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AREVA Topical Report ANP-3127, Revision 1,
Oconee Nuclear Station Units 1, 2, & 3
Pressure-Temperature Limits at 54 EFPY

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Revision No.	Pages/Sections/Paragraphs Changed	Brief Description / Change Authorization
000	All	Original Release
001	Section 4.3	Changed words of description
	Section 4.4	Added reference to 10CFR Part 50 Appendix G
	Section 7.0	Added reference to 10CFR Part 50 Appendix G
		Added Tables 7-6 and 7-7.
		Changed Figures 7-1 through 7-9 adding more markers.
	Section 3.0	Added Statements on fluence and ART exemption requests
	Through out	Deleted the word "basis" from "Technical Specification P-T Limits"
	Section 8.0	Added 4 more references.

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1.0 INTRODUCTION

This report provides Reactor Coolant Pressure Boundary (RCPB) Technical Specification Pressure-Temperature (P-T) operating limits of Oconee Nuclear Station Units 1, 2, and 3 (ONS-1, ONS-2 and ONS-3) for 54 effective full-power years (EFPY). The P-T limits are established in accordance with the requirements of 10 CFR Part 50, Appendix G [1]. These P-T limits are generated for normal operation heatup, normal operation cooldown, inservice leak and hydrostatic test (ISLH) conditions, and reactor core operations. These limits are expressed in the form of curves of allowable pressure versus temperature. The uncorrected P-T limits for the three ONS units were determined for 54 effective full power years (EFPY) of operation. Pressure correction factors were determined between the pressure sensor locations (pressure tap in the DHRS drop line and two pressure taps in the RCS hot leg) and various regions of the reactor vessel (RV). The Technical Specification pressure-temperature operating limits applicable to ONS-1, ONS-2 and ONS-3 are developed for 54 EFPY of reactor operation. In addition, the minimum temperature for core criticality is determined to satisfy the regulatory requirements of 10 CFR Part 50, Appendix G [1].

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 pressure vessel 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 of 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}). The RT_{NDT} is defined as the greater of the drop weight nil-ductility transition temperature (per ASTM E208 [3]) or the temperature at which the material exhibits 50 ft-lbs absorbed energy and 35 mils lateral expansion minus 60°F. 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 [2]. 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 beltline region of the reactor vessel is the most highly exposed to neutron irradiation. The general effects of fast neutron irradiation on the mechanical properties of low-alloy ferritic steels such as

SA-302, Grade B, modified and SA-508, Class 2 forging material used in the fabrication of the ONS units reactor vessels and inlet and outlet nozzles, are well characterized and documented in the literature. The effects of irradiation on these steels include an increase in the yield and ultimate strengths and a decrease in ductility. The most significant effect, however, is an increase in the temperature associated with the transition from brittle to ductile fracture and a reduction in the Charpy upper-shelf energy value.

Pressure-temperature limits for the ONS Units reactor vessels 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, Revision 2 [4] and ASME Code Section XI, Appendix G [2].

The ONS-1 reactor vessel contains both axially and circumferentially oriented welds. Therefore, the P-T limits for ONS-1 are based on the postulation of both axial and circumferential flaws in the most limiting axial and circumferential welds. Since ONS-2 and ONS-3 RV do not contain any axial welds in their beltline regions, axial flaws are postulated in the most limiting forging materials of these reactor vessels.

3.0 ADJUSTED NIL-DUCTILITY TRANSITION REFERENCE TEMPERATURES

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. The adjusted RT_{NDT} (ART) values are calculated by adding a radiation-induced ΔRT_{NDT} to the initial RT_{NDT} plus a margin term using Regulatory Guide 1.99 Revision 2 [5] to predict the radiation induced ΔRT_{NDT} values as a function of the material's copper and nickel content and neutron fluence. The projected fluence values at 54 EFPY are based on NRC approved Topical Report BAW-2241P-A, Revision 2 [6], which complies with Regulatory Guide 1.190 [7].

The ¼ t (t- thickness of the section) and ¾ t ART values for the ONS units reactor vessels beltline materials applicable to 54 EFPY are listed in Table 3-1 through Table 3-3. These values were calculated in accordance with Regulatory Guide 1.99, Revision 2. The calculation of the ART values for the weld metals used the following information from BAW-2308 Revision 1A and 2A [8]; the initial RT_{NDT}, the associated standard deviation and the added chemistry factor requirement. Duke Energy made an exemption request [9] and already received NRC approval of the exemption request [10] to utilize BAW-2308 Revision 1A and 2A for determining the ART values for the Linde 80 weld metals for the ONS units. Table 3-4 summarizes the limiting ART for ONS units used in the calculation of P-T limits. The characters in parentheses next to the ART values are the material identification.

The circumferential welds with the highest ART values for the ONS-1 reactor vessel are the Intermediate Shell to Upper Shell Circumferential Weld (ID 61%), SA-1229, with an ART value of 164.2°F at the ¼t wall location and Intermediate Shell to Upper Shell Circumferential Weld (OD 39%), WF-25, with an ART value of 132.1°F at the ¾t wall location. Considering the base metal and the longitudinal welds, the materials with the highest ART values are the Upper Shell Longitudinal Weld, SA-1493, with an ART value of 171.0°F at the ¼t wall location and the Intermediate Shell Plate, C2197-2, with an ART value of 132.9°F at the ¾t wall location. At the nozzle belt the highest ART values are 111.9°F and 83.5°F at ¼t and ¾t locations, respectively, for Nozzle belt forging, AHR 54.

The circumferential weld with the highest ART values for the ONS-2 reactor vessel is the Upper Shell to Lower Shell Circumferential Weld, WF-25, with an ART value of 193.1°F at the ¼t wall location and 132.5°F at the ¾t wall location. Considering the base metal (there are no longitudinal welds in ONS-2), the material with the highest ART values is the Lower Nozzle Belt Forging (Location 3), AMX 77, with an ART value of 161.8°F at the ¼t wall location and 135.7°F at the ¾t wall location. At the nozzle belt the highest ART values are 102.4°F and 79.4°F at ¼t and ¾t locations, respectively, for Nozzle belt forging, AMX 77.

The circumferential welds with the highest ART values for the ONS-3 reactor vessel are the Upper Shell to Lower Shell Circumferential Weld (ID 75%), WF-67, with an ART value of 195.6°F at the ¼t wall location and the Upper Shell to Lower Shell Circumferential Weld (OD 25%), WF-70, with an ART value of 162.1°F at the ¾t wall location. Considering the base metal (there are no longitudinal welds in ONS-3), the material with the highest ART values is the Lower Nozzle Belt Forging (Location 3), 4680; with an ART value of 161.4°F at the ¼t wall location and 135.2°F at the ¾t wall location. At the nozzle belt the highest ART values are 102.9°F and 79.5°F at ¼t and ¾t locations, respectively, for Nozzle belt forging, 4680.

Table 3-1: Adjusted Reference Temperature Evaluation for the ONS-1 Reactor Vessel Beltline Materials at 54 EFPY

Material Description				Chemical Composition		Initial RT_{NDT} (°F)	Chemistry Factor	54 EFPY Fluence (n/cm²)			ΔRT_{NDT} (°F) at 54 EFPY		Margin (°F)		ART (°F) at 54 EFPY	
Reactor Vessel Beltline Region Location	Matl. Ident.	Heat Number	Type [11]	Cu wt%	Ni wt%			Inner Wetted Surface	¼ t Location	¾ t Location	¼ t Location	¾ t Location	¼ t Location	¾ t Location	¼ t Location	¾ t Location
Lower Nozzle Belt (LNB) Forging (Location 1)	AHR 54	ZV-2861	A-508, Cl. 2[a]	0.16	0.65	+3	119.3	1.25E+18	7.29E+17	2.65E+17	42.5	24.3	70.7	66.6	116.2	93.9
Lower Nozzle Belt (LNB) Forging (Location 2)	AHR 54	ZV-2861	A-508, Cl. 2[a]	0.16	0.65	+3	119.3	1.25E+18	5.90E+17	1.40E+17	38.2	16.4	70.7	64.1	<111.9>	<83.5>
Intermediate Shell (IS) Plate	C2197-2	C2197-2	SA-302 Gr. B Mod.[b]	0.15	0.50	+1	104.5	1.32E+19	7.74E+18	2.81E+18	97.0	68.3	63.6	63.6	161.6	{132.9}
Upper Shell (US) Plate	C3265-1	C3265-1	SA-302 Gr. B Mod.[b]	0.10	0.50	+1	65.0	1.46E+19	8.55E+18	3.11E+18	62.1	44.2	63.6	63.6	126.7	108.8
Upper Shell Plate	C3278-1	C3278-1	SA-302 Gr. B Mod.[b]	0.12	0.60	+1	83.0	1.46E+19	8.55E+18	3.11E+18	79.4	56.4	63.6	63.6	144.0	121.0
Lower Shell (LS) Plate	C2800-1	C2800-1	SA-302 Gr. B Mod.[b]	0.11	0.63	+1	74.5	1.48E+19	8.63E+18	3.13E+18	71.4	50.8	63.6	63.6	136.0	115.4
Lower Shell Plate	C2800-2	C2800-2	SA-302 Gr. B Mod.[b]	0.11	0.63	+1	74.5	1.48E+19	8.63E+18	3.13E+18	71.4	50.8	63.6	63.6	136.0	115.4
LNB to IS Circ. Weld (100%)	SA-1135	61782	Linde 80	0.23	0.52	-58.5	167.0[c]	1.25E+18	7.29E+17	2.65E+17	59.5	34.1	63.9	63.9	64.9	39.5
IS Long. Weld (100%)	SA-1073	1P0962	Linde 80	0.21	0.64	-48.6	170.6	1.04E+19	6.05E+18	2.20E+18	146.6	101.0	66.6	66.6	164.6	119.0
IS to US Circ. Weld (ID 61%)	SA-1229	71249	Linde 80	0.23	0.59	-53.5	167.6	1.34E+19	7.82E+18	N/A	156.1	N/A	61.6	N/A	[164.2]	N/A
IS to US Circ. Weld (OD 39%)	WF-25	299L44	Linde 80	0.34	0.68	-74.3	220.6	1.34E+19	N/A	2.84E+18	N/A	144.8	N/A	61.6	N/A	[132.1]
US Long. Weld (100%)	SA-1493	8T1762	Linde 80	0.19	0.57	-48.6	167.0[c]	1.27E+19	7.42E+18	2.70E+18	153.0	107.4	66.6	66.6	{171.0}	125.4
US to LS Circ. Weld (100%)	SA-1585	72445	Linde 80	0.22	0.54	-72.5	167.0[c]	1.42E+19	8.31E+18	3.02E+18	158.3	112.2	60.9	60.9	146.7	100.6
LS Long. Weld (100%)	SA-1426	8T1762	Linde 80	0.19	0.57	-48.6	167.0[c]	1.21E+19	7.09E+18	2.57E+18	150.9	105.4	66.6	66.6	168.9	123.4
LS Long. Weld (100%)	SA-1430	8T1762	Linde 80	0.19	0.57	-48.6	167.0[c]	1.21E+19	7.09E+18	2.57E+18	150.9	105.4	66.6	66.6	168.9	123.4

