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WCAP-13962

SETPOINT PROGRAM DETERMINATION FOR THE WESTINGHOUSE COLD OVERPRESSURE MITIGATING SYSTEM IN THE HOUSTON LIGHTING & POWER SOUTH TEXAS UNITS 1 & 2

(Rev. 2)

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I. DISCUSSION/BASES

This report documents the development of the power-operated relief valve (PORV) setpoint programs (pressure setpoint vs. reactor coolant system temperature) as determined for the Westinghouse Cold Overpressure Mitigating System (COMS), to be applied during startup and shutdown operations in the South Texas Units 1 & 2. These programs are intended to maintain the reactor coolant system pressure within acceptable limits following overpressurization incidents occurring during low temperature, water-solid operation. The results of the LOFTRAN transient analyses, utilized in the determination of the setpoint program, are also included.

This report is a revision to that developed in Reference 2 to account for the pressure difference from the wide-range pressure transmitters to the location of the maximum pressure limit.

Operating Limits

The PORV setpoint program was developed for this plant, utilizing the algorithm provided in WCAP 10529 (Reference 1). Relief valve operation based on the setpoint program will prevent overpressures produced by valve opening from exceeding the limit which is based on the more limiting of the 10CFR50 Appendix G reactor vessel NDT limit or the maximum RCS pressure requirement as dictated by PORV piping reaction force considerations and will prevent underpressures produced by valve closure from violating the reactor coolant pump No. 1 Seal minimum pressure requirement. This was accomplished by considering both the Mass Input (MI) and Heat Input (HI) mechanisms and by utilizing staggered relief valve operation.

Heatup and cooldown curves for isothermal conditions and without instrument errors, applicable to 32 EFPY, were utilized for the Appendix G limit (see Appendix A of this document for details on the Appendix G limit calculation). A notch was incorporated at 120°F and 621 psig to accommodate the vessel flange limit. The maximum allowable pressurizer pressure based on PORV piping force considerations is 800 psig.

The minimum RCS pressure curve utilized in the setpoint determination is based on the system pressure as determined by a wide range pressure instrument in a loop not containing the active reactor coolant pump. This ensures the utilization of a minimum pressure limit curve which will cover this eventuality as well as that case in which the instrument is directly located in the loop with the active pump.

Due to the difference in location of the pressure transmitters used for RCS presssure measurement (located in RHR piping connection off of hot leg) and the pressure at the location of the maximum pressure limit (reactor vessel downcomer for Appendix G; top of pressurizer for PORV piping force), the appropriate pressure difference must be accounted for. This is done by subtracting off the pressure difference from the maximum pressure limit.

When the Appendix G limit is applicable, the pressure difference was based upon a maximum of either two or four reactor coolant pumps operating. When the PORV piping force limit is applicable, no additional pressure difference is accounted for since for all transients of concern the pressure at the pressure transmitter is greater than the pressure at the top of the pressurizer.

The minimum RCS pressure curve is based upon a reactor coolant pump No. 1 Seal ΔP equal to 200 psid.

Mass Input Considerations

From the standpoint of determining maximum setpoint overpressure and proximity to Appendix G, the mass input (MI) mechanisms considered in the analysis involves the following operations:

1. RCS Temperature < 200°F

   One centrifugal charging pump with inadvertent isolation of letdown flow and charging control valve fully open.

2. RCS Temperature ≥ 200°F

   Combined maximum deliverable flow from one high head safety injection pump and one centrifugal charging pump with letdown isolation and charging control valve fully open.

From the standpoint of determining maximum setpoint underpressure and proximity to the RCP number 1 Seal minimum pressure limit, an envelope of mass injection rates was investigated to ensure that the worst case was considered for ultimate setpoint determination. For both the underpressure and overpressure transients, mass injection rates ranging from 50 gpm to 1600 gpm were considered.

Heat Input Considerations

The heat input (HI) mechanism considered for analysis involved the inadvertent startup of a reactor coolant pump in one loop. Temperature asymmetries in the reactor coolant system, whereby the steam generators were at a higher temperature than the remainder of the system, were assumed in the analysis. The magnitude of the temperature difference between the steam generators and the reactor coolant system depends on the previous plant operations which allowed the asymmetry to develop. For this study, it was considered realistic to assume a maximum temperature difference of 50°F as the design case because much higher differences would be difficult to develop and would be easily recognized by the operator as an abnormal condition requiring special attention.

PORV Operation

Staggered operation of the two power-operated relief valves was selected to minimize the potential for larger pressure undershoots, which could result from multiple valve operation, from compromising the reactor coolant pump No. 1 Seal integrity. It is also desirable to restrict the total number of ports for the discharge of primary coolant at any given moment to that absolutely necessary for pressure control. The dual setpoints required for staggered operation were determined such that the multiple valve operation is minimized. In addition, the operation of either PORV provides the relief capacity required by the design basis. This redundancy is an essential factor in allowing the COMS to comply with the single failure criteria design objective. For South Texas 1 and 2, for RCS temperature ≥200°F, the power operated relief valves are staggered, to the extent practicable, to minimize multiple valve operation for the required relief capacity from one high head safety injection pump plus 100 gpm net charging flow. The required relief capacity for the design basis will result in multiple valve operation if both COMS trains are operable. However, our analysis indicates that the operation of one PORV provides the relief capacity required by the design basis without exceeding either the 10CFR50 Appendix G reactor vessel NDT limit or the maximum allowable PORV piping force requirement if failure does occur to preclude operation of the other valve. Our analysis also indicates that the undershoot resulting from multiple valve operation will not violate the reactor coolant pump No. 1 seal minimum pressure requirement.

Manufacturer's data was used for the development of the Garrett PORV opening and closing characteristics. Delay times for the PORV solenoid actuation (from receipt of signal to start of valve motion) were based on data measured at various sites employing the Garrett relief valve.

The setpoint program utilizes 0.3 sec for the effect of time delays associated with transmission of the wide range RCS pressure signal. In addition to this, 0.1 seconds was used as the PORV solenoid actuation delay time (time from receipt of signal at solenoid to start of valve motion).

Should the time delays or valve characteristics mentioned above prove to be more adverse (i.e., longer delay times or longer PORV stroke times) upon installation and testing, the setpoint program developed in this report would have to be re-evaluated; sensitivity runs to quantify the correlation between longer delay times and/or valve stroke characteristics are not available for the South Texas specific configuration or design bases.

II. SPECIFICATION FOR MASS INPUT TRANSIENTS

Transients Analyzed

A parametric study (Section V) was performed using constant mass injection rates between 50 gpm and 1600 gpm with the RCS in a water solid condition. For the range of setpoints considered, this mass input range was sufficiently extensive to envelope the RCS mass injection rates associated with the maximum possible from one centrifugal charging pump following letdown isolation while RCS temperature is less than 200°F or from one high head SI pump and one centrifugal charging pump with letdown isolation while RCS temperature is greater than or equal to 200°F.

System/Operating Parameters

A. Temperatures

Reactor Coolant System temperature is equal to 100°F.

B. Reactor Coolant System Volume

The RCS Volume is [ ]^{b,c} cu. ft. for South Texas 1 & 2.

C. Reactor Coolant System Relief Capability

The transient is either analyzed for actuation of one power operated relief valve to determine the most limiting overshoot or actuation of two power operated relief valves to determine the most limiting undershoot.

D. Power Operated Relief Valve Characteristics

1. Opening/closing characteristics - see Figures 3.1 and 3.2.
2. Opening time = 1.65 seconds (plus 0.4 second channel delay)

3. Closing time = 1.00 seconds (plus 0.4 second channel delay)

4. C_v = 60

E. Mass Injection Flow Capability

1. Normal flow into the RCS: 100 gpm

2. Infrequent operation:

For RCS temperature < 200°F, refer to Figure 2.1 for the maximum credible flow rate that can be delivered at a given RCS pressure by one centrifugal charging pump. For RCS temperature ≥200°F, refer to Figure 2.3 for the maximum credible flow rate that can be delivered at a given RCS pressure by one high head SI pump and one centrifugal charging pump with letdown isolation.

F. Pressure Signal Transmission Characteristics

Time delay to PORV actuation = 0.4 sec

G. Results Required

Table summarizing the setpoint pressure overshoot, setpoint pressure undershoot, maximum RCS pressure and minimum RCS pressure reached for all transients during either one PORV operation or two PORV operation.

INJECTED FLOW VS. RCS PRESSURE
ONE CENTR. CHARGING PUMP

b,c

RCS PRESSURE (PSIG)

FLOW (GPM)

Figure 2.1

INJECTED FLOW VS. RCS PRESSURE
ONE SAFETY INJECTION PUMP

b,c

RCS PRESSURE (PSIG)

FLOW (GPM)

Figure 2.2

INJECTED FLOW VS. RCS PRESSURE
CHARGING PLUS SI PUMP

b,c

RCS PRESSURE (PSIG)

FLOW (GPM)

Figure 2.3

III. SPECIFICATION FOR HEAT INPUT TRANSIENTS

Transient Analyzed

Inadvertent startup of a RCS pump with temperature asymmetry between the RCS and SG and with the RCS in a water solid condition (Heat Input mechanism producing the worst case overpressurization).

System/Operating Parameters

A. Temperatures

SG - RCS temperature difference = 50°F

Steam generator (heat source) temperatures are 120°F, 150°F, 175°F, 200°F, 220°F, 250°F, 300°F, 350°F; corresponding RCS temperatures are 50°F lower.

B. Reactor Coolant System Volume

The RCS volume is [$]^{b,c}$ cu. ft. for South Texas 1 & 2.

C. Reactor Coolant System Relief Capability

The transient is analyzed for either the actuation of one power operated relief valve to determine the most limiting overshoot or the actuation of two power operated relief valves to determine the most limiting undershoot.

D. Power Operated Relief Valve Characteristics

Opening

1. Opening characteristic, see Figure 3.1

2. Opening time = 1.65 seconds (plus 0.4 second channel delay)

3. $C_v = 60$

Closure

1. Closing characteristic, see Figure 3.2

2. Closing time = 1.00 seconds (plus 0.4 second channel delay)

3. $C_v = 60$

E. Steam Generator Design Characteristics

SG Tube Heat Transfer Surface Area is [$]^{b,c}$ ft^2 per steam generator.
SG Type - Model E2

F. Reactor Coolant Pump Design Characteristics

RCP Type = Model 100A
RCP Motor HP = 8000

G. Pressure Signal Transmission Characteristics

Time delay to PORV actuation = 0.4 sec

H. Results Required

Table summarizing the setpoint pressure overshoot, setpoint pressure undershoot, maximum RCS pressure and minimum RCS pressure reached for all transients during either one PORV operation or two PORV operation.

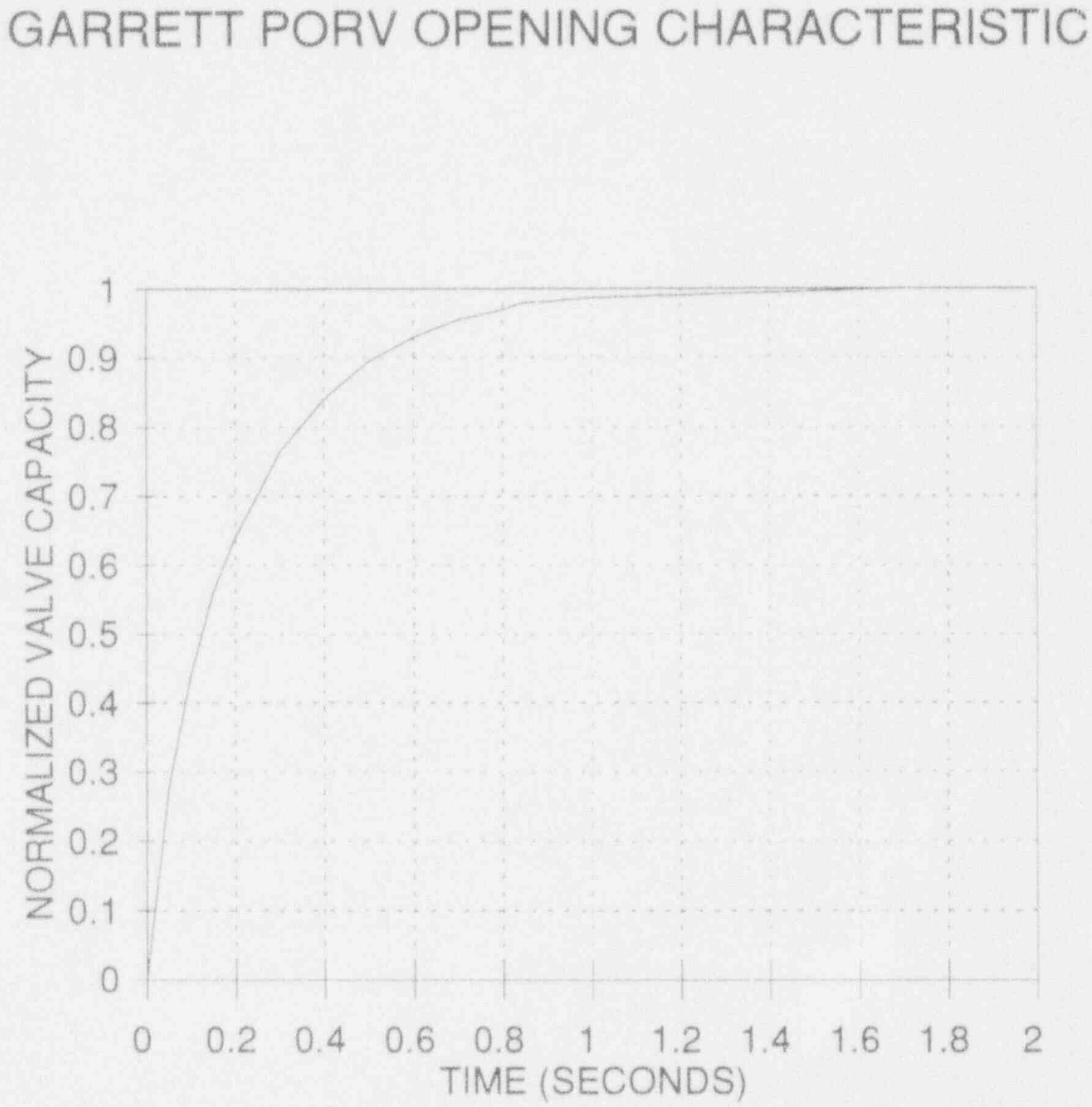

GARRETT PORV OPENING CHARACTERISTIC
NORMALIZED VALVE CAPACITY
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
TIME (SECONDS)

Figure 3.1


GARRETT PORV CLOSING CHARACTERISTIC
NORMALIZED VALVE CAPACITY
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.2
0.4
0.6
0.8
1
TIME (SECONDS)

Figure 3.2

IV. SPECIFICATION FOR DETERMINATION OF SETPOINT PROGRAM

A. SETPOINT PROGRAM ALGORITHM

Procedure described in WCAP 10529.

