St. Lucie Unit 1
Extended Power Uprate
Licensing Report

Attachment 5
Appendix G

WCAP-17197-NP
Revision 0

St. Lucie Unit 1
RCS Pressure and Temperature Limits and
Low-Temperature Overpressure Protection Report
For 54 Effective Full Power Years

This coversheet plus 52 pages

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WCAP-17197-NP
Revision 0

February 2010

St. Lucie Unit 1 RCS Pressure and Temperature Limits and Low-Temperature Overpressure Protection Report for 54 Effective Full Power Years

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Revision 0

St. Lucie Unit 1 RCS Pressure and Temperature Limits and Low-temperature Overpressure Protection Report for 54 Effective Full Power Years

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1 INTRODUCTION

The following sections describe the basis for developing reactor vessel beltline pressure-temperature (P-T) limitations and low-temperature overpressure protection (LTOP) requirements for the St. Lucie, Unit 1, Nuclear Generating Station. These limits are calculated to meet the regulations of the U.S. Nuclear Regulatory Commission (NRC) 10 CFR 50, Appendix A (Reference 1), Design Criterion 14 and Design Criterion 31. These design criteria require that the reactor coolant pressure boundary be designed, fabricated, erected and tested in order to have an extremely low probability of abnormal leakage, of rapid propagating failure, and of gross rupture. The criteria also require that the reactor coolant pressure boundary be designed with sufficient margin to assure that when stressed under operating, maintenance and testing the boundary behaves in a non-brittle manner and the probability of rapidly propagating fracture is minimized.

The P-T limits are developed using the requirements of 10 CFR 50 Appendix G (Reference 2). This appendix describes the requirements for developing the P-T limits and provides the general basis for these limitations. The margins of safety against fracture provided by the P-T limits using the requirements of 10 CFR 50 Appendix G are equivalent to those recommended in the ASME Boiler and Pressure Vessel Code Section III, Appendix G, "Fracture Toughness Criteria for Protection against Failure" (Reference 3). The general guidance provided in those procedures was utilized to develop the St. Lucie Unit 1 P-T limits with the requisite margins of safety for the heatup and cooldown conditions.

The reactor pressure vessel beltline P-T limits are based upon the irradiation damage prediction methods of Regulatory Guide 1.99, Revision 2 (Reference 4). This methodology was used to calculate the limiting material adjusted reference temperatures for St. Lucie Unit 1 utilizing fluence values corresponding to 54 effective full power years (EFPY).

This report provides reactor vessel beltline P-T limits generated in accordance with 10 CFR 50, Appendix G for 54 EFPY. The events analyzed are the isothermal, 20 through 100°F/hr cooldown conditions and both 50°F/hr and 70°F/hr heatup conditions. These conditions were analyzed to provide a data base of reactor vessel P-T limits for use in establishing LTOP requirements.

LTOP requirements were established based upon the guidance provided in U.S. NRC Standard Review Plan (SRP), 5.2.2 (Reference 5). Using this guidance, the limiting transient pressures were determined for mass and energy addition transients to establish the appropriate LTOP setpoints, heatup and cooldown rates, and administrative requirements.

Based upon the P-T limit analyses and LTOP requirements provided within this report, no limiting vessel operability issues are anticipated.

2 PRESSURE–TEMPERATURE LIMITS

2.1 ADJUSTED REFERENCE TEMPERATURE PROJECTIONS

In order to develop P-T limits over the design life of the reactor vessel, adjusted reference temperatures (ARTs) for the controlling beltline material need to be determined. The ARTs for the St. Lucie Unit 1 reactor vessel beltline materials were calculated for 54 EFPY at both the 1/4t and 3/4t locations. The vessel material with the highest ART (i.e., the controlling material) was used as the input to the P-T limits for St. Lucie Unit 1.

The ART values have been calculated using the procedures in Regulatory Positions 1.1 and 1.2 of Regulatory Guide 1.99, Revision 2 (Reference 4). The calculation for the ART values for each material in the beltline is shown below.

$$\text{ART} = \text{Initial } RT_{NDT} + \quad RT_{NDT} + \text{margin}$$

The neutron fluence is attenuated through the vessel wall using the nominal reactor vessel thickness of 8.625 inches (Reference 6), conservatively neglecting cladding thickness. The material input data are listed in Table 2-1. The St. Lucie Unit 1 reactor vessel is weld limited, with the limiting 1/4t and 3/4t ART values of 210°F and 156°F, respectively. The 54 EFPY ART projections for all beltline materials are provided in Table 2-2.

The following information provides the basis for the calculated ART values for St. Lucie Unit 1.

1. The material data were obtained from References 7, 8, and 9, including copper content, nickel content and initial reference temperature (initial RT_{NDT}). These data are summarized in Table 2-1 for St. Lucie Unit 1.

2. The peak neutron fluence at 54 EFPY for the Unit 1 beltline region was determined to be 4.21×10^{19} n/cm^2 (E>1 MeV) for the base metal and the circumferential weld, and 2.74×10^{19} n/cm^2 (E>1 MeV) for the axial welds. The fluence analysis was based on a plant and fuel-cycle-specific basis for the first 26 reactor operating cycles. For Cycles 1 through 23, the effective full power is 2700 MWt. Cycles 24 and 25 are EPU transition cycles at 3020 MWt and Cycle 26 is representative of the equilibrium for EPU at 3020 MWt. Projections were made to 54 EFPY beginning from the end of Cycle 24 assuming the uprated core power of 3020 MWt.

3. The reactor vessel beltline thickness was 8.625 inches. (Reference 6).

4. Calculations were based on the procedures in Regulatory Guide 1.99, Revision. 2 (Reference 4).

ARTs for all beltline materials at the 1/4t and 3/4t locations after 54 EFPY were calculated using Regulatory Guide 1.99, Revision 2. The results of the calculation are listed in Table 2-2 for St. Lucie Unit 1. The vessel material with the highest ART is shown in Table 2-3. These limiting ART values were then used to develop the P-T limits for the corresponding time period. In the case of St. Lucie Unit 1, the lower shell axial welds (3-203 A/C) are controlling at the 1/4t and 3/4t location after 54 EFPY based on the predicted ART values of 210°F and 156°F, respectively.

Table 2-1 St. Lucie Unit 1 Reactor Vessel Beltline Materials

Material Description	Material Heat Number	Cu (%)	Ni (%)	Initial RT_{NDT}
Intermediate Shell Plate C-7-1	A-4567-1	0.11	0.64	0°F
Intermediate Shell Plate C-7-2	B-9427-1	0.11	0.64	-10°F
Intermediate Shell Plate C-7-3	A-4567-2	0.11	0.58	10°F
Lower Shell Plate C-8-1	C-5935-1	0.15	0.56	20°F
Lower Shell Plate C-8-2	C-5935-2	0.15	0.57	20°F
Lower Shell Plate C-8-3	C-5935-3	0.12	0.58	0°F
Intermediate to Lower Shell Girth Weld 9-203	90136	0.27	0.07	-60°F
Intermediate Shell Axial Weld 2-203 A/C	A-8746 and 34B009	0.19	0.09	-56°F
Lower Shell Axial Weld 3-203 A/C	305424	0.27	0.63	-60°F

Table 2-2 St. Lucie Unit 1 Reactor Vessel Beltline Material Data for 1/4T and 3/4T

Beltline Material	Initial RT_{NDT} (°F)	CF (°F)	FF	ΔRT_{NDT}(1) (°F)	σ_I (°F)	σ_Δ (°F)	Margin(2) (°F)	ART(3) (°F)
1/4 T								
C-7-1	0°F	74.6	1.246997	93	0	17	34	127
C-7-2	-10°F	74.6	1.246997	93	0	17	34	117
C-7-3	10°F	73.8	1.246997	92	0	17	34	136
C-8-1	20°F	81.80(4)	1.246997	102	0	8.5	17	139
C-8-2	20°F	82.22(4)	1.246997	103	0	8.5	17	140
C-8-3	0°F	62.68(4)	1.246997	78	0	8.5	17	95
9-203	-60°F	84.97(4)	1.246997	106	0	14	28	74
2-203 A/C	-56°F	90.7	1.135602	103	17	28	65.5	112
3-203 A/C	-60°F	188.8	1.135602	214	0	28	56	210
3/4 T								
C-7-1	0°F	74.6	0.967610	72	0	17	34	106
C-7-2	-10°F	74.6	0.967610	72	0	17	34	96
C-7-3	10°F	73.8	0.967610	71	0	17	34	115
C-8-1	20°F	81.80(4)	0.967610	79	0	8.5	17	116
C-8-2	20°F	82.22(4)	0.967610	80	0	8.5	17	117
C-8-3	0°F	62.68(4)	0.967610	61	0	8.5	17	78
9-203	-60°F	84.97(4)	0.967610	82	0	14	28	50
2-203 A/C	-56°F	90.7	0.848024	77	17	28	65.5	86
3-203 A/C	-60°F	188.8	0.848024	160	0	28	56	156

Notes:

(1) ΔRT_{NDT} = CF * FF

(2) Margin = M = $2\sqrt{\sigma_i^2 + \sigma_\Delta^2}$

(3) ART = Initial RT_{NDT} + ΔRT_{NDT} + M

(4) Regulatory Position 2.1 [6]

Table 2-3 St. Lucie Unit 1 Controlling Materials and their ARTs			
Reactor Vessel	**Material**	**ART at 54 EFPY, °F**	
Location	**ID No.**	**1/4T**	**3/4T**
Lower Shell Axial Welds	3-203 A/C	210	156

According to Position 1.1 of Regulatory Guide 1.99, Revision 2 (Reference 4), there are two values of uncertainty. One is specific to the value of the initial RT_{NDT}. If the RT_{NDT} is derived in accordance with NB2300 of the ASME Boiler and Pressure Vessel Code, Section III, the uncertainty is assumed to be zero. If the RT_{NDT} is based a generic value, then the uncertainty is derived from the data used to establish the generic value. For the one case in which a generic value was used, intermediate shell axial welds (2-203 A/C), the uncertainty associated with the -56°F initial RT_{NDT} was 17°F.

The other uncertainty applies to the shift prediction. If the prediction applies to base metal (plate), the one-sigma uncertainty was 17°F. If the prediction applies to weld metal, the one-sigma uncertainty was 28°F. In the case where the chemistry factor was based on credible surveillance data (Position 2.1 of Regulatory Guide 1.99), the one-sigma uncertainty can be reduced to 8.5°F for base metal, and 14°F for welds.

2.2 GENERAL APPROACH FOR CALCULATING PRESSURE-TEMPERATURE LIMITS

The analytical procedure for developing reactor vessel P-T limits utilizes the methods of linear elastic fracture mechanics (LEFM) and guidance found in the ASME Boiler and Pressure Vessel Code Section XI, Appendix G (Reference 3), in accordance with the requirements of 10 CFR 50 Appendix G. For these analyses, the Mode I (opening mode, according to fracture mechanics terminology) stress intensity factors were used for the solution basis.

The St. Lucie, Unit 1, 54 EFPY P-T limits analysis utilizes a Westinghouse-developed and quality assured computer code to generate P-T limits for the reactor beltline region. That computer code uses superposition technique and influence coefficients to calculate these curves.

The reactor coolant system (RCS) P-T limit curves were based on the beltline P-T limits for a set of heatup and cooldown rates. These curves were then adjusted to represent pressurizer (PZR) pressure conditions (the adjustment addresses both the RCS hydraulic pressure drop due to flow and PZR-to-beltline region elevation) and, where appropriate, adjusted for temperature and pressure instrumentation uncertainties.

The final P-T limits include the minimum bolt-up temperature, lowest service temperature, and the flange limit. The minimum bolt-up temperature is specified in Reference 6.

The LTOP enable temperatures were also determined using heat transfer results from the P-T limits analysis, and applying ASME Boiler and Pressure Vessel Code Section XI, Appendix G methodology.

The temperature distribution throughout the reactor vessel wall was characterized by a partial differential equation, defined for the applicable boundary conditions and geometry, and solved numerically. The numerical solution uses a finite element model to determine wall temperature as a function of radius, time, and thermal rate.

This method utilizes three-noded, isoparametric finite elements suitable for one-dimensional, axisymmetric radial conduction-convection heat transfer. The wall was divided into 11 elements. The first element represents cladding, and the remaining 10 elements represent base metal. The analysis code utilizes convective boundary conditions on the inside wall and an insulation boundary on the outside wall of the reactor vessel. Variation of material properties through the wall was permitted, which allows for the change in material thermal properties between the cladding and the base metal.

The reactor vessel beltline region was analyzed assuming a semi-elliptical surface flaw oriented in the axial direction, with a depth of one-quarter of the reactor vessel beltline thickness. This assumed flaw has an aspect ratio of one to six. The postulated flaw was analyzed at both the inside diameter location (referred to as the 1/4t location) and the outside diameter location (referred to as the 3/4t location) to ensure that the most limiting condition was achieved.

At each of the postulated flaw locations, the Mode I stress intensity factor, K_I, produced by each of the specified loadings, was calculated. The summation of the K_I values was compared to reference stress intensity, K_{IC}, which is the critical value of K_I for the involved material and temperature. The result of this method is a relationship of pressure versus temperature for reactor vessel operating limits, which conservatively precludes brittle fracture.

K_{IR} is obtained from a reference fracture toughness curve for reactor vessel low alloy steels, and is defined in Appendices A and G of Section XI of the ASME Code (References 10 and 3 respectively). In this calculation, K_{IR} was defined as K_{IC}, and it was the lower bound of static initiation critical K_I values measured as a function of temperature. This governing curve is defined by Equation 3 below.

For operational events, P-T limits were calculated using the following equation.

$$2K_{IM} + K_{IT} \leq K_{IC} \qquad \text{Equation 1}$$

where:

K_{IM}	=	Membrane (pressure) stress intensity factor, $\text{ksi}\sqrt{\text{in}}$
K_{IT}	=	Thermal stress intensity factor, $\text{ksi}\sqrt{\text{in}}$
K_{IC}	=	Reference stress intensity factor, $\text{ksi}\sqrt{\text{in}}$

Rearranging the terms in the above equation:

$$K_{IM} = \frac{K_{IC} - K_{IT}}{2} \qquad \text{Equation 2}$$

Allowable pressure was then computed using the allowable membrane stress intensity factor from Equation 2 and the pressure influence coefficients. The fracture toughness is shown in the following.

$$K_{IC} = 33.2 + 20.734e^{0.02(T - RT_{NDT})} \qquad \text{Equation 3}$$

For the hydrostatic test limits, the structural factor 2 in Equation 1 is replaced by 1.5.

$$1.5K_{IM} \leq K_{IC} \qquad \text{Equation 4}$$

$$K_{IM} = \frac{K_{IC}}{1.5} \qquad \text{Equation 5}$$

For any instant during the postulated heatup or cooldown, K_{IC} was calculated at the metal temperature and at the adjusted RT_{NDT} at the tip of the flaw. The temperature distribution and the temperature at the flaw tip were calculated using a one-dimensional, three-noded isoparametric finite element suitable for one-dimensional radial conduction-convection heat transfer analysis.

