ENTERGY OPERATIONS, INC.
ARKANSAS NUCLEAR ONE UNIT 2

FINAL

ENGINEERING REPORT NO. A-PENG-ER-004, REVISION 00

LOW TEMPERATURE OVERPRESSURE PROTECTION
FOR
21 EFFECTIVE FULL POWER YEARS

ABB COMBUSTION ENGINEERING NUCLEAR OPERATIONS
COMBUSTION ENGINEERING, INC.
WINDSOR, CONNECTICUT

Authored by A. A. Ostrov and C. D. Stewart Date 2/28/96

Approved by F. P. Ferraraccio and C. J. Gimbrone Date 2/28/96

Report: 24 pages
Appendices: N/A
Other Attachments: N/A

FOREWORD

This report provides a summary, in part, of the work performed for Entergy Operations, Inc. under Contract Order Number NAC00132. The report, with the exception of Sections 1.1 and 1.2, has been reviewed for accuracy against the bases documentation listed below.

"Pressure Correction Factors for ANO-2 P-T Limits," Calculation No. A-PENG-CALC-007, Rev. 00, dated January 12, 1996.

"LTOP P-T Limits & Enable Temperatures for 21 EFPY per ASME Code Case N-514 for ANO-2," Calculation No. A-PENG-CALC-009, Rev. 00, dated February 12, 1996.

"Low Temperature Overpressure Protection for ANO-2 for 21 EFPY," A-PENG-CALC-008, Rev. 00, dated February 28, 1996.

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Section 1.0
INTRODUCTION

1.1 Background

In 1991, ABB performed a scope of work for ANO-2 developing revised Appendix G pressure-temperature (P-T) limits for 21 Effective Full Power Years (EFPY) and new requirements for low temperature overpressure protection (LTOP). That effort also included the development of LTOP P-T limits to be used exclusively for establishing LTOP requirements. Those LTOP P-T limits were based upon Combustion Engineering Owner's Group (CEOG) fracture mechanics methodology that was documented in a topical report.

Based on the results of that effort, Entergy Operations, Inc. applied for license amendments of P-T limit and LTOP related LCO's. The submittal for incorporation of Appendix G P-T limits for 21 EFPY was subsequently approved by the NRC. The LTOP-related submittal, however, was not accepted, because the NRC has declined endorsing the CEOG methodology. The NRC staff has requested an alternate approach using a currently NRC accepted methodology. Therefore, an analysis has been performed using ASME Code Case N-514 procedures.

The current requirements for LTOP are provided in NRC Branch Technical Position (BTP) RSB 5-2, which is a part of Standard Review Plan 5.2.2 (Reference 1). However, a recently issued ASME Code Case N-514 (Reference 2) contains new guidance for developing LTOP requirements that are typically less restrictive than the requirements in BTP RSB 5-2. Specifically, the code case recommends that "LTOP systems shall limit the maximum pressure in the vessel to 110% of the pressure determined to satisfy Appendix G, paragraph G-2215 of Section XI, Division 1". Thus P-T limits that are 10% greater, i.e., less restrictive, than the basic Appendix G limits at the reactor vessel beltline can be used for establishing LTOP limitations. (In this report, these "relaxed" P-T limits are called LTOP P-T limits). Using LTOP P-T limits in LTOP analyses will improve heatup/cooldown limitations, and/or allow an expansion of the operating window. While the code case has not been acknowledged in the current regulations, the NRC has publicly endorsed its use for establishing LTOP limitations. Currently, several utilities have successfully utilized it. In addition, Code Case N-514 has recently been incorporated into Appendix G (G-2215) to Section XI of the ASME Code, 1996 Edition

In light of the above, an analytical effort was undertaken to identify ANO-2 LTOP limitations for 21 EFPY, based upon the guidance provided in the code case, to support a new Entergy Operations, Inc.'s LTOP-related licensing submittal. This effort is documented in this report.

1.2 Objective

The primary goal of this effort as identified by Entergy Operations, Inc. personnel, was to maintain the current basis for the Technical Specification RCS heatup and cooldown limitations thereby not requiring a licensing change. The secondary goal was to minimize operational restrictions that may be necessary to satisfy LTOP requirements.

1.3 General Approach

The following tasks represent the overall scope of the services provided by ABB:

a) Development of ma... assumptions and inputs to be used in the analyses for approval by Entergy Operations, Inc. These are provided in Section 2.0 separately for each analysis performed.

b) Calculation of new pressure correction factors (PCF) for indexing the uncorrected LTOP P-T limits at the reactor vessel beltline to the pressurizer upper pressure instrument nozzle elevation. Three new PCF's were calculated applicable to operation of zero, two, and three reactor coolant pumps (RCP) over specific temperature ranges. Previously only one PCF (for three RCP's) was conservatively applied for the entire P-T limit temperature range. The PCF's are addressed in Subsection 3.3.

c) Development of the LTOP P-T limits and LTOP enable temperatures, using the guidance in ASME Code Case N-514 and the PCF's developed as part of this effort. The LTOP P-T limits were developed to be consistent with the current ANO-2 Technical Specification rates and associated temperature ranges. The method and results are presented in Section 3.0.

d) Analysis of LTOP limitations, using the LTOP P-T limits and enable temperatures developed in the previous task and the existing LTOP relief valve setpoint of 430 psig. The analysis is described in Section 4.0.

1.4 LTOP System Description

At ANO-2, LTOP is provided by two redundant valves connected to the top of the pressurizer. The valves (Tag Nos. 2PSV-4732 and 2PSV-4742) are safety relief valves, Model DB-32P/SP/S4, orifice area 6.38 in^2, made by J. E. Lonergan Company. Each valve has the same opening setpoint of 430 psig (445 psia) and is capable of mitigating the design basis pressurization event, which is full safety injection initiation from water-solid conditions, with simultaneous operation of three charging pumps.

