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Title: STUDY OF SAFETY RELIEF VALVE OPERATION
UNDER ATWS CONDITIONS

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TECHNICAL DATA RECORD

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L. J. Auge		STATEMENT OF PROBLEM To search the literature to ascertain if sufficient data has been generated since mid-1975 to substantiate the method of determining safety relief valve capacity under ATWS conditions.			
J. O. Bates					
R. J. Beeley					
J. B. Brukiewa					
J. R. Cleveland					
J. C. Cochran					
R. E. Fenton					
E. S. Hutmacher		ABSTRACT: A literature survey and analysis project has been performed to determine if recent (since mid-1975) data has been reported which could influence the current approach to predicting PWR relief valve capacity under ATWS conditions. This study was conducted by the Energy Technology Engineering Center for NRC. Results indicate that the current relief valve capacity model tends to predict less capacity than actually obtains, however, no experimental verification at PWR ATWS conditions was found. Other project objectives were to establish the availability of methods for evaluating reaction forces and back pressure effects on relief valve capacity, and to determine if facilities exist which are capable of testing PWR relief valves at ATWS conditions.			
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I. INTRODUCTION

During certain anticipated transients without scram (ATWS) events postulated for pressurized-water nuclear reactors, the plant safety relief valves (designed for operation with steam) are forced to relieve saturated or subcooled water at pressures ranging to over 3000 psia. Since the flow capacity rating of these valves is based upon tests conducted with steam only, it became necessary to obtain realistic (but conservatively low) estimates for safety relief flow capacity for saturated and subcooled water under ATWS conditions.

In pursuit of these off-design valve capacity estimates, the U.S. Nuclear Regulatory Commission (NRC) conducted a literature search through mid-1975. The NRC search revealed only one source of experimental data on a 1/2-in. nozzle-type safety valve flowing saturated water (at relatively low pressure, however) and only sparse data on saturated and subcooled water flow through orifices, nozzles, or valves at various pressures. Correlations were made from the available data and it was concluded that the isentropic homogeneous equilibrium (IHE) model with the 0.9 ASME conservatism factor best simulated the ATWS conditions. Based on uncertainties in safety relief valve certification test data and possible variations in flow due to manufacturing tolerances, it was recommended that additional tests of safety relief valves at ATWS conditions would be useful in establishing a realistic flow model and obtaining information concerning the opening pressure.

The above conclusions and recommendations were repeated in a NRC staff report of April, 1978 (Reference 2); however, before commencing a test program at this point, it was considered prudent to survey the literature again to determine if anything of substance had become available since mid-1975. Consequently, the Energy Technology Engineering Center (ETEC) was requested by NRC in 1978 to update the 1975 study. Specifically, ETEC was requested to conduct a comprehensive search of literature and industrial data from mid-1975 to:

- 1) Evaluate the procedure (Reference 1) for determining safety relief valve operating characteristics under ATWS conditions (e.g., 3000 psia, -40°F subcooled water).
- 2) Understand methods of determining back pressure and its effect on valve capacity.
- 3) Understand methods of calculating valve reaction forces under dynamic flow conditions.
- 4) Determine with NRC the availability of test facilities which could be used to provide any requisite data not available in literature and industry.

II. SUMMARY

Safety relief valves designed to protect pressurized-water nuclear reactors are tested and certified with steam as the test fluid. Under certain postulated ATWS events, these valves are required to flow saturated or subcooled water. NRC conducted a literature survey to mid-1975 seeking experimental data to substantiate the conservative IHE model.* It was concluded that additional tests of safety relief valves at ATWS conditions would be useful in establishing a realistic flow model and obtaining information concerning the valve opening pressure. Before conducting the recommended tests, NRC wanted to determine if any data had become available since mid-1975. In October 1978 ETEC commenced a literature survey to update the NRC study.

Printouts of four searches made by the Nuclear Safety Information Center (NSIC) for NRC, prior to ETEC participation, were made available to ETEC. An additional nine searches were made by ETEC into the Energy Information Data Base (EDB) at the U.S. Department of Energy (DOE), Technical Information Center. Printout abstracts were evaluated for useful information and data and papers and reports ordered for further evaluation.

Since the study was of short duration, manual searches of indexes available to ETEC were made. A series of subjects were developed and the various indexes checked. Subjects of interest were further pursued to the abstracts and finally, papers and reports ordered.

*ASME Section VIII:

$$W = 0.9 G_M A_t K_D$$

In this equation, W is the mass flowrate, 0.9 is the ASME conservatism factor, A_t is the flow area at the throat, and K_D is the nozzle coefficient obtained with steam under the Section III certification tests. It is assumed that full lift with water at the inlet is obtained at 110% of the set pressure.

An industry and related-organization search was made to see if recent published data or unpublished data of any date were available for evaluation. Representative companies and related organizations were selected and letters of inquiry sent out.

Papers and reports from the searches were submitted to ETEC Systems Analysis Unit for evaluation. Appendix D (Reference 1) was used as the basis for the evaluation and papers and reports analyzed to determine if additional data were included to substantiate the conclusions drawn and negate the recommendation for further testing.

Flow capacity data was not found in the literature or industry survey for safety relief valves of any size operating under ATWS conditions. Considerable data was found on nozzles and other devices at pressures to 2500 psia with various degrees of subcooling. This data included in Table 1 of this report illustrates the tendency of the IHE model to under predict (flow is greater than predicted) flow. The under prediction is due to metastable (superheated liquid) flow conditions. Certain conditions may, however, cause the IHE model to overpredict: dissolved gases which may prevent metastable flow conditions, subcooling in excess of 100°F where discontinuity of the sonic velocity occurs at the saturated liquid line, and the nozzle geometry where increased diameter reduces the critical mass flux.

A combined effort by NRC and ETEC was made to find facilities capable of testing full scale safety relief valves under ATWS conditions. While no domestic or foreign existing or planned test facility was found capable of full scale test under the desired conditions, it was apparent that some facilities have the potential for modification to enable performance of part or all of the tests required.

III. CONCLUSIONS

From analysis of the referenced papers and reports, the following conclusions were reached:

- 1) The Isentropic Homogeneous Equilibrium (IHE) flow model tends to under predict flow due to metastable (superheated liquid) flow conditions.
- 2) Metastable flow is caused by the 0.001 second vapor nucleation delay time which corresponds approximately to a 5 in. path length. Nozzles longer than 5 in. are closely predicted by the IHE model.
- 3) Dissolved gases in water act as nucleation sites, thus preventing metastable flow conditions. Dissolved gas concentration in light water reactors is high enough to prevent metastable flow.
- 4) The IHE model under certain highly subcooled conditions over predicts actual flow due to the discontinuity of the sonic velocity at the saturated liquid line.
- 5) Nozzle geometry, size, and inlet conditions significantly influence the critical mass flux. Increased nozzle diameter will reduce the critical mass flux.
- 6) Homogeneous choking seems to control flow at pipe entrances while a secondary slip flow choke occurs at the pipe exit during blowdown.
- 7) Virtually no information is available on two-phase safety/relief valve backpressure and reaction forces. Single-phase approaches are cited extensively by authors of piping design papers and manuals.
- 8) No facility was found which is capable of testing full size safety relief valves under ATWS conditions; however, limited testing could be conducted by modification to some facilities.

IV. RECOMMENDATION

Since no full scale safety relief valve test facility was found, and assuming NRC decides additional test information is desired, a study should be conducted to determine what facility or facilities could best be used to test safety relief valves under ATWS conditions. This would include estimating costs and schedules for modifying both foreign and domestic existing test facilities as well as the establishment of a new domestic test facility.

Additionally, a test program for evaluation of safety relief valve(s) should be defined so that cost and schedule could be estimated for a complete facilitization and testing program.

V. LITERATURE AND DATA SEARCH

A. COMPUTER SEARCH OF INDEXES

Prior to ETEC participation in the safety relief valve survey, NCR requested the Nuclear Safety Information Center (NSIC), Oak Ridge National Laboratory, to make a literature survey of their data files. They developed various descriptors and made four searches, the results of which are described in Appendix A of this report.

ETEC (using the Energy Information Data Base (EDB) at the U.S. Department of Energy (DOE), Technical Information Center (TIC), Oak Ridge, Tennessee) made nine searches, described in Appendix A, into Nuclear Science Abstracts (NSA), Energy Data Base (EDB), Engineering Index (EIX), and Research in Progress (RIP) record data bases. Descriptors and sets were varied to cover the ATWS condition. Some searches were made using authors known to have published literature as checks on the other searches. Searches were varied to make the best use of available files and descriptors and sets selected to best fit the flow device and the flow conditions.

From these citations, 1907 abstracts were printed out for evaluation. Pertinent reports and papers were ordered from these printouts for analysis.

B. MANUAL SEARCH OF INDEXES

Since the project schedule was relatively short (three months), it was decided that some time could be saved by making manual index searches of the technical libraries at ETEC, the Science Center and Rocketdyne. Twenty subjects were developed to cover the components and flow regimes.

The manual search also proved of value in developing new descriptors and sets for the computer searches. The subjects of interest were easily

pursued to the abstracts, and in some cases to the papers and reports. Thus, the subjects producing most papers and reports were then used as descriptors in the computer searches.

Eight searches, as described in Appendix A, were made into the following indexes:

- Scientific and Technical Aerospace Reports
- Government Reports Announcements and Index
- International Space Abstracts
- Chemical Abstract Index
- Transactions of the ASME
- Mechanical Engineering
- The Engineering Index
- ETEC Kwik Index

These searches produced 9776 subjects for evaluation of which 119 were further pursued to the abstracts. Sixty-four papers and reports, many of which were duplicated in the computer search, were finally selected for analysis.

C. LETTERS TO INDUSTRY AND RELATED ORGANIZATIONS

Recognizing that published indexes lag the published papers and reports by several months and that much data is not published, a letter of inquiry was sent to 45 companies or related organizations seeking information or data on flow devices under ATWS flow conditions.