The fracture mechanics algorithms use a superposition technique using influence coefficients to calculate the Mode I stress intensity factors.

At the conditions of 54 EFPY, isothermal and transient conditions were analyzed. The cooldown transients analyzed at rates of 10°F/hr, 20°F/hr, 30°F/hr, 40°F/hr, 50°F/hr, and 100°F/hr began at a bulk coolant temperature of 550°F and terminated at 80°F. The heatup transient analyzed had rates of 50°F/hr and 70°F/hr, and began at a bulk temperature of 80°F, terminating at 550°F. The hydrostatic limits were obtained for the isothermal condition only.

2.2.1 Application of Pressure Correction Factors

The P-T limits, as directly calculated by ASME methodology, typically represent the limiting material conditions at the reactor vessel beltline. However, these beltline P-T limits could not be used directly by the plant operations staff, since pressure measurement in the RCS was limited to the PZR and, as such, the beltline values require adjustment to representative values relative to the PZR location.

Pressure correction factors (PCFs) were used to adjust the beltline P-T limits to PZR pressure. These PCFs were updated for the current plant operations for this analysis, and consist of:

1. The pressure difference due to the static head of fluid between the PZR pressure instrument nozzle elevation and reactor vessel beltline lowest point

2. The flow-induced pressure drop between the applicable point in the reactor vessel and hot leg surge line nozzle, due to flow resulting from operating reactor coolant pumps (RCPs)

3. The uncertainty associated with the pressure instrumentation, as applicable

These PCFs were applied to the beltline P-T limits in two ways. An actual pressure correction factor (APCF) was applied to the beltline P-T limits to provide representative actual (or analysis) values relative to the PZR location. An APCF was developed from plant data associated with items (1) and (2) in the prior paragraph's explanation. APCFs have been developed to represent multiple plant operating conditions (e.g., combinations of operating RCPs). A bounding static head condition (1) and both a bounding consideration of three operating RCPs (2) as well as a bounding consideration of two operating RCPs (2) were selected. These two PCFs encompass the entire LTOP range for temperatures above 200°F, including three RCPs and temperatures below 200°F limited to two RCPs. These updated APCFs were developed to be bounding for each condition. For temperatures above 200°F, the APCF value was 72.8 psid; and for temperatures below 200°F, the APCF value was 59.8 psid.

The potential condition of up to three operating RCPs fully bounds the plant operating conditions within the LTOP applicable range. Current plant procedures limit the operation of four RCPs to greater than 500°F. An inspection of the P-T limits, shown in Figures 2-1 and 2-2, indicates that the most limiting pressures were greater than 2400 psia at any temperature value above 300°F. Revisions of plant procedures will be established to ensure no more than two RCPs are operating below 200°F.

Due to uncertainties in the PZR pressure instrument loop components, indicated PZR pressure observed by control room operators can differ from the actual PZR pressure. If unaccounted for, the actual PZR pressure can be greater than the indicated PZR pressure, which could potentially lead to a violation of the actual P-T limits. To prevent this, an indicated pressure correction factor (IPCF) was applied. For temperatures above 200°F the IPCF value was 107.8 psid, and for temperatures below 200°F the IPCF value was 94.8 psid. This accounts for the instrumentation uncertainty (item 3 from the previous page), in addition to the previously described adjustments for actual limits, to represent the indicated P-T limits.

In conditions where the indicated P-T limits are developed (IPCF are applied), corresponding conservative temperature value adjustments are accommodated by a temperature correction factor, which acknowledges the possible uncertainty of the temperature indication loop. A value of 7°F was applied to adjust the P-T limits as well as the LTOP enable temperature, presented in the Technical Specification figures, since this represents the control room instrument error. Figures 2-3 and 2-4 show the limiting indicated pressures as a function of indicated temperature, accounting for this uncertainty. As a note, an additional 2°F must be applied to the setpoint for PORV actuation to account for the total loop uncertainty of 9°F associated with the LTOP actuation channels.

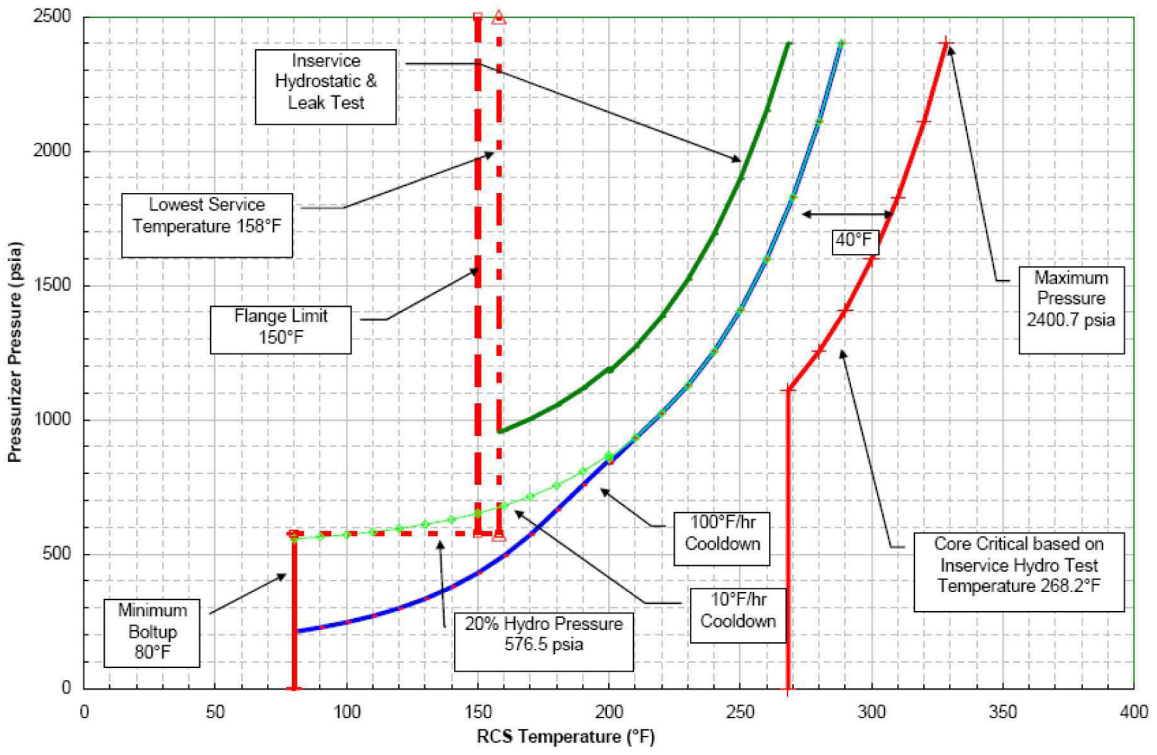


Figure 2-1 St. Lucie Unit 1 Cooldown P-T Limits 54 EFPY, APCF Adjusted to PZR Pressure

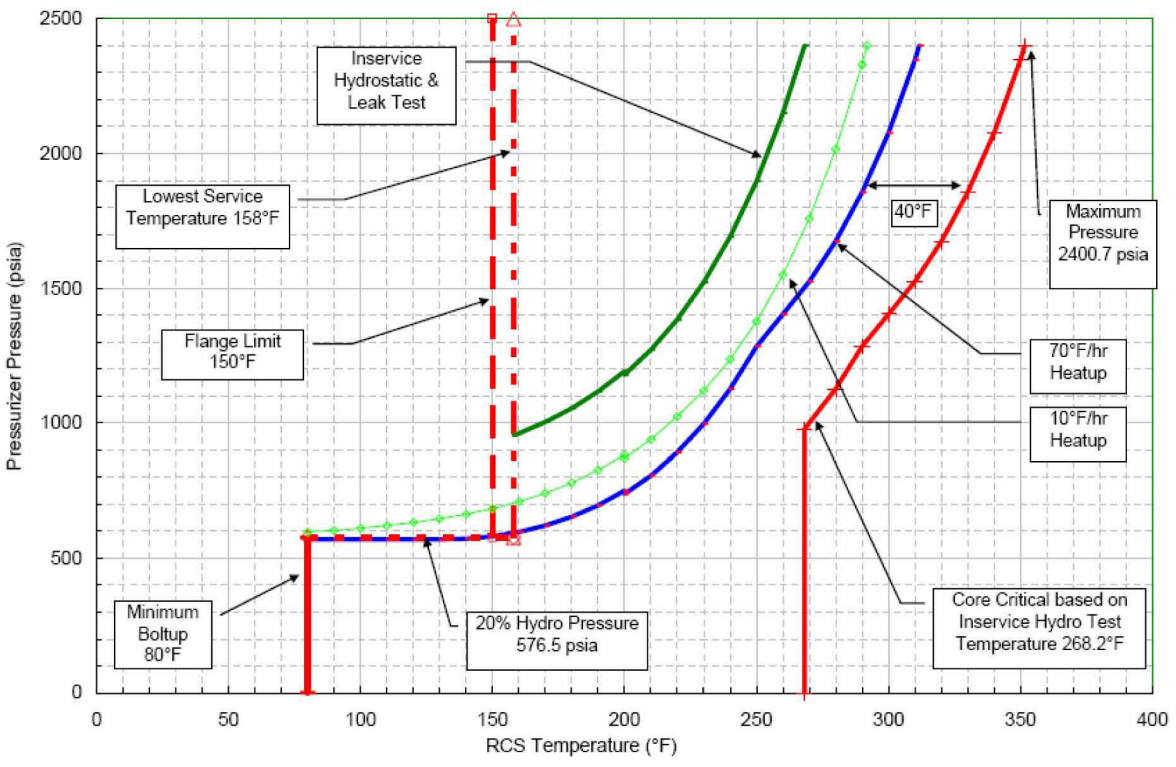


Figure 2-2 St. Lucie Unit 1 Heatup P-T Limits 54 EFPY, APCF Adjusted to PZR Pressure

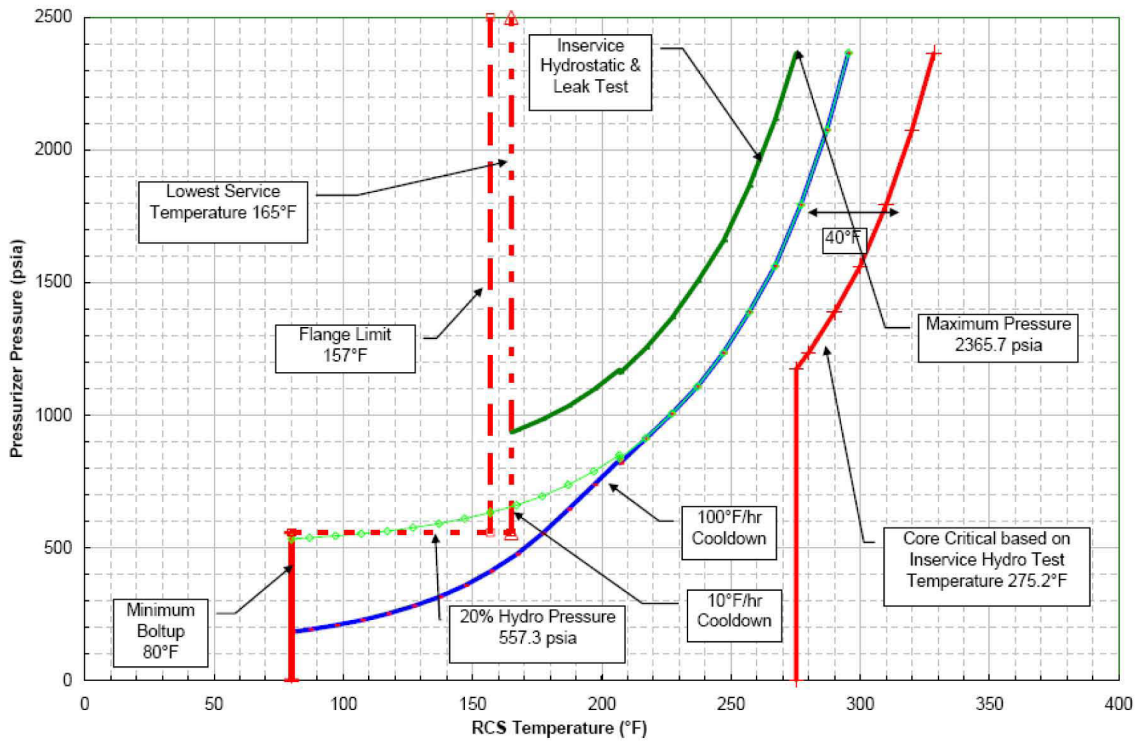


Figure 2-3 St. Lucie Unit 1 Cooldown P-T Limits 54 EFPY, IPCF Adjusted to Indicated PZR Pressure

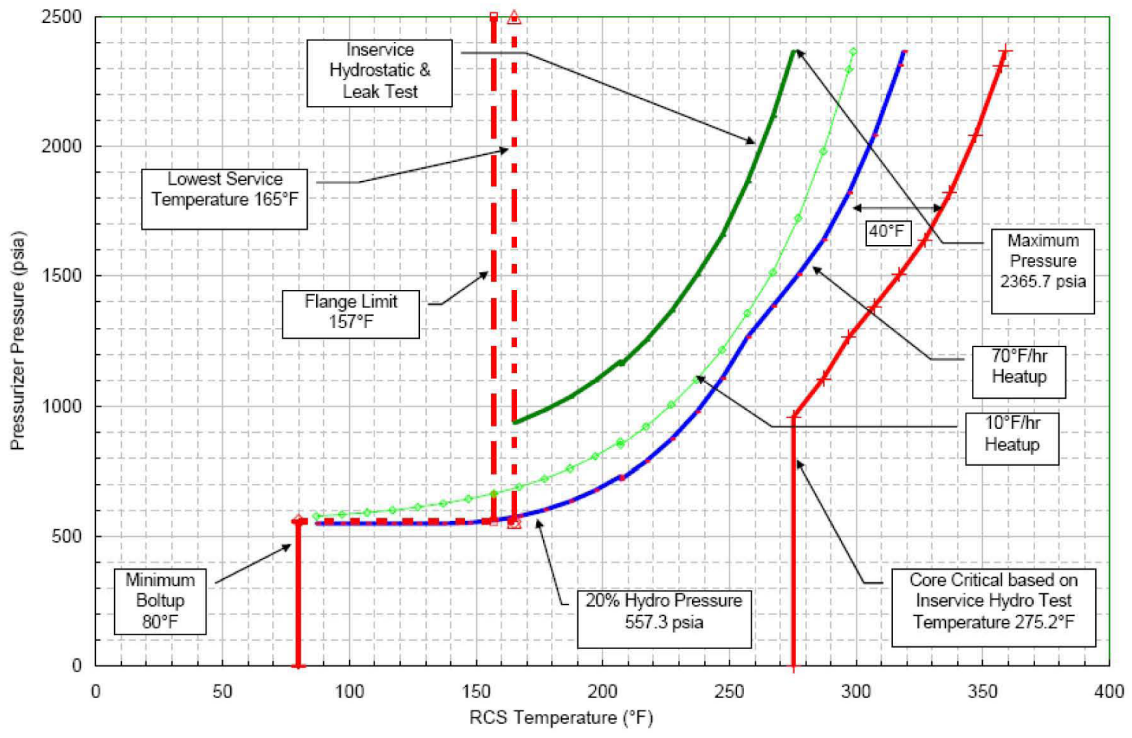


Figure 2-4 St. Lucie Unit 1 Heatup P-T Limits 54 EFPY, IPCF Adjusted to Indicated PZR Pressure

2.3 THERMAL ANALYSIS METHODOLOGY

The thermal stress intensity factors were found by using the temperature differences through the wall as a function of transient time. They were then subtracted from the available K_{IR} value to calculate the allowable pressure stress intensity factor and, consequently, the allowable pressure.