B. TRANSIENTS CONSIDERED

1. Mass Input

All cases described in the specification for mass input transients (Section II).

2. Heat Input

All cases described in the specification for heat input transients (Section III).

C. 10CFR50 APPENDIX G PRESSURE LIMIT

South Texas Units 1 & 2

Limits Considered

The 32 EFPY isothermal curve without instrument errors as shown in Figure 4.1. These values are calculated specifically for Unit 1 and also bound Unit 2 (see Appendix A).

Curve Utilized

The 32 EFPY isothermal curve described in Figure 4.1 (Most limiting for applicability rates given below).

Applicability

South Texas Units 1 & 2 for isothermal conditions. Isothermal curves are considered to be appropriate for use in the development of the setpoints since the majority of the pressure transients occur during isothermal metal conditions. This is the standard Westinghouse position and has been included in analyses done on other plants.

D. REACTOR COOLANT PUMP NO. 1 SEAL PRESSURE LIMIT

1. Curve Utilized

Minimum RCS pressure vs. RCS temperature correlation described in Figure 4.2.

2. Applicability

a. RCP No. 1 Seal ΔP = 200 psid

E. PRESSURE MEASUREMENT DIFFERENCES

The COMS logic uses the wide range pressure signal to actuate the PORVs. This signal is measured in the RHR suction line connection to the RCS hot leg. The maximum pressure limit is the lower of the following:

a) Appendix G limit, evaluated either at the reactor vessel downcomer at the elevation equivalent to the core midplane or at the reactor vessel bolted flange

b) PORV piping limit, defined as a pressurizer pressure at the PORV inlet of no greater than 800 psig

For when the Appendix G limit is controlling, the pressure difference between the pressure at the vessel and the pressure at the location of the pressure transmitters will be subtracted from the Appendix G limit to arrive at the limiting pressure at the transmitter location. The value is based upon either a maximum of two reactor coolant pumps operating or a maximum of all four reactor coolant pumps operating.

	Vessel Flange	Downcomer
a) Four RCP operating:	[ ]^{b,c} psid	[ ]^{b,c} psid
b) Two RCP operating:		
Pressure transmitter in active loop	[ ]^{b,c} psid	[ ]^{b,c} psid
Pressure transmitter in inactive loop	[ ]^{b,c} psid	[ ]^{b,c} psid

For when the PORV discharge piping limit is controlling, no additional pressure difference need be considered. This is due to the wide-range pressure transmitters always measuring a pressure which is no greater than the pressure existing at the inlet to the pressurizer PORVs.

F. OTHER CONSTRAINTS

1. Staggered PORV Setpoints

a. Either PORV provides the required relief capacity (single failure of either valve is considered).

b. Higher setpoint of second PORV reduces the likelihood of its operation if first PORV (at lower setpoint) operates.

2. Plant Operability

The highest possible setpoints were determined, consistent with the limits and constraints described in this section (Section IV), to provide the plant operator with maximum pressure margin for plant operation during startup and shutdown.

3. Thermal Transport

For a heat input transient as described in Section III, it is possible for the temperature RTD to measure a higher temperature than that of the vessel. To account for this effect, it was conservatively assumed that the RTD was measuring a temperature 77°F higher than the vessel temperature (50°F difference between primary and secondary plus 27°F for instrument accuracy).

TGX COOLDOWN CURVES
R.G. 1.99, REV2 32 EFPY W/O MARGINS

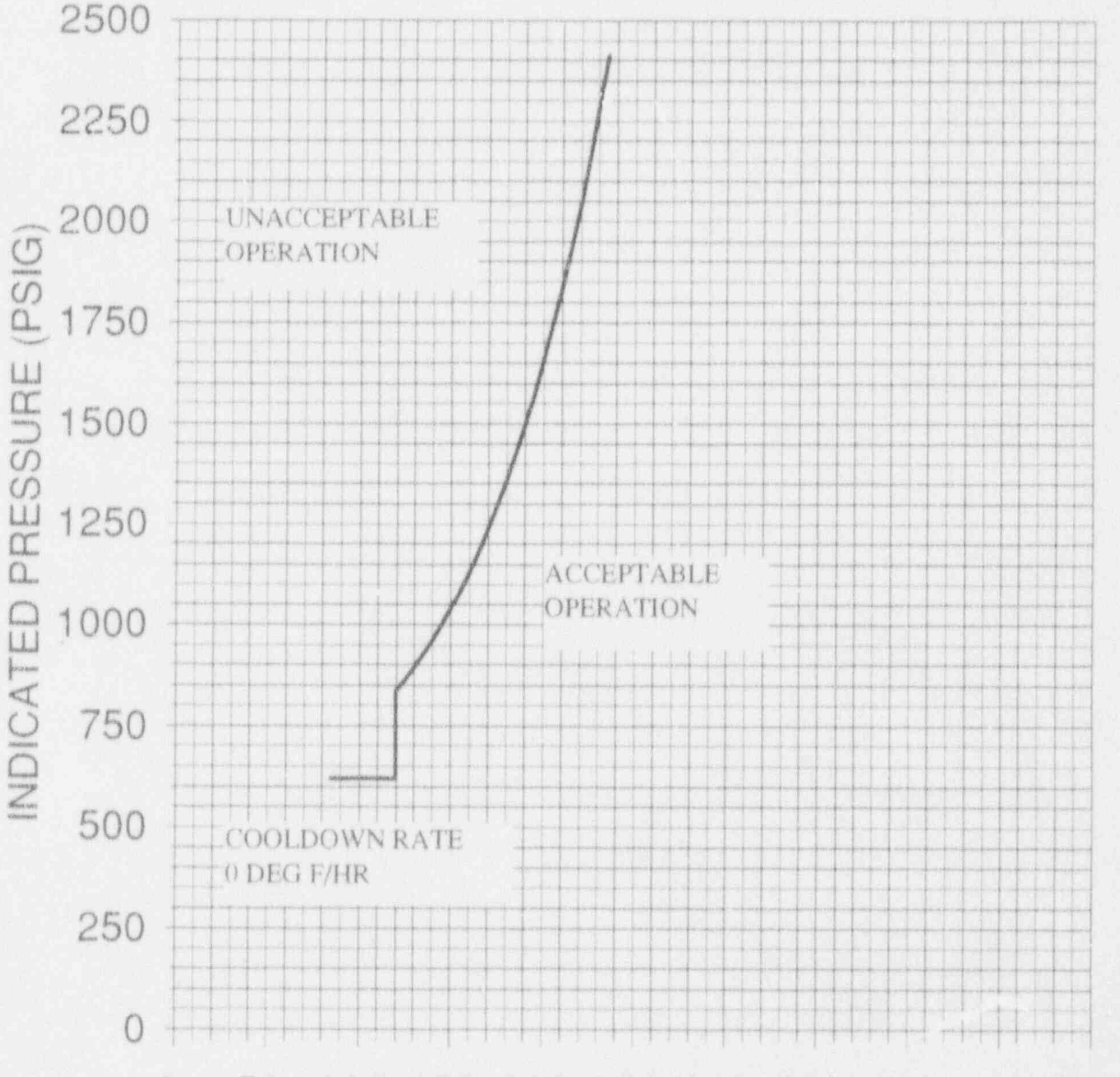
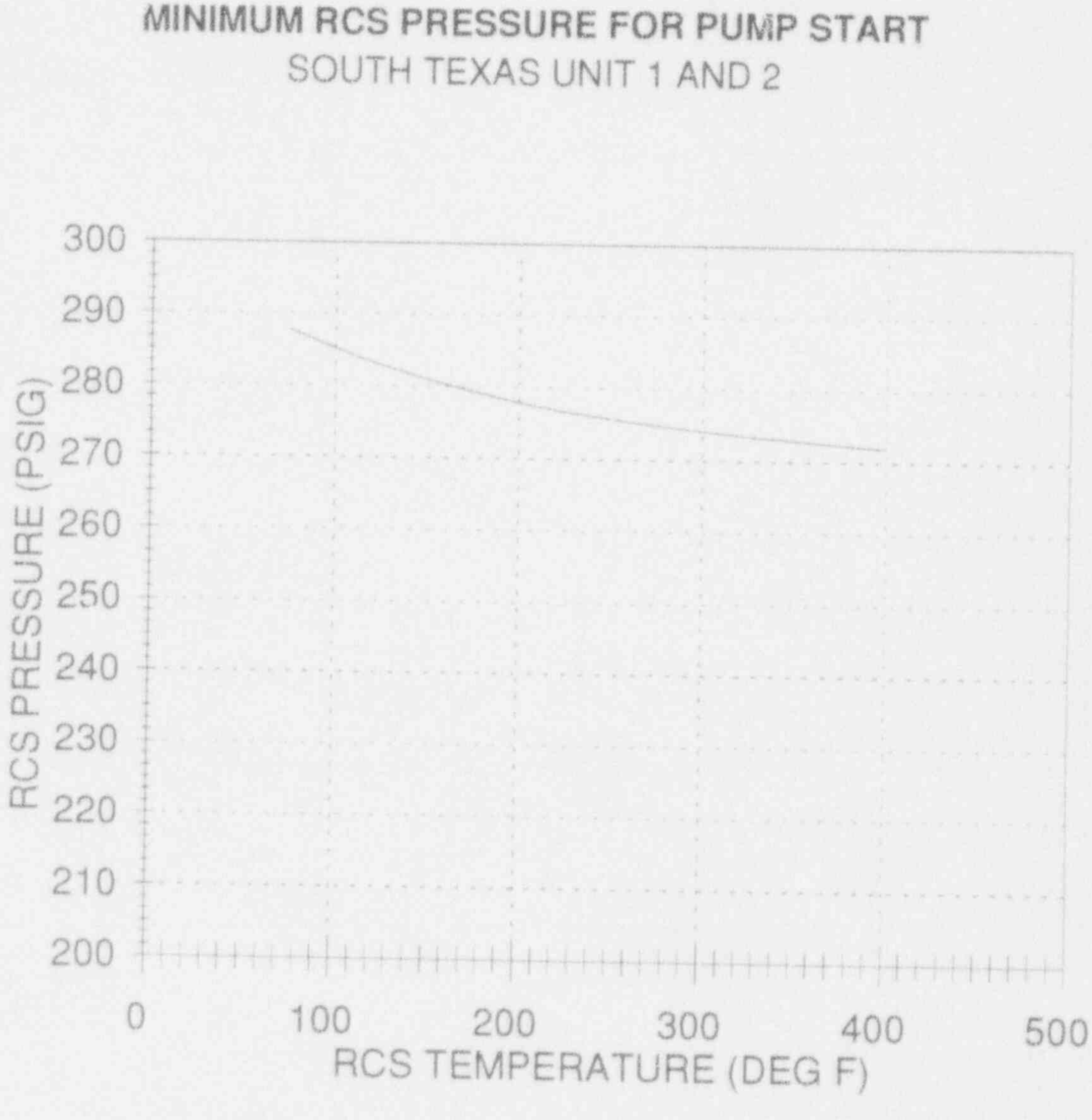


Figure 4.1



MINIMUM RCS PRESSURE FOR PUMP START

SOUTH TEXAS UNIT 1 AND 2

Figure 4.2

V. RESULTS OF PARAMETRIC REACTOR COOLANT SYSTEM (CONSTANT) MASS INPUT TRANSIENT ANALYSES

SOUTH TEXAS UNITS 1 & 2

TABLE 5.1

SUMMARY OF MASS INPUT RESULTS FOR ONE PORV OPERATION

Mass Input Rate (gpm)	Setpoint PS PORV Setpoint (psig)	ΔP_{OVER} Peak Pressure Overshoot* (psi)	P_{MAX} Setpoint RCS Pressure (psig)	ΔP_{UNDER} Minimum Pressure Undershoot** (psi)	P_{MIN} RCS Pressure (psig)
50	200				
	300				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				
100	200				
	300				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				

b,c

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* $P_{MAX} - P_S$

** $P_S - P_{MIN}$

TABLE 5.1 (Con't)

SUMMARY OF MASS INPUT RESULTS
FOR ONE PORV OPERATION

b,c

Mass Input Rate (gpm)	Setpoint PS PORV Setpoint (psig)	ΔP_{OVER} Peak Pressure Overshoot* (psi)	P_{MAX} Setpoint RCS Pressure (psig)	ΔP_{UNDER} Minimum Pressure Undershoot** (psi)	P_{MIN} RCS Pressure (psig)
200	200				
	300				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				
400	200				
	300				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				

