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VENT CLEARING DURING A SIMULATED LOSS-OF-COOLANT
ACCIDENT IN A MARK I BOILING-WATER-REACTOR
PRESSURE-SUPPRESSION SYSTEM

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CHARACTERISTICS OF THE VENT CLEARING PROCESS

The conditions present in a non-analogue test¹⁰ included a pressure of 20 kPa at 1.5 g/min in the drywell, a vent line, a header, a downcomer system, and the wetwell air space. Pressures below the water level in the wetwell varied from 1 to 200 kPa only by the hydrostatic head of the water present. Data from our experiments with N₂ are shown in Fig. 4. The hydrostatic head that was present was 0.82 m (0.076 MPa). The 20 kPa pressure difference between the bottom of the wetwell water pool and the wetwell atmosphere was indicated by an electronic signal sent to a solenoid valve in the line connecting the drywell to the wetwell atmosphere. The actual start of the test (drywell pressurization) occurred at about 3.095 s.

The following discussion covers the various hydrodynamic phases that occurred during a pressure buildup from 0 to 200 kPa, starting through bubble breakthrough. Similar phases were identified in the tests with nitrogen.

PRE-VENT CLEARING PHASE (BEFORE 3.095 s)

As the gas pressure in the drywell started to rise (see Fig. 4), the drywell pressure-time history was assumed that it would be simulated 100%¹¹. To equalize the pressure, gas flows into the vent line and then down the system from the drywell. However, because the exit ends of the downcomers are submerged in water, the flow rate from the drywell¹² is small until the downcomers are clear of water. The flow characteristics of the vent line/header/downcomer system is nearly identical to that in the drywell. Figure 4 shows comparing the drywell and downcomer pressures before a time of 3.095 s. At 3.095 s, the pressures were 17.06 and 3.095 s, the pressure buildup just above the water in the downcomer is the same as the pressure build downward and out of the downcomer. This pre-vent-clearing process is shown in sequence of Fig. 5. This sequence views a downcomer as shown by the

¹⁰ A non-analogue test is a test where the boundary conditions predicted for a full size plant are scaled directly to the test facility. In this case, the drywell pressurization rate is taken as 0.42 MPa/s.

the $\mathcal{H}_2$ norm of the error signal $\|e\|_2$ is bounded by the $\mathcal{H}_2$ norm of the disturbance $\|w\|_2$ multiplied by the $\mathcal{H}_2$ norm of the transfer function $\|G\|_2$ from w to e . The $\mathcal{H}_2$ norm of the transfer function G is the square root of the trace of the product of the controllability Gramian P and the observability Gramian Q of the system (A, B, C) with $D = 0$ and A replaced by $A - B K$. The $\mathcal{H}_2$ norm of the error signal $\|e\|_2$ is bounded by the $\mathcal{H}_2$ norm of the disturbance $\|w\|_2$ multiplied by the $\mathcal{H}_2$ norm of the transfer function $\|G\|_2$ from w to e . The $\mathcal{H}_2$ norm of the transfer function G is the square root of the trace of the product of the controllability Gramian P and the observability Gramian Q of the system (A, B, C) with $D = 0$ and A replaced by $A - B K$.

surface area than that of the air space, and the pressure in the air space is slightly higher than that in the bubble, causing bubble growth.

The hydrodynamic downward force is shown in Fig. 8. At 3.17 s the load peaks abruptly because of the unsteady downward force of the ringheader. The slope of the hydrodynamic downward changes at this time, and the downward force on the wetwell reduces rapidly (see Fig. 7). As the ringheader impact load passes, an inflection point in the hydrodynamic load occurs, and the hydrodynamic load changes from downward to upward in a relatively short time. From vent clearing onward, the wetwell response load has an oscillatory overtone compared to the hydrodynamic load history. This results from the structural response of the wetwell. The difference between the hydrodynamic and wetwell response load histories has been predicted using finite-element analysis and experimental analysis techniques.

BUBBLE BREAKTHROUGH (BEYOND 3.240 s)

When gas first breaks through the pool surface, the pressure in the wetwell air space is greater than the pressure within the pool bubbles. Air rushes into the bubble region from the wetwell air space, causing a decrease in the wetwell air space pressure history (Fig. 7). The difference between pressures in the air space and the pool bubbles on the wetwell increases because the bubbles no longer penetrate as closely to the bottom of the wetwell as they did previously. After this, the more complex of the hydrodynamic phenomena have basically finished, and pressure traces shown in Fig. 4 rise at approximately the same rate.

CONCLUSIONS

Peak downward forces on the wetwell occur at about the time of vent clearing. Peak upward forces occur at the time of bubble breakthrough. An abrupt peak in the ringheader load occurs as the surface of the water passes the vent.

The vent clearing process is three dimensional in nature, with gas first exiting the downcomers at the outer edges from the wetwell vertical centerline. This asymmetric nature of the vent clearing is caused by the downcomers being above the downcomer nutte point.

Fig. 1. Cross section of the full scale pressure-suppression system of a Mark I BWR nuclear power plant.

Fig. 2. Schematic and overhead view of the 1/6 scale system of the drywell.

(a) Vortex formation

Gas-liquid interface

Bubble formation

(a) Vortex forms before vent clearing.

(b) Gas-liquid interface approaching opening is asymmetric (gas is in upper left).

(d) Bubble formation below downcomer is asymmetric.

(e) Bubble grows causing pool to swell.

(c) First gas reaches bottom of downcomer.

Fig. 7. Photographs sequence of vent clearing viewed along the toroidal axis (air test 1.3.1)

(a) Gas growing location

(a) Vortex forms before vent clearing.

(b) Gas-liquid interface approaches opening

(c) First gas reaches bottom of downcomers.

(d) Bubble formation below downcomers is symmetric.

(e) Bubbles grow causing pool to swell

Figure 10: Photographs depicting the evolution of a gas pool in a structure with two downcomers.

Fig. 10 Vent load histories in the 90 deg toroidal wetwell sector (air test 1.1.1)

Fig. 11 Amphheader strut load history (air test 1.1.1)