# SUMMARY OF THE SMALL SCALE ECC BYPASS RESEARCH INFORMATION LETTER

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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. 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). Research investigating the penetration of ECC water through the downcomer to the lower plenum has been underway for the past five years. Testing in small scale models of a PWR vessel has been performed by Battelle Columbus Laboratories (BCL) and Creare Incorporated, with supporting air-water flooding tests being performed at Dartmouth College. The phenomena governing ECC penetration at small scale are now well understood and these programs are currently being phased out. The information learned from these programs was formally summarized in a Research Information Letter (RIL)[1] prepared in fiscal year 1979. References 2-6 support the RIL and provide a comprehensive summary of this research. The information obtained from these small scale programs has been used in developing preliminary models describing ECC penetration, planning for full scale penetration tests to be conducted in the Upper Plenum Test Facility (UPTF) in FY 82 and 83 and has provided evidence of the conservatism in models used in licensing calculations.

## Transient Hot Wall Penetration Model

A transient penetration model has been developed based on the correlation of small scale steady state test data[5]. This model successfully predicts small scale transient penetration tests including the penetration delay caused by steam generated from the hot vessel walls. No fundamental differences between steady state and transient tests have been found when transit times, storage effects and hot wall effects are properly considered.

## Scaling of Pressure Effects

Pressure effects on ECC penetration 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 (Figure 1). Condensation effects are also adequately correlated through the use of steam properties (Figure 2). 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 (Figure 3). 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.

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Scaling of Facility Size

While ECC penetration is understood at small scale, scaling theories must be used to extrapolate the results to a PWR. 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).[4]

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. Evidence exists, however, that J* also breaks down in the small scale ECC penetration tests but that this effect is offset by an increase in condensation effects as shown in Figures 4 and 5.[6] 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 has been recommended for licensing calculations.

PWR Sensitivity Studies

Sensitivity studies of the effect of the transient hot wall penetration model uncertainties (primarily scaling) on calculated ECC delivery during a PWR LOCA transient have been performed.[3] 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 (Figure 6). A version of the transient hot wall model which used K* scaling and a condensation effect similar to that at small scale (no credit for possible increase in condensation effect with scale) has been recommended for use in licensing calculation. A comparison of this model with LOFT test results is shown in Figure 7.

Conclusions and Future Work

A transient hot wall penetration model to predict ECC penetration has been developed from small scale tests. While the scaling of pressure effects to PWR pressures seems to be understood, the scaling of physical size still contains uncertainty. Thus, a version of this model using the more conservative K* scaling has been recommended for use in licensing calculations. This model is conservative with respect to all BCL 2/15 scale data 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.

The issuance of the ECC Bypass RIL marks the completion of the majority of small scale work. Fiscal year 1980 will be the last year of significant small

scale work in this area. BCL will continue to obtain detailed downcomer flow topology and break flow data started in fiscal year 1979 and Creare will complete work investigating lower plenum voiding, flasing and level swell. Both these efforts will be presented in papers later in this session.

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1. Letter from S. Levine to H. R. Denton, "Research Information Letter No. 57, Small Scale ECC Bypass Research Results," dated August 10, 1979.

2. Collier, R. P. et al., Status Report on ECC Penetration Scaling Research;" NUREG/CR-0651, Battelle Columbus Laboratories, February 1979.

3. Rothe, P. H., "Technical Summary Attachments to ECC Bypass RIL;" NUREG/CR-0885, Creare, Incorporated, July 1979.

4. Richter, H. J. and Wallis, G. B., "ECC Bypass Scaling;" NUREG/CR-0850, Dartmouth College, June 1979.

5. Crowley, C. J. and Rothe, P. H., "Analysis of Superheated Wall Effects During Refill at Small Scale;" NUREG/CR-0599, Creare, Incorporated, April 1979.

