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

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AUG 10 1979

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

FROM: Saul Levine, Director
Office of Nuclear Regulatory Research

SUBJECT: RESEARCH INFORMATION LETTER # 57, "SMALL SCALE ECC BYPASS RESEARCH RESULTS"

This memorandum transmits the results of ECC bypass research performed at Battelle Columbus Laboratories (BCL), Creare, Inc., and Dartmouth College. These programs have produced large amounts of data and have significantly improved our understanding of the phenomena at small scale sizes (1/30-2/15). Many of these data have already been used in the licensing process. The purpose of the Research Information Letter (RIL) is to summarize the significant findings and to indicate the applicability and limitations of the data. This material has been reviewed by the ECC Bypass Review Group (LTR, Serkiz to Tong, "ECC Bypass RIL Review," 6/11/79). The review group agreed with the findings and conclusions, and most minor suggestions were incorporated in the final RIL.

1.0 INTRODUCTION

Emergency core coolant (ECC) injection during a loss-of-coolant accident (LOCA) in a pressurized water reactor (PWR) involves complex mixing processes between steam and water which may impede ECC penetration to the lower plenum and thus delay filling of the lower plenum and subsequent reflooding of the core. Upward flow of steam in the downcomer may prevent downward flow of ECC (flooding) and cause the ECC water to be bypassed out the break. Condensation of steam by the subcooled ECC water influences the ECC penetration in competing ways. Low pressure in the region of ECC injection due to condensation increases the upward flow of steam toward the flooding point but steam condensation at the flooding point results in less "effective" steam flow to cause bypass. The hot vessel walls may boil the ECC water and create additional steam to cause bypass until they are cooled sufficiently to allow water penetration (hot wall delay). All these mechanisms and their effect on ECC penetration have been investigated at small scale and are presented in the RIL. Once ECC penetrates to the lower plenum, escaping steam may prevent the complete filling of the lower plenum and flashing of lower plenum liquid may swell the level and entrain liquid out the break (called lower plenum voiding, entrainment or sweep-out). This topic is not discussed in this RIL but will be summarized in a later RIL. Research investigating the mixing of ECC fluid in the cold leg with cold leg steam has been performed also. It has been determined that, other than changing the temperature of the ECC fluid, cold leg steam is unimportant in the bypass process.

Because of the complexity of these processes, conservative licensing assumptions have been made when calculating the amount of ECC fluid which remains in the vessel to start the reflood process. The rule governing such calculations

(10 CFR Part 50, Appendix K) states that "...bypassing shall end in the calculation at a time designated as the 'end-of-bypass,' after which the expulsion or entrainment mechanisms responsible for the bypassing are calculated not to be effective." The ECC bypass rule does not specify the end-of-bypass definition but requires that the definition "...be justified by a suitable combination of analysis and experimental data...." NRC now requires that licensing models be shown to be consistent with the small scale steady state bypass experiments presented herein using the most conservative of two existing scaling theories. It is also required that additional hot wall delay and transient time delay periods be added after end-of-bypass is calculated based on small scale test results. (Ref. WCAP-8302, WCAP-8479, BAW-10104, BAW-10102, CENPD-132, XN-76-27.)

The purpose of NRC's ECC bypass research programs is to show that the licensing end-of-bypass definitions and calculational procedures are conservative and also to provide a best estimate modeling of the ECC bypass phenomenon to be used in best estimate codes. These research efforts are continuing in an orderly phase down and the small scale studies are expected to be complete in FY-1980. The work is summarized herein because it is complete in the sense that the bulk of the information expected from small scale testing has been obtained. Future efforts will consist of making detailed measurements of downcomer flow topology for use by advanced codes and studies of lower plenum voiding and flashing. The latter work will be summarized in a later RIL.

The current program results are useful in order to develop preliminary models and correlations. These results also suggest a more consistent method of comparing vendor licensing calculations with the small scale test results. The results support, however, the general philosophy followed currently by NRC in scaling the small scale results to full scale. The applicability of the present research to a PWR is limited, however, because of uncertainty in extrapolating the small scale results to full scale, and cannot be fully assessed until larger scale data are available. These data will be obtained from the Upper Plenum Test Facility (UPTF) in the Federal Republic of Germany in FY-1982 and FY-1983.