[ ] –Highest values of the adjusted reference temperatures for circumferential welds

{ } – Highest values of the adjusted reference temperatures for base metal or longitudinal welds

< > - Highest values of the adjusted reference temperature for the thick 12-inch nozzle belt section

[a] ASTM A-508-64 Cl. 2 Mod. By ASME Code Case 1332-2

[b] ASME SA-302 Gr. B Mod. To ASME Code Case 1339

[c] Per BAW-2308 Rev. 2-A

Table 3-2: Adjusted Reference Temperature Evaluation for the ONS-2 Reactor Vessel Beltline Materials at 54 EFPY

Material Description				Chemical Composition				54 EFPY Fluence (n/cm^2)			ΔRT_{NDT} (°F) at 54 EFPY		Margin (°F)		ART (°F) at 54 EFPY	
Reactor Vessel Beltline Region Location	Matl. Ident.	Heat Number	Type [11]	Cu wt%	Ni wt%	Initial RT_{NDT} (°F)	Chemistry Factor	Inner Wetted Surface	¼ t Location	¾ t Location	¼ t Location	¾ t Location	¼ t Location	¾ t Location	¼ t Location	¾ t Location
LNB Forging (Location 3)	AMX 77	123T382	A-508, Cl. 2[a]	0.13	0.76	+3	95.0	1.32E+19	7.72E+18	2.80E+18	88.1	62.0	70.7	70.7	{161.8}	{135.7}
LNB Forging (Location 4)	AMX 77	123T382	A-508, Cl. 2[a]	0.13	0.76	+3	95.0	1.25E+18	5.90E+17	1.40E+17	30.4	13.0	69.0	63.4	<102.4>	<79.4>
US Forging	AAW 163	3P2359	A-508, Cl. 2[b]	0.04	0.75	+20	26.0	1.40E+19	8.19E+18	2.98E+18	24.5	17.4	24.5	17.4	69.0	54.8
LS Forging	AWG 164	4P1885	A-508, Cl. 2[b]	0.02	0.80	+20	20.0	1.40E+19	8.20E+18	2.98E+18	18.9	13.4	18.9	13.4	57.8	46.8
LNB to US Circ. Weld (100%)	WF-154	406L44	Linde 80	0.27	0.59	-98.0	182.6	1.32E+19	7.72E+18	2.80E+18	169.4	119.2	60.6	60.6	132.0	81.8
US to LS Circ. Weld (100%)	WF-25	299L44	Linde 80	0.34	0.68	-74.3	220.6	1.35E+19	7.88E+18	2.86E+18	205.8	145.2	61.6	61.6	[193.1]	[132.5]

[ ] –Highest values of the adjusted reference temperatures for circumferential welds

{ } – Highest values of the adjusted reference temperatures for base metal (no longitudinal welds in ONS-2)

< > - Highest values of the adjusted reference temperature for the thick 12-inch nozzle belt section

[a] ASTM A-508-64 Cl. 2 Mod. By ASME Code Case 1332-2

[b] ASTM A-508-64 Cl. 2 Mod. By ASME Code Case 1332-4

Table 3-3: Adjusted Reference Temperature Evaluation for the ONS-3 Reactor Vessel Beltline Materials at 54 EFPY

Material Description				Chemical Composition				54 EFPY Fluence (n/cm²)			ΔRT_{NDT} (°F) at 54 EFPY		Margin (°F)		ART (°F) at 54 EFPY	
Reactor Vessel Beltline Region Location	Matl. Ident.	Heat Number	Type[11]	Cu wt%	Ni wt%	Initial RT_{NDT} (°F)	Chemistry Factor	Inner Wetted Surface	¼ t Location	¾ t Location	¼ t Location	¾ t Location	¼ t Location	¾ t Location	¼ t Location	¾ t Location
LNB Forging (Location 3)	4680	4680	A-508, Cl. 2[a]	0.13	0.91	+3	96.0	1.26E+19	7.36E+18	2.67E+18	87.7	61.5	70.7	70.7	{161.4}	{135.2}
LNB Forging (Location 4)	4680	4680	A-508, Cl. 2[a]	0.13	0.91	+3	96.0	1.25E+18	5.90E+17	1.40E+17	30.7	13.2	69.2	63.4	<102.9>	<79.5>
US Forging	AWS 192	522314	A-508, Cl. 2[b]	0.01	0.73	+40	36.0[c]	1.38E+19	8.07E+18	2.93E+18	33.8	23.9	34.0	34.0	107.8	97.9
LS Forging	ANK 191	522194	A-508, Cl. 2[b]	0.02	0.76	+40	17.4[c]	1.39E+19	8.16E+18	2.96E+18	16.4	11.6	16.4	11.6	72.8	63.2
LNB to US Circ. Weld (100%)	WF-200	821T44	Linde 80	0.24	0.63	-84.2	178.0	1.26E+19	7.36E+18	2.67E+18	162.7	114.0	59.2	59.2	137.7	89.0
US to LS Circ. Weld (ID 75%)	WF-67	72442	Linde 80	0.26	0.60	-33.2	180.0	1.34E+19	7.83E+18	N/A	167.7	N/A	61.1	N/A	[195.6]	N/A
US to LS Circ. Weld (OD 25%)	WF-70	72105	Linde 80	0.32	0.58	-31.1	199.3	1.34E+19	N/A	2.85E+18	N/A	130.9	N/A	62.3	N/A	[162.1]

[ ] –Controlling values of the adjusted reference temperatures for circumferential welds

{ } – Highest values of the adjusted reference temperatures for base metal (no longitudinal welds in ONS-3)

< > - Highest values of the adjusted reference temperature for the thick 12-inch nozzle belt section

[a] ASTM A-508-64 Cl. 2 Mod. By ASME Code Case 1332-3

[b] ASTM A-508-64 Cl. 2 Mod. By ASME Code Case 1332-4

[c] This Chemistry Factor was determined from surveillance data

Table 3-4: Limiting Adjusted Reference Temperature for ONS Units Locations

Vessel Component	Wall Location	Limiting RT_{NDT} (°F)		
		ONS-1	**ONS-2**	**ONS-3**
Beltline Axial Weld/Base Metal	¼ t	171.0 (SA-1493)	161.8 (AMX-77)	161.4 (4680)
	¾ t	132.9 (C2197-2)	135.7 (AMX-77)	135.2 (4680)
Beltline Circ. Weld	¼ t	164.2 (SA-1229)	193.1 (WF-25)	195.6 (WF-67)
	¾ t	132.1 (WF-25)	132.5 (WF-25)	162.1 (WF-70)
Nozzle Belt Upper (t=12")	¼ t	111.9 (AHR-54)	102.4 (AMX-77)	102.9 (4680)
	¾ t	83.5 (AHR-54)	79.4 (AMX-77)	79.5 (4680)

4.0 DESIGN BASIS FOR PRESSURE-TEMPERATURE LIMITS

Essential analytical parameters used in the preparation of ONS-1, 2 and 3 P-T limits are described below.

4.1 Material Properties

Table 4-1 describes the material properties used in the development of the P-T limits for the ONS units.

