UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

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November 1, 1979

MEMORANDUM FOR: D. F. Ross, Jr., Director, Bulletins & Orders Task Force

FROM: C. C. Graves, Reactor Systems Branch, DSS

SUBJECT: PRESSURIZER POWER-OPERATED RELIEF VALVES

As you requested, a brief study was made of the flow capacity of pressurizer power-operated relief valves. As I understood the problem, the objectives of this study were (a) to resolve some apparent discrepancies in tabular presentations of valve capacities and mass velocities prepared by the staff, (b) check vendors use of valve manufacturer data in calculating valve flow rates during transients, and (c) express my judgment of the merits of any valve test results and analysis methods. All of these objectives were not met. In particular, I was not able to get sufficient information from Westinghouse and Babcock & Wilcox during the time available. However, I believe that you will find the information presented in the enclosure useful to your effort. (Time charged for study, 34 hours.)

The following conclusions result from this study:

1. Tests on the capacity of the particular valves used as PORVs with dry, saturated steam at the inlet are:

   a. either at very low pressures (30 to 50 psig) with one valve size as in the case of Dresser valves, or

   b. nonexistent, as in the case of Copes-Vulcan valves.

2. For the case of dry, saturated steam at the inlet, the uncertainty in valve capacity at, say, 2400 psig, due to lack of test data may not be excessively large because of the calculation methods and general information available on choked flow of steam. However, it is recommended that the staff require confirmatory tests with steam at representative inlet pressures.

3. I am not aware of any test data for these valves with subcooled water, saturated water, or two-phase flow at the inlet. There would be large uncertainties in predicted valve capacity for these conditions.

4. The valve manufacturers, Combustion Engineering and probably Babcock & Wilcox and Westinghouse, do not use the 0.9 conservative factor in calculating PORV flow as required for safety valves in NB-7000. They would not be required to use this factor or to have certified valve tests if no credit is taken for PORVs in overpressure report (NB-7000).

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5. Dresser and Copes-Vulcan do not use the same procedure to obtain the valve name plate capacity and would get different name plate values for the same valve at the same inlet conditions. Copes-Vulcan uses formulas in the Instrument Society of America Standard ISA-SP39.3, "Control Valve Sizing Equations for Compressible Fluids." Dresser uses the Napier formula with a flow coefficient obtained from tests (see ASME NB-7000). Because of this, the reactor vendor's method for calculating valve capacity should be checked (see C-E method in enclosure).

6. The tabular data for valve capacity for C-E and Westinghouse in the B&O draft report are incorrect. The valves are for minimum capacity required by the vendor and are not predicted capacities which, at least for C-E, are much higher (see enclosure).

Charles C. Graves

Charles C. Graves
Reactor Systems Branch

Enclosure:
Valve Information

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cc: R.P. Denise
T. Speis
T. Novak
Z. Rosztoczy
S. Israel
P. Norian
F. Cherny
A. Thadani
M. Stolzenberg

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ENCLOSURE

1.0 Comparison of Methods for Calculating Valve Flow with Saturated Steam at Inlet

A. Isentropic Flow of Compressible Fluid with Constant κ

The choked flow mass velocity at the throat of a nozzle for a perfect gas which undergoes a frictionless expansion in accordance with the relation pv^{κ} = constant where $\kappa = \frac{c_p}{c_v}$ = constant is given by

$$\frac{W}{A_t} \frac{\text{lbm}}{\text{ft}^2\text{-sec}} = \sqrt{2gc \frac{p_0}{v_0} \left(\frac{\kappa}{\kappa+1}\right) \left(\frac{2}{\kappa+1}\right)^{2/(\kappa-1)}} \quad (1)$$

where p_0 is the stagnation pressure lbf/ft^2 and v_0 is the stagnation specific volume lbm/ft^3. For a real fluid which is assumed to follow the pv^{κ} = constant relation, v_0 would be obtained from a table of properties. For the isentropic expansion of saturated steam under condition of thermal equilibrium there would be a large change in κ with decrease in pressure since the fluid is in the quality region. However, if κ is assumed constant at, say, the value for dry, saturated steam, equation (1) could be used. It is noted that low pressure ($\lesssim$100 psia) tests with nozzles and saturated steam at the inlet indicate partial expansion without formation of water (see standard texts and Wilson line).

