Figure 13.4-2 and its lower and upper ranges, Figures 13.4-3 and 13.4-3.1, 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, Figures 13.4-5 and 13.4-5.1 show plots of the subject ΔT at the exterior surface as a function of the water temperature. In the determination of this stress, the ΔT values shown in Figure 13.4-5 are are used at water temperatures $\leq$ 100°F. For water temperatures above 100 °F, the maximum ΔT for the transient, 5 °F, is used. (The apparent oscillations in Figure 13.4-5.1 are numerical noise.)

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

Unit: inch, kip, °F

	Notes				
Water Temp	(1)	85.00	90.00	95.00	100.00
Metal Temp	(2)	85.00	85.22	86.57	89.00
Press	(1)	568.00	581.00	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	75.22	76.57	79.00
K_{Ia}	(5)	64.02	64.14	64.88	66.25
K_{Ic}	(5)	126.12	126.53	129.09	133.86
σ_m pres	(6)	4.41	4.51	4.61	4.73
ΔT memb	(7)	0	0.84	1.78	2.45
$\sigma_m\ \Delta T$	(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
$\sigma_b\ \Delta T$	(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
$\sqrt{2}K_I/K_{Ic}$	(15)	0.17	0.18	0.18	0.18
$\sqrt{10}K_I/K_{Ia}$	(15)	0.75	0.77	0.79	0.79

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 $E = 29.9E3$, $\alpha = 7.12E-6$ in/in/°F, $\mu = 0.3)$. 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^b 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 & Figures 13.4-5 & 13.4-6), 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.

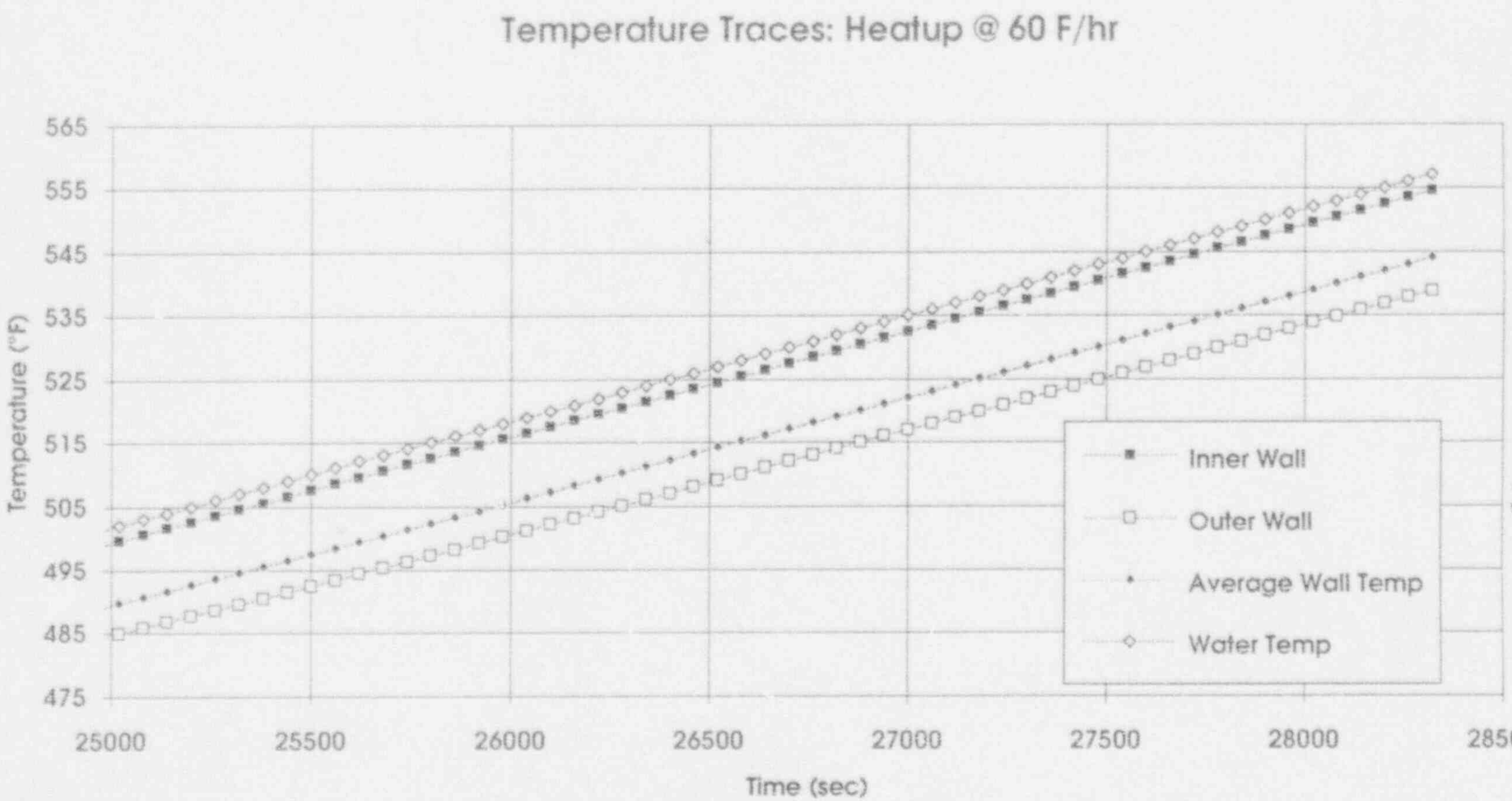

Figure 13.4-3.1

McGuire Nuclear Station File No: MCC-1201.01-00-0027 Rev. 1
Subject: Evaluation of R... or Vessel OD Flaw (PIP 2-M93-0717)
Page: 18.1 By: Date: Ck: Date: 8-24-93