Table 4-1: Material Properties

Temp. (°F)	Elastic Modulus (10^6 psi)	Thermal(2) Expansion (10^{-6} in/in/°F)	Thermal Conductivity (Btu-in/hr-ft^2-°F)	Specific Heat (Btu/lb-°F)	Density (lb/ft^3)	Thermal Conductivity for Cladding Material (Btu-in/hr-ft^2-°F)
70	29.9	6.07	278.4	0.104	490.9	103.9
100	29.8(1)	6.13	275.1	0.107	490.5	105.6
150	29.7(1)	6.25	270.8	0.111	489.9	108.4
200	29.5	6.38	267.6	0.115	489.2	111.3
250	29.3(1)	6.49	265.3	0.118	488.6	114.2
300	29.0	6.60	263.7	0.120	487.9	117.0
350	28.8(1)	6.71	262.5	0.123	487.3	119.9
400	28.6	6.82	261.6	0.125	486.7	122.7
450	28.3(1)	6.92	260.6	0.126	486.0	125.6
500	28.0	7.02	259.5	0.128	485.4	128.5
550	27.7(1)	7.12	257.8	0.130	484.7	131.3
600	27.4	7.23	255.6	0.133	484.1	134.2
650	27.0(1)	7.33	252.5	0.135	483.4	137.0
700	26.6	7.44	248.4	0.139	482.8	139.9

Note: (1) The values are obtained by interpolating the available values; (2) Mean coefficients of thermal expansion are used.

4.2 Postulated Flaws

a. Postulated Reactor Vessel Beltline Flaws

Semi-elliptical surface flaws that are $^1/_4$ t deep and $1^1/_2$ 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 $^1/_4$ t_{NB} (t_{NB} - the thickness at the nozzle belt) deep corner flaw is postulated on the inside surface of the reactor vessel inlet and outlet nozzles and core flood nozzle corner.

4.3 Upper Shelf Toughness

A maximum value of 200 ksi√in is assumed for the upper shelf fracture toughness (K_{Ic})of the reactor vessel beltline. For the nozzle forging materials, a "no cut-off" limit is assumed.

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 ONS reactor vessel closure heads based on the K_{Ic} fracture toughness curve. The Pressure-Temperature limits derived for the reactor vessel head-to-flange conservatively bounds the minimum required temperature requirements as given in Table 1 of the Appendix G to 10CFR Part 50[1].

4.5 Convection Film Coefficient

A value of 1000 BTU/hr-ft^2-°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 354 BTU/hr-ft^2-°F is used as an effective film coefficient at the cladding-to-base metal interface. For LPI swap a value of 430 BTU/hr-ft^2-°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 54°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 temperate-time histories are considered:

Normal Ramp Heatup, 60°F/hr to 270°F and then 100°F/hr to 550°F

Normal Step Heatup, 60°F/hr to 270°F and then 100°F/hr to 550°F

Normal Ramp Cooldown, 100 °F/hr to 270 °F and then 50 °F/hr to 60 °F

Normal Step Cooldown, 100 °F/hr to 270 °F and then 50 °F/hr to 60 °F

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 an approved linear elastic fracture mechanics methodology described in topical report BAW-10046A, Revision 2[4]. The fundamental equation used to calculate the allowable pressure is

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

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 $^1/_4$t and $^3/_4$t 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 [2], which permits the use of K_{IC} fracture toughness,

$$K_{Ic} = 33.2 + 20.734 \exp [0.02 (T - RT_{NDT})]$$

The upper shelf fracture toughness is limited to an upper bound value of 200 ksi√in for the reactor vessel welds and shell base metal and "no cut-off" limit 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:

$$\sigma_\theta(r) = \frac{E\alpha}{1-\nu}\frac{1}{r^2}\left(\frac{r^2+R_i^2}{R_o^2-R_i^2}\int_{R_i}^{R_o} T\,r\,dr + \int_{R_i}^{r} T\,r\,dr - T\,r^2\right) \qquad [12, \text{Eqn } (255)]$$

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 ¼ -thickness x $^3/_2$ -thickness semi-elliptical surface flaw:

at the inside surface,

M_m = 1.85 for $\sqrt{t} < 2$

= 0.926 $\sqrt{t}$ for $2 \le \sqrt{t} \le 3.464$

= 3.21 for $\sqrt{t} > 3.464$

at the outside surface,

M_m = 1.77 for $\sqrt{t} < 2$

= 0.893 $\sqrt{t}$ for $2 \le \sqrt{t} \le 3.464$

= 3.09 for $\sqrt{t} > 3.464$

5.4 Unit Pressure Stress Intensity Factor for Reactor Vessel Nozzles

Considering a nozzle as a hole in a shell, WRC Bulletin 175 [13] 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. The plants use two instrument locations for indicated pressures, the low range taps in the decay heat drop lines and two taps (a narrow range tap and a wide range tap) in the hot legs. Therefore, the uncorrected P-T limits may be corrected to one or both of these locations. These location corrections were analyzed for various temperatures and pump combinations. The location corrections for ONS-1 are summarized in Table 6-1. The location correction factors for ONS-2 and ONS-3 are shown in Table 6-2. The limiting correction factors at various temperature ranges are then determined for beltline and closure head, as tabulated in Table 6-1 for ONS-1; and Table 6-2 for ONS-2 and ONS-3. The correction factors for the beltlines are also applicable to the nozzles.

Table 6-1: Limiting Location Pressure Corrections Factors for ONS-1

Temperature Range, °F	50-99		100-299		300-399		400-532‡	
Component	ΔP, psi	RCP	ΔP, psi	RCP	ΔP, psi	RCP	ΔP, psi	RCP
Beltline & Nozzle	21† (E12 WR)	0/0	93 (D7A1 WR)	2/0 or 0/2	105 (D51 WR)	2/1 or 1/2	115	2/2
RVCH	13† (E12 WR)	0/0	72 (D7A1 WR)	2/0 or 0/2	N/A		N/A	

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

†These correction factors are from Table 8-2 in Ref. 2

Table 6-2: Limiting Location Pressure Corrections Factors for ONS-2 and ONS-3

Temperature Range, °F	50-99		100-299		300-399		400-532‡	
Component	ΔP, psi	RCP	ΔP, psi	RCP	ΔP, psi	RCP	ΔP, psi	RCP
Beltline & Nozzle	21 (E12 WR)	0/0	88 (E7A1 WR)	2/0 or 0/2	100 (E51 WR)	2/1 or 1/2	109	2/2
RVCH	13 (E12 WR)	0/0	68 (E7A1 WR)	2/0 or 0/2	N/A		N/A	

‡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 ONS-1, ONS-2 and ONS-3 P-T limits at 54 EFPY. The analyses are corrected for location only. Correction due to instrument uncertainty is not included.

Technical Specification (Tech. Spec.) P-T limits for normal heatup and criticality conditions; normal cooldown, and inservice leak hydrostatic conditions are provided in Figure 7-1 through Figure 7-3 for ONS-1, Figure 7-4 through Figure 7-6 for ONS-2 and Figure 7-7 through Figure 7-9 for ONS-3, respectively. These P-T limits have been developed considering the operational conditions described in Section 4.0.

Maintaining the reactor coolant system pressure below the upper limit of the pressure-temperature limit curves ensures protection against non-ductile failure. Acceptable pressure and temperature combinations for reactor vessel operation are below and to the right of the applicable P-T limit curves. These P-T limit curves have been adjusted based on pressure differential between point of system pressure measurement and the point in the reactor vessel that establishes the controlling unadjusted pressure limit. The P-T limit curves provided in Figure 7-1 through Figure 7-9 do not include margins for instrument error. The reactor is not permitted to be critical until the pressure-temperature combinations are, as a minimum, to the right of the criticality curve. The numerical values for the Technical Specification P-T curves provided in Figure 7-1 through Figure 7-9 are shown in Table 7-1 through Table 7-5. The operational constraints for these curves are tabulated in Table 7-6 and Table 7-7. These Technical Specification P-T curves meet all the pressure and temperature requirements for the reactor pressure vessel listed in Table 1 of 10CFR Part 50, Appendix G[1].

The Tech. Spec. P-T limits for normal heatup for ONS units 1, 2 and 3 are shown in Table 7-1. The Tech. Spec. P-T limits for normal cooldown for ONS units 1, 2 and 3 are generated as the limiting allowable pressure at every calculated temperature as shown in Table 7-2. The Tech. Spec. P-T limits for ISLH heatup of the three ONS units are shown in Table 7-3. The limiting composite curves for Tech. Spec. P-T limits for ISLH are shown in Table 7-4. The criticality limit temperature corresponding to a pressure of 2500 psig is determined through interpolation of ISLH heatup data in Table 7-3. As shown in Table 7-5(a), the criticality limit temperatures for ONS-1, ONS-2 and ONS-3 are 252.9°F, 243.5°F and 243.2°F, respectively. The criticality-limit P-T limits data are shown in Table 7-5(b).

The Low Temperature Overpressurization Protection (LTOP) pressure limit at 54 EFPY that bounds all three ONS units is 540 psig (ONS-1). The 54 EFPY LTOP limiting pressure remains above the current Pressurizer Power-Operated Relief Valve (PORV) setpoint of 535 psig. Therefore, the current PORV low-pressure setpoint (535 psig) remains acceptable for plant operation to 54 EFPY for all three ONS units.

The minimum 54 EFPY LTOP enable temperature that bounds all three ONS units with instrument uncertainty is 276.8°F (ONS-3). This value is lower than the current LTOP enable temperature of 325°F at 33 EFPY. Therefore, the current LTOP temperature of 325°F remains acceptable for plant operation to 54 EFPY for all three ONS units.