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B. Napier Formula

The Napier formula used in the ASME code section NB-7000 is

$$W_t \frac{\text{lbm}}{\text{hr}} = 51.5 A_t P \quad (2)$$

where A_t is the throat area in in^2 and P is the inlet pressure in psia. Note that the inlet pressure used in a test would most likely be the static pressure as obtained from a wall tap.

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In NB-7000 a coefficient of discharge K_d, is obtained from testing, where

$$W_{measured} = K_d W_t \qquad (3)$$

In the 1978 summer addendum, a modification to the Napier formula for 1500 psia $\leq P \leq$ 3200 psia is given as

$$W_t \frac{lbm}{hr} = 51.5 A_t P K_N \qquad (4)$$

$$\text{where } K_N = \frac{0.1906P-1000}{0.2292P-1061} \qquad (5)$$

The correction factor K_N makes Equation (4) agree well with the predictions of the homogeneous equilibrium (HEM) model.

Note that for safety valves, a 0.9 conservatism factor would be applied.

$$W_{rated} = 0.9 K_d W_t \qquad (6)$$

and P would correspond to 3% accumulation when the valve is rated for steam.

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C. ISA Formula

The Instrument Society of America Standard ISA-Sp39.3, "Control Valve Sizing Equations for Compressible Fluids," contains a number of formulas and correction factors for sizing valves.

For the present study, the following equation was obtained from the standard for choked flow with dry, saturated steam:

$$W \frac{lb}{hr} = 35.68 \, F_p C_v \sqrt{\frac{p_1 x_T}{v_g}} \qquad (7)$$

F_p is called a piping geometry factor which corrects for the effect of reducers or expanders attached to the valve body. In a call to Westinghouse I was told that the valves are attached directly to the piping; hence, I set $F_p = 1.0$.

For $F_p = 1.0$ and an $x_T = 0.72$ for the Copes-Vulcan valves, this equation would give a value for C_v of 46.5 to get a flow rate of 210,000 lb/hr of dry, saturated steam at 2400 psia. The 210,000 lb/hr value is a minimum required valve capacity specified by Westinghouse for 2400 psia set pressure for some plants.

D. Comparison of Various Model Results for Dry, Saturated Steam

Figure 1 was originally presented in Appendix D of Reference 1 which I prepared in 1974. It illustrates the effect of changes in inlet stagnation pressure on the predicted throat mass velocity under choked flow conditions. It is evident that there is fairly close agreement between the HEM, Moody, and Napier formula results at lower pressures. However, at, say, 2400 psia, there are relatively large differences. Table 1 gives a tabular comparison of the results of all models considered in this study.

Figure 2 (from Reference 2) gives a comparison of predicted and experimental results for a small Crosby safety-relief valve. The valve model number is 1½D2½ JO-66-SIM. The Crosby catalog indicates that this valve has a throat area of 0.110 in^2. Note that the valve capacity is generally larger than predicted. From comparison of Figure 2 and Table 1, note the good agreement between the test data on some models at the higher pressures.

2.0 Dresser and Copes-Vulcan Valve Information

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A. Dresser Power-Operated Relief Valves

Dresser Elecromatic Relief Valves, Model Number 31533VX or 31533VX-30, are used in most CE and B&W plants. The two models differ only with respect to the pilot valve region and, hence should have the same capacity for a given orifice size and inlet pressure.

An initial check of the Dresser valve capacities was made by using tabular values given in Dresser catalogs dated April 1973 and November 1974. The resulting values for the coefficient of discharge, K_d, were appreciably lower than those obtained from CE. Mr. William Casey, Manager, Engineering Department, at Dresser was contacted to resolve this difference. He called back and stated that the values in the Dresser catalogs were incorrect, that the catalogs were no longer being used, and that the Kd of 0.95 used by CE was correct for all orifice diameters of the 31533VX and 31533VX-30 valves. The Dresser valve nameplate capacity is based on this K_d, the Napier formula and the set pressure (0% accumulation).

I asked for information on the tests used to determine this value for K_d. He did not have specific information on the test but believed that only one orifice diameter was tested with low pressure steam during the valve development program. The test results were not recorded at the National Board of Boiler and Pressure Vessel Inspections since the valve is not certified for capacity in accordance with NB-7000 of the ASME Code.

