PWR SAFETY AND RELIEF VALVE
ADEQUACY REPORT
FOR
CAROLINA POWER AND LIGHT COMPANY
H. B. ROBINSON UNIT 2

Revision 1
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Prepared By: [signature]

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1.0 INTRODUCTION

In accordance with the initial recommendation of NUREG 0578, Section 2.1.2 as later clarified by NUREG 0737, item II.D.1 and revised September 29, 1981, each Pressurizer Water Reactor (PWR) Utility on or before July 1, 1982, was to submit information relative to the pressurizer safety and relief valves in use at their plant. Specifically, this submittal should include an evaluation supported by test results which demonstrate the capability of the relief and safety valves to operate under expected operating and accident conditions.

The primary objective of the Electric Power Research Institute (EPRI) test program was to provide full scale test data confirming the functionability of the primary system power operated relief valves and safety valves for expected operating and accident conditions. The second objective of the program was to obtain sufficient piping thermal hydraulic load data to permit confirmation of models which may be utilized for plant specific analysis of safety and relief valve discharge piping systems. Relief valve tests were completed in August 1981 and safety valve tests were completed in January 1982. Reports have been prepared by EPRI which document the results of the test program. Additional reports were written to provide necessary justification for test valve selection and valve inlet fluid test conditions. These reports were transmitted to the USNRC by David Hoffman of the Consumers Power Company on behalf of the participating PWR Utilities and are referenced herein.

This report provides the final evaluation of these and other submittals and reports prepared during the review of the test data as they apply to the valves used at H. B. Robinson Unit 2.

2.0 VALVE AND PIPING PARAMETERS

Table 2-1 provides a list of pertinent valve and piping parameters for the H. B. Robinson Unit 2 Safety and Power-Operated Relief Valves. The safety and PORV valve designs installed at H. B. Robinson were not specifically tested by EPRI; however, valves of a simialar design and operation were tested in a configuration similar to that of the actual system configuration at the plant. Justification that the valves tested envelope those valves at H. B. Robinson is provided in the Valve Justification report.(1) The justification was developed based on evaluation performed by the valve manufacturers and considered effects of differences in operating characteristics, materials, orifice sizes and manufacturing processes on valve operability.

Typical inlet piping configurations for H. B. Robinson Unit 2 are provided in Figures 2-1 and 2-2.

Tables 2-2 and 2-3 compare the H. B. Robinson inlet loop seal piping configuration with that of the EPRI test piping arrangement for the Crosby 3K6 and 6M6 Safety Valves and compares the actual plant-specific pressure drop with the test pressure drop for the two (2) test valve arrangements. As can be seen, the plant-specific pressure drops for H. B. Robinson are less than that for the 3K6 or the 6M6 test valve arrangement with the exception that the opening drop is greater than for the 6M6 test valve arrangement. Data will be compared to both test valves in this report.

TABLE 2-1

VALVE AND PIPING INFORMATION

1. SAFETY VALVE INFORMATION

Number of valves	3
Manufacturer	Crosby Valve and Gage
Type	Self Actuated
Size	4K26
Steam Flow Capacity, lbs/hr	288,000
Design Pressure, psig	2485
Design Temperature, ^{o}F	650
Set Pressure, psig	2485
Accumulation	3 percent of set pressure
Blowdown	5 percent of set pressure
Original Valve Procurement Spec.	E-676279

2. RELIEF VALVE INFORMATION

Number of Valves	2
Manufacturer	Copes-Vulcan
Type	Pressurizer Power Relief
Size	2"-NPS
Steamflow Capacity, lbs/hr	210,000 max
Design Pressure, psi	1500 (USAS)
Design Temperature, ^{o}F	650
Opening Pressure, psig	2335

TABLE 2.1 Continued . . .

