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A Preliminary Planning Study
for
Safety Relief Valve Experiments
in a Mark III BWR Pressure
Suppression System

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A B S T R A C T

In response to a request from the Water Reactor Safety Research Division of the U.S. NRC, a preliminary study is provided which identifies key features and consideration involved in planning a comprehensive in-plant Safety Relief Valve experimental program for a Mark III containment design. The report provides identification of program objectives, measurement system requirements, and some details quantifying expected system response. In addition, a preliminary test matrix is outlined which involves a supporting philosophy intended to enhance the usefulness of the experimental results for all members of the program team; experimentalists, analysts, and plant operator.

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A Preliminary Planning Study for
Safety Relief Valve Experiments in
the Mark III BWR Wetwell

INTRODUCTION

The purpose of this report is to provide preliminary guidance in planning ⁽¹⁾ for confirmatory research which addresses loads induced by safety relief valve (SRV) discharge in a MkIII BWR pressure suppression wetwell. In addition to obtaining confirmatory load information, the test program, to be conducted at the Kuosheng #1 plant in Taiwan, is implicitly intended to develop data useful to the development and validation of advanced, best estimate computer codes.

The BWR MkIII suppression pool (Fig. 1) is a safety design feature provided in the BWR-6 design⁽²⁾ to ensure pressure control in the primary containment following a loss of coolant accident (LOCA). It provides a large, low temperature water volume sufficient to rapidly and safely condense all anticipated two phase primary effluent following this hypothetical, design basis accident.

This wetwell is also used as a convenient sink for the discharge of primary coolant following system relief valve lifts which routinely occur. As indicated in Figs. 2 and 3, the relief valves are located at a distance above the wetwell and, as shown in Figs. 4 and 5, their discharge ports are each connected to the wetwell by separate pipe strings extending for approximately 100 feet. The terminal end of each such pipe is located ~ 1.2 m above the wetwell floor; its discharge is circumferentially directed parallel to this floor.

From a phenomenological view, following a relief valve lift, the total air volume in the pipe is expelled into the wetwell by the primary coolant. During this air clearing transient, the initial water inventory in the terminal end of the SRV line is violently expelled ahead of the air. The contained air then enters the pool, creating a substantial void but little pool swell due both to the relatively large water volume and the localized nature of the discharge. Saturated steam then enters the pool where it is condensed in a non-steady manner called condensation oscillation. Following closure of the relief valve, a transient pressure reduction occurs in the discharge pipe due to condensation of the steam remaining in the pipe. If not relieved by a vacuum breaker, this can result in a substantial, if temporary, water leg ~ 20 m in height.

Test Program

The test program primary objectives are two-fold

- measurement of structural response
 - SRV piping and support systems
 - wetwell boundaries
- measurement of pressure and temperature response
 - discharge piping
 - wetwell

Fig. 1. BWR-6 with MkIII Pressure Suppression System Design

Fig. 2. Schematic of High Pressure Piping

Fig. 3. BWR-6 Drywell - Elevation

Fig. 5. Plans of the MkIII SRV Discharge Piping

Major experimental parameters are

- lift duration of the SRV(s)
- sequenced SRV lifts
- multiplexed SRV lifts
- wetwell pool temperature.

Measurement System

In order to accomplish these objectives, the measurement system will include

- pressure transducers with minimal temperature sensitivity
 - absolute, e.g., strain gage bridge
 - relative, e.g., piezoelectric
- thermocouples
- strain gages
- accelerometers
- water level gages, e.g., "spark plugs" or thermocouples

Table 1 provides a summary of desired instrumentation, its purpose, and location. In order to insure suitable characterization of each test, safety relief valve and vacuum breaker operation parameters should also be measured. Final transducer locations should be reviewed by appropriate code development personnel to assure compatibility between experiment and analysis. In this manner, the plant-unique results from the Kuosheng experimental program will provide a suitable data base for the validation of best-estimate predictive computer codes.

Past experimental work has clarified the fundamental importance of a common timing system for all instrumentation channels in order to insure the opportunity for later coherence studies of the data. The ability to provide pretest pressure calibrations (systematic error) is important; the pressure transducer housing design can readily provide for this. In this regard, it is important that the wetwell boundary transducers are mounted in low mass fixtures of a high natural frequency so as to avoid influencing the actual wetwell boundary response. A sound and well-documented instrument calibration procedure is most important(3).