The selection of the companies or related organizations was based on information from personal files, the Chemical Engineering Buyers' Guide (Reference 3) and Instruments and Control Systems Guide to Selecting Pressure Relieving Devices (Reference 4). These provided information on the companies fabricating relief devices and gave the temperature and pressure limitations of their products.

The 62% response to these letters listed in Appendix C was much better than anticipated. Some references and contacts were made which were followed up for possible usefulness. Many of the responses offered no information at all. Other responses by authors publishing papers on sizing relief valves, sizing piping for letdown conditions, and sizing control valves offered no information or commented on the uncertainties of the codes and standards presently used for sizing of these devices.

In addition to the letters of inquiry sent to United States Industry, NRC personnel directed inquiries to French and Japanese sources.

VI. ANALYSIS OF REPORTS AND PAPERS

A. GENERAL

This study was conducted to provide NRC with information made available since mid-1975 for assessing the adequacy of methods for determining the behavior of pressurizer safety/relief valves during subcooled discharges. A literature search was conducted to determine safety/relief valve capacities under ATWS conditions. The search comprised the major portion of the report since the two-phase flow phenomena is poorly understood and there is a significant amount of continuing research. Other topics investigated included methods for determining effects of back pressure on valve capacity and valve reaction forces. Finally, the study investigated the need and type of testing which would provide data if it were not available in the literature. The discussion reviews the most relevant sources in the order previously described.

B. DISCUSSION

1. Flow Capacity and Pressure Drop Correlations

a. Baseline of Comparison

The following baseline of comparison for the various flow models presented in this report is the current staff recommendation for calculating safety relief valve capacity (Reference 1).

(1) For saturated or slightly subcooled water at the inlet, the theoretical mass velocity at the throat under choked flow conditions, G_M , is obtained from the homogeneous equilibrium model (reversible, adiabatic expansion from inlet to throat with equal phase velocities). The maximum mass velocity for these inlet conditions corresponds to a finite equilibrium flow quality and a Mach number of unity at the throat. For more highly subcooled inlet conditions, the theoretical maximum mass velocity is taken as that corresponding to zero equilibrium flow quality.

(2) The estimated relieving capacity at full lift condition is obtained (following the ASME Section VIII type of approach) from:

$$W = 0.9 G_M A_t K_D$$

In this equation, W is the mass flowrate, 0.9 is the ASME conservatism factor, A_t is the flow area at the throat, and K_D is the nozzle coefficient obtained with steam under the Section III certification tests. Discharge coefficient (K_D) is calculated in accordance with Section VIII of the ASME Code. It is assumed that full lift with water at the inlet is obtained at 110% of the set pressure.

b. Report and Paper Analyses

(1) A study conducted by Schrock, Starkman, and Brown (Reference 5) 15 years ago was not widely known since it was available only as a government document and a thesis. This study described the process of flashing sub-cooled water in convergent-divergent nozzles and offers comparisons with cold water (Bernoulli), homogeneous equilibrium, and nucleation delay flow models. Schrock described the flow as being single-phase at the nozzle entrance and decreasing in pressure through the convergent portion of the nozzle, possibly to the saturation pressure even before reaching the throat. The fluid continued in a single-phase metastable state, superheating until nucleation processes introduced a vapor phase.

A number of models of the flow were made and compared with test data in Figure 1. The cold water (Bernoulli) model over predicted the actual flow and the homogeneous equilibrium model under predicted actual flow. Two models were developed based on nucleation delay where, downstream of the sudden vaporization plane, flow was assumed to be isentropic homogeneous equilibrium in one model and a constant quality frozen composition in another model. These were referred to as the two-step models; the former gave unreasonable answers and the latter was simulated assuming two different bubble radii (Step I, $R = 2.54 \times 10^{-5}$ cm; Step II, $R_o = 1.27 \times 10^{-4}$ cm).

Figure 1. Comparison of Observed and Theoretical Flowrate for Nozzle No. 3 (Figure 10 from Reference 5)

The inability to independently determine the bubble radii was an inherent weakness in the two-step model because this influenced the vaporization plane location which in turn affected the mass flowrate. The importance of bubble size and nucleation indicated the significance of dissolved gas concentration which acts as nucleation sites, thus affecting the critical mass flowrate in the nozzle. Other observations made were that flashing occurred upstream of the throat when subcooling was less than 60°C and mass flowrate was very sensitive to pressure and temperature near the liquid saturation line.

(2) Malnes (Reference 6) made observations similar to those made by Schrock, et al., regarding the significance of gas content of the water. Malnes concluded that gas content was an important parameter and should be measured in all critical two-phase flow experiments. For low gas content, surface boiling and a metastable liquid core may be dominating even in long tubes. The gas content in light water reactors was determined to be high enough to ensure absence of metastable phenomena during a LOCA.

(3) Sozzi and Sutherland (Reference 7) conducted vessel blowdown tests using saturated and subcooled water to determine the critical flowrate through various nozzle sizes (0.5 to 3.0 in. diameter) Figure 2. Initial vessel conditions were with pressure at 1000 psia and temperatures between 450 and 550°F.

Figure 3 shows the sensitivity of the critical mass flux for qualities less than 0.002 and the relative insensitivity for qualities greater than 0.002. Figures 4, 5, and 6 show the critical mass flux as a function of quality and tube length. Notice the same low quality sensitivity noted before and the decreasing critical mass flux with increasing length. The effect of length is also shown in Figure 7 where critical mass flux is plotted for various qualities as a function of length. Notice the sharply declining flowrate for lengths less than 5 in. This is indicative of the non-equilibrium effects created by the nucleation delay time of approximately 0.001 seconds which corresponds to a 5 in. path length. Figure 8 is shown only to indicate the inlet and outlet nozzle geometry effects on flow.

NOZZLE	D (MM.)	L (MM.)
5	54	732
6	76.2	696

Figure 2. Nozzle Identification and Description
(Figure 1 of Reference 7)

Figure 3. Critical, Two-Phase Flow through a 0.5-in.(12.7 mm)-Diameter Converging-Diverging Nozzle (Figure 4 of Reference 7)

Figure 5. Effect of Flow Length on Critical Two-Phase Flow through
0.5-in.(12.7 mm)-Diameter Tubes
(Tube Length 4.5-12.5 in.) (Figure 6B of Reference 7)

Figure 7. Effect of Flow Length on Critical Two-Phase Flow through 0.5-in.(12.7 mm)-Diameter Tubes
 (Critical Mass Flux vs Length) (Figure 7 of Reference 7)

Figures 9 and 10 plot the critical mass flux for different diameter nozzles. Notice that the larger the nozzle diameter the smaller the critical mass flux.

Sozzi and Sutherland concluded that critical two-phase flow at high pressures and low quality are shown to be strongly dependent on upstream stagnation quality. Critical mass flux through both short and long nozzles decreases with increasing throat diameter. The strong length dependence on critical flow is credited to non-equilibrium effects due to insufficient nucleation time. Critical flowrates for flow lengths long enough to approach equilibrium ($L \approx 5$ in.) are closely predicted by the homogeneous equilibrium model.

(4) Moody (Reference 8) contends that two-phase equilibrium blowdown rates are controlled by homogeneous choking near the pipe entrance, followed by a second choking condition for slip flow near the exit. Figure 11 presents blowdown mass flux and pipe exit data of Sozzi and Sutherland (Reference 7) for 0.5 in. ID pipes of various lengths and vessel stagnation pressures between 65 and 70 atmospheres. The data is plotted as a function of stagnation quality:

$$X_0 = \frac{V - V_f (P_0)}{V_{fg} (P_0)} .$$

In the equation X_0 is the stagnation quality, V is the specific volume in the vessel, V_f is the specific volume of the saturated liquid, V_{fg} is the specific volume of the saturated liquid-vapor mixture, and P_0 is the stagnation pressure.

Homogeneous theory better predicts the mass flux data, indicating that blowdown rates are limited by homogeneous critical flow near the pipe entrance. Notice also that slip model predictions of blowdown rate are too high; however, the slip model exit pressure predictions are better than those predicted by the homogeneous model. Moody noted that close agreement between mass flux data of Henry for steam-water discharge through a 3 ft long 0.313 in. ID pipe and the homogeneous model as shown in Figure 12.

Figure 9. Effect of Throat Diameter on Critical Flow through a Short Nozzle (Figure 10 of Reference 7)

Figure 10. Effect of Nozzle Geometry on Critical Flow through Converging-Diverging Nozzles (Figure 11 of Reference 7)

Figure 11. Blowdown Rates and Exit Pressures of Sozzi and Sutherland at 70 Atmospheres (Figure 4 of Reference 8)

Figure 12. Blowdown Rates of Henry (Figure 6 of Reference 8)

This close comparison gives added support to the homogeneous critical flow limit at the pipe entrance. Figures 13 and 14 present pipe exit data as a function of static pressure and quality. All data was taken for flow passages longer than 4 in. so equilibrium conditions were assumed. The solid curves were calculated using the slip model at the maximum slip ratio. Agreement further indicates that, near the pipe exit, a choked slip flow occurs.

Moody concluded that, for liquid-vapor saturated equilibrium flow, blowdown rates from vessels are predicted by homogeneous equilibrium choked flow at vessel stagnation properties. Downstream of the pipe entrance flow tends toward a slip flow pattern which may result in pipe exit choke flow. For pipe friction factors (fL/D) less than 3.0, the pipe exit choked flow state does not influence choking at the entrance. For pipe friction factors greater than 3.0, flow will unchoke and blowdown rates will be less than predicted by homogeneous choking in terms of vessel stagnation properties.