---

* $P_{MAX} - P_S$

** $P_S - P_{MIN}$

TABLE 5.1 (Con't)

SUMMARY OF MASS INPUT RESULTS
FOR ONE PORV OPERATION

b,c

Mass Input Rate (gpm)	Setpoint PS PORV Setpoint (psig)	ΔP_{OVER} Peak Pressure Overshoot* (psi)	P_{MAX} Setpoint RCS Pressure (psig)	ΔP_{UNDER} Minimum Pressure Undershoot** (psi)	P_{MIN} RCS Pressure (psig)
600	200				
	300				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				
700	200				
	300				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				

---

* $P_{MAX} - P_S$

** $P_S - P_{MIN}$

TABLE 5.1 (Con't)

SUMMARY OF MASS INPUT RESULTS
FOR ONE PORV OPERATION

b,c

Mass Input Rate (gpm)	Setpoint PS PORV Setpoint (psig)	ΔP_{OVER} Peak Pressure Overshoot* (psi)	P_{MAX} Setpoint RCS Pressure (psig)	ΔP_{UNDER} Minimum Pressure Undershoot** (psi)	P_{MIN} RCS Pressure (psig)
800	200				
	300				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				
900	200				
	300				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				

---

* $P_{MAX} - P_S$

** $P_S - P_{MIN}$

TABLE 5.1 (Con't)
SUMMARY OF MASS INPUT RESULTS
FOR ONE PORV OPERATION

b,c

Mass Input Rate (gpm)	Setpoint PS PORV Setpoint (psig)	ΔP_{OVER} Peak Pressure Overshoot* (psi)	P_{MAX} Setpoint RCS Pressure (psig)	ΔP_{UNDER} Minimum Pressure Undershoot** (psi)	P_{MIN} RCS Pressure (psig)
1000	200				
	300				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				
1200	200				
	300				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				

---

* $P_{MAX} - P_S$

** $P_S - P_{MIN}$

Note: (1) ΔP_{OVER} and P_{max} are unlisted because the corresponding mass input rate exceeds the PORV relief capacity at the designated setpoint. Figure 7.1 will be used for the resulting peak RCS pressure for the transient scenarios resulting in these flow rates.

TABLE 5.1 (Con't)

SUMMARY OF MASS INPUT RESULTS

FOR ONE PORV OPERATION

b,c

Mass Input Rate (gpm)	Setpoint PS PORV Setpoint (psig)	ΔP_{OVER} Peak Pressure Overshoot* (psi)	P_{MAX} Setpoint RCS Pressure (psig)	ΔP_{UNDER} Minimum Pressure Undershoot** (psi)	P_{MIN} RCS Pressure (psig)
1400	200				
	300				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				
1600	200				
	300				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				

---

* $P_{MAX} - P_S$

** P_S - PMIN

Note: (1) ΔP_{OVER} and P_{max} are unlisted because the corresponding mass input rate exceeds the PORV relief capacity at the designated setpoint. Figure 7.1 will be used for the resulting peak RCS pressure for the transient scenarios resulting in these flow rates.

TABLE 5.2

SUMMARY OF MASS INPUT RESULTS FOR TWO PORV OPERATION (NOTE)

Mass Input Rate (gpm)	Setpoint PS PORV Setpoint (psig)	ΔP_{OVER} Peak Pressure Overshoot* (psi)	P_{MAX} Setpoint RCS Pressure (psig)	ΔP_{UNDER} Minimum Pressure Undershoot** (psi)	P_{MIN} RCS Pressure (psig)
50	300				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				
100	300				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				

b,c

---

* $P_{MAX} - P_S$

** $P_S - P_{MIN}$

NOTE: Two PORV operation is only applicable to RCS ≥ 200°F and the mass input basis of one HHSI pump and one centrifugal charging pump with letdown isolation.

TABLE 5.2 (Con't)

SUMMARY OF MASS INPUT RESULTS
FOR TWO PORV OPERATION (NOTE)

b,c

Mass Input Rate (gpm)	Setpoint PS PORV Setpoint (psig)	ΔP_{OVER} Peak Pressure Overshoot* (psi)	P_{MAX} Setpoint RCS Pressure (psig)	ΔP_{UNDER} Minimum Pressure Undershoot** (psi)	P_{MIN} RCS Pressure (psig)
200	300				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				
400	300				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				

---

* $P_{MAX} - P_S$

** $P_S - P_{MIN}$

NOTE: Two PORV operation is only applicable to RCS ≥ 200°F and the mass input basis of one HHSI pump and one centrifugal charging pump with letdown isolation.

TABLE 5.2 (Con't)

SUMMARY OF MASS INPUT RESULTS
FOR TWO PORV OPERATION (NOTE)

Mass Input Rate (gpm)	Setpoint PS PORV Setpoint (psig)	ΔP_{OVER} Peak Pressure Overshoot* (psi)	P_{MAX} Setpoint RCS Pressure (psig)	ΔP_{UNDER} Minimum Pressure Undershoot** (psi)	P_{MIN} RCS Pressure (psig)
800	300				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				
1200	300				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				

b,c

---

* $P_{MAX} - P_S$

** $P_S - P_{MIN}$

NOTE: Two PORV operation is only applicable to RCS ≥ 200°F and the mass input basis of one HHSI pump and one centrifugal charging pump with letdown isolation.

TABLE 5.2 (Con't)

SUMMARY OF MASS INPUT RESULTS FOR TWO PORV OPERATION (NOTE)

b,c

Mass Input Rate (gpm)	Setpoint PS PORV Setpoint (psig)	ΔP_{OVER} Peak Pressure Overshoot* (psi)	P_{MAX} Setpoint RCS Pressure (psig)	ΔP_{UNDER} Minimum Pressure Undershoot** (psi)	P_{MIN} RCS Pressure (psig)
1600	300				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				

---

* $P_{MAX} - P_S$

** $P_S - P_{MIN}$

NOTE: Two PORV operation is only applicable to RCS ≥ 200°F and the mass input basis of one HHSI pump and one centrifugal charging pump with letdown isolation.

VI. RESULTS OF REACTOR COOLANT SYSTEM HEAT INPUT TRANSIENT ANALYSES

SOUTH TEXAS UNITS 1 & 2

TABLE 6.1
SUMMARY OF HEAT INPUT RESULTS FOR ONE PORV OPERATION

b,c

RCS/SG Temperatures (°F/°F)	P_S PORV Setpoint (psig)	ΔP_{OVER} Setpoint Pressure Overshoot* (psi)	P_{MAX} Peak RCS Pressure (psig)	ΔP_{UNDER} Setpoint Pressure Undershoot** (psi)	P_{MIN} Minimum RCS Pressure (psig)
70/120	320				
	350				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				
100/150	320				
	350				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				

---

* $P_{MAX} - P_S$

** $P_S - P_{MIN}$

TABLE 6.1 (Con't)
SUMMARY OF HEAT INPUT RESULTS
FOR ONE PORV OPERATION

RCS/SG Temperatures (°F/°F)	PS PORV Setpoint (psig)	ΔP_{OVER} Setpoint Pressure Overshoot* (psi)	P_{MAX} Peak RCS Pressure (psig)	ΔP_{UNDER} Setpoint Pressure Undershoot** (psi)	P_{MIN} Minimum RCS Pressure (psig)
125/175	350				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				
150/200	320				
	350				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				

b,c

---

* $P_{MAX} - P_S$

** $P_S - P_{MIN}$

TABLE 6.1 (Con't)
SUMMARY OF HEAT INPUT RESULTS
FOR ONE PORV OPERATION

b,c

RCS/SG Temperatures (°F/°F)	PS PORV Setpoint (psig)	ΔP_{OVER} Setpoint Pressure Overshoot* (psi)	P_{MAX} Peak RCS Pressure (psig)	ΔP_{UNDER} Setpoint Pressure Undershoot** (psi)	P_{MIN} Minimum RCS Pressure (psig)
170/220	350				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				
200/250	320				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				

---

* $P_{MAX} - P_S$

** $P_S - P_{MIN}$

TABLE 6.1 (Con't)
SUMMARY OF HEAT INPUT RESULTS FOR ONE PORV OPERATION

b,c

RCS/SG Temperatures (°F/°F)	PS PORV Setpoint (psig)	ΔP_{OVER} Setpoint Pressure Overshoot* (psi)	P_{MAX} Peak RCS Pressure (psig)	ΔP_{UNDER} Setpoint Pressure Undershoot** (psi)	P_{MIN} Minimum RCS Pressure (psig)
250/300	320				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				
300/350	320				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				

---

* $P_{MAX} - P_S$

** $P_S - P_{MIN}$

TABLE 6.2
SUMMARY OF HEAT INPUT RESULTS FOR TWO PORV OPERATION (NOTE)

b,c

RCS/SG Temperatures (°F/°F)	PS PORV Setpoint (psig)	ΔP_{OVER} Setpoint Pressure Overshoot* (psi)	P_{MAX} Peak RCS Pressure (psig)	ΔP_{UNDER} Setpoint Pressure Undershoot** (psi)	P_{MIN} Minimum RCS Pressure (psig)
200/250	320				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				
250/300	320				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				

---

* $P_{MAX} - P_S$

** $P_S - P_{MIN}$

NOTE: Two PORV operation is only applicable to RCS ≥ 200°F and the mass input basis of one HHSI pump and one centrifugal charging pump with letdown isolation.

TABLE 6.2 (Cont'd)
SUMMARY OF HEAT INPUT RESULTS
FOR TWO PORV OPERATION (NOTE)

b,c

RCS/SG Temperatures (°F/°F)	PS PORV Setpoint (psig)	ΔP_{OVER} Setpoint Pressure Overshoot* (psi)	P_{MAX} Peak RCS Pressure (psig)	ΔP_{UNDER} Setpoint Pressure Undershoot** (psi)	P_{MIN} Minimum RCS Pressure (psig)
300/350	320				
	400				
	500				
	600				
	700				
	800				
	900				
	1000				

---

* $P_{MAX} - P_S$

** $P_S - P_{MIN}$

NOTE: Two PORV operation is only applicable to RCS ≥ 200°F and the mass input basis of one HHSI pump and one centrifugal charging pump with letdown isolation.

VII. SETPOINT DETERMINATION

A. BASES

Specification delineated in Section IV.

B. LEGEND APPLICABLE TO GRAPHICAL ALGORITHMS

Figures 7.2 through 7.9 show the graphical algorithms used in the development of the COMS setpoints. Included on these curves are:

- Maximum pressure limit (either Appendix G limit minus pressure differential or 800 psig maximum pressurizer pressure for PORV discharge piping limits). For when the Appendix G limit applies, the maximum limit was based upon both a maximum of 2 RCP operating and a maximum of 4 RCP operating.

- Minimum pressure limit (minimum pressure to ensure 200 psid differential pressure across reactor coolant pump seals).

- Locus of pressure overshoots due to design basis mass injection transient with one PORV operation.

- Locus of pressure overshoots due to design basis heat injection transient with one PORV operation.

- Locus of pressure undershoots due to limiting mass injection transient. For temperatures below 200°F, one PORV operation is considered; for temperatures above 200°F, two PORV operation is considered.

- Locus of pressure undershoots due to design basis heat injection transient. For temperatures below 200°F, one PORV operation is considered; for temperatures above 200°F, two PORV operation is considered.

The pressure range over which setpoints can be developed is based on (1) the intersection of the lower of either the mass or heat injection undershoot curve with the RCP seal limit (lowest permitted setpoint) and (2) the intersection of the higher of either the mass or heat injection overshoot curve with the maximum pressure limit (highest permitted setpoint).

C. DATA UTILIZED

1. Mass Input

a. Parametric Correlations for South Texas 1 & 2

As is noted in Table 5.1 for one PORV operation, LOFTRAN runs have given unrealistic large overshoots which occur for the cases where the maximum mass injection rate exceeds the flow capacity of a fully open PORV at its setpoint. This is because LOFTRAN utilizes a constant mass injection rate throughout the transient. In other words, it does not account for the fact that the ability to inject mass into the system decreases as system pressure increases. In actuality, as the system pressure reaches the valve setpoint, the PORV opens fully and discharges an amount of fluid equal to its capacity at the set pressure. For the mass input design basis of one HHSI pump and one centrifugal charging pump with letdown isolation, if the valve capacity is less than the mass injection rate, the system pressure will continue to increase along the dotted line in Figure 7.1. This will increase the valve flow and decrease the mass input rate until an equilibrium is reached at [ ]^{b,c}. Some pressure overshoot could occur here due to the pressure sensing delay time and the valve stroke time. LOFTRAN runs indicate that a maximum overshoot of [ ]^{b,c} psi for a mass injection rate of [ ]^{b,c} gpm and valve setpoint at [ ]^{b,c} psig. For conservatism, a maximum overshoot of [ ]^{b,c} psi is used and the P_{MAX} for setpoints less than [ ]^{b,c} psig should be no greater than [ ]^{b,c} psig overshoot) which is below the 800 psig PORV piping force requirement (limiting maximum allowable pressure for RCS temperatures when this mass imput design basis is applicable).

