

ATTACHMENT 2

AREVA Document No. ANP-3102, Revision 3, "Three-Mile Island Unit 1 Appendix G Pressure-Temperature Limits at 50.2 EFPY with MUR," Revision 3, dated July 2013

**Three-Mile Island Unit 1 Appendix G
Pressure-Temperature Limits
at 50.2 EFPY with MUR**



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Temperature Limits
at 50.2 EFPY with MUR**

Prepared by

S. H. Mahmoud

Reviewed by

A.D. Nana

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Exelon Generation Co., LLC

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Record of Revision

Revision No.	Pages/Sections/Paragraphs Changed	Brief Description / Change Authorization
000	All	Original Release
001	Page 2	Changed first sentence of first paragraph and deleted second and third paragraphs.
001	Page 49	Corrected graph format.
002	Pages 3 and 4	Corrected the entry on the first column last row from "IS to LS Circ. Weld (63%)" to "LS Longit. Weld (OD 63%)" in both Tables 1 and 2
003	Page 2	Corrected misrepresentation of reference number to Regulatory Guide 1.99, Revision 2 in the reference list.
	Page 6	Corrected description of the input temperature-time histories (225 is changed to 255)
	Page 13	<ol style="list-style-type: none"> 1. Changed "The location adjusted P-T limits calculated for normal step cooldown are shown in Table 10" to "The location adjusted P-T limits calculated for ISLH step cooldown are shown in Table 10" 2. Changed "The criticality limit temperature corresponding to a pressure of 2500 psig read from Figure 2, or it can be can be determined through interpolation of ISLH heatup data in Table 6." to "The criticality limit temperature corresponding to a pressure of 2500 psig can be determined through interpolation of ISLH heatup data in Table 6. 3. Changed "The criticality limit curve is shown in Figure 1" to "The criticality limit curve is shown in Figure 3"
	Page 53	Inserted reference 10.

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1.0 INTRODUCTION

This report presents operational pressure-temperature (P-T) limits for the reactor vessel at Three-Mile-Island Unit 1 (TMI-1). These limits are expressed in the form of a curve of allowable pressure versus temperature. In addition, the minimum temperature for core criticality is determined to satisfy the regulatory requirements of 10 CFR Part 50, Appendix G [1]. The uncorrected P-T limits for TMI-1 were determined for 50.2 effective full power years (EFPY) of operation with Measurement Uncertainty Re-capture (MUR). Pressure-temperature limits are calculated for the reactor vessel beltline, inlet and outlet nozzles, and closure head locations for normal heatup, normal cooldown, and inservice leak and hydrostatic (ISLH) test conditions. Pressure correction factors were determined between the RCS hot leg pressure taps and various other RCS locations.

2.0 BACKGROUND

The ability of the reactor pressure vessel to resist fracture is the primary factor in ensuring the safety of the primary system in light water-cooled reactors. The three areas of the reactor coolant pressure boundary addressed in the present report are the beltline shell region, the reactor coolant nozzles, and the closure head flange region.

A method for guarding against brittle fracture in reactor pressure vessels is described in Appendix G to the ASME Boiler and Pressure Vessel Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components." [2]. This method utilizes fracture mechanics concepts and the reference temperature for nil-ductility transition, RT_{NDT} , which is defined as the greater of the drop weight nil-ductility transition temperature (per ASTM E208 [3]) or the temperature that is 60 °F below that at which the material exhibits 50 ft-lbs and 35 mils lateral expansion. The RT_{NDT} of a given material is used to index that material to a reference stress intensity factor curve (K_{Ic}). The K_{Ic} curve appears in Appendix G of ASME Code Section XI. When a given material is indexed to the K_{Ic} curve, allowable stress intensity factors can be obtained for this material as a function of temperature. Plant operating limits can then be determined using these allowable stress intensity factors.

The RT_{NDT} of the reactor vessel materials, and in turn, the pressure/temperature limits of a reactor vessel, must be adjusted to account for the effects of irradiation. Neutron embrittlement and the resultant changes in mechanical properties of a given pressure vessel steel are monitored by a surveillance program consisting of periodic removal of surveillance capsules from an operating reactor and testing of reactor vessel material specimens obtained from the capsules. The increase in the Charpy V-notch 30 ft-lb temperature is added to the unirradiated RT_{NDT} to adjust it for neutron embrittlement. This adjusted RT_{NDT} is used to index the material to the K_{Ic} curve, which in turn, is used to set new operating limits for the nuclear power plant. These new limits take into account the effects of irradiation on the reactor vessel materials.

Pressure-temperature limits for the TMI-1 reactor vessel are developed in accordance with the requirements of 10 CFR Part 50, Appendix G [1], utilizing the analytical methods and flaw acceptance criteria of topical report BAW-10046A [4] and ASME Code Section XI, Appendix G [2].

As mentioned earlier, the three areas of the reactor coolant pressure boundary addressed in this report are the beltline shell region, the reactor coolant nozzles, and the closure head flange region. The beltline and nozzle regions are analyzed specifically for TMI-1 using the K_{Ic} reference fracture toughness. The effect of the change in the reference fracture toughness curve on the P-T limits for the closure head flange region is included by utilizing generic limits that have been derived for B&W-designed 177FA reactor vessels.

The TMI-1 reactor vessel contains both axially and circumferentially oriented welds. Therefore, the P-T limits for TMI-1 is based on the postulation of both axial and circumferential flaws in the most limiting axial and circumferential welds and the postulation of an axial flaw in the most limiting forging material of the reactor vessel.

One-hundred percent steady state condition Appendix G limits were considered for the development of low temperature overpressure protection (LTOP) P-T limits. To further support the development LTOP system limits, temperature differences between the reactor coolant in the downcomer region and the $\frac{1}{4}$ t wall location are determined for the maximum heatup rate transient. The $\frac{1}{4}$ t wall location is defined as a point within the vessel wall that is located at a distance of one quarter of the vessel thickness from the cladding-base metal interface.

3.0 ADJUSTED NIL-DUCTILITY TRANSITION REFERENCE TEMPERATURES

The $\frac{1}{4}$ t and $\frac{3}{4}$ t ART values for the TMI-1 reactor vessel beltline materials applicable to 50.2 EFPY with MUR are listed in Table 1 and Table 2. These values were calculated in accordance with Regulatory Guide 1.99, Revision 2 [10]. The calculation of the ART values for the weld metals also used BAW-2308 Revision 1A and 2A [5]. The controlling beltline materials for the Three Mile Island Unit 1 reactor vessel are the lower nozzle belt to upper shell circumferential weld with ART values at 50.2 EFPY with MUR of 216.0 °F at the $\frac{1}{4}$ T wall location and 161.1 °F at the $\frac{3}{4}$ T wall location and the axial welds of the lower shell and upper shell, respectively with ART values at 50.2 EFPY with MUR of 183.9 °F at the $\frac{1}{4}$ T wall location and 126.8 °F at the $\frac{3}{4}$ T wall location.

The ART values used for the development of the Three Mile Island Unit 1 reactor vessel P-T limits curves, calculated in 2006 for license renewal, were 234.5°F at the $\frac{1}{4}$ T wall location and 178.5°F at the $\frac{3}{4}$ T wall location for the circumferential welds. The ART values used for the axial welds were 184.7 °F at the $\frac{1}{4}$ T wall location and 126.8 °F at the $\frac{3}{4}$ T wall location. Thus, in all instances the actual ART values or conservative ART values were used in the development of P-T limit curves performed in 2006.

Table 1: Adjusted Reference Temperature Evaluation for the TMI-1 Reactor Vessel Beltline Materials at the 1/4-Thickness Locations Applicable Through 50.2 EFPY with MUR

Reactor Vessel Beltline Region Location	Matl. Ident.	Heat Number	Type	Cu	Ni	Estimated Fluence @ 50.2 EFPY, n/cm ²		Adjusted Reference Temperature Evaluation at 1/4T Location							
						IS	1/4T	Chem. Factor	Fluence Factor	Initial RT _{NDT} , °F	σ _i	σ _D	RT _{NDT} Shift, °F	Margin	1/4T ART
Regulatory Guide 1.99, Revision 2, Position 1.1															
Lower Nozzle Belt Forging (LNB)	ARY 59	123S454	SA-508 Cl 2	0.08	0.72	1.32E+19	7.698E+18	51.0	0.927	3	31	17	47.3	70.7	121.0
Upper Shell Plate (US)	C2789-1	C2789-1	SA-302 Gr B Mod.	0.09	0.57	1.47E+19	8.575E+18	58.0	0.957	1	26.9	17	55.5	63.6	120.1
Upper Shell Plate (US)	C2789-2	C2789-2	SA-302 Gr B Mod.	0.09	0.57	1.47E+19	8.575E+18	58.0	0.957	1	26.9	17	55.5	63.6	120.1
Lower Shell Plate (LS)	C3307-1	C3307-1	SA-302 Gr B Mod.	0.12	0.55	1.47E+19	8.575E+18	82.0	0.957	1	26.9	17	78.5	63.6	143.1
Lower Shell Plate (LS)	C3251-1	C3251-1	SA-302 Gr B Mod.	0.11	0.5	1.47E+19	8.575E+18	73.0	0.957	1	26.9	17	69.9	63.6	134.5
LNB to US Circ. Weld (100%)	WF-70	72105	Linde 80 Flux	0.32	0.58	1.32E+19	7.698E+18	199.3	0.927	-31.1	13.7	28	184.8	62.3	[216.0]
US Longit. Weld (Both 100%)	WF-8	8T1762	Linde 80 Flux	0.19	0.57	1.31E+19	7.662E+18	167.0	0.925	-47.6	17.2	28	154.5	65.7	172.6
US to LS Circ. Weld (100%)	WF-25	299L44	Linde 80 Flux	0.34	0.68	1.43E+19	8.335E+18	220.6	0.949	-74.3	12.8	28	209.3	61.6	196.6
LS Longit. Weld (100%)	SA-1526	299L44	Linde 80 Flux	0.34	0.68	1.16E+19	6.778E+18	220.6	0.891	-74.3	12.8	28	196.6	61.6	{183.9}
LS Longit. Weld (ID 37%)	SA-1526	299L44	Linde 80 Flux	0.34	0.68	1.15E+19	6.755E+18	220.6	0.890	-74.3	12.8	28	196.3	61.6	183.6
LS Longit. Weld (OD 63%)	SA-1494	8T1554	Linde 80 Flux	0.16	0.57	1.15E+19	N/A	167.0	N/A	-47.6	17.2	28	N/A	N/A	N/A

[] - Highest values of the adjusted reference temperature for circumferential welds.

