UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

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MEMORANDUM FOR: Harold Denton, Director
Office of Nuclear Reactor Regulation

FROM: Saul Levine, Director
Office of Nuclear Regulatory Research

SUBJECT: RESEARCH INFORMATION LETTER - 78 - VERTICAL LOADS IN MARK I CONTAINMENT TORUS

1.0 INTRODUCTION

1.1 Topics Reported in this RIL

Research results are transmitted pertaining to (a) the hydrodynamic vertical loads experienced by the 1/5-scale wetwell torus of the Mark I pressure suppression containment system, during the air-venting phase of a postulated LOCA; and (b) the concurrent verification of the Moody scaling law which allows extrapolation of the measured loads to full scale geometries.

The research project on the hydrodynamic vertical load was performed by the Lawrence Livermore Laboratory (LLL) while the scaling law verification was performed by the Massachusetts Institute of Technology (MIT). The final reports for both projects are given in Enclosures 1 and 2, respectively.

Both the LLL 1/5-scale experiment and the scaling law verification study were undertaken in response to NRR research request (March 17, 1976, Ben C. Rusche to H. J. Kouts). Extended analyses of the 1/5-scale data and a comprehensive error analysis were also undertaken in response to a September 26, 1978 memo, H. Denton to S. Levine, and the subsequent task endorsement memo, S. Levine to H. Denton, dated December 13, 1978. The final report for the extended analyses and error analysis is in printing. A draft was transmitted to NRR in May 1979 which contains the same information as will appear in the final report.

1.2 Research Justification

The LLL 1/5-scale test facility was designed to provide understanding of the hydrodynamic loads on the Mark I pressure suppression containment torus (including the ringheader) - resulting from a postulated LOCA.

During a hypothetical LOCA, discharge of steam/water mixture through the break causes a rapid increase of drywell pressure. Within a very short time the increasing drywell pressure is large enough to cause the downcomer to clear, forcing the air initially present in the drywell to vent into the wetwell below the water surface. The clearing of the downcomer results in the initial (peak) downward load on the wetwell, followed by an upload as the pool swells and compresses the air initially present above the liquid level. These loads are dependent on several factors and understanding of their dependency is important for the safety evaluation of the current BWR Mark I containment system.

The so-called Moody scaling law involves four dimensionless parameters. Identical values of these dimensionless parameters, in a model and in a full-scale system, enable extrapolation of the small-scale test data to full-scale condition. The MIT study concentrated on verifying the scaleability of the dimensionless pressures on the wetwell floor and ceiling, including the dimensionless time of the occurrence of their maximum and minimum. It should be noted that the Moody scaling law is applicable only to the early blowdown period during which air is ejected from the drywell to the wetwell pool. As venting proceeds, steam gradually replaces air as the venting fluid.

2.0 DISCUSSION

2.1 Experimental Approach in LLL Tests

In the LLL project, testing was performed using two principal test configurations: a 7.5° torus sector (two-dimensional, containing one pair of downcomers) and a 90° torus sector (three-dimensional, containing twelve pairs of downcomers). Both configurations were fully instrumented and were operated simultaneously in each test run.

The early test data base for Mark I torus pool dynamics was obtained by General Electric Co. from two-dimensional (slab shape) 1/12-scale test geometries.[1] The LLL 7.5° torus sector provided an additional scale to this test data base. Furthermore, comparison of the 7.5° torus sector and the 90° torus sector test data allows quantification of three-dimensional effects.

A complete 360° 1/64-scale model of the Mark I pressure suppression containment was also constructed to examine the validity of the assumption that

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1. Subsequent tests undertaken by the Mark I Owners Group included 1/4-scale 2D tests (GE) and 1/12-scale 3D tests (EPRI).

a 90° torus sector provides representative three-dimensional effects. During these preliminary tests, partitions could be placed in the 360° torus to form boundaries of the 90° and 45° sector. The effects of these sector boundaries on bubble growth and pool swell dynamics were recorded with high speed movies. The data indicated no observable influence, thus validating the initial choice of the 90° torus sector for studies of multidimensional effects.

A total of twenty-seven tests were performed in the 1/5-scale test facility. Test parameters included the initial drywell pressurization rate, the initial drywell overpressure, the downcomer submergence, the enthalpy flux into the wetwell as controlled by the pipe orifice size, and the asymmetry of air supply to the vent pipes. It should be noted that, in LLL tests, two-vent pipes connected the drywell with the 90° torus sector. The effect of asymmetry was investigated by alternately blocking off one of the two vents. A number of tests were repeated to assess the reproducibility of test data.