The mass input data of Section V, attributable to one PORV operation, is plotted in Figures 7.10 and 7.12. Figure 7.10 covers the undershoot for mass input rates from 50 to 1600 gpm. Figure 7.12 covers the overshoot for mass input rates from 0 to 1600 gpm; however, it does not include the overshoot for setpoints less than [ ]^{b,c} psig with combined mass input from both a charging and an SI pump. The P_{MAX} should be [ ]^{b,c} psig for any setpoint less than [ ]^{b,c} psig as it is explained in the above paragraph. The mass input undershoot, attributable to two PORV operation, is plotted in Figure 7.11. Setpoint parametric correlations of setpoint overshoot $\Delta P_{OVER} = P_{MAX} - P_{SETPOINT}$ and setpoint undershoot $\Delta P_{UNDER} = P_{SETPOINT} - P_{MIN}$ were developed to facilitate drawing the locus of maximum RCS pressures produced by MI transients and the locus of minimum RCS pressures produced by the MI transients as a function of setpoint ($P_{SETPOINT}$). As noted in Section II, the range of mass input rates analyzed (50 gpm to 1600 gpm) was sufficiently broad to envelope the maximum possible mass injection rates.

b. Development of the Algorithmic RCS Pressure Extreme Curves

Table 7.1, applicable to RCS < 200°F, summarizes the development of the MI maximum and minimum RCS pressure locus curves for letdown isolation with one centrifugal charging pump operating. Table 7.2, applicable to RCS $\geq$ 200°F, summarizes the development of the MI maximum and minimum RCS pressure locus curves for SI actuation with one high head SI pump plus one centrifugal charging pump with letdown isolation. In Table 7.2, the maximum MI RCS pressure is produced by one PORV operation and the minimum MI RCS pressure is produced by two PORV operation. For setpoints less than [ ]^{b,c} psig, the P_{MAX} for one valve operation is [ ]^{b,c} psig and the ΔP_{OVER} is calculated as P_{MAX} minus $P_{SETPOINT}$. In the development of the RCS pressure overshoot curve, the generalized correlations of Figure 7.12 were adjusted to account for specific MI rates as prescribed in Figure 2.1 for one centrifugal charging pump operation at RCS temperature < 200°F, and the generalized correlations of Figure 7.12 were adjusted to account for the specific MI rates as prescribed in Figure 2.3 for one high head SI pump and one centrifugal charging pump operation at RCS temperature $\geq$ 200°F. The minimum RCS pressure curve was developed from Figure 7.10 for RCS temperature < 200°F and from Figure 7.11 for RCS temperature $\geq$200°F using the largest ΔP_{UNDER} expected to occur for a prescribed setpoint over the entire MI range (50 gpm to 1600 gpm).

2. Heat Input

The data of Table 6.1 of Section V, attributable to one PORV operation, was used directly in determining the ΔP_{OVER} and ΔP_{UNDER} values plotted on Figures 7.2 through 7.6 for RCS < 200°F, and in determining the ΔP_{OVER} values plotted on Figures 7.7 through 7.9 for RCS $\geq$ 200°F. The ΔP_{UNDER} values plotted on Figures 7.7 through 7.9 for RCS $\geq$ 200°F was determined by the data of Table 6.2 for two PORV operation.

In developing the PORV setpoint for a given measured RTD temperature, one must take into account the heat transport effect. If a heat input event were to occur, the cold leg temperature would rapidly rise to that corresponding to the steam generator, while the vessel would still be at the RCS temperature which existed prior to the transient. Therefore, the PORV setpoint must be defined so that it corresponds to the Appendix G limit at the vessel temperature, not the measured RTD temperature. As described in Section III, it was assumed that the RTD was measuring a temperature 77°F higher than the vessel (50°F due to primary to secondary temperature difference plus 27°F instrument error).

D. ALGORITHM APPLICATION

Figures 7.2 through 7.9 illustrate the application of the algorithm described in WCAP 10529, Section 6 to South Texas Units 1 & 2.

There are a few intermediate temperature ranges for which the pressure limits indicated on Figures 7.2 through 7.9 are not valid. These ranges are as follows:

1) Temperatures just below 120°F: The 120°F value is when the pressure limit switches from a flange limit of 621 psig to the Appendix G limit applicable to the vessel (see Figure 4.1) . Therefore, for temperatures <120°F, the limits shown on Figure 7.3 are applicable; at a temperature of 120+°F, a Appendix G limit of 841 psig applies.

2) Temperatures just below 200°F: Figure 7.7 is applicable for the case of 200°F and just above, where the mass input design basis has switched to being a combination of a charging plus a safety injection pump. Just below 200°F, the mass input design basis is just a single charging pump, and the mass injection overshoot/undershoot values would be those shown on Figure 7.6. Likewise, just below 200°F, the heat injection undershoot would be most representative of Figure 7.6 rather than 7.7, since the two PORV setpoints can be staggered suffiiciently to preclude dual PORV actuation for a mass input design basis of just a single charging pump.

The maximum underpressure (ΔP_{UNDER}) utilized for the development of the locus of minimum RCS pressure produced by MI transients for RCS temperature < 200°F is obtained from Figure 7.10 for one PORV operation and for RCS temperature $\geq$ 200°F is obtained from Figure 7.11 for two PORV operation. The maximum overpressure (ΔP_{OVER}) utilized for the development of the locus of maximum RCS pressures produced by MI transients is obtained from Table 7.1 for RCS temperature < 200°F and from Table 7.2 for RCS temperature $\geq$ 200°F. These ΔP_{UNDER} and ΔP_{OVER} values are consistent with all normal and abnormal (infrequent) modes of mass input (Section II. E). These values also take into account the maximum expected injection rate provided in Figure 2.1 for RCS temperature < 200°F or in Figure 2.3 for RCS temperature $\geq$ 200°F.

Algorithm application is extended to reflect the specific requirements of South Texas Units 1 & 2 as listed in Section IV. E. If the range of permissible setpoints falls within the range of potential RHR valve opening as is the case at lower RCS temperatures, then potential operation of both the PORV and RHR valves must be expected.

It should be noted that while pressure measurement uncertainties are not included in the setpoint analysis, temperature uncertainties are. This is because the temperature uncertainties can readily be accommodated without adversely affecting plant operation, unlike the pressure uncertainties which can severely limit the pressure range during heatup/cooldown. In addition, the design basis heat input transient is the inadvertent start of one reactor coolant pump when the RCS has been cooled down to an extent such that the steam generators are 50°F hotter than the RCS. When the one RCP is started, the wide-range temperature transmitters will be measuring the warmed RCS fluid temperature, which is greater than the vessel temperature. Therefore, the setpoints should reflect the temperature difference between the measured fluid temperature and the reactor vessel temperature; for conservatism the full 50°F is used besides the 27°F instrument uncertainty.

The setpoint development considers two possible modes of operating the reactor coolant pumps. The first is a maximum of two RCPs in operation; the second is a maximum of all four RCPs in operation. Separate setpoints were developed for both cases. The maximum pressure limit shown on Figures 7.2 through 7.9 reflects this pump limitation. It should be noted, however, that once the 800 psig pressurizer PORV piping limit is in effect, there is no restriction on RCP operation, since in all cases the pressurizer pressure is less than that existing in the RCS.

The heat injection transient is defined as an inadvertent start of a single RCP from a complete natural circulation condition; RCS cooling is through the RHR system, and as the RCS cools down the steam generators remain at a relatively high temperature. Therefore, the maximum pressure differential that need be considered from the W/R pressure transmitters to the reactor vessel (where Appendix G applies) is only the two RCP case (this brackets the actual case of a single RCP operating).

The procedure for the development of the setpoints for the two PORVs was as follows:

1) Determine the nominal maximum pressure limit vs. RCS temperature. This is shown on Figures 7.2 through 7.9 as the minimum applicable limit based upon:

- Two RCP operation
- Four RCP operation
- PORV piping limit

2) Shift the pressure vs. temperature limits determined in (1) to the right by 27°F to account for the generic temperature measurement uncertainty.

3) Determine the maximum allowable pressure setpoint for the mass injection transient. This is the intersection of the mass input overshoot curve (higher curve designated "MI" on Figures 7.2 - 7.9) with the pressure limit defined in (2) above.

4) Shift the pressure vs. temperature limits determined in (1) to the right by 77°F (27°F temperature measurement uncertainty plus 50°F for the heat injection design basis). For this case, the 4 RCP case is not considered, since the design basis is the inadvertent start of a single RCP.

5) Determine the maximum allowable pressure setpoint for the heat injection transient. This is the intersection of the heat input overshoot curve (higher curve designated "HI" on Figures 7.2 - 7.9) with the pressure limit defined in (4) above.

6) Maximum allowable setpoint is the locus of the minimum of (3) and (5).

With the maximum allowable setpoints defined, the setpoints to be recommended for implementation in the process equipment can then be determined. This is done in the following manner:

a) The higher PORV setpoint is first determined (called PORV #2). This is done by choosing setpoints that are close to the maximum allowable values at an even multiple of 5 psi. For those areas where the maximum allowable setpoint changes in a step manner, the implemented setpoint change is limited to a [ ]^{a,b,c} psi/°F ramp due to the generic limitations of the function generator process card.

b) The PORV # 1 setpoint is then chosen by using the mass injection overshoots from Tables 7.1 and 7.2 and the heat injection overshoots from Tables 6.1 and 6.2. The PORV #1 setpoint is chosen as an even multiple of 5 psi such that the difference between the two PORV setpoints is greater than the maximum overshoot resulting from either the mass injection or the heat injection transient at the chosen RCS temperature. This is an attempt to minimize the potential for actuation of both PORVs simultaneously.

On reviewing Figures 8.3 and 8.4 and Table 8.1, it can be seen there are certain temperature regions below 197°F where the Maximum Allowable setpoint decreases for increasing RCS temperature. For the purposes of setpoint implementation, it was decided that a "negative slope" for the setpoints should not be included, since it could result in a potential inadvertent COMS actuation during RCS heatup conditions. The setpoint program was selected such that the PORV setpoints are either constant or increasing with increasing RCS temperature.

In the selection of the implemented setpoints, while the Maximum Allowable values shown on Figures 8.3 and 8.4 were used for the PORV #1 setpoint and the pressure overhoots from Tables 6.1, 6.2, 7.1, and 7.2 were used to determine the amount the PORV #2 setpoint had to be below the PORV #1 setpoint, some additional conservatism was added. This was to select PORV pressure setpoints that are even multiples of 5 psi and temperature setpoints that are even multiples of 10°F in order to provide an ease of setpoint scaling and implementation. At a minimum, this resulted in the PORV setpoints being moved to the right of the Maximum Allowable values by 3°F (i.e., 197°F becomes 200°F) and down from the Maximum Allowable values by 6 psi (i.e., 556 psig becomes 550 psig).