Both valves are aligned to the RCS, by opening the corresponding isolation (block) valves between 275°F and 270°F during cooldown. The valves are isolated from the RCS, by closing the isolation valves between 275°F and 280°F during heatup. An alarm circuit is provided to alert the operator if RCS temperature drops to 270°F and any isolation valve is not fully open. A description of the ANO-2 LTOP system is provided in Reference 3, Sections 5.2.2.4, 7.6.1.3, and 7.6.2.3.

The above provisions, in combination with the Technical Specification heatup and cooldown limitations per Reference 4, comprise the current LTOP system.

Section 2.0
DESIGN INPUTS AND ASSUMPTIONS

This section presents the major assumptions and inputs that were utilized in the three analyses. Also included are the RCS heatup and cooldown limit targets established by Entergy Operations. Inc.

2.1 Pressure Correction Factors Analysis

(a) RCP Configurations:

A justifiable reduction in the pressure correction factor (PCF) relaxes the P-T limit, i.e., increases pressure for a given temperature. The main contributor to the PCF is the flow induced pressure drop between a reference point for the reactor vessel beltline (bottom of the core) and the surge line nozzle in the hot leg. As this pressure drop varies with the number of operating RCP's, this term can be reduced by limiting the number of operating RCP's at low RCS temperatures. The basis for the current Technical Specification RCS P-T limits is a single PCF that includes flow induced pressure drop for three operating RCP's over the entire applicable temperature region.

However, to reduce that PCF, Entergy Operations, Inc. agreed to impose administrative limitations on RCP operation at low RCS temperatures. The following RCP configurations were agreed upon and assumed for the analysis:

No. of Operating Pumps	Temperature Range, t_{actual}
0	50°F ≤ t < 120°F
2	120°F ≤ t <200°F
3	t ≥ 200°F

The temperatures represent reactor coolant cold leg temperature and are actual, i. e., without temperature uncertainty applied.

(b) Instrument Uncertainties:

Pressurizer pressure and reactor coolant temperature indication instrumentation uncertainties were conservatively assumed to equal (- 85) psi and (+20°F). These values were provided as design input by Entergy Operations, Inc. in Reference 5. With a (+20°F) temperature indication uncertainty applied, the above temperature ranges are expressed in indicated cold leg temperature as follows:

No. of Operating Pumps	Temperature Range, t_{ind}
0	70°F ≤ t < 140°F
2	140°F ≤ t <220°F
3	t ≥ 220°F

(c) Pressurizer Fluid Condition:

The pressurizer was assumed to be water-solid. The entire water column between the bottom of the core, the lower reference point, and the top of the pressurizer, the upper reference point, was assumed to be at a uniform temperature equal to the lowest RCS temperature of 50°F. Both these assumptions maximize the elevation head term in the PCF's.

2.2 LTOP P-T Limit Development

(a) RCS P-T Limit Basis:

The LTOP P-T Limits will be based upon the current Technical Specification 3.4.9 "Pressure/Temperature Limits," Reference 4. Specifically, the existing rates and associated temperature ranges will form the basis for the LTOP P-T limits (see Table below).

Technical Specification Cooldown Rates

RCS Temperatures (T_C)	Maximum Cooldown Rate
T_C > 220°F	100°F/hr (linear) or 50°F in any one-half hour (step)
140°F ≤ T_C ≤ 220°F	60°F/hr (linear) or 30°F in any one-half hour (step)
T_C < 140°F	25°F/hr (linear) or 12.5°F in any one-half hour (step)

Technical Specification Heatup Rates

RCS Temperatures T_C	Maximum Heatup Rate
All Temperatures	80°F/hr (linear)

Note: The preceding temperatures are treated as indicated values.

The basis associated with the existing Technical Specifications RCS heatup and cooldown limitations is documented in Reference 6 and transmitted to Entergy Operations in Reference 7.

(b) Pressure Correction Factors:

The pressure correction factors applicable to "actual" pressurizer pressure and developed during the course of this effort will be used to adjust the LTOP P-T Limits to "actual" pressurizer pressure. (See Subsection 3.3 for details.) In addition, the LTOP P-T Limits will be corrected by 20°F for instrument uncertainty.

(c) LTOP Enable Temperatures:

The LTOP Enable Temperatures will be developed on a consistent basis with the LTOP P-T Limits. The adjusted reference temperature (ART) for the one-quarter thickness location shall be based upon the 21 EFPY P-T Limit analysis. This value was previously calculated to be 111.0°F per References 6 and 7.

2.3 LTOP Analysis

(a) Means for LTOP:

LTOP is provided by two existing safety relief valves, Tag Nos. 2PSV-4732 and 2PSV-4742. Each valve is a Lonergan safety relief valve Model DB-32P/SP/S4, orifice area 6.38 in^2, per Reference 10. Both valves are required to be aligned to the RCS for LTOP between the minimum boltup temperature and the LTOP enable temperature, whenever the RCS is pressurized and the reactor vessel head is fully tensioned. Only one valve, however, is assumed for mitigation of the design basis pressurization event to satisfy the single failure criterion of Reference 1.