Table 7-1: Tech. Spec. P-T Limits for Normal Heatup

ONS-1		ONS-2		ONS-3	
Fluid Temp	Governing Adjusted Pressure	Fluid Temp	Governing Adjusted Pressure	Fluid Temp	Governing Adjusted Pressure
(°F)	(psi)	(°F)	(psi)	(°F)	(psi)
60	528	60	527	60	528
65	528	65	527	65	528
70	528	70	527	70	528
72	528	72	527	72	528
75	528	75	527	75	528
80	528	80	527	80	528
85	528	85	527	85	528
90	528	90	527	90	528
95	528	95	527	95	528
100	528	100	527	100	528
105	528	105	527	105	528
110	534	110	532	110	533
115	545	115	543	115	544
120	553	120	550	120	552
125	553‡	125	550‡	125	552‡
130	553	130	550‡	130	552‡
135	557‡	135	550‡	135	552‡
140	557‡	140	550‡	140	552‡
145	557‡	145	550‡	145	552‡
150	557‡	150	550‡	150	552‡
155	557‡	155	550‡	155	552‡
160	557‡	160	550‡	160	552‡
165	557	165	550	165	552
167	557	167	550	167	552
170	557	170	550	170	552
170	567	170	582	170	582
170	593	170	613	170	614
170	729	170	776	170	778
175	804	175	825	175	829
180	834	180	867	180	872
185	867	185	914	185	919
190	903	190	965	190	970
195	943	195	1021	195	1027
200	987	200	1083	200	1090

ONS-1		ONS-2		ONS-3	
Fluid Temp	Governing Adjusted Pressure	Fluid Temp	Governing Adjusted Pressure	Fluid Temp	Governing Adjusted Pressure
(°F)	(psi)	(°F)	(psi)	(°F)	(psi)
205	1035	205	1145	205	1150
210	1089	210	1210	210	1215
215	1148	215	1281	215	1287
220	1213	220	1360	220	1366
225	1285	225	1446	225	1452
230	1364	230	1542	230	1548
235	1451	235	1648	235	1654
240	1547	240	1764	240	1770
245	1653	245	1893	245	1899
250	1771	250	2035	250	2041
255	1900	255	2192	255	2198
260	2044	260	2365	260	2372
265	2202	265	2557	265	2564
270	2374	270	2755	270	2773
275	2500	275	2906	275	2925
280	2655	280	2984	280	2984
285	2834	285	2984	285	2984
290	2978	290	2984	290	2984
295	2978	295	2984	295	2984
300	2978	300	2984	300	2984
305	2978	305	2984	305	2984
310	2978	310	2984	310	2984
315	2978	315	2984	315	2984
320	2978	320	2984	320	2984
325	2978	325	2984	325	2984
330	2978	330	2984	330	2984
335	2978	335	2984	335	2984
340	2978	340	2984	340	2984
345	2978	345	2984	345	2984
350	2978	350	2984	350	2984
355	2978	355	2984	355	2984
360	2978	360	2984	360	2984
365	2978	365	2984	365	2984
370	2978	370	2984	370	2984
375	2978	375	2984	375	2984
380	2978	380	2984	380	2984
385	2978	385	2984	385	2984
390	2978	390	2984	390	2984

ONS-1		ONS-2		ONS-3	
Fluid Temp	Governing Adjusted Pressure	Fluid Temp	Governing Adjusted Pressure	Fluid Temp	Governing Adjusted Pressure
(°F)	(psi)	(°F)	(psi)	(°F)	(psi)
395	2978	395	2984	395	2984
400	2978	400	2984	400	2984
405	2978	405	2984	405	2984
410	2978	410	2984	410	2984
415	2978	415	2984	415	2984
420	2978	420	2984	420	2984
425	2978	425	2984	425	2984
430	2978	430	2984	430	2984
435	2978	435	2984	435	2984
440	2978	440	2984	440	2984
445	2978	445	2984	445	2984
450	2978	450	2984	450	2984
455	2978	455	2984	455	2984
460	2978	460	2984	460	2984
465	2978	465	2984	465	2984
470	2978	470	2984	470	2984
475	2978	475	2984	475	2984
480	2978	480	2984	480	2984
485	2978	485	2984	485	2984
490	2978	490	2984	490	2984
495	2978	495	2984	495	2984
500	2978	500	2984	500	2984
505	2978	505	2984	505	2984
510	2978	510	2984	510	2984
515	2978	515	2984	515	2984
520	2978	520	2984	520	2984
525	2978	525	2984	525	2984
530	2978	530	2984	530	2984
535	2978	535	2984	535	2984
540	2978	540	2984	540	2984
545	2978	545	2984	545	2984
550	2978	550	2984	550	2984
554	2978	554	2984	554	2984
558	2978	558	2984	558	2984

‡Value adjusted to avoid negative slope in the curve

Table 7-2: Tech. Spec. P-T Limits for Normal Cooldown

ONS-1		ONS-2		ONS-3	
Fluid Temp	Governing Adjusted Pressure	Fluid Temp	Governing Adjusted Pressure	Fluid Temp	Governing Adjusted Pressure
(°F)	(psi)	(°F)	(psi)	(°F)	(psi)
550	2978	550	2984	550	2984
545	2969	545	2975	545	2975
540	2952	540	2958	540	2958
535	2933	535	2939	535	2939
530	2913	530	2919	530	2919
525	2893	525	2899	525	2899
520	2873	520	2879	520	2879
515	2853	515	2859	515	2859
510	2833	510	2839	510	2839
505	2815	505	2821	505	2821
500	2796	500	2802	500	2802
495	2779	495	2785	495	2785
490	2761	490	2767	490	2767
485	2745	485	2751	485	2751
480	2729	480	2735	480	2735
475	2714	475	2720	475	2720
470	2699	470	2705	470	2705
465	2685	465	2691	465	2691
460	2672	460	2678	460	2678
455	2659	455	2665	455	2665
450	2646	450	2652	450	2652
445	2634	445	2640	445	2640
440	2623	440	2629	440	2629
435	2611	435	2617	435	2617
430	2601	430	2607	430	2607
425	2591	425	2597	425	2597
420	2581	420	2587	420	2587
415	2571	415	2577	415	2577
410	2562	410	2568	410	2568
405	2554	405	2560	405	2560
400	2546	400	2552	400	2552
395	2546	395	2552	395	2552
390	2540	390	2545	390	2545
385	2533	385	2538	385	2538
380	2526	380	2531	380	2531
375	2519	375	2524	375	2524
370	2513	370	2518	370	2518

ONS-1		ONS-2		ONS-3	
Fluid Temp	Governing Adjusted Pressure	Fluid Temp	Governing Adjusted Pressure	Fluid Temp	Governing Adjusted Pressure
(°F)	(psi)	(°F)	(psi)	(°F)	(psi)
365	2506	365	2511	365	2511
360	2501	360	2506	360	2506
355	2495	355	2500	355	2500
350	2490	350	2495	350	2495
345	2485	345	2490	345	2490
340	2480	340	2485	340	2485
335	2475	335	2480	335	2480
330	2471	330	2476	330	2476
325	2467	325	2472	325	2472
320	2463	320	2468	320	2468
315	2459	315	2464	315	2464
310	2456	310	2461	310	2461
305	2452	305	2457	305	2457
300	2449	300	2454	300	2454
295	2449	295	2454	295	2454
290	2449	290	2454	290	2454
285	2449	285	2454	285	2454
280	2449	280	2454	280	2454
275	2447	275	2452	275	2452
270	2444	270	2449	270	2449
265	2444	265	2449	265	2449
260	2444	260	2449	260	2449
255	2444	255	2449	255	2449
251	2231	251	2365	251	2365
250	2231‡	250	2365‡	250	2365‡
246	2221	246	2365	246	2365
245	2187	245	2365‡	245	2365‡
241	2058	241	2365	241	2365
240	2028	240	2338	240	2353
236	1912	236	2199	236	2212
235	1884	235	2165	235	2179
231	1779	231	2039	231	2051
230	1754	230	2009	230	2021
226	1659	226	1895	226	1906
225	1636	225	1867	225	1878
221	1550	221	1764	221	1774
220	1529	220	1739	220	1749
216	1452	216	1646	216	1655

ONS-1		ONS-2		ONS-3	
Fluid Temp	Governing Adjusted Pressure	Fluid Temp	Governing Adjusted Pressure	Fluid Temp	Governing Adjusted Pressure
(°F)	(psi)	(°F)	(psi)	(°F)	(psi)
215	1433	215	1623	215	1632
211	1363	211	1539	211	1547
210	1346	210	1518	210	1526
206	1282	206	1442	206	1449
205	1267	205	1423	205	1431
201	1209	201	1354	201	1361
200	1195	200	1338	200	1344
196	1143	196	1275	196	1281
195	1131	195	1260	195	1266
191	1083	191	1203	191	1209
190	1053	190	1166	190	1172
186	1029	186	1138	186	1143
181	981	181	1079	181	1084
176	910	176	1021	176	1026
171	837	171	907	171	910
166	824	166	907	166	910
161	765	161	871	161	876
156	720	156	814	156	818
155	710	155	802	155	806
146	636	146	708	146	711
135	611	135	670	135	672
110	531	110	557	110	557
105	527	105	557	105	557
100	513	100	544	100	545
95	513	95	544	95	545
90	513	90	544	90	545
85	513	85	544	85	545
80	513	80	544	80	545
75	513	75	544	75	545
70	513	70	534	70	535
65	512	65	525	65	526
60	506	60	518	60	519