RCS INJECTION VS PORV RELIEF FLOW
CHARGING PLUS SI PUMP, ONE PORV

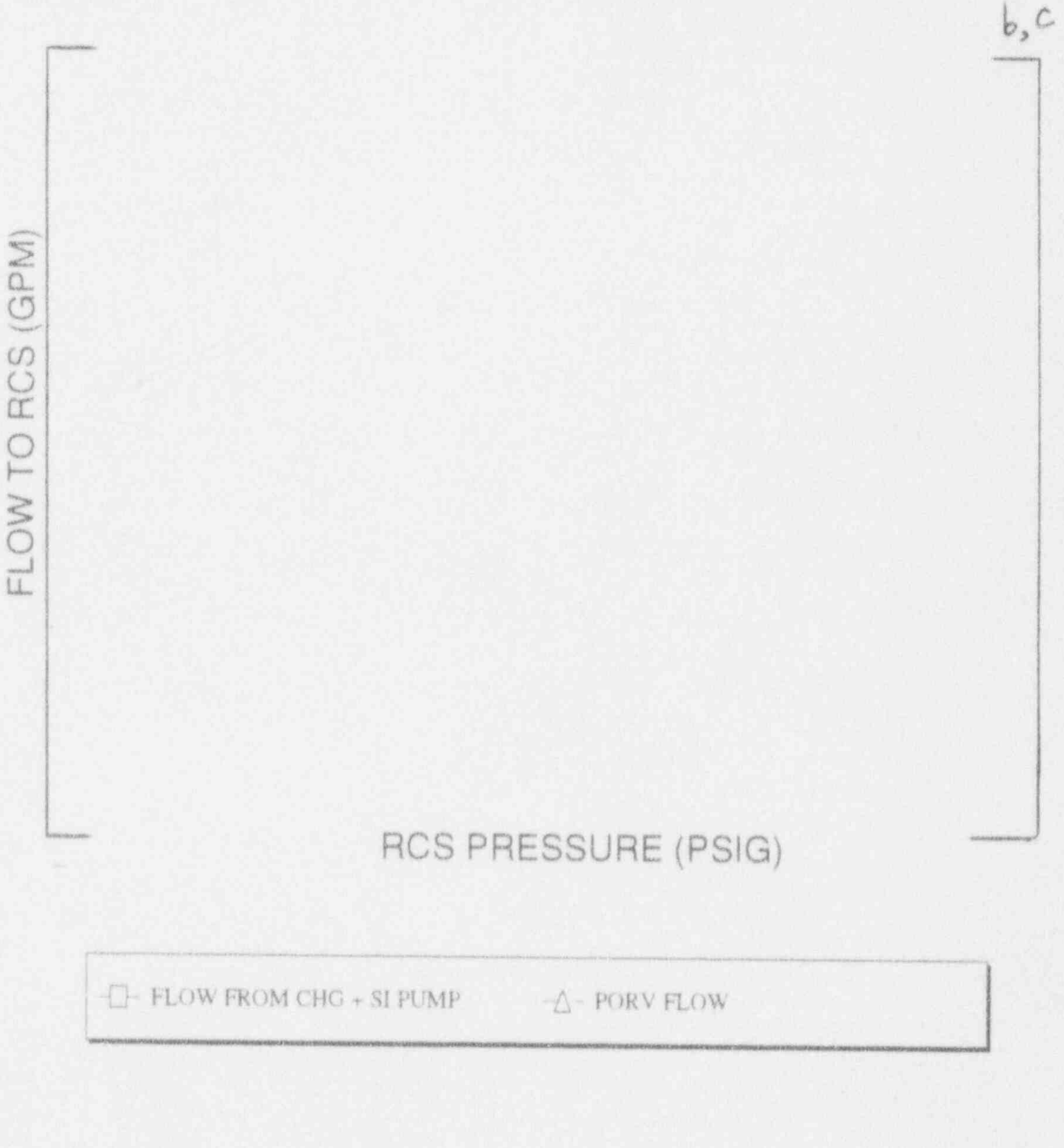

Figure 7.1

RCS PRESSURE EXTREMA VS PORV SETPOINT
RCS TEMP = 70 DEG F

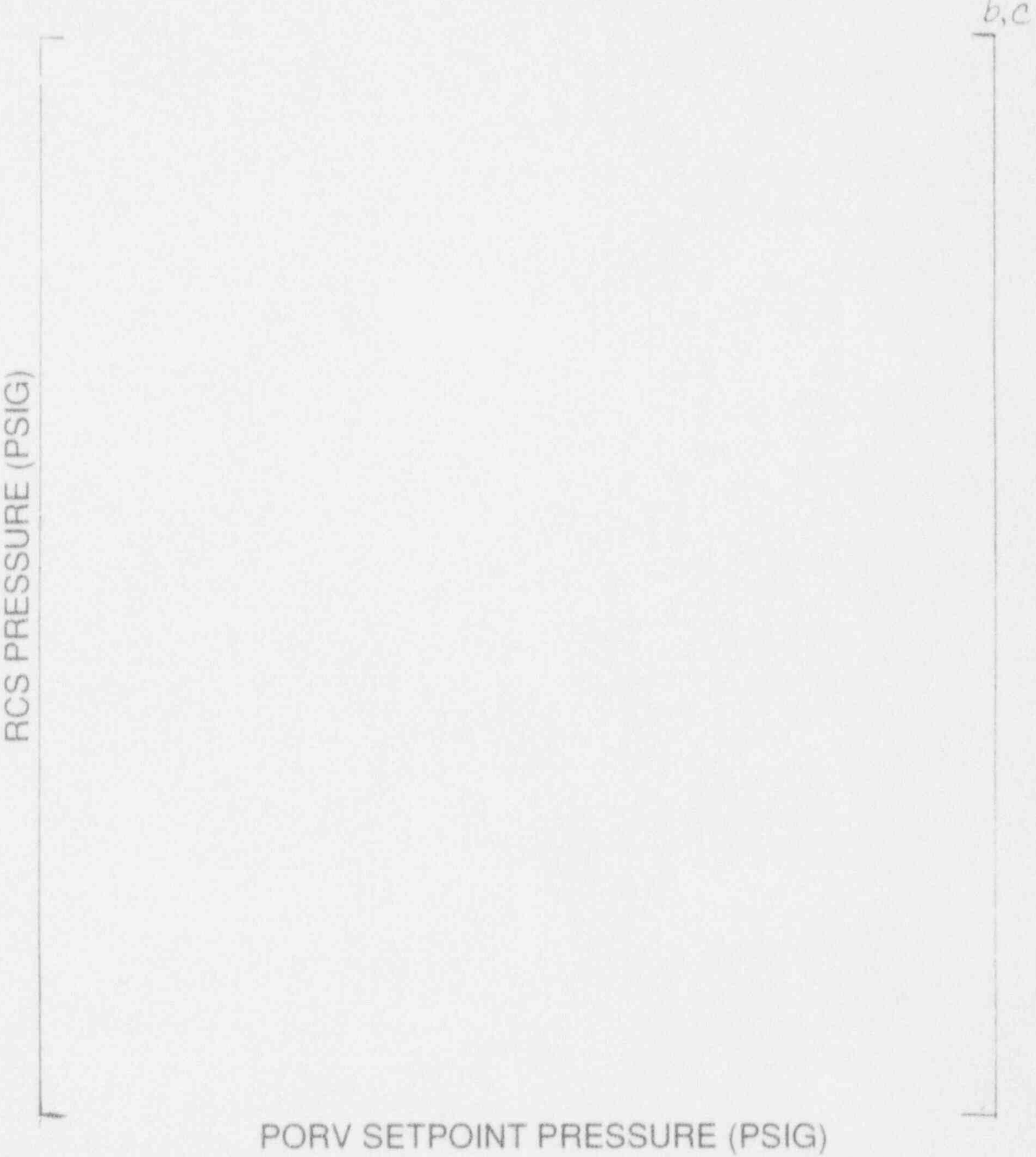

Figure 7.2

RCS PRESSURE EXTREMA VS PORV SETPOINT

RCS TEMP = 100 DEG F

b,c

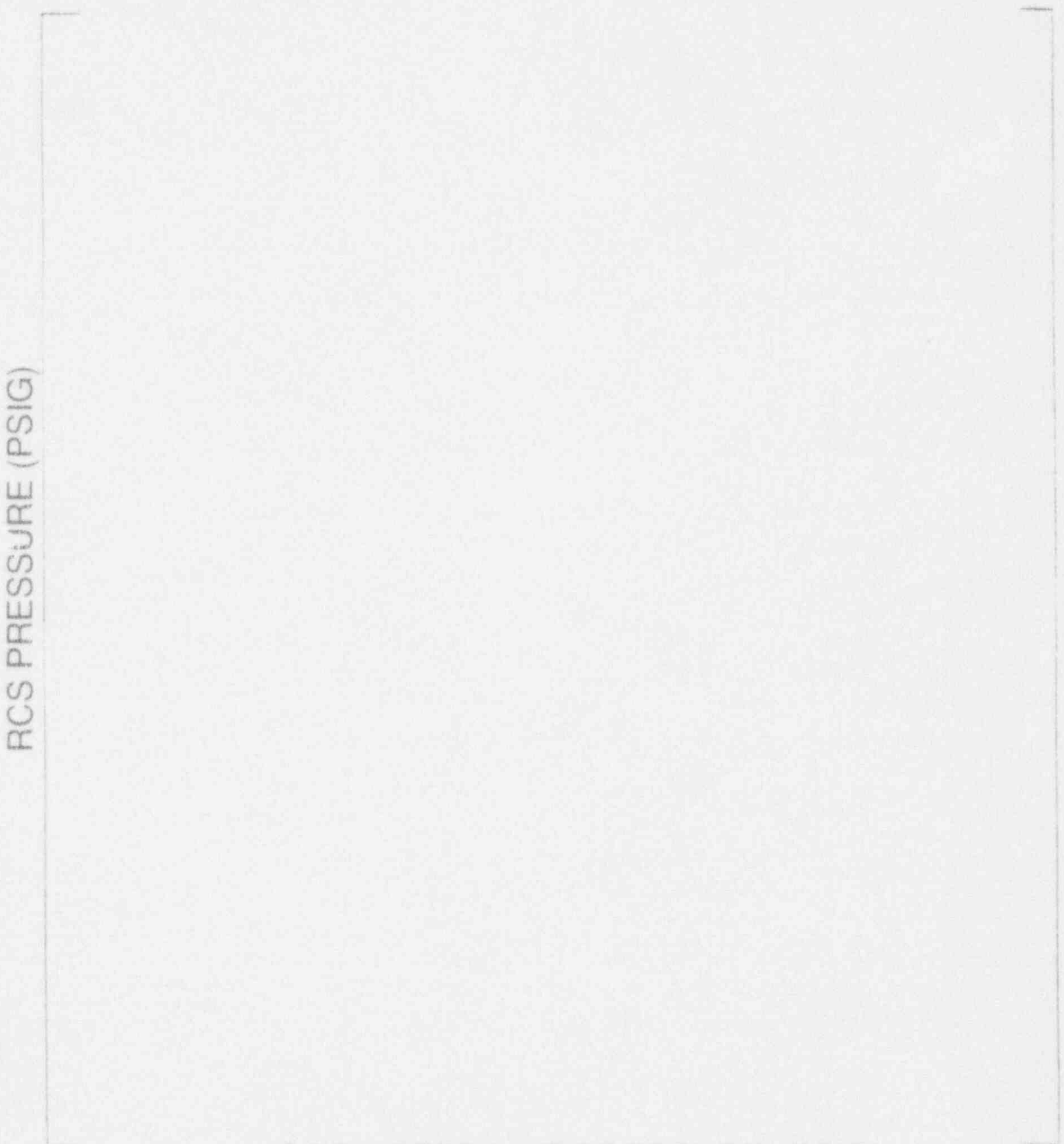

Figure 7.3

RCS PRESSURE EXTREMA VS PORV SETPOINT

RCS TEMP = 125 DEG F

b,c

RCS PRESSURE (PSIG)

PORV SETPOINT PRESSURE (PSIG)

Figure 7.4

RCS PRESSURE EXTREMA VS PORV SETPOINT

RCS TEMP = 150 DEG F

b,c

RCS PRESSURE (PSIG)

PORV SETPOINT PRESSURE (PSIG)

Figure 7.5

RCS PRESSURE EXTREMA VS PORV SETPOINT

RCS TEMP = 170 DEG F

b,c

RCS PRESSURE (PSIG)

PORV SETPOINT PRESSURE (PSIG)

Figure 7.6

RCS PRESSURE EXTREMA VS PORV SETPOINT

RCS TEMP = 200 DEG F

b,c

RCS PRESSURE (PSIG)

PORV SETPOINT PRESSURE (PSIG)

Figure 7.7

RCS PRESSURE EXTREMA VS PORV SETPOINT
RCS TEMP = 250 DEG F

b,c

RCS PRESSURE (PSIG)

PORV SETPOINT PRESSURE (PSIG)

Figure 7.8

RCS PRESSURE EXTREMA VS PORV SETPOINT

RCS TEMP = 300 DEG F

b,c

RCS PRESSURE (PSIG)

PORV SETPOINT PRESSURE (PSIG)

Figure 7.9

RCS PRESSURE U'SHOOT VS. MASS INPUT
ONE PORV OPERATION

b,c

RCS PRESSURE UNDERSHOOT (PSI)

MASS INPUT RATE (GPM)

Figure 7.10

RCS PRESSURE U'SHOOT VS. MASS INPUT

TWO PORV OPERATION

b,c

RCS PRESSURE UNDERSHOOT (PSI)

MASS INPUT RATE (GPM)

Figure 7.11

RCS PRESSURE O'SHOOT VS. MASS INPUT
ONE PORV OPERATION

b,c

RCS PRESSURE OVERSHOOT (PSI)

FLOW (GPM)

Figure 7.12

TABLE 7.1

DEVELOPMENT OF THE MASS INPUT RCS PRESSURE EXTREMES FOR RCS TEMPERATURE < 200°F

PS Setpoint Pressure (psig)	Maximum Credible MI Rate @ PS (1) (gpm)	ΔP_{OVER} (2) (3) @ Max MI Rate (psi)	P_{MAX} (2) of Algorithm (psig)	ΔP_{UNDER} (2) (3) from Fig. 7.10 (psi)	P_{MIN} of Algorithm (psig)
200					
300					
400					
500					
600					
700					
800					
900					
1000					

b,c

---

(1) Based on Figure 2.1

(2) ΔP_{over}, P_{max}, ΔP_{under} and P_{min} are based on one PORV operation.

(3) $\Delta P_{over} = P_{max} - P_S$; $\Delta P_{under} = P_S - P_{min}$

TABLE 7.2

DEVELOPMENT OF THE MASS INPUT RCS PRESSURE EXTREMES FOR RCS TEMPERATURE ≥ 200°F

b,c

PS Setpoint Pressure (psig)	Maximum Credible MI Rate @ PS[1] (gpm)	ΔP_{OVER} [3] [4] @ Max MI Rate (psi)	P_{MAX} [4] of Algorithm (psig)	ΔP_{UNDER} [3] [5] from Fig. 7.11 (psi)	P_{MIN} of Algorithm (psig)
300					
400					
500					
600					
700					
800					
900					
1000					

---

(1) Based on Figure 2.3

(2) See Section VII.C.1.a for detailed explanation.

(3) $\Delta P_{over} = P_{max} - P_s$; $\Delta P_{under} = P_s - P_{min}$

(4) ΔP_{over} and P_{max} is based on one PORV operation.

(5) ΔP_{under} and P_{min} is based on two PORV operation.

VIII. SETPOINT PROGRAM

The pressure limits and the maximum allowable PORV setpoints are shown on Figures 8.1 and 8.2 for the two RCP operation limitation and four RCP operation limitation, respectively. From these figures, the maximum allowable setpoints to be included in the Technical Specifications were determined and are shown on Figures 8.3 and 8.4 and in Table 8.1 for the two RCP pump operation cases.

For hardware application, the total number of linear segments is limited to a total of 8, which are defined by a total of 9 breakpoints. Linear interpolation is used to calculate valve setpoints between the breakpoints defining the individual line segments. A listing of the PORV setpoints for the 2 RCP pump limitied operation and the 4 RCP pump limited operation are included in Tables 8.2 and 8.3, respectively.