The vertical loads were evaluated in two ways: by integrating the pressure measurements over the torus wall surface and, also, by the load cells. The pressure integrations were performed using pressure data from available instrument locations in each test and supplemented by inferred pressures at other locations based on interpolation between measured data or symmetry arguments.

2.2 <u>Experimental Approach in the MIT Study</u>

A series of tests were performed with a wetwell model consisting of a vertical cylindrical vessel containing a single downcomer. The top of the downcomer was connected to a large reservoir representing the dry-well. In some tests, identical values of the dimensionless scaling parameters were employed while varying the magnitudes of the individual constituent variables. Their variation included the wetwell diameter, the type of fluid in the drywell and the wetwell, and the orifice size in the downcomer. In the other tests the dimensionless scaling parameters were themselves varied to examine their influence on the wetwell pressure and the characteristic times.

3.0 RESULTS

3.1 <u>LLL Torus Tests</u>

(a) Both the 90° and 7.5° torus sectors exhibited similar <u>trends</u> in all tests. However, the three-dimensional effects in the 90° torus sector frequently caused the peaks of both the down and uploads to be more sensitive to the variation of test parameters.

(b) The results of the 1/5-scale tests can be used to compare loads measured in a two-dimensional simulation (the 7.5° test sector) and a three-dimensional simulation (the 90° test sector). Table 1 provides the ratios (3D to 2D) of peak downloads and peak uploads for the 1/5-scale test series. It will be observed that the download ratios are nearly unity whereas the upload ratios are generally greater than 1, even after account is taken for experimental error. This would indicate that peak uploads measured in a 3D test facility tend to be higher than those measured in a 2D facility.

(c) The accumulated experimental errors in the measured vertical loads are small. The standard error on peak down forces ranges from 0.5 percent to 1.4 percent. The corresponding error on peak up forces ranges from 3.2 percent to 5.8 percent.

(d) The sensitivities of the vertical loads to variations of principal parameters were derived from the data. For the peak download it was confirmed that it is an inverse function of the initial drywell pressure and it is strongly dependent on the initial drywell pressurization rate and on the downcomer submergence. It was also found that the effects of vent flow asymmetry and the enthalpy flux are much less important. With respect to the peak upload there is also a lack of strong dependence on vent flow asymmetry and enthalpy flux, and much less sensitivity to drywell overpressure than for the download. The upload is, however, strongly dependent on drywell pressurization rate and downcomer submergence.

(e) A comparison was done of the vertical load sensitivities in the 7.5° sector compared to the 90° sector. It was found that the sensitivities of the upload to drywell pressurization rate and drywell overpressure are significantly greater in the 90° sector. This could be another indication of a 3D sensitivity in the upload.

3.2 <u>MIT Study Results</u>

(a) The study proved the validity of the Moody scaling law for the early blowdown air-venting period. Numerous tests have indicated that the wetwell pressure depended solely on the four dimensionless scaling parameters.

(b) The dimensionless parameter containing the enthalpy flux was found to be important for proper scaling of the peak upload.

TABLE 1

3D/2D VERTICAL LOAD RATIOS

Test No.	Test Condition	R[1] (Download)	σ_R[2]	R(Upload)	σ_R
1.1	nominal[3]	0.87	0.01	1.18	0.06
1.3	nominal	0.82	0.01	1.29	0.08
1.3.1	nominal	1.03	0.01	1.18	0.06
1.4	drywell $\dot{p}$ = 20.5 psi/s	1.08	0.01	1.03	0.05
1.5	drywell $\dot{p}$ = 33.8 psi/s	1.00	0.01	1.11	0.06
1.6	drywell $\dot{p}$ = 38.2 psi/s	0.93	0.01	1.23	0.07
2.1	drywell Δp = 4.8 in. H_2O	—	—	1.10	0.05
2.2	drywell Δp = 7.2 in. H_2O	—	—	1.18	0.06
2.3	drywell Δp = 7.2 in. H_2O	—	—	1.20	0.07
2.4	nominal	0.99	0.01	1.30	0.07
2.5	submergence 13.4 in.	1.08	0.01	0.93	0.05
2.6	submergence 5.8 in.	—	—	1.17	0.06
2.7	submergence 12.0 in.[4]	1.06	0.01	1.04	0.05
2.8	submergence 9.6[5]	1.02	0.01	1.10	0.05
2.9	sub.=12in[4], $\dot{p}$=20.5 psi/s	1.09	0.01	1.12	0.06
2.10	sub.=12in[4], $\dot{p}$=33.8 psi/s	1.07	0.01	1.10	0.06
2.11	sub.=12in[4], $\dot{p}$=38.2 psi/s	1.08	0.01	1.12	0.06
3.1	med. vent orifice	1.02	0.01	1.21	0.07
3.2	no vent orifice	0.94	0.01	1.26	0.07
3.3a	right vent blocked	1.01	0.01	1.02	0.05
3.3b	left vent blocked	0.97	0.01	1.36	0.05
3.4a	right vent blocked,no orifice	1.05	0.01	1.00	0.06
3.4b	left vent blocked,no orifice	0.97	0.01	1.02	0.06
3.5	nominal	1.09	0.01	1.22	0.06