(5) Collins (Reference 9), in his article "Choked Expansion of Subcooled Water and the Isentropic Homogeneous Equilibrium (IHE) Flow Model," pointed out that under certain reservoir conditions the IHE model over predicted mass flowrates. This was caused by the discontinuity of the IHE model's speed of sound, which may play an important role in choking. The IHE model's mass flux-pressure derivative is not continued at the saturated liquid line, resulting in a maximum error of 60% in the flowrate at the liquid saturation line. Numerous early investigations indicate that, for saturated and subcooled liquid flows through nozzles and orifices, the IHE model severely under predicts the actual flow due to the existence of a non-equilibrium metastable superheated liquid state at the throat.

Experimental Data by Sozzi and Sutherland (Reference 7) and Schrock, et al. (Reference 5), for highly subcooled water was compared with critical mass flowrates calculated with the IHE model and the model over predicted the actual flow. Collins reemphasized the strong metastable effects in low L/D apertures, the reduced critical mass flux with increased flow diameter and

Figure 13. Critical Flow Properties at Pipe Exit
(Figure 8 of Reference 8)

Figure 14. Low Quality Data of Henry (Figure 9 of Reference 8)

the inlet homogeneous and outlet slip model choking phenomena. Emphasis in this paper is on low L/D apertures with small diameters. Experimental data indicates that choking may be controlled by strong discontinuities of the IHE acoustic speed in spite of the highly metastable character of the actual flow at the aperture exit or throat plane. It is important to note that theoretical choking of single component IHE flows from highly subcooled states does not occur at the sonic condition of $M = 1$.

Assuming that the mass flux is a continuous function with continuous derivatives along an isentrope, a necessary condition that G be a maximum is:

$$(dG/dB)_S = 0 \quad . . . (1)$$

$$B = \frac{\text{Actual Pressure}}{\text{Critical Pressure}} = \text{Reduced Pressure}$$

$$\theta = \frac{\text{Actual Temperature}}{\text{Critical Temperature}} = \text{Reduced Temperature}$$

This condition is used extensively in literature as a key step in determining theoretical models of choked flow. Equation (1) is not necessary for a maximum G if G has discontinuous derivatives at some point along an isentrope since maximums could occur there. Equation (1) is generally valid on isentropes only when the reservoir is saturated liquid or a two-phase mixture. If the reservoir is subcooled, G will have discontinuous derivatives at the saturated liquid line; therefore, Equation (1) is not a necessary condition although it may still be useful in determining $G_{\max}$.

The velocity of the fluid when isentropically expanded from a slightly subcooled condition will be equal to the saturated liquid acoustic speed; but when expanded from a highly subcooled state to saturation, the fluid velocity will exceed the Mach number. An example of the rapid variation in acoustic velocity is at 300°F; the speed of sound is 4500 ft/sec as a liquid and 30 ft/sec at 0 + quality; i.e., very small amount of vapor. This phenomena

is graphically shown in Figure 15. The IHE model produces its largest and most conservative error at inlet saturation conditions due to metastable effects. This conservative error diminishes with increasing compression or subcooling. Figures 16 and 17 indicate the IHE model may over predict flow for low temperature reservoirs with short converging passages and reduced pressures greater than 0.05. Figure 18 shows a map of the IHE flow model over extensive reservoir pressure and temperature conditions. Note that the range of pressures and temperatures is significantly removed from LWR conditions but it is conceivable the same phenomena could exist.

Collins concluded that the IHE model does not under predict observed flowrates in every case but does in fact over predict under certain reservoir conditions. The IHE discontinuous choking condition produces Mach numbers greater than unity at the downstream side of the choke plane. The IHE model under predicts experimental data by 60% as the reservoir approaches the saturated liquid line from either the subcooled or mixture region. Finally, the IHE model has a significant role in future model development that will predict expansion of sub cooled liquids of varying area. Future models should predict flow, choking property profiles, and interface transfer effects while satisfying continuity, momentum, and energy equations.

c. Data Matrix

A data matrix (Table 1) was generated from the reports reviewed in the safety relief valve literature survey. The matrix includes reservoir pressure, fluid temperature, quality, degree of subcooling, critical mass flux, and nozzle geometry and size data. The data for the matrix were extracted from the graphs and tables presented in the following reports:

- 1) Shrock (Reference 5) presented observed and equilibrium model data for a convergent-divergent nozzle. The data included mass flowrate as a function of temperature and pressure.

Figure 15. Temperature-Entropy Diagram Illustrating IHE Flow from Four Reservoir Pressures at a Reservoir Temperature of $\theta_0 = 0.8$ - Not to Scale (Figure 1 of Reference 9)

(Dashed lines are orifice data from Yarnall and solid lines are Collins IHE calculations. Parameters indicated are reduced reservoir temperature.)

Figure 16. IHE Experimental Data Correlation for Subcooled Water Reservoir
(Figure 5 of Reference 9)

(Dashed lines are data of Henry and Fauske and solid lines are Collins IHE model. Parameters indicated are reduced reservoir temperature.)

Figure 17. Comparison of Theoretical Models (Figure 6 of Reference 9)

Figure 18. Map of IHE Flow Model for H_2O Properties Over Extensive Reservoir Pressure and Temperature Conditions in Subcooled Liquid Region and Into Two-Phase Reservoir Region (Figure 7 of Reference 9)

Table 1. Data Matrix (Sheet 1 of 4)

NOZZLE GEOMETRY SIZE AND LENGTH	PRESSURE (PSIA)	TEMPERATURE (F)	QUALITY	SUBCOOLING (F)	CRITICAL MASS FLUX (lbm/Sec-Ft ²)	
					EXPERIMENTAL	.9 HEM
Convergent-Divergent Nozzle, Schrock No. 3	450	450	NA	6.3	7536	4748
Throat Diameter 0.396 Cm (.156 in)	700	450	NA	53.1	13941	5426
Exit Diameter 2.56 Cm	900	450	NA	82	16956	5765
Convergent 40 DEG-Half Angle	1050	550	NA	0.6	7536	5087
Divergent 12 DEG-Half Angle	1100	550	NA	6.3	11304	5426
	1200	550	NA	17.2	13188	5595
Orifice - Collins (Yarnell Data)	64	297	NA	0	3081	616
	192	378	NA	0	5049	1478
	321	424	NA	0	6675	2234
	144	350	NA	5	4279	1232
	192	350	NA	28	7274	4621
	64	300	NA	3	3081	616
	192	300	NA	78	8558	7317
	96	250	NA	75	6504	5777
	192	250	NA	128	8900	8627
Sezzi & Sutherland Nozzle 1	610	489	.00280	0	6200	3420
Inlet Diameter 1.75 in.	660	490	.00050	0	8420	3690
Well rounded inlet	680	486	-.00050	14	11500	5850
Throat diameter 0.5 in.	700	474	-.00100	29	12100	8640
Diffuser Section - 4.5 in.	725	507	.00380	0	6007	4140
long with a 3 deg. half angle	780	515	.00050	0	9210	4410
	825	522	.00060	0	9080	4590
	850	527	.00460	0	6050	4410
	890	449	-.00380	82	16850	14850
	900	532	.00050	0	9780	4590
	955	539	.00680	0	6900	4500
	960	465	-.00410	75	15500	14400
NA - NOT AVAILABLE -						

Table 1. Data Matrix (Sheet 2 of 4)

NOZZLE GEOMETRY SIZE AND LENGTH	PRESSURE (PSIA)	TEMPERATURE (F)	QUALITY	SUBCOOLING (F)	CRITICAL MASS FLUX (lbm/Sec-Ft ²)	
					EXPERIMENTAL	.9 HEM
Sozzi & Sutherland Nozzle 2 Inlet Diameter 1.75. in. Well Rounded Inlet Throat Diameter 0.5 in. Throat Length						
0.0 in.	950	517	-.00130	20	15530	8550
0.5 in.	949	540	.00400	0	7750	5040
1.5 in.	955	540	.00340	0	6541	4950
2.5 in.	952	540	.00320	0	6230	4680
4.5 in.	948	540	.00310	0	5750	4500
7.5 in.	949	540	.00300	0	5488	4500
9.0 in.	950	539	.00050	0	6450	4680
12.5 in.	951	540	.00300	0	4875	4500
20.0 in.	952	522	-.00100	18	7320	5940
25.0 in.	951	540	.00250	0	4675	4590
70.0 in.	925	535	-.00006	<1.0	3940	4500
Sozzi & Sutherland Nozzle 3 0.5 in. Diameter Sharp-Edged Orifice Length downstream of Orifice Plate:						
0.0 in.	950	540	.00450	0	8248	4770
7.5 in.	949	540	.00280	0	5050	4725
12.5 in.	952	522	-.00100	16	5850	6300
20.0 in.	951	495	-.00250	43	8400	9900
25.0 in.	951	505	-.00200	33	7950	9000

NOZZLE GEOMETRY SIZE AND LENGTH	PRESSURE (PSIA)	TEMPERATURE (F)	QUALITY	SUBCOOLING (F)	CRITICAL MASS FLUX (lbm/Sec-Ft ²)	
					EXPERIMENTAL	.9 HEM
Sozzi & Sutherland Nozzle 4 Well-Rounded Inlet Throat Diameter .75 in. Abrupt Expansion Length 0.0 in.	954	534	-.00030	5	10500	5310
Nozzle 5 Convergent-Divergent Throat Diameter 2.125 in. Convergent 11 DEG-Half Angle Length ~28 in. Divergent 7.5 DEG-Half Angle Length ~15 in.	955	540	.00610	0	5690	4500
Nozzle 6 Same as Nozzle 5 except Throat Diameter 3.0 in.	925	540	.00825	0	5080	4320
Nozzle 7 2.5 in. long well-rounded Inlet Throat Diameter 1.108 in. 6.5 in. long 7 DEG-Half Angle Diffuser	988	542	0	0	8330	4500
Moody (Fauske Data) Throat Diameter .25 in. Throat Length >4.0 in. (Allemann Data) Throat Diameter 6.80 in. Throat Length >4.0 in.	1000 2000 1250 1600	545 636 572 605	0 0 0 0	0 0 0 0	5000 8200 6000 5800	4950 7650 5760 6750

Table 1. Data Matrix (Sheet 3 of 4)

NOZZLE GEOMETRY SIZE AND LENGTH	PRESSURE (PSIA)	TEMPERATURE (F)	QUALITY	SUBCOOLING (F)	CRITICAL MASS FLUX (lbm/Sec-Ft ²)	
					EXPERIMENTAL	.9 HEM
NRC STATUS REPORT (Powell Data)						
Well Rounded Inlet	1200	450	NA	117	19110	17550
Throat Diameter .438 in.	1800	450	NA	171	24000	22500
Throat Length .656 in.	2500	450	NA	218	30080	28800
(Zaloudek Data)						
20° Conical Reducer	1000	485	NA	60	14338	13950
Throat Diameter .505 in.	1400	485	NA	102	17000	18000
Throat Length 10 in.	1800	535	NA	86	17640	17640
Safety Valves @ ATWS Condition	2400 -	560-695	0	0 to 100	None	9000-18000
Throat Diameter	3000				Available	
1 in. to 2 in.						

