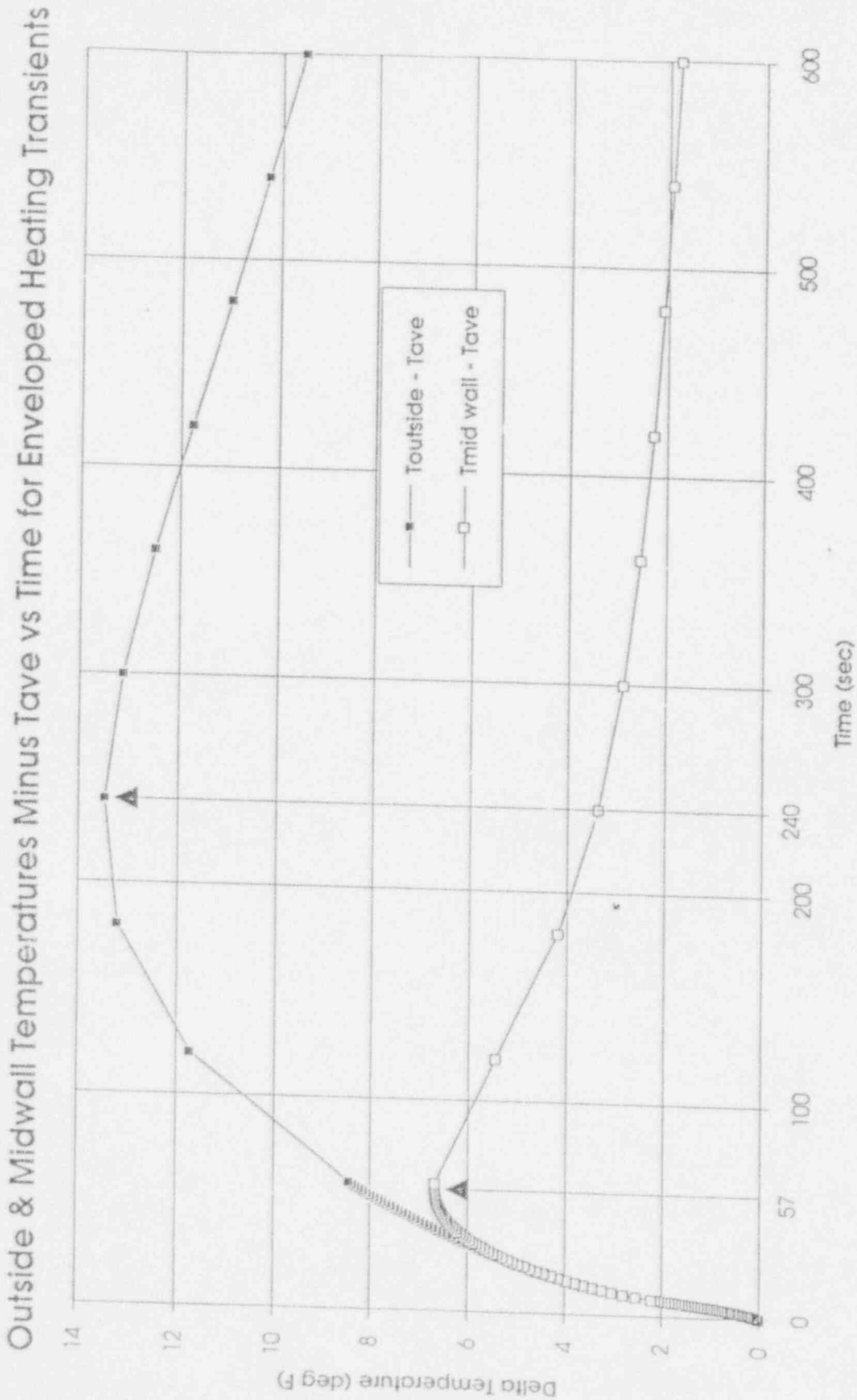

Figure 13.5-2

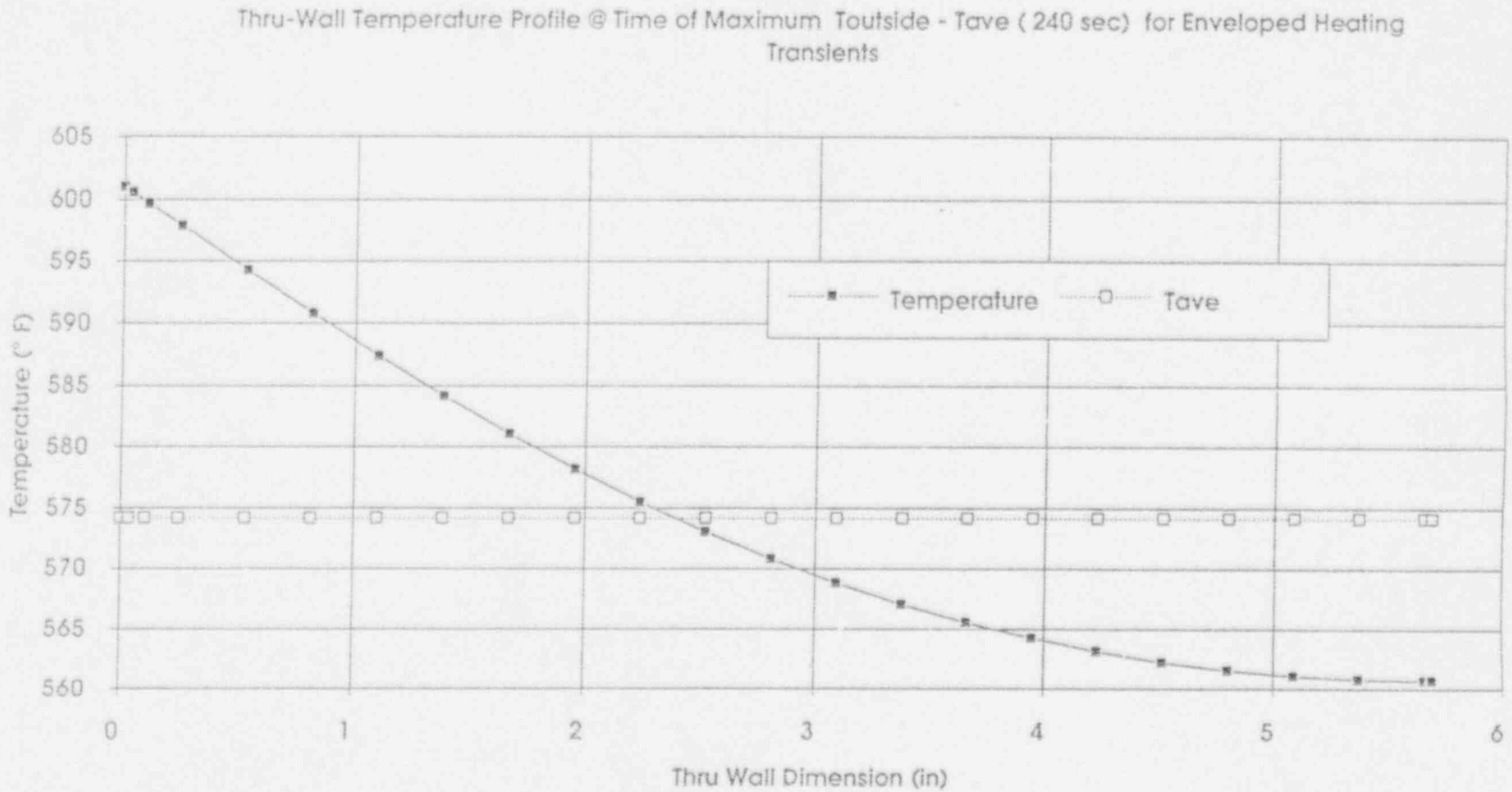

Figure 13.5-3

McGuire Nuclear Station Unit 2 File No: MCC 1201.01-00-0027 Rev. 0
Subject: Evaluation of Reactor Vessel OD Flaw (PIP 2-M93-0717)
Page: 38 By: MFJ Date: 8/14/93 Ck: [illegible] Date: 8-16-93