3. SAFETY AND RELIEF VALVE INLET PIPING INFORMATION

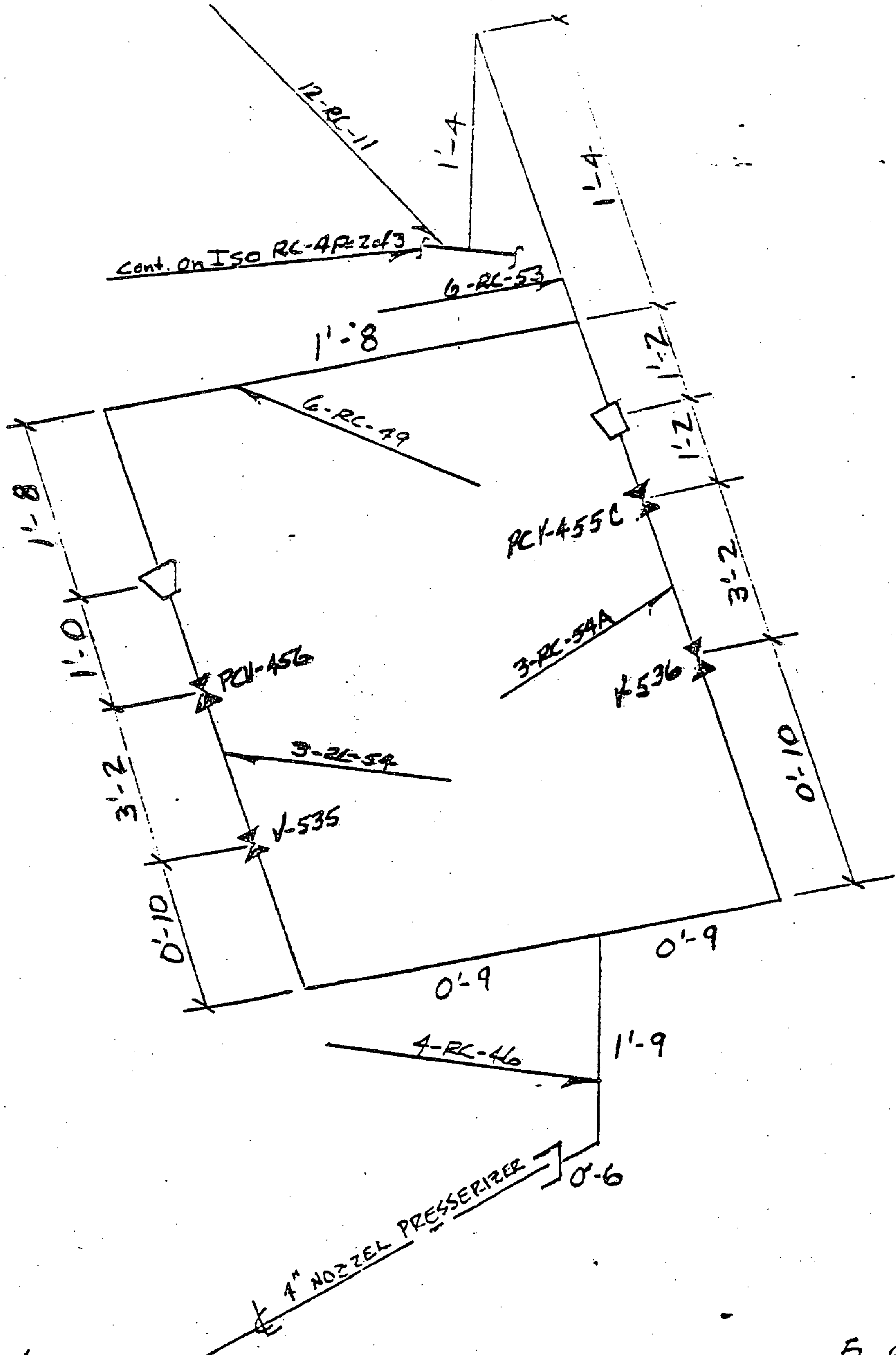
Design pressure, psig	2485
Design Temperature, ^{o}F	650
Configuration of Piping	CPL ISO. RC-4
Pressurizer Nozzle Configuration	CPL ISO. RC-4
Steady State Flow	
Pressure Drop	See Appendix 1
Acoustic Wave Pressure	
Amplitude	See Appendix 1

4. SAFETY AND RELIEF VALVE DISCHARGE PIPING INFORMATION

Design Pressure, psig	600
Design Temperature, ^{o}F	650
Configuration	CPL ISO. RC-4
Pressurizer Relief Tank	
Design Pressure, psig	100
Backpressure, Normal, psig	3
Backpressure, Developed, psig	350