‡Value adjusted to avoid negative slope in the curve

Table 7-3: Tech. Spec. P-T Limits for ISLH Heatup

ONS-1		ONS-2		ONS-3	
Fluid Temp	Governing Adjusted Pressure	Fluid Temp	Governing Adjusted Pressure	Fluid Temp	Governing Adjusted Pressure
(°F)	(psi)	(°F)	(psi)	(°F)	(psi)
60	553	60	557	60	557
65	553	65	557	65	557
70	553	70	557	70	557
72	553	72	557	72	557
75	553	75	557	75	557
80	553	80	557	80	557
85	553	85	557	85	557
90	553	90	557	90	557
95	553	95	557	95	557
100	553	100	557	100	557
105	553	105	557	105	557
110	610	110	622	110	614
115	752	115	753	115	755
120	774	120	763	120	766
125	774‡	125	763‡	125	766‡
130	774‡	130	763‡	130	766‡
135	774‡	135	763‡	135	766‡
140	774‡	140	763‡	140	766‡
145	774‡	145	763‡	145	766‡
150	774‡	150	763‡	150	766‡
155	774‡	155	763‡	155	766‡
160	774‡	160	763‡	160	766‡
165	774	165	763	165	766
167	774	167	763	167	766
170	774	170	763	170	766
170	787	170	805	170	806
170	821	170	847	170	848
170	1002	170	1065	170	1067
175	1103	175	1130	175	1135
180	1143	180	1186	180	1192
185	1187	185	1248	185	1255
190	1235	190	1316	190	1323
195	1288	195	1390	195	1399
200	1347	200	1473	200	1483
205	1412	205	1557	205	1563
210	1483	210	1643	210	1650

ONS-1		ONS-2		ONS-3	
Fluid Temp	Governing Adjusted Pressure	Fluid Temp	Governing Adjusted Pressure	Fluid Temp	Governing Adjusted Pressure
(°F)	(psi)	(°F)	(psi)	(°F)	(psi)
215	1562	215	1738	215	1746
220	1649	220	1842	220	1850
225	1745	225	1958	225	1966
230	1852	230	2085	230	2093
235	1969	235	2226	235	2234
240	2098	240	2382	240	2390
245	2241	245	2553	245	2562
250	2398	250	2743	250	2751
255	2572	255	2952	255	2960
260	2765	260	3183	260	3192
265	2977	265	3438	265	3447
270	3197	270	3702	270	3726
275	3364	275	3904	275	3929
280	3571	280	4015	280	4015
285	3809	285	4015	285	4015
290	4009	290	4015	290	4015
295	4009	295	4015	295	4015
300	4009	300	4015	300	4015
305	4009	305	4015	305	4015
310	4009	310	4015	310	4015
315	4009	315	4015	315	4015
320	4009	320	4015	320	4015
325	4009	325	4015	325	4015
330	4009	330	4015	330	4015
335	4009	335	4015	335	4015
340	4009	340	4015	340	4015
345	4009	345	4015	345	4015
350	4009	350	4015	350	4015
355	4009	355	4015	355	4015
360	4009	360	4015	360	4015
365	4009	365	4015	365	4015
370	4009	370	4015	370	4015
375	4009	375	4015	375	4015
380	4009	380	4015	380	4015
385	4009	385	4015	385	4015
390	4009	390	4015	390	4015
395	4009	395	4015	395	4015
400	4009	400	4015	400	4015

ONS-1		ONS-2		ONS-3	
Fluid Temp	Governing Adjusted Pressure	Fluid Temp	Governing Adjusted Pressure	Fluid Temp	Governing Adjusted Pressure
(°F)	(psi)	(°F)	(psi)	(°F)	(psi)
405	4009	405	4015	405	4015
410	4009	410	4015	410	4015
415	4009	415	4015	415	4015
420	4009	420	4015	420	4015
425	4009	425	4015	425	4015
430	4009	430	4015	430	4015
435	4009	435	4015	435	4015
440	4009	440	4015	440	4015
445	4009	445	4015	445	4015
450	4009	450	4015	450	4015
455	4009	455	4015	455	4015
460	4009	460	4015	460	4015
465	4009	465	4015	465	4015
470	4009	470	4015	470	4015
475	4009	475	4015	475	4015
480	4009	480	4015	480	4015
485	4009	485	4015	485	4015
490	4009	490	4015	490	4015
495	4009	495	4015	495	4015
500	4009	500	4015	500	4015
505	4009	505	4015	505	4015
510	4009	510	4015	510	4015
515	4009	515	4015	515	4015
520	4009	520	4015	520	4015
525	4009	525	4015	525	4015
530	4009	530	4015	530	4015
535	4009	535	4015	535	4015
540	4009	540	4015	540	4015
545	4009	545	4015	545	4015
550	4009	550	4015	550	4015
554	4009	554	4015	554	4015
558	4009	558	4015	558	4015

‡Value adjusted to avoid negative slope in the curve

Table 7-4: Tech. Spec. P-T Limits for ISLH Composite Curve

ONS-1		ONS-2		ONS-3	
Fluid Temp	Governing Adjusted Pressure	Fluid Temp	Governing Adjusted Pressure	Fluid Temp	Governing Adjusted Pressure
(°F)	(psi)	(°F)	(psi)	(°F)	(psi)
60	553	60	557	60	557
65	553	65	557	65	557
70	553	70	557	70	557
75	553	75	557	75	557
80	553	80	557	80	557
85	553	85	557	85	557
90	553	90	557	90	557
95	553	95	557	95	557
100	553	100	557	100	557
105	553	105	557	105	557
110	610	110	614	110	614
115	752	115	753	115	755
120	774	120	763	120	766
125	774	125	763	125	766
130	774	130	763	130	766
135	774	135	763	135	766
140	774	140	763	140	766
145	774	145	763	145	766
150	774	150	763	150	766
155	774	155	763	155	766
160	774	160	763	160	766
165	774	165	763	165	766
167	774	167	763	167	766
170	774	170	763	170	766
170	787	170	805	170	806
170	821	170	847	170	848
170	1002	170	1065	170	1067
175	1103	175	1130	175	1135
180	1143	180	1186	180	1192
185	1187	185	1248	185	1255
190	1235	190	1316	190	1323
195	1288	195	1390	195	1399
200	1347	200	1473	200	1483
205	1412	205	1557	205	1563
210	1483	210	1643	210	1650
215	1562	215	1738	215	1746

ONS-1		ONS-2		ONS-3	
Fluid Temp	Governing Adjusted Pressure	Fluid Temp	Governing Adjusted Pressure	Fluid Temp	Governing Adjusted Pressure
(°F)	(psi)	(°F)	(psi)	(°F)	(psi)
220	1649	220	1842	220	1850
225	1745	225	1958	225	1966
230	1852	230	2085	230	2093
235	1969	235	2226	235	2234
240	2098	240	2382	240	2390
245	2241	245	2553	245	2562
250	2398	250	2743	250	2751
255	2572	255	2952	255	2960
260	2765	260	3183	260	3192
265	3290	265	3295	265	3295
270	3290	270	3295	270	3295
275	3293	275	3298	275	3298
280	3297	280	3302	280	3302
285	3300	285	3305	285	3305
290	3300	290	3305	290	3305
295	3300	295	3305	295	3305
300	3300	300	3305	300	3305
305	3305	305	3310	305	3310
310	3309	310	3314	310	3314
315	3314	315	3319	315	3319
320	3319	320	3324	320	3324
325	3324	325	3329	325	3329
330	3330	330	3335	330	3335
335	3336	335	3341	335	3341
340	3342	340	3347	340	3347
345	3348	345	3353	345	3353
350	3355	350	3360	350	3360
355	3362	355	3367	355	3367
360	3369	360	3374	360	3374
365	3377	365	3382	365	3382
370	3385	370	3390	370	3390
375	3394	375	3399	375	3399
380	3403	380	3408	380	3408
385	3412	385	3417	385	3417
390	3422	390	3427	390	3427
395	3432	395	3437	395	3437
400	3432	400	3438	400	3438
405	3443	405	3449	405	3449

ONS-1		ONS-2		ONS-3	
Fluid Temp	Governing Adjusted Pressure	Fluid Temp	Governing Adjusted Pressure	Fluid Temp	Governing Adjusted Pressure
(°F)	(psi)	(°F)	(psi)	(°F)	(psi)
410	3455	410	3461	410	3461
415	3467	415	3473	415	3473
420	3479	420	3485	420	3485
425	3492	425	3498	425	3498
430	3506	430	3512	430	3512
435	3520	435	3526	435	3526
440	3536	440	3542	440	3542
445	3551	445	3557	445	3557
450	3567	450	3573	450	3573
455	3583	455	3589	455	3589
460	3601	460	3607	460	3607
465	3619	465	3625	465	3625
470	3637	470	3643	470	3643
475	3657	475	3663	475	3663
480	3677	480	3683	480	3683
485	3698	485	3704	485	3704
490	3720	490	3726	490	3726
495	3743	495	3749	495	3749
500	3767	500	3773	500	3773
505	3791	505	3797	505	3797
510	3816	510	3822	510	3822
515	3842	515	3848	515	3848
520	3869	520	3875	520	3875
525	3896	525	3902	525	3902
530	3923	530	3929	530	3929
535	3950	535	3956	535	3956
540	3975	540	3981	540	3981
545	3997	545	4003	545	4003
550	4008	550	4014	550	4014
554	4009	554	4015	554	4015
558	4009	558	4015	558	4015

Table 7-5: Tech. Spec. Criticality Limit P-T Limits

(a) Criticality Limit Determination

ONS-1		ONS-2		ONS-3	
Pressure (psig)	Temp. (F)	Pressure (psig)	Temp. (F)	Pressure (psig)	Temp. (F)
2398	250	2382	240	2390	240
2572	255	2553	245	2562	245
Interpolating		Interpolating		Interpolating	
2500	**252.9**	**2500**	**243.5**	**2500**	**243.2**