13.6 Evaluation 3: Other Bounding Pressure-Temperature-Transient Cases

To be further assured of having bounded all combinations of stress and temperature, this evaluation considered the worst combination of cold metal and high stress defined at any point in all Normal, Upset, and Faulted Transients. This evaluation is performed to consider cases in which the metal is cooled in contrast to the previous evaluations in which the metal is heated.

Table 13.6-1 and its notes describe in summary form the results of this evaluation. Further discussion is given here.

Table 13.6-2 shows all transients with either a decrease in temperature or an increase in pressure and the resulting combination. Figure 13.6-1 graphically compares these combinations with the combinations for Normal Heatup and Leak Test.

These combinations are shown evaluated in Table 13.6-1. To add conservatism, a local temperature stress equivalent to that used in evaluation 2 is included. (Examination of Tables 13.5-2, 13.6-2 and reference [11-4] shows this to be appropriately bounding.)

SUMMARY

Table 13.6-1 shows that the worst comparison of calculated KI to allowable is 63.1%, even with all the conservatisms employed.

Table 13.6-1

1980 ASME Section XI Appendix A Analysis of Flaw Indications Bounding Pressure/Temperature Values

Units inch, kip, °F

	Note	Figure per Table 13.3-1							
		3	3	4	5 & 6	7	8	10	12
Temp	(1)	571.000	543.000	545.000	555.000	513.000	547.000	547.000	212.000
Press	(1)	2325.000	2310.000	2350.000	2500.000	1875.000	1875.000	1870.000	2500.000
a	(2)	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
l	(2)	2.400	2.400	2.400	2.400	2.400	2.400	2.400	2.400
t	(2)	5.690	5.690	5.690	5.690	5.690	5.690	5.690	5.690
a/t		0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088
a/l		0.208	0.208	0.208	0.208	0.208	0.208	0.208	0.208
RT_{NDT}	(3)	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000
$T-RT_{NDT}$		561.000	533.000	535.000	545.000	503.000	537.000	537.000	202.000
K_{Ia}	(4)	200.000	200.000	200.000	200.000	200.000	200.000	200.000	200.000
K_{Ic}	(4)	200.000	200.000	200.000	200.000	200.000	200.000	200.000	200.000
σ_m	(5)	18.056	17.939	18.250	19.415	14.561	14.561	14.522	19.415
σ_m ΔT	(6)	4.090	4.090	4.090	4.090	4.090	4.090	4.090	4.090
σ_m resid	(7)	0	0	0	0	0	0	0	0
σ_m	(8)	22.146	22.029	22.340	23.505	18.651	18.651	18.612	23.505
σ_b pres	(5)	0	0	0	0	0	0	0	0
σ_b ΔT	(6)	0	0	0	0	0	0	0	0
σ_b resid	(7)	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000
σ_b	(8)	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000
M_m	(9)	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100
M_b	(9)	0.920	0.920	0.920	0.920	0.920	0.920	0.920	0.920
σ_{ys}	(10)	42.100	42.800	42.800	42.300	43.000	42.800	42.800	47.000
Q	(11)	1.222	1.226	1.224	1.212	1.251	1.250	1.250	1.237
K_I	(12)	38.056	37.835	38.258	39.905	33.297	33.309	33.258	39.495
$\sqrt{2}K_I/K_{Ic}$	(13)	0.269	0.268	0.271	0.282	0.235	0.236	0.235	0.279
$\sqrt{10}K_I/K_{Ia}$	(13)	0.602	0.598	0.605	0.631	0.526	0.527	0.526	0.624

Notes:

(1) Reactor coolant temperature & pressure for miscellaneous transients. Reference Table 13.6-2.