FIGURE 2-1

TYPICAL PORV INLET PIPING CONFIGURATION



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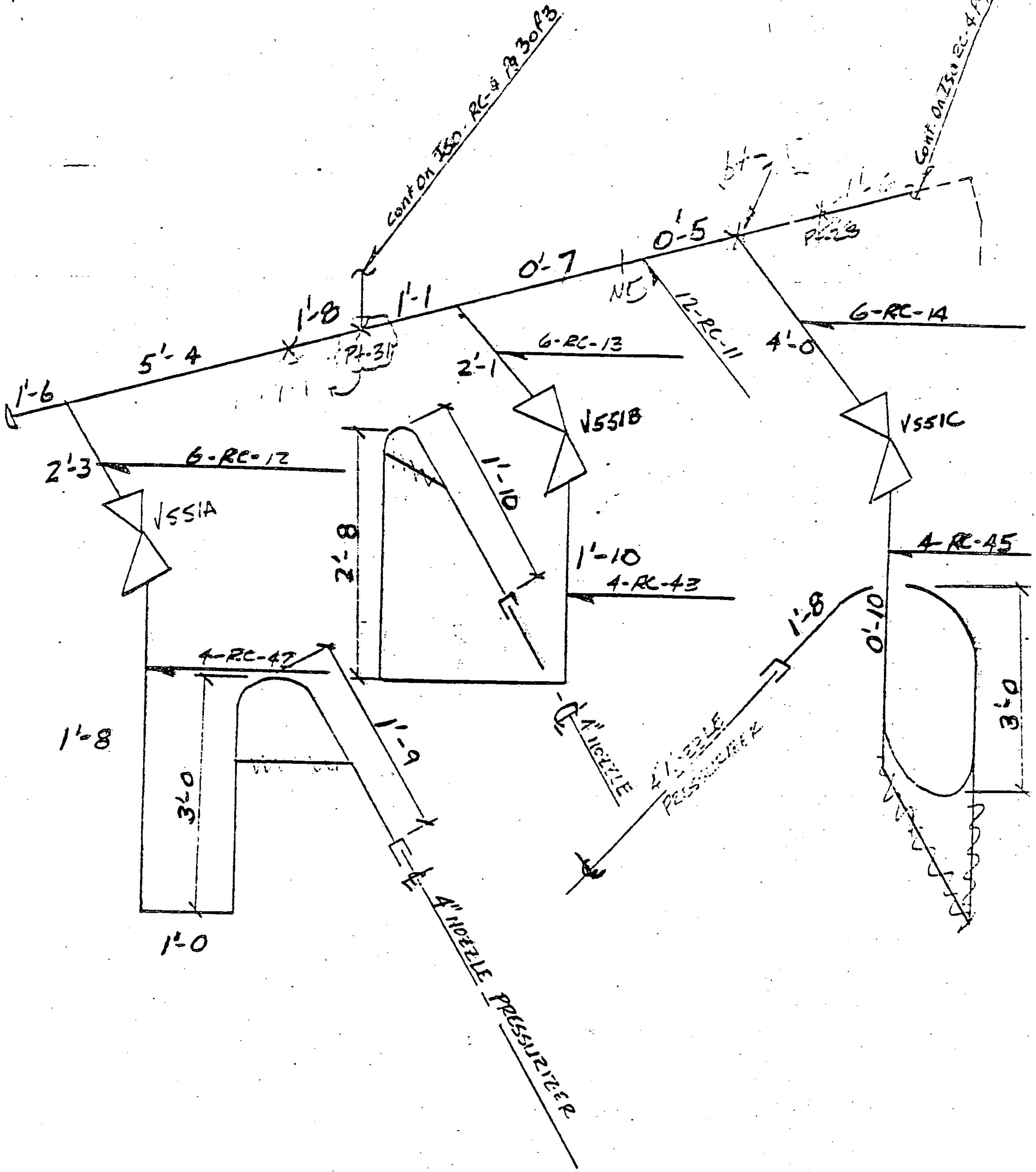
CAROLINA POWER & LIGHT CO.
H.B. ROBINSON S.E.G. PLANT
UNIT NO.-2
ISO. No. RC-4 Pg 3 Of 3

FIGURE 2-2

TYPICAL SAFETY VALVE INLET PIPING CONFIGURATION



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INSPECTED BY:	DATE: 8/ /80
REVIEWED BY: Marvin H. Page	8/21/80

CAROLINA POWER & LIGHT CO.
H.B. ROBINSON S.E.G. PLANT
UNIT NO.-2
ISO. No. RC-4 Pg. 2 Of 3

TABLE 2-2

SAFETY VALVE INLET PIPING COMPARISON

	Typical H. B. Robinson Inlet Piping	3K6 Inlet Piping*	6M6 Inlet Piping*
Length of straight pipe, in.	89	60	61
Number of 90° elbows	3	4	-
Number of 180° bends	-	-	2
Number of 45° Elbows	1	-	-
Misc. fittings, in.	-	72	71
Loop seal water Volume, Ft^3	0.44	0.27	1.02

* Source: Reference (7)

TABLE 2-3

COMPARISON OF TEST PRESSURE DROP WITH PLANT SPECIFIC PRESSURE DROP

Plant Specific* Pressure Drop		6M6 Test** Pressure Drop		3K6 Test** Pressure Drop	
H. B. Robinson					
Opening	Closing	Opening	Closing	Opening	Closing
362	180	263	181	391	194

* Appendix I
** Source: Reference (8)

3.0 VALVE INLET FLUID CONDITIONS

Justification for inlet fluid conditions used in the EPRI Safety and Relief Valve tests are summarized in References 2 and 3. These conditions were determined based on consideration of FSAR, extended High Pressure Injection, and Cold Overpressurization events, where applicable.