I called Mr. David Ray of the National Board to obtain data on Dresser and Copes-Vulca PORV's. He did not know of any tests on the Copes-Vulcan valve, but did have data on Dresser Electromatic Relief Valve (Model 1533VX(V) with a 1.8125" orifice diameter and 2 1/2" inlet diameter). The valve, which is somewhat similar to the V1533VX valve, had a K_d of 0.87. The valve was tested in 1968 at four inlet pressures ranging from about 34 to 49 psig.

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B. Copes-Vulcan Power-Operated Relief Valves

Copes-Vulcan Type D-100 diaphragm-operated control valves are used as PORVs for most Westinghouse plants. Copes-Vulcan personnel at the main plant engineering department were contacted to obtain information on these valves. These Copes-Vulcan valves are not certified for capacity in accordance with NB-7000 of the ASME Code. The valve capacity is calculated using formulas in the Instrument Society of America Standard ISA-SP39.3 (April 1973). No tests of this valve were run with steam.

Two valve parameters (X_T and C_v) and two steam properties (density, specific heat ratio) are used in the calculations. X_T is a dimensionless pressure ratio (pressure drop across value, p_1-p_2, divided by inlet pressure, p_1). From tests at constant p_1, p_2 is decreased until the flow rate becomes independent of p_2 (choked flow). The pressure ratio at this point is $F_K X_T$ (F_K = K/1.4). The valve sizing coefficient, C_v, is a measure, in part, of trim size (i.e., proportional to flow area). The ISA standard permits use of water tests to determine C_v. This was done for the Copes-Vulcan valves. It was noted that the ISA standard has been adopted as an ANSI standard for control valve sizing. Note also that the pressures are static pressures.

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3.0 Reactor Vendor Information

A. Combustion Engineering

Table 2 provides values for PORVs of plants with a CE NSSS. It is noted that three values of valve relief capacity are given. The smallest values are the minimum required values specified by CE (these values were incorrectly given as actual valve capacities in the table of the B&O draft report on CE). The valve nameplate capacities at the set pressure (i.e. 0% accumulation) were calculated by Dresser using the Napier formula and the discharge coefficient, K_d, of 0.95 obtained from the low pressure tests with steam. The valve nameplate capacities are given by:

$$W \frac{lb}{hr} = 51.5\ K_d\ AP$$

Where K_d = 0.95, A = orifice area in inches^2 and P (for this case) is 2400 psi Values of the orifice diameter and area are supplied in the table.

The product K_dA representes an effective orifice area which is used with a critical flow model for the mass velocity G in lb/hr - ft^2 to calculate valve flow during a transient. CE used the following models for G:

1. $G = 51.5P \frac{(0.1906P - 1000)}{(0.2792P - 1061)}$

   The factor in parentheses is a correction to the Napier formula used at P≥1500 psia which was developed to give approximately the same value for G as that obtained from the Homogeneous Equilibrium Model. It is given in the Summer 1978 Addenda to the ASME Code.

2. For two phase flow:

   G from Moody Model

3. For subcooled:

   G from Henry-Fauske Model as modified by CE

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B. Westinghouse

The only information obtained was that valve capacities such as 210,000 lb/hr for North Anna and 169,000 lb/hr for Ginna are Westinghouse-specified minimum capacities. Hence, the B&O tabular values for Westinghouse relief valves should be corrected.

C. B&W

I asked for specific information from B&W. They have not supplied this information.

References

1. Appendix D of "Evaluation of LOCA Hydrodynamics," Regulatory Staff: Technical Review, USAEC, November 1974.

2. Thompson, L., and Buxton, O. E., Jr., "Maximum Isentropic Flow of Dry Saturated Steam Through Pressure Relief Valves," June 1979.