6. Beckner, W. D., Reyes, J. N. and Anderson, R., "Analysis of ECC Bypass Data;" NUREG-0573, July 1979.

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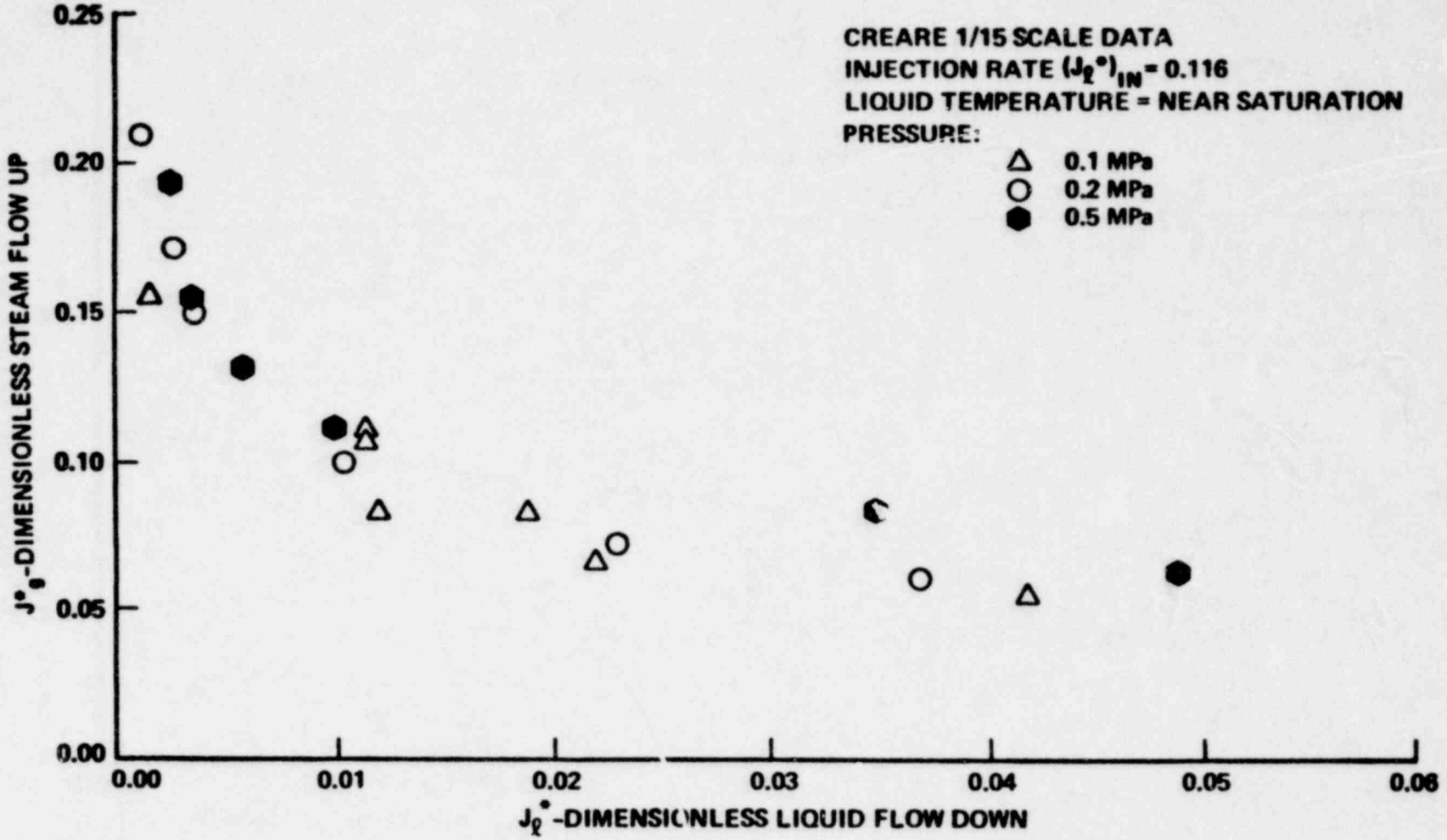