For plants of which Westinghouse is the NSSS supplier, a methodology was used such that a reference plant was selected for each grouping of plant considered.(3) Valve fluid conditions resulting from limiting FSAR events, which result in steam discharge and an Extended High Pressure Injection event which may result in liquid discharge, are presented for each reference plant. Use of reference plants results in fluid conditions enveloping those expected for H. B. Robinson Unit 2.

Table 3-1 presents the results of loss of load and locked rotor analysis for three loop plants in which H. B. Robinson Unit 2 was included. The inlet fluid conditions expected at the safety valve and PORV inlets are identified. As can be seen, the Locked Rotor event is considered as the limiting overpressure transient for three loop plants.

The limiting Extended High Pressure Injection event was the spurious activation of the safety injection system at power. For three-loop plants Table 3-2 provides the fluid conditions for safety and PORV's. As the high head Injection Pump cutoff head is 1500 psi, no liquid discharge is expected through the safeties.

Fluid conditions for cold overpressure protection are provided in Table 3-3. Cold overpressure is not a design basis for the Safety Valves but is for the PORV's.

The H. B. Robinson Unit No. 2 cold overpressurization system utilizes the pressurizer power operated relief valves to relieve excess pressure occurring when the RCS temperature is below 350°F. There are two PORV's which are controlled independently by a combination of temperature and pressure instrumentation, and the PORV's are opened if the NDT curve is violated. The system is activated only when the RCS temperature is below 350°F.

TABLE 3-1

VALVE INLET CONDITIONS FOR FSAR EVENTS RESULTING IN STEAM DISCHARGE

Reference Plant	Valve Opening Pressure (psia)	Maximum Pressurizer Pressure(psia)/ Limiting Event	Maximum Pressure Rate (psia/sec)/ Limiting Event
Safety Valves Only			
3-Loop	2500	2592/Locked Rotor	216/Locked Rotor
Safety and Relief Valves			
3-Loop	2350	2555/Locked Rotor	200/Locked Rotor

Source: Reference (2)

TABLE 3-2

SAFETY AND RELIEF VALVE INLET CONDITIONS RESULTING FROM SPURIOUS INITIATION OF HIGH PRESSURE INJECTION AT POWER WHEN VALVES ARE DISCHARGING LIQUID

Reference Plant	Valve Opening Setpoints(psia)	Fluid State on Valve Opening(a)	Maximum Pressurizer Pressure (psia)	Range of Pressurization Rates(psi/sec)	Range of Surge Rates When Valve Is Passing Liquid(GPM)	Range of Liquid Temperature At Valve Inlet(°F)
Safety Valves						
3-Loop	No Discharge					
Relief Valves						
3-Loop	2350	Steam/Liquid	2352	0-12	0.0-781	408-502

a. First/subsequent openings.

TABLE 3-3

PORV INLET CONDITIONS FOR COLD OVERPRESSURE PROTECTION RESULTING IN WATER DISCHARGE

Reactor Coolant Pressure (psig)	Temperature Range, °F
400	350

4.0 COMPARISON OF EPRI TEST DATA WITH PLANT-SPECIFIC REQUIREMENTS

The Electric Power and Research Institute (EPRI) conducted full scale flow tests on pressurizer safety and relief valves.[4] Tests were conducted at three sites over a period of 1-1/2 years. PORVs were tested at Marshall Steam Station[5] and Wyle Laboratories,[6,7] while safety valves were tested at the Combustion Engineering Test Site in Connecticut.[7]

4.1 Relief Valve Testing

Test results applicable to the PORVs installed in H. B. Robinson Unit 2 are contained in Section 4.7 of Reference 7, Copes-Vulcan Relief Valve (17-4PH Plug and Cage).

This valve fully opened and closed on demand for each of the eleven evaluation tests at the Marshall Test Facility. Eight additional tests were conducted at the Wyle Test Facilitiy; during all of these tests the valve fully opened and closed on demand. Subsequent disassembly and inspection revealed the cage to body gasket had partially washed out during the testing. No damage was observed that would affect future valve performance.

A comparison of the "As-Tested" inlet fluid conditions for the Marshall and Wyle tests is provided in Table 4-1. This table indicates the H. B. Robinson Unit 2 fluid conditions summarized in Section 3.0 of this report were tested. The results of this testing as shown in Tables 4-1 and 4-2 indicate the valves functioned satisfactorily, opening and closing in the required time and discharging the required flow rate.