{ } - Highest values of the adjusted reference temperature for base metal or longitudinal welds.

Table 2: Adjusted Reference Temperature Evaluation for the TMI -1 Reactor Vessel Beltline Materials at the 3/4-Thickness Locations Applicable Through 50.2 EFPY with MUR

Reactor Vessel Beltline Region Location	Matl Ident.	Heat Number	Type	Cu	Ni	Estimated Fluence @ 50.2 EFPY, n/cm ²		Adjusted Reference Temperature Evaluation at 3/4T Location							
						IS	3/4T	Chem. Factor	Fluence Factor	Initial RT _{NDT} , °F	σ ₁	σ _D	RT _{NDT} Shift, °F	Margin	3/4T ART
						Regulatory Guide 1.99, Revision 2, Position 1.1									
Lower Nozzle Belt Forging (LNB)	ARY 59	123S454	SA-508 Cl 2	0.08	0.72	1.32E+19	2.80E+18	51.0	0.652	3	31	17	33.3	70.4	106.7
Upper Shell Plate (US)	C2789-1	C2789-1	SA-302 Gr B Mod.	0.09	0.57	1.47E+19	3.12E+18	58.0	0.680	1	26.9	17	39.4	63.6	104.0
Upper Shell Plate (US)	C2789-2	C2789-2	SA-302 Gr B Mod.	0.09	0.57	1.47E+19	3.12E+18	58.0	0.680	1	26.9	17	39.4	63.6	104.0
Lower Shell Plate (LS)	C3307-1	C3307-1	SA-302 Gr B Mod.	0.12	0.55	1.47E+19	3.12E+18	82.0	0.680	1	26.9	17	55.8	63.6	120.4
Lower Shell Plate (LS)	C3251-1	C3251-1	SA-302 Gr B Mod.	0.11	0.50	1.47E+19	3.12E+18	73.0	0.680	1	26.9	17	49.6	63.6	114.2
LNB to US Circ. Weld (100%)	WF-70	72105	Linde 80 Flux	0.32	0.58	1.32E+19	2.80E+18	199.3	0.652	-31.1	13.7	28	129.9	62.3	[161.1]
US Longit. Weld (Both 100%)	WF-8	8T1762	Linde 80 Flux	0.19	0.57	1.31E+19	2.78E+18	167.0	0.651	-47.6	17.2	28	108.7	65.7	{126.8}
US to LS Circ. Weld (100%)	WF-25	299L44	Linde 80 Flux	0.34	0.68	1.43E+19	3.03E+18	220.6	0.673	-74.3	12.8	28	148.5	61.6	135.8
LS Longit. Weld (100%)	SA-1526	299L44	Linde 80 Flux	0.34	0.68	1.16E+19	2.46E+18	220.6	0.620	-74.3	12.8	28	136.8	61.6	124.1
LS Longit. Weld (ID 37%)	SA-1526	299L44	Linde 80 Flux	0.34	0.68	1.15E+19	N/A	220.6	N/A	-74.3	12.8	28	N/A	N/A	N/A
LS Longit. Weld (OD 63%)	SA-1494	8T1554	Linde 80 Flux	0.16	0.57	1.15E+19	2.45E+18	167.0	0.619	-47.6	17.2	28	103.4	65.7	121.5

[] - Highest values of the adjusted reference temperature for circumferential welds.

{ } - Highest values of the adjusted reference temperature for base metal or longitudinal welds.

4.0 DESIGN BASIS FOR PRESSURE/TEMPERATURE LIMITS

Essential geometric data and analytical parameters used in the preparation of TMI-1 P-T limits are described below.

4.1 Material Properties

Table 3 describes the material properties used in the development of the P-T limits for the TMI-1.

Table 3: Material Properties

Temp.	Elastic Modulus	Thermal Expansion	Thermal Conductivity	Specific Heat	Density	Poisson's Ratio
	Ref. [6]	Ref.[6]	Ref.[6]	Ref.[6]		(assumed)
(°F)	(10 ⁶ psi)	(10 ⁻⁶ in/in/°F)	Btu/hr-ft-°F)	(Btu/lb-°F)	(lb/ft ³)	
70	29.20	7.02	23.3	0.104	490.9	0.3
100	29.04	7.06	23.6	0.107	490.5	0.3
150	28.77	7.16	24.1	0.111	489.9	0.3
200	28.50	7.25	24.4	0.114	489.2	0.3
250	28.25	7.34	24.6	0.117	488.6	0.3
300	28.00	7.43	24.7	0.121	487.9	0.3
350	27.70	7.50	24.7	0.124	487.3	0.3
400	27.40	7.58	24.6	0.127	486.7	0.3
450	27.20	7.63	24.4	0.129	486.0	0.3
500	27.00	7.70	24.2	0.132	485.4	0.3
550	26.70	7.77	23.9	0.135	484.7	0.3
600	26.40	7.83	23.5	0.138	484.1	0.3
650	25.85	7.90	23.2	0.141	483.4	0.3
700	25.30	7.94	22.8	0.144	482.8	0.3

4.2 Postulated Flaws

a. Postulated Reactor Vessel Beltline Flaws

Semi-elliptical surface flaws that are $\frac{1}{4}t$ deep and $1\frac{1}{2}t$ long are postulated on the inside and outside surfaces of the reactor vessel beltline region. A longitudinal flaw is postulated in the base metal and the axial seam welds and a circumferential flaw is postulated in the circumferential welds.

b. Postulated Nozzle Corner Flaw

A 3" ($\frac{1}{4}t_{NB}$) deep corner flaw is postulated on the inside surface of the reactor vessel inlet and outlet nozzles.

4.3 Upper Shelf Toughness

A maximum value of 200 ksi $\sqrt{\text{in}}$ is used for the upper shelf fracture toughness of the reactor vessel beltline. For the nozzle forging materials, a "no cut-off" limit is used.

4.4 Uncorrected Reactor Vessel Closure Head Limits

Pressure-temperature limits for the reactor vessel head-to-flange closure region for normal operation and ISLH operation were derived for TMI-1 reactor vessel closure head region based on the K_{Ic} fracture toughness curve.

4.5 Convection Film Coefficient

A value of 1000 BTU/hr-ft²-°F is used for an effective convective heat transfer film coefficient at the cladding-to-base metal interface for all times during heatup and cooldown when reactor coolant pumps (RCPs) are in use. When no reactor coolant pumps are running (i.e., before the first RCP is started during heatup and after the last RCP is shut off during cooldown), a value of 430 BTU/hr-ft²-°F is used as an effective film coefficient at the cladding-to-base metal interface. This value was developed for flow conditions when no RCPs are running and 40 °F water enters the vessel through the core flood nozzle as the decay heat removal system switches to an idle low pressure injection cooler. The outside surface is always modeled as a perfectly insulated boundary.

4.6 Reactor Coolant Temperature-Time Histories

Both ramped and stepped transient definitions are modeled for normal operation heatup and cooldown. The limiting normal heatup and cooldown transients (as determined by the controlling P-T limits) are also used to simulate the reactor coolant transients used for inservice leak and hydrostatic (ISLH) pressure testing.

The following input temperature-time histories are considered:

Normal Ramp Heatup, 50 °F/hr.

Normal Step Heatup, 15 °F/ 18 min. steps.

Normal Ramp Cooldown, 100 °F/hr to 255 °F then 30 °F/hr to 70 °F.

Normal Step Cooldown, 15°F/ 9 min. steps to 255 °F then 15 °F/ 30 min. steps to 70 °F.

4.7 Adjusted Reference Temperatures

As discussed in Section 3.0, limiting values of the adjusted reference temperature were evaluated. The limiting ART or RT_{NDT} values that were used for determining the P-T curves are also listed in Table 4 for the $1/4t$ and $3/4t$ locations of the reactor vessel beltline wall at 50.2 EPY with MUR. An RT_{NDT} of 60 °F is used for the reactor vessel nozzles.

Table 4: Limiting RT_{NDT} 's for TMI-1 Beltline Materials

Vessel Component	Wall Location	Limiting Material	RT_{NDT} (°F) at 50.2 EFPY
Beltline Axial Weld	$1/4t$	SA-1526	184.7
	$3/4t$	WF-8	126.8
Beltline Circ. Weld	$1/4t$	WF-70	234.5
	$3/4t$	WF-70	178.5

5.0 TECHNICAL BASIS FOR PRESSURE/TEMPERATURE LIMITS

Pressure-temperature limits are developed using an analytical approach that is in accordance with the requirements of the ASME Boiler and Pressure Vessel Code, Section XI, Appendix G [2]. Additional requirements are contained in Table 1 of Appendix G to Title 10, Code of Federal Regulations, Part 50 [1]. The analytical techniques used to calculate P-T limits are based on approved linear elastic fracture mechanics methodology described in topical report BAW-10046A [4]. The fundamental equation used to calculate the allowable pressure is

$$P_{\text{allow}} = \frac{K_{\text{IR}} - K_{\text{IT}}}{\text{SF} \times \hat{K}_{\text{IP}}}$$

where, P_{allow}	=	allowable pressure
K_{IR}	=	reference stress intensity factor (K_{Ia} or K_{Ic})
K_{IT}	=	thermal stress intensity factor
\hat{K}_{IP}	=	unit pressure stress intensity factor (due to 1 psig)
SF	=	safety factor

For each analyzed transient and steady state condition, the allowable pressure is determined as a function of reactor coolant temperature considering postulated flaws in the reactor vessel beltline, inlet nozzle, outlet nozzle, and closure head. In the beltline region, flaws are postulated to be present at the $1/4t$ and $3/4t$ locations of the controlling material (shell forging, or circumferential weld), as defined by the fluence adjusted RT_{NDT} . The reactor vessel nozzle flaws are located at the inside juncture (corner) with the nozzle shell, and the closure head flaw is located near the outside juncture with the head flange. P-T limits for the beltline and nozzle regions are calculated using a safety factor of 2 for normal operation and 1.5 for ISLH operation. The P-T limit curves presented consist of the allowable pressures for the controlling beltline flaw, inlet and outlet nozzles, and closure head, as a function of fluid temperature. These curves have been "smoothed", as necessary, to eliminate irregularities associated with the startup of the first reactor coolant pump during heatup and the initiation of decay heat removal during cooldown. After the initial determination of the P-T limit curves, location specific curves were adjusted for sensor location. No instrument error correction has been applied. The final results include the determination of a minimum/lower bound P-T curve.