(b) Criticality Limit P-T Limits

ONS-1		ONS-2		ONS-3	
Fluid Temp	**Governing Adjusted Pressure**	**Fluid Temp**	**Governing Adjusted Pressure**	**Fluid Temp**	**Governing Adjusted Pressure**
(°F)	(psi)	(°F)	(psi)	(°F)	(psi)
		243.5	0	243.2	0
		243.5	1126	243.2	1128
252.9	0	245	1145	245	1150
252.9	1124	250	1210	250	1215
255	1148	255	1281	255	1287
260	1213	260	1360	260	1366
265	1285	265	1446	265	1452
270	1364	270	1542	270	1548
275	1451	275	1648	275	1654
280	1547	280	1764	280	1770
285	1653	285	1893	285	1899
290	1771	290	2035	290	2041
295	1900	295	2192	295	2198
300	2044	300	2365	300	2372
305	2202	305	2557	305	2564
310	2374	310	2755	310	2773
315	2500	315	2906	315	2925
320	2655	320	2984	320	2984
325	2834	325	2984	325	2984
330	2978	330	2984	330	2984
335	2978	335	2984	335	2984
340	2978	340	2984	340	2984
345	2978	345	2984	345	2984
350	2978	350	2984	350	2984
355	2978	355	2984	355	2984

ONS-1		ONS-2		ONS-3	
Fluid Temp	Governing Adjusted Pressure	Fluid Temp	Governing Adjusted Pressure	Fluid Temp	Governing Adjusted Pressure
(°F)	(psi)	(°F)	(psi)	(°F)	(psi)
360	2978	360	2984	360	2984
365	2978	365	2984	365	2984
370	2978	370	2984	370	2984
375	2978	375	2984	375	2984
380	2978	380	2984	380	2984
385	2978	385	2984	385	2984
390	2978	390	2984	390	2984
395	2978	395	2984	395	2984
400	2978	400	2984	400	2984
405	2978	405	2984	405	2984
410	2978	410	2984	410	2984
415	2978	415	2984	415	2984
420	2978	420	2984	420	2984
425	2978	425	2984	425	2984
430	2978	430	2984	430	2984
435	2978	435	2984	435	2984
440	2978	440	2984	440	2984
445	2978	445	2984	445	2984
450	2978	450	2984	450	2984
455	2978	455	2984	455	2984
460	2978	460	2984	460	2984
465	2978	465	2984	465	2984
470	2978	470	2984	470	2984
475	2978	475	2984	475	2984
480	2978	480	2984	480	2984
485	2978	485	2984	485	2984
490	2978	490	2984	490	2984
495	2978	495	2984	495	2984
500	2978	500	2984	500	2984
505	2978	505	2984	505	2984
510	2978	510	2984	510	2984
515	2978	515	2984	515	2984
520	2978	520	2984	520	2984
525	2978	525	2984	525	2984
530	2978	530	2984	530	2984
535	2978	535	2984	535	2984
540	2978	540	2984	540	2984
545	2978	545	2984	545	2984

ONS-1		ONS-2		ONS-3	
Fluid Temp	**Governing Adjusted Pressure**	**Fluid Temp**	**Governing Adjusted Pressure**	**Fluid Temp**	**Governing Adjusted Pressure**
(°F)	(psi)	(°F)	(psi)	(°F)	(psi)
550	2978	550	2984	550	2984
555	2978	555	2984	555	2984
560	2978	560	2984	560	2984
565	2978	565	2984	565	2984
570	2978	570	2984	570	2984
575	2978	575	2984	575	2984
580	2978	580	2984	580	2984
585	2978	585	2984	585	2984
590	2978	590	2984	590	2984
594	2978	594	2984	594	2984
598	2978	598	2984	598	2984

Table 7-6: Operational Constraints for Plant Heatup

CONSTRAINT	RC TEMPERATURE	HEATUP RATE	ALLOWED PUMP COMBINATION
RC Temperature	T < 270°F	≤ 30°F in any 1/2 hr period	NA
	T ≥ 270°F	≤ 50°F in any 1/2 hr period	NA
RC Pumps	T < 100°F	NA	No pumps
	100°F ≤ T < 300°F	NA	≤ two pumps
	T ≥ 300°F	NA	Any

Table 7-7: Operational Constraints for Plant Cooldown

CONSTRAINT	RC TEMPERATURE	COOLDOWN RATE	ALLOWED PUMP COMBINATION
RC Temperature	T ≥ 270°F	≤ 50°F in any 1/2 hr period	NA
	140°F ≤ T < 270°F	≤ 25°F in any 1/2 hr period	NA
	T<140°F	≤ 50°F in any one hr period	NA
	RCS depressurized	≤ 50°F in any one hr period	NA
RC Pumps	T ≥ 300°F	NA	Any
	100°F ≤ T < 300°F	NA	≤ two pumps
	T < 100°F	NA	No pumps

Figure 7-1: Tech. Spec. P-T Limits of ONS-1 for Normal Heatup and Criticality Limit

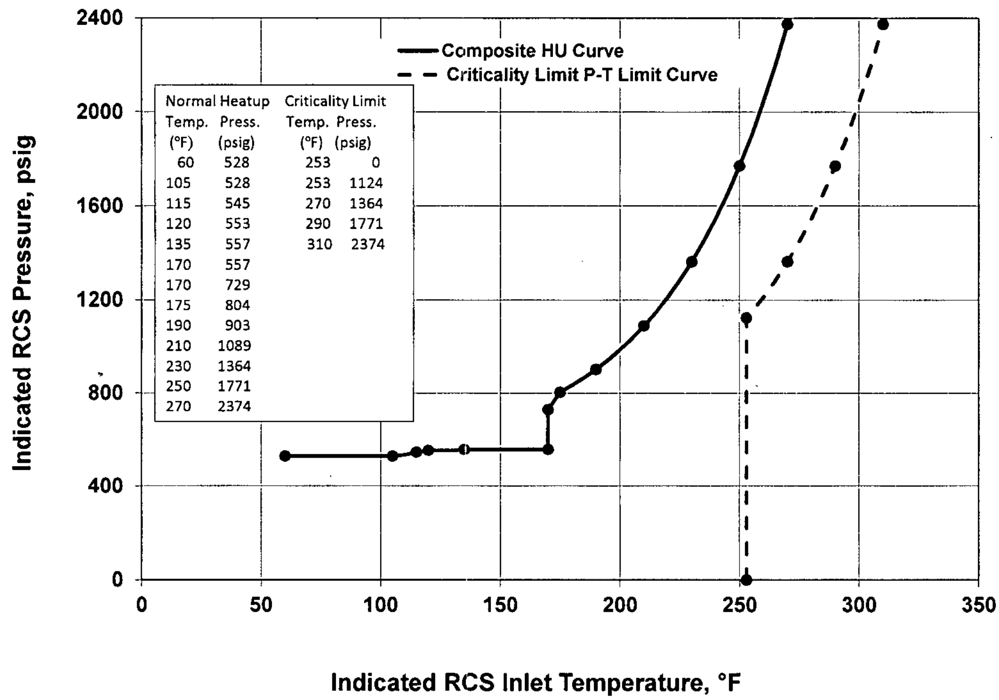


Figure 7-2: Tech. Spec. P-T Limits of ONS-1 for Normal Cooldown

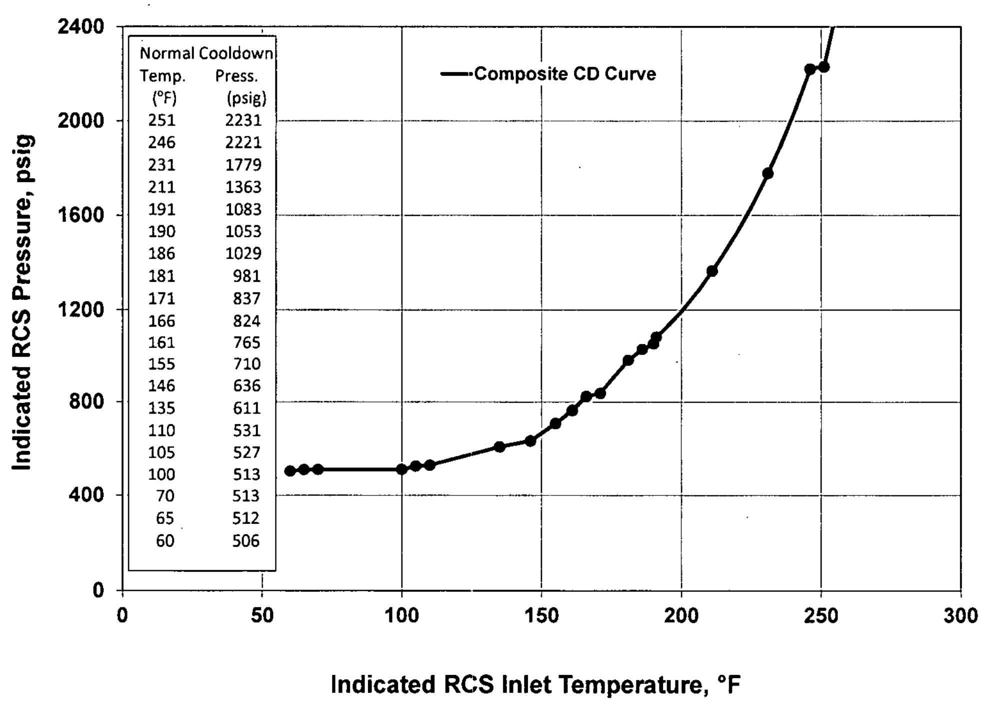


Figure 7-3: Tech. Spec. P-T Limits of ONS-1 for ISLH Composite Curve (Heatup, Cooldown)