(b) Relief Valve Setpoint:

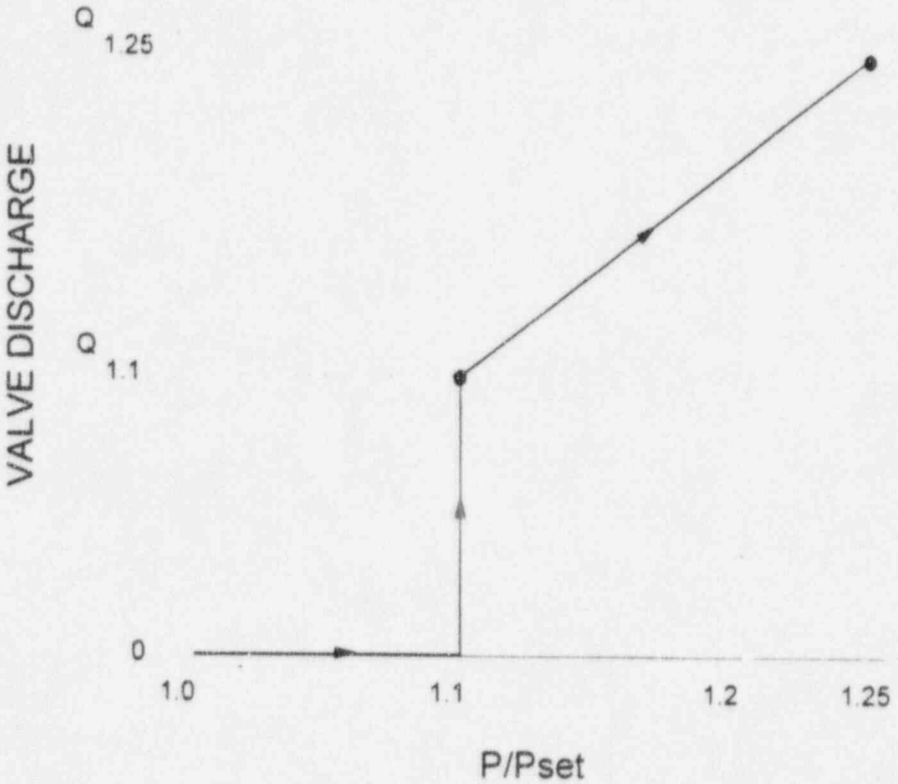
The opening setpoint of each LTOP relief valve remains at the current value of 430 psig.

(c) Relief Valve Opening Model:

An actual valve opening model is unavailable, therefore the model utilized was based upon conservative assumptions. The assumed model was a result of a comparison between the flow characteristics assumed in the original LTOP analysis, Reference 9, and the information provided in Reference 8.

It was assumed that during a pressurization event the relief valve remains closed until inlet pressure reaches 10% accumulation above the opening setpoint, at which point the valve opens instantaneously to reach rated capacity at 10% accumulation (see Figure 1). This is a conservative assumption, since it results in valve opening delay, which, in turn, yields a greater opening pressure.

FIGURE 1. RELIEF VALVE OPENING MODEL



(d) Relief Valve Back Pressure:

Relief valve back pressure used to calculate valve capacity is 100 psig (Reference 10).

(e) Inlet Piping Pressure Drop:

The existing relief valve inlet piping pressure drop, i.e., between the pressurizer and the valve inlet (30 psid, Reference 9), was assumed in the calculation of the peak transient pressure in the pressurizer.

(f) Reference P-T Limits:

The LTOP P-T limits for 21 EFPY that were developed in the course of this effort and described in Section 3.0 were used as the basis for determining the adequacy of the Technical Specification heatup and cooldown limitations.

(g) Design Basis Event:

The existing LTOP design basis pressurization event was assumed as the basis for establishing the peak transient pressure. The event is mass addition to the RCS due to spurious safety injection actuation, that results in simultaneous operation of two (2) HPSI pumps and three (3) charging pumps (Reference 9).

(h) LTOP Enable Temperature:

The LTOP enable temperature is 220°F for both heatup and cooldown. This represents an indicated temperature value.

(i) Pressurizer Fluid Conditions:

For calculation of relief valve discharge, the pressurizer was assumed to be filled with saturated water at pressure equal 90% of the valve opening setpoint. This value is recommended by the valve manufacturer as the maximum pressure for operation with the valve aligned for protection. This assumption reduces water subcooling which, in turn, conservatively reduces discharge flow and thus raises system pressure.

For adjustment of pressurizer pressure to the cold leg elevation where HPSI pump injection to the RCS was assumed to take place, pressurizer level was assumed to be at 50%. This assumption is conservative as compared to water-solid conditions, as it reduces RCS pressure which, in turn, increases HPSI pump flow to the RCS.

(k) RCS heatup and cooldown limit targets:

A maximum heatup rate of 80°F/hr at all RCS temperatures should remain valid. The following cooldown limitations should remain valid:

RCS Temperature (t_{cold})	Maximum Cooldown Rate
$t_{cold} > 220°F$	100°F/hr (constant), or 50°F in any half hour period (step)
$140°F \leq t_{cold} \leq 220°F$	60°F/hr (constant), or 30°F in any half hour period (step)
$t_{cold} < 140°F$	25°F/hr (constant), or 12.5°F in any half hour period (step)

where t_{cold} is indicated cold leg temperature.

Section 3.0
DEVELOPMENT OF LTOP P-T LIMITS

3.1 Basis

The basis for the existing ANO-2 Technical Specification 3.4.9 "Pressure/Temperature Limits", Reference 4, is documented in References 6 and 7. These limits were developed in accordance with 10 CFR 50 Appendix G which mandates the use of ASME Boiler and Pressure Vessel Code Section III Appendix G. The beltline limitations developed comply with paragraph G-2215 of Section XI of the ASME Boiler and Pressure Vessel Code, 1986 Edition. The adjusted reference temperatures supporting the reactor vessel beltline P-T limits were calculated with the best available material and fluence information using the prescriptive methods of Regulatory Guide 1.99, Rev. 2. These values were 111.0°F and 96.0°F for the one-quarter and three-quarter thickness locations, respectively.

3.2 Method

The method employed in the development of LTOP P-T limits for ANO-2 was based upon ASME Code Case N-514 (Reference 2). This method requires that the LTOP system limit pressure to 110% of the pressure determined to satisfy Appendix G, paragraph G-2215 of Section XI, Division 1. In addition, ASME Code Case N-514 also requires that the LTOP system be active at coolant temperatures less than 200°F or at coolant temperatures corresponding to a metal temperature of RT_{NDT} + 50°F, whichever is greater. The Code Case clarifies that the coolant temperature is the reactor coolant inlet temperature and that the RT_{NDT} is the highest adjusted reference temperature for the weld or base metal in the vessel beltline region at the one-quarter thickness location determined in accordance with Regulatory Guide 1.99, Revision 2. As noted previously, the beltline limits associated with the ANO-2 RCS pressure/temperature limits comply with paragraph G-2215 of Appendix G and the ART's were developed in accordance with Regulatory Guide 1.99, Revision 2, satisfying this guidance.