Equation 1 provides the expression used to derive P-T limits. The superposition technique used was temperature profile-based rather than the commonly used stress profile-base. A third-order polynomial fit to the temperature distributions in the wall was used (Reference 11).

$$T(x) = C_0 + C_1 (1-\frac{x}{h}) + C_2 (1-\frac{x}{h})^2 + C_3 (1-\frac{x}{h})^3 \qquad \text{Equation 6}$$

where:

T(x)	=	temperature at radial location x from inside wall surface
C_0-C_3	=	coefficients in polynomial fit
x	=	distance through beltline wall, inches
h	=	beltline wall thickness, inches

The unit K_I values were calculated for each term of the polynomial using a two-dimensional finite element code. These unit values were used to determine the total K_I value for the applied loads under any general temperature profile in the wall that develops during the thermal transient.

The thermal stress intensity factor is represented by Equation 7.

$$K_{IT}(a) = \sum_{i=0}^{3} C_i K_i \qquad \text{Equation 7}$$

where:

K_{IT}	=	Thermal stress intensity factor
C_i	=	Coefficients in polynomial fit
K_i	=	Polynomial influence coefficients

Temperature-based influence coefficients for determining the thermal stress intensity factor, K_{IT} were used. Using Reference 12 methods, these coefficients were computed using a two-dimensional reactor vessel model with a crack adjusted to account for three-dimensional effects.

2.4 COOLDOWN LIMIT ANALYSIS

During cooldown, membrane and thermal bending stresses act together in tension at the reactor vessel inside wall. This results in the pressure stress intensity factor, K_{IM}, and the thermal stress intensity factor, K_{IT}, acting in unison to create high stress intensity. At the reactor vessel outside wall, the tensile pressure stress and the compressive thermal stress act in opposition, resulting in a lower total stress than at the

inside wall location. Also, neutron embrittlement, the shift in RT_{NDT}, and the reduction in fracture toughness were less severe at the outside wall when compared to the inside wall location. Consequently, the inside flaw location is more limiting for the cooldown event.

The reference stress intensities were determined by utilizing the material metal temperature and adjusted RT_{NDT} at the 1/4t and 3/4t locations. The finite element method was used to perform the heat transfer analysis and the resulting through-wall temperature gradient, calculated for the assumed cooldown rate, is used to determine the thermal stress intensity factor. The thermal stress intensity factors were determined by using the temperature difference through the wall as a function of transient time. Those factors were then, subtracted from the available K_{IC} value to calculate the allowable pressure stress intensity factor and, consequently, the allowable pressure.

The cooldown P-T curves were thus generated by calculating the allowable pressure on the reference flaw at the 1/4t and 3/4t locations. This was based upon Equation 2 of Section 2.2.

To develop a minimum P-T limit for the cooldown event, the isothermal P-T limit must be calculated, after which the isothermal P-T limit was compared to the P-T limit associated with a cooling rate. The more restrictive allowable P-T limit was chosen, which results in a minimum limit curve for the reactor vessel beltline.

Table 2-4 shows the P-T limits results for conditions at the beltline (without applied correction factors) for cases for isothermal and 20°F/hr, 30°F/hr, 40°F/hr, 50°F/hr, and 100°F/hr cooldown. Tables 2-5 and 2-6 provide results that include the APCF and IPCF, respectively. APCF data were compared to the design basis LTOP transient results, which were also referenced to the PZR pressure location. IPCF data were used for the recommended Technical Specification P-T Limit figure changes. Uncorrected values are provided for completeness.

Table 2-4 Cooldown Allowable Pressures, Uncorrected

Temperature (°F)	Isothermal P_{all} (psia)	20°F/hr P_{all} (psia)	30°F/hr P_{all} (psia)	40°F/hr P_{all} (psia)	50°F/hr P_{all} (psia)	100°F/hr P_{all} (psia)
80	657	577	537	498	459	271
90	663	584	546	507	469	287
100	671	594	556	518	481	306
110	680	605	568	532	496	330
120	692	619	583	548	514	359
130	706	636	602	569	536	394
140	723	656	624	594	564	437
150	744	681	652	624	597	490
160	769	712	686	660	637	554
170	801	750	727	706	687	632
180	839	796	777	761	748	724
190	885	851	838	828	821	817
199.9	942	919	913	910	910	910
200	942	920	914	911	911	911
210	1,012	1,003	1,003	1,003	1,003	1,003
220	1,097	1,097	1,097	1,097	1,097	1,097
230	1,200	1,200	1,200	1,200	1,200	1,200
240	1,327	1,327	1,327	1,327	1,327	1,327
250	1,481	1,481	1,481	1,481	1,481	1,481
260	1,670	1,670	1,670	1,670	1,670	1,670
270	1,901	1,901	1,901	1,901	1,901	1,901
280	2,182	2,182	2,182	2,182	2,182	2,182
290	2,526	2,526	2,526	2,526	2,526	2,526
300	2,947	2,947	2,947	2,947	2,947	2,947

Table 2-5 St. Lucie Unit 1 Cooldown and Heatup Allowable Pressure 54 EFPY, Adjusted to Actual PZR Pressure, APCF

Heatup

Temperature (°F)	Isothermal P_{all} (psia)	50°F/hr P_{all} (psia)	70°F/hr P_{all} (psia)
80	597	597	570
90	603	601	570
100	611	601	570
110	621	601	570
120	632	601	570
130	646	608	570
140	663	622	572
150	684	644	581
160	710	674	597
170	741	714	621
180	779	765	654
190	826	826	696
199.9	882	882	750
200	869	869	738
210	939	939	806
220	1,024	1,024	891
230	1,127	1,117	996
240	1,254	1,211	1,126
250	1,408	1,308	1,284
260	1,597	1,429	1,403
270	1,828	1,575	1,525
280	2,110	1,751	1,674
290	2,454	1,971	1,856
300	2,874	2,237	2,077
310	3,387	2,557	2,347
320		2,958	2,676
330		3,442	3,078

Cooldown

Temperature (°F)	Isothermal P_{all} (psia)	20°F/hr P_{all} (psia)	30°F/hr P_{all} (psia)	40°F/hr P_{all} (psia)	50°F/hr P_{all} (psia)	100°F/hr P_{all} (psia)
80	597	517	477	438	399	211
90	603	525	486	447	409	227
100	611	534	496	458	421	246
110	621	545	508	472	436	270
120	632	559	523	489	455	299
130	646	576	542	509	477	334
140	663	597	565	534	504	377
150	684	622	592	564	537	430
160	710	652	626	601	577	494
170	741	690	667	646	628	572
180	779	736	718	701	688	664
190	826	792	779	768	761	757
199.9	882	860	853	850	850	850
200	869	847	841	838	838	838
210	939	931	931	931	931	931
220	1,024	1,024	1,024	1,024	1,024	1,024
230	1,127	1,127	1,127	1,127	1,127	1,127
240	1,254	1,254	1,254	1,254	1,254	1,254
250	1,408	1,408	1,408	1,408	1,408	1,408
260	1,597	1,597	1,597	1,597	1,597	1,597
270	1,828	1,828	1,828	1,828	1,828	1,828
280	2,110	2,110	2,110	2,110	2,110	2,110
290	2,454	2,454	2,454	2,454	2,454	2,454
300	2,874	2,874	2,874	2,874	2,874	2,874
310	3,387	3,387	3,387	3,387	3,387	3,223

Table 2-6 St. Lucie Unit 1 Cooldown and Heatup Allowable Pressure 54 EFPY, Adjusted to Indicated PZR Pressure, IPCF

Heatup

Temperature (°F)	Isothermal P_{all} (psia)	50°F/hr P_{all} (psia)	70°F/hr P_{all} (psia)
87	578	578	550
97	584	582	550
107	592	582	550
117	601	582	550
127	613	582	550
137	627	588	550
147	644	603	553
157	665	625	562
167	690	655	578
177	722	695	602
187	760	746	635
197	806	806	677
206.9	863	863	731
207	850	850	719
217	920	920	787
227	1,005	1,005	872
237	1,108	1,098	977
247	1,235	1,192	1,106
257	1,389	1,289	1,265
267	1,562	1,410	1,384
277	1,793	1,540	1,506
287	2,075	1,716	1,639
297	2,419	1,936	1,821
307	2,839	2,202	2,042
317	3,352	2,522	2,312
327		2,923	2,641
337			3,043

Cooldown

Temperature (°F)	Isothermal P_{all} (psia)	20°F/hr P_{all} (psia)	30°F/hr P_{all} (psia)	40°F/hr P_{all} (psia)	50°F/hr P_{all} (psia)	100°F/hr P_{all} (psia)
87	578	498	458	419	380	192
97	584	505	467	428	390	208
107	592	515	477	439	402	227
117	601	526	489	453	417	251
127	613	540	504	469	435	280
137	627	557	523	490	457	315
147	644	577	545	515	485	358
157	665	602	573	545	518	411
167	690	633	607	581	558	475
177	722	671	648	627	608	553
187	760	717	698	682	669	645
197	806	772	759	749	742	738
206.9	863	840	834	831	831	831
207	850	828	822	819	819	819
217	920	911	911	911	911	911
227	1,005	1,005	1,005	1,005	1,005	1,005
237	1,108	1,108	1,108	1,108	1,108	1,108
247	1,235	1,235	1,235	1,235	1,235	1,235
257	1,389	1,389	1,389	1,389	1,389	1,389
267	1,562	1,562	1,562	1,562	1,562	1,562
277	1,793	1,793	1,793	1,793	1,793	1,793
287	2,075	2,075	2,075	2,075	2,075	2,075
297	2,419	2,419	2,419	2,419	2,419	2,419
307	2,839	2,839	2,839	2,839	2,839	2,839
317	3,352	3,352	3,352	3,352	3,352	3,188

2.5 HEATUP LIMIT ANALYSIS

During heatup, the thermal bending stress was compressive at the reactor vessel inside wall and was tensile at the reactor vessel outside wall. Internal pressure creates a tensile stress at the inside wall and outside walls. Consequently, the outside wall, when compared to the inside wall, has the larger total stress. However, neutron embrittlement, shift in material RT_{NDT}, and reduction in fracture toughness were greater at the inside wall. Therefore, results from both the inside and outside flaw locations must be compared to ensure the recognition of the most limiting condition.

As described in the cooldown case, the reference stress intensity was calculated at the metal temperature, and the adjusted RT_{NDT} was calculated at the tip of the flaw. Using a finite element method for the heat transfer analysis, the temperature profile through the wall and the metal temperatures at the tip of the flaw were calculated for the transient history. This information, in conjunction with the calculated wall gradient and thermal influence coefficients, was used to calculate the thermal stress intensity factor at 1/4t and 3/4t. The allowable pressure stress intensity was then determined by superpositioning the thermal stress intensity factor—with the available reference stress intensity—at the flaw tip. The allowable pressure was derived from the calculated allowable pressure stress intensity factor.

A sign change occurs in the thermal stress through the reactor vessel beltline wall. Assuming there is a reference flaw at the 1/4t location, the thermal stress tends to alleviate the pressure stress, indicating that the isothermal steady-state condition represents the limiting P-T limit. However, the isothermal condition

may not always provide the limiting P-T limit for the 1/4t location during a heatup transient. This is due to the difference between the base metal temperature and the RCS fluid temperature at the inside wall. For a given heatup rate (non-isothermal), the differential temperature through the clad and film increases as a function of thermal rate, resulting in a crack tip temperature that was lower than the RCS fluid temperature. Therefore, to ensure an accurate representation of the 1/4t P-T limit during heatup, both the isothermal and heatup rate dependent P-T limits were calculated. This also ensured that the limiting condition was recognized. These limits, in conjunction with the cooling limits, account for clad and film differential temperatures, as well as the gradual buildup of wall differential temperatures with time.

To develop minimum P-T limits for the heatup transient, the isothermal conditions at 1/4t and 3/4t, 1/4t heatup, and 3/4t heatup P-T limits were compared for a given thermal rate. Then, the most restrictive P-T limits were combined, resulting in a minimum limit curve for the reactor vessel beltline for the heatup event.

Table 2-7 presents the P-T results for conditions at the beltline, without applied correction factors, for isothermal, 50°F/hr, and 70°F/hr heatup P-T limits. Table 2-5 provides the results with APCF. Table 2-6 provides results with the IPCF, which includes temperature and PCFs. Tables 2-5 and 2-6 supply the allowable PZR pressure values versus reactor coolant temperature. APCF data were compared to the design basis LTOP transient results, which are also referenced to the PZR pressure location. IPCF data were used for the recommended Technical Specification P-T limit figure changes. Uncorrected values are provided for completeness.

Table 2-7 Heatup Allowable Pressures, Uncorrected

Temperature (°F)	Isothermal P_{all} (psia)	50°F/hr P_{all} (psia)	70°F/hr P_{all} (psia)
80	657	657	629
90	663	661	629
100	671	661	629
110	680	661	629
120	692	661	629
130	706	667	629
140	723	682	632
150	744	704	641
160	769	734	657
170	801	774	681
180	839	825	714
190	885	885	756
199.9	942	942	810
200	942	942	811
210	1,012	1,012	879
220	1,097	1,097	964
230	1,200	1,190	1,069
240	1,327	1,284	1,198
250	1,481	1,381	1,357
260	1,670	1,502	1,476
270	1,901	1,648	1,598
280	2,182	1,824	1,747
290	2,526	2,044	1,928
300	2,947	2,310	2,150
310	3,460	2,630	2,420
320		3,031	2,749

2.6 HYDROSTATIC TEST AND CORE CRITICAL LIMIT ANALYSIS

Hydrostatic test limits have been calculated for 54 EFPY using the methodology of the ASME Boiler and Pressure Vessel Code, Section XI, Appendix G. The governing equation for determining the hydrostatic test limits is shown in Equation 4 from Section 2.2.

The procedure was similar to calculating normal operations' heatup and cooldown limits. The one exception was the factor of safety that was applied to the allowable pressure stress intensity (K_{IM}). To account for this exception, the analysis method utilized for this calculation modified the applied factor of safety from 2.0 (for normal operation) to 1.5, for hydrostatic limits.