TABLE 8.1

MAXIMUM ALLOWABLE COLD OVERPRESSURE MITIGATION SYSTEM SETPOINTS

2 RCP Operation		4 RCP Operation	
RCS Temperature (°F)	Max. PORV setpoint (psig)	RCS Temperature (°F)	Max. PORV Setpoint (psig)
70	571	70	522
177	564	147	522
197	556	148	567
198	737	197	556
350	737	198	737
		350	737

TABLE 8.2
REVISED COLD OVERPRESSURE MITIGATION SYSTEM SETPOINTS
2 RCP PUMP OPERATION

Indicated RCS Temp (°F)	PORV #2 Setpoint (psig)	PORV #1 Setpoint (psig)
70	550	510
140	550	510
180	550	510
200	550	510
210	640	590
220	730	660
245	730	660
380	730	660
450	2350	2350

TABLE 8.3
REVISED COLD OVERPRESSURE MITIGATION SYSTEM SETPOINTS
4 RCP PUMP OPERATION

Indicated RCS Temp (°F)	PORV #2 Setpoint (psig)	PORV #1 Setpoint (psig)
70	515	475
140	515	475
180	515	475
200	515	475
210	640	590
220	730	660
245	730	660
380	730	660
450	2350	2350

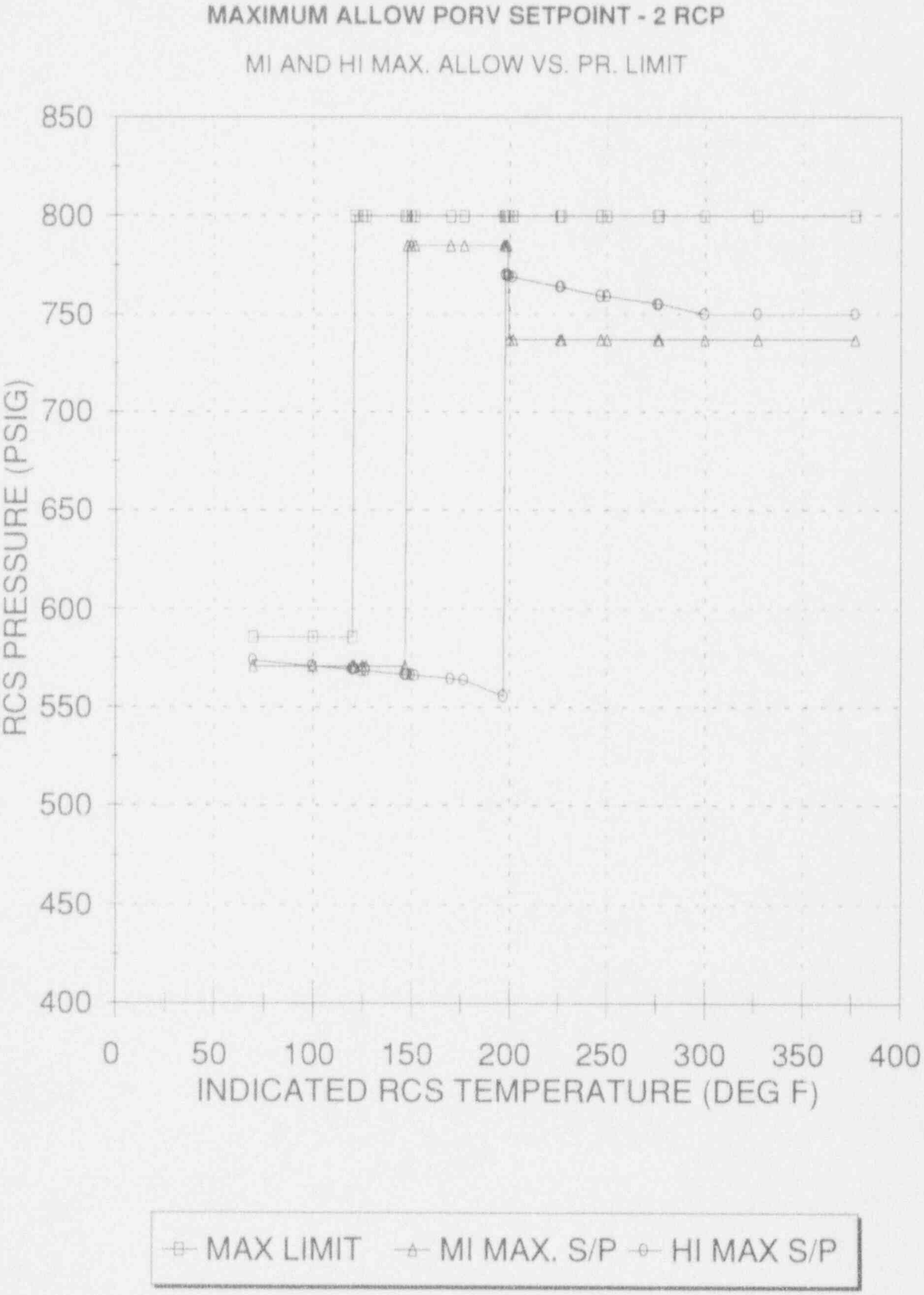
MAXIMUM ALLOW PORV SETPOINT - 2 RCP
MI AND HI MAX. ALLOW VS. PR. LIMIT
RCS PRESSURE (PSIG)
850
800
750
700
650
600
550
500
450
400
0
50
100
150
200
250
300
350
400
INDICATED RCS TEMPERATURE (DEG F)
MAX LIMIT
MI MAX. S/P
HI MAX S/P

Figure 8.1

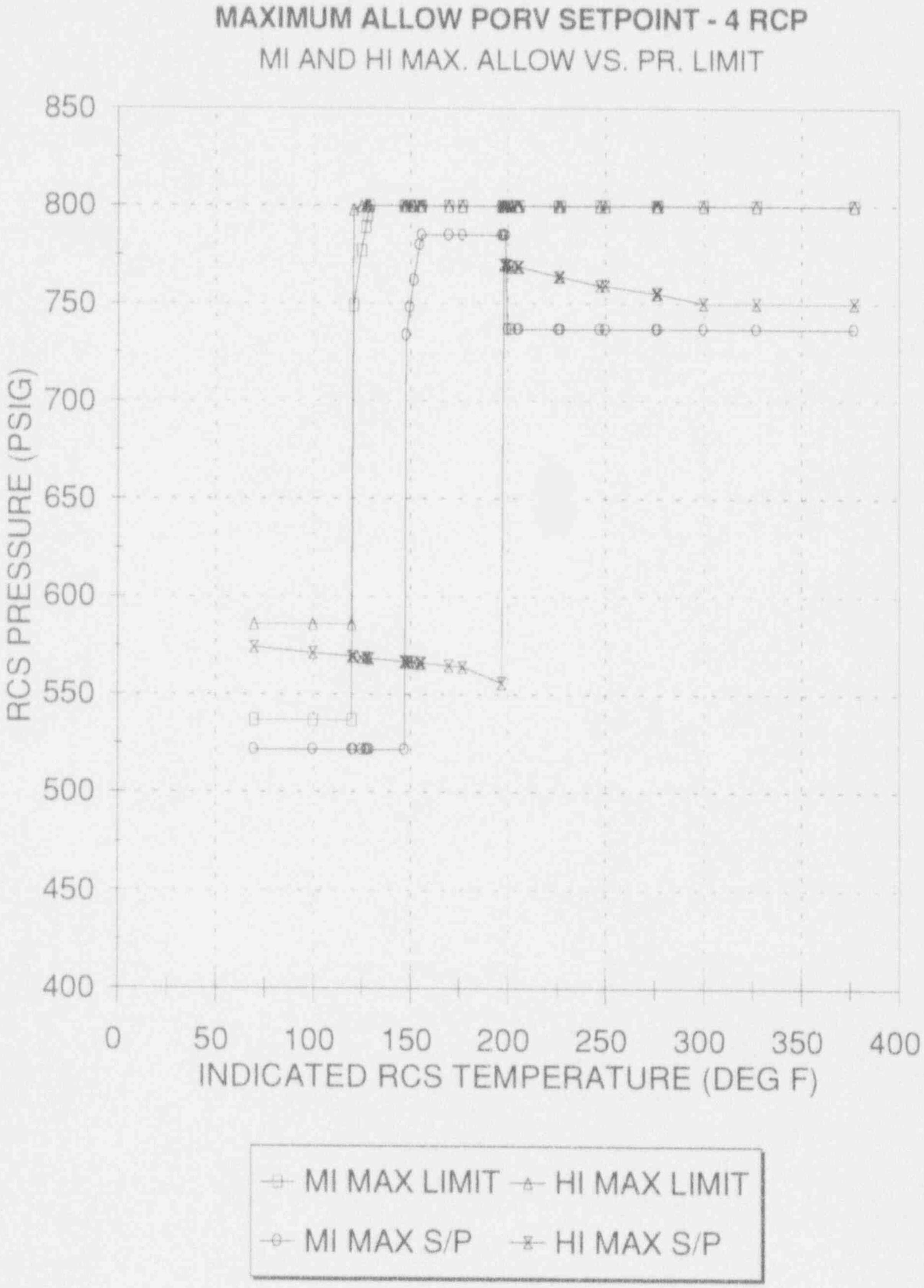
MAXIMUM ALLOW PORV SETPOINT - 4 RCP
MI AND HI MAX. ALLOW VS. PR. LIMIT
RCS PRESSURE (PSIG)
850
800
750
700
650
600
550
500
450
400
0
50
100
150
200
250
300
350
400
INDICATED RCS TEMPERATURE (DEG F)
MI MAX LIMIT
HI MAX LIMIT
MI MAX S/P
HI MAX S/P

Figure 8.2

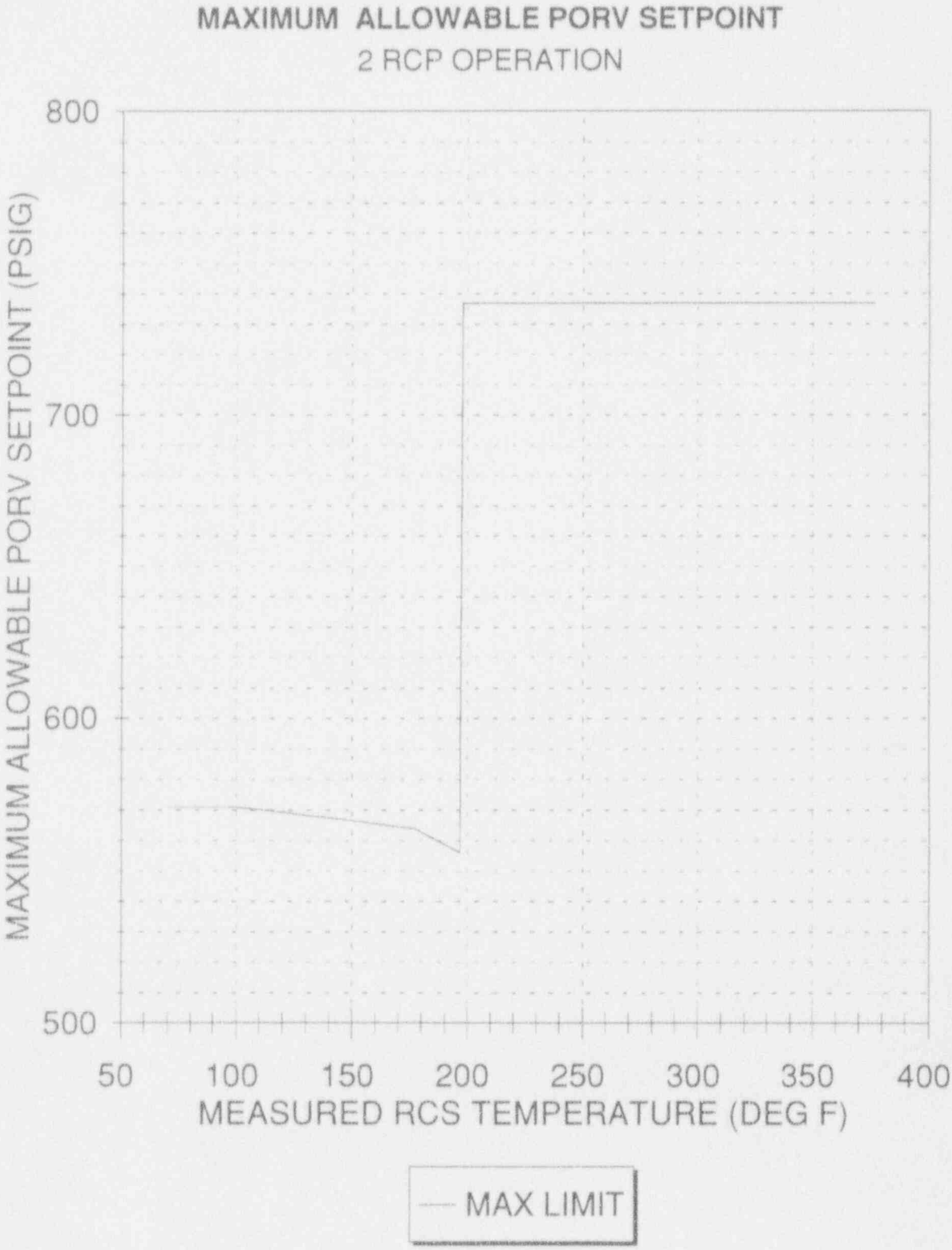
MAXIMUM ALLOWABLE PORV SETPOINT
2 RCP OPERATION
MAXIMUM ALLOWABLE PORV SETPOINT (PSIG)
800
700
600
500
50
100
150
200
250
300
350
400
MEASURED RCS TEMPERATURE (DEG F)
MAX LIMIT