(2) Crack depth, length & vessel wall thickness, Reference 12-4 & "Characterization of Flaw" section 13.2

(3) Determination of Reference Transition/Nil Ductility Temperature, reference section 13.1

(4) Available fracture toughness based on crack arrest & fracture initiation, respectively, for the corresponding crack tip temperature (ksi√in) as defined in ASME Section XI, Appendix A, Figure A-4200-1 (reference section 4.0).

(5) Membrane pressure stress = PD/4t (thin wall theory hoop stress in a spherical shell) where D = 176.75". Bending component of pressure stress = 0.

(6) Use a value of stress for thermal transients equivalent to Table 13.5-1

(7) Residual stress is conservatively assumed to be 10 ksi bending per the 1986 edition of the ASME Section XI Appendix E, Table E-2.

(8) Total membrane/bending stress to be used in K_I determination. Sum of pressure, transient & residual stresses.

(9) Correction factors for membrane & bending stress as defined in ASME Section XI, Appendix A, article A-3300. See Figures A-3300-3 & A-3300-5 (M_m = 1.1 & M_b = 0.9).

(10) Yield stress of material @ temperature. Reference Figure 13.4-7 & ASME Section III, Appendix I, 1977.

(11) Shape factor for flaw as defined in Figure A-3300-1 of ASME Section XI Appendix A.

(12) Stress intensity factor as defined in ASME Section XI Appendix A, article A-3300. $K_I = \sigma_m M_m \sqrt{\pi}\sqrt{(a/Q)} + \sigma_b M_b \sqrt{\pi}\sqrt{(a/Q)}$

(13) Ratio to allowables; $K_I < K_{Ia}/\sqrt{10}$ for normal conditions and $K_I < K_{Ic}/\sqrt{2}$ for emergency & faulted conditions, are required by ASME Section XI article IWB-3612.

Table 13.6-2

Thermal Transients

Bounding Pressure/Temperature Values for Selected Design Transients

Reference Westinghouse Equipment Specification 952564 Rev. 1

Figure	Description	ΔT (°F)	T (°F)	ΔP (psig)	P (psig)
3	10% Step Load Increase	14	571	75.00	2325
3	10% Step Load Decrease	-14	543	60.00	2310
4	Large Step Load Decrease	-12	545	100.00	2350
5	Loss of Load	0	557	250.00	2500
6	Loss of Power	-2	555	250.00	2500
7	Loss of Flow in 1 Loop	-44	513	-375.00	1875
8	Loss of Flow in 1 Loop	-10	547	-375.00	1875
10	Reactor Trip From Full Power	-10	547	-380.00	1870
12	Steam Line Break From No Load		212		2500
11	Reactor Coolant Pipe Break (Enveloped by Normal Heatup by inspect.)				

