In-Plant SRV Discharge Tests and Their Use in Peach Bottom Structural Requalification

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ABSTRACT:

Sixteen in-plant SRV tests were conducted at Peach Bottom Unit 2 to obtain baseline plant specific information on interface pressures and structural response to be used in the structural requalification of the primary containment. The SRVs were actuated in a preselected sequence, with data being measured by the pressure gages, strain gages, and other instruments. The results were used to calibrate the computer programs developed to predict the design case pressures.

1.0 INTRODUCTION:

One of the significant hydrodynamic loads in a Mark I boiling water reactor results from initial air clearing upon discharge of the main steam safety relief valve(s) (SRV) into the primary containment suppression pool. The loads resulting from an SRV discharge were based on in-plant tests at Monticello Nuclear Plant and quarter scale parametric tests. Computer programs were developed to calculate plant unique SRV discharge loads. The loads and the accompanying structural analysis techniques proved to be very conservative. Recognizing this, the Nuclear Regulatory Commission (NRC) has given the utilities the option of using the results from in-plant tests to calibrate both load calculation models and structural analysis techniques. The calibrated models can then be used to calculate more realistic plant unique design SRV discharge loads. For this purpose, a test program was conducted in Peach Bottom Unit 2. This paper describes the tests and summarizes the test results and their use in the structural requalification of the Peach Bottom Units 2 and 3.

2.0 SYSTEM DESCRIPTION:

The suppression chamber in Peach Bottom is a toroidal steel pressure vessel (torus) having a 111'-6" major diameter. The torus is made up of 16 mitered cylindrical segments, each about 31 feet in diameter and 22 feet long. The torus has a ring girder at each miter joint and is also supported at these locations.

The SRV system consists of eleven 6 inch by 10 inch Target Rock relief valves. These may be actuated by a pressure in excess of the setpoint value or by certain signals from the reactor system instrumentation. The pressure setpoints are arranged in a 4-4-3 grouping, with the lowest SRV group set at 1105 psig. The discharge piping is routed from the valves in the drywell, through the containment vent pipes, and into the suppression pool. The T-quenchers, which mitigate loads caused by SRV discharge, are located at the end of each discharge pipe.

3.0 IN-PLANT SRV DISCHARGE TESTS:

Sixteen tests were conducted, out of which 13 were single-valve actuations and three were two-valve actuations. The tests consisted of actuating four different SRVs. The tests represent 12 first (cold) and four subsequent (hot) actuations. Subsequent actuations refer to the hot pipe only with a normal water level.

The objective of these tests was to obtain baseline plant specific information on interface pressures and the torus response due to an SRV discharge for use in the plant requalification. The instrumentation chosen to acquire this data included pressure transducers, strain gages, displacement transducers, accelerometers, and a thermocouple.

Because the SRV discharge line routing is similar in three of the four quadrants of the torus, only one quadrant was instrumented with bay 15 designated as the test bay. One of the shortest lines, G, the longest line, K, and line H all discharge into this area. The majority of the instrumentation was located there. Two pressure transducers were located in the adjacent bay 14. The torus support between bays 14 and 15 was instrumented to determine support responses.

To ensure repeatability of the data base, a special air bleed valve was installed on the discharge lines that were planned to be tested more than once. This system ensured that the water leg in the discharge line was at the normal level prior to each test.

Pressure Gages. Eleven Sensotec pressure transducers were used in the test. Two were mounted in bay 14 and nine were mounted in the test bay. The transducers were mounted as shown in Figure 1.

In addition, diffferential pressure transducers were installed on SRV discharge pipes G, H, and K. The pressure taps were placed 12 inches above the nominal water level and 3 feet below the water level. These transducers were used to ensure that the water in the individual SRV lines returned to its normal level following valve actuation so that the subsequent actuation could be conducted with a known water level.