Figure 8.3

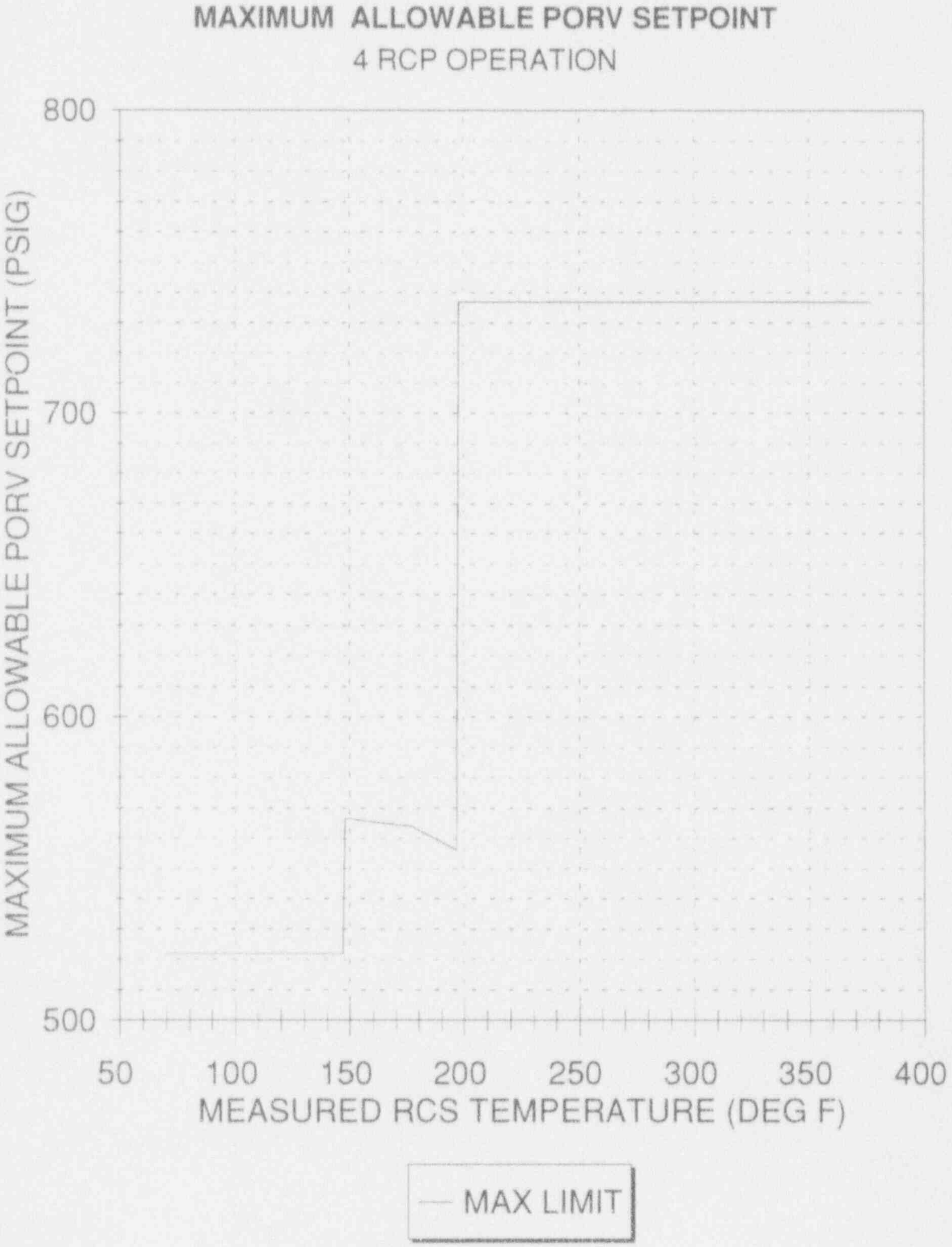
MAXIMUM ALLOWABLE PORV SETPOINT
4 RCP OPERATION
800
700
600
500
50
100
150
200
250
300
350
400
MEASURED RCS TEMPERATURE (DEG F)
MAXIMUM ALLOWABLE PORV SETPOINT (PSIG)
MAX LIMIT

Figure 8.4

REFERENCES

1. WCAP-10529, February, 1984 (non-proprietary)

2. CST&S-CSDT-104, 1/6/86 (proprietary)

APPENDIX A

HEATUP AND COOLDOWN LIMIT CURVES FOR NORMAL OPERATION FOR SOUTH TEXAS UNITS 1 AND 2

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

A-1. INTRODUCTION

Heatup and cooldown limit curves are calculated using the most limiting value of RT_{NDT} (reference nil-ductility temperature) corresponding to the limiting beltline region material for the reactor vessel. The most limiting RT_{NDT} of the material in the core region of the reactor vessel is determined by using the unirradiated reactor vessel material fracture toughness properties and estimating the radiation-induced ΔRT_{NDT}. The unirradiated RT_{NDT} is designated as the higher of either the drop weight nil-ductility transition temperature (NDTT) or the temperature at which the material exhibits at least 50 ft-lb of impact energy and 35-mil lateral expansion (normal to the major working direction) minus 60°F.

RT_{NDT} increases as the material is exposed to fast-neutron radiation. Therefore, to find the most limiting RT_{NDT} at any time period in the reactor's life, ΔRT_{NDT} due to the radiation exposure associated with that time period must be added to the original unirradiated RT_{NDT}. The extent of the shift in RT_{NDT} is enhanced by certain chemical elements (such as copper and nickel) present in reactor vessel steels. The Nuclear Regulatory Commission (NRC) has published a method for predicting radiation embrittlement in Regulatory Guide 1.99 Rev. 2 (Radiation Embrittlement of Reactor Vessel Materials)[A1]. Regulatory Guide 1.99, Revision 2 is used for the calculation of ART values at 1/4-T and 3/4-T locations. T is the thickness of the vessel at the beltline region measured from the clad/base metal interface.

The pressure-temperature limit curves in this report represent the reactor coolant system pressure at the limiting beltline region of the reactor vessel. Since pressure readings are measured at other locations than the limiting beltline region, the pressure differences between the pressure transmitter and the limiting beltline region must be accounted for when using the pressure-temperature limit curves herein.

A-2. FRACTURE TOUGHNESS PROPERTIES

The fracture-toughness properties of the ferritic material in the reactor coolant pressure boundary are determined in accordance with the NRC Regulatory Standard Review Plan[A2]. The pre-irradiation fracture-toughness properties of the South Texas Units 1 and 2 reactor vessel are presented in Tables A-1 and A-2.

A-3. CRITERIA FOR ALLOWABLE PRESSURE-TEMPERATURE RELATIONSHIPS

The ASME approach for calculating the allowable limit curves for various heatup and cooldown rates specifies that the total stress intensity factor, K_I, for the combined thermal and pressure stresses at any time during heatup or cooldown cannot be greater than the reference stress intensity factor, K_{IR}, for the metal temperature at that time. K_{IR} is obtained from the reference fracture toughness curve, defined in Appendix G of the ASME Code[A3]. The K_{IR} curve is given by the following equation:

$$K_{IR} = 26.78 + 1.223 * e^{[0.0145\,(T-RTNDT\,+\,160)]} \qquad (1)$$

where

K_{IR} = reference stress intensity factor as a function of the metal temperature T and the metal reference nil-ductility temperature RT_{NDT}

Therefore, the governing equation for the heatup-cooldown analysis is defined in Appendix G of the ASME Code[A3] as follows:

$$C * K_{IM} + K_{IT} \leq K_{IR} \qquad (2)$$

where

K_{IM} = stress intensity factor caused by membrane (pressure) stress

K_{IT} = stress intensity factor caused by the thermal gradients

K_{IR} = function of temperature relative to the RT_{NDT} of the material

C = 2.0 for Level A and Level B service limits

C = 1.5 for hydrostatic and leak test conditions during which the reactor core is not critical

At any time during the heatup or cooldown transient, K_{IR} is determined by the metal temperature at the tip of the postulated flaw, the appropriate value for RT_{NDT}, and the reference fracture toughness curve. The thermal stresses resulting from the temperature gradients through the vessel wall are calculated and then the corresponding (thermal) stress intensity factors, K_{IT}, for the reference flaw are computed.

From Equation 2, the pressure stress intensity factors are obtained and, from these, the allowable pressures are calculated.

For [illegible] calculation of the allowable pressure versus coolant temperature during cooldown, the reference flaw of Appendix G to the ASME Code is assumed to exist at the inside of the vessel wall. During cooldown, the controlling location of the flaw is always at the inside of the wall because the thermal gradients produce tensile stresses at the inside, which increase with increasing cooldown rates. Allowable pressure-temperature relations are generated for both steady-state and finite cooldown rate situations. From these relations, composite limit curves are constructed for each cooldown rate of interest.

The use of the composite curve in the cooldown analysis is necessary because control of the cooldown procedure is based on the measurement of reactor coolant temperature, whereas the limiting pressure is actually dependent on the material temperature at the tip of the assumed flaw.

During cooldown, the 1/4-T vessel location is at a higher temperature than the fluid adjacent to the vessel ID. This condition, of course, is not true for the steady-state situation. It follows that, at any given reactor coolant temperature, the ΔT developed during cooldown results in a higher value of K_{IR} at the 1/4-T location for finite cooldown rates than for steady-state operation. Furthermore, if conditions exist so that the increase in K_{IR} exceeds K_{IT}, the calculated allowable pressure during cooldown will be greater than the steady-state value.

The above procedures are needed because there is no direct control on temperature at the 1/4-T location and, therefore, allowable pressures may unknowingly be violated if the rate of cooling is decreased at various intervals along a cooldown ramp. The use of the composite curve eliminates this problem and ensures conservative operation of the system for the entire cooldown period.

Three separate calculations are required to determine the limit curves for finite heatup rates. As is done in the cooldown analysis, allowable pressure-temperature relationships are developed for steady-state conditions as well as finite heatup rate conditions assuming the presence of a 1/4-T defect at the inside of the wall. The heatup results in compressive stresses at the inside surface that alleviate the tensile stresses produced by internal pressure. The metal temperature at the crack tip lags the coolant temperature; therefore, the K_{IR} for the 1/4-T crack during heatup is lower than the K_{IR} for the 1/4-T crack during steady-state conditions at the same coolant temperature. During heatup, especially at the end of the transient, conditions may exist so that the effects of compressive thermal stresses and lower K_{IR}'s do not offset each other, and the pressure-temperature curve based on steady-state conditions no longer represents a lower bound of all similar curves for finite heatup rates when the

1/4-T flaw is considered. Therefore, both cases have to be analyzed in order to ensure that at any coolant temperature the lower value of the allowable pressure calculated for steady-state and finite heatup rates is obtained.

The second portion of the heatup analysis concerns the calculation of the pressure-temperature limitations for the case in which a 1/4-T deep outside surface flaw is assumed. Unlike the situation at the vessel inside surface, the thermal gradients established at the outside surface during heatup produce stresses which are tensile in nature and therefore tend to reinforce any pressure stresses present. These thermal stresses are dependent on both the rate of heatup and the time (or coolant temperature) along the heatup ramp. Since the thermal stresses at the outside are tensile and increase with increasing heatup rates, each heatup rate must be analyzed on an individual basis.

Following the generation of pressure-temperature curves for both the steady state and finite heatup rate situations, the final limit curves are produced by constructing a composite curve based on a point-by-point comparison of the steady-state and finite heatup rate data. At any given temperature, the allowable pressure is taken to be the lesser of the three values taken from the curves under consideration. The use of the composite curve is necessary to set conservative heatup limitations because it is possible for conditions to exist wherein, over the course of the heatup ramp, the controlling condition switches from the inside to the outside, and the pressure limit must at all times be based on analysis of the most critical criterion.

Finally, the 1983 Amendment to 10CFR50[A4] has a rule which addresses the metal temperature of the closure head flange and vessel flange regions of both South Texas Unit 1 and South Texas Unit 2, since the heatup and cooldown curves are applied to both units. This rule states that the metal temperature of the closure flange regions must exceed the material unirradiated RT_{NDT} by at least 120°F for normal operation when the pressure exceeds 20 percent of the preservice hydrostatic test pressure (621 psig for South Texas Units 1 and 2).

Table A-1 indicates that the limiting unirradiated RT_{NDT} of 0°F occurs in the vessel flange of South Texas Unit 1, so the minimum allowable temperature of this region is 120°F. This limit is shown in Figure A-1 whenever applicable.

A-4. HEATUP AND COOLDOWN PRESSURE-TEMPERATURE LIMIT CURVES

Pressure-temperature limit curves for normal heatup and cooldown of the primary reactor pressure vessel have been calculated for the pressure and temperature in the reactor vessel beltline region using the methods discussed in Section A-3. Figure A-1 presents the heatup/cooldown curves using a heatup/cooldown rate of 0°F/hr applicable for the first 32 EFPY.

Allowable combinations of temperature and pressure for specific temperature change rates are below and to the right of the limit line shown in Figure A-1. This is in addition to other criteria which must be met before the reactor is made critical.

Figure A-1 defines limits for ensuring prevention of nonductile failure for South Texas Units 1 and 2 reactor vessels.

The data points used to develop the heatup and cooldown pressure-temperature limit curves shown in Figure A-1 are presented in Attachment A1.

A-5. CALCULATION OF ADJUSTED REFERENCE TEMPERATURE

From Regulatory Guide 1.99 Rev. 2[A1] the adjusted reference temperature (ART) for each material in the beltline is given by the following expression:

$$\text{ART} = \text{Initial } RT_{NDT} + \Delta RT_{NDT} + \text{Margin} \qquad (3)$$

Initial RT_{NDT} is the reference temperature for the unirradiated material as defined in paragraph NB-2331 of Section III of the ASME Boiler and Pressure Vessel Code. If measured values of initial RT_{NDT} for the material in question are not available, generic mean values for that class of material may be used if there are sufficient test results to establish a mean and standard deviation for the class.

ΔRT_{NDT} is the mean value of the adjustment in reference temperature caused by irradiation and should be calculated as follows:

$$\Delta RT_{NDT} = [CF] * f^{(0.28-0.10 \log f)} \qquad (4)$$

To calculate ΔRT_{NDT} at any depth (e.g., at 1/4-T or 3/4-T), the following formula must first be used to attenuate the fluence at the specific depth.

$$f_{(\text{depth } X)} = f_{\text{surface}} * e^{(-.24x)} \qquad (5)$$

where x (in inches) is the depth into the vessel wall measured from the vessel clad/base metal interface. The resultant fluence is then put into equation (4) to calculate ΔRT_{NDT} at the specific depth.