The criticality limit temperature is obtained by determining the maximum required ISLH test temperature at a pressure of 2500 psig (approximately 10% above the normal operating pressure). The ISLH analysis considers the most limiting heatup and cooldown transients. The approach satisfies the requirement of Item 2.d in Table 1 of 10 CFR 50, Appendix G [1]. It requires the minimum temperature to be the larger of minimum permissible temperature for inservice system hydrostatic pressure test or the RT_{NDT} of the closure flange material + 160 °F.

Various aspects of the calculation procedures utilized in the development of P-T limits are discussed below.

5.1 Fracture Toughness

The fracture toughness of reactor vessel steels is expressed as a function of crack-tip temperature, T , indexed to the adjusted reference temperature of the material, RT_{NDT} . Pressure-Temperature limits developed in accordance with ASME Code, Section XI, Appendix G, as permitted by RIS 2004-04 [7], utilize the crack initiation fracture toughness,

$$K_{Ic} = 33.2 + 2.806 \exp [0.02 (T - RT_{NDT} + 100 \text{ }^\circ\text{F})]$$

The upper shelf fracture toughness is limited to an upper bound value of 200 ksi $\sqrt{\text{in}}$ for the reactor vessel welds and base metal and 250 ksi $\sqrt{\text{in}}$ for the inlet and outlet nozzles. The crack-tip temperature needed for these fracture toughness equations is obtained from the results of a transient thermal analysis, described below.

5.2 Thermal Analysis and Thermal Stress Intensity Factor

Through-wall temperature distributions are determined by solving the one-dimensional transient axisymmetric heat conduction equation,

$$\rho C_p \frac{\partial T}{\partial t} = k \left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r} \frac{\partial T}{\partial r} \right) ,$$

subject to the following boundary conditions:

at the inside surface, where $r = R_i$,

$$-k \frac{\partial T}{\partial r} = h(T_w - T_b)$$

at the outside surface, where $r = R_o$,

$$\frac{\partial T}{\partial r} = 0$$

where,

ρ = density

C_p = specific heat

k = thermal conductivity

T = temperature

r = radial coordinate

t = time

h = convection heat transfer coefficient

T_w = wall temperature

T_b = bulk coolant temperature

R_i = inside radius of vessel

R_o = outside radius of vessel

The above equation is solved numerically using a finite difference technique to determine the temperature at 17 points through the wall as a function of time for prescribed changes in the bulk fluid temperature, such as multi-rate ramp and step changes for heatup and cooldown transients.

An equivalent linear thermal bending stresses (based on ΔT through the wall) is derived from the through-wall temperature distribution at each solution time point. Through-wall thermal stress distributions are determined by trapezoidal integration of the following expression:

Thermal hoop stresses:

$$\sigma_{\theta}(r) = \frac{E\alpha}{1-\nu} \frac{1}{r^2} \left(\frac{r^2 + R_i^2}{R_o^2 - R_i^2} \int_{R_i}^{R_o} T r dr + \int_{R_i}^r T r dr - T r^2 \right) \quad [8, \text{Eqn (255)}]$$

Expressing the thermal stress distributions by

$$\sigma(x) = C_0 + C_1 (x/a) + C_2 (x/a)^2 + C_3 (x/a)^3,$$

where,

x = is a dummy variable that represents the radial distance from the appropriate (i.e., inside or outside) surface, in.

a = the flaw depth, in.

The thermal stress intensity factors are defined by the following relationships:

For a $1/4$ t inside surface flaw during cooldown,

$$K_{It} = (1.0359 C_0 + 0.6322 C_1 + 0.4753 C_2 + 0.3855 C_3) \sqrt{\pi a}$$

For a $1/4$ t outside surface flaw during heatup,

$$K_{It} = (1.043 C_0 + 0.630 C_1 + 0.481 C_2 + 0.401 C_3) \sqrt{\pi a}$$

5.3 Unit Pressure Stress Intensity Factor for Reactor Vessel Beltline Region

The membrane stress intensity factor in the reactor vessel shell due to a unit pressure load is

$$K_{Im} = M_m \times R_i / t$$

where

R_i = vessel inner radius, in.

$t =$ vessel wall thickness, in.

For a longitudinal $\frac{1}{4}$ -thickness x $\frac{3}{2}$ -thickness semi-elliptical surface flaw:

at the inside surface,

$$\begin{aligned} M_m &= 1.85 && \text{for } \sqrt{t} < 2 \\ &= 0.926 \sqrt{t} && \text{for } 2 \leq \sqrt{t} \leq 3.464 \\ &= 3.21 && \text{for } \sqrt{t} > 3.464 \end{aligned}$$

at the outside surface,

$$\begin{aligned} M_m &= 1.77 && \text{for } \sqrt{t} < 2 \\ &= 0.893 \sqrt{t} && \text{for } 2 \leq \sqrt{t} \leq 3.464 \\ &= 3.09 && \text{for } \sqrt{t} > 3.464 \end{aligned}$$

5.4 Unit Pressure Stress Intensity Factor for Reactor Vessel Nozzles

Considering a nozzle as a hole in a shell, WRC Bulletin 175 [9] presents the following method for estimating stress intensity factors for a nozzle corner flaw:

$$K_{Im} = \sigma \sqrt{\pi a} F(a/r_n)$$

where

$$\sigma = R_i / t$$

$R_i =$ nozzle belt shell inner radius, in.

$t =$ nozzle belt shell wall thickness, in.

$a =$ flaw depth, in.

$r_n =$ apparent radius of nozzle, in.

$$= r_i + 0.29r_c$$

$r_i =$ inner radius of nozzle, in.

$r_c =$ nozzle corner radius, in.

and

$$F(a/r_n) = 2.5 - 6.108(a/r_n) + 12(a/r_n)^2 - 9.1664(a/r_n)^3$$

6.0 PRESSURE CORRECTIONS

The uncorrected P-T limits are calculated at the required locations or components in the RCS. However, the plant uses only two instruments locations for indicated pressure, the pressurizer low range tap and the hot leg wide range tap. Therefore, the uncorrected P-T limits may be corrected to one or both of these locations. These location corrections were calculated using a TMI-1 Cycle 19 RCS hydraulics model with 0% steam generator tube plugging, and analyzing it for various temperatures and pump combinations.

The location corrections are based on 0/0 pumps operating up to 100 °F (the conservative start temperature for the first two pumps) and then based on 2/0 pumps up to ~ 200 °F, and 2/1 pumps up to ~ 350 °F. The low range corrections (taken from the pressurizer) are conservatively estimated to be a constant 10 psi less than the wide range corrections (taken from the hot leg tap). Thus the limiting location corrections are from hot leg (wide range) tap and are applied to the P-T limits. The hot leg (wide range) tap pressure corrections are presented below in Table 5.

Table 5: Limiting Location Corrections Factors for Pressure

Temperature Range, °F	70 [†] -100		101-199		200-349		350-499		500-532 [‡]	
	ΔP, psi	RCP	ΔP, psi	RCP	ΔP, psi	RCP	ΔP, psi	RCP	ΔP, psi	RCP
Beltline	22 (WR)	0/0	90 (WR)	2/0	104 (WR)	2/1	111	2/2	99	2/2
Outlet Nozzle	17 (WR)	0/0	74 (WR)	2/0	74 (WR)	2/0	67	2/0	51	2/1
RVCH	13 (WR)	0/0	70 (WR)		N/A		N/A		N/A	

[†] The correction factor was used for 60°F as well, since the rounded correction factors are found to be bounding

[‡] The correction factor is used for temperatures above 532°F since the values are bounding for higher temperature

7.0 SUMMARY OF RESULTS

The following is a summary of results for the TMI-1 P-T limits at 50.2 EFPY with MUR analysis corrected for location only. No correction due to instrument uncertainty is applied.

7.1 P-T Curves for ISLH Heatup / Cooldown

The Pressure-Temperature limits are developed for ISLH test operations. For ISLH heatup, adjusted location specific (i.e. on a per component basis) P-T limits are presented in Table 6. The Tech. Spec. basis P-T limits for ISLH heatup are shown in Table 8. The location adjusted P-T limits for ISLH ramp cooldown are presented in Table 9. The location adjusted P-T limits calculated for ISLH step cooldown are shown in Table 10. The Technical specification (Tech. Spec.) basis P-T limits for ISLH cooldown generated as the limiting allowable pressure at every calculated temperature is shown in Table 11. The adjusted P-T limits for ISLH heatup and cooldown are plotted in Figure 1. A limiting composite curve for Tech. Spec. Basis P-T limits for ISLH is developed, the pressure-temperature data is shown in Table 12 and the curve is plotted in Figure 2. The criticality limit temperature corresponding to a pressure of 2500 psig can be determined through interpolation of ISLH heatup data in Table 6. As shown in Table 7, the criticality limit temperature is 262.7 °F. The criticality limit curve is shown in Figure 3 along with the normal heatup Tech. Spec. basis P-T limit curve.