The hydrostatic test limit establishes the minimum temperature required at the corresponding hydrostatic test pressure. Westinghouse recommends that the in-service hydrostatic test for Combustion Engineering (CE) nuclear steam supply system (NSSS) designs be performed at a test pressure corresponding to 1.1 times the operating pressure, with the reactor core not critical. Under these conditions, 10 CFR 50, Appendix G requires that the minimum temperature for the reactor vessel be at least as high as the RT_{NDT} for the limiting material in the closure flange region, plus 90°F. However, the beltline hydrostatic test, at the recommended test pressure, has greater limitations. Therefore, it is only necessary to control plant operations to the beltline in-service hydrostatic test limits in the vicinity of this pressure.

To define minimum temperature criteria for core critical operation, Appendix G of 10 CFR 50 specifies the following P-T limits.

- If the RCS pressure is less than or equal to 20% of the pre-service hydrostatic test pressure (PHTP), the minimum temperature requirement for the reactor vessel must be at least as high as the RT_{NDT} for the limiting material in the closure flange region stressed by bolt preload, plus 40°F, or the minimum permissible temperature for the in-service hydrostatic pressure test, whichever is larger.

- If the RCS pressure is greater than 20% of the PHTP, the minimum temperature requirement for the reactor vessel must be at least as high as the RT_{NDT} for the limiting material in the closure flange region stresses by bolt preload, plus 160°F, or the minimum permissible temperature for the in-service hydrostatic pressure test, whichever is larger.

According to Appendix G to 10 CFR 50, the following calculation specifies P-T limits for core critical operation to provide additional margin during actual power operation.

In-service hydrostatic pressure =

= (1.1 x operating pressure) + instrumentation uncertainty
= (1.1 x (2,250-15) + 15 psia) + 0 psi = 2,473.5 psia

Pressure instrumentation uncertainty was not included. Furthermore, the factor 1.1 was used for the gauge units (psig) of operating pressure instead of the absolute units (psia).

The minimum temperature for the core critical operation and the hydrostatic test was the temperature corresponding to the in-service hydrostatic pressure. The minimum temperature for the hydrostatic and leak test cases was 270.7°F. This temperature value was obtained from Table 2-8 (unadjusted, beltline data) by interpolating the temperature values to the pressure given in the equation above.

Hydrostatic test limits are tabulated in Table 2-8, and are adjusted using the correction factors for both the APCF and IPCF cases.

For both the APCF and IPCF cases, the specified beltline heatup P-T limit was more restrictive at temperatures above 270.7°F and 277.7°F respectively. Consequently, the core critical limits have been established as a combination of this temperature and the specified heatup P-T limit from ASME Appendix G, plus 40°F.

The core critical limits established were based solely on fracture mechanics considerations and do not consider core physics safety analyses. Core physics safety analyses can control the temperature at which the core can be brought critical.

Table 2-8 St. Lucie Unit 1 Hydrostatic Test P-T Limit Data

Actual Pressurizer, APCF Conditions		Indicated Pressurizer, IPCF Conditions		Beltline (Uncorrected) Conditions	
Temperature (°F)	P_{all} (psia)	Temperature (°F)	P_{all} (psia)	Temp (°F)	P_{all} (psia)
80	811	87	792	80	871
90	820	97	800	90	879
100	830	107	811	100	890
110	842	117	823	110	902
120	858	127	838	120	917
130	876	137	857	130	936
140	899	147	880	140	959
150	927	157	908	150	987
160	961	167	942	160	1,021
170	1,003	177	984	170	1,063
180	1,054	187	1,034	180	1,113
190	1,116	197	1,097	190	1,176
199.9	1,191	206.9	1,172	199.9	1,251
200	1,179	207	1,159	200	1,251
210	1,271	217	1,252	210	1,344
220	1,384	227	1,365	220	1,457
230	1,522	237	1,503	230	1,595
240	1,691	247	1,656	240	1,764
250	1,897	257	1,862	250	1,970
260	2,149	267	2,114	260	2,222
268.2	2,400.7	275.2	2,365.7	270	2,529
550	2,400.7	550	2,365.7	280	2,905
				290	3,363

2.7 LOWEST SERVICE TEMPERATURE, MINIMUM BOLTUP TEMPERATURE, FLANGE LIMIT TEMPERATURE, MINIMUM PRESSURE LIMITS AND LTOP ENABLE TEMPERATURES

In addition to the computation of the reactor vessel beltline P-T limits, additional limits have been provided for reference. These additional limits were the lowest service temperature (LST), minimum bolt-up temperature, flange limit temperature, and minimum pressure limit.

LST is defined in ASME Section III, NB-3211 as the minimum temperature for piping, pumps, and valves (the remainder of the RCS) in the RCS in order to exceed the 20% of the pre-service hydrostatic test pressure. The LST is established as a temperature not less than RT_{NDT} of the remainder of the RCS plus 100°F. Previously, an RT_{NDT} of 90°F had been applied in such calculations for St. Lucie Unit 1. It was found that this limitation was associated with an estimate related to the RCP materials. It was determined that the RCP pump shaft, casing, casing wear ring, hydrostatic bearing, and pump cover are made of stainless steel and, therefore, do not affect the limiting RT_{NDT}. The next most limiting RT_{NDT} documented for the RCS piping was 58°F. Therefore, the LST was 158°F.

When the pressure exceeds 20% of pre-service hydrostatic test pressure, the temperature of the closure flange regions must exceed the initial RT_{NDT} of the material by at least 120°F for normal operation, and by 90°F for hydrostatic and leak testing.

The minimum pressure limit is applicable between the minimum bolt-up temperature, lowest service temperature, and the flange limit temperature. Defined by the ASME Boiler and Pressure Vessel Code as 20% of the pre-operational hydrostatic test pressure, the minimum pressure is as follows.

$$\text{20\% of pre-service hydrostatic test} = (1.25 \times \text{design pressure}) \times 0.20$$
$$= 1.25 \times (2{,}500\text{-}15) \times 0.20 + 15 = 636.25 \text{ psia}$$

With the correction factors as developed in Section 2.2.1 (P_{APCF} = 59.8 psid, P_{IPCF} = 79.0 psid), this pressure was adjusted to 576.5 psia for APCF, and 557.3 psia for the IPCF cases.

The scale factor used on the design pressure in the previous calculation was the gauge value (psig) instead of the absolute pressure (psia).

The minimum bolt-up temperature was defined as 80°F, which provides margin to protect the vessel head, vessel flange, and upper shell from being stressed at a temperature below the RT_{NDT} of those materials. The P-T curves include a 7°F margin shift for indicated instrument uncertainty so that the operator does not need to account for the instrument error at bolt-up. For steady state, a 30°F margin on minimum bolt-up temperature was already in place since the lowest RT_{NDT} of the flange region was 50°F.

Low Temperature Overpressure Protection (LTOP) enable temperatures are determined per ASME Boiler and Pressure Vessel Code Section XI, Appendix G. The Code states that the LTOP systems become effective at coolant temperatures less than 200°F, or at coolant temperatures corresponding to RV temperatures less than RTNDT + 50°F, whichever is greater. The LTOP enable temperature for cool-down is based on the isothermal pressure-temperature (P-T) limit. For cool-down, including instrumentation uncertainty (IPCF case assumed):

$$\text{LTOP enable temperature} = RT_{NDT} + 50°F$$
$$= 210°F + 50°F + 7°F = 267°F$$

For heat-up transients with a 70°F/hr rate, the coolant temperature that corresponds to the crack tip temperature of RTNDT + 50°F = 260°F (from the heat transfer analysis results) is 291.9°F. With instrument uncertainty added, it is 298.9°F (IPCF assumed). Details of LTOP enable temperatures are given in Table 2-9.

Table 2-9 LTOP Enable Temperature Limits

Case	Uncorrected $T_{coolant}$ (°F)	LTOP Enable (°F)
HU 10°F/hr	264.6	271.6
HU 20°F/hr	269.2	276.2
HU 30°F/hr	273.8	280.8
HU 40°F/hr	278.4	285.4
HU 50°F/hr	283.0	290.0
HU 60°F/hr	287.5	294.5
HU 70°F/hr	291.9	298.9
CD / Isothermal	260.0	267.0

2.8 DATA

Reactor Vessel Data		Reference
Design Pressure	= 2500 psia	16
Design Temperature	= 650°F	16
Operating Pressure	= 2250 psia	16
Beltline Thickness	= 8.625 in	16
Inside Radius	= 86.914 in	16
Outside Radius	= 95.85 in	16
Cladding Thickness	= 0.3125 in	16

Material SA-533-65 Grade B		Reference
Thermal Conductivity	= 23.8 BTU/hr-ft-°F	13
Youngs Modulus	= 28 x 10^6 psi	13
Coefficient of Therma1 Expansion	= 7.8 x 10^{-6} in/in-°F	13
Specific Heat	= 0.122 BTU/lb-°F	13
Density	= 490 lb/ft^3	13

Material SA-533-65 Grade B		Reference
Thermal Conductivity	= 23.8 BTU/hr-ft-°F	13
Youngs Modulus	= 28 x 10^6 psi	13
Coefficient of Therma1 Expansion	= 7.8 x 10^{-6} in/in-°F	13
Specific Heat	= 0.122 BTU/lb-°F	13
Density	= 490 lb/ft^3	13

Stainless Steel Cladding		Reference
Thermal Conductivity	= 10.1 BTU/hr-ft-°F	13
Film coefficient on inside surface	= 1000 BTU/hr-ft^2-°F	Assumption

Pressure Correction Factors for Elevation and Flow as Developed in Section 2.2.1

Applicable to all plant condition with two or less RCP in operation:

APCF APCF = 59.8 psid

Indicated pressure correction factor:

Narrow-range pressure instruments: IPCF = 79.0 psid
Wide-range pressure instruments: IPCF = 94.8 psid

Corresponding information values for three or less operating RCP:

APCF APCF = 72.8 psid

Indicated pressure correction factor:

Narrow-range pressure instruments: IPCF = 92.0 psid
Wide-range pressure instruments: IPCF = 107.8 psid

3 LOW-TEMPERATURE OVERPRESSURE PROTECTION

3.1 GENERAL

The primary objective of the LTOP system is to preclude the violation of applicable Technical Specification P-T limits during startup and shutdown conditions. These P-T limits were usually applicable to a finite time period of operation and were based upon the irradiation damage prediction by the end of the period. Accordingly, each time new P-T limits become effective, the LTOP system needs to be re-analyzed and modified, if necessary, to continue its function.

The LTOP system prevents the violation of the RCS brittle fracture P-T limits in the event of an overpressure event within the LTOP temperature range. An RCP start overpressure event is one of two design basis events for the LTOP system. The RCP start is referred to as the "energy addition event." The other design basis event is the "mass addition transient," which is typically based on an inadvertent safety injection actuation signal (SIAS) in the LTOP temperature range.

A typical LTOP system includes pressure-relieving devices and a number of administrative and operational controls. At St. Lucie Unit 1, the current LTOP system uses two power-operated relief valves (PORVs) for the LTOP temperature range from the minimum bolt-up temperature, to the LTOP enable temperature. The PORVs (tag numbers V1402 and V1404) have two opening setpoints of 350 and 530 psia.

These relief valves, in combination with certain other limiting conditions for operation contained in Technical Specifications, comprise the St. Lucie Unit 1 LTOP system.

Since the new P-T limits described in this report cover the operating period ending at 54 EFPY, the existing LTOP system was re-analyzed to determine if modifications are required or improvements can be implemented in order for the system to provide adequate LTOP through 54 EFPY. The LTOP system was analyzed for the expected conditions following implementation of the EPU.

3.2 METHOD AND ASSUMPTIONS

The approach taken in performing the LTOP evaluation was to analyze the existing PORV setpoints. Accordingly, the existing PORV setpoints of 350 psia and 530 psia were used.

The following existing general assumptions were used in the LTOP analyses.

1. Only one PORV is available.
2. The RCS is in a water solid condition.
3. The letdown flow paths are isolated.
4. The PZR heater input and decay heat input was considered as additional energy sources.
5. There is no heat absorption or metal expansion at the primary pressure boundaries.

The PORV opening characteristics were adjusted for control circuit uncertainty and valve response time. This was addressed in the following manner.

1. The RCS pressure just prior to PORV opening was conservatively assumed to be greater than the nominal PORV setpoint, because of the relative pressure instrument uncertainty between the pressure indication and the PORV actuation channels. This 26 psi uncertainty is provided in Reference 14.

2. The PORV opening time was previously assumed to equal 0.25 seconds, which enveloped the opening times observed in applicable tests. Based on an evaluation of the test data, it was conservatively assumed that this total opening time was a better indication of the PORV stroke time. The computer code that was used to model the energy addition transient could not model a ramped PORV opening. To account for a ramp opening during stroke time, a delay in the PORV opening equal to a sum of a conservative solenoid delay time of 0.65 seconds, and one half of the previously discussed stroke time (0.125 seconds), were assumed in the energy addition transient analysis. This delay was assumed to be followed by instantaneous opening. The PORV opening setpoint used in the energy addition transient analysis code was adjusted based on this delay time, assuming a bounding pressure ramp rate prior to valve opening. In the mass addition transient analysis, the PORV was opened in time steps following the solenoid delay. The product of the PORV capacity and the time passed over the stroke time was credited as the stroke time passes, until the PORV was full open.

3. The impact of the PORV opening time was taken into account in the energy addition transient analysis by adding transient-specific pressure accumulation during 0.775 seconds (0.65 seconds plus 0.125 seconds) to the opening pressure to arrive at the maximum opening pressure. Pressure accumulation was assumed to be a function of an applicable pressurization ramp rate moments prior to reaching the valve setpoint.

Based on the existing analyses, modified assumptions and inputs, and new maximum transient pressures for the same design basis transients were determined as appropriate. Out of these, the most limiting pressures in given temperature ranges were selected as “controlling” the limiting temperatures for LTOP.

Finally, by comparing these controlling pressures to the P-T limit curves for 54 EFPY, limiting conditions for operation were identified.

3.3 PRESSURE TRANSIENT ANALYSES

3.3.1 Energy Addition Transients

The energy addition analysis determined the peak pressure that would occur as a result of the RCS pressure transient caused by an RCP start with an initial steam generator-to-reactor-vessel temperature differential of 30°F (Reference 15, LCO 3.4.1.4.1), during RCS water-solid, low-temperature conditions.

PORVs, in accordance with Reference 15, LCO 3.4.9.1 and LCO 3.4.13, provide LTOP system overpressure protection at St. Lucie Unit 1. This calculation analyzed cases with a single PORV providing LTOP overpressure protection.

An analysis methodology, consistent with the transient analysis of record, was used. Plant-specific volumes, masses, decay heat, RCP heat, PZR heater contributions, selected initial temperatures, and heat transfer coefficients were incorporated into the analysis input, which produced results in the form of RCS system pressure values versus time.

The PORV mitigated energy addition transient was analyzed for the existing PORV setpoints of 350 psia and 530 psia (Reference 15, LCO 3.4.13).

The analysis assumed that the pressure transient was taking place in the PZR. The effect of the PORV inlet piping on the analysis results was taken into account by determining PORV flow rates at PORV inlet pressure, which was corrected from PZR pressure for elevation difference and flow losses. This correction reduces PORV discharge, thus maximizing the transient pressures.

The following major assumptions were used in the analysis of the RCP start transient, in addition to the assumptions mentioned above and in Section 3.2.