NA - NOT AVAILABLE

Table 1. Data Matrix (Sheet 4 of 4)

- 2) Collins (Reference 9) presented experimental and homogeneous equilibrium model, reduced mass flux data for an orifice as a function of reduced pressure and temperature. These data were converted into dimensional values.
- 3) Sozzi and Sutherland (Reference 7) presented the most extensive data found in the literature survey. The throat diameter of the test nozzles varied from 0.5 in. to 3.0 in. and the throat length varied from 0.0 in. to 70 in. Reservoir pressures varied from about 600 to 1000 psia. The homogeneous equilibrium model (HEM) values, corresponding to each of the test conditions, were obtained from Moody (Reference 8).
- 4) Moody (Reference 8) and NRC Status Report (Reference 1) presented critical mass flux data from several investigators. Note that under certain test conditions the HEM values are less than the observed values.

There was no experimental data available for any size safety relief valve at ATWS conditions.

2. Effects of Back Pressure on Valve Capacity

Only a few papers were available for determining effects of back pressure on valve capacity. Liao (Reference 10) offered a design equation for relief valve vent stack analysis. Baumann (Reference 11) discussed effects of piping geometry on valve capacity which dealt primarily with control valves; however, some of his correlations should be helpful in determining effects on safety relief valve back pressure. Finally, Driskell (Reference 12) warned against problems with slug flow in relief valve vent lines. The slug flow creates both pressure and inertia problems in the piping system. Any back pressure on a safety relief valve will reduce flow and if sufficient will cause cycling with marked reduction in flow.

3. Safety Relief Valve Reaction Forces

A significant amount of literature (References 13 to 18) was available for all types of forces that act on safety relief valves including reaction forces. The reaction force correlations were based on the single-phase total mass flowrate from the valve and did not deal specifically with two-phase discharge; however, the single phase calculation should be on the conservative side.

VII. FACILITY SURVEY

In the course of conducting the literature survey, an attempt was made by ETEC and NRC to locate facilities with a capability, or at least a potential, for full scale testing of safety relief valves under these postulated ATWS conditions:

Pressure range: 2400 to over 3000 psia

Water temperature: approximately 40°F subcooling (550 - 600°F)

Flowrate: 2.07×10^6 lb/hr

Flow volume: approximately 1100 ft³ of subcooled water

In the earlier NRC survey, it was concluded that no ASME facilities large enough to meet the above requirements existed. This is still the case.

A summary of the joint NRC/ETEC findings during the current survey is as follows:

- 1) Two large facilities mentioned were located in Japan at the Nuclear Power Engineering Test Center (References 20 and 25) and in Germany (Reference 21). Both were limited to approximately 2500 psia, which is below the ATWS requirement. In addition, volume is limited to 22 M³ (786 ft³).
- 2) In a response to the industry letter of inquiry, R. F. Lytle of Fisher Controls Co. stated that they had done some work on small systems prior to 1975 and that they planned to work on larger size systems in 1979. When contacted by telephone on December 19, 1978, he indicated that they had a change in management and did not plan to test relief valves with water at other than ambient temperature.

- 3) In a telephone response to the industry letter of inquiry, Dr. H. S. Kemp of the Design Institute for Emergency Relief Systems (DIERS) indicated that they were doing work on heavy gases and that they possibly could adapt their systems for subcooled water tests. He stated that he would send information listing their capabilities. When contacted by telephone on December 19, 1978, he stated that they were not interested in a relief valve test program and that they could not give any information on their test facilities.
- 4) In the data presentation meeting at NRC on December 14, 1978 it was stated that NRC personnel had visited Wyle Test Laboratories at Huntsville, Alabama and had obtained descriptive brochures (References 22 and 23). This facility was also listed in Reference 24.
 - a) A steam loop testing area is designed to support the nuclear power industry and to help the valve manufacturer's meet the test requirements set by the Nuclear Regulatory Commission. It is designed for steam at 1500 psia and 600°F, which is well below the pressure requirements for the ATWS conditions.
 - b) An ambient water flow loop designed for 4000 psig, 8500 gpm and a blowdown of 5000 gallons (668 ft³) can be modified for subcooled water tests to 600°F by the addition of heaters and associated equipment and instrumentation to allow limited duration tests.
- 5) In the December 14, 1978 meeting, Peter Anderson (NRC) stated he was going to Grenoble France the following week and that he would obtain information on their test facilities. He found that the Grenoble facilities did not have sufficient capacity; however, he was informed that the electrical industries were probably testing valves at or near ATWS conditions.
- 6) On Mr. Anderson's return he contacted Mr. Sureau at the Paris headquarters of Electricite' de France (EDF) and found the following:

- a) They have a facility and are currently testing full scale Crane Co. safety relief valves through a four phase program as follows:
- (1) Steady state full flow tests at 120 bars (1764 psia) with subcooling. Tests completed two months ago.
 - (2) Dynamics of valve opening. Tests start in February 1979.
 - (3) Dynamics of valve opening with downstream piping. No date for tests.
 - (4) Complete dynamics, opening and closing. No date for tests.
- b) System blowdown is limited to 7 m³ (250 ft³) and the pressure is supplied by high pressure steam.
- c) The facility is also used for critical flow nozzle and other component tests.
- d) The Electric Power Research Institute (EPRI) of Palo Alto California had contacted them for possible exchange of data.
- e) EPRI indicated to the French that EPRI may sponsor a 1/10 scale test at ATWS conditions.

Examination of the existing facilities above clearly revealed that they are limited by pressure, temperature, flow, duration or combinations of these. None of the facilities had capacity for full duration tests. Most of the limitations require total changeout or addition to the pressurizing and blowdown vessels which are the major cost items of the facility.

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APPENDIX A

COMPUTER AND MANUAL INDEX SEARCHES

1. Computer Searches

Prior to ETEC's participation in the safety relief valve survey, NRC requested the Nuclear Safety Information Center (NSIC), Oak Ridge National Laboratory make a literature survey of their data files. The results of this survey which consists of four searches are listed below:

Search 1

<u>Session Number</u>	<u>Subject</u>	<u>Number of Accessions</u>
5	Accident, ATWS + REACTOR, PWR	39
18	Accident, ATWS - Session Number 5	63
16	Pressure relief + valves + (accident analysis or safety analysis)	47
17	Valves + (accident analysis or safety analysis) - Session Number 16	68
19	Pressurizer + (pressure relief or valves) + (accident analysis or safety analysis)	9

Search 2

19	Valves + (R AND D program or testing or experiment or test, proof or test, on line or test, preoperation) - (responses to NRC question or reactor, LMFBR or reactor, HTGR or failure or technical specifications)	69
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Search 3

<u>Session Number</u>	<u>Subject</u>	<u>Number of Accessions</u>
99	ATWS + reactor, PWR	4

Search 4

99	Nuclear power plants + valves	4
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The 312 accessions were printed out. In search 1, session number 5 represents ATWS conditions relative to PWR's while session number 18 presents all other accessions on file on ATWS. Session number 16 presents accident analysis and safety analysis for pressure relief valves while session number 17 presents the same type of information for all other types of valves. Session number 19 is an extension of session number 16 using key word PRESSURIZER.

Searches 1 and 2 came from the NSIC computer file. Searches 3 and 4 present additional accessions from other files on RECON pertaining to PWR-ATWS conditions and valves, respectively. The references in search number 3 from Energy Data Base are generally repeats of items that appeared in various parts of search number 1. Search number 4 from Engineering Index was not too productive.

PWR pressurizer safety relief valves under ATWS conditions, for information retrieval purposes, represents a very specific search. Thus, a more general strategy was employed where the behavior of pressurizer safety relief valves was one of several events analyzed under ATWS conditions within the report or document.

ETEC, using the Energy Information Data Base (EDB) at the United States Department of Energy (DOE), Technical Informations Center (TIC), Oak Ridge, Tennessee, made searches into four of the RECON Data Bases:

Nuclear Science Abstracts (NSA)
Energy Data Base (EDB)
Engineering Index (EIX)
Research in Progress (RIP)

Nine major searches were made using various descriptors and sets with the four data bases listed above. Other searches were made using authors known to have published literature as checks on the system.