Table 6: TMI-1 Adjusted Location Specific P-T Limits for ISLH Heatup

Fluid Temp.	Allowable Pressures			
	Limiting Beltline Weld	Outlet Nozzle	Inlet Nozzle	Closure Head
	(°F)	(psi)	(psi)	(psi)
60	832	873	907	671
65	833	878	912	811
70	835	892	927	953
75	838	912	947	1095
80	841	934	971	1237
85	841	948	985	1435
90	850	991	1030	1633
95	857	1029	1069	1831
100	863	1071	1113	2029
105	802	1059	1102	2170
110	810	1108	1153	
115	819	1162	1210	
120	828	1222	1272	
125	839	1289	1341	
130	851	1363	1418	
135	864	1444	1503	
140	879	1534	1596	
145	895	1634	1700	
150	913	1744	1814	
155	932	1866	1941	
160	954	2001	2080	
165	978	2149	2235	
170	1005	2314	2405	
175	1035	2495	2594	
180	1067	2696	2802	
185	1103	2918	3033	
190	1143	3163	3287	
195	1187	3433	3568	
200	1222	3732	3878	
205	1275	4050	4208	
210	1335	4050	4208	
215	1400	4050	4208	
220	1473	4050	4208	
225	1553	4050	4208	
230	1642	4050	4208	
235	1740	4050	4208	
240	1848	4050	4208	
245	1967	4050	4208	
250	2099	4050	4208	
255	2244	4050	4208	
260	2405	4050	4208	

Fluid Temp.	Allowable Pressures			
	Limiting Beltline Weld	Outlet Nozzle	Inlet Nozzle	Closure Head
	(°F)	(psi)	(psi)	(psi)
265	2582	4050	4208	
270	2777	4050	4208	
275	2993	4050	4208	
280	3231	4050	4208	
285	3494	4050	4208	
290	3785	4050	4208	
295	4106	4050	4208	
300	4460	4050	4208	
305	4788	4050	4208	
310	4788	4050	4208	
315	4788	4050	4208	
320	4787	4050	4208	
325	4787	4050	4208	
330	4787	4050	4208	
335	4786	4050	4208	
340	4786	4050	4208	
345	4786	4050	4208	
350	4778	4057	4215	
355	4778	4057	4215	
360	4777	4057	4215	
365	4777	4057	4215	
370	4776	4057	4215	
375	4776	4057	4215	
380	4775	4057	4215	
385	4775	4057	4215	
390	4774	4057	4215	
395	4774	4057	4215	
400	4773	4057	4215	
405	4773	4057	4215	
410	4772	4057	4215	
415	4772	4057	4215	
420	4771	4057	4215	
425	4771	4057	4215	
430	4771	4057	4215	
435	4770	4057	4215	
440	4770	4057	4215	
445	4770	4057	4215	
450	4770	4057	4215	
455	4769	4057	4215	
460	4769	4057	4215	
465	4768	4057	4215	
470	4768	4057	4215	
475	4766	4057	4215	
480	4766	4057	4215	
485	4766	4057	4215	

Fluid Temp.	Allowable Pressures			
	Limiting Beltline Weld	Outlet Nozzle	Inlet Nozzle	Closure Head
(°F)	(psi)	(psi)	(psi)	(psi)
490	4765	4057	4215	
495	4765	4057	4215	
500	4776	4073	4231	
505	4776	4073	4231	
510	4775	4073	4231	
515	4775	4073	4231	
520	4774	4073	4231	
525	4773	4073	4231	
530	4773	4073	4231	
535	4772	4073	4231	
540	4772	4073	4231	
545	4772	4073	4231	
550	4771	4073	4231	
555	4771	4073	4231	
560	4770	4073	4231	
565	4769	4073	4231	
570	4769	4073	4231	

Table 7: TMI-1 Criticality Limit Temperature Determination

Criticality Limit Temp. at 2500 psig	
Pressure	Temp.
(psig)	(°F)
2405	260
2582	265
Interpolating:	
2500	262.7

Table 8: TMI-1 Tech. Spec. Basis P-T Limits for ISLH Heatup

Fluid Temp.	Governing Adjusted Pressure
(°F)	(psi)
60	671
65	802
70	802
75	802
80	802
85	802
90	802
95	802
100	802
105	802
110	810
115	819
120	828
125	839
130	851
135	864
140	879
145	895
150	913
155	932
160	954
165	978
170	1005
175	1035
180	1067
185	1103
190	1143
195	1187
200	1222
205	1275
210	1335
215	1400
220	1473
225	1553
230	1642
235	1740
240	1848
245	1967
250	2099
255	2244
260	2405

Fluid Temp.	Governing Adjusted Pressure
(°F)	(psi)
265	2582
270	2777
275	2993
280	3231
285	3494
290	3785
295	4050
300	4050
305	4050
310	4050
315	4050
320	4050
325	4050
330	4050
335	4050
340	4050
345	4050
350	4057
355	4057
360	4057
365	4057
370	4057
375	4057
380	4057
385	4057
390	4057
395	4057
400	4057
405	4057
410	4057
415	4057
420	4057
425	4057
430	4057
435	4057
440	4057
445	4057
450	4057
455	4057
460	4057
465	4057
470	4057
475	4057
480	4057
485	4057

Fluid Temp.	Governing Adjusted Pressure
(°F)	(psi)
490	4057
495	4057
500	4073
505	4073
510	4073
515	4073
520	4073
525	4073
530	4073
535	4073
540	4073
545	4073
550	4073
555	4073
560	4073
565	4073
570	4073

Table 9: TMI-1 Adjusted Location Specific P-T Limits for ISLH Ramp Cooldown

Fluid Temp.	Allowable Pressures			
	Limiting Beltline Weld	Outlet Nozzle	Inlet Nozzle	Closure Head
	(°F)	(psi)	(psi)	(psi)
70	733	937	974	953
75	742	992	1031	1095
80	753	1041	1081	1237
85	765	1094	1137	1435
90	780	1154	1199	1633
95	786	1219	1267	1831
105	724	1295	1347	2170
110	727	1361	1416	
115	743	1501	1562	
120	759	1609	1674	
125	776	1728	1798	
130	795	1860	1935	
135	816	2006	2086	
140	840	2167	2254	
145	866	2346	2439	
150	894	2542	2643	
155	926	2760	2869	
160	961	3001	3119	
165	999	3266	3395	
170	1042	3560	3700	
175	1089	3772	3919	
180	1141	3761	3908	
185	1199	3748	3895	
190	1263	3733	3879	
195	1334	3716	3862	
200	1397	3696	3841	
205	1469	3674	3818	
210	1549	3646	3789	
215	1638	3616	3757	
220	1735	3581	3721	
225	1844	3540	3679	
230	1963	3492	3629	
235	2066	3395	3528	
240	2193	3462	3598	
245	2402	3405	3538	
250	2580	3342	3473	
255	2777	3293	3423	
260	2995	3295	3424	
265	3235	3296	3426	
270	3501	3298	3428	
275	3795	3300	3430	

Fluid Temp.	Allowable Pressures			
	Limiting Beltline Weld	Outlet Nozzle	Inlet Nozzle	Closure Head
	(°F)	(psi)	(psi)	(psi)
280	4119	3302	3432	
285	4308	3304	3434	
290	4308	3307	3436	
295	4307	3309	3439	
300	4306	3312	3442	
305	4306	3315	3445	
310	4305	3318	3448	
315	4305	3323	3454	
320	4305	3326	3457	
325	4304	3330	3461	
330	4304	3334	3465	
335	4304	3338	3469	
340	4304	3342	3473	
345	4304	3347	3478	
350	4297	3358	3490	
355	4298	3363	3495	
360	4298	3369	3501	
365	4298	3375	3507	
370	4298	3378	3511	
375	4299	3385	3518	
380	4299	3392	3525	
385	4300	3399	3533	
390	4301	3407	3541	
395	4302	3415	3549	
400	4304	3424	3558	
405	4304	3433	3568	
410	4306	3442	3577	
415	4308	3452	3588	
420	4311	3463	3598	
425	4314	3474	3610	
430	4318	3485	3622	
435	4322	3496	3633	
440	4326	3509	3646	
445	4331	3522	3660	
450	4337	3536	3674	
455	4343	3550	3689	
460	4349	3565	3705	
465	4356	3581	3721	
470	4364	3597	3738	
475	4373	3614	3756	
480	4383	3632	3774	
485	4393	3651	3793	
490	4405	3670	3814	
495	4418	3690	3834	
500	4444	3727	3872	

Fluid Temp.	Allowable Pressures			
	Limiting Beltline Weld	Outlet Nozzle	Inlet Nozzle	Closure Head
	(°F)	(psi)	(psi)	(psi)
505	4459	3749	3895	
510	4476	3769	3916	
515	4494	3793	3941	
520	4513	3818	3966	
525	4533	3843	3993	
530	4556	3870	4020	
535	4582	3897	4049	
540	4609	3925	4077	
545	4638	3953	4107	
550	4670	3982	4137	
555	4703	4010	4166	
560	4738	4037	4194	
565	4772	4060	4218	
570	4793	4072	4231	

Table 10: TMI-1 Adjusted Location Specific P-T Limits for ISLH Step Cooldown

Fluid Temp.	Allowable Pressures			
	Limiting Beltline Weld	Outlet Nozzle	Inlet Nozzle	Closure Head
(F)	(psi)	(psi)	(psi)	(psi)
70	766	910	945	953
80	781	1038	1078	1237
85	788	1094	1137	1435
100	813	1292	1342	2029
105	757	1324	1377	2170
115	780	1501	1562	
130	828	1860	1935	
145	893	2346	2439	
160	980	3001	3119	
175	1098	3811	3960	
190	1258	3772	3920	
205	1464	3712	3858	
220	1735	3619	3761	
235	2050	3435	3570	
240	2241	3501	3638	
255	2777	3314	3444	
270	3501	3318	3448	
285	4347	3323	3454	
300	4345	3330	3461	
315	4343	3338	3470	
330	4343	3351	3482	
345	4342	3362	3495	
360	4336	3383	3516	
375	4336	3398	3531	
390	4337	3418	3552	
405	4341	3442	3577	
420	4345	3470	3606	
435	4353	3502	3639	
450	4366	3538	3676	
465	4382	3580	3720	
480	4405	3628	3770	
495	4436	3682	3826	
510	4487	3759	3906	
525	4539	3827	3976	
540	4605	3905	4057	
555	4690	3989	4144	