4.2 Safety Valve Testing

Test results applicable to the safety valves installed at H. B. Robinson Unit 2 are contained in Section 3.4 and 3.5 of Reference 7. Although the Crosby 4K26 safety valve used at H. B. Robinson Unit 2 was not specifically tested by EPRI, justification for extension of the EPRI test results to this valve was provided by the valve vendor.[1]

4.2.1 Crosby 3K6 Safety Valve Tests

The Crosby 3K6 test valve underwent a series of tests at the EPRI/CE Test Facility. The "As-Tested" fluid inlet conditions for the 3K6 test valve are compared to the H. B. Robinson Unit 2 fluid inlet conditions in Table 4-3 of this report. This comparison shows the EPRI "As-Tested" fluid conditions envelope those for H. B. Robinson.

The Crosby 3K6 test valve was tested using various inlet piping configurations and with the loop seal filled and drained. Results of tests conducted on the long inlet piping configuration with loop seal internals installed are summarized herein.

Seven tests were performed with the 3K6 valve mounted on a long inlet piping configuration and with loop seal internals installed. Ring settings used during these tests were established during earlier tests on this valve (with steam internals installed). Steam tests were conducted both with the loop seal drained and filled. For the test with a drained loop seal the valve opened within the EPRI criteria and had stable behavior. When the pressure accumulated to 6 percent above set pressure, rated lift was achieved. Valve blowdown was reported to be 15.7 to 20 percent for these tests.

Four loop seal-steam tests were run at ramp rates of 3-220 psi/sec. Initial valve lift was reported at pressures from 2356-2630 psi. The valve fluttered at partial lift positions while discharging the loop seal water and then popped open at steam pressures from 2555-2707 psi. This behavior is typical of loop seal safety valve performance. Valve behavior was reported to be stable on steam and the valve achieved rated lift when the pressure was 6 percent above the valve design set pressure. The valve closed with 17-20 percent blowdown.

The test valve was subjected to a steam to water transition test. The valve was observed to undergo a typical loop seal discharge at partial lift, popped open on steam within ± 3 percent criteria, was stable on steam flow, and began to flutter and subsequently chatter during the water flow portion of the test.

4.2.2 Crosby 6M6 Safety Valve Tests

The Crosby 6M6 test valve underwent a series of tests at the EPRI/CE Test Facility. The "As Tested" Fluid Inlet Conditions for the 6M6 are compared to the H. B. Robinson Unit 2 Fluid inlet conditions in Table 4-3.

This comparison shows the EPRI "As Tested" Fluid Conditions envelope those for H. B. Robinson.

Two groups of tests were conducted on the Crosby 6M6 (Loop Seal Internals) Test Valve, one group with "As Installed" ring settings and one group with "lowered" ring settings.

For the "As-Installed" ring settings four loop-seal steam tests were conducted, all at pressurization rates far above that expected for H. B. Robinson. Two tests were conducted with a cold loop seal while the other two tests were conducted with 350°F loop seals.

For the four tests conducted, the test valve popped open on steam at pressures ranging from 2675-2757 psia following a typical loop seal (water) discharge and for the first actuation cycle, the valve stem stabilized and closed with 5.1-9.6 percent blowdown.

For the last test, the valve opened, closed (with stable performance) and then reopened when test system pressure was allowed to keep increasing causing an inadvertent second lift. The test was terminated after the valve was manually opened to stop chattering. It is noted that chatter didn't occur until the second valve lift, after a successful test lift.

A transition test with 650°F water was successfully conducted. Subsequently a 550°F water test was tried with the test terminated when the valve started to chatter. Note no water discharge is expected at the safety valves at H. B. Robinson.

Seven additional loop seal tests were conducted with "lowered" ring settings as well as two additional transition tests. The results of those tests are detailed in Section 3.5 of Reference 7.

Five cold loop seal steam tests were performed at ramp rates from 3-375 psi/sec. The valve exhibited typical loop seal openings with the full opening pressures varying from 2580-2732 psia depending on ramp rate. The valve closed in a range of 7.4 to 8.2 percent blowdown.

Two hot loop seal tests were conducted with full opening pressures of 2655-2692 psia after the typical loop seal opening, and closed with 8.2-9.0 percent blowdown. In the second test the valve again reopened and chattered when system pressure was permitted to increase causing the second lift. The chatter occurred during the second valve lift, after a successful test lift.

4.2.3 Discussion of Observed Safety Valve Performance

In addressing observed valve performance, one must differentiate between the valves and fluid conditions tested and the actual valves and actual fluid conditions for the specific plant. The EPRI inlet piping arrangement, flow and acoustic pressure drops, and inlet fluid conditions bound the same plant-specific parameters for the H. B. Robinson unit. Valve performance observed during the EPRI tests, therefore, reflects worst case performance as compared to results that would be observed had the testing been conducted using actual plant-specific piping arrangements and fluid conditions.