With regard to data acquisition rate, two criteria are important. The first, definition of important system frequencies, can be used to set the minimum data acquisition rate, i.e., if η_a is the data acquisition rate (data point/chn.-sec.) and f_s is the maximum system frequency of interest (Hz), then

$$\eta_a^{\min} \geq 4 f_s.$$

Table 1
Instrumentation Requirements

<u>Purpose</u>	<u>Location</u>	<u>Transducer Type</u>
Source definition (steam discharge)	SRV discharge line	pressure - absolute pressure - relative temperature water level O ₂ /air
structural response of piping system including supports	SRV discharge line and supports	strain acceleration temperature
hydrodynamic loading	wetwell	pressure - absolute temperature

System frequencies of interest are upwards of 100 Hz so that the minimum data sampling rate would be ~ 2.5 ms ($n_{\text{min}} \geq 400/\text{sec}$). This criteria is necessary but insufficient to capture pressure amplitudes⁽⁴⁾ since such data often contain frequencies greater than 1 kHz. For this reason the pulse code modulation (PCM) acquisition method is recommended with an $n \geq 4000$ data points/chn.-sec in order to yield valid data of frequency 1.0 kHz or greater. Due to the relative cost of PCM channels compared to the lower speed acquisition system, as well as the quantity of data generated, only those transducers which are required to measure high frequency information, i.e., pressure, strain, and accelerometers, should be placed in the high rate PCM category. Useful information for review of such a measurement system has been provided by the GKSS⁽⁵⁾.

Selection of Transducer Measurement Range

General criteria for pressure transducer range selection provides for a 50% excess to avoid physical damage to the sensitive diaphragm for the worst expected case and then specifies the gain for a particular experiment to maximize sensitivity. In this way, should an unexpected overpressure occur in a particular channel, signal saturation is the worst that happens.

Little physical damage occurs with accelerometers and strain gages; rather temperature drift is of concern. Again, gain setting control is used to maximize sensitivity of these transducers for a particular test. Actually, since SRV experiments offer an unusual opportunity for relative ease in conducting repetitive tests, a series of controlled discharge pretests can be used to determine and insure the readiness of all channels prior to the full-discharge main tests. At least one diver qualified as an instrumentation technician should be part of the measurements team.

Care must be taken to minimize electronic noise and to ensure adequate grounding, particularly in the strain gauge channels. The response of pressure transducers, in particular, will benefit substantially from use of separate and integral connector/cables, each of which pass from the transducer directly to the main junction box before the amplifier; a 20 to 40 m integral cable would likely be required. Such an approach minimizes both ground-loop problems and inter-connector noise while maximizing system reliability.

Explicit peak pressure response information from which range selection can be made is taken from several sources: SRV load tests at the Monticello plant⁽⁶⁾; our past three dimensional analytical studies, for the U.S. NRC (DOR), of fluid-structure interaction in the MkI wetwell⁽⁷⁾; and the G.E. SAR⁽¹⁾. Upstream of an SRV, system pressure and temperature exist, thus peak temperature can be expected to be $> 300^\circ\text{C}$. The relief settings can be variable but are estimated here as ranging from ~ 8 bar for purp suction-side relief valves to ~ 110 bar for the main relief valves; critical flow conditions to the discharge lines are not expected but allow bounding (or range selection) of the SRV line maximum discharge pressure as ~ 60 bar. Final selection should be based on test data of the actual relief valves. Peak SRV discharge line exit pressure can be expected to range from ~ 1 bar to ~ 20 bar depending on lift time, line length, and pool and line temperature. Although such a range can be accurately handled without switching transducers, care will be required as was mentioned earlier to properly set amplifier gain to avoid signal saturation or loss of sensitivity. Again, the testing flexibility which SRV experiments offer strongly suggests that pretest studies be used to determine this important data.

Although the SRV discharge into the wetwell is horizontal and the discharge pipe is masked from the wetwell floor by the support beam, no significant pressure pulse attenuation is expected between discharge line exit pressure and wetwell boundary beyond that afforded by the nominal 1.2 m separation of the MkIII containment. Based on the earlier data, both experimental and analytical, an unimpeded pressure pulse transmitted through water to a relatively rigid boundary would be attenuated by 80 - 90%, with the SRV line discharge pressure peak ranging from 1 to 20 bars. On this basis, boundary peak pressures would be

- at SRV discharge line inlet - 60b
- at SRV discharge line outlet - 20b
- at wetwell floor - 4b

More realistically, these estimates can be reduced by a factor of two for expected measurements. They do, however, serve to guide transducer selection.