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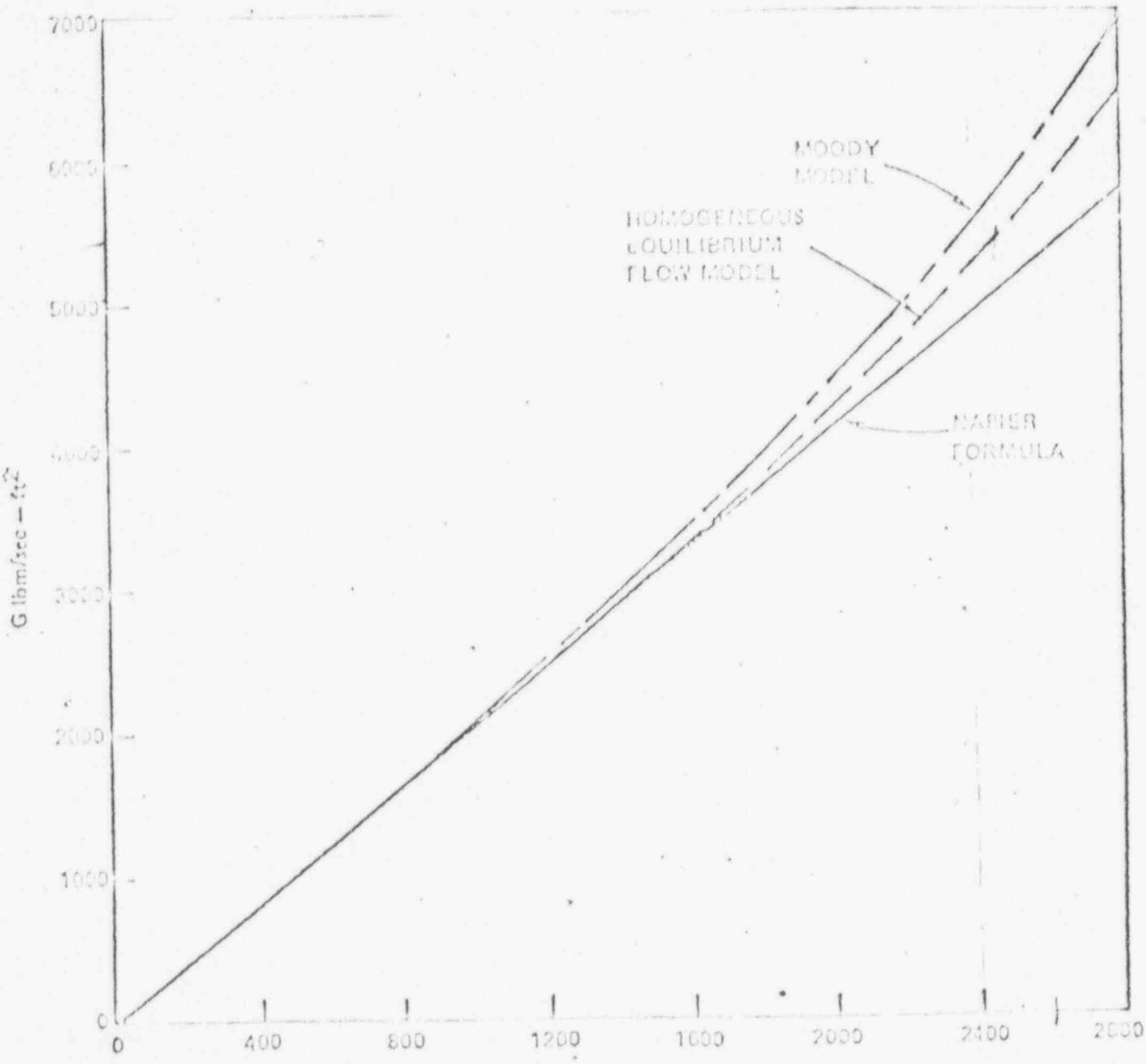

Figure D-1 Comparison of Theoretical Values for Choked Flow Mass Velocities for Dry Saturated Steam at Inlet