Table 11: TMI-1 Tech Spec. Basis P-T Limits for ISLH Cooldown

Fluid Temp.	Governing Adjusted Pressure
(°F)	(psi)
70	724
75	724
80	724
85	724
90	724
95	724
105	724
110	727
115	743
120	759
125	776
130	795
135	816
140	840
145	866
150	894
155	926
160	961
165	999
170	1042
175	1089
180	1141
185	1199
190	1258
195	1334
200	1397
205	1464
210	1549
215	1638
220	1735
225	1844
230	1963
235	2050
240	2193
245	2402
250	2580
255	2777
260	2995
265	3235
270	3298
275	3300
280	3302
285	3304

Fluid Temp.	Governing Adjusted Pressure
(°F)	(psi)
290	3307
295	3309
300	3312
305	3315
310	3318
315	3323
320	3326
325	3330
330	3334
335	3338
340	3342
345	3347
350	3358
355	3363
360	3369
365	3375
370	3378
375	3385
380	3392
385	3399
390	3407
395	3415
400	3424
405	3433
410	3442
415	3452
420	3463
425	3474
430	3485
435	3496
440	3509
445	3522
450	3536
455	3550
460	3565
465	3580
470	3597
475	3614
480	3628
485	3651
490	3670
495	3682
500	3727
505	3749
510	3759

Fluid Temp.	Governing Adjusted Pressure
(°F)	(psi)
515	3793
520	3818
525	3827
530	3870
535	3897
540	3905
545	3953
550	3982
555	3989
560	4037
565	4060
570	4072

Table 12: TMI-1 Tech Spec. Basis P-T Limits for ISLH Composite Curve

Fluid Temp. (°F)	Governing Adjusted Pressure (psi)
60	671
65	724
70	724
75	724
80	724
85	724
90	724
95	724
100	724
105	724
110	727
115	743
120	759
125	776
130	795
135	816
140	840
145	866
150	894
155	926
160	954
165	978
170	1005
175	1035
180	1067
185	1103
190	1143
195	1187
200	1222
205	1275
210	1335
215	1400
220	1473
225	1553
230	1642
235	1740
240	1848
245	1967
250	2099
255	2244
260	2405
265	2582

Fluid Temp. (°F)	Governing Adjusted Pressure (psi)
270	2777
275	2993
280	3231
285	3304
290	3307
295	3309
300	3312
305	3315
310	3318
315	3323
320	3326
325	3330
330	3334
335	3338
340	3342
345	3347
350	3358
355	3363
360	3369
365	3375
370	3378
375	3385
380	3392
385	3399
390	3407
395	3415
400	3424
405	3433
410	3442
415	3452
420	3463
425	3474
430	3485
435	3496
440	3509
445	3522
450	3536
455	3550
460	3565
465	3580
470	3597
475	3614
480	3628
485	3651
490	3670
495	3682

Fluid Temp. (°F)	Governing Adjusted Pressure (psi)
500	3727
505	3749
510	3759
515	3793
520	3818
525	3827
530	3870
535	3897
540	3905
545	3953
550	3982
555	3989
560	4037
565	4060
570	4072

Figure 1: TMI-1 Adjusted P-T Limits for ISLH Heatup and Cooldown

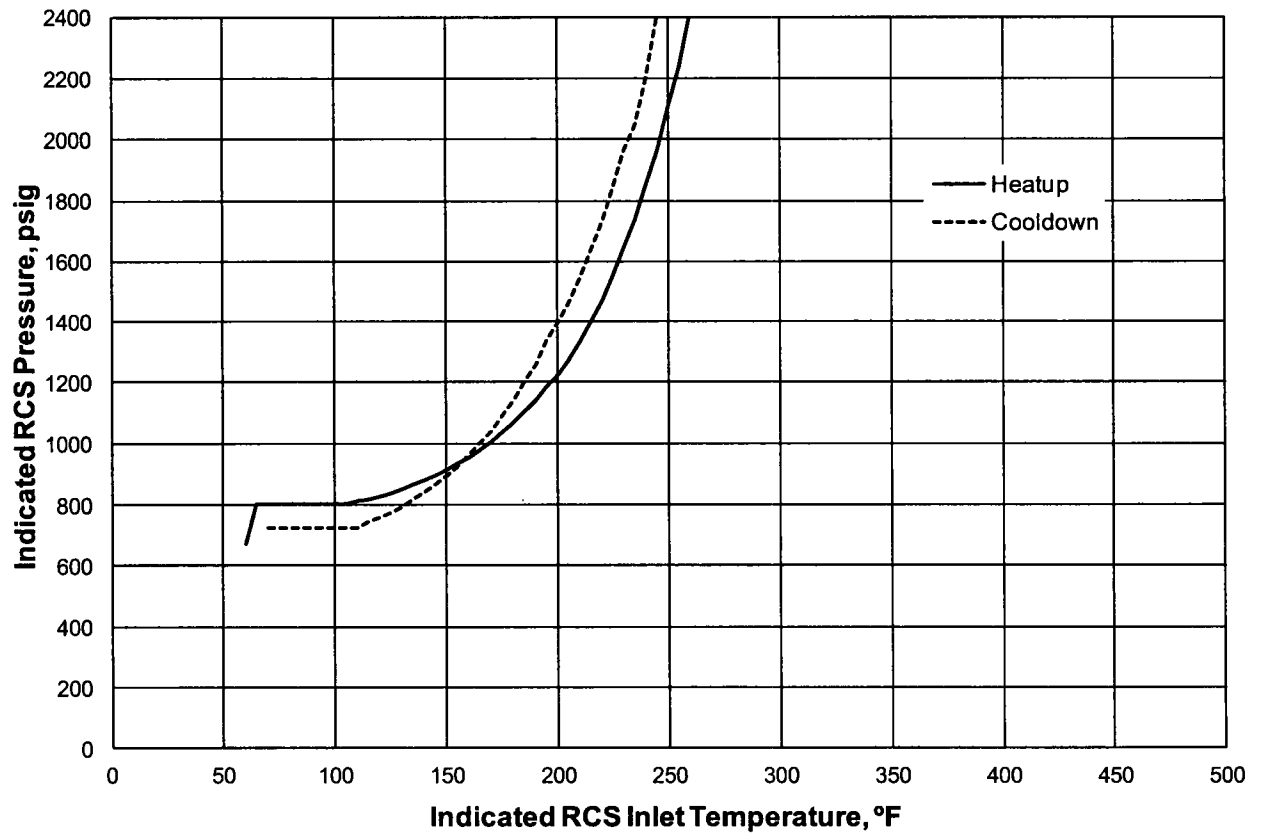
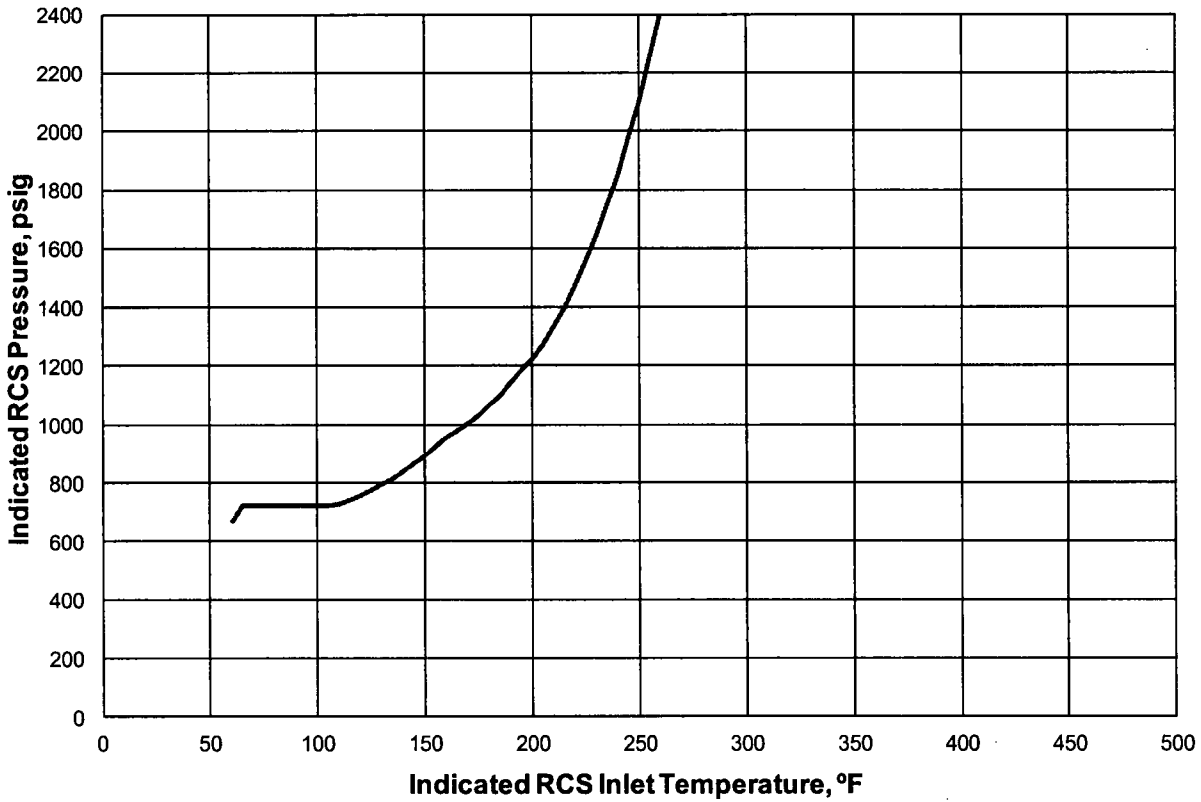


Figure 2: TMI-1 Tech. Spec. Basis P-T Limits for ISLH (Composite Curve)



7.2 P-T Curves for Normal Heatup / Cooldown

The Pressure-Temperature limits are developed for both normal heatup and cooldown operations. For heatup, location specific adjusted P-T limits are presented in Table 13. The Tech. Spec. basis P-T limits for normal heatup are shown in Table 14. The location specific adjusted P-T limits for ramp cooldown are presented in Table 15. The location adjusted P-T limits calculated for normal step cooldown are shown Table 16. The Technical specification (Tech. Spec.) basis P-T limits for cooldown generated as the limiting pressure at every calculated temperature is shown in Table 17. The Tech. Spec. basis P-T limits for heatup are plotted in Figure 3 and the Tech. Spec. basis cooldown P-T limits are plotted in Figure 4.