A review of Table 4-3 shows both Crosby safety valves tested exhibited stable operation on a loop seal piping configuration at pressurization rates of 1.1-375 psi/sec with initial opening pressures of 2455-2630 psi and pop pressures of 2455-2757 psi.

The EPRI data also indicates that steam flow rates in excess of rated flows are attainable. However, data also shows these flow rates are delayed some period of time following the assumed valve opening point resulting in the high pop pressures.

Safety valve performance observed in the EPRI tests is addressed in Reference 9 for Westinghouse Plants and the results and conclusions of this report can be extended to H. B. Robinson Unit 2.

4.2.3.1 Loop Seal Opening Response

To assess the effect on reactor coolant system pressure due to valve opening response on loop seal discharge, a series of overpressure transients were run with various time delays inserted for the valve opening. Results of the analysis are presented in Reference 9. For the limiting Condition II events, safety valve functioning is not required if the reactor trips on high pressurizer pressure. If the reactor does not trip until the second protection grade trip, a valve opening delay time of two seconds for the loss of load transient would still provide acceptable overpressure protection. Note that the test results showed valve delay time in the range of 0-2 seconds at pressurization rates similar to the loss of load transient. Evaluation of the limiting condition IV event shows all components of the reactor coolant system would remain within 120 percent of the system design pressure even in the event of no safety valve opening.

4.2.3.2 Inlet Piping Pressure Oscillations

As observed during the loop seal discharge tests, oscillations occur upstream of a spring loaded Safety valve while water is flowing through the valve. An analysis of this phenomenon was conducted and the results are documented in Reference 9. Table 4-4 provides the maximum permissible pressures for pressurizer Safety valve inlet piping size and schedule representative of H. B. Robinson. These pressures are shown for upset (level B) and emergency (level C) conditions at 300°F and 400°F. It is assumed that H. B. Robinson's inlet piping temperatures will be in this range. Reference 9 indicates level C stress limits may be applied for Safety Valve discharge transients. Based on tests and analytical work to date, all acoustic pressures observed or calculated prior to and during safety valve discharge are below the maximum permissible pressure.

4.2.3.3 Valve Chatter on Steam

Since the EPRI testing was conducted at enveloping fluid and piping conditions, adjustments were made to the safety valve ring positions in order to obtain stable valve performance on steam discharge for the test arrangement. These adjustments resulted in longer blowdowns for the test valves, as opposed to what would be expected in a plant-specific situation. The ring positions determined during the test represent the adjustment required to provide stable operation for a particular test valve when exposed to the particular test piping arrangement, fluid conditions, backpressure and pressurization rate. Valves installed at H. B. Robinson were set by the valve manufacturer to operate on a 7'-10' loop seal. As H. B. Robinson loop seal meets these conditions it is expected that stable performance will result.

An investigation was conducted to determine those parameters which are critical to the onset of valve chatter under steam discharge conditions. The results of this study are detailed in Reference 9.

TABLE 4-1

COMPARISON OF PORV INLET FLUID CONDITIONS WITH "AS-TESTED" CONDITIONS

Steam Conditions

	PORV Inlet Fluid Conditions	Wyle Test 63-CV 174-1S	Marshall Test (No. 1 - No. 11)
Set Point Pressure (psia)	2350	2477	(2430-2505)
Temperature (^oF)	650	670	(sat.)
Fluid Type	steam	steam	steam
Flow Rate (lbs/hr)	210,000	255,600	(221,000-220,000)

Water Conditions

	PORV Inlet Fluid Conditions		Wyle Test 63-CV-174-1S 69-CV-174-7S/W		Marshall Test (No. 1-No. 11)
Set Point Pressure (psia)	400	2350	675	2352	675
Temperature (^oF)	350	408-502	442	649	106
Fluid Type	Water	S/L	Water	S/L	Water
Flow Rate (lbs/hr)	-	-	399,600	576,000	630,000

TABLE 4-2

TABULATION OF OPENING/CLOSING TIMES FOR PORV

Test	Opening Time (Sec.)	Closing Time (Sec.)
Marshall		
1	1.600	1.950
2	1.300	2.000
3	1.100	2.100
4	1.300	2.000
5	1.400	2.000
6	1.400	1.700
7	1.300	1.700
8	1.300	1.655
9	1.400	1.700
10	1.400	1.600
11	1.500	1.700
Wyle		
63-CV-174-1S	0.57	1.34
64-CV-174-2S	0.49	1.34
65-CV-174-4W	0.57	1.15
66-CV-174-3W	0.97	0.54
67-CV-174-5W	0.90	0.61
68-CV-174-6W	0.66	1.29
69-CV-174-7W/W	0.52	1.27
70-CV-174-8W/W	0.50	1.35

Note: Required Opening Time - 2.0 Sec.
Required Closing Time - 2.0 Sec.