Using the basis beltline P-T limits associated with the ANO-2 Technical Specification heatup and cooldown rates (both linear and step-and-hold), the original temperature and pressure correction factors were removed. Subsequently, the uncorrected beltline P-T limit pressures were increased by ten percent and then conservatively corrected with the revised temperature instrument uncertainty of 20°F and "actual" pressure correction factors (see Subsection 3.3) to obtain LTOP P-T limits indexed in terms of indicated RCS temperature and actual pressurizer pressure. The resulting LTOP P-T limits were used as input to the LTOP evaluation. These limits are shown graphically in Figures 2 and 3 and tabulated in Tables 2 and 3.

LTOP enable temperatures were developed for both the heatup and cooldown condition. Both Code Case criteria were investigated and the limiting value selected to ensure satisfactory compliance.

The first criteria considered is the coolant temperature corresponding to a metal temperature of RT_{NDT} + 50°F. During the cooldown scenario, the limiting condition for the enable temperature is an isothermal vessel wall temperature profile and permitted by ANO-2

Technical Specifications. Since there is no thermal gradient, the one-quarter thickness ART is added directly to 50°F, resulting in a temperature of 161°F satisfying this requirement. In the case of heatup, the maximum heatup rate consistent with the ANO-2 Technical Specifications of 80°F/hr provides the limiting condition. However, the fluid temperature corresponding to a metal temperature of RT_{NDT} + 50°F requires evaluation. This evaluation was performed using the detailed heat transfer output associated with the beltline P-T limits development. This approach accounts for both the through-wall thermal gradient due to the transient conduction and the effect of the convective boundary temperature differential. The resulting fluid temperature was calculated to be 189.1°F and represents this one condition requiring consideration. Note, these values do not include instrument uncertainty.

The Code Case also requires that the enable temperature be at least 200°F. Since the previous values do not satisfy this criterion, both the heatup and cooldown LTOP enable temperatures should be 200°F plus instrument uncertainty, or 220°F.

3.3 Pressure Correction Factors

The pressure correction factors (PCF's) are subtracted from the LTOP P-T limits at the beltline to index them to the pressurizer pressure instrument nozzle location. Actual PCF's (APCF) and indicated PCF's (IPCF's) were determined, although only the APCF's were used for the subject LTOP P-T limits. The IPCF's, which include pressure indication uncertainty, were calculated for future use, if the need arises to revise the current Technical Specification Appendix G P-T limits.

The PCF's include an elevation head term, flow induced pressure drop term, and flow induced pressure drop uncertainty. The elevation head term is the pressure difference between the bottom of the core, the lower reference point, and the pressurizer level, the upper reference point (see Paragraph. 2.1). The flow induced pressure drop term is described in Paragraph 2.1. The resulting PCF's are provided in Table 1:

TABLE 1. SUMMARY OF PRESSURE CORRECTION FACTORS

ACTUAL RCS TEMPERATURE	ACTUAL PRESSURE CORRECTION FACTOR (APCF)	INDICATED PRESSURE CORRECTION FACTOR (IPCF)
50°F ≤ t < 120°F	25.6 psid	110.6 psid
120°F ≤ t < 200°F	52.6 psid	132.3 psid
t ≥ 200°F	87.3 psid	164.2 psid

3.4 Analysis Results

Application of the ASME Code Case N-514 to the existing ANO-2 Technical Specification RCS pressure/temperature limits provide relaxed (higher) pressures for the sole purpose of establishing LTOP requirements. In addition, revised pressure and temperature correction factors account for plant operating practice while providing additional relaxation. Application of these revised correction factors to the LTOP P-T limits properly index the LTOP P-T limits in terms of indicated RCS temperature and "actual" pressurizer pressure.

The LTOP P-T limits were developed for the maximum heatup and cooldown rates, and associated temperature ranges provided by the ANO-2 Technical Specification RCS P-T limits and explicitly consider the applicable linear and step-and-hold functions. The resultant LTOP P-T limits are shown graphically in Figures 2 and 3. This information is also provided in tabular form in Tables 2 and 3.

It is important to note at this time that the current Technical Specifications were reviewed in light of the methodology change applicable to pressure correction factor calculations. Results of this assessment indicate the Technical Specification RCS P-T limits could also be relaxed if the revised indicated pressure correction factors were applied instead of the current basis values. However, the existing ANO-2 Technical Specification RCS P-T limits remain appropriate although conservative in light of this recent effort.

The LTOP enable temperatures calculated using the ASME Code Case guidance were 220°F for both the heatup and cooldown conditions. The value of 220°F includes the instrument loop uncertainty.