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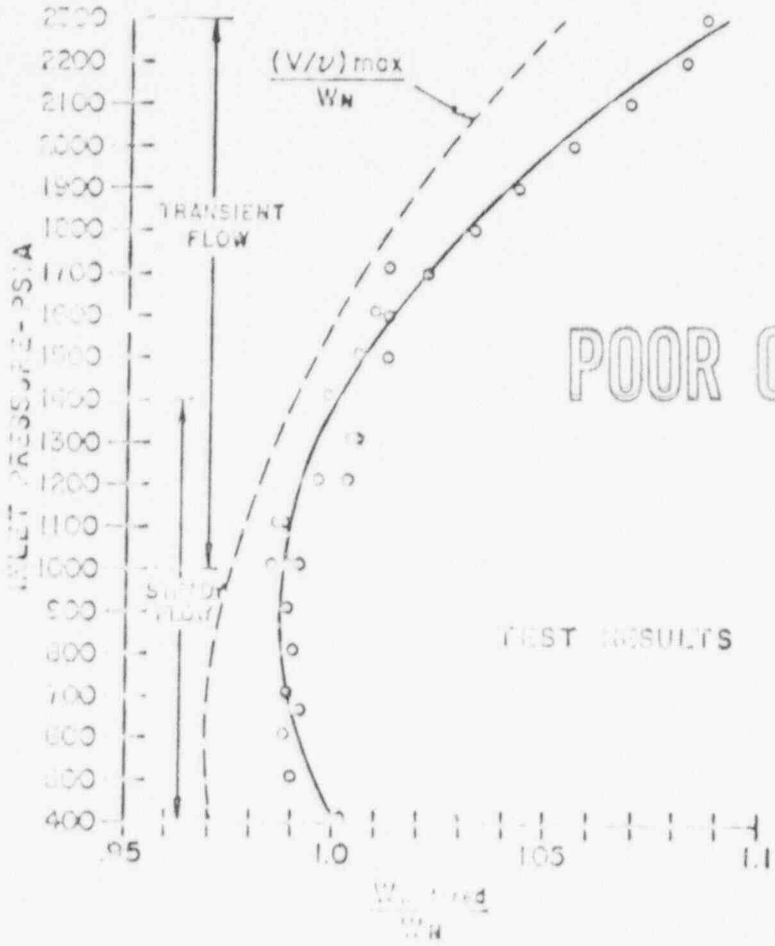

Figure 2. Comparison of Predicted and Experimental Capacity of Small Crosby Valve (0.110 in² Orifice).

Table 1: Effect of Pressure on Choked Flow Mass Velocity for Dry Saturated Steam

P psia	G Moody lb/sec - ft^2	G Moody / G Napier	G HEM / G Napier	GSIA* / E Napier	$C_{constant}$ κ / G Napier
50	107	1.036	1.020		
100	210	1.017	1.0		
200	413	1.0	.983	1.0	1.031
400	819	.993	.971	.989	1.020
600	1229	.994	.969	.984	1.017
800	1646	1.0	.972	.987	1.022
1000	2074	1.007	.977	.997	1.032
1200	2513	1.016	.983	1.006	1.042
1400	2965	1.028	.992	1.012	1.051
1600	3434	1.042	1.002	1.037	1.075
1800	3922	1.058	1.103	1.057	1.096
2000	4435	1.076	1.027	1.094	1.130
2200	4979	1.099	1.044	1.130	1.165
2400	5565	1.126	1.064	1.164	[illegible]

*Normalized to G Napier at 200 psia.
If formalized to $G_{constant}$ κ at 200 psia
G_{ISA} would agree with $G_{constant}$ κ to within ±1/2%

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Table 2: Combustion Engineering PORVs

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Plant Name	Calvert Cliffs 1/2	Palisades	Millstone 2	Ft. Calhoun 1	Maine Yankee	St. Lucie 1
Minimum Required Valve Capacity as Specified by C-E, lb/hr	153,000	153,000	153,000	29,000	150,000	153,000
Orifice Area, in^2	1.354	1.484	1.354	0.94	1.354	1.354
Discharge Coefficient, K_d	0.95	0.95	0.95	0.95	0.95	0.95
Name Plate Capacity, lb/hr	158,537	174,251	158,850	110,200	158,869	158,850
Capacity with Name Plate Capacity Multiplied by K_N, lb/hr	168,200	184,900	168,500	116,900	168,500	168,500

Note 1. ANO-2 does not have PORV. All others have two PORVs.

Note 2. All PORVs Consolidated Electromatic by Dresser.

Note 3. PORVs are Model No. 31533 VX-30 for all plants but Palisades which is 31533VX.

Note 4. Inlet diameter [illegible] inches for all PORVs.

Note 5. All capacities for inlet pressure = 2400 psia = set pressure.