Table 13: TMI-1 Adjusted Location Specific P-T Limits for Normal Heatup

Fluid Temp.	Allowable Pressures			
	Limiting Beltline Weld	Outlet Nozzle	Inlet Nozzle	Closure Head
	(°F)	(psi)	(psi)	(psi)
60	618	650	676	612
65	619	654	680	612
70	621	665	691	612
75	623	679	706	612
80	626	696	724	612
85	629	716	744	761
90	632	738	767	910
90	632	738	767	910
90	632	739	768	910
95	637	768	798	1058
100	642	799	830	1207
101	575	749	780	1180
105	579	776	808	1360
110	585	813	847	1585
115	592	853	889	1810
120	599	898	936	2035
123	604	928	967	2170
125	607	948	988	
130	616	1004	1045	
135	626	1065	1108	
140	637	1132	1179	
145	649	1207	1256	
150	662	1290	1342	
155	677	1381	1437	
160	693	1482	1542	
165	711	1593	1658	
170	731	1717	1786	
175	753	1853	1927	
180	778	2003	2083	
185	805	2170	2256	
190	835	2353	2447	
195	868	2556	2657	
200	890	2780	2890	
205	931	3019	3138	
210	975	3019	3138	
215	1024	3019	3138	
220	1079	3019	3138	
225	1139	3019	3138	
230	1205	3019	3138	
235	1279	3019	3138	
240	1360	3019	3138	

Fluid Temp.	Allowable Pressures			
	Limiting Beltline Weld	Outlet Nozzle	Inlet Nozzle	Closure Head
	(°F)	(psi)	(psi)	(psi)
245	1449	3019	3138	
250	1548	3019	3138	
255	1657	3019	3138	
260	1777	3019	3138	
265	1910	3019	3138	
270	2057	3019	3138	
275	2219	3019	3138	
280	2398	3019	3138	
285	2595	3019	3138	
290	2813	3019	3138	
295	3053	3019	3138	
300	3319	3019	3138	
305	3565	3019	3138	
310	3565	3019	3138	
315	3565	3019	3138	
320	3564	3019	3138	
325	3564	3019	3138	
330	3564	3019	3138	
335	3564	3019	3138	
340	3563	3019	3138	
345	3563	3019	3138	
350	3556	3026	3145	
355	3556	3026	3145	
360	3555	3026	3145	
365	3555	3026	3145	
370	3555	3026	3145	
375	3554	3026	3145	
380	3554	3026	3145	
385	3553	3026	3145	
390	3553	3026	3145	
395	3553	3026	3145	
400	3552	3026	3145	
405	3552	3026	3145	
410	3551	3026	3145	
415	3551	3026	3145	
420	3551	3026	3145	
425	3551	3026	3145	
430	3550	3026	3145	
435	3550	3026	3145	
440	3550	3026	3145	
445	3550	3026	3145	
450	3549	3026	3145	
455	3549	3026	3145	
460	3549	3026	3145	
465	3548	3026	3145	

Fluid Temp.	Allowable Pressures			
	Limiting Beltline Weld	Outlet Nozzle	Inlet Nozzle	Closure Head
	(°F)	(psi)	(psi)	(psi)
470	3548	3026	3145	
475	3547	3026	3145	
480	3547	3026	3145	
485	3546	3026	3145	
490	3546	3026	3145	
495	3546	3026	3145	
500	3558	3042	3161	
505	3557	3042	3161	
510	3557	3042	3161	
515	3556	3042	3161	
520	3556	3042	3161	
525	3555	3042	3161	
530	3555	3042	3161	
535	3555	3042	3161	
540	3554	3042	3161	
545	3554	3042	3161	
550	3554	3042	3161	
555	3553	3042	3161	
560	3553	3042	3161	
565	3552	3042	3161	
570	3552	3042	3161	

Table 14: TMI-1 Tech. Spec. Basis P-T Limits for Normal Heatup

Fluid Temp.	Governing Adjusted Pressure
(°F)	(psi)
60	575
65	575
70	575
75	575
80	575
85	575
90	575
90	575
90	575
95	575
100	575
101	575
105	579
110	585
115	592
120	599
123	604
125	607
130	616
135	626
140	637
145	649
150	662
155	677
160	693
165	711
170	731
175	753
180	778
185	805
190	835
195	868
200	890
205	931
210	975
215	1024
220	1079
225	1139
230	1205
235	1279
240	1360
245	1449
250	1548

Fluid Temp.	Governing Adjusted Pressure
(°F)	(psi)
255	1657
260	1777
265	1910
270	2057
275	2219
280	2398
285	2595
290	2813
295	3019
300	3019
305	3019
310	3019
315	3019
320	3019
325	3019
330	3019
335	3019
340	3019
345	3019
350	3026
355	3026
360	3026
365	3026
370	3026
375	3026
380	3026
385	3026
390	3026
395	3026
400	3026
405	3026
410	3026
415	3026
420	3026
425	3026
430	3026
435	3026
440	3026
445	3026
450	3026
455	3026
460	3026
465	3026
470	3026
475	3026

Fluid Temp.	Governing Adjusted Pressure
(°F)	(psi)
480	3026
485	3026
490	3026
495	3026
500	3042
505	3042
510	3042
515	3042
520	3042
525	3042
530	3042
535	3042
540	3042
545	3042
550	3042
555	3042
560	3042

Table 15: TMI-1 Adjusted Location Specific P-T Limits for Normal Ramp Cooldown

Fluid Temp.	Allowable Pressures			
	Limiting Beltline Weld	Outlet Nozzle	Inlet Nozzle	Closure Head
	(°F)	(psi)	(psi)	(psi)
70	545	699	726	612
75	551	740	769	612
80	559	776	807	612
85	568	817	849	761
90	579	861	895	910
95	584	910	946	1058
101	519	913	951	1180
110	523	1002	1044	1585
115	535	1107	1153	1810
120	547	1188	1237	2035
123	555	1242	1293	2170
125	560	1278	1330	
130	574	1377	1433	
135	590	1486	1546	
140	607	1607	1672	
145	627	1741	1810	
150	648	1888	1964	
155	672	2052	2133	
160	698	2232	2321	
165	727	2431	2528	
170	759	2652	2756	
175	794	2810	2921	
180	834	2802	2912	
185	877	2792	2902	
190	925	2781	2891	
195	978	2768	2878	
200	1022	2754	2862	
205	1076	2737	2845	
210	1136	2716	2823	
215	1202	2693	2799	
220	1276	2667	2772	
225	1357	2636	2741	
230	1446	2600	2703	
235	1524	2527	2627	
240	1619	2578	2680	
245	1775	2535	2635	
250	1909	2488	2586	
255	2057	2451	2548	
260	2220	2453	2550	
265	2400	2454	2551	
270	2600	2455	2552	
275	2820	2456	2554	
280	3063	2458	2555	

Fluid Temp.	Allowable Pressures			
	Limiting Beltline Weld	Outlet Nozzle	Inlet Nozzle	Closure Head
	(°F) (psi)	(psi)	(psi)	(psi)
285	3205	2460	2557	
290	3205	2461	2559	
295	3204	2463	2561	
300	3204	2465	2563	
305	3203	2468	2565	
310	3203	2470	2568	
315	3203	2474	2572	
320	3202	2476	2574	
325	3202	2479	2577	
330	3202	2482	2580	
335	3202	2485	2583	
340	3202	2488	2586	
345	3202	2491	2590	
350	3195	2502	2601	
355	3196	2506	2605	
360	3196	2510	2609	
365	3196	2514	2613	
370	3196	2517	2616	
375	3196	2522	2621	
380	3197	2527	2627	
385	3197	2533	2633	
390	3198	2539	2639	
395	3199	2545	2645	
400	3200	2551	2652	
405	3200	2558	2659	
410	3202	2565	2666	
415	3203	2573	2674	
420	3205	2580	2682	
425	3208	2589	2691	
430	3210	2597	2699	
435	3214	2606	2708	
440	3217	2615	2718	
445	3221	2625	2728	
450	3225	2635	2739	
455	3229	2646	2750	
460	3234	2657	2762	
465	3239	2669	2774	
470	3245	2681	2787	
475	3252	2694	2800	
480	3259	2707	2814	
485	3267	2721	2828	
490	3276	2736	2843	
495	3286	2751	2859	
500	3308	2783	2891	
505	3320	2799	2908	

Fluid Temp.	Allowable Pressures			
	Limiting Beltline Weld	Outlet Nozzle	Inlet Nozzle	Closure Head
	(°F)	(psi)	(psi)	(psi)
510	3332	2814	2924	
515	3346	2832	2943	
520	3360	2850	2962	
525	3375	2870	2982	
530	3392	2889	3002	
535	3411	2910	3024	
540	3432	2931	3045	
545	3454	2952	3067	
550	3478	2973	3090	
555	3503	2995	3112	
560	3529	3015	3133	
565	3554	3032	3151	

