Relief Valve Discharge Piping Calculational Methods and Results

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Abstract

The analysis of a safety relief valve and its connecting discharge pipe is an important parameter in the design of a light water reactor plant. This paper addresses the computer modelling techniques and methods used for this analysis and presents guidelines, cautions and improvements which should be used for design. Specific discussions include considerations for loop seal design, heat transfer effects, pipe submergence, reflow effects and vacuum breaker design.

1. Introduction

Following the Three Mile Island accident, United States Nuclear Power Plant licensees and applicants were required to verify the acceptability of the design of specific plant safety valve discharge lines (SRVDL). The Electric Power Research Institute (EPRI) formulated, conducted and completed an extensive testing program (1) to improve understanding of the operation of the SRV's and the resultant phenomenon in the discharge piping. Data acquired via this testing program has been used to benchmark and verify analytical tools and models employed for the verification of the adequacy of existing safety relief discharge piping systems and design of new ones. Modelling of SRVDL's has been done for quite sometime. In the following, the salient phenomena and parameters are discussed for both pressurized and boiling water reactor typical SRVDL's.

2. Verification, Modelling and Analysis

Light water reactor relief piping systems can consist of safety relief valves (SRV) only or combinations of SRV's and power operated relief valves (PORV). The PORV's generally open in a relatively long time, greater than .25 seconds, and do not normally produce significant piping forces. The SRV's, however, open in a very short time, typically in tens of milliseconds and produce forces which can significantly effect the design of the discharge piping and its supports and restraints. Further, the effect of the valves' discharges on the piping system is drastically influenced by the presence or absence of a water low seal upstream of the valves.

The conditions downstream of an opening SRV can be divided into two phases. The first is dominated by the travel of a shock or acoustic wave. The second phase is momentum flow dominated. The methodology used to design the piping system and supports must be able to address both phases of the transient. Most methods and computer codes used to date account for the second phase, but have mixed success with the first one. Failure to properly
consider the acoustic disturbances introduced in the system can result in an inadequate analysis with possible adverse effects on design. As an example, Figure 1 compares results obtained by two different simulations of a test discharge piping system. One simulation employed the RELAP5 MOD2 (2) code to generate the thermal hydraulic conditions in the system, while the other employed RELAP4 MOD6 (1). In both instances a similar postprocessor code, CALPLOT4 (4), and structural code, PIPESTRESS (5), were used to generate the fluid forces and predict the piping response as a function of time. Test results include, of course, the piping response. It is readily apparent that RELAP4 predicts lower hydraulic forces. This effect is due to the inability of the code to correctly follow the propagation of steep pressure waves through the piping system. Thus, the RELAP4 results should be combined with a one dimensional compressible flow code, such as PIPESHOCK (6) to follow the travel of a shock wave in the downstream portion of the piping system. This combination was confirmed by comparison to EPRI test results. The RELAP5 code however, has been shown to be an acceptable tool for modelling the entire transient if certain guidelines outlined in the EPRI study are followed.

In order to eliminate the possibility of steam leakage through an SRV during normal operation, a number of PWR plants employ water loop seals upstream of each SRV. Depending on the initial loop seal temperature, a one or two-phase slug of water will accelerate down the discharge piping following valve actuation. Codes which are limited in number of control volumes or assume homogeneous fluid flow, clearly cannot describe the discharge phenomenon correctly. Codes like RELAP5, which can handle a non-homogeneous, non-thermal equilibrium solution of the momentum equation for different two phase flow regimes do describe the behavior reasonably well as evidenced by comparison of their predictions to the results of tests (7).

3. Design Recommendations

All experimental and analytical results have indicated that the most severe downstream loadings occur for low loop seal temperatures. This condition maximizes the density of the fluid passing through the valve, and thus maximizes the downstream force cause by the acceleration of that fluid. Downstream pipe forces are affected by both the upstream loop seal water temperature and volume. Since, in many instances, changes in the volume of the loop seal are either unfeasible or very difficult to realize on existing designs, controlling the loop seal temperature by insulation is the logical alternative. For new designs both can be considered; however, the principal variable which affects downstream discharge forces is the loop seal temperature, not the volume. The volume changes affect the downstream forces only indirectly by increasing the average loop seal temperature as the volume decreases. Figure 2 illustrates this effect of loop seal average temperature on downstream forces.

To optimize the design of the loop seal it is necessary to compute accurately the steady state loop seal water temperature distribution. This requires an independent heat transfer model of the loop seal and adjacent piping, which considers heat transfer both radially from the pipe and axially along it. The valve manufacturer requirements for a low loop steam temperature at the valve seat conflict with the desire to maximize water temperature. The loop seal design will generally emerge from a compromise of the two requirements.
The lengthening of the opening time of the SRV would help decrease forces for conditions with or without loop seals, but this decrease of opening time is not always desirable or achievable.

For the case in which loop seals are not present, studies performed as part of the EPRI verification indicated that the modelling of heat transfer to the pipe walls was necessary to reproduce test results. This heat transfer effect becomes more pronounced for subsequent actuation of an SRV. More severe forces can result from the accumulation of condensed water which must be accelerated in the downstream piping.

Considerations must also be made for the end section of the SRVOL which is normally submerged in a pool of water to induce condensation. This length of pipe must be designed to withstand the large forces caused by the acceleration of the high density submerged water slug following SRV actuation. For this situation, a smaller submerged water portion would of course produce smaller forces.

For the BWR SRV actuation, not only the water expulsion from the submerged portion, but the reflood water transient following closure of the SRV is of great significance. The actual reflood level depends on the ability of the SRVOL vacuum breaker valve to allow a rapid depressurization of the line.

The choice of the modelling technique and code can also significantly affect the design of the piping and vacuum breaker. Proper analysis requires that the code employed permit consideration of two-phase fronts upon reflooding and heat transfer between the various surfaces including the steam-water and air-water interface. Codes which do not permit such considerations will tend to overestimate the amount of water drawn into the SRVOL upon reflood. Figure 3 illustrates the comparison between results obtained using a code which treats the water portion as a moving slug, and those obtained using RELAPS. The latter modelling clearly shows that the water does not advance with a clearly defined front as the former code predicts, but rather the void fraction (volume of gas/total volume) at any one point in the pipe decreases with time as the water advances. Two idealized fronts are shown in Figure 3, one having a very high void fraction of 0.997 and the other having a void fraction of 0.5. The result for reflood length of the single-phase code (all water) is very close to the results of RELAPS for void fraction of 0.997 (0.3% water in volume). This means that significantly less water is drawn in the pipe than predicted by the one-phase code. This difference is very significant when water clearing is considered for a second actuation, since instead of clearing all water, a mixture of water, steam and air will be cleared, producing much lower forces on the discharge line and the suppression pool boundary.

The choice of the vacuum breakers, size as well as type, profoundly influence the design of SRVOL's. For instance, sensitivity studies performed using RELAPS indicated that swing-type disk check valves vacuum breakers of sufficient size are capable of responding more quickly to a transient depressurization than motor operated ones, thus limiting the height of reflood water entering the SRVOL.
4 REFERENCES


Figure 1: Comparison of Measured and Calculated SRV Discharge Forces

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Figure 2  SRV Discharge Force as a Function of Average Loop Seal Temperature
(Maximum Force Directed towards SRV, Minimum Force Directed Away from SRV)

Figure 3  Calculated SRV Offload Lengths