Search 1. Terminal LME, Session 0010, File EDB, 10/3/78

<u>Set</u>	<u>Descriptor</u>	<u>Cits</u>	<u>Abstract Printout</u>
1	IT = PWR Type Reactors/ATWS	14	-
2	IT = ATWS	217	-
3	IT = Reactor Cooling Systems	5086	-
4	IT = Multiphase Flow	29	-
5	IT = Relief Valves	985	-
6	IT = Fluid Flow	3959	-
7	IT = Transients	2568	-
8	IT = Transients	2568	-
9	1 + 2	217	200 only
10	2 + 3	5268	-
11	4 + 5 + 6	4964	-
12	10 * 11	266	-
13	12 * 7	45	45

Search 2. Terminal LME, Session 0018, File EIX, 10/13/78

<u>Set</u>	<u>Descriptor</u>	<u>Cits</u>	<u>Abstract Printout</u>
1	IT = Valves	316	-
2	IT = Valves and Valve Gear	487	-
3	IT = Fluid Flow	3	-
4	IT = Fluid Mechanics/Valves	2	-
5	IT = Two Phase	981	-
6	IT = Two Phase	1	-
7	IT = Nozzles	739	-
8	IT = Safety Valves	79	79
9	IT = Safety	53	-
10	IT = Performace	302	-
11	1 + 2	703	-
12	3 + 4	5	-
13	5 + 6	982	-
14	11 * 10	1	-
15	11 * 8	22	22
16	7 * 10	2	2
17	13*	1	1

Search 3. Terminal LME, Session 0011, File NSC, 10/18/78

<u>Set</u>	<u>Descriptor</u>	<u>Cits</u>	<u>Abstract Printout</u>
1	IT = Valves	5393	-
2	IT = Safety Analysis	1277	-
3	IT = Safety Device	105	-
4	IT = Safety Evaluation	1385	-
5	IT = Safety Injection	570	-
6	IT = Nozzle	505	-
7	IT = Flow, Two Phase	698	-

Search 3 (Continued)

<u>Set</u>	<u>Descriptor</u>	<u>Cits</u>	<u>Abstract Printout</u>
8	IT = Steam	1840	-
9	IT = Transient	726	-
10	2 - 5/+	3250	-
11	1 + 6	5877	-
12	7 + 8	2495	-
13	10 • 11	199	199
14	13 • 12	13	13
15	14 * 9	1	-
16	IT = Performance	1061	-
17	IT = Testing	4618	-
18	16 + 17	5554	-
19	1 • 18	305	-
20	19 * 10	10	10

Search 4. Terminal LME, Session 0012, File EDB, 10/18/78

<u>Set</u>	<u>Descriptor</u>	<u>Cits</u>	<u>Abstract Printout</u>
1	IT = ATWS/Reactor Cooling Systems	1	-
2	IT = Reactor Cooling Systems/Blowdown	1	-
3	IT = Steam Ejectors	8	-
4	IT = Vapor Jet Ejectors	40	-
5	3 + 4	48	48
6	IT = Scram Cooling	1	-
7	IT = Scram Valves	1	-
8	IT = Relief Valves/Nozzles	1	-
9	IT = Relief Valves/Operation	30	-
10	IT = Relief Valves/Performance	38	-
11	IT = Relief Valves/Performance Testing	3	-
12	8 = 11/+	72	72

Search 5. Terminal LME, Session 0023, File RIP, 10/19/78

<u>Set</u>	<u>Descriptor</u>	<u>Cits</u>	<u>Abstract Printout</u>
1	IT = Valves	39	-
2	IT = Fluid Flow	199	199
3	IT = Two - Phase Flow	27	-
4	IT = Nozzles	9	-
5	IT = Safety	371	-
6	IT = Safety Engineering	24	-
7	IT = Water Moderated Reactors	137	-
8	IT = Performance	411	-
9	IT = Performance Testing	587	-
10	2 + 3	199	-
11	1 + 4	46	-
12	5 + 6	392	-
13	8 + 9	984	-
14	10 * 13	38	-
15	11 * 13	7	-
16	10 + 11	243	-
17	16 * 13	44	-
18	17 - 7	40	40

Search 6. Terminal LME, Session 0013, File NSA, 10/23/78

<u>Set</u>	<u>Descriptor</u>	<u>Cits</u>	<u>Abstract Printout</u>
1	IT = Subcooled Boiling	54	-
2	IT = Subcooling	70	-
3	1 + 2	121	121

Search 7. Terminal LME, Session 0012, File EDB, 10/23/78

<u>Set</u>	<u>Descriptor</u>	<u>Cits</u>	<u>Abstract</u> <u>Printout</u>
1	NC = 42.0400	1753	-
2	NC = 42.0600	117	-
3	1 * 2	-	-
4	IT = Subcooled Boiling	36	-
5	IT = Subcooled Boiling/Bubble Growth	1	-
6	IT = Subcooling	38	-
7	4 + 5 + 6	73	73

Search 8. Terminal LME, Session 0015, File EDB, 11/2/78

<u>Set</u>	<u>Descriptor</u>	<u>Cits</u>	<u>Abstract</u> <u>Printout</u>
1	IT = Steam Condenser/Two-Phase Flow	1	-
2	IT = Steam Condensers/Valves	20	-
3	IT = Steam Generators/Blowdown	22	-
4	IT = Steam Generators/Nozzles	9	-
5	IT = Steam Generators/Relief Valves	2	-
6	IT = Steam Generators/Two-Phase Flow	5	-
7	IT = Steam Generators/Valves	31	-
8	IT = Nozzles/Gas Flow	5	-
9	IT = Orifices	192	-
10	IT = Orifices/Gas Flow	2	-
11	IT = Orifices/Valves	3	-
12	IT = Relief Valves	1026	-
13	IT = Relief Valves/Blowdown	1	-
14	IT = Relief Valves/Nozzles	1	-
15	IT = Relief Valves/Pipelines	19	-
16	IT = Steam	3738	-
17	IT = Steam Generation	268	-
18	IT = Water Vapor	688	-

Search 8 (Continued)

<u>Set</u>	<u>Descriptor</u>	<u>Cits</u>	<u>Abstract Printout</u>
19	IT = Two-Phase Flow	1090	-
20	IT = Two-Phase Flow/Flow Models	15	-
21	IT = Two-Phase Flow/Flow Rate	7	-
22	IT = Two-Phase Flow/Mathematics/Models	40	-
23	IT = Two-Phase Flow/Research Programs	2	-
24	IT = Two-Phase Flow/Pressure Drop	12	-
25	IT = Two-Phase Flow/Stability	3	-
26	IT = Two-Phase Flow/Subcooled Boiling	1	-
27	IT = Two-Phase Flow/Test Facilities	1	-
28	IT = Two-Phase Flow/Transients	3	-
29	IT = Pressure Drop	649	-
30	IT = Pressure Gradients	993	-
31	1-7/+	90	-
32	8-11/+	197	-
33	12-15/+	1026	-
34	16-18/+	4663	-
35	19-28/+	1090	-
36	29 + 30	1603	-
37	31 - 33/*	-	-
38	31 * 32	-	-
39	32 * 33	2	2
40	31 - 33/+	1309	-
41	34 * 40	41	41
42	35 * 36	134	134
43	34 - 36/+	7071	-
44	40 * 43	66	66

Search 9. Terminal LME, Session 0002, File EIX, 11/3/78

<u>Set</u>	<u>Descriptor</u>	<u>Cits</u>	<u>Abstract</u> <u>Printout</u>
1	IT = Nozzles	739	-
2	IT = Orifices	137	-
3	IT = Piping Systems/Flow	2	-
4	IT = Piping Systems/Nozzles	2	-
5	IT = Piping Systems/Pressure Measurement	1	-
6	IT = Piping Systems/Valves	3	-
7	IT = Valves	316	-
8	IT = Valves and Valve Gear	487	200 only
9	IT = Steam	351	-
10	IT = Two Phase	981	-
11	IT = Flow	485	-
12	IT = Flow of Fluids/Flow Interactions	42	-
13	IT = Flow of Fluids/Mixing	144	-
14	IT = Flow of Fluids/Nozzles	183	-
15	IT = Flow of Fluids/Orifices	73	-
16	IT = Flow fo Fluids/Pipes	373	-
17	IT = Flow of Fluids/Piping Systems	2	-
18	IT = Flow of Fluids/Pressure Measurement	10	-
19	IT = Flow of Fluids/Research	6	-
20	IT = Flow of Fluids/Safety Valves	1	-
21	IT = Flow of Fluids/Two-Phase	470	-
22	IT = Flow of Fluids/Valves	10	-
23	IT = Pressure Measurement	396	-
24	3 - 6/+	8	8
25	1 + 2	871	-
26	13-22/+	1272	-
27	25 * 26	277	-
28	27 + 12	319	-
29	7 + 8	703	-
30	29 + 7	703	-
31	28 * 30	1	-
32	21 * 25	20	20

2. Manual Searches

Eight manual searches (listed below) were made into the various indexes available at the ETEC, AI, Science Center and Rocketdyne libraries. Twenty subjects were developed to cover the components and flow regimes experienced under ATWS conditions.

Search 1. ETEC Library, Scientific and Technical Aerospace Reports,
Jan. 1975 through Aug. 1978.