Strain Gages. A total of 76 single weldable strain gages was installed for the test. Sixty-six of the gages were mounted to form 22 (3-gage) strain rosettes. The remaining 10 were used as single axis gages. Eleven of the strain rosettes were mounted on the outside surface of the torus shell in bay 15 between SRV lines H and K. The remaining 11 strain rosettes were installed on the inside surface of the torus shell at corresponding locations. The strain rosettes were located in a plan similar to that of the pressure transducers. Figure 1 shows the locations of the strain gages also.

Four uniaxial strain gages were mounted outside of the torus on the 24-inch RHR pump suction nozzle in bay 16. These gages were located to determine bending and thrust loads in the piping attached to the torus. Six uniaxial strain gages were mounted on the torus support under SRV discharge line K. Locations were selected to determine the column load and the load distribution between the column and saddle support.

In addition to pressure and strain gages, displacement gages and accelerometers were used at selected locations to measure deflections and accelerations respectively. All instrumentation mounted inside the torus atmosphere (both above and below water level) was installed using magnesium oxide stainless steel jacketed cabling which was hydrostatically qualified prior to installation.

Data Recording and Digitizing Systems. All the transducer signals were recorded in digital form during the test using a pulse code modulated data acquisition system. Selected channels were also plotted in analog form on a 6-inch oscillograph.

Sensor Calibration. All the sensors were installed when the torus was drained. The sensors used for this test were calibrated prior to refilling the torus. Zero levels were established prior to each test run. Thus, only dynamic oscillations about the zero level were measured.

Test Plan and Procedure. The test procedure consisted of actuation of the SRVs in a preselected sequence, with data being recorded by the instrumentation system described here. All actuations were effected manually by the plant operators for approximately 15 seconds duration. The tests were performed with the reactor near nominal operating pressure (975 psi) between 39.5% and 50% power. No drywell to wetwell differential pressure existed during the tests.

4.0 SUMMARY OF TEST RESULTS:

(a) The maximum measured pressures were +10.2 psi and -6.3 psi for the two-valve cases. The maximum pressure for the single-valve actuation was found to be +9.3 psi and -5.9 psi for the subsequent actuation. For single valve first actuation the pressures were 7.2 psi and -5.2 psi respectively.

(b) The pressure distribution was symmetric about the centerline of the quencher (Figure 2) and the results were repeatable (Figure 3).

The pressures in the test bay caused by valve actuation 90° away were negligible.

(c) The frequency of the dynamic pressure increased as the line length decreased. The frequency values for the cold pipe were 6.1 Hz and 7.0 Hz for line K (154 feet long) and line H (113 feet long) respectively. The frequencies for the hot pipe were found to be 10.2 Hz and 10.5 Hz for lines K and H respectively. The frequency of the dynamic pressure increased as the temperature of the SRV line increased from cold to hot, 6.1 Hz to 10.2 Hz for line K and 7.0 Hz to 10.5 Hz for line H.

5.0 CALIBRATION OF SHELL PRESSURE MODEL (QBUBS):

Using GE code RVFOR, the maximum pressure at the air/water interface (at the time the water is expelled from the discharge device) and the water clearing time are determined. These two values serve as input to QBUBS, which calculates the pressure distribution in the torus assuming rigid boundaries.

5.0 CALIBRATION OF SHELL PRESSURE MODEL (QBUBS): (Con't.)

The pressure time-histories at a location of maximum test pressure were calculated by QBUBS. The code-calculated torus shell pressure time-histories were compared with in-plant test data (pressures which include the contribution due to fluid-structure interaction) at the corresponding sensor locations. From this comparison, calibration factors were computed to match the largest measured positive peak pressure. These factors account for the effects of the fluid-structure interaction (FSI). The calibration factors for two cold pipe and two hot pipe tests vary from a minimum of 1.33 to a maximum of 2.11. Conservatively, the maximum value of 2.11 was used for calculating the design case pressures which account for FSI.