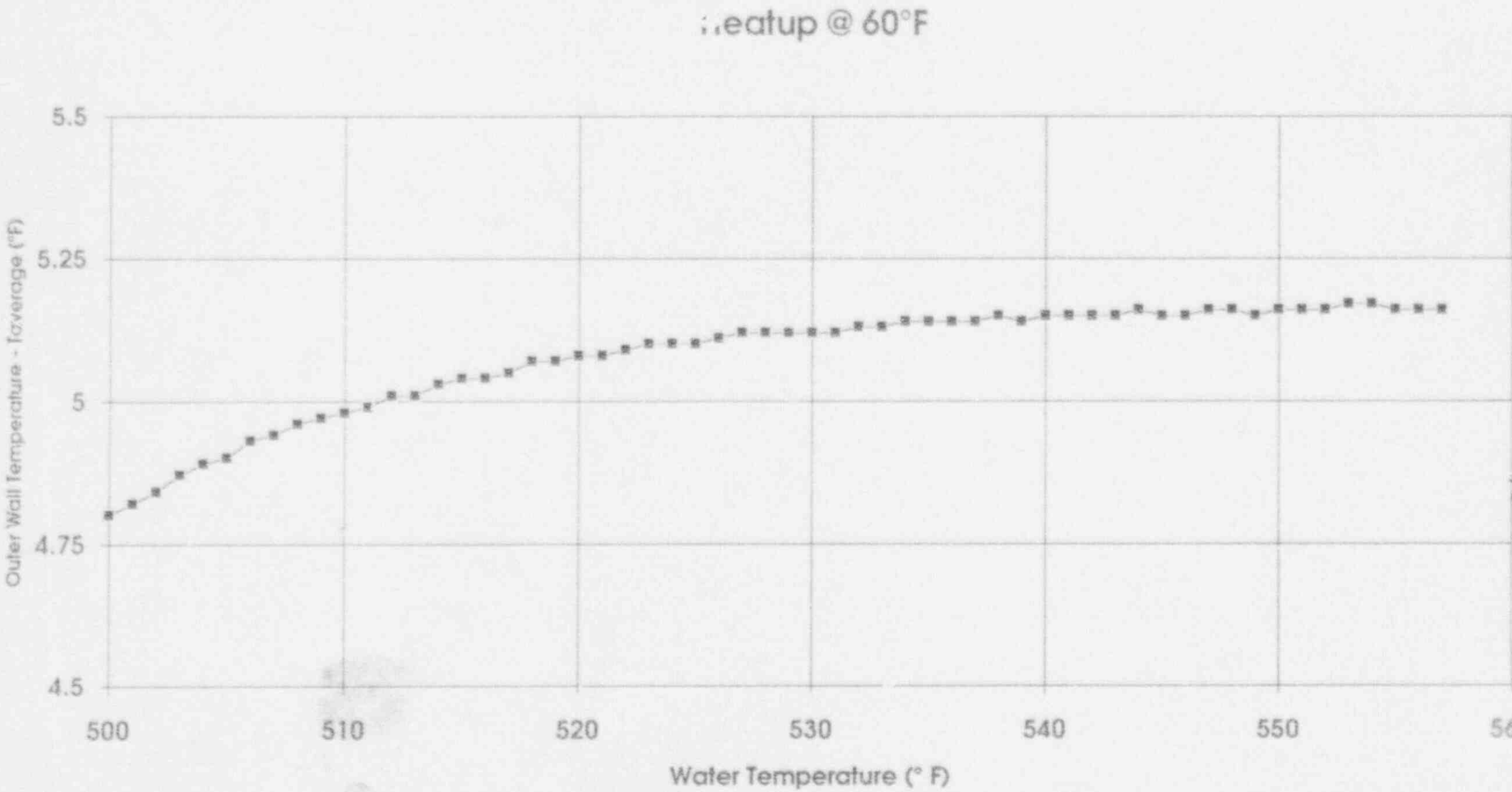

Figure 13.4-5.1

McGuire Nuclear Station Unit 2 File No: MCC-1201.01-00-0027 Rev. 1
Subject: Evaluation of Reactor Vessel OD Flaw (PIP 2-M93-0717)
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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
7,9	Loss of Flow in 1 Loop	-44	513	-375.00	1875
8,9	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.)			
13	Turbine Roll Test	(Enveloped by Normal Heatup by inspect.)			