<u>Subject</u>	<u>Citations Listed and Searched</u>	<u>Abstracts Searched</u>	<u>Reports for Evaluation</u>
Condensate Flow	0	-	-
Discharge Flow	0	-	-
Feedwater Flow	0	-	-
Flash Steam Flow	0	-	-
Flow Capacity	0	-	-
Fluid Flow	172	0	0
High Pressure	69	0	0
High Pressure Letdown	0	-	-
Hot Water Flow	0	-	-
Nozzle Flow	95	0	0
Orifice Flow	11	1	1
Pressure Drop	8	2	2
Pressure Gradient	59	2	2
Reaction Force-Valves	0	-	-
Relief Valve	3	0	0
Safety/Relief Valve	0	-	-
Steam/Water Flow	0	-	-
Steam Trap Flow	0	-	-
Two Phase Flow	82	6	6
Valve Flow	<u>15</u>	<u>0</u>	<u>-</u>
Total	505	11	11

Search 2. ETEC Library, Government Reports Announcements and Index,
Jan. 1975 through July 1978

Subject	Citations Listed and Searched	Abstracts Searched	Reports for Evaluation
Condensate Flow	1	0	-
Discharge Flow	4	0	-
Feedwater Flow	0	-	-
Flash Steam Flow	0	-	-
Flow Capacity	0	-	-
Fluid Flow	182	1	1
High Pressure	29	0	-
High Pressure Letdown	0	-	-
Hot Water Flow	2	0	-
Nozzle Flow	36	-	-
Orifice Flow	5	1	1
Pressure Drop	9	3	3
Pressure Gradient	34	0	-
Reaction Force - Valves	0	-	-
Relief Valve	4	0	-
Safety/Relief Valve	1	0	-
Steam/Water Flow	0	-	-
Steam Trap Flow	0	-	-
Two Phase Flow	71	5	5
Valve Flow	<u>1</u>	<u>0</u>	<u>-</u>
Total	378	10	10

Search 3. Science Center Library, International Space Abstracts,
Jan. 1975 through July 1978

Subject	Citations Listed and Searched	Abstracts Searched	Reports for Evaluation
Condensate Flow	0	-	-
Discharge Flow	0	-	-
Feedwater Flow	0	-	-
Flash Steam Flow	0	-	-
Flow Capacity	0	-	-
Fluid Flow	56	0	-
High Pressure	84	0	-
High Pressure Letdown	0	-	-
Hot Water Flow	0	-	-
Nozzle Flow	389	1	0
Orifice Flow	38	1	0
Pressure Drop	28	1	0
Pressure Gradient	135	0	-
Reaction Force - Valves	0	-	-
Relief Valve	1	1	1
Safety/Relief Valve	0	-	-
Steam/Water Flow	0	-	-
Steam Trap Flow	0	-	-
Two Phase Flow	323	3	0
Valve Flow	<u>0</u>	<u>-</u>	<u>-</u>
Total	1053	7	1

Search 4. Science Center Library, Chemical Abstract Index,
Jan. 1972 through Dec. 1976

Subject	Citations Listed and Searched	Abstracts Searched	Reports for Evaluation
Condensate Flow	0	-	-
Discharge Flow	0	-	-
Feedwater Flow	0	-	-
Flash Steam Flow	0	-	-
Flow Capacity	0	-	-
Fluid Flow	0	-	-
High Pressure	0	-	-
High Pressure Letdown	0	-	-
Hot Water Flow	0	-	-
Nozzle Flow	5	0	-
Orifice Flow	1	0	-
Pressure Drop	70	2	0
Pressure Gradient	0	-	-
Reaction Force - Valves	0	-	-
Relief Valve	0	-	-
Safety/Relief Valve	0	-	-
Steam/Water Flow	9	2	0
Steam Trap Flow	0	-	-
Two Phase Flow	1	0	-
Valve Flow	<u>12</u>	<u>0</u>	<u>-</u>
Total	98	4	0

Search 5. ETEC and AI Libraries, Transactions of the ASME,
Jan. 1975 through July 1978

Subject	Citations Listed and Searched	Abstracts Searched	Reports for Evaluation
Condensate Flow	0	-	-
Discharge Flow	1	0	-
Feedwater Flow	0	-	-
Flash Steam Flow	1	1	1
Flow Capacity	0	-	-
Fluid Flow	7	0	-
High Pressure	0	-	-
High Pressure Letdown	0	-	-
Hot Water Flow	0	-	-
Nozzle Flow	3	1	1
Orifice Flow	2	1	1
Pressure Drop	8	0	-
Pressure Gradient	9	0	-
Reaction Force - Valves	0	-	-
Relief Valve	2	2	2
Safety/Relief Valve	1	1	1
Steam/Water Flow	0	-	-
Steam Trap Flow	0	-	-
Two Phase Flow	6	0	-
Valve Flow	<u>1</u>	<u>0</u>	<u>-</u>
Total	41	6	6

Search 6. ETEC and AI Libraries, Mechanical Engineering
Jan. 1975 through Oct. 1978

Subject	Citations Listed and Searched	Abstracts Searched	Reports for Evaluation
Condensate Flow	0	-	-
Discharge Flow	0	-	-
Feedwater Flow	0	-	-
Flash Steam Flow	1	1	1
Flow Capacity	0	-	-
Fluid Flow	21	0	-
High Pressure	2	0	0
High Pressure Letdown	0	-	-
Hot Water Flow	0	-	-
Nozzle Flow	3	2	2
Orifice Flow	3	1	1
Pressure Drop	10	1	1
Pressure Gradient	6	0	-
Reaction Force - Valves	0	-	-
Relief Valve	2	1	1
Safety/Relief Valve	5	5	5
Steam/Water Flow	0	-	-
Steam Trap Flow	0	-	-
Two Phase Flow	20	1	1
Valve Flow	<u>4</u>	<u>2</u>	<u>2</u>
Total	57	14	14

Search 7. AI Library, the Engineering Index,
Jan. 1975 through Sept. 1978

Subject	Citations Listed and Searched	Abstracts Searched	Reports for Evaluation
Condensate Flow	0	-	-
Discharge Flow	0	-	-
Feedwater Flow	0	-	-
Flash Steam Flow	0	-	-
Flow Capacity	0	-	-
Fluid Flow	6094	-	-
High Pressure	33	0	-
High Pressure Letdown	1	0	-
Hot Water Flow	0	-	-
Nozzle Flow	123	2	1
Orifice Flow	382	0	-
Pressure Drop	0	-	-
Pressure Gradient	0	-	-
Reaction Force - Valves	0	-	-
Relief Valve	0	-	-
Safety/Relief Valve	8	7	2
Steam/Water Flow	0	-	-
Steam Trap Flow	11	3	3
Two-Phase Flow	429	4	2
Valve Flow	<u>122</u>	<u>2</u>	<u>2</u>
Total	7203	18	10

Search 8. ETEC Library, ETEC Kwik Index,
Jan. 1972 through Oct. 1978

Subject	Citations Listed and Searched	Abstracts Searched	Reports for Evaluation
Condensate Flow	0	-	-
Discharge Flow	1	1	0
Feedwater Flow	0	-	-
Flash Steam Flow	0	-	-
Flow Capacity	0	-	-
Fluid Flow	286	16	2
High Pressure	9	3	1
High Pressure Letdown	0	-	-
Hot Water Flow	0	-	-
Nozzle Flow	1	1	0
Orifice Flow	24	4	1
Pressure Drop	16	4	0
Pressure Gradient	0	-	-
Reaction Force - Valves	0	-	-
Relief Valve	3	2	1
Safety/Relief Valve	1	1	1
Steam/Water Flow	0	-	-
Steam Trap Flow	1	1	1
Two-Phase Flow	24	15	4
Valve Flow	<u>75</u>	<u>1</u>	<u>1</u>
Total	441	49	12

In the eight searches, 9776 subjects of interest were found and evaluated. Of these subjects, 119 were pursued to the abstracts for further evaluation. Sixty-four papers and reports, many duplicated in the computer search, were selected for analysis.

APPENDIX B
LETTER SEARCH TO INDUSTRIAL AND RELATED ORGANIZATIONS

Assuming that relief valve manufacturers and related organizations could be performing tests in the flow regimes of interest, the Chemical Engineering Buyer's Guide (July 17, 1978), the Guide to Selecting Pressure Relieving Devices (Instruments and Control Systems, April 1973), and various papers on relief valves were screened for representative companies or organizations. A standard letter (Fig. B-1) was then sent out to the companies or organizations listed below:

- 1) AMETEK, Schutte & Koerting Division, Engineering Department.
- 2) Armstrong Steam Trap Co., Engineering Department (1)*, W.F. Sisson, Chief Engineer.
- 3) Burgess-Manning, Engineering Department (1), E.J. Halter, P.E. Chief R&D Engineer.
- 4) Fike Metal Products Corp., Engineering Department (1), D.E. Fritsche, Director of Engineering.
- 5) Dresser Industries, T.R. Bordelon (1).
- 6) The Trane Company, Engineering Department.
- 7) Control Components, Inc., Engineering Department (1), F.O. Seger, Director, Design Engineering.
- 8) Aquatrol Inc., Engineering Department.

*Notes:

- (1) Received answer to letter.
- (2) Moved - no forwarding address.
- (3) Telephone inquiry.

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Operated for U.S. Department of Energy

Rockwell
International

October 24, 1978

78ETEC-DRF-2941

Dr. Harold S. Kemp
Chairman, Administrative Committee
c/o E. I. duPont de Nemours & Co.
Engineering Department
Wilmington, DE 19898

Subject: Subcooled Hot Water Flow Through Nozzle Type Relief Valves,
Orifices, Nozzles or Valves

Dear Dr. Kemp:

The Energy Technology Engineering Center (ETEC), under contract to the Nuclear Regulatory Commission (NRC), is conducting a literature survey to substantiate the method of determining the safety valve relief capacity under Anticipated Transient Without Scram (ATWS) conditions. Under these conditions, a 2-inch nozzle type safety valve is flowing subcooled (~655°F) hot water at ~3000 psia.

An earlier literature survey by NRC through mid-1975 revealed only one source of experimental data on a 1/2-inch nozzle type safety valve flowing saturated water at low pressure. Only sparse data was available on saturated and subcooled water flow through orifices, nozzles or valves at various pressures.

The Design Institute for Emergency Relief Systems has come to ETEC's attention, as suggested by F. J. Howes of Kunkle Valve Co., as one possibly having information in these flow regimes. Items of particular interest are published papers or reports since mid-1975 and unpublished reports or data of any date; also leads to other sources of information.

Since the literature survey project is of short duration (approximately three months), an early reply would be appreciated. If there are any questions concerning this request, please contact Mr. E. S. Hutmacher, extension 6188.