1. The PORV opening occurs at an opening pressure that is greater than the nominal setpoint by a sum of the pressure instrument uncertainty and pressure accumulation due to finite opening time. This assumption maximizes RCS pressure at the PORV opening.

2. The cases were analyzed for initial RCS fluid temperatures of 140°F, 200°F, and 300°F. These temperatures were consistent with those assumed in existing analyses, as well as with the updated LTOP enable temperature 300°F for cooldown (Table 3-1).

3. The initial RCS pressure is 300 psia, which is consistent with existing analyses.

4. The historical St. Lucie Unit 1 LTOP energy addition analyses only consider the water and metal masses in the region of the tube bundle to contribute as heat sources. This analysis maintains the assumption.

5. The RCP heat input is considered as an additional energy source.

The PORV mitigated pressure transient at the 350 psia setpoint is illustrated in Figures 3-1 and 3-2. The resulting maximum transient pressures (adjusted to PZR pressures) of 420 psia and 393 psia at 200°F and 140°F, respectively, are provided in Table 3-2. The PORV mitigated pressure transients at the 530 psia setpoint is illustrated in Figures 3-3 and 3-4 and the resulting maximum transient pressure (adjusted to PZR pressure) of 580 psia is provided in Table 3-1.

Table 3-1 Maximum Transient Pressures at 530 psia Setpoint

Transient Type	Applicable Transient	PORV Setpoint 530 psia HU or CD	
		T (°F)	P (psia)
Mass Addition Transients	2 HPSI 3 CP	300	1080
	2 HPSI 3 CP	220	1048*
	1 HPSI 3 CP	300	834
	1 HPSI 3 CP	220	723*
	3 CP	220	570
	3 CP	140	570
	1 HPSI	220	595
	1 HPSI	140	591
Energy Addition Transients	RCP Start	300	580
	RCP Start	200	580

*** Transient pressures are provided for temperatures that envelope the range of applicability. TS LCO 3.5.3 (Reference 15) requires that a maximum of one HPSI pump be operable below 270°F and that all HPSI pumps be disabled below 236°F unless, as specified by TS LCO 3.1.2.1 and 3.1.2.3 (Reference 15), one HPSI pump is established to ensure boration capability and all CP are disabled.**

Table 3-2 Maximum Transient Pressures at 350 psia Setpoint

Transient Type	Applicable Transient	PORV Setpoint 350 psia HU or CD	
		T (°F)	P (psia)
Mass Addition Transients	2 HPSI 3 CP	N/A	N/A
	2 HPSI 3 CP	N/A	N/A
	1 HPSI 3 CP	N/A	N/A
	1 HPSI 3 CP	N/A	N/A
	3 CP	200	392
	3 CP	140	392
	1 HPSI	200	595
	1 HPSI	140	500
Energy Addition Transients	RCP Start	200	420
	RCP Start	140	393

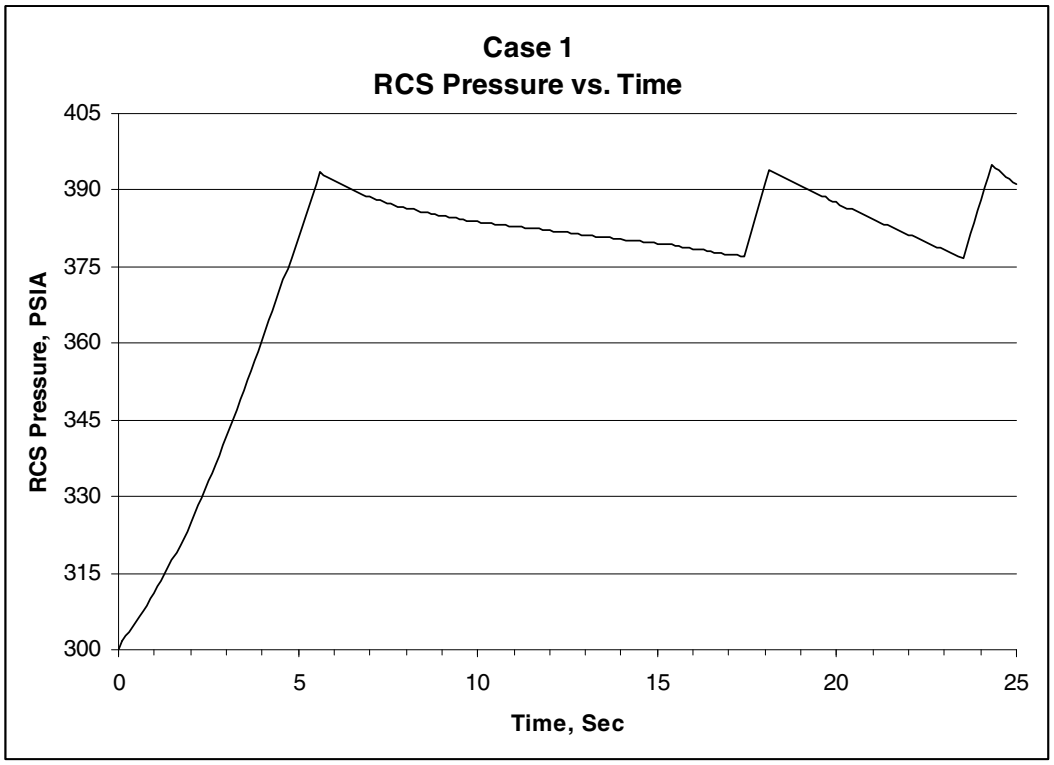


Figure 3-1 St. Lucie 1, Energy Addition Transient Case 1, PORV, P_{SET} = 350 psia, T_C = 140°F

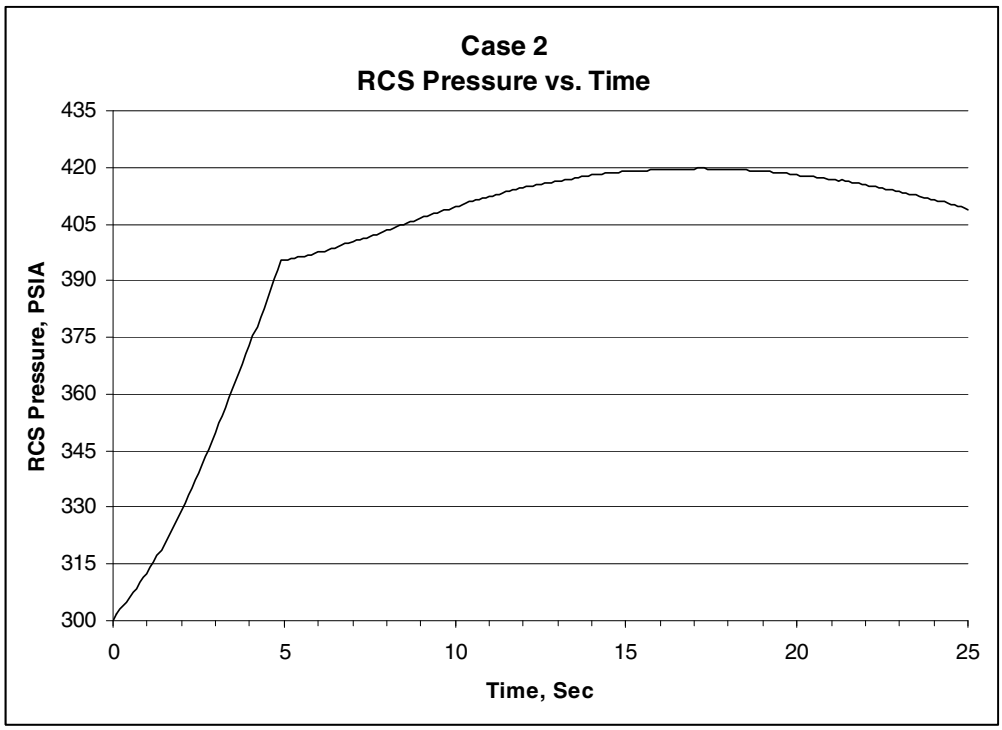


Figure 3-2 St. Lucie 1, Energy Addition Transient Case 2, PORV, P_{SET} = 350 psia, T_C = 200°F

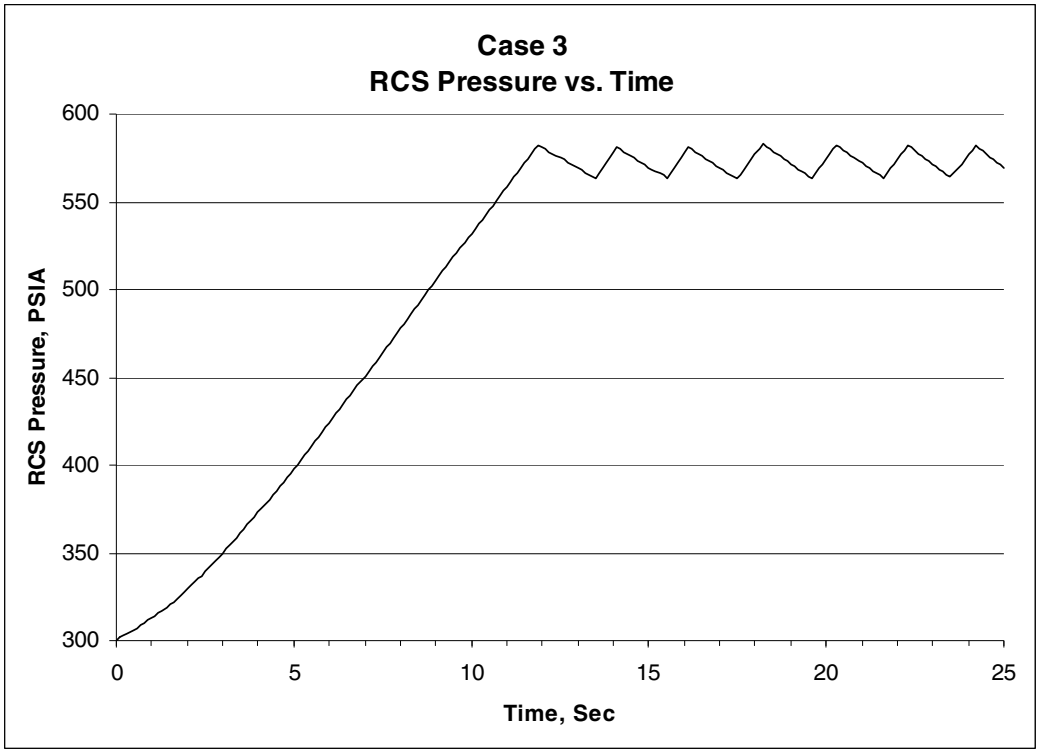


Figure 3-3 St. Lucie 1, Energy Addition Transient Case 3, PORV, P_{SET} = 530 psia, T_C = 200°F

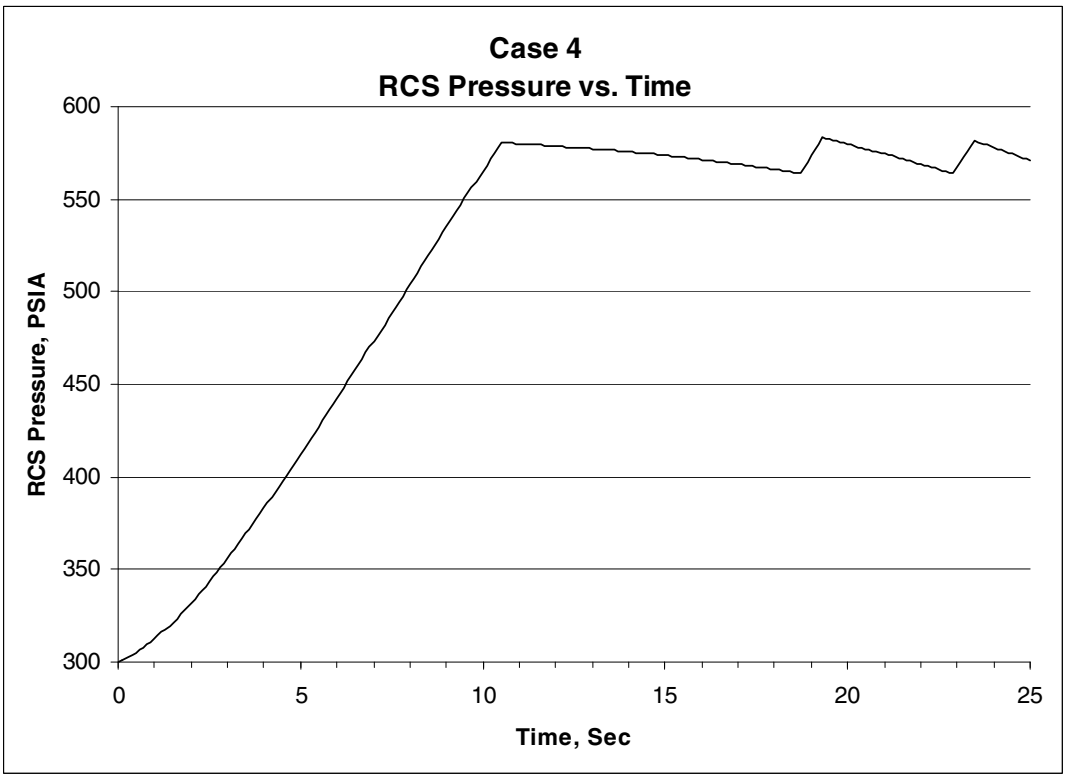


Figure 3-4 St. Lucie 1, Energy Addition Transient Case 4, PORV, P_{SET} = 530 psia, T_C = 300°F

3.3.2 Mass Addition Transients

The RCS pressure transient due to an inadvertent safety injection actuation was the design basis mass addition transient. The most severe mass addition transient occurs due to simultaneous actuation of two high-pressure safety injection (HPSI) pumps and three charging pumps (CPs) while letdown is isolated. This transient, however, was only analyzed at RCS temperature above 270°F, consistent with existing LTOP controls on HPSI pump availability limitations in the Reference 15, LCO 3.5.3. As a result, at RCS temperature below 270°F, the most limiting mass addition transient was due to one HPSI and three CPs input.

The following major assumptions were used in the analysis of the mass addition transients, in addition to the assumptions mentioned above and in Section 3.2.

1. It was assumed that the shut down cooling system (SDCS) will be aligned below 200°F. In this configuration, one HPSI and three CPs may be aligned.

2. The configuration with the SDCS isolated may allow two HPSI pumps and three CPs to be aligned. The PORV is the primary LTOP protection device.

3. In all transient cases, only a single pressure protection relief valve was assumed.

4. As many as three RCPs were operational at startup and during fill and vent and could be operating during the LTOP mass addition transient. However, the RCP heat input for the mass addition transient (consistent with current methodology) need not be considered since the transient initiates with the plant in a steady-state condition (operator controlled heatup or cooldown) and instantaneous RCP start is not a credible transient input.

5. PZR initial conditions were assumed to be 500 psia, 260 psia, and 75 psia for RCS hydraulic temperatures of 300°F, 220°F and 140°F respectively. The PZR was assumed to be saturated in each condition with temperatures of 467°F, 404°F and 308°F respectively, consistent with existing analyses.