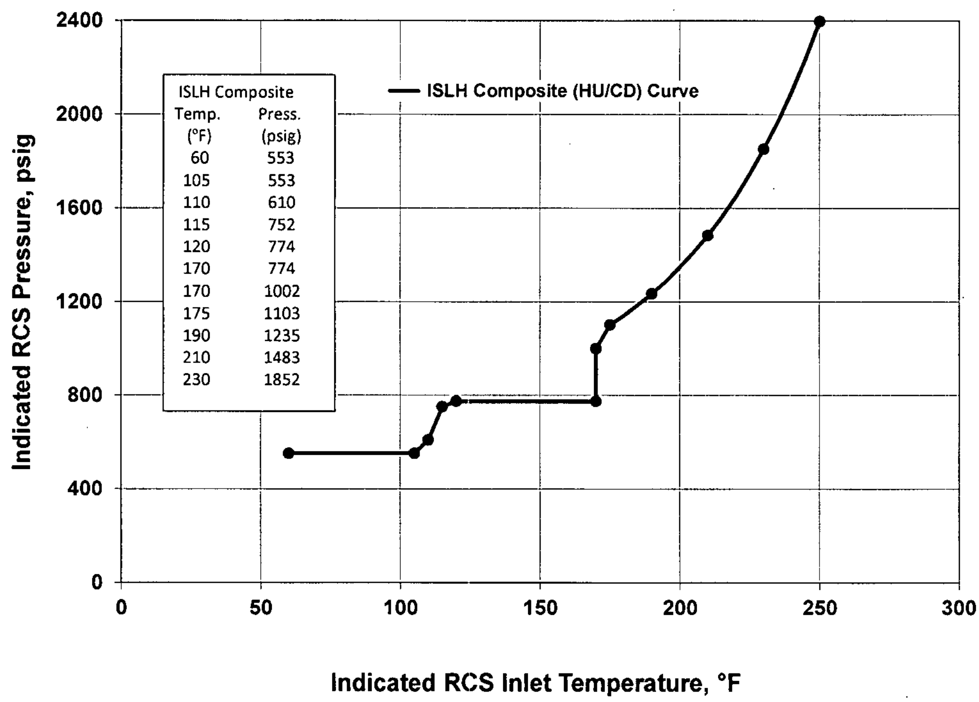


Figure 7-4: Tech. Spec. P-T Limits of ONS-2 for Normal Heatup and Criticality Limit

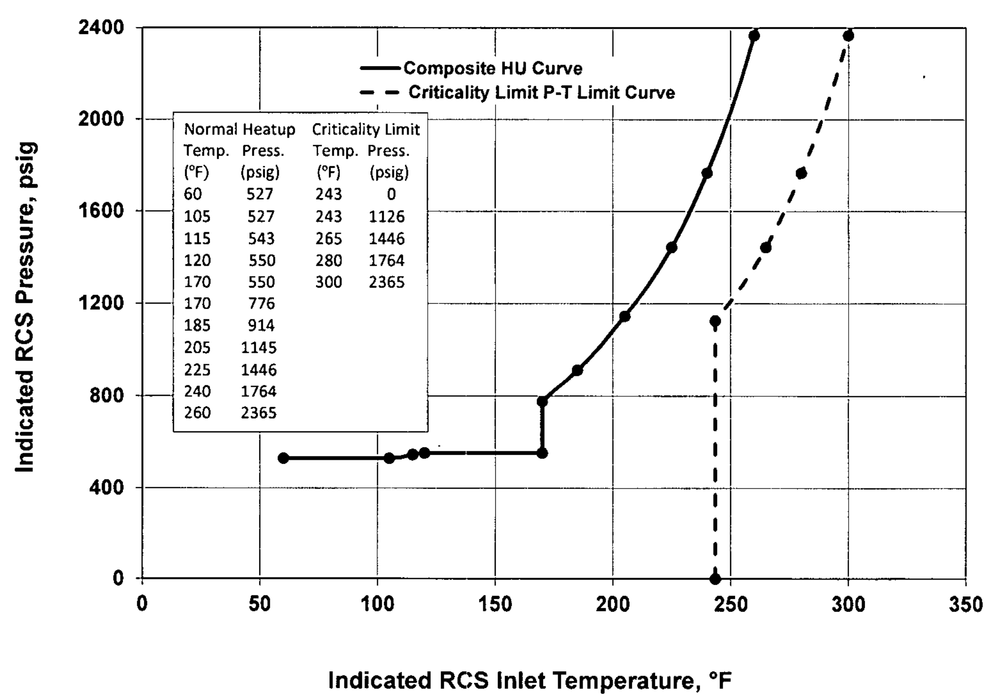


Figure 7-5: Tech. Spec. P-T Limits of ONS-2 for Normal Cooldown

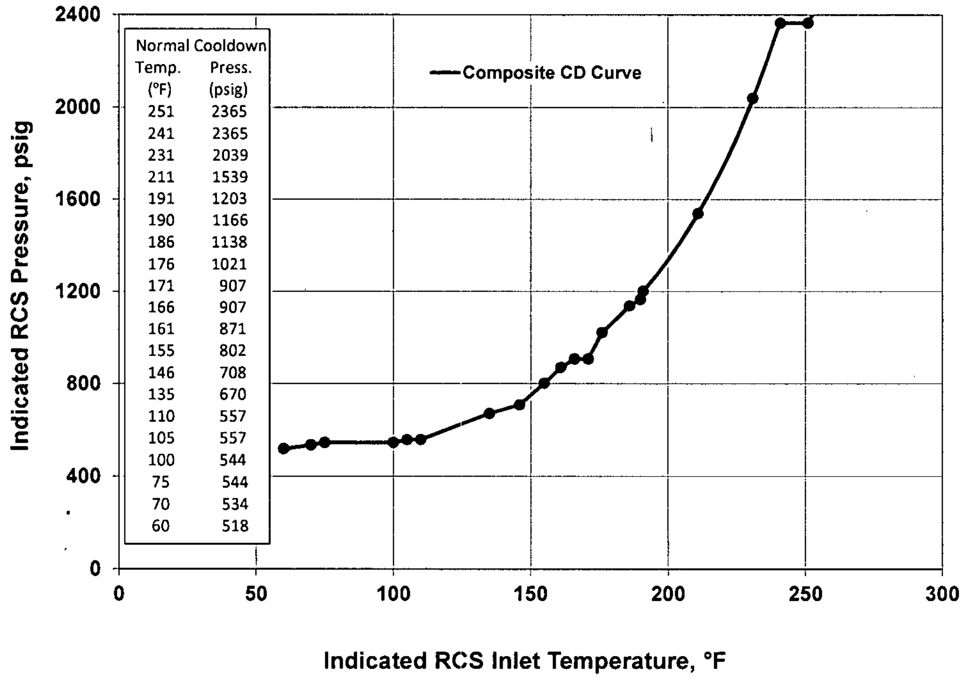


Figure 7-6: Tech. Spec. P-T Limits of ONS-2 for ISLH Composite Curve (Heatup, Cooldown)

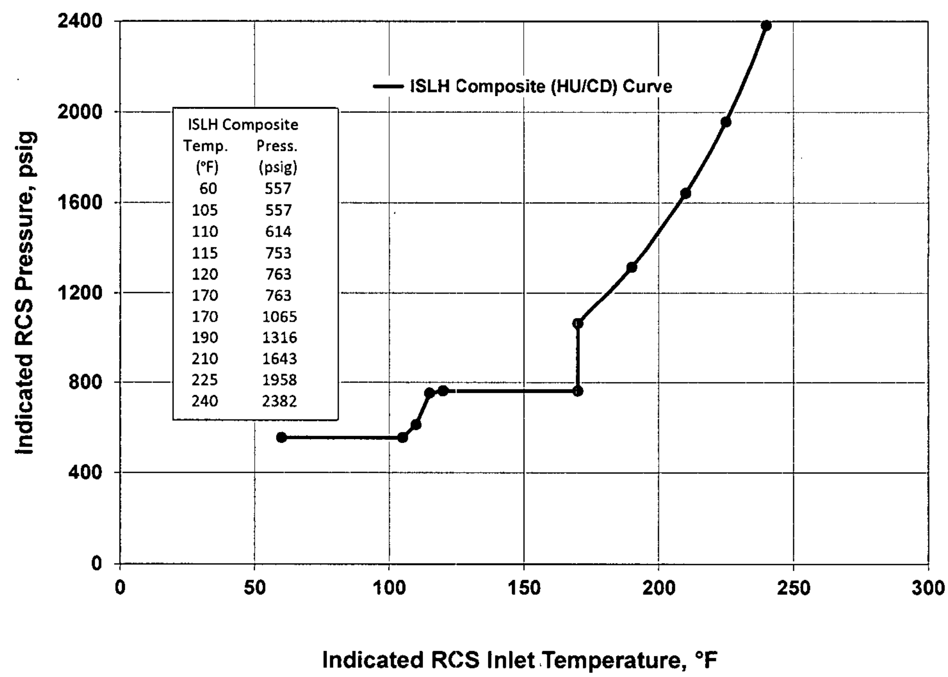


Figure 7-7: Tech. Spec. P-T Limits of ONS-3 for Normal Heatup and Criticality Limit