TABLE 2

ANO-2 CODE CASE N-514 LTOP P-T LIMITATIONS
CORRECTED VALUES

	COOLDOWN				HEATUP
RCS Temp (°F)	Isothermal (psia)	25°F/hr (psia)	60°F/hr (psia)	100°F/hr (psia)	80°F/hr (psia)
60	641.7	560.4	449.9	329.6	641.7
70	656.2	577.2	470.3	354.6	656.2
80	673.3	596.8	493.8	383.8	651.3
90	693.1	619.3	521.0	417.6	624.9
100	716.0	645.4	552.3	456.4	606.9
110	742.4	675.7	588.6	501.2	598.1
120	773.0	710.4	630.7	552.7	596.1
130	808.3	750.9	679.2	613.2	602.0
139.9	848.8	797.1	734.7	682.1	613.5
140	822.2	770.5	708.3	655.8	586.6
150	869.4	824.4	773.1	736.0	605.6
160	924.0	886.8	848.1	828.4	630.6
170	987.1	958.6	934.8	934.7	663.4
180	1060.2	1042.2	1035.0	1059.5	702.9
190	1144.5	1138.4	1144.5	1144.5	751.5
200	1242.0	1242.0	1242.0	1242.0	808.4
210	1354.7	1354.7	1354.7	1354.7	876.7
219.9	1483.8	1483.8	1483.8	1483.8	954.5
220	1450.4	1450.4	1450.4	1450.4	920.6
230	1601.0	1601.0	1601.0	1601.0	1014.2
240	1775.2	1775.2	1775.2	1775.2	1121.3
250	1976.5	1976.5	1976.5	1976.5	1247.9
260	2209.4	2209.4	2209.4	2209.4	1392.3
270	2478.5	2478.5	2478.5	2478.5	1562.5
270.7	2500.0	2500.0	2500.0	2500.0	--
280	2789.5	2789.5	2789.5	2789.5	1756.4
290	3149.1	3149.1	3149.1	3149.1	1984.7
300	--	--	--	--	2244.6
308.4	--	--	--	--	2500.0
310	--	--	--	--	2550.2
320	--	--	--	--	2898.0
330	--	--	--	--	3212.7

Correction Factors: Temperature: +20°F
Pressure: at 70°F ≤ t < 140°F, -25.6 psi
at 140°F ≤ t < 220°F, -52.6 psi
at t ≥ 220°F, -87.3 psi

TABLE 3

ANO-2 CODE CASE N-514 LTOP P-T LIMITATIONS
CORRECTED VALUES
(STEP CHANGE RATES) - COOLDOWN
ASCENDING ORDER

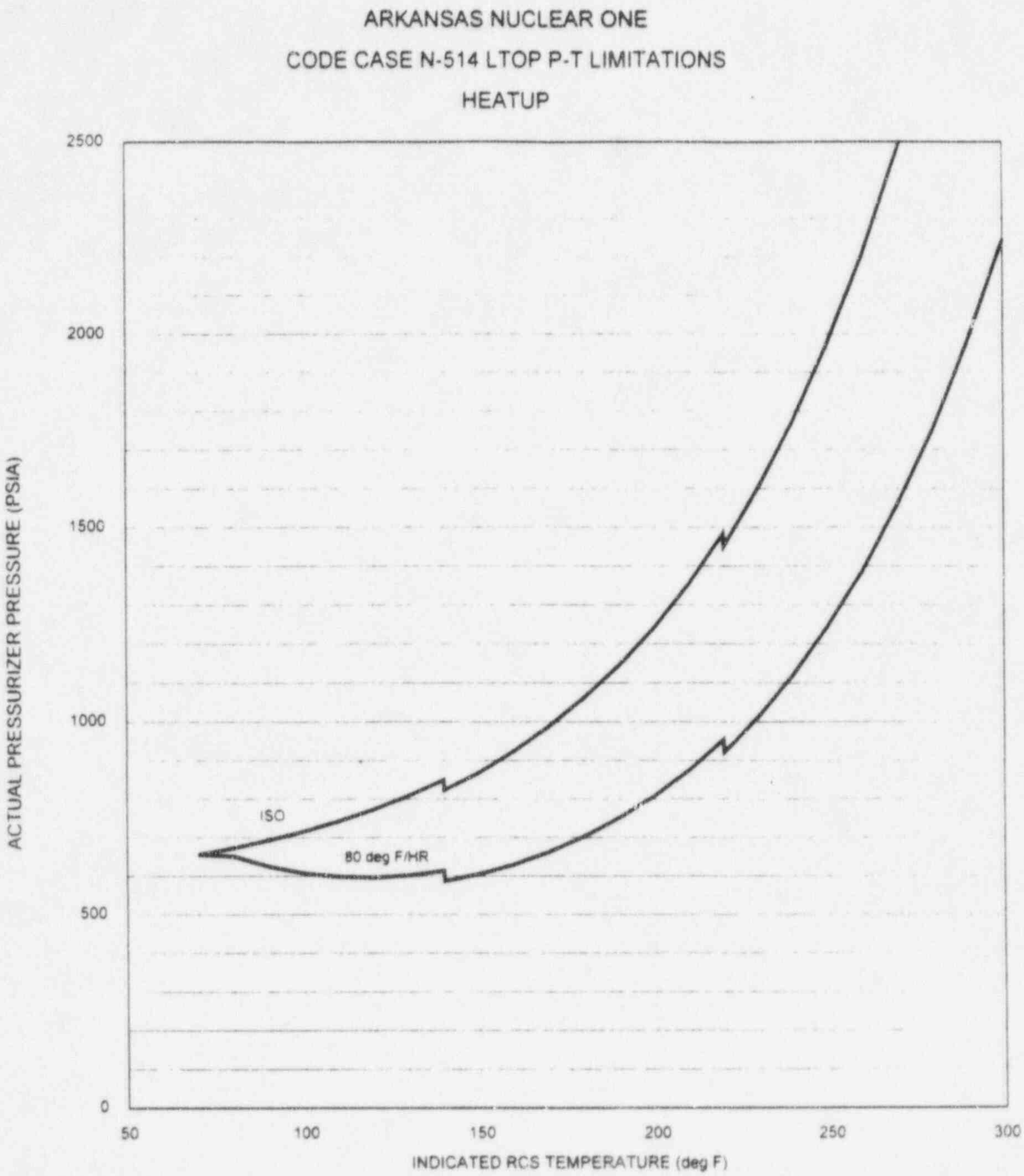
12.5°F/½ hr		30°F/½ hr		50°F/½ hr	
RCS Temp (°F)	Press @ 25°F/hr (psia)	RCS Temp (°F)	Press @ 60°F/hr (psia)	RCS Temp (°F)	Press @ 100°F/hr (psia)
60	590.4	140	684.4	220	1540.7
60	546.4	140	838.4	220	2024.7
70	601.4	150	750.4	270	2948.7
70	557.4	150	926.4		
72.5	601.4	160	827.4		
72.5	568.4	160	1025.4		
82.5	623.4	170	904.4		
82.5	579.4	170	1135.4		
85	590.4	180	1003.4		
85	634.4	180	1267.4		
95	656.4	190	1113.4		
95	612.4	190	1421.4		
97.5	623.4	200	1234.4		
97.5	667.4	200	1597.4		
102.5	634.4	210	1366.4		
102.5	678.4	210	1795.4		
107.5	656.4	220	1496.7		
107.5	700.4	220	1991.7		
115	678.4				
115	722.4				
120	700.4				
120	744.4				
127.5	722.4				
127.5	777.4				
132.5	744.4				
132.5	799.4				
140	761.4				
140	816.4				