Sincerely yours,

R. E. Fenton
Manager - Test Engineering
Energy Technology Engineering Center

cc: M. D. Stolzenberg, Nuclear Regulatory Commission, Washington, D. C.
Director, ETEC Project Office, Santa Susana

Figure B-1. Typical Letter to Industry

ETEC-TDR-78-19

B-2

- 9) Crane Co., Engineering Department (1), W.N. McLean, Director of Engineering.
- 10) Flodyne Controls, Inc., Engineering Department.
- 11) Continental Disc Corp., Engineering Department (2).
- 12) Jayco, Inc., Engineering Department (2).
- 13) Kunkle Valve Co., Inc., Engineering Department (1), F.J. Howes V.P. Engineering.
- 14) The Lee Company, Engineering Department.
- 15) J.E. Lonergan Co., Engineering Department.
- 16) Sage Engineering & Valve Co., Engineering Department.
- 17) Target Rock Corp., Engineering Department (1) Mr. Langseeder.
- 18) Rockwell International, Flow Control Division, E.A Bake (1).
- 19) Foster Wheeler Energy Corp., Jorge A. Bonilla.
- 20) Hoffman-La Roche Inc., Robert Kern (1).
- 21) Union Carbide Technical Center, L.L. Simpson (1), M.L. Weirick, for L.L. Simpson Manager, Heat Transfer & Fluid Dynamics.
- 22) E.I. duPont de Nemours & Co., J.B. Arant.
- 23) E.I. duPont de Nemours & Co., D.P. Lovett, Jr. (1).
- 24) E.I. duPont de Nemours & Co., E.S. Monroe, Jr. (1).

- 25) Fisher Controls Co., D. Hammit (1) Richard F. Lytle, Director, Research.
- 26) Masoneilan International, Inc., Engineering Department (1).
- 27) Yarway Corporation, Engineering Department (1) R.D. Schmitt, Manager, Application Engineering.
- 28) Fluor Engineers and Constructors, F.E. Anderson.
- 29) Dravo Corporation, Chemical Plants Division, L. Driskell (1).
- 30) Bingham Williamette Co., Engineering Department, L.D. Brown, District Sales Manager (1).
- 31) Control Specialists Inc., Engineering Department.
- 32) Crosby Valve & Gage Co., Engineering Department (1), R.J. O'Neill Power Products Manager.
- 33) Teledyne Farris Engineering, Engineering Department (1) C.G. Weber, Vice President, Engineering.
- 34) Lukenheimer, A Division of Conval Corp., Engineering Department (1), Craig B. Klimon, Product Manager Engineering Specialties.
- 35) Anderson, Greenwood & Co., Engineering Department.
- 36) National Board of Boiler & Pressure Vessel Inspectors, S. Harrison.
- 37) The Design Institute for Emergency Relief Systems, H.S., Kemp, (1) Chairman Administrative Committee.
- 38) American Society of Mechanical Engineers, A. Bagner, Standards (1) Engineering Administrator.

- 39) Spraying Systems Company, Engineering Department.
- 40) Westinghouse Electric Corp., Valve Group for Naval Programs, D. Akey (1).
- 41) Westinghouse Electric Corp., Bettis Atomic Power Laboratory, M. Sloman (1).
- 42) Valve Manufacturer's Association, Mr. Jerry Hendrickson (1).
- 43) The Knowledge Availability Systems Center, University of Pittsburgh, R. Kenny (3).
- 44) NASA Industrial Applications Center, University of Southern California, D.Haley (3).
- 45) O.E. Buxton, Consultant, Formerly a professor at Ohio State University, Columbus, Ohio (3).
- 46) A L'Energie Atomique Centre D'Etudes Nucleaires De Saclay, Department De Surete Nucleaire Boite Postale No. 2, Gif-Sur-Yvette, France, Commissariat Dr. P. Tanguy. (Letter originated by Dr. G. Bennett of NRC.)
- 47) The Nuclear Power Engineering Test Center, Tokyo Japan, Toshimasa Aoki, Assistant Manager Equipment and Components Department (Mail-gram originated by Dr. L.S. Tong of NRC) (1).
- 48) Electricite' de France, Paris Headquarters, Mr. Sureau (Phone call originated by Mr. Peter Anderson of NRC) (3).

Response to these letters was as follows:

Fisher Controls Co. (R.F. Lytle) - They did some work on small systems prior to 1975. They plan to conduct a study in 1979. In a followup telephone conversation it was found that they have cancelled plans for testing with water at other than ambient temperture.

Crosby Valve & Gage Co. (R.J. O'Neil) - No information.

Yarway Corporation (R.D. Schmitt) - No information. They request information on ETEC's facility capability and availablity for valve tests.

Lunkenheimer Valve Co. (C.B. Klimon) - No information. In a second letter from J. Vincent Smyth, The Knowledge Availability Systems Center at the University of Pittsburgh was suggested as a contact.

Crane Co. (W.N. McLean) - No information.

Dresser Industries (T.R. Bordelon) - Telephone call - no information.

Fike Metal Products Corp. (D.E. Fritsche) - No information.

Hoffman - LaRoche (R. Kern) - No information.

DIERS (H.S. Kemp) (Dupont) - In a telephone conversation Dr. Kemp indicated they were testing with heavy gases. He indicated that they could possibly test with subcooled water. He stated he would send some information on their capabilities. In a follow-up telephone conversation Dr. Kemp stated DIERS was not interested in a test program and that he could not give any information on their test facility.

DuPont (E.S. Monroe Jr.) - No data - ASME Paper No. 76-WA/FM-3 suggested as a reference.

Rockwell (E. Bake) - He indicated he had done some work at Westinghouse Mishawaka Flow Loop which was probably published in 1960 (work published by Powell). He sent a copy of their handbook "Flow Calculation Handbook for Piping Status."

Dravo Corporation (L. Driskell) - He made some observations. He stated that, in the case of control valves, the method of predicting the effective vena contracta pressure, as established in ISA S75.01, is based on theory which has been contradicted by experiment. He offered six references.

DuPont (O.P. Lovett) - He suggested ANSI/ISA S75.01-1977 as standard covering flow regimes of interest.

Control Components (F.O. Serger) - He suggested, for state-of-the-art in control valves, the ISA Handbook of Control Valves.

Union Carbide (M.L. Weirick) - He knows of no single technique applicable to all situations. He refers to work of Fauske and Tong. He concludes there is a considerable amount of confusion and uncertainty in the field of flashing two-phase flow. He requests further information from the valve survey if anything of value is found.

Burgess-Manning (E.S. Halter) - No information. He suggested contacting Spraying Systems Co.

Armstrong Machine Works (W. Sisson) - No information. He suggested contacting sub-committee 3 of ISO/TC153.

Kunkle Valve Co. (F.J. Howes) - No information. He suggested contacting S. Harrison, National Board of Boiler and Pressure Vessel Inspectors and H.S. Kemp of Design Institute for Emergency Relief Systems (at Dupont).

ISO/TC-153 (A. Bagner) - He is sending the letter to all members of sub-committee 3.

Valve Manufacturer's Assoc. (J. Hendricksen) - In a telephone conversation with Mr. Novak it was stated that the letter would be sent to all members as a news letter.

Target Rock Corp. (Mr. Langseeder) - In a telephone conversation, contact with Mr. Akey of Westinghouse Pittsburgh and Mr. Sloman of Westinghouse Mishawaka was suggested. The Mishawaka Flow Loop tests many of their valves.

Westinghouse, Pittsburgh (D. Akey) and Westinghouse, Mishawaka (M. Sloman) - Mr Akey responded for both, suggesting that NRC contact DOE division of Naval Reactors for data which may be both classified and sensitive.

Teledyne Farris Engineering (C.G. Weber) - He indicated they had done only limited theoretical work for selection of valve sizes. He recommended contacting Prof. O.E. Buxton of Ohio State University.

The Knowledge Availability Systems Center, University of Pittsburgh (R. Kenny) - He suggested contacting NASA Industrial Applications Center at the Univertisy of Southern California who have access to the same 100 indexes.

NASA Industrial Applications Center, University of Southern California (D. Haley) - After describing the searches performed, he stated that the 100 indexes available to them would provide no further information.

O.E. Buxton, Consultant, Columbus Ohio - He indicated he had done some work with small valves at 150 psi eight or ten years ago. He did not think there was any data of value and indicated none of the data had been documented. He observed that the flow capacity was configuration sensitive.

The Nuclear Power Engineering Test Center, Tokyo Japan - Yasuo Kajiyama responded to the letter, briefly listing their facility capabilities and enclosing a schedule which indicated completion of the facility in late 1978 and testing through 1982.

Electricite' de France, Paris France - Mr. Sureau, in a telephone conversation with Peter Anderson, gave information on their test facility and schedule which is described in detail in Section VII, Facility Survey.

APPENDIX C

LIST OF REPORTS AND PAPERS SELECTED FOR EVALUATION

The original intent was to evaluate papers or reports published from mid-1975 to the present. This was expanded to earlier dates as letters to industry or other recommendations suggested that something of interest might be included in earlier reports and papers. The papers and reports selected for evaluation are listed below:

Anon, Anticipated Transients Without Scram for Light Water Reactors, NUREG-0460, Vol. 2; Appendices, Division of Systems Safety, U.S. Nuclear Regulatory Commission, April 1978, pages IX-1 through IX-3.

Anon, ASME Pressure Vessel Code, ASME Section VIII, 1977 (1978 Summer Addenda), pages 73-75 and 403-405.

Anon, Control Valve Sizing Equations, ANSI/ISA S75.01, 1977, 11 pages.

Anon, Evaluation of Pressure Drop Across Area Changes During Blowdown, NUREG-75/085, Cincinnati University, Ohio, September 1975, 20 pages.

Anon, Flow Calculation Handbook, Valve Division, Rockwell International, 1977 Rev. 3/78, 145 pages.