TABLE 4-3

COMPARISON OF SAFETY VALVE INLET FLUID CONDITIONS WITH "AS-TESTED" CONDITIONS

	Safety Valve Inlet Fluid Conditions	Tests 3K6 525-532 and 536	Tests 6M6 No. 906-913, 917-923, 925 1406, 1415 and 1419
Set Point Pressure (psia)	2500	2500	2500
Temperature (^{o}F)	650	650	650
Fluid Type	Steam	loop seal/steam	loop seal/steam
Flow Rate (lbs/hr)	288,000	*	*
Pressurization Rate (psi/sec)	200-216	3.4-200	1.1-375
Back Pressures	350	485-625	227-775
Stability		Stable**	Stable**
Initial opening Pressure (psia)		2536-2630	2455-2600
Pop Pressure, (psia)		2532-2707	2455-2757

* Rated flow achieved but not reported in EPRI Tables, reference (7).
** As reported by EPRI in Performance data tables of Reference (7).

TABLE 4-4

MAXIMUM PERMISSIBLE PRESSURE FOR PRESSURIZER SAFETY VALVE INLET PIPING

Pipe Size	Outside Diameter (in)	Nominal Thickness(in)	Permissible Pressure (psi)			
			300°F		400°F	
			Level B	Level C	Level B	Level C
** 4-inch Sch. 120	4.500	0.438	4644	6333	4458	6080

Source: Reference (9)

**H. B. Robinson Inlet Piping

5.0 CONCLUSIONS

The preceeding sections of this report and the reports referenced herein indicate the valves, piping arrangements, and fluid inlet conditions for H. B. Robinson Unit 2 are indeed bounded by those valves and test parameters of the EPRI Safety and Relief Valve Test Program. The EPRI tests confirm the ability of the Safety and Relief Valves to open and close under the expected operating fluid conditions.

APPENDIX

APPENDIX I

INLET PIPING PRESSURE EFFECTS

1. Transient Flow Pressure Difference (ΔP_F) Calculation

The flow pressure difference due to pipe friction and fittings is given by:

- If $T \leq 2 L/a$,

$$\Delta P_F = \frac{\left(K + \frac{fL}{D}\right)(CM)^2}{2 g_c \rho A^2}$$

- If $T > 2L/a$,

$$\Delta P_F = \frac{\left(K + \frac{fL}{D}\right)(CM)^2 \left(\frac{2L}{aT}\right)^2}{2 g_c \rho A^2}$$

where,

- K = summation of expansion and contraction loss coefficients corrected if required to correspond to the inlet piping flow area. (NOTE: The contraction from the pressurizer to the inlet pipe can be assumed to be smooth and therefore the loss coefficient can be assumed to be zero)(dimensionless)
- f = friction factor (dimensionless)
- $\frac{L}{D}$ = piping equivalent length/diameter considering effects of elbows and friction (dimensionless)
- M = rated valve flow rate for steam as specified in Table B-1 (lb/sec)
- g_c = gravitational constant (32.2 lb-ft/lb-sec^2)
- ρ = steam density at nominal valve set pressure (lb/ft^3)
- A = inlet piping flow area (ft^2)
- a = steam sonic velocity (ft/sec) - use 1100 ft/sec for all calculations

L = inlet piping length (from the pressurizer inside diameter to the interface between the inlet pipe flange and the valve inlet flange) (ft)

T = valve opening or closing time for steam inlet conditions (sec)

C = flow rate constant for valve opening or closing.

2. Transient Acoustic Wave Amplitude (ΔP_{AW}) Calculation

The acoustic wave amplitude is calculated based on information in Reference 2. There are two situations to consider:

- If $T \leq 2L/a$,

$$\Delta P_{AW} = \frac{a(CM)}{g_c A} + \frac{(CM)^2}{2g\ \rho A^2}$$

- If $T > 2L/a$,

$$\Delta P_{AW} = \frac{2L\ (CM)}{g_c AT} + \frac{(CM)^2 \left(\frac{2L}{aT}\right)^2}{2\ g_c \rho A^2}$$

All parameters are defined in Section 1 above.

3. Plant-Specific Transinet Pressure Difference Calculation

The plant-specific pressure difference associated with valve opening or closing is equal to the sum of the flow pressure difference (ΔP_F) and the acoustic wave amplitude (ΔP_{AW}) as determined above.