Correction Factors:

Temperature: +20°F

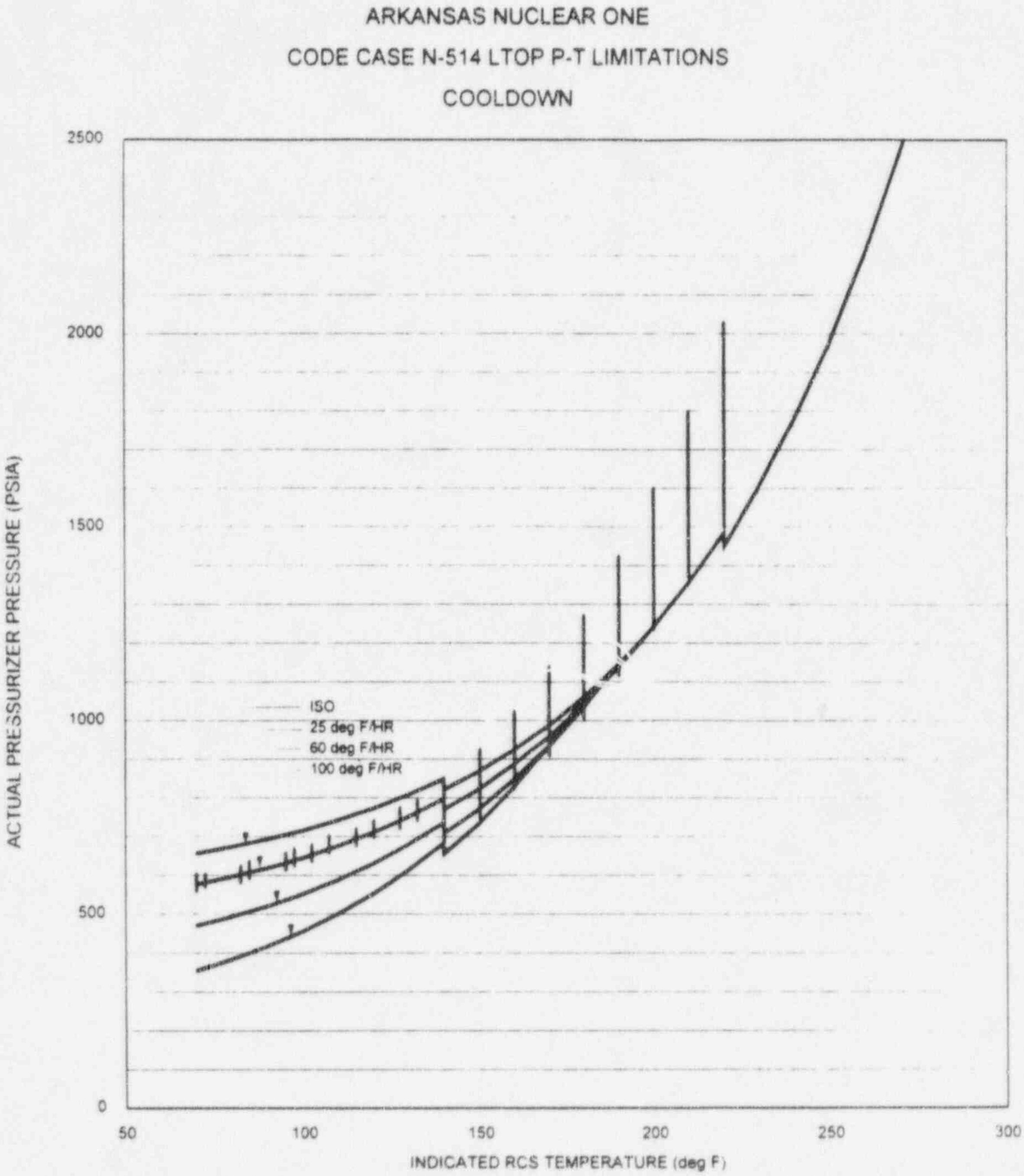
Pressure: at 70°F ≤ t < 140°F, -25.6 psi
at 140°F ≤ t < 220°F, -52.6 psi
at t ≥ 220°F, -87.3 psi

FIGURE 2



$\Delta T = +20°F$
$70°F \leq Trcs < 140°F$, $\Delta P = -25.6$ psia
$140°F \leq Trcs < 220°F$, $\Delta P = -52.6$ psia
$Trcs \geq 220°F$, $\Delta P = -87.3$ psia

FIGURE 3



ΔT = + 20°F
70°F ≤ Trcs < 140°F, ΔP = -25.6 psia
140°F ≤ Trcs < 220°F, ΔP = -52.6 psia
Trcs ≥ 220°F, ΔP = -87.3 psia

Section 4.0
LTOP ANALYSIS DESCRIPTION

4.1 Method

The peak transient pressure in the design basis pressurization event was compared with the applicable LTOP P-T limits to determine whether the existing Technical Specification RCS heatup and cooldown rate limitations per Reference 2 remain conservative. The applicable LTOP P-T limits are the limits developed, using guidance provided in ASME Code Case N-514, for the following rates: ramp rate of 80°F/hr for heatup, ramp rates of 100, 60, and 25°F/hr for cooldown, and step change rates of 50, 30, and 12.5°F/hr in any half hour period, also for cooldown (see Section 3.0). Note that these are the same rates as in the Technical Specifications, Reference 4.