Anon, Flow of Flashing Mixtures of a Liquid and its Vapor, Tube Turns Bulletin TT725, 1952, pages 23-25.

Anon, ISA Handbook of Control Valves, Instrument Society of America, 533 pages.

Anon, Non-Mandatory Rules for the Design of Safety Valve Installations, ASME, American National Standard Code for Pressure Piping, Power Piping, ANSI B31.1, 1977 Edition, Appendix 11, pages 145-168.

Anon, NRC visit to Wyle Laboratories Huntsville Facility, Wyle Laboratories, June 22, 1978, 101 pages.

Anon, Preprints of AIChE Papers - 17th National Heat Transfer Conference, American Institute of Chemical Engineers, Aug. 14-17, 1977, 281 pages.

Anon, Proving Test on the Reliability of Valves, the Nuclear Power Engineering Test Center, Japan, January 1978, 12 pages.

Anon, Qualifying Safety Relief Valves Demands Lengthy Programme, Nuclear Engineering International, May 1978, pages 58-59.

Anon, Safety and Relief Valves, PTC 25.3, ASME Performance Test Codes, 1976, 54 pages.

Anon, Safety Valves and Safety Relief Valves, ASME Boiler and Pressure Vessel Code, Section I, Power Boilers, 1971 pages 44-52.

Anon, Status Report on Anticipated Transients Without Scram for Westinghouse Reactors, Appendix D, Division of Systems Safety, U.S. Nuclear Regulatory Commission, 12/9/75, 25 pages.

Anon, Testing --- Testing at Wyle Labs., Vol. 37, Flowline, Rockwell International, Third Quarter 1978, pages 21 and 22.

Anon, The Selection and Procurement of Pressure Relief Valves for Light-Water-Cooled Nuclear Reactor Systems, ORNL-TM-3782, Oak Ridge National Laboratory, June 1972, 92 pages.

Anon, Two-Phase Flow and Heat Transfer Symposium - Workshop held at Ft. Lauderdale, Florida on Oct. 18 through 20, 1976, National Science Foundation, Washington, D.C. PB271790, 24 pages.

Anderson, Floyd E., Pressure Relieving Devices, Chemical Engineering, May 24, 1976, pages 128-134.

Azzopardi, B.J., and Williams, N.M., The Calculations of Two-Phase Pressure Drop by Means of an Annular Flow Model, QUEL-1181-77, (Atomic Energy Research Establishment Harwell, England) Nov. 1976, 36 pages.

Baumann, Hans D., Does Piping Geometry Affect Valve Flow Capacity?" Flow - Its Measurement and Control in Science and Industry, Part III, 1974, pages 1091-1096.

Baumann, Hans D., How to Estimate Pressure Drop Across Liquid Control Valves, Chemical Engineering, April 29, 1974, pages 137-142.

Beattie, D.R.H., Friction Factors and Regime Transitions in High Pressure Steam - Water Flows, ASME Paper No. 75 - WA/HT-4, July 25, 1975, 8 pages.

Boger, Henry W., Pressure Recovery in Control Valves, Flow - Its Measurement and Control in Science and Industry, Part III, 1974, pages 1065-1070.

Bonilla, Jorge A., Estimate Safe Flare Headers Quickly, Chemical Engineering, April 10, 1978, pages 135-140.

Bordelon, T.R., Temperature Effects on Pressure Relief Valve Function, Power Engineering, Vol. 82, No. 11, November 1978, pages 73-76.

Boure', J.A., On a Unified Presentation of the Non-Equilibrium Two-Phase Flow Models, ASME Non-Equilibrium Two-Phase Flows, 11/30 -12/5/75, 9 pages.

Brandmaier, H.E. and Knebel, M.E., Steam Flow Through Safety Valve Vent Pipes, ASME Paper No. 75-Wa/Fe-23, August 14, 1975, 11 pages.

Brown, D.J., Jensen, A., and Whalley, P.B., Non-Equilibrium Effects in Heated and Unheated Annular Two-Phase, ASME Paper No. 75-WA/HT-7, July 25, 1975, 8 pages.

Brown, R.A., Flashing Expansion of Water Through a Diverging Converging Nozzle, MS Thesis University of California, Berkeley, USAEC Report, UCRL-6665-T, 1961.

Calder, Clarence A., Flow-Regime Characterization for Horizontal Two-Phase Steam Flow, UCRL-52186, Lawrence Livermore Laboratory, October 5, 1976, 24 pages.

Carey, James A., and Hammitt, Donn, How to Select Liquid-Flow Control Valves, Chemical Engineering, April 3, 1978, pages 131-148.

Carpenter, D.M., Relief Device System Installation, Rocketdyne Santa Susana Field Laboratory Directive 19, October 31, 1963, 7 pages.

Chalfin, Sanford, Sizing Control Valves, Chemical Engineering, October 14, 1974, pages 105-114.

Choe, W.G., and Weisman, J., Flow Patterns and Pressure Drop in Horizontal Two-Phase Pipe Flow, University of Cincinnati, PB-263080, March 1976, 192 pages.

Collier, J.G., Introduction to Two-Phase Flow Problems in the Power Industry, Brookhaven/Hemisphere Two-Phase Course, 10/30 - 11/3/78, 12 pages.

Collins, R.L., Choked Expansion of Subcooled Water and the I.H.E. Flow Model, Transactions of the ASME, Journal of Heat Transfer, Vol. 100, May 1978, pages 275-280.

Crowe, C.T., and Weiss, H., Metering Low-Quality Steam-Water Flows, UCRL-52271, Lawrence Livermore Laboratory, April 26, 1977, 31 pages.

Custer, F.A., Capacity Rating of Nozzle Type Safety Valves on Saturated Hot Water, SV69-3, January 1971.

Daugherty, R.L., and Ingersoll, A.C., Fluid Dynamics, 1954 Ed., pages 336-339.

Delhaye, J.M., Singular Pressure Drops, Brookhaven/Hemisphere Two-Phase Course, 10/30-11/3/78, 13 pages.

Delhaye, J.M., Frictional Pressure Drops, Brookhaven/Hemisphere Two-Phase Course, 10/30-11/3/78, 26 pages.

Dokainish, M.A., and Elmadany, M.N., On the Nonlinear Response of a Relief Valve, ASME Paper No. 77-DET-81, Journal of Mechanical Design, Vol. 100, October 1978, pages 675-680.

Driskell, L., Control Valve Sizing with ISA Formulas, Instrumentation Technology, July 1974, pages 33-48.

Driskell, Les, Coping with High Pressure Letdown, Chemical Engineering, October 25, 1976, pages 113-118.

English, Marvin L., The Energy Equation Used in Valve Sizing, Flow - Its Measurements and Control in Science and Industry, Part III, 1974, pages 1055-1063.

Fox, C.T., Blast It Clean with Water, Chemical Engineering, August 14, 1967, pages 180-186.

Fujita, R.K., and Hughs, E.D., Comparisons of RELAP-4 Predictions with Steady-State Two-Phase Critical Flow Data, ASME Paper No. 76-WA/HT-51, August 9, 1976, 9 pages.

Goode, William, Sizing Relief Valves for Liquids, Heating/Piping/Air Conditioning, Vol. 49, No. 10, October 1977, pages 109-111.

Guzick, Lawrence L., Phase Out of High Pressure Steam Traps, NAVMIRO Manufacturing Technology Bulletin 59, February 1975, 9 pages.

Head, V.P., Statistical Improvement in Differential Producer Type Flowmeters, ASME Paper No. 76-WA/FM-1, Journal of Fluids Engineering, July 29, 1976, 7 pages.

Helf, H., and Dernbach, B., Investigation in the Operational Reliability of the Pressurizer Safety valves and the Relief Tank During Blowdown of Hot Pressurized Water, Report No. RE23, Kraftwerk Union, Reactor Technology Erlanger, September 1978, 31 pages.

Hewlett, G.F., and Lovegrove, P.C., Experimental Methods in Two-Phase Flow Studies, Final Report, Atomic Energy Research Establishment, Harwell, England, PB-252227/4, March 1976, 247 pages.

Holster, J.L., Bass, R.L., III, and Schroeder, E.C., A Facility for Qualification Testing of Subsurface Safety Valves, ASME Paper No. 75-PET-14, June 13, 1975, 8 pages.

Howard, Paul A., One-Component Two-Phase Critical Flow: An Experimental Study Using Freon II at Subatmospheric Pressures, ANL-75-8, Argonne National Laboratory, January 1975, 75 pages.

Hsu, Y.Y. (Editor), Two-Phase Flow Instrumentation Review Group Meeting - Procedures of Meeting January 13 to 14, 1977, USNRC, NUREG-0375, March 1978, 261 pages.

Husain, A., and Weismann, J., Two-Phase Pressure Drop Across Abrupt Area Changes, C00-2152-5, Cincinnati University, Ohio, January 1975, 123 pages.

Ishii, M., Study on Flow Instabilities in Two-Phase Mixtures, ANL-76-23, Argonne National Laboratory, March 1976, 53 pages.

Ivany, R.D., Hammitt, F.G., and Mitchell, T.M., Cavitation Bubble Collapse Observations in a Venturi, Transactions of the ASME, Journal of Basic Engineering, September 1966, pages 649-657.

Kajiyama, Yasuo, Safety Relief Valve Test Planning, Letter to Dr. Long Sun Tong, USNRC Describing Genshiyoku Kogaku Shiken Center, January 4, 1979, 3 pages.

Kern, Robert, Pressure-Relief Valves for Process Plants, Chemical Engineering, February 28, 1977, pages 187-194.

Kim, K.K., Koronkevich, M.A., and Tomilin, D.D., Cavitation Regimes of a Hot-Water Flow in a Laval Nozzle, UDC 532.525:532, Institute of Thermal Physics, Siberian Branch, Academy of Science of the USSR, January 1, 1976, pages 730-735.

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