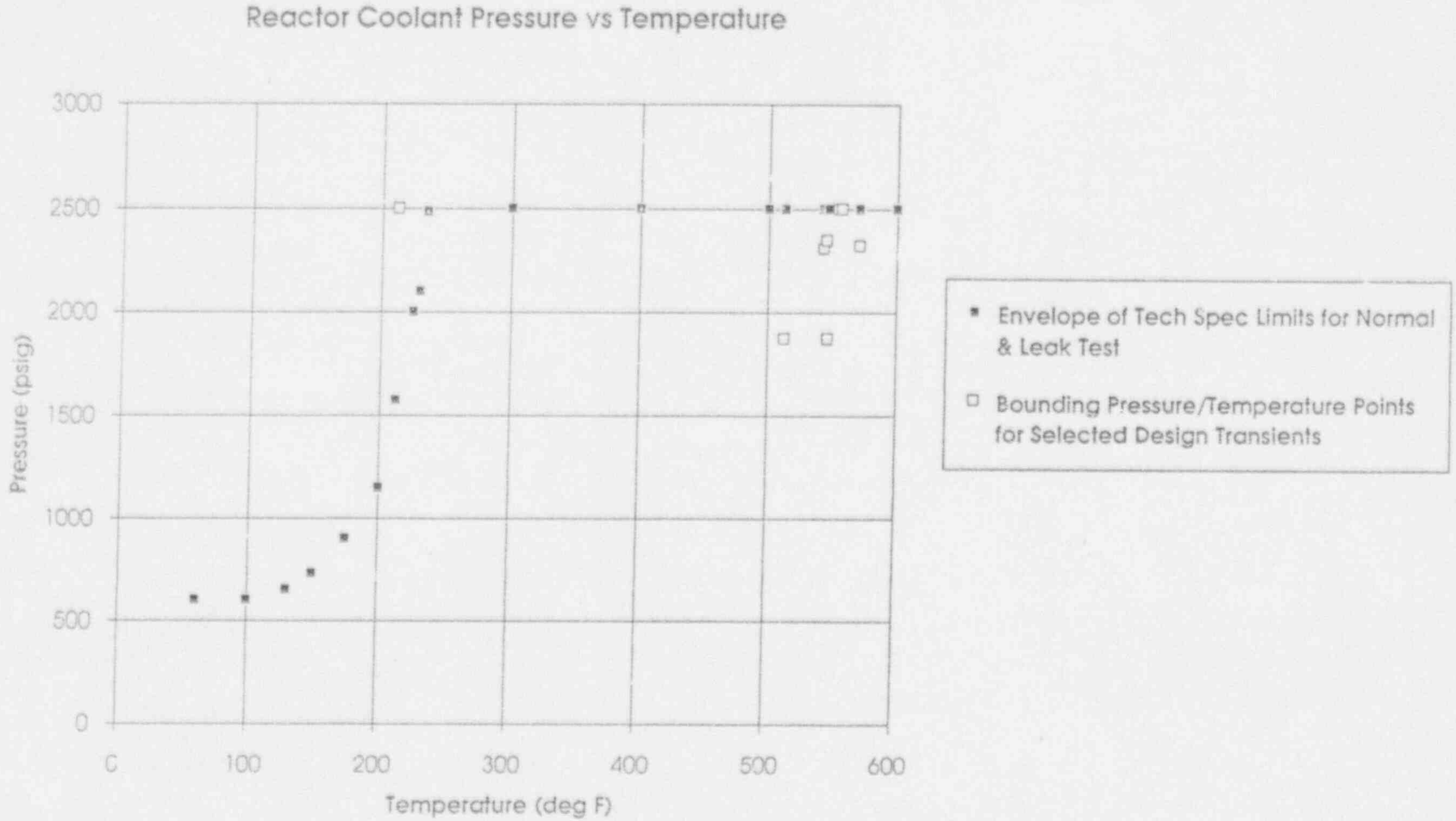
Reactor Coolant Pressure vs Temperature
Pressure (psig)
3000
2500
2000
1500
1000
500
0
0
100
200
300
400
500
600
Temperature (deg F)
Envelope of Tech Spec Limits for Normal & Leak Test
Bounding Pressure/Temperature Points for Selected Design Transients

Figure 13.6-1

13.7 Crack Growth Evaluation

Table 13.7-1 shows the evaluation of crack growth, evaluated in two parts.

Only those Normal and Upset stresses which cycle will contribute to crack growth. These are limited to those caused by pressure and uneven temperature fields.