For a Reference 4 heatup or cooldown limitation to remain conservative, the applicable P-T limit curve must be located above the peak transient pressure starting at RCS temperature less than, or equal to, the Technical Specification lower temperature boundary for the subject rate. Further, this applicable P-T limit curve must remain above the peak transient pressure in the entire LTOP temperature range. The positioning of a P-T limit curve above the peak transient pressure means that the curve is protected, i. e., it would not be exceeded during the design basis pressurization event.

The peak transient pressure was determined based upon the current LTOP relief setpoint, a conservative valve discharge model, and mass input into the RCS during the design basis pressurization event.

Finally, the adequacy of the operating window was determined, based upon the applicable Appendix G P-T limits and relief valve setpoint.

4.2 Relief Valve Capacity

Liquid discharge through the relief valve was determined, using the guidance provided in the "Special Water Sizing" section of Reference 8 that applies to less than saturated high temperature liquids which flash to vapor at relief conditions, and applicable data and assumptions of Section 2.0. At the valve inlet pressure equal to 10% accumulation above the opening setpoint of 430 psig, i. e., P_{inlet} = 487.7 psia, discharge flow rate was calculated to equal 1565 gpm. This flow rate is for saturated water at 401.7 psia, which is the assumed pressure in the pressurizer and at the valve inlet, prior to the transient initiation. For comparison, for water at 70°F and the same initial pressure, discharge flow rate would be 1920 gpm.

Taking into account pressure drop between the pressurizer and valve inlet during valve discharge (30 psid), pressurizer pressure corresponding to P_{inlet} = 487.7 psia is equal to 517.7 psia. Thus at pressurizer pressure of 517.7 psia, a single LTOP relief valve at ANO-2 is capable of relieving 1565 gpm of saturated water.

4.3 Peak Transient Pressure

The design basis pressurization event for the ANO-2 LTOP system is inadvertent safety injection actuation from water-solid conditions, which results in mass addition to the RCS from two (2) HPSI pumps and three (3) charging pumps. Charging pump capacity is 44 gpm and is independent of RCS pressure, whereas HPSI pump capacity is a function of RCS pressure.

Assuming that RCS pressure refers to the cold leg elevation, where HPSI pump injection takes place, the RCS pressure that corresponds to pressurizer pressure of 517.7 psia was calculated to equal 526.6 psia. The difference is due to static head of fluid between the pressurizer two-phase level and cold leg. At RCS pressure of 526.6 psia, volumetric flow rate input from two HPSI pumps was determined to be 1400 gpm. This results in a total 2 HPSI + 3 charging pumps' input into the RCS of 1532 gpm.

A comparison of the above flow rate with a single LTOP relief valve discharge capacity at the same pressurizer pressure (1565 gpm, Subsection 4.2) indicates that valve capacity exceeds mass input during the design basis pressurization event. As a result, the equilibrium between mass input and valve discharge would occur at a smaller pressure than 517.7 psia. This smaller pressure, which is called "equilibrium pressure", should be considered as the peak transient pressure, as it is the maximum pressure that could be reached during the transient. However, since the valve opening characteristic between the set pressure and 10% accumulation is unavailable, it is not possible to determine the equilibrium pressure and associated equilibrium flow rate. Accordingly, 517.7 psia is a conservative value for the peak transient pressure in the pressurizer.

4.4 Heatup and Cooldown Limitations

Evaluation of the applicable LTOP P-T limits together with the peak transient pressure demonstrates that the existing Technical Specification heatup and cooldown limitations, per Reference 4, are conservative, with large margin, and continue to be adequate as part of LTOP-driven restrictions.

Specifically:

- Heatup at a linear rate of 80°F/hr can be utilized at any RCS temperature.
- Cooldown at a linear rate of 100°F/hr or at a step change rate of 50°F in any half hour period can be utilized at RCS temperature above 220°F.
- Cooldown at a linear rate of 60°F/hr or at a step change rate of 30°F in any half hour period can be utilized at RCS temperature equal to or greater than 140°F.
- Cooldown at a linear rate of 25°F/hr or at a step change rate of 12.5°F in any half hour period can be utilized at any RCS temperature.

The analysis margin can accommodate significant relaxation of the above limitations, if needed.

4.5 Operating Window

The LTOP region extends from 70°F, the minimum boltup temperature, to 220°F, a new LTOP enable temperature for both heatup and cooldown, which was calculated using the guidance provided in ASME Code Case N-514 (see Section 3.0). The LTOP region signifies the temperature range in which both LTOP relief valves must be properly aligned for LTOP.

The pressure correction factors used to develop the LTOP P-T limits are less restrictive than those used for the Technical Specification Appendix G P-T limits. This was achieved by limiting the number of operating reactor coolant pumps at low RCS temperatures (see Section 3.0). As a result, the Technical Specification Appendix G P-T limits are conservative with large margin for operation up to 21 EFPY.

As the Technical Specification Appendix G P-T limits and the existing LTOP relief valve setpoint (430 psig) remain unchanged, operating window is not adversely impacted.

4.6 Analysis Results

(1) With the existing LTOP relief valve setpoint of 430 psig and based upon the new Code Case LTOP P-T limits, the current ANO-2 Technical Specification RCS heatup and cooldown limitations, Reference 4, are conservative with large margin. These limitations are as follows:

For heatup: A maximum heatup of 80°F in any one hour period at any RCS temperature.