The analysis updates the existing design inputs and assumptions to more accurately represent the current operating configuration. RCS volume expansion due to contributions from decay heat and full PZR heater heat were taken into account. PORV discharge flowrates as a function of PZR pressure are plotted in Figures 3-5 through 3-12. The mass addition events (including the RCS volume expansions) are compared to the PORV (Figures 3-5 through 3-12) cases and equilibrium pressures were determined. An equilibrium pressure is the pressure at which the mass inputs match the relief valve discharge. PORV transient analyses were performed to determine maximum transient pressures for both the PORV set pressures of 350 psia and 530 psia. The transient analysis calculated RCS pressure over time steps until an equilibrium was reached between HPSI and CPs, inflow and PORV outflow.

The equilibrium pressures relevant at a PORV setpoint of 530 psia were as follows.

Transient	Equilibrium Pressure (psia) (PORV Mitigation at 530 psia Setpoint)		
	300°F	220°F	140°F
2 HPSI + 3 CPs	1080	1048	
1 HPSI + 3 CPs	834	723	
3 CPs		286	113
Single HPSI		595	521

The equilibrium pressure was limiting in most of these cases. However, similar to in the case of the energy transient, pressure accumulation prior to the opening of the PORV can exceed the equilibrium pressure. This occurs during the transient specific to the three CPs, as well as for the lower temperature range of the single HPSI transient. The equilibrium pressure for the single HPSI case bounds the peak opening pressure for the three CP case and therefore the equilibrium pressure remains limiting. The maximum opening pressure for the single HPSI case was 591 psia, and therefore this value was used in place of the 140°F value of 521 psia.

The equilibrium pressures relevant at a PORV setpoint of 350 psia were as follows:

Transient	Equilibrium Pressure (psia) (PORV Mitigation at 350 psia Setpoint)	
	220°F	140°F
3 CPs	286	113
Single HPSI	595	521

The equilibrium pressure associated with the single HPSI transient was limiting for all cases.

The final results of the mass addition transient analysis are provided in Tables 3-1 and 3-2.

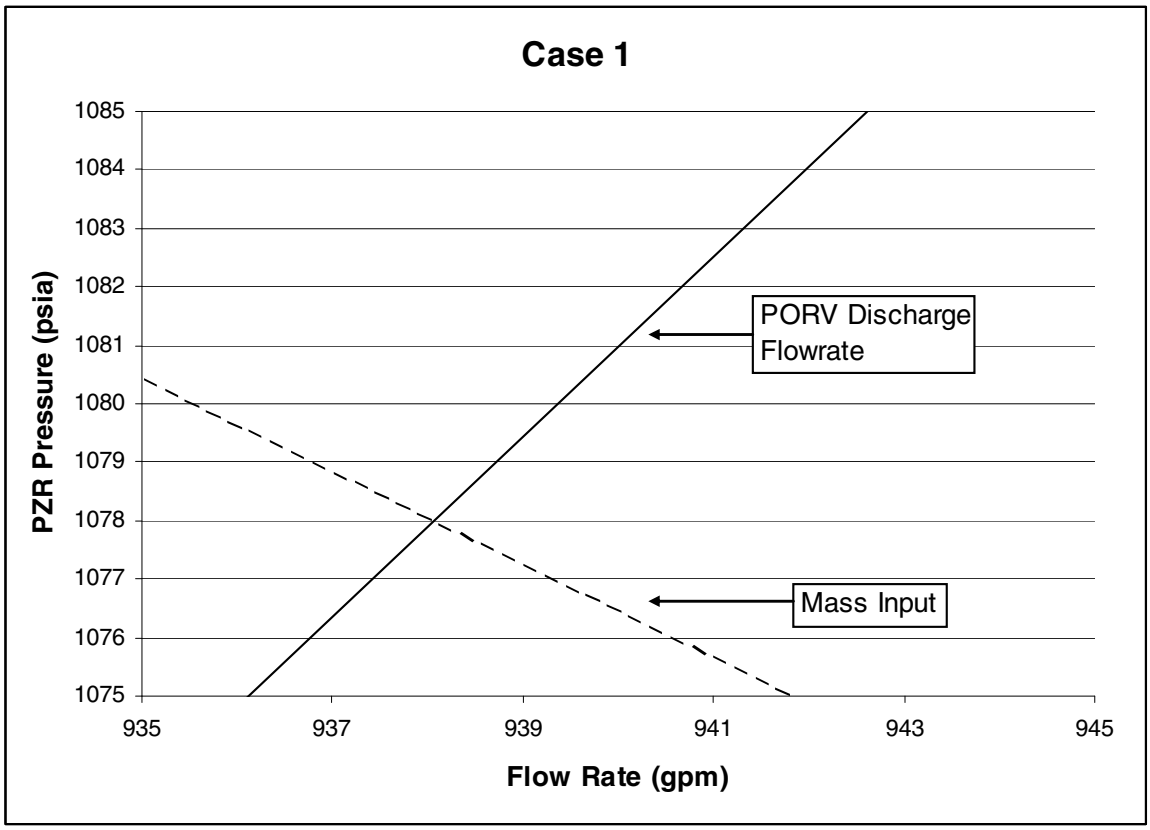


Figure 3-5 St. Lucie Unit 1 LTOP Mass Addition Transient Case 1 2 HPSI + 3 CPs, 300°F

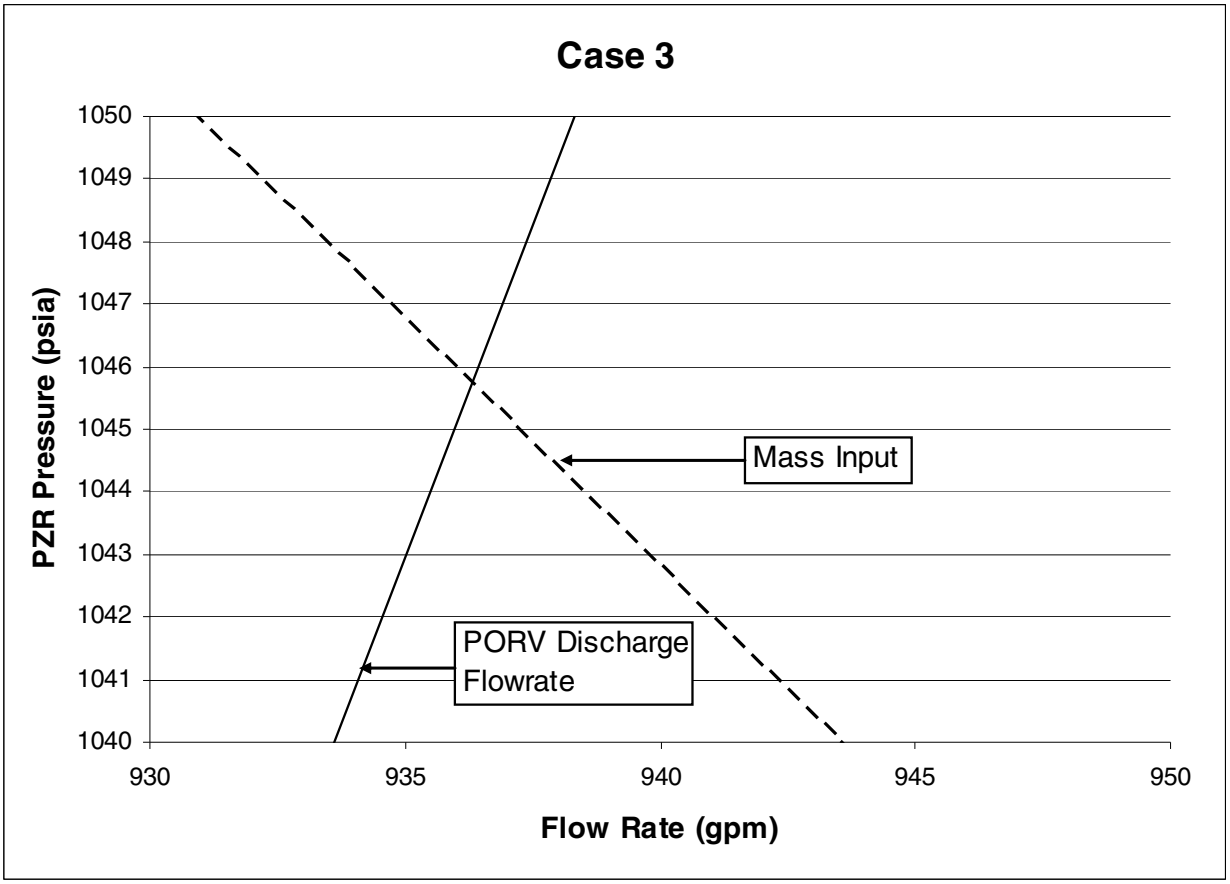


Figure 3-6 St. Lucie Unit 1 LTOP Mass Addition Transient Case 3
2 HPSI + 3 CPs, 220°F

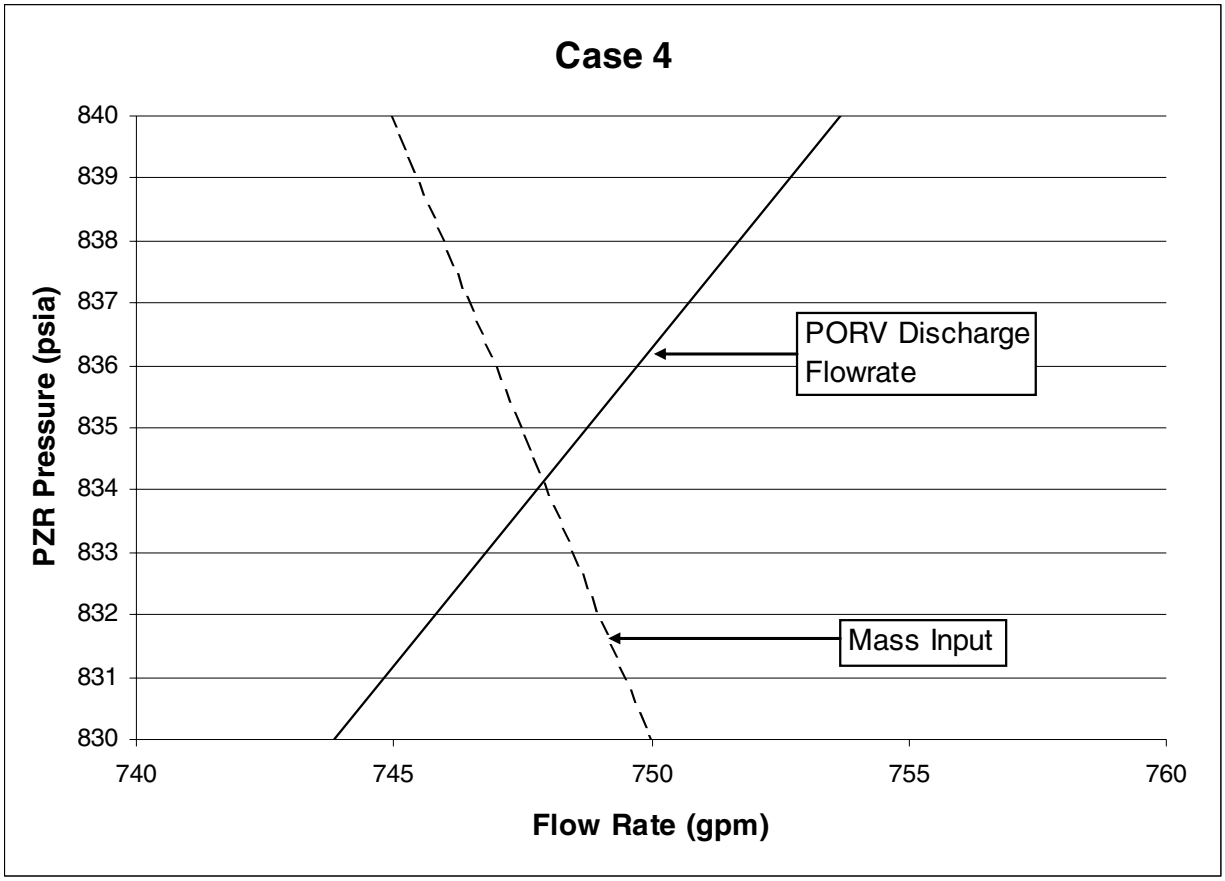


Figure 3-7 St. Lucie Unit 1 LTOP Mass Addition Transient Case 4 1 HPSI + 3 CPs, 300°F

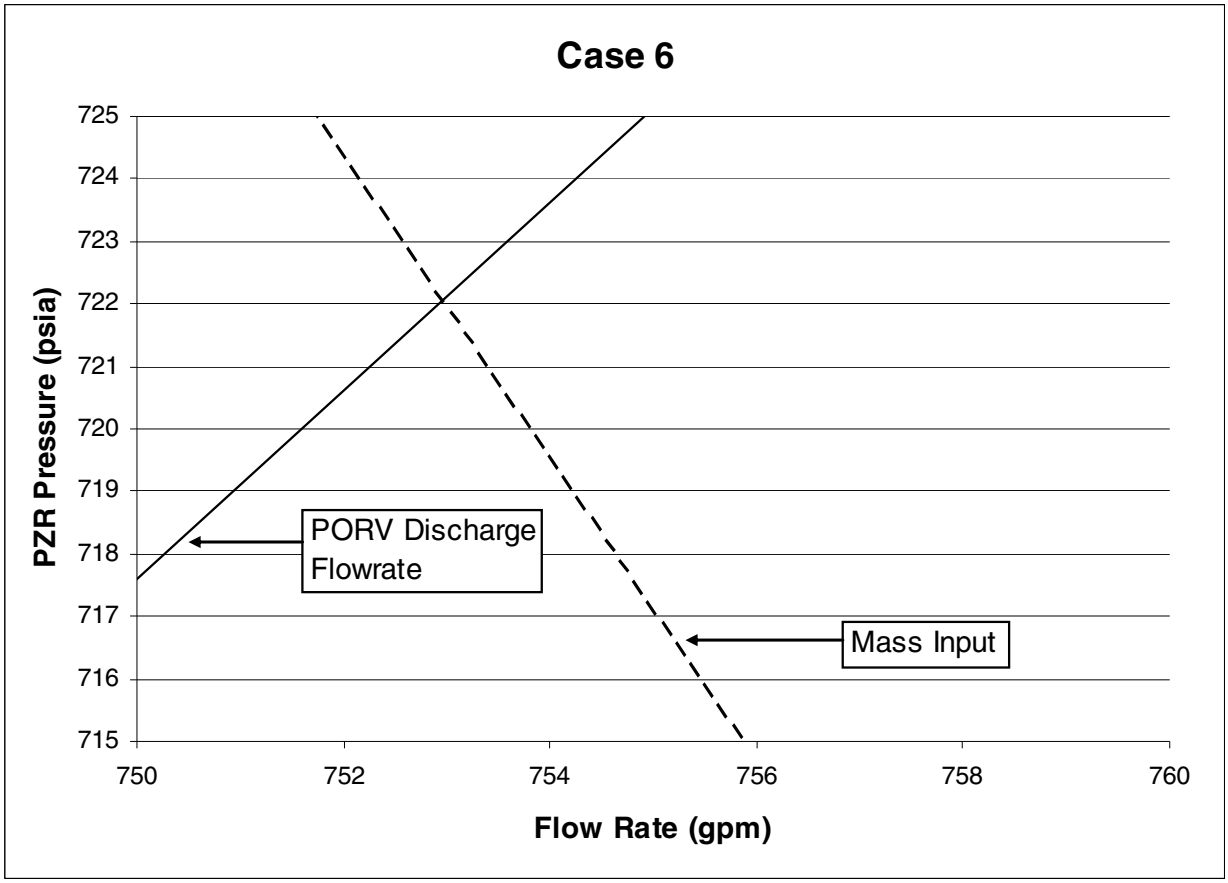


Figure 3-8 St. Lucie Unit 1 LTOP Mass Addition Transient Case 6 1 HPSI + 3 CPs, 220°F