2.0 DISCUSSION OF RESULTS

2.1 Test Results

Tests of ECC penetration have been conducted in 1/30, 1/15 and 2/15 scale models of a PWR vessel and downcomer. ECC penetration in the presence of a constant steam flow (steady state tests), a constant steam flow with superheated vessel walls (hot wall delay tests), and a time dependent steam flow (transients with hot walls) has been conducted. Supporting studies of flooding with air and water in tubes have also been conducted to aid in the scaling analysis.

2.2 Analysis of ECC Bypass Tests

Semiempirical correlations have been constructed from the small scale steady state tests. The general form of the correlation developed from air-water flooding experiments has been improved to account for a reduction in effective steam flow because of condensation of steam by the ECC water. A transient hot wall penetration model has been developed by combining this "modified Wallis" correlation with the effects of an input transient steam flow and the calculated additional steam flow generated by the hot vessel walls.

2.3 Transient Versus Steady State Tests

The transient hot wall penetration model is based on a correlation of the results of the more simple steady state tests. This model successfully predicts the hot wall delay tests and transients with hot walls. No fundamental differences between the steady state and transient tests have been found when the transit times, storage effects and hot wall effects are properly considered.

2.4 Scaling of Pressure Effects

Pressure effects appear through the effect of vapor density on flooding and in the effect of steam properties in a condensation process. Tests without condensation (air-water or steam with saturated water) have shown that the vapor momentum flux correlates the effect of vapor density on the hydraulics of flooding. Condensation effects are also adequately correlated through the use of steam properties. While the range of pressures tested (0.1-0.5 MPa) appears small, the range of steam properties in the pressure range tested is large compared to the additional range of property change at pressures of interest in LOCA calculations. Since pressure effects have been correlated using steam properties without the use of empiricism, extrapolation of the test results to LOCA pressures can be performed with a high degree of confidence. Testing at higher pressures may not be needed.

2.5 Scaling of Facility Size

Two competing scaling theories have been studied: Wallis (J^*) indicates that the critical momentum flux for flooding increases as the square root of facility size and Kutateladze (K^*) indicates that the critical momentum flux is constant with scale size. Air-water flooding tests in tubes indicate that J^* scales the flooding in small tubes but that J^* scaling breaks down for diameters above 5-10 cm and the critical momentum flux becomes scale size independent (K^* scaling).

The scaling of steam-water ECC bypass tests is uncertain because of the small range of scale sizes available and because of difficulties in separating the hydraulic effect (K^* vs. J^*) from the condensation effect. Condensation effects appear to be increasing with scale size which would tend to offset any transition from J^* to K^* scaling. The arguments of scale dependence are subtle and a complete agreement over the scaling issue cannot be resolved by these small scale tests. Thus, the continued use of the more conservative K^* scaling and constant condensation effect to extrapolate small scale results to full scale is recommended.

2.6 Scaling of Hot Wall Effects

Scaling of the transient hot wall model developed under these programs is heavily dependent on the scaling of flooding. If J^* scales flooding, the hot wall delay decreases with increasing scale. If K^* scales flooding and condensation effects are constant, the hot wall delay is constant with scale. 2/15 scale hot wall delay tests indicate a significantly shorter delay than at 1/15 scale. This reduction in delay is even greater than the reduction in delay predicted by J^* scaling. It is believed that the increased effect of condensation in the larger vessel causes the shorter delays. Further 2/15 scale hot wall delay tests will be conducted to confirm this finding.