Table 16: TMI-1 Adjusted Location Specific P-T Limits for Normal Step Cooldown

Fluid Temp.	Allowable Pressures			
	Limiting Beltline Weld	Outlet Nozzle	Inlet Nozzle	Closure Head
	(F)	(psi)	(psi)	(psi)
70	569	678	705	612
80	580	774	804	612
85	586	817	849	761
100	604	965	1002	1207
101	538	921	959	1180
115	562	1107	1153	1810
123	581	1251	1302	2170
130	598	1377	1433	
145	647	1741	1810	
160	713	2232	2321	
175	801	2839	2951	
190	921	2811	2921	
205	1072	2766	2875	
220	1276	2696	2802	
235	1511	2558	2659	
240	1655	2607	2710	
255	2057	2467	2564	
270	2600	2470	2568	
285	3234	2474	2572	
300	3232	2479	2577	
315	3231	2485	2584	
330	3231	2495	2593	
345	3231	2503	2602	
360	3224	2521	2620	
375	3224	2531	2631	
390	3225	2547	2647	
405	3228	2565	2666	
420	3231	2586	2687	
435	3237	2609	2712	
450	3247	2637	2740	
465	3259	2668	2773	
480	3276	2704	2810	
495	3299	2745	2853	
510	3341	2807	2917	
525	3380	2858	2969	
540	3429	2916	3030	
555	3493	2979	3096	

Table 17: Tech Spec. Basis P-T Limits for Normal Limiting Cooldown

Fluid Temp.	Governing Adjusted Pressure
(°F)	(psi)
70	519
75	519
80	519
85	519
90	519
95	519
101	519
110	523
115	535
120	547
123	555
125	560
130	574
135	590
140	607
145	627
150	648
155	672
160	698
165	727
170	759
175	794
180	834
185	877
190	921
195	978
200	1022
205	1072
210	1136
215	1202
220	1276
225	1357
230	1446
235	1511
240	1619
245	1775
250	1909
255	2057
260	2220
265	2400
270	2455

Fluid Temp.	Governing Adjusted Pressure
(°F)	(psi)
275	2456
280	2458
285	2460
290	2461
295	2463
300	2465
305	2468
310	2470
315	2474
320	2476
325	2479
330	2482
335	2485
340	2488
345	2491
350	2502
355	2506
360	2510
365	2514
370	2517
375	2522
380	2527
385	2533
390	2539
395	2545
400	2551
405	2558
410	2565
415	2573
420	2580
425	2589
430	2597
435	2606
440	2615
445	2625
450	2635
455	2646
460	2657
465	2668
470	2681
475	2694
480	2704
485	2721
490	2736
495	2745

Fluid Temp.	Governing Adjusted Pressure
(°F)	(psi)
500	2783
505	2799
510	2807
515	2832
520	2850
525	2858
530	2889
535	2910
540	2916
545	2952
550	2973
555	2979
560	3015
565	3032

Figure 3: TMI-1 Tech. Spec. Basis P-T Limits for Normal Heatup and Criticality Limit

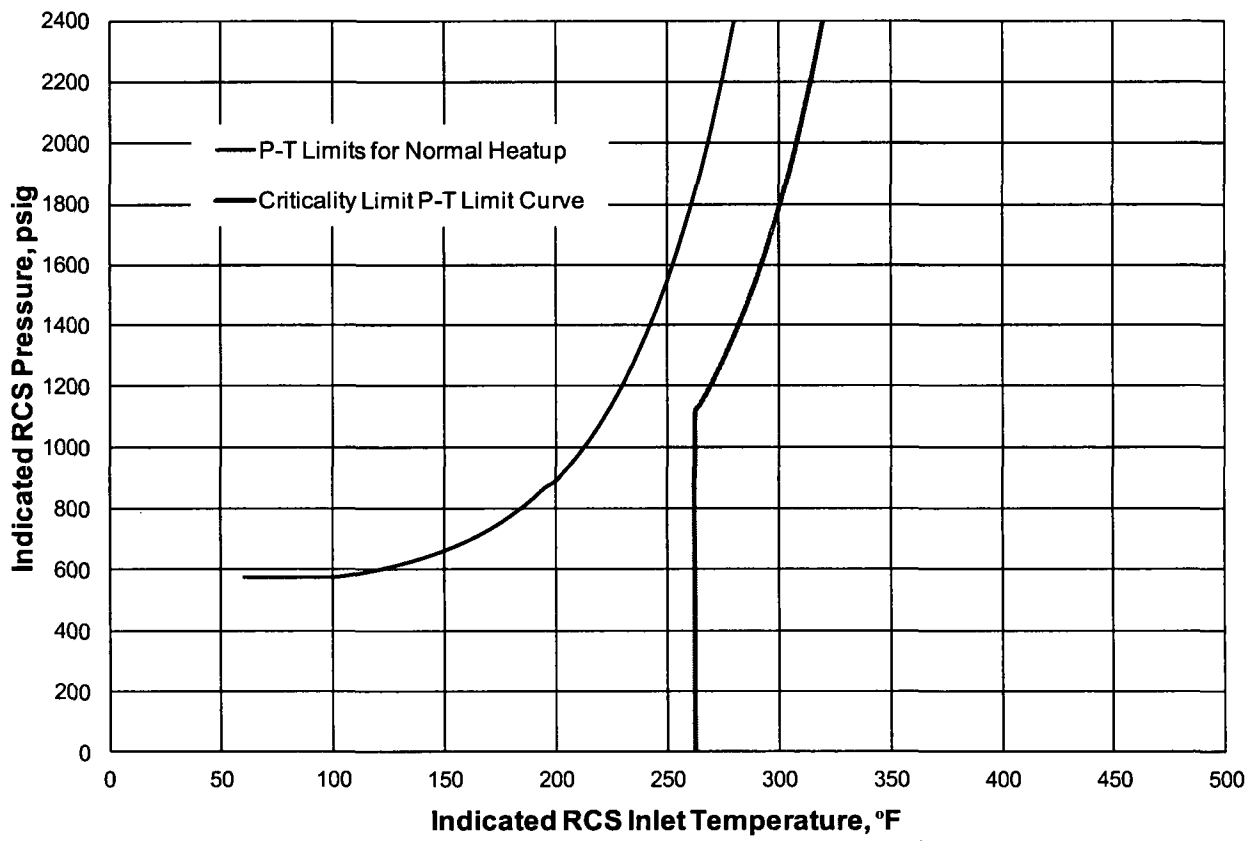
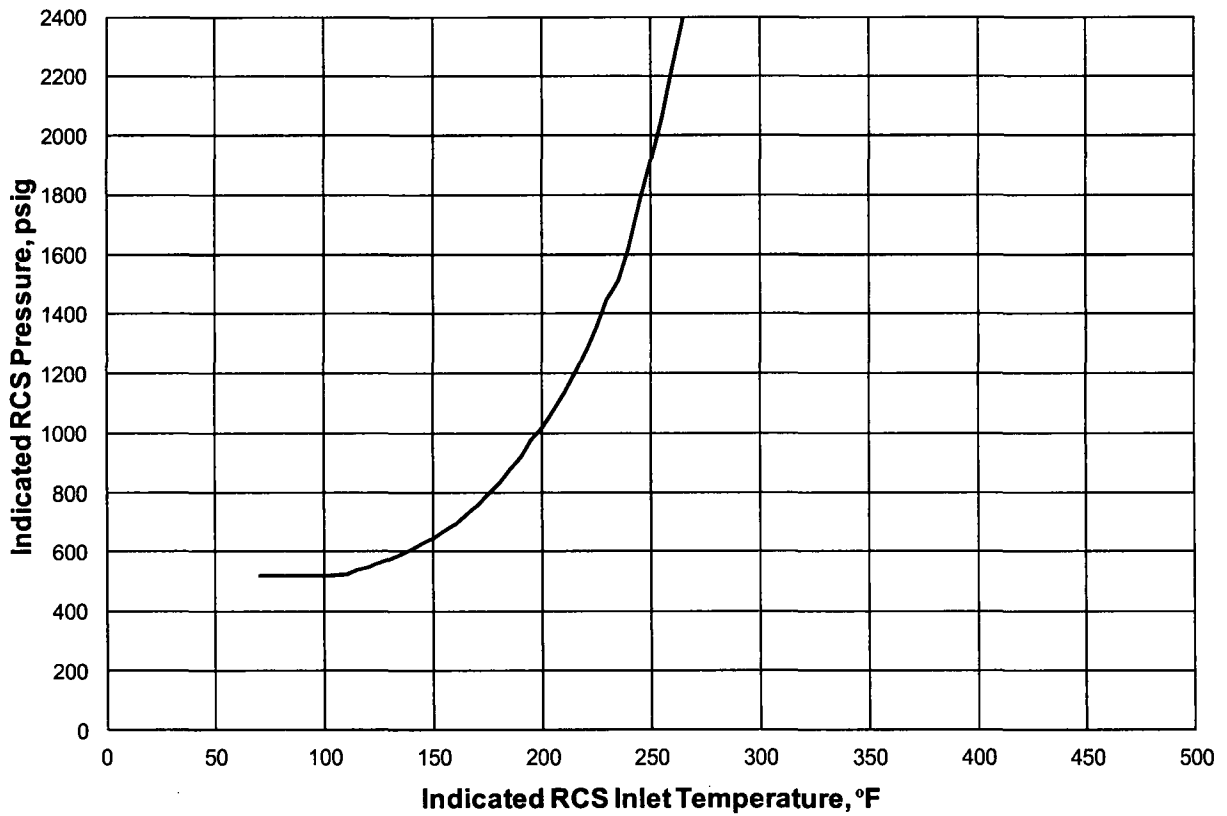


Figure 4: TMI-1 Tech. Spec. Basis P-T Limits for Normal Cooldown



8.0 SUMMARY

The Tech. Spec. basis P-T limits for normal operating heatup and cooldown and ISLH operation were reported in the previous section for TMI-1 at 50.2 EFPY with MUR. This section provides summary P-T curves for heatup, cooldown, and ISLH with some key points (P-T limits) indicated on the plot.

Figure 5 shows a summary of the TMI-1 Tech. Spec. basis P-T Limits for normal heatup and criticality limit with some key points noted on the plot. Figure 6 shows a summary of the TMI-1 Tech. Spec. basis P-T Limits for normal cooldown with some key points noted on the plot. Figure 7 shows a summary of TMI-1 Tech. Spec. Basis P-T Limits for ISLH (Composite Curve).