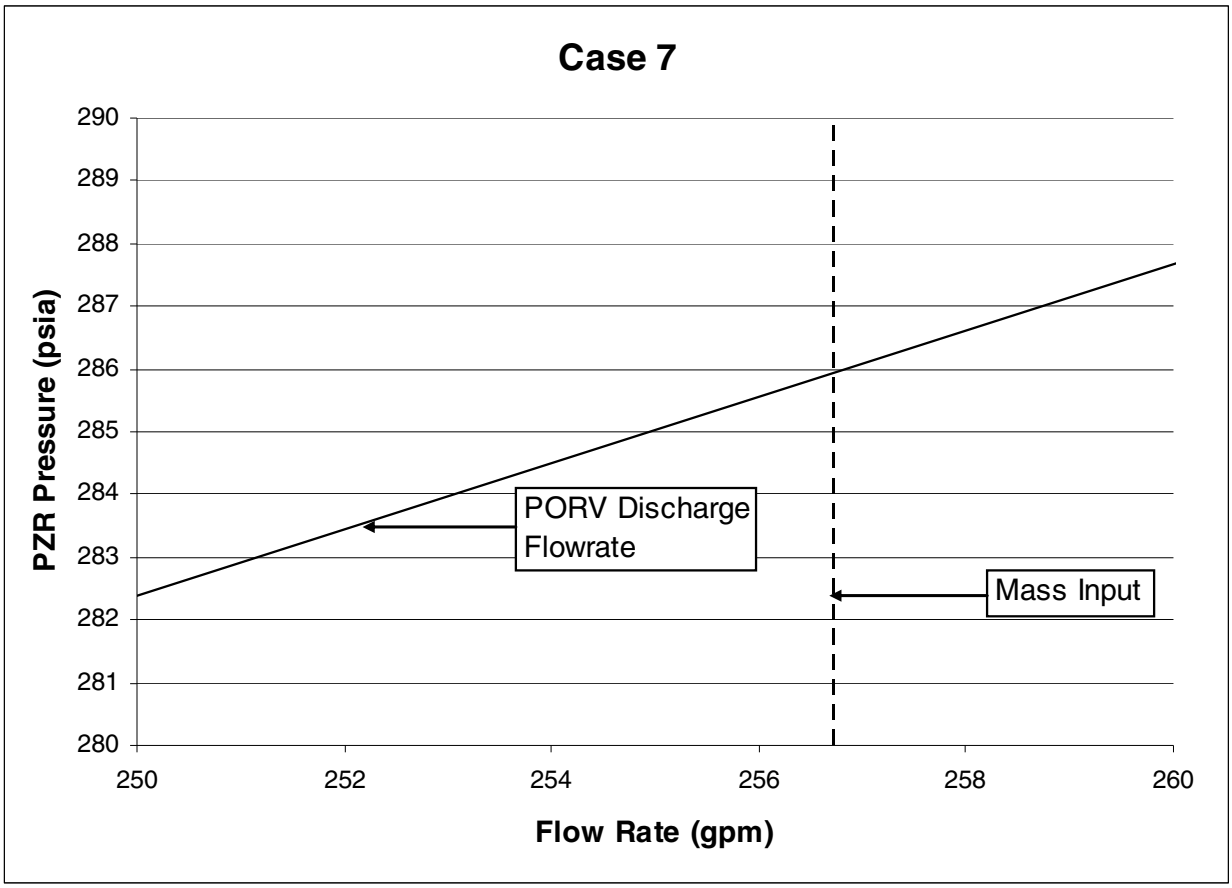


Figure 3-9 St. Lucie Unit 1 LTOP Mass Addition Transient Case 7 3 CPs, 220°F

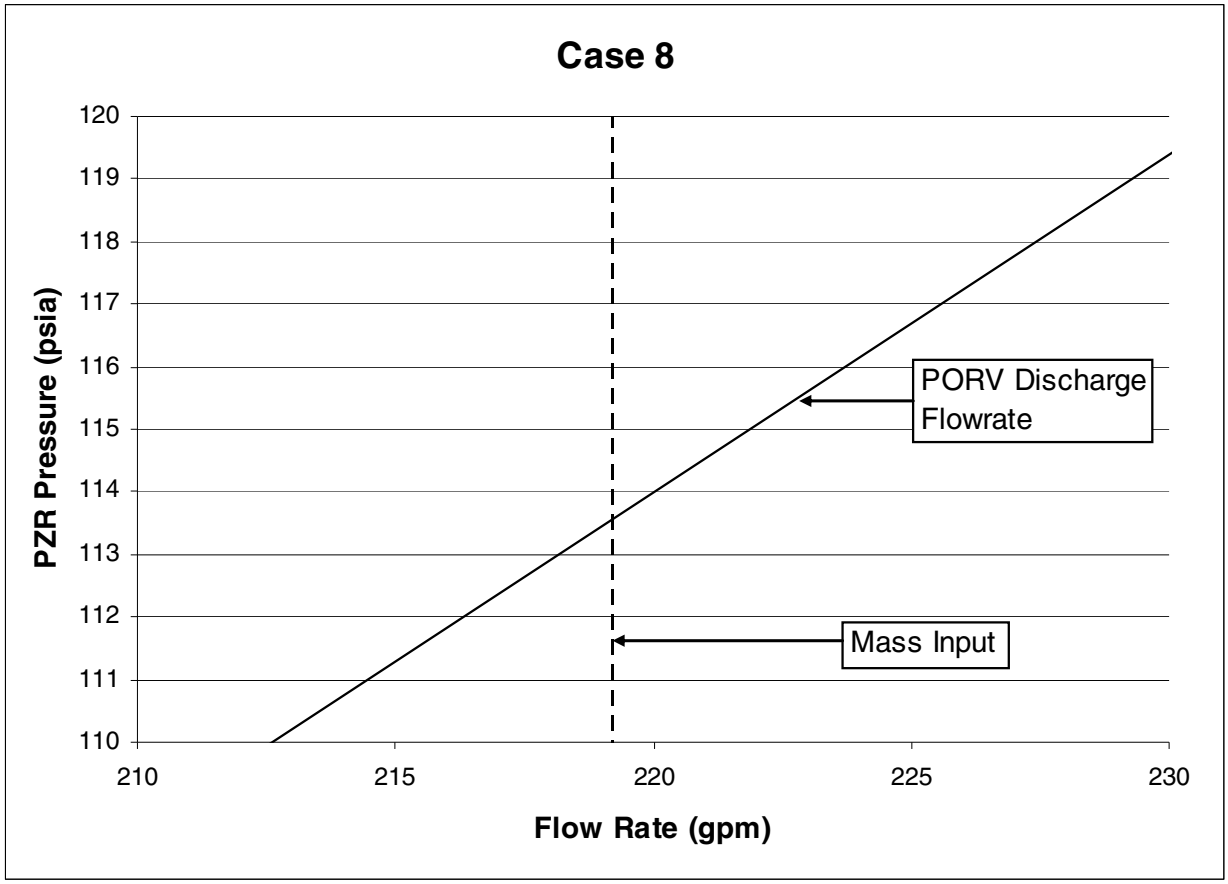


Figure 3-10 St. Lucie Unit 1 LTOP Mass Addition Transient Case 8 3 CPs, 140°F

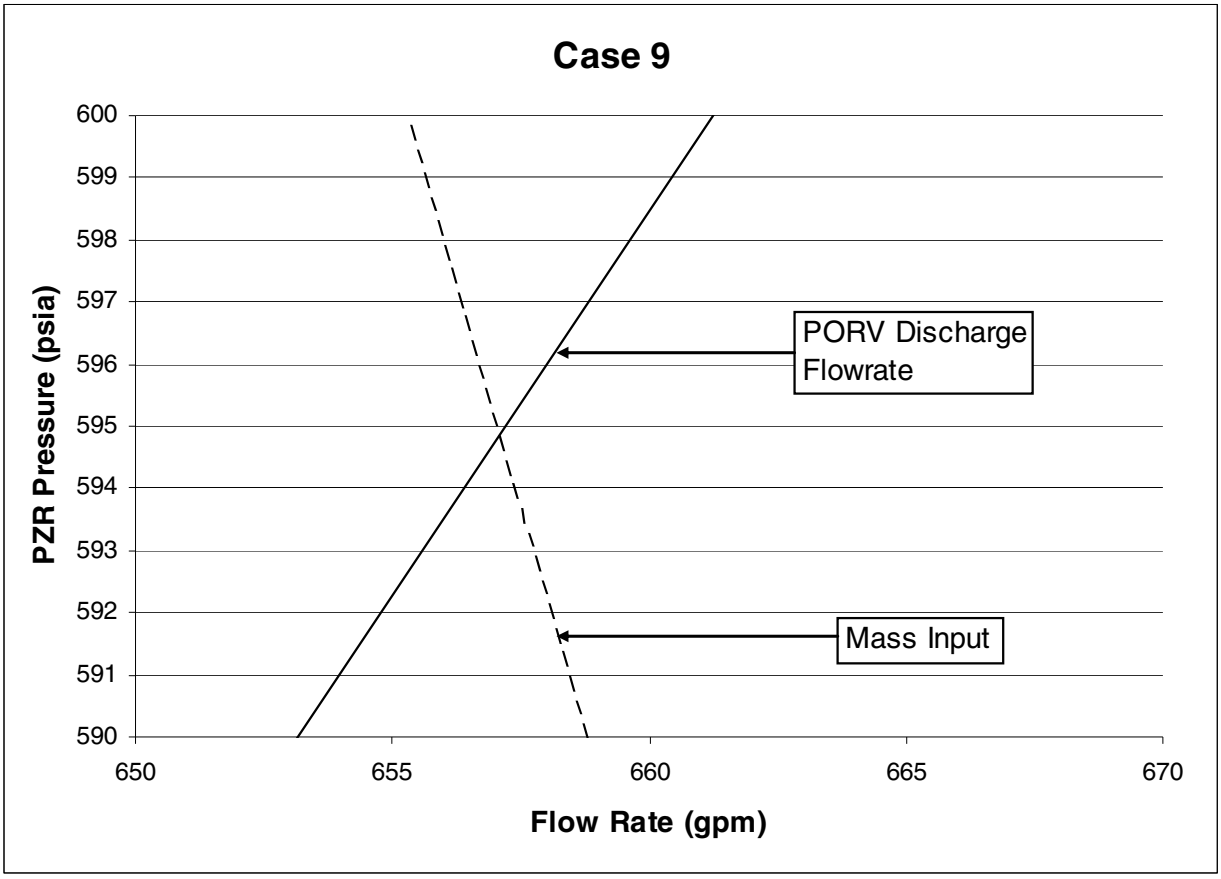


Figure 3-11 St. Lucie Unit 1 LTOP Mass Addition Transient Case 9 Single HPSI Pump, 220°F

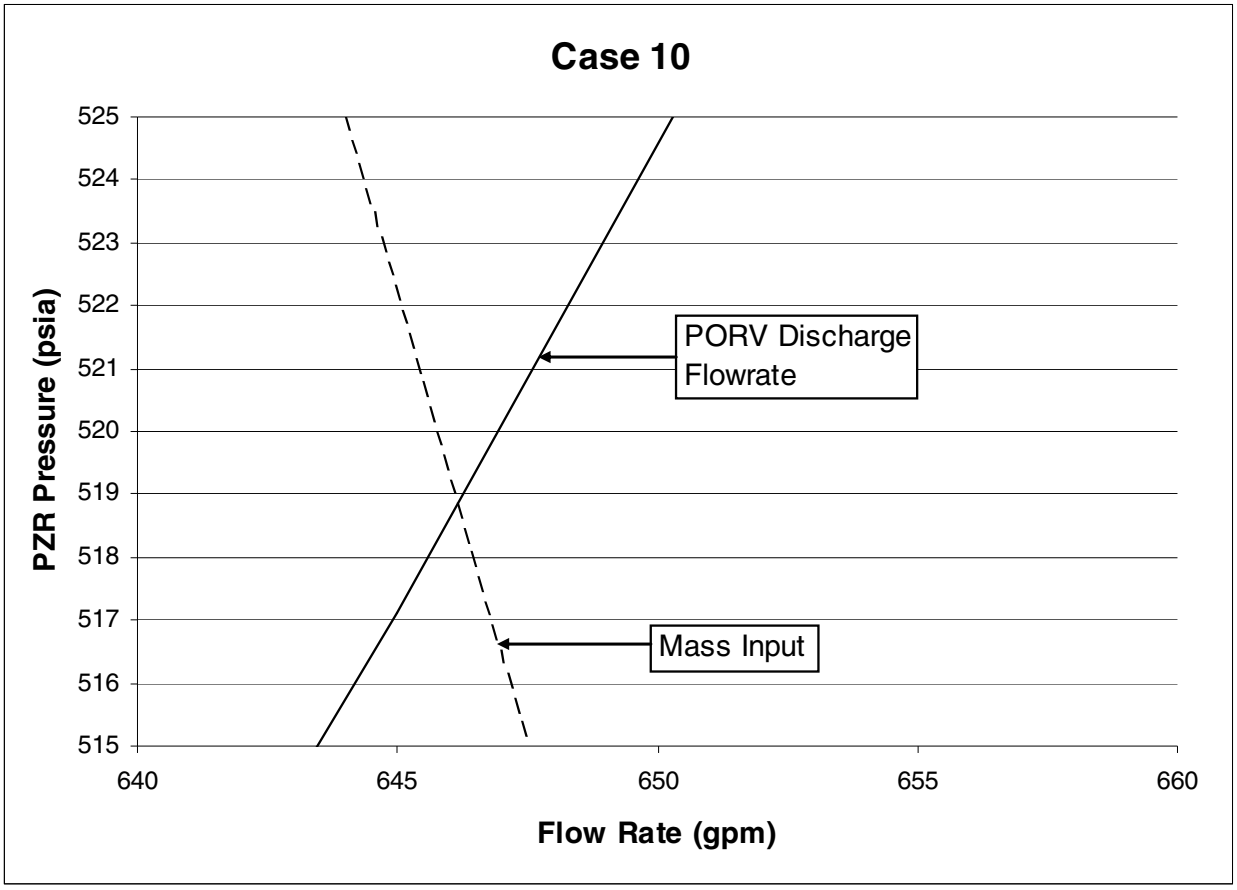


Figure 3-12 St. Lucie Unit 1 LTOP Mass Addition Transient Case 10 Single HPSI Pump, 140°F

3.3.3 Controlling Pressures

The pressure transient analysis results contained in Tables 3-1 and 3-2 were evaluated to identify the controlling pressures and applicable temperature ranges. The controlling pressures were the maximum transient pressures of all applicable transients in a particular temperature region. The maximum pressure was determined for each transient by conservative interpolation for the temperature range pertinent to the specific transient. The maximum pressures for the range of temperatures were used to determine the appropriate limiting conditions for operation. These limiting conditions for operation are provided in Section 3.4.