2.7 PWR Sensitivity Studies

Sensitivity studies of the effect of model uncertainties (primarily scaling) on calculated ECC delivery during a PWR LOCA transient have been performed. If J^* scales flooding, then hot wall effects are negligible and other uncertainties in the model are unimportant. Under this assumption, ECC penetration is calculated to occur significantly earlier than in licensing calculations. Under the assumption of K^* scaling, the other model assumptions become important. Even under the assumptions of K^* scaling and the conservative bound of no condensation, calculated ECC penetration is earlier than in current licensing calculations. Only under the extreme assumptions of the worst bounds on all the major uncertainties are long penetration delays calculated. The major cause of the long calculated delay is due to the extreme bound used for the heat partition. This bound of no heating of ECC fluid other than that actually boiled by the hot walls seems highly unrealistic. Thus, the best estimate heat partition obtained from small scale tests will be recommended.

2.8 Steam Flow Determination

The transient hot wall penetration model requires the steam flow transient to be an input. In the majority of the tests discussed herein, the steam flow was known since it was a fixed experimental input. In the LOCA, the value of steam flow rate is a complex function of the total system response including the effect of condensation caused by subcooled ECC injection. An independent calculation of the steam flow transient is required for use as an input to the transient hot wall penetration model. Equilibrium model codes cannot adequately account for the effect of subcooled ECC injection on the steam flow transient. However, these codes result in the highest possible increase in steam flow due to condensation by virtue of their equilibrium models. This upper limit combined with the break size sensitivity study, which in effect looks at lower steam flows for longer time periods, appears to be a conservative approach to calculate steam flow to cause ECC bypass. Thus, evaluation model steam flow calculations can be used by the transient hot wall model to calculate ECC bypass.

3.0 CONCLUSIONS AND RECOMMENDATIONS

Small scale transient ECC penetration tests with hot walls are well correlated using simple semiempirical models. Pressure effects seem to be adequately accounted for using steam properties, and no indication of the need for higher pressure tests has been found. The knowledge about how to scale the phenomenon is still lacking. This uncertainty in scaling is caused by the small range in scale sizes tested. Scale effects must be inferred from subtle data changes that are on the order of the data uncertainty. Thus, complete agreement even over the scale effects observed in the sizes tested is difficult to obtain. Several general conclusions can be made, however: (1) evidence exists that there may be a transition to K* scaling in larger facilities, (2) evidence exists that condensation effects increase in importance over the range from 1/30 to 2/15 scale, and (3) hot wall delays are shorter at 2/15 scale than at 1/15 scale.

Four sets of recommended coefficients for use in the modified Wallis correlation and the transient hot wall penetration model are included in Attachment 1. Three sets are the best estimate coefficients that should be used to represent data from the BCL 1/15 and 2/15 scale vessels and the Creare 1/15 scale vessel. The fourth set is a recommended set for use in Evaluation Model (EM) comparisons. The EM model utilizes K* scaling and a condensation effect similar to the best estimate BCL 2/15 scale value. The condensation coefficient was chosen because, at small scale, the condensation coefficient appears to increase with scale size. This is no guarantee that it will continue to increase or not even be smaller at full scale. However, the flow patterns suggested by K* scaling suggest good condensation. Thus, K* scaling and a smaller condensation effect appear inconsistent. It is felt that the combination of K* scaling and 2/15 scale best estimate condensation effects is conservative. This EM correlation is conservative with respect to all 2/15 scale data.

A transient hot wall penetration model is available to predict ECC delivery. It is recommended that this model be used in comparisons with licensing calculations using the EM coefficients listed in Attachment 1. This model has been shown to be conservative with respect to BCL 2/15 scale hot wall and transient ECC penetration tests and LOFT test results. The small scale tests continue to support the need for larger scale tests such as those planned in the UPTF in the Federal Republic of Germany. In addition, studies of lower plenum entrainment, flashing and level swell are underway and are scheduled for completion in FY-1980.

4.0 ATTACHMENTS

Attachment 1 greatly expands and documents the topics discussed. The outline of this report is similiar to the main letter for ease of reference. Attachments 2, 3 and 4 are summary reports by the three major contractors. These reports summarize and place in perspective many previous reports and also allow the contractors to provide their own views concerning major findings.

If you have any questions concerning this report, please contact Dr. William Beckner (427-4260).

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