CF (°F) is the chemistry factor, obtained from Tables in Reference A1, using the mean values of the copper and nickel content as reported in Tables A-1 and A-2. All materials in the beltline region of South Texas Units 1 and 2 were considered in determining the limiting material. The results of the ART's at 1/4-T and 3/4-T are summarized in Table A-3. From Table A-3, it can be seen that the limiting material is the South Texas Unit 1 intermediate shell plate, R1606-3 for heatup and cooldown curves applicable up to 32 EFPY. Sample calculations to determine the ART values for the South Texas Unit 1 intermediate shell plate, R1606-3 for 32 EFPY are shown in Table A-4.

TABLE A-1
SOUTH TEXAS UNIT 1 REACTOR VESSEL TOUGHNESS TABLE (UNIRRADIATED)

Material Description	Cu (wt. %)	Ni (wt. %)	Initial RT_{NDT} (°F) (a)
Closure Head Flange (b)	--	--	0
Vessel Flange (b)	--	--	-10
Intermediate Shell Plate, R1606-1	0.04	0.63	10
Intermediate Shell Plate, R1606-2	0.04	0.61	0
Intermediate Shell Plate, R1606-3	0.05	0.62	10
Lower Shell Plate, R1622-1	0.05	0.61	-30
Lower Shell Plate, R1622-2	0.07	0.64	-30
Lower Shell Plate, R1622-3	0.05	0.66	-30
Inter. Shell Longitudinal Weld at 0° Azimuth	0.03	0.06	-50
Inter. Shell Longitudinal Weld at 120° Azimuth	0.03	0.06	-50
Inter. Shell Longitudinal Weld at 240° Azimuth	0.03	0.06	-50
Lower Shell Longitudinal Weld at 90° Azimuth	0.03	0.06	-50
Lower Shell Longitudinal Welds at 210° and 330° Azimuths	0.03	0.06	-50
Inter. Shell to Lower Shell Circumferential Weld	0.03	0.06	-70

(a) Initial RT_{NDT} values were estimated per U.S. NRC Standard Review Plan [A2]. The initial RT_{NDT} values for the plates and welds are measured values.

(b) These values are used for considering flange requirements for the heatup/cooldown curves[A4].

TABLE A-2
SOUTH TEXAS UNIT 2 REACTOR VESSEL TOUGHNESS TABLE (UNIRRADIATED)

Material Description	Cu (wt. %)	Ni (wt. %)	Initial RT_{NDT} (°F) (a)
Closure Head Flange (b)	--	--	-50
Vessel Flange (b)	--	--	-10
Intermediate Shell Plate, R2507-1	0.04	0.65	-10
Intermediate Shell Plate, R2507-2	0.05	0.64	-10
Intermediate Shell Plate, R2507-3	0.05	0.61	-40
Lower Shell Plate, R3022-1	0.03	0.63	-30
Lower Shell Plate, R3022-2	0.04	0.61	-40
Lower Shell Plate, R3022-3	0.04	0.60	-40
Inter. Shell Longitudinal Weld at 0° Azimuth	0.03	0.17	-70
Inter. Shell Longitudinal Weld at 120° Azimuth	0.03	0.17	-70
Inter. Shell Longitudinal Weld at 240° Azimuth	0.03	0.17	-70
Lower Shell Longitudinal Weld at 90° Azimuth	0.01	0.15	-70
Lower Shell Longitudinal Welds at 210° and 330° Azimuths	0.01	0.15	-70
Inter. Shell to Lower Shell Circumferential Weld	0.01	0.15	-70

(a) Initial RT_{NDT} values were estimated per U.S. NRC Standard Review Plan [A2]. The initial RT_{NDT} values for the plates and welds are measured values.

(b) These values are used for considering flange requirements for the heatup/cooldown curves[A4].

TABLE A-3
SUMMARY OF ADJUSTED REFERENCE TEMPERATURES (ART's) AT 1/4-T and 3/4-T LOCATIONS FOR 32 EFPY FOR SOUTH TEXAS UNITS 1 AND 2

South Texas Unit 1			South Texas Unit 2		
Material Description	**1/4-T**	**3/4-T**	**Material Description**	**1/4-T**	**3/4-T**
Intermediate Shell Plate, R1606-1	70	55	Intermediate Shell Plate, R2507-1	50	35
Intermediate Shell Plate, R1606-2	60	45	Intermediate Shell Plate, R2507-2	60	43
Intermediate Shell Plate, R1606-3	80*	64*	Intermediate Shell Plate, R2507-3	30	13
Lower Shell Plate, R1622-1	41	27	Lower Shell Plate, R3022-1	18	7
Lower Shell Plate, R1622-2	57	44	Lower Shell Plate, R3022-2	23	8
Lower Shell Plate, R1622-3	41	27	Lower Shell Plate, R3022-3	23	8
Inter. Shell Longitudinal Weld at 0° Azimuth	1	-13	Inter. Shell Longitudinal Weld at 0° Azimuth	-4	-23
Inter. Shell Longitudinal Weld at 120° Azimuth	3	-11	Inter. Shell Longitudinal Weld at 120° Azimuth	-1	-20
Inter. Shell Longitudinal Weld at 240° Azimuth	2	-13	Inter. Shell Longitudinal Weld at 240° Azimuth	-3	-22
Lower Shell Longitudinal Weld at 90° Azimuth	1	-13	Lower Shell Longitudinal Weld at 90° Azimuth	-30	-41
Lower Shell Longitudinal Welds at 210° and 330° Azimuths	8	-6	Lower Shell Longitudinal Welds at 210° and 330° Azimuths	-24	-36
Inter. Shell to Lower Shell Circumferential Weld	-12	-26	Inter. Shell to Lower Shell Circumferential Weld	-24	-36

* These values were used in the development of the heatup and cooldown limit curves.

TABLE A-4

CALCULATION OF ADJUSTED REFERENCE TEMPERATURES AT 32 EFPY FOR THE LIMITING REACTOR VESSEL MATERIAL FOR SOUTH TEXAS UNITS 1 AND 2 - SOUTH TEXAS UNIT 1 INTERMEDIATE SHELL PLATE, R1606-3

Parameter	1/4-T	3/4-T
Chemistry Factor, CF (°F)	31	31
Fluence, f (10^{19} n/cm^2) (a)	1.728	0.6134
Fluence Factor, ff	1.150	0.863
ΔRT_{NDT} = CF x ff (°F)	36	27
Initial RT_{NDT}, I (°F)	10	10
Margin, M (°F) (b)	34	27
Regulatory Guide 1.99, Revision 2		
Adjusted Reference Temperature, ART		
ART = I + ΔRT_{NDT} + M	80	64

Notes

(a) Fluence, f, is based upon the surface fluence (10^{19} n/cm^2, E > 1.0 MeV) = 2.90 at 32 EFPY. The South Texas Units 1 and 2 reactor vessel wall thickness is 8.63 inches at the beltline region.

(b) Margin is calculated as, $M = 2 [\sigma_I^2 + \sigma_\Delta^2]^{0.5}$. The standard deviation for the initial RT_{NDT} margin term, σ_I, is assumed to be 0°F since the initial RT_{NDT} is a measured value. The standard deviation for ΔRT_{NDT} term, σ_Δ, is 17°F for the plate, except that σ_Δ need not exceed 0.5 times the mean value of ΔRT_{NDT}. σ_Δ is 8.5°F for the plate (half the value) when surveillance data is used.

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: South Texas Unit 1 Intermediate Shell Plate, R1606-3

LIMITING ART AT 32 EFPY: 1/4-T, 80°F

3/4-T, 64°F

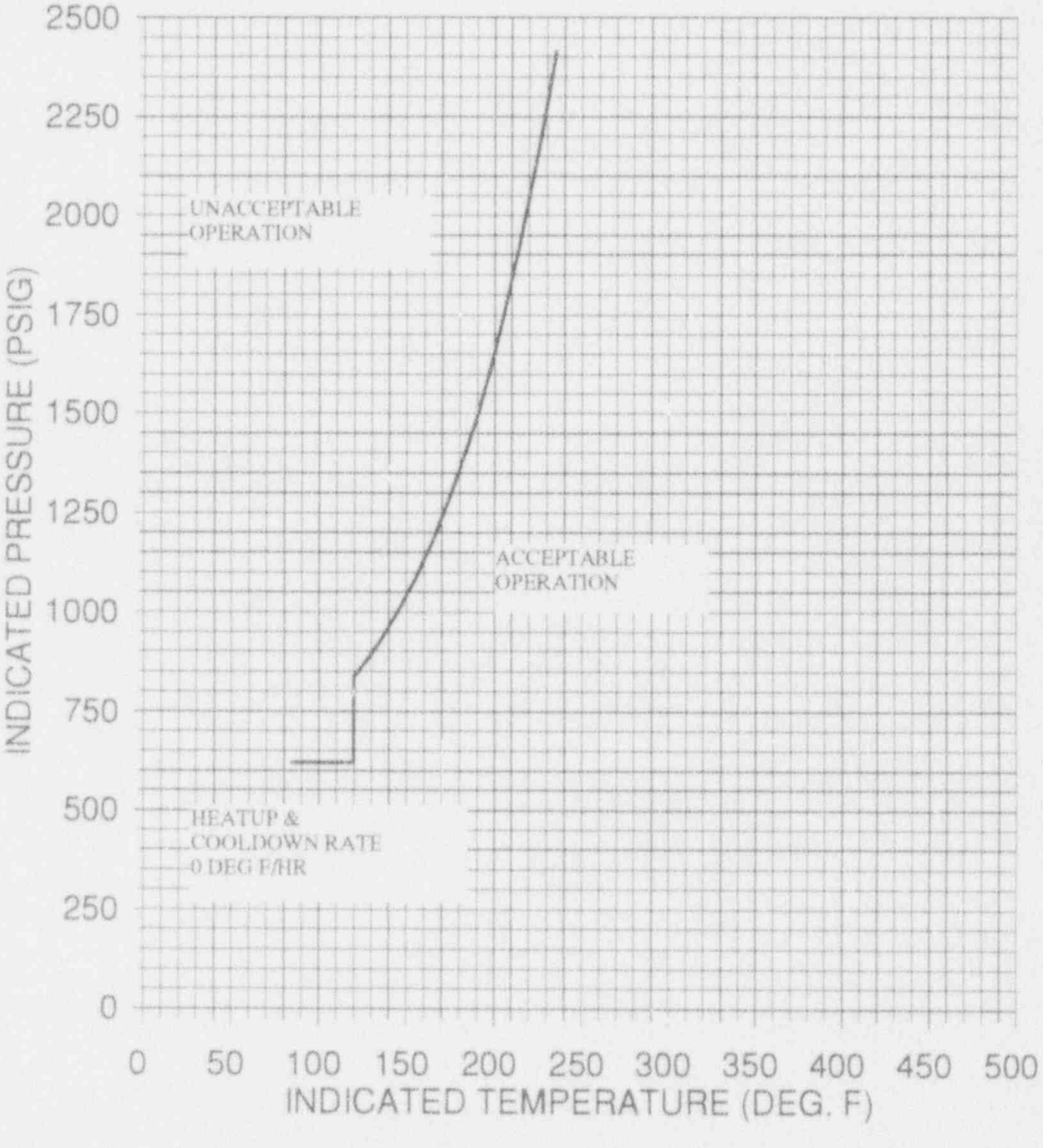

Figure A-1. South Texas Units 1 and 2 Reactor Coolant System Steady State Heatup/Cooldown Limitations (Heatup/Cooldown rate of 0°F/hr) Applicable for the first 32 EFPY (without margins for instrumentation errors).

A-6. REFERENCES

[A1] Regulatory Guide 1.99, Revision 2, "Radiation Embrittlement of Reactor Vessel Materials", U.S. Nuclear Regulatory Commission, May, 1988.

[A2] "Fracture Toughness Requirements", Branch Technical Position MTEB 5-2, Chapter 5.3.2 in Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, LWR Edition, NUREG-0800, 1981.

[A3] ASME Boiler and Pressure Vessel Code, Section III, Division 1 - Appendixes, "Rules for Construction of Nuclear Power Plant Components, Appendix G, Protection Against Nonductile Failure", pp. 558-563, 1986 Edition, American Society of Mechanical Engineers, New York, 1986.

[A4] Code of Federal Regulations, 10CFR50, Appendix G, "Fracture Toughness Requirements", U.S. Nuclear Regulatory Commission, Washington, D.C., Federal Register, Vol. 48 No. 104, May 27, 1983.

[A5] WCAP-12629, "Analysis of Capsule U from the Houston Lighting and Power Company South Texas Unit 1 Reactor Vessel Radiation Surveillance Program", E. Terek, et al., August 1990.

[A6] WCAP-13182, "Analysis of Capsule V from the Houston Lighting and Power Company South Texas Unit 2 Reactor Vessel Radiation Surveillance Program", J. M. Chicots, et. al., February 1992.

ATTACHMENT A1

DATA POINTS FOR HEATUP AND COOLDOWN CURVES

INDICATED TEMPERATURE (DEG. F)	INDICATED PRESSURE (PSIG)		INDICATED TEMPERATURE (DEG. F)	INDICATED PRESSURE (PSIG)
85	621.00		160	1130.30
90	621.00		165	1180.50
95	621.00		170	1234.44
100	621.00		175	1292.33
105	621.00		180	1354.34
110	621.00		185	1420.86
115	621.00		190	1492.38
120	621.00		195	1569.00
120.1	835.50		200	1650.86
125	863.80		205	1739.13
130	894.11		210	1833.39
135	926.90		215	1933.95
140	961.99		220	2042.19
145	999.67		225	2157.74
150	1040.12		230	2281.16
155	1083.59		235	2412.68