3.4 LIMITING CONDITIONS FOR OPERATION

The temperature requirements for selecting the setpoints for the PORVs for LTOP and the limitations on heatup and cooldown rates are provided in Table 3-3. These requirements were based on PORV setpoints of 350 and 530 psia.

An LTOP enable temperature of 300°F for both heatup and cooldown is conservative with respect to the values presented in Table 2-9. This conservative approach, especially with respect to the cooldown limit of 267°F, is appropriate from the human performance perspective as it provides operational consistency and simplicity.

It should be noted that during heatup, the PORV setpoint can be changed to 530 psia at any temperature above the minimum cold leg PORV setpoint transition temperature of 200°F in Table 3-3. During cooldown the PORV setpoint must be changed to 350 psia before or upon reaching the indicated temperature of 200°F in Table 3-3.

The existing Technical Specification LTOP requirements related to the limitations on RCP starts, operating RCP and HPSI pump alignment to the RCS remain unchanged except for the temperature range of applicability for the RCP start limitations as well as the elimination of the HPSI throttling requirements and case specific heatup and cooldown rates for HPSI alignment below the 236°F limit due to failure of all three CPs.

Table 3-3 LTOP Requirements, 54 EFPY

Low-temperature RCS Overpressure Protection Range		
Operating	**Cold Leg Temperature, °F**	
Period, EFPY	**During Heatup**	**During Cooldown**
< 54	< 300	< 300
Minimum Cold Leg Temperature for PORV Setpoint Transition for LTOP		
Operating	**Cold Leg Temperature, °F**	
Period, EFPY	**During Heatup**	**During Cooldown**
< 54	200	200

Table 3-3 (cont.)	**LTOP Requirements, 54 EFPY**
Maximum Allowable Heatup Rates	
70°F /hr,	at all temperatures
Maximum Allowable Cooldown Rates	
20°F /hr,	at T_c < 125°F
30°F /hr,	at T_c > 125°F
40°F /hr,	at T_c > 145°F
50°F /hr,	at T_c > 160°F
100°F /hr,	at T_c > 180°F

Note:
The applicability of the following restrictions is established as T_C < 300°F (This is a modified applicability band.)

- A RCP shall not be started with two idle loops, unless the secondary water temperature of each steam generator is less than 30°F above each of the RCS cold leg temperatures. (This is an existing limitation.)
- Prior to decreasing the RCS temperature below 270°F, a maximum of only one HPSI pump shall be operable with its associated header stop valve open. (This is an existing limitation.)
- Prior to decreasing the RCS temperature below 236°F, all HPSI pumps shall be disabled and their associated header stop valves closed except in the case where all CPs have failed. In this case, the previous single HPSI limitation remains, with the added restriction that all CPs shall be disabled. (This is an existing limitation.)

3.5 SUMMARY OF PROPOSED CHANGES

The proposed LTOP system is designed in accordance with the requirements set forth in the NRC Branch Technical Position BTP 5-2, contained within SRP 5.2.2, Reference 5.

The proposed system is adequate to prevent violation of Appendix G P-T limits during the operating period ending at 54 EFPY. In order to implement the proposed LTOP system the following is required:

- Modification of appropriate Technical Specifications
- Modification of appropriate plant operating procedures

The implementation of the proposed LTOP system will not result in a reduction in the margin of safety presently afforded by Technical Specifications.

4 REFERENCES

1. Code of Federal Regulations, 10 CFR 50, Appendix A, "General Design Criteria for Nuclear Power Plants," January 2006.

2. Code of Federal Regulations, 10 CFR 50, Appendix G, "Fracture Toughness Requirements," December 1995.

3. ASME Boiler and Pressure Vessel Code Section XI, Appendix G, "Fracture Toughness Criteria for Protection against Failure," 2002 Edition with the 2003 Addenda.

4. Regulatory Guide 1.99, "Radiation Embrittlement of Reactor Vessel Materials," U.S. Nuclear Regulatory Commission, Revision 2, May 1988.

5. U. S. Nuclear Regulatory Commission Standard Review Plan (SRP) 5.2.2, "Overpressure Protection," Revision 3, March 2007.

6. Florida Power and Light Letter, L-2004-244, "St. Lucie Unit 1 Docket No. 50-335 Proposed License Amendment Extension of the Reactor Coolant System Pressure/Temperature Curve Limits and LTOP to 35 EFPY," December 20, 2004.

7. Florida Power and Light Letter, L-97-136, "St. Lucie Units 1 and 2 Docket Nos. 50-335 and 50-389 NRC TAC Nos. M95484 and M95485 Request for Additional Information – Response to 10 CFR 50.61 – Pressurized Thermal Shock Evaluation," May 16, 1997.

8. Florida Power and Light Letter, L-97-10, "St. Lucie Units 1 and 2 Docket Nos. 50-335 and 50-389 NRC TAC Nos. M95484 and M95485 Request for Additional Information (RAI) – Response to 10 CFR 50.61 – Pressurized Thermal Shock Evaluation," January 14, 1997.

9. NRC Reactor Vessel Integrity Database, Version 2.0.1 (RVID-2), July 6, 2000.

10. ASME Boiler and Pressure Vessel Code Section XI, Appendix A, "Analysis of Flaws," 1998 Edition with the 2000 Addenda.

11. Westinghouse Report, CE-NPSD-683-A Task-1174, Revision 06, "Development of a RCS Pressure and Temperature Limits Report for the Removal of P-T Limits and LTOP Requirements from the Technical Specifications," April 2001.

12. J. Heliot, R.C. Labbens, and Pellisser-Tanon, "Semi-Elliptical Cracks in a Cylinder Subjected to Stress Gradients," ASTM Special Technical Publication 677, August 1979.

13. ASME Boiler and Pressure Vessel Code Section III, Appendix I, "Design Stress Intensity Values, Allowable Stresses, Material Properties, and Fatigue Design Curves," 1989 Edition.

14. FPL Calculation, PSL-1FJI-09-001, Revision 0, "Instrument Uncertainty Calculation for Pressure – Temperature Limit Curves and LTOP St Lucie Unit 1," April 2009.

15. St. Lucie Plant Unit No. 1 Technical Specifications, Amendment 204, February 22, 2008.

16. CE Report "Pressure-Temperature Limits and Low Temperature Overpressure Protection for St. Lucie Unit 1 for 15 Effective Full Power Years," Revision 1, September 1989. Transmitted to FPL via Letter F-MPS-89-046, P. J. Hijeck to T. E. Roberts, September 27, 1989.

APPENDIX A
TECHNICAL SPECIFICATION FIGURES

FIGURE 3.4-2a

ST. LUCIE UNIT 1 P/T LIMITS, 54 EFPY
HEATUP AND CORE CRITICAL

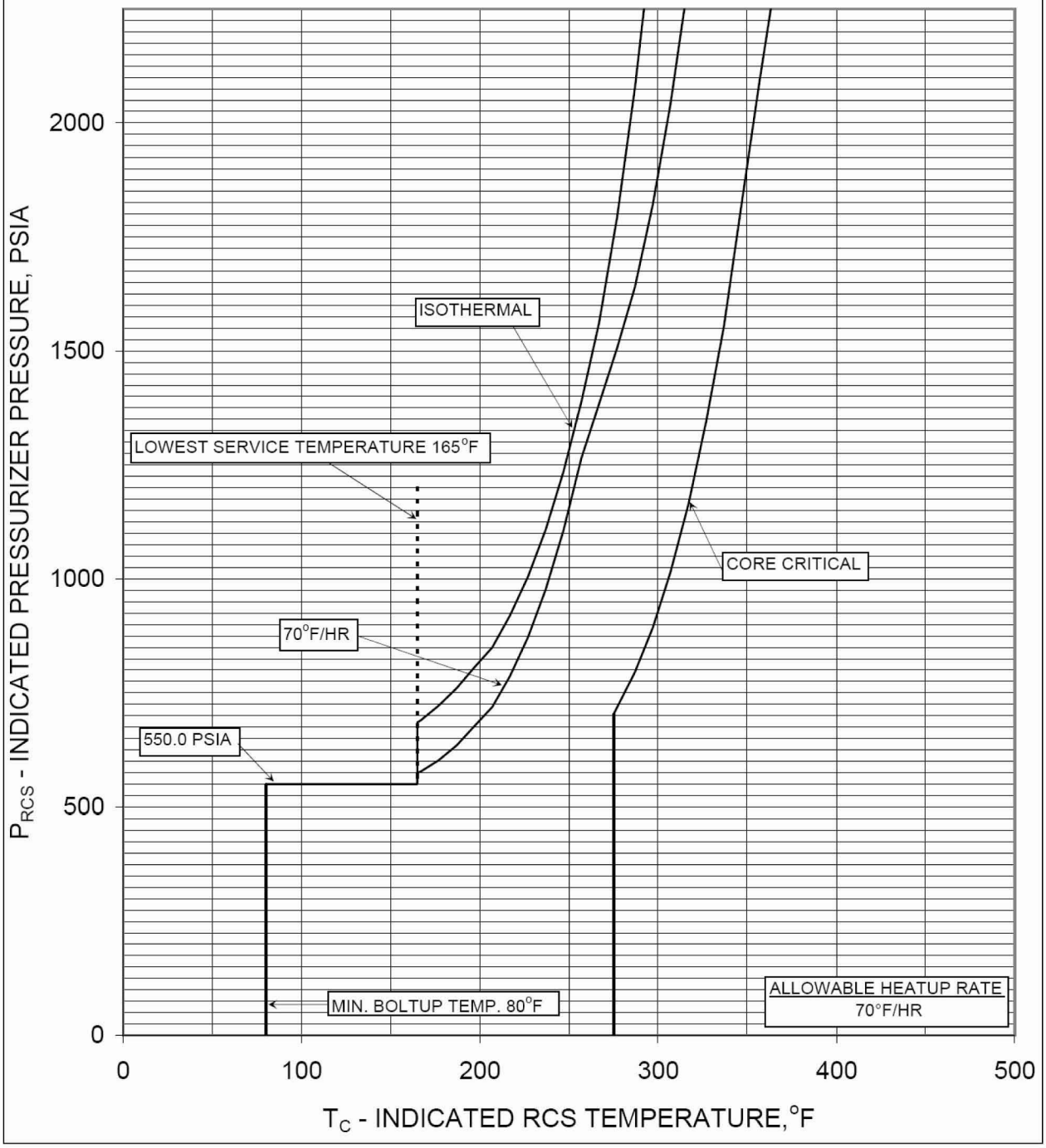
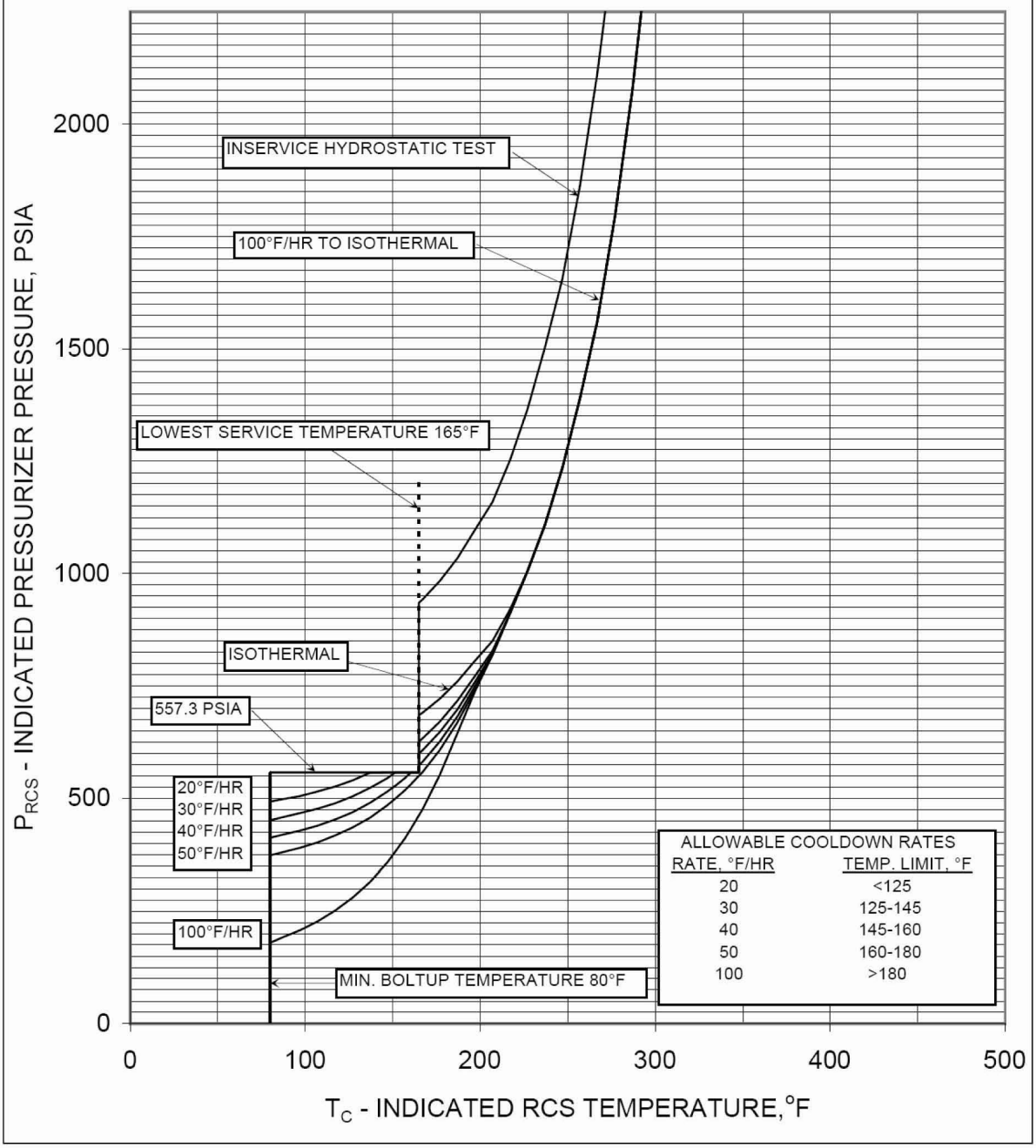


FIGURE 3.4-2b

ST. LUCIE UNIT 1 P/T LIMITS, 54 EFPY
COOLDOWN AND INSERVICE TEST