Figure 5: TMI-1 Summary Tech Spec. Basis P-T Limits at 50.2 EFPY with MUR for Normal Heatup and Criticality Limit

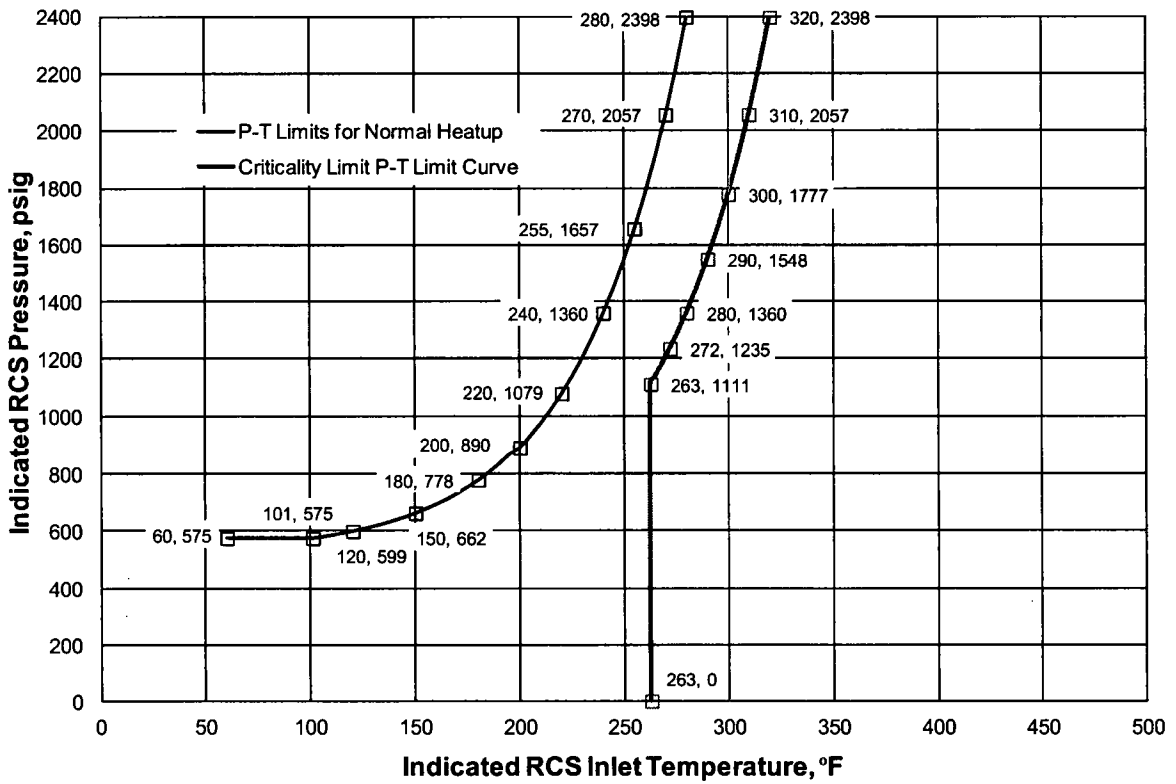


Figure 6: TMI-1 Summary Tech. Spec. Basis P-T Limits at 50.2 EFPY with MUR for Normal Cooldown

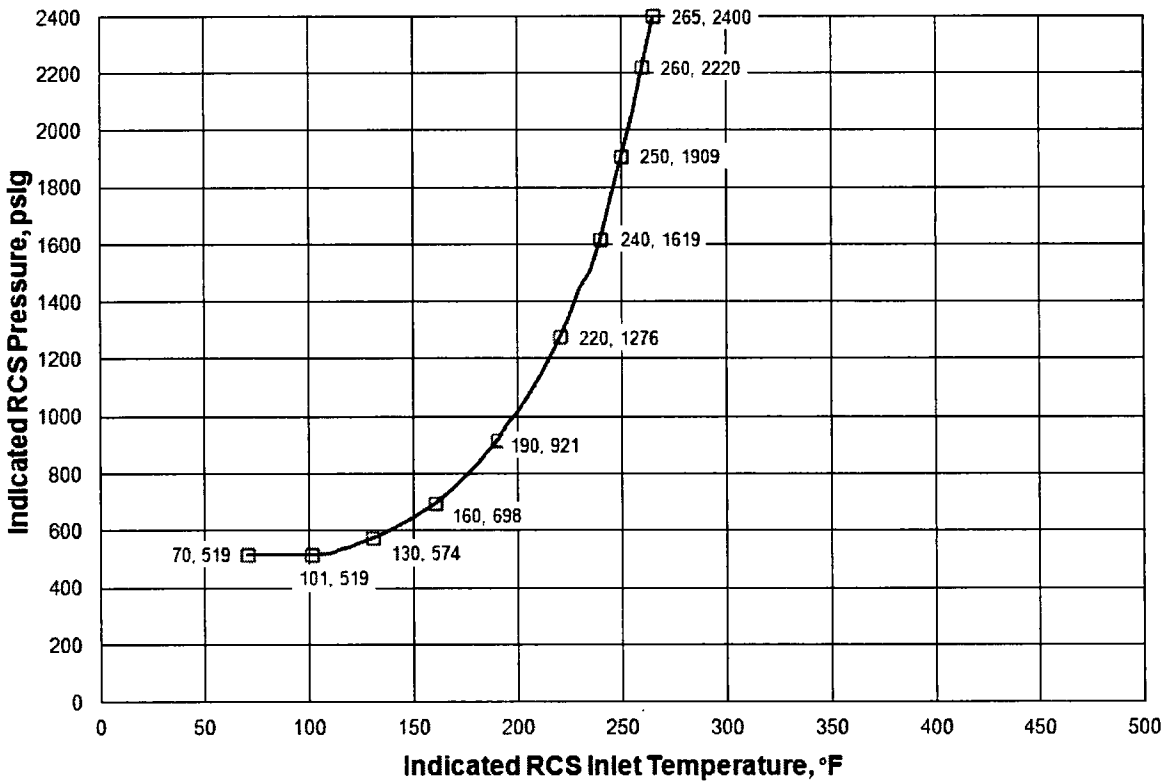
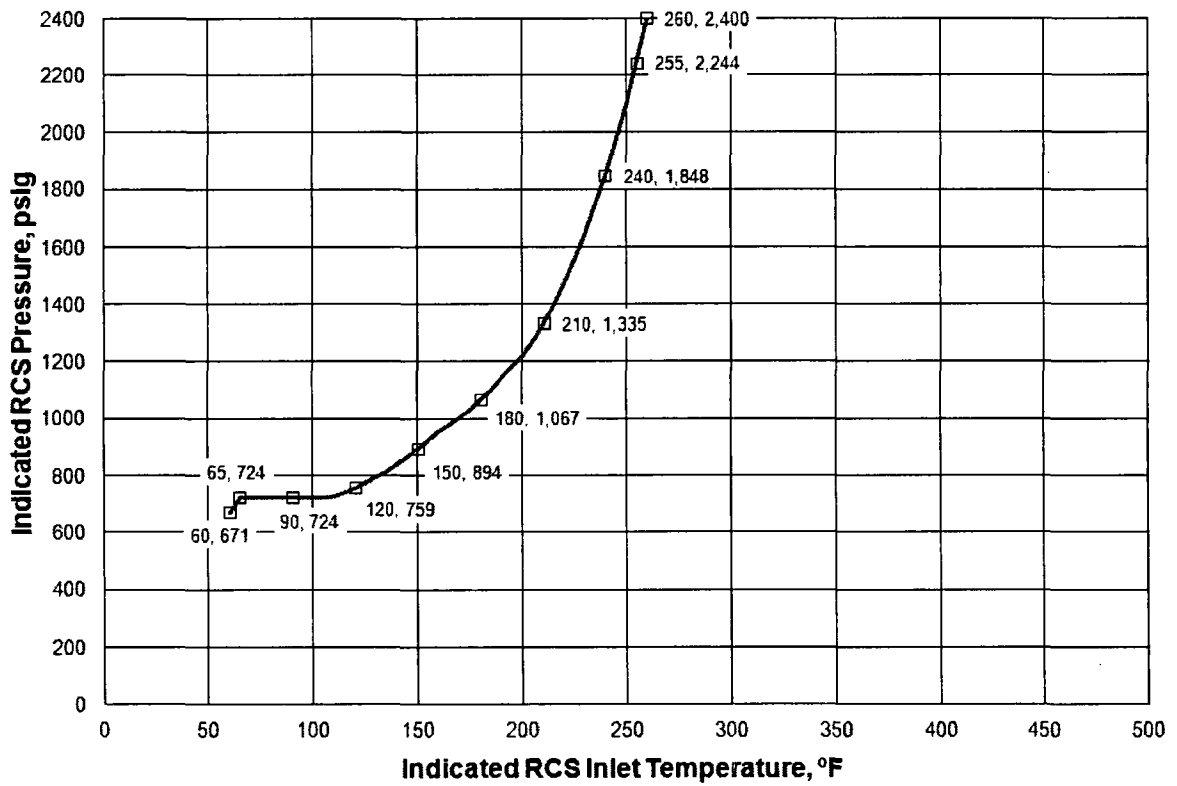


Figure 7: TMI-1 Summary Tech. Spec. Basis P-T Limits at 50.2 EFPY with MUR for ISLH (Composite Curve)



9.0 CERTIFICATION

Pressure/temperature limits for the TMI-1 reactor vessel have been calculated to satisfy the requirements of 10 CFR Part 50, Appendix G using analytical methods and acceptance criteria of the ASME Boiler and Pressure Vessel Code, Section XI, Appendix G, 1995 Edition.

S. H. Mahmoud

7-23-13

Samer H. Mahmoud, Principal Engineer
Component Analysis and Fracture Mechanics

Date

This report has been reviewed for technical content and accuracy.

A. D. Nana

7/25/13

Ashok D. Nana, Supervisor
Component Analysis and Fracture Mechanics

Date

Verification of independent review.

H. Charles for Tim Wiger

7/26/13

Tim M. Wiger, Manager I
Component Analysis and Fracture Mechanics

Date

This report is approved for release

B. Watson
Beverly Watson for
David Skulina, Project Manager

7/26/13

Date

10.0 REFERENCES

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