FIGURE 1 – CREARE 1/15 SCALE DATA SHOWING A NEGLIGIBLE EFFECT OF PRESSURE FOR SATURATED LIQUID

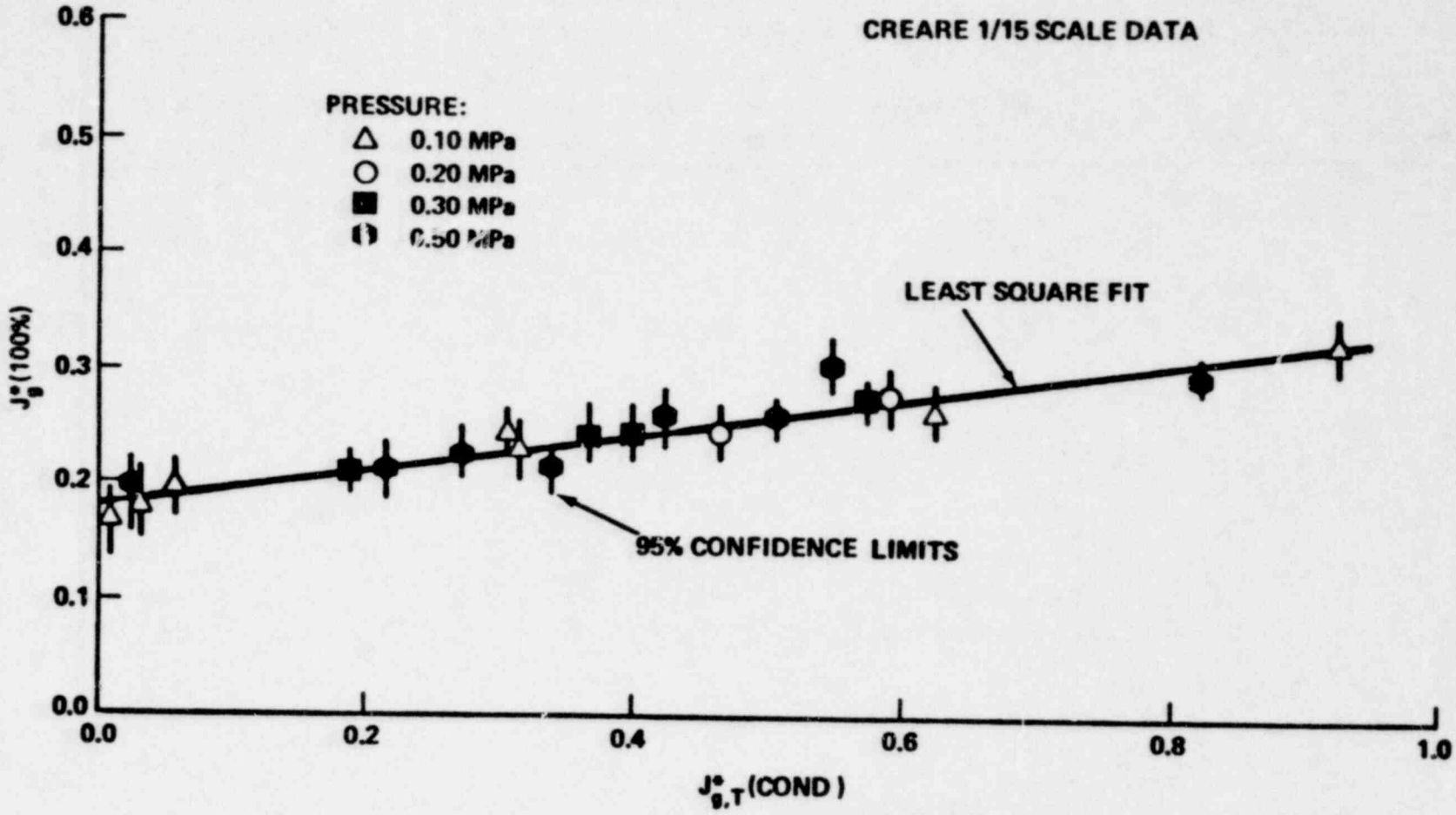


FIGURE 2 – PLOT OF STEAM FLOW REQUIRED FOR 100% BYPASS VERSUS