The pressure cycling is grouped into two parts. Refer to Tables 13.3-1, 13.4-2, and 13.6-2. A full pressurization occurs only 200 times. The maximum thermal stress accompanying this is 1.5 ksi. The next highest pressure excursion is 380 psig. An exterior temperature difference of 15 °F, which bounds all cases, is assumed to accompany this pressure excursion, resulting in a thermal stress of 4.56 ksi. The number of cycles for this condition is bounded by 5267, found by summing all cycles in Table 13.3-1 and removing those for loading and unloading at 5%/min, which have no stress contribution.

Table 13.7-1 shows that the crack growth is bounded by 0.001 inches, a negligible amount.

Table 13.7-1

1980 ASME Section XI Appendix A Analysis of Flaw Indications

Bounding Cyclic Stress for Crack Growth
Units inch, kip, °F

Reactor	Note	N & U	Heatup
Temp	(1)	557.000	557.00
ΔPress	(1)	380.000	2485.00
a	(2)	0.500	0.500
l	(2)	2.400	2.400
t	(2)	5.690	5.690
a/t		0.088	0.088
a/l		0.208	0.208
RT_{NDT}	(3)	10.000	10.000
$T-RT_{NDT}$		547.000	547.00
K_{Ia}	(4)	200.000	200.00
K_{Ic}	(4)	200.000	200.00
$\Delta\sigma_m$ pres	(5)	2.951	19.298
ΔT memb	(6)	15.000	
σ_m ΔT	(6)	4.562	1.572
σ_m resid	(7)	0	0
$\Delta\sigma_m$	(8)	7.513	20.878
σ_b pres	(5)	0	0
ΔT bend	(6)	0	0
σ_b ΔT	(6)	0	0
σ_b resid	(7)	0	0
$\Delta\sigma_b$	(8)	0	0
M_m	(9)	1.100	1.100
M_b	(9)	0.920	0.920
σ_{ys}	(10)	42.516	42.516
Q	(11)	1.339	1.294
ΔK_I	(12)	8.952	25.293
N	(13)	5267.000	200.00
Δa	(14)	0.000	0.001

Total Crack Growth 0.001 inches

See notes on the following page.

Table 13.7-1

1980 ASME Section XI Appendix A Analysis of Flaw Indications

Bounding Cyclic Stress for Crack Growth

Notes:

(1) Bounding cyclic reactor coolant pressure and associated temperature for Normal & Upset transients. Reference Tables 13.3-1, 13.5-2 & 13.6-2.
(2) Crack depth, length & vessel wall thickness, Reference 12-4 & "Characterization of Flaw" section 13.2
(3) Determination of Reference Transition/Nil Ductility Temperature, reference section 13.1
(4) Available fracture toughness based on crack arrest & fracture initiation, respectively, for the corresponding crack tip temperature (ksi√in) as defined in ASME Section XI, Appendix A, Figure A-4200-1 (reference section 4.0).
(5) ΔMembrane pressure stress = PD/4t (thin wall theory hoop stress in a spherical shell) where D = 176.75". Bending component of pressure stress = 0.
(6) Use a bounding value of 15 °F for Normal & Upset transients. See Tables 13.4-1, -2 & 13.5-1. Use a bounding value of 1.572 °F for Heatup transient. See Table 13.4-2.
(7) Residual stress is non cyclic.
(8) Total membrane/bending stress to be used in ΔK_I determination. Sum of pressure, transient & residual stresses.
(9) Correction factors for membrane & bending stress as defined in ASME Section XI, Appendix A, article A-3300. See Figures A-3300-3 & A-3300-5 ($M_m = 1.1$ & $M_b = 0.9$).
(10) Yield stress of material @ temperature. Reference Figure 13.4-7 & ASME Section III, Appendix I, 1977.
(11) Shape factor for flaw as defined in Figure A-3300-1 of ASME Section XI Appendix A.
(12) ΔStress intensity factor as defined in ASME Section XI Appendix A, article A-3300. $K_I = \sigma_m M_m \sqrt{\pi}\sqrt{(a/Q)} + \sigma_b M_b \sqrt{\pi}\sqrt{(a/Q)}$
(13) Plant Loading 5%/minute has a negligible effect on the outside wall temperature. Use an envelope of all transient cycles excluding Plant Loading/Unloading @5%/minute. See Table 13.3-1.
(14) Crack Growth is determined using ASME Section XI, Apendix A, article A-4000, Figure A-4300-1. The subsurface crack growth law was used on this surface crack since the crack is on the outside in an air environment.

