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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
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MEMORANDUM FOR: I. Catton, P. R. Davis, T. S. Kress, R. L. Seale, J. E. Wilkins, Jr.

FROM: M. E. Stella, ACRS Senior Fellow

SUBJECT: REVIEW OF ROSA-V GRAVITY INJECTION TEST RESULTS AND RELATED ANALYSES

The Japan Atomic Energy Research Institute (JAERI) performed a series of gravity injection tests at the ROSA Large Scale Test Facility (LSTF). The tests simulated a 3-inch cold leg break in a pressurized water reactor plant equipped with a gravity injection tank connected directly to the vessel downcomer. They were performed to obtain data on the thermohydraulic behavior of a gravity drain injection tank similar in function to the core makeup tanks in the Westinghouse AP600 passive plant design.

I reviewed three draft reports prepared by JAERI personnel documenting the test data and post-test analyses of the gravity-injection tests. This was an independent series of tests performed by JAERI, bearing no relation to the joint JAERI/USNRC confirmatory test series planned for ROSA/LSTF. These three reports were forwarded to the ACRS by RES (Shotkin memo to Paul Boehnert of June 16, 1993) and subsequently distributed to Thermal Hydraulics Phenomena Subcommittee members and consultants in Paul Boehnert's briefing package of June 22, 1993.

Because all modifications needed to convert the ROSA facility to a scaled representation of the AP600 reactor coolant and safety injection systems had not been completed at the time of the gravity injection tests, they were useful only as a means of improving the experimenters' qualitative understanding of the phenomena and general performance of passive injection systems similar to those used in the Westinghouse AP600 and Mitsubishi MS-600 nuclear plant designs. The test system configuration was modeled using both RELAP5/MOD2 (R5/2) and RELAP5/MOD3 (R5/3). Consequently, comparisons of the test data with the predictions of these two codes will also offer information as to their limitations and strengths in predicting the performance of gravity injection systems in test facilities and in the plant.

The tests required conversion of one of the existing ROSA-IV/LSTF cold leg accumulators to represent a simulated core makeup tank (CMT). This was accomplished by connecting the tank to the pressurizer, one cold leg, and the vessel of the test facility using piping and valving configurations similar to the AP600 systems interconnections. The gravity injection test tank is called the ACH (for Accumulator - Hot) in the three Japanese papers describing the tests and analyses undertaken by JAERI.

Although ROSA/LSTF is a full-pressure test facility, the gravity injection tests reported on in the three papers could not be initiated from full system pressure (15.5 MPa/2250 psia) because the ACH tank design pressure was lower than full system design pressure; initial "primary" pressure for the test was 11.3 MPa/1650 psia. One other apparent deviation from similitude with the AP600 configuration was the fact that the ACH was not located at the same height with respect to the bottom of the test facility "core" as the CMT will be in the ROSA-V facility and in the AP600 plant. None of these differences affected the limited objectives of the test series.

A. <u>RELAP5/MOD2 Analysis of System Thermal Hydraulic Responses for a Passive Safety Injection Experiment at ROSA-V/Large Scale Test Facility</u> - Asaka, H., Yonomoto, Kukita, and Mucksin.

This report clearly describes the results of the tests, and compares the output of an analysis of the gravity injection test using R5/2 with the test results. Review of the text, analysis results, and authors' evaluations suggests that the version of R5/2 used for the analysis is unsuitable for predicting the behavior of the AP600, the ROSA-V and SPES integral systems test facilities, or separate effects test facilities that are used to explore the behavior of gravity injection tanks and the performance of the passive injection system.

The code did not model the thermohydraulic behavior of the ACH properly. It is especially deficient in predicting the transient behavior of the ACH discharge through the direct vessel injection (DVI) line following the onset of stratification in the cold leg of the test facility. Oscillations in the differential pressure across the cold leg pressure balance line caused large changes in the injection flow from the ACH to the vessel. Although the code predicts oscillatory behavior, the following important differences between the data and the computed performance are noted:

- The amplitudes of the oscillations in differential pressure and mass flow are exaggerated in the calculation.

- The frequency of the oscillations is poorly predicted by the code - the actual frequency of oscillation is approximately twice that predicted by R5/2 during the tank draindown. Differences in the predicted and actual frequencies of oscillation and phase relationships suggest that the R5/2 models are deficient in their representation of the physical phenomena driving (and damping) the oscillations.

Oscillations in the ACH delivery are attributed to the effects of liquid carryover into the cold leg pressure balance line (C-PBL). Some of the variation in pressure noted could also have been caused by variations in the simulated ADS valve blowdown rates, or by liquid entrainment in the fluid being vented through the surge line to the pressurizer (which is also connected directly to the ACH via the pressurizer pressure balance line P-PBL). The instrumentation suite used in this set of tests was apparently not extensive enough to identify all forcing functions for the oscillations.

Oscillations in ACH delivery were apparently <u>not</u> significantly affected by condensation phenomena in the ACH, because a relatively stable hot layer of liquid was formed just below the liquid surface during the "recirculation" phase (i.e., before sufficient primary system mass loss uncovered the C-PBL connection to the cold leg). Data from the experiments suggest that the ACH liquid surface was relatively quiescent during the tank draindown[1].

The authors note that the R5/2 analysis represented the couplings between pressure variations in the DVI and P/C-PBL "only qualitatively", and that such couplings must be "considered" (my interpretation: modeled more accurately in R5/2 and other similar codes) "for accurate prediction of the injection rate".