For cooldown:

RCS Temperature (t_{cold})	Maximum Cooldown Rate
$t_{cold} > 220°F$	100°F/hr (constant), or 50°F in any half hour period (step)
$140°F \leq t_{cold} \leq 220°F$	60°F/hr (constant), or 30°F in any half hour period (step)
$t_{cold} < 140°F$	25°F/hr (constant), or 12.5°F in any half hour period (step)

(2) Although each relief valve, 2PSV-4732 or 2PSV-4742, is capable of mitigating the design basis event, both are required to be aligned to the RCS for LTOP between 70-220°F, whenever the RCS is pressurized and the reactor vessel head is fully tensioned, in order to satisfy the single failure criterion of Reference 1. The 70°F and 220°F are the minimum boltup temperature and the LTOP enable temperature, respectively.

(3) The existing operating window remains intact.

Section 5.0
LTOP LIMITATIONS

This section summarizes the administrative and operational limitations which resulted from the subject analytical effort and which need to be imposed to ensure that the reactor vessel material brittle fracture limits are not exceeded during the design basis pressurization event.

5.1 Operation of the reactor coolant pumps will be restricted as follows:

No. of Operating Pumps	Temperature Range, t_{actual}
0	50°F ≤ t < 120°F
2	120°F ≤ t <200°F
3	t ≥ 200°F

The temperatures represent reactor coolant cold leg temperature and are actual, i. e., without temperature uncertainty applied. With a [20]°F temperature indication uncertainty applied, the above temperature range is expressed in indicated cold leg temperature as follows:

No. of Operating Pumps	Temperature Range, t_{ind}
0	70°F ≤ t < 140°F
2	140°F ≤ t <220°F
3	t ≥ 220°F

5.2 During start-up and shutdown operations, whenever the RCS is pressurized and the reactor vessel head is fully tensioned, both LTOP relief valves, 2PSV-4732 or 2PSV-4742, are required to be aligned to the RCS for LTOP between 70°F, the minimum boltup temperature, and 220°F, the LTOP enable temperature.

5.3 The Technical Specification RCS heatup and cooldown limitations, Reference 4 (see also Paragraph 4.6, item 1), are conservative for operation up to 21 EFPY and should be adhered to.

Section 6.0
CONCLUSION

Use of ASME Code Case N-514 procedures for establishing LTOP requirements for the ANO-2 Reactor Coolant System provide a method which has been uniformly accepted across the industry and been accepted as the license basis for several other utilities by the NRC. Application of the Code Case to the current ANO-2 Technical Specification RCS P-T limits for 21 EFPY demonstrate that the existing heatup and cooldown limitations satisfy LTOP requirements. In addition, there is sufficient analysis margin which could be used to relax the existing heatup and cooldown limitations, if needed.

In light of this effort it was also confirmed that the existing ANO-2 Technical Specification RCS P-T limits are appropriate but conservative. This is due to the administrative restrictions placed upon operation of reactor coolant pumps and the associated reduction in flow induced pressure differences.

In summary, the ANO-2 LTOP system, including two redundant LTOP relief valves having an opening setpoint of 430 psig, is adequate for protecting the ASME Code Case LTOP P-T limits, provided that the recommended administrative and operational modifications are implemented.

Section 7.0
IMPLEMENTATION OF RESULTS

The following describes the recommended actions to implement the analysis results:

7.1 Develop a new Technical Specification dedicated to LTOP and corresponding Bases.

7.2 Revise SAR Sections 5.2.2.4. 5.5.13.2. 7.6.1.3. and 7.6.2.3 to account for the new LTOP enable temperature.

7.3 Revise operating procedures to account for new restrictions on RCP operation and new LTOP enable temperature:

- 2103.002. Filling and Venting the RCS
- 2102.002. Plant Heatup
- 2102.010. Plant Cooldown.

Review other procedures that may be affected and revise, as appropriate.

Section 8.0
REFERENCES

1. Branch Technical Position RSB 5-2, "Overpressurization Protection of Pressurized Water Reactors While Operating at Low Temperatures", Rev. 1. Attached to NRC Standard Review Plan 5.2.2, "Overpressure Protection", Rev. 2, November 1988.

2. Cases of ASME Boiler and Pressure Vessel Code, Case N-514, "Low Temperature Overpressure Protection, Section XI, Division 1", approved February 12, 1992.

3. Arkansas Nuclear One - Unit 2, Safety Analysis Report, Amendment No. 12.

4. Arkansas Nuclear One - Unit 2, Technical Specifications, Amendment No. 171, LCO 3.4.9.1, Amendment No. 124.

5. Entergy Operations, Inc., Mr. J. N. Miller to ABB Combustion Engineering Nuclear Power, "Development of ANO-2's LTOP Limitations," dated December 20, 1995.

6. ABB Calculation No. A-MPS-CALC-008 Revision 00, "Arkansas Nuclear One Unit 2 RCS Appendix G P-T Limits for 21 EFPY," dated May 1, 1991.

7. "Final Report on Reactor Vessel Appendix G Pressure-Temperature Limits for Arkansas Nuclear One Unit 2 for 21 Effective Full Power Years," ABB Combustion Engineering Nuclear Power, Report A-MPS-ER-002, dated May 1991. [This report was submitted to the NRC in Entergy Operations' letter to the NRC dated June 18, 1991 (2CAN069109)].

8. Lonergan Safety Relief Valves, Manufacturer's Handbook, 1986.

9. ABB Report, "Low Temperature Overpressure Protection for Arkansas Nuclear One-Unit 2", June , 1977. Attached to ABB Letter A-CE-6352, F. C. Sernatinger to E. H. Smith (Bechtel), dated June 17, 1977.

10. Lonergan Drawing No. A2895, "Composite Drawing DB-30/SP-S4, Safety Relief Valve for Nuclear Service, Rev. D.