15.0 CONCLUSION

This calculation evaluated the McGuire Unit 2 Reactor Vessel for an external flaw indication as described in PIR 2-M93-0717. The vessel has been evaluated using the linear elastic fracture mechanics analysis methods of the ASME Boiler and Pressure Vessel Code Section XI, Appendix A and the acceptance criteria of IWB-3612.

The evaluation included all Transient and Heatup-Cooldown conditions described in the Equipment Specification as modified or otherwise limited by the Technical Specification. Specifically, it has been evaluated for a bounding Heatup event commencing from isothermal conditions at 85 °F and linearly ramping to 557 °F at 60 °F/hr.

This analysis was not intended to determine any actual margins, but to show compliance with Code criteria. The worst case comparison to Code allowables was found to be 86%.

Further note that analysis of the reactor vessel heatup using the allowable pressure from the Technical Specification Pressure-Temperature (P-T) curves (Figures 3.4-3 and 3.4-5) results in a conservative bounding of actual Unit operation. The low temperature overpressure protection (LTOP) system prevents the reactor coolant system from being pressurized above the P-T curve up to the LTOP enable temperature of 300F. The Unit startup procedure (OP/2/A/6100/01) administratively maintains LTOP up to 320F. Up to the enable temperature, the pressurizer PORV's limit pressure by the 365 - 395 low pressure mode setpoint. The peak pressure, including instrument accuracies, PORV opening times and valve accumulation is calculated to be 483 psig (ref. Duke Power calculation MCC-1223.03-00-0033). This pressure is adequate to maintain the reactor vessel below the P-T limits for a 60 °F/Hr heatup, down to temperatures as low as 85 °F. Maintaining the same PORV setpoint up to the enable temperature of 300 °F keeps actual operation well below the P-T curves of the Technical Specification and makes the pressure stresses very low during the heatup portion when vessel temperature is low and brittle fracture is a concern. For the above reasons, the analysis using actual P-T limits rather than the LTOP imposed peak pressure is very conservative.

This calculation concludes that the subject flaw does not limit operation beyond any previously set criteria for the 40 year life of the unit.

13.8 Net Section Evaluation

Acceptable by inspection.

14.0 DESCRIPTION OF COMPUTER PROGRAMS USED

TRANS2A

TRANS2A is a computer program which determines radial temperature distributions and gradients in a pipe wall experiencing fluid temperature excursions TRANS2A determines these temperature distributions by solution of the unsteady one-dimensional axisymmetric heat transfer equation. The fluid boundary properties (temperature, flow) at the end of each calculation step are used to determine the heat transfer for that step. For aid in Class 1 piping analysis values of the thermal gradients, ΔT_1 and ΔT_2 and the average temperatures (T_a and/or T_b) are calculated in accordance with ASME B&PVC Section III Article NB-3650. To be of more aid to the analyst in choosing values of the average and temperature gradient data to be input to the combined stress analysis, TRANS2A evaluates the actual histories of the thermal stress terms according to the equations of Section III, Article NB-3650 with as many as ten sets of stress indices and summarizes them in a table by extreme and time of occurrence.

TRANS2A has been extensively tested and compared with independent results for sample problems. TRANS2A temperature distributions agree favorably with calculations using TRANS1A and the EDS proprietary finite element program TAPAS. Calculations for thermal gradient terms ΔT_1 and ΔT_2 compare favorably with results from TRANS1A and with values derived from charts published by McNeill and Brock in "Engineering Data File - Charts for Transient Temperatures in Pipes", 1971.