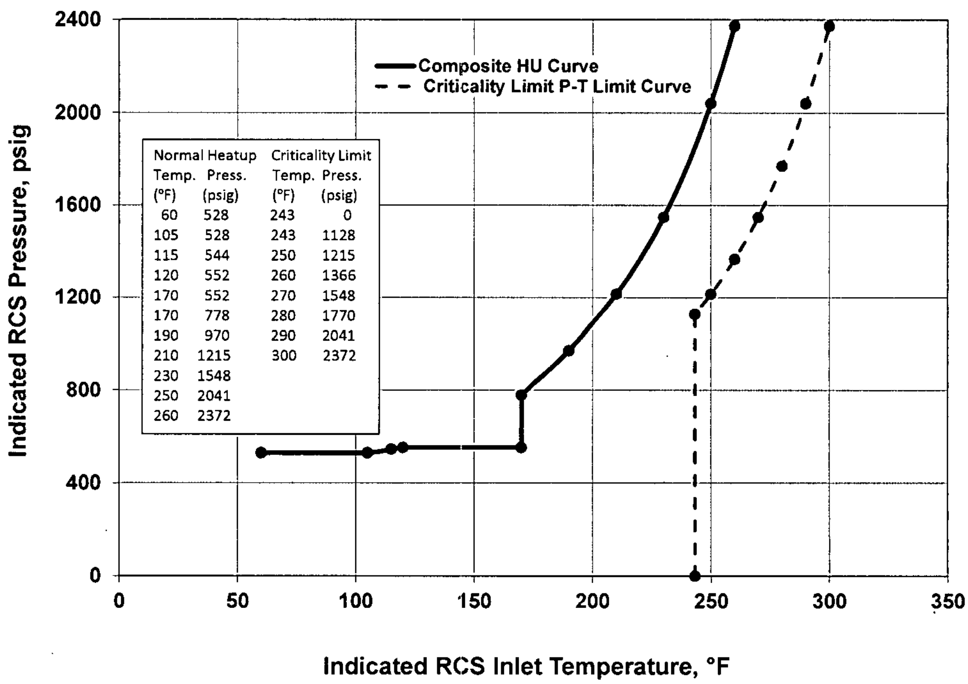


Figure 7-8: Tech. Spec. P-T Limits of ONS-3 for Normal Cooldown

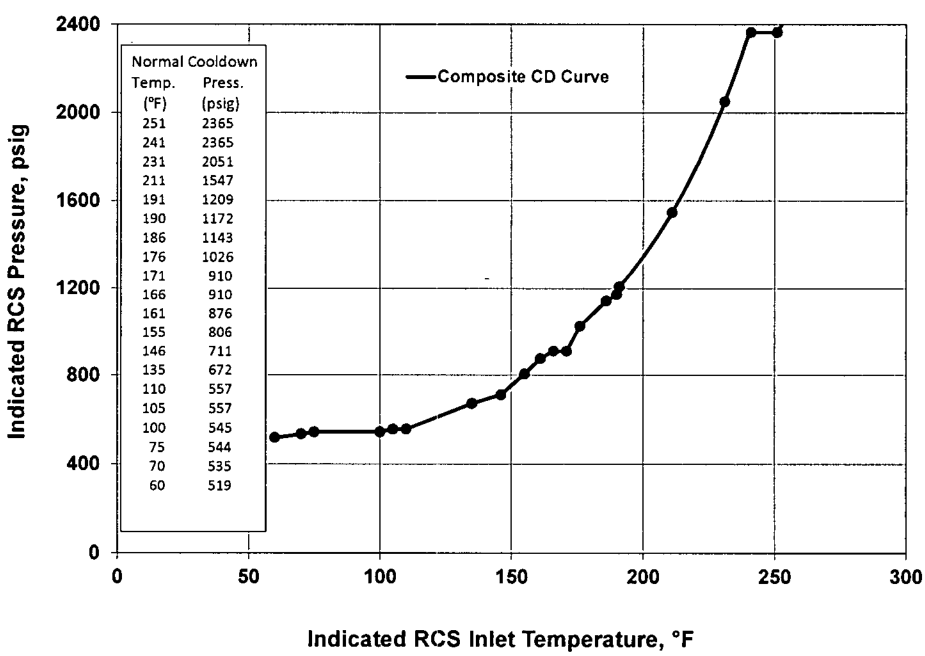
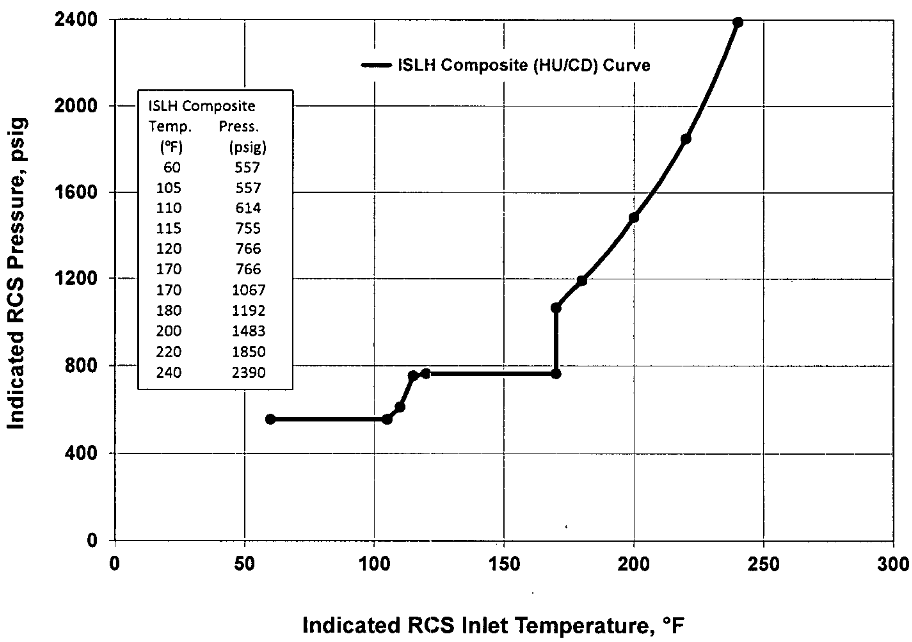


Figure 7-9: Tech. Spec. P-T Limits of ONS-3 for ISLH Composite Curve (Heatup, Cooldown)



ISLH Composite Temp. (°F)	Press. (psig)
60	557
105	557
110	614
115	755
120	766
170	766
170	1067
180	1192
200	1483
220	1850
240	2390

8.0 REFERENCES

1. Code of Federal Regulations, Title 10, Part 50 – Domestic Licensing of Production and Utilization Facilities, Appendix G – Fracture Toughness Requirements, Federal Register Vol. 60, No. 243, January 31, 2008

2. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," Appendix G, "Fracture Toughness Criteria for Protection Against Failure," 1998 Edition with Addenda through 2000

3. ASTM Standard E 208-81, "Standard Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels," American Society for Testing and Materials, Philadelphia, PA

4. AREVA NP Document BAW-10046A, Rev. 2, "Methods of Compliance with Fracture Toughness and Operational Requirements of 10CFR50, Appendix G," by H. W. Behnke et al., June 1986

5. US Nuclear Regulatory Commission, "Radiation Embrittlement of Reactor Vessel Materials," Regulatory Guide 1.99, Revision 2, May 1988

6. AREVA NP Document BAW-2241P-A, Rev. 2, "Fluence and Uncertainty Methodologies,"

7. US Nuclear Regulatory Commission, "Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence," Regulatory Guide 1.190, March 2001

8. AREVA NP Document BAW-2308, Rev. 1A and Rev. 2A, "Initial RTNDT of LINDE 80 Weld Materials," by K. K. Yoon, August 2005 and March 2008

9. Duke Energy to NRC Letter dated August 3, 2011 "Request for Exemption from Certain Requirements Contained in 10 CFR 50.61 and 10 CFR 50, Appendix G" (Accession No. ML11223A010)

10. NRC Letter to Duke Energy dated March 30, 2012 "Oconee Nuclear Station, Units 1, 2 and 3 – Environmental Assessment and Finding of No Significant impact related to the Proposed Exemption from the Requirements of Title 10 of the Code of Federal Regulations (10 CFR), Part 50.61 and 10CFR Part 50, Appendix G" (Accession No. ML120580101)

11. AREVA NP Document BAW-2313 Rev. 6, "B&W Fabricated Reactor Vessel Materials and Surveillance Data Information," November 2008

12. Timoshenko, S.P., and Goodier, J.N., "Theory of Elasticity," Third Edition, McGraw-Hill Book Company, 1970

13. PVRC Ad Hoc Group on Toughness Requirements, "PVRC Recommendations on Toughness Requirements for Ferritic Materials," Bulletin No. 175, Welding Research Council, August 1972

9.0 CERTIFICATION

Pressure-Temperature limits for the ONS-1, 2 and 3 reactor vessels 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, 1998 Edition with 2000 Addenda.

1/31/13

Silvester J. Noronha, Engineer IV — Date
Component Analysis and Fracture Mechanics

1/31/13

Pei-Yuan Cheng, Engineer III — Date
Component Analysis and Fracture Mechanics

This report has been reviewed for technical content and accuracy.

1/31/13

Ashok D. Nana, Supervisor — Date
Component Analysis and Fracture Mechanics

Verification of independent review.

1/31/13

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

This report is approved for release

L. M. LESNIAK
JAN 3 1 2013

Larry M. Lesniak, Project Manager — Date