The discussion has addressed the near-boundary response, and it is desirable to also estimate the wetwell boundary response at significant distances away from the SRV discharge. Again we turn to our existing data base. In Fig. 6 we show information extracted from Ref. 6 and Ref. 7 which provides spatial attenuation information. Curve A provides an attenuation estimate along the wetwell floor while curve B provides an attenuation estimate along the SRV discharge plane. Note that this discharge plane is associated with the MkI which is ~ 1.4 m above the wetwell floor; the MkIII discharge plane is 1.2 m above the floor. No significant effect is expected due to this small elevation difference. Both of these estimates are taken along the axis of discharge. It is evident that peak floor pressures can be expected to fall off more rapidly than those in the plane. We feel the particular importance to be placed in this data is in recognition that within less than 5 m from the vertical source plane, the floor pressure can be expected to drop by nearly a factor of 20. Thus, if a peak pressure of 2 bar were to be observed near the source, at 6 m it would be observed as order 0.1 bar; the signal to noise ratio should be 100:1 to reliably observe this.

Test Matrix

A comprehensive test program will need to explore system response to single, multiple, and sequential SRV actuation, with both hot and cold SRV discharge pipes, and with various bulk wetwell pool temperatures. In addition, the potential load increase due to the substantial water leg arising from multiple actuation of a single SRV should be investigated. It will be recalled that the large pressure drop expected across the SRV during lift occurs because the SRV discharge line is assumed as fluid-free, i.e., the discharge effluent is allowed to accelerate. If, however, due to a prior lift, the water leg is close to the discharge port during a subsequent attenuation, a near stagnation can occur at the gas-water interface while the water is being accelerated allowing the discharge piping to see near system pressure and experience weak shocks. In addition, the greater than normal water leg can cause a substantial wetwell load increase during the clearing transient.

Fig. 6. Estimated Pressure Pulse Attenuation in the MkIII Wetwell Pool

Table 2 provides listing of parameters from which a full test matrix can be developed. As indicated earlier and shown in Figs. 4 and 5, substantial difference in discharge pipe lengths exist. Coupling this fact with the variation in source strengths available in the different lines suggests that the time taken to carefully define the detailed goals of the experimental program prior to its design will be easily recovered by the implicit savings from unneeded measurements and unrequired data analyses. Experiment preplanning should also include definition of both in-lab and installed transducer calibration procedures as well as the explicit error analyses to which the finally acquired data will be subjected. Data presentation methods should be outlined in the goal setting phase and software designs developed as an integral part of the experiment design phase in order to ensure that realistic manpower estimates are made; timely and useful reporting of test results can then occur. In this regard, it is important that consideration be given to careful specification of the contents of data reports. These traditionally suffer from the conflicting requirements of the

- need by the customer for immediate test results
- need by experimental team to hold to test schedule
- need by analyst to understand test results prior to further testing

By placing an emphasis on the use of a test's data report, its contents can be tailored to the needs of all parties - customer, experimentalist, and analyst. It will become a test result just as basic as the digitized magnetic tapes and its contents sought after with equal interest by all concerned.

We have evolved a procedure with the GKSS-DAS staff which attempts to gain this position by a two-step procedure:

1. Define a Characteristic Data Set (CDS) agreed to by all parties which
 - (a) specifies minimum number of key data channels
 - (b) specifies time intervals to display, by plots, both general and detailed test results on a consistent basis
 - (c) is developed and distributed to facility staff 1 - 2 days after a test
 - (d) is reviewed and commented on by facility staff for 1 - 2 days
 - (e) is collated with comments and preliminary evaluations and copied as a DRAFT-Characteristic Data Set
 - (f) subject to revision, is distributed to all parties within 7 days.
2. Define the final test report contents required in addition to the CDS, and, on a reasonable time schedule
 - (a) prepare final data plots
 - (b) revise CDS as required
 - (c) prepare written test evaluation based on all contained data
 - (d) publish test report.

Table 2. Test Parameters

<u>Variable</u>	<u>Conditions</u>	<u>Purpose</u>
Single SRV	Unique event	Establish baseline for piping and wetwell loads
	Sequential	baseline load effects due to high water leg
Multiple SRV*	Unique events (simultaneous)	Piping & wetwell load combination
	Sequential (simultaneous)	Load combination effect due to high water leg
Consecutive SRV*	Pseudo random	Load combination
Wetwell temperature	Bulk change	Effect on wetwell loading
	Localized	Effect on wetwell loading
SRV line temperature	Cold	Establish baseline
	Hot	Bounding load effect on piping system and on discharge phenomena

* to include both adjacent and separated SRV discharge points

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