6.0 DESIGN PRESSURE CALCULATION:

Due to the nature of an SRV discharge, various loading cases were defined. These cases included single-valve or multiple-valve first or subsequent actuation under normal or accident conditions.

For each of these loading cases, the GE code RVFOR was used to determine the maximum pressure at the air/water interface and the water clearing time for the discharge lines under consideration. These two values were then used in the QBUBS program to obtain torus shell pressures.

The above analyses were performed for the two discharge lines, K (the longest line) and H (one of the shortest lines). The longest line yields the maximum pressure amplitude and lowest frequency and the shortest line yields the highest frequency. From these resutls, the bounding rigid boundary (wall) pressures and frequencies were determined for each loading case. These were multiplied by the FSI factor, 2.11, to obtain the flexible wall pressure including FSI.

7.0 TORUS REQUALIFICATION:

Finite element model of the torus shell only was developed. The pressures including FSI calculated above were applied to the shell-water interface. Structural analyses were performed. Stresses were calculated at critical locations and compared with the allowables.

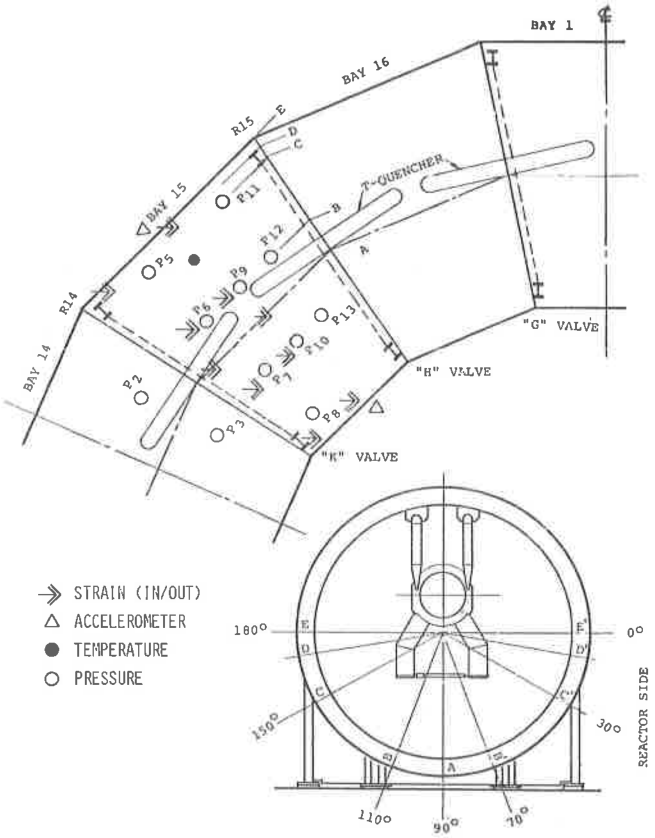

Figure 1: Instrument Locations

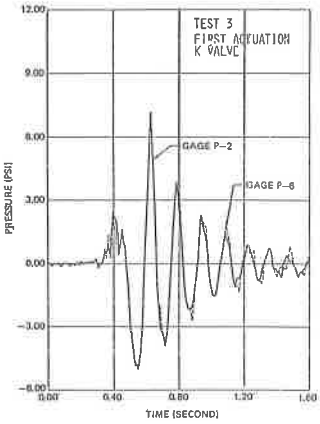

Figure 2: Comparison of Pressures at P-2 and P-6

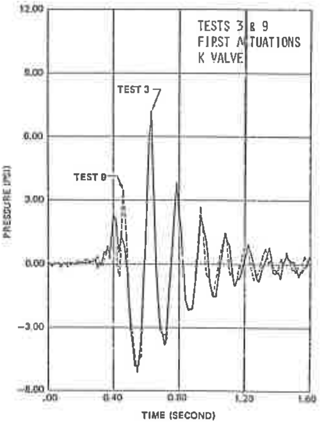

Figure 3: Comparison of Pressures at P-2