THE AMOUNT OF STEAM THAT THEORETICALLY COULD BE CONDENSED

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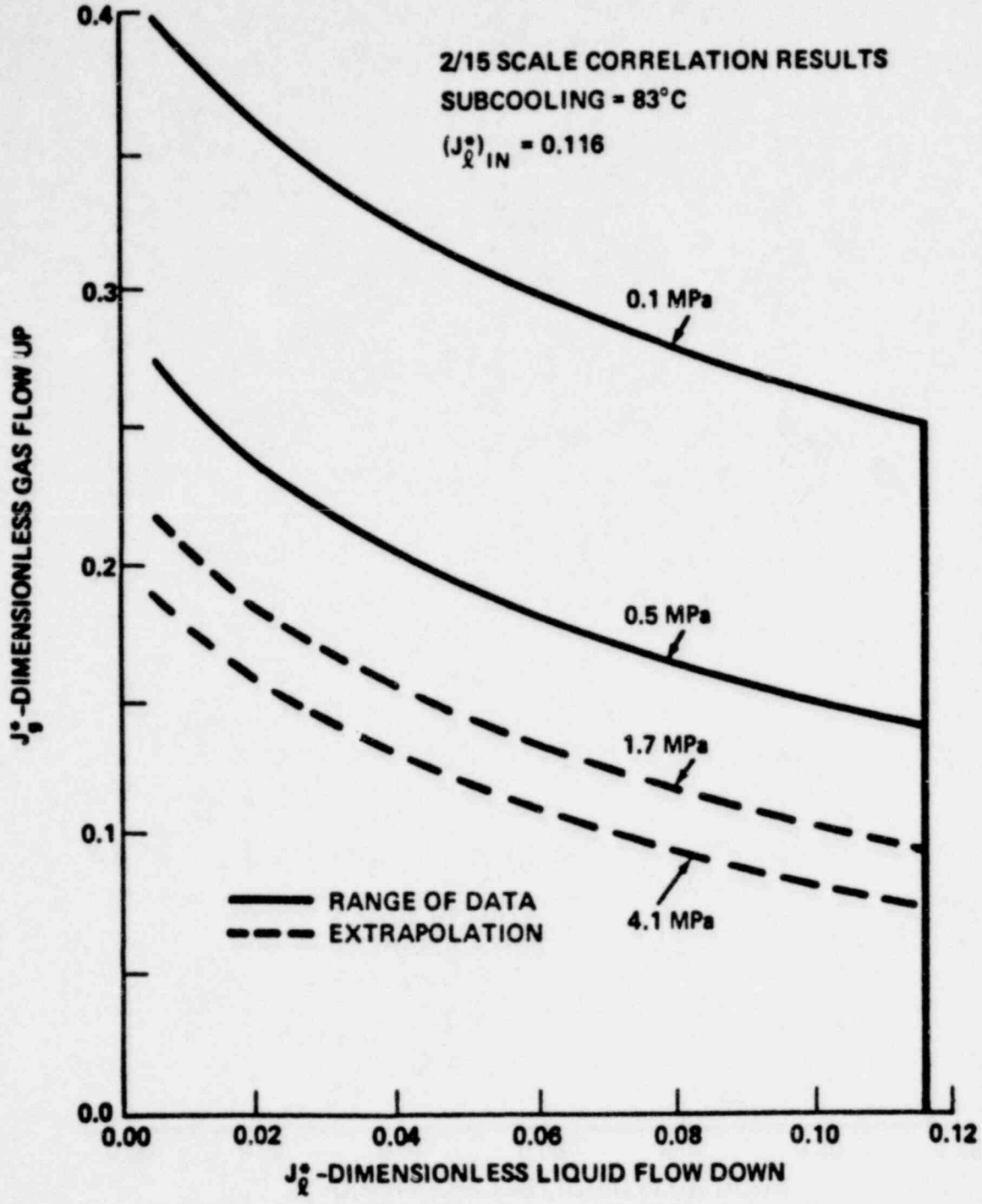


FIGURE 3 – EFFECT OF PRESSURE ON ECC PENETRATION