[1] Condensation phenomena in the gravity drain tank could become more significant for larger system break sizes.

While it may be sufficient for certain accident conditions to be able to predict only the integrated delivery or the time-averaged delivery rate from the gravity drain tanks to the vessel (ignoring rapid temporal variations in delivery as seen in these tests) the accurate prediction of the gravity drain injection rate and timing is probably an essential element in successfully demonstrating the effectiveness of the AP600 passive safety systems during limiting accident conditions.

B. RELAP5 analysis of a gravity-driven injection experiment at ROSA-V/Large Scale Test Facility-Yonomoto, T., and Kukita.

This report compares the results of R5/3 analyses with the experimental data from the gravity draindown tests of the ACH performed at ROSA. Special attention was given to the modeling and prediction of the temperature of the liquid in the gravity drain tank.

A clever analysis of the tank temperature data by the authors provides a basis for accepting the fact that a layer of hot water is formed by flow of reactor coolant from the cold leg to the top of the ACH during the recirculation phase (after the DVI and PBL isolation valves are opened but before mass loss from the primary system is sufficient to drop the free liquid surface in the cold leg to a level that uncovers the C-PBL inlet nozzle). The analysis also suggests that the layer remains relatively undisturbed during tank discharge, at least for the quiescent conditions pertaining in the ACH during this test.

The liquid temperature distribution in the gravity drain tank affects the static head available to drive flow to the vessel through the DVI line. Liquid temperature at the gravity drain tank surface also determines whether or not condensation of steam vented through the PBLs will occur at the liquid free surface, causing temporal variations in the total pressure available to drive flow between the tank and the vessel injection nozzle. Because CMT delivery to the vessel is the salient performance criterion for the AP600 passive safety injection systems during near-term transient and accident conditions, the ability to predict flow behavior (including anticipated rapid temporal variations in delivery rate) should be a key objective of the integral systems testing and code qualification programs for AP600 design certification and confirmation.

The R5/3 predictions of the tank liquid temperature distribution initially computed were significantly in error. R5/3 overpredicts the fluid temperature at the top of the tank during the recirculation phase but underpredicts the temperature at the free liquid surface during tank discharge to the vessel. Improved accuracy using R5/3 in computing the tank liquid temperature distribution during discharge was obtained for this by increasing the number of computational cells in the tank volume and in the heat structure of the tank wall. This comes at the expense of greatly extended computation time and increased cost, and the inversion of the "computational bias" with respect to the observed temperature distributions in the recirculation and draindown (injection) phases was not eliminated by the procedure.

A separate calculation using a Lagrangian coordinate system fixed at the (moving) tank liquid surface reduced further the computational inaccuracies introduced by the R5/3 models. The authors demonstrate (see Figure 11) the accuracy of their computations using this method for a fixed time late in the ACH discharge, but under the condition that the actual tank temperatures at the end of the recirculation phase are used as the initial conditions for the computation, which begins at 475 seconds after initiation of the test.

These more extreme measures to better compute the temperature distributions in the tank liquid may not be necessary, because the effect of differences in density between the predicted and actual situations may cause inconsequential perturbations in the total head available for driving flow to the vessel. For example, the difference in static head imposed by the liquid in the full ACH tank at t = 475 seconds (the initiation of the gravity draindown phase in this test) is approximately 0.03 psi (.06 feet) when the computed and measured temperature distributions are used to estimate the contribution from tank liquid in each case. This estimate pertains only to this particular test and test condition, and should be verified for the full range of expected conditions under which the system must operate.

Multidimensional mixing in the upper portion of the tank liquid caused by liquid jetting from the PBL connection to the tank upper head during the recirculation phase cannot yet be modeled properly with either R5/3 or with the improved Lagrangian coordinate computation scheme demonstrated by the JAERI analysts. The authors discuss some other potential improvements to R5/3 computational models to improve its performance in calculating liquid temperature distributions in the ACH and CMT.

C. Passive Safety Injection Experiment at the ROSA-V Large Scale Test Facility - Yonomoto, T., Kukita, and Anoda.

This paper describes the experiment and associated analysis of data in some detail. It also reviews some of the more interesting results reviewed in the R5/3 paper, above. The authors discuss the experimental evidence for evaporation as the controlling interfacial mass and heat transfer phenomenon in the ACH during tank discharge; this is indicated by the formation of a superheated liquid layer just below the free surface of the ACH liquid. More detail on the construction and use of the improved computational model for tank liquid temperature described in paper B is provided by the authors of this paper.

One important experimental result reported is the sensitivity of the gravity injection delivery rate to small variations in system differential pressure. The authors report that variations of only 5 kpa/0.7 psi in the DVI line differential pressure caused observed variations of 4 kg/s in a (maximum) ACH injection rate of approximately 5 kg/s. This sensitivity suggests that models used to compute pressure losses in the analytical codes must be carefully compared with the results of separate effects tests to verify their accuracy over the range of conditions expected in the test facilities and in actual operational transients. Indeed, the effect of the uncertainty in flow loss modeling for piping and fittings is apparently much more significant to the accurate prediction of passive safety system performance than is the prediction of the temperature distributions within the gravity injection tank liquid.

Accuracy in pressure loss prediction may be especially important for ensuring the performance of the gravity injection systems in the near-post-accident time frame, when decay heat generation rates are high and both the gravity injection flowrate and integrated injection flow from the passive safety injection systems must be predicted with some degree of confidence.

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