1. R = ratio of force in 90° sector to six times the force in the 7.5° sector.
2. σ_R = standard deviation of R
3. The nominal conditions are:

   Torus water level (below centerline): 2.40 in.
   Downcomer submergence: 9.6 in.
   Initial drywell, wetwell pressure: 2.95 psia
   Initial drywell pressurization rate: 27.3 psi/sec
   Nominal vent line orifice diameter: (90° sector) 9.5 in.
   (7.5° sector) 3.63 in.
4. Downcomer extended
5. Downcomer extended, pool lowered

(c) The peak download (pressure) and all characteristic times were found to be insensitive to that parameter, except at its low values.

Two important problems were discovered during this study. However, they were subsequently eliminated and, therefore, do not affect final results and conclusions. The first problem involved excessive amounts of water vapor in the wetwell in tests featuring very small scale, especially when the wetwell air space pressure was of the order of one atmosphere. The excessive water vapor tended to reduce the peak ceiling pressure i.e., peak upload. It was found that this problem could be minimized either by lowering the wetwell liquid temperature or by employing liquids which have a very low vapor pressure. The second problem involved the presence of small gas bubbles; either attached to the wetwell wall or suspended in the water. These bubbles increased the compressibility of the wetwell pool and caused high amplitude oscillation in the floor pressure immediately following the downcomer clearance. Since these effects were not accounted for in the Moody scaling law, the download measured after the downcomer clearance could not be used for extrapolation purposes if trapped gas bubbles were present. Addition of a chemical known as Photo-Flo into the pool eliminated the oscillation problem by decreasing surface tension and thus removing the trapped gas bubbles. The use of different wetwell liquid, such as Meriam instead of water, achieved identical results.

4.0 RSR EVALUATION OF RESULTS

The 1/5-scale tests were carefully performed and extensively instrumented measurements of the hydrodynamic vertical loads that could occur in Mark I containments. The 90° test section is the most accurate three dimensional representation of the Mark I containment available for air venting loads. Together, the 7 1/2° and 90° test sections provided a unique capability for direct comparison of loads measured simultaneously in two-dimensional and three-dimensional models. The 1/5-scale tests provide confirmation of the absolute values and sensitivities of the air venting loads measured in other experiments. In addition the 1/5-scale data provide evidence of a three-dimensional character of the upload not heretofore recognized.

The data in the MIT scaling law verification experiment are, in general, excellent, showing a minimum amount of scatter. These data have verified the Moody scaling law; meaning that small scale test data, with proper accounting of multidimensional effects, can be scaled up to prototypical plant size. The immediate importance of this verification is the ability to apply the 1/5-scale LLL data to full scale plant conditions.

5.0 RECOMMENDATION

Both the LLL and MIT experiments were performed in response to the specific directive given RES by NRR to quantitatively evaluate the hydrodynamic load in the Mark I type containment in the event of a LOCA. These research results are offered for NRR consideration.

Because the objectives of the LLL experiment have been accomplished, we plan no further air-water testing at the LLL 1/5-scale test facility.

By virtue of their three-dimensional nature and accuracy, the LLL 1/5-scale torus test results supplemented by the verified scaling law, provide an appropriate yardstick for licensing assessment of the Mark I containment concerning air venting loads.

The RES staff is available to provide any assistance that you may require concerning this RIL.

Saul Levine

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Office of Nuclear Regulatory Research

Enclosures:
1. E. W. McCauley & J. H. Pitts, "Final Air Test Results for the 1/5-Scale Mark I Boiling Water Reactor Pressure Suppression Experiments," 10/31/77, ~~UCRL-52371~~. NUREG CR 0151
2. W. G. Anderson, P. W. Huber, and A. A. Sonin, "Small Scale Modeling of Hydrodynamic Forces in Pressure Suppression Systems," 12/77, NUREG/CR-0003.

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