4. Plant-Specific Steady-State Flow Pressure Difference Calculation

The steady-state flow pressure difference associated with valve opening or closing is given by:

$$\Delta P_F = \frac{\left(K + \frac{fL}{D}\right)(CM)^2}{2g_c \rho A^2}$$

All parameters are defined in Section B.1 above. Note that the values of the flow rate constant, C, are different for valve opening and closing.

5. Plant-Specific Pressure Difference for H. B. Robinson

A. Valve Opening

T_{op} = .010 sec.

$$\frac{2L}{a} = \frac{2x\ 7.7\ ft}{1100\ ft/sec} = .014\ sec.$$

$T_{op} < 2L/a$

(1) Transient Flow Pressure Difference

Since $T_{op} < 2L/a$, the flow pressure difference is,

$$\Delta P_f = \frac{(K + \frac{fL}{D})\ (CM)^2}{2g_c\rho A^2}$$

where,

$$M = \frac{288{,}000\ lb/hr}{3600\ sec/hr} = 80\ lb/sec$$

C = 1.11 (Ref. 8)

k = 0 (Ref. 8)

f = .017 (Reference 10)

$$\frac{L}{D} = \frac{7.7\ ft}{.302} = 25.5$$

ρ = 7.65 lb/ft^3 (saturated steam at 2500 psia)

A = 0.072 ft^2

The Flow Pressure Difference is,

$$\Delta P_F = \frac{0 + (.017)(25.5 + (3x30) + (1x16))(1.11x80)^2}{64.4 \times 7.65 \times .072^2 \times 144}$$

ΔP_F = 47.9 psi

(2) Transient Acoustic Wave Amplitude

Since $T_{op} < 2L/a$, the acoustic wave amplitude is,

$$\Delta P_{AW} = \frac{a(CM)}{g_c A} + \frac{(CM)^2}{2\, g_c \rho A^2}$$

$$\Delta P_{AW} = \frac{1100 \times (1.11 \times 80)}{32.2 \times .072 \times 144} + \frac{(1.11 \times 80)^2}{64.4 \times 7.65 \times .072^2 \times 144}$$

$$\Delta P_{AW} = 314 \text{ psi}$$

(3) Plant Specific Transient Pressure Difference

Plant-specific pressure difference for valve opening is,

$$\Delta P = \Delta P_F + \Delta P_{AW}$$

$$\Delta P = 48 + 314 = 362 \text{ psi}$$

(4) Plant-Specific Steady-State Flow Pressure Difference

$$\Delta P_F = \frac{(K + \frac{fL}{D})\,(CM)^2}{2 g_c \rho A^2}$$

ΔP_F = 47.9 psi (From above)

(5) Plant-Specific Pressure Difference for Plant Versus Test Evaluation (Opening)

Based on the above, the controlling pressure difference is the transient pressure difference, is 362 psi

(b) Valve Closing

$T_{CL} = .016$ sec $\qquad\qquad C = .69$

Also, $2L/a = \dfrac{2 \times 7.7}{1100} = .014$

$T_{CL} > 2L/a$

(1) Transient Flow Pressure Difference

$$\Delta P_F = \frac{\left(K + \frac{fL}{D}\right)(CM)^2 \left(\frac{2L}{aT}\right)^2}{2 g_c \rho A^2}$$

$$\Delta P_F = \frac{0 + (.017)(25.5 + (3 \times 30) + (1 \times 16))(.69 \times 80)^2 \left(\frac{2 \times 7.7}{1100 \times .016}\right)^2}{2 \times 32.2 \times 7.65 \times .072^2 \times 144}$$

$\Delta P_F = 14.2$ psi

(2) Transient Acoustic Wave Amplitude

Since $T_{CL} > 2L/a$, the acoustic wave amplitude is,

$$\Delta P_{AW} = \frac{2L\,(CM)}{g_c A T} + \frac{(CM)^2 \left(\frac{2L}{aT}\right)^2}{2\, g_c \rho A^2}$$

$$\Delta P_{AW} = \frac{2 \times 7.7\ (.69 \times 80)}{32.2 \times .072 \times .016 \times 144} + \frac{(.69 \times 80)^2 \left(\frac{2 \times 7.7}{1100 \times .016}\right)^2}{64.4 \times 7.65 \times .072^2 \times 144}$$

$\Delta P_{AW} = 165.5$ psi

(3) Plant-Specific Transient Pressure Difference

The plant-specific pressure difference for valve closing is,

$\Delta P = \Delta P_F + \Delta P_{aW} = 14.2 + 165.5 = 180$ psi

(4) Plant-Specific Steady-State Flow Pressure Differences

The steady-state flow pressure difference is 47.9 psi

(5) Plant-Specific Pressure Difference For Plant Versus Test Evaluation (Closing)

Based on the above, the controlling pressure difference is the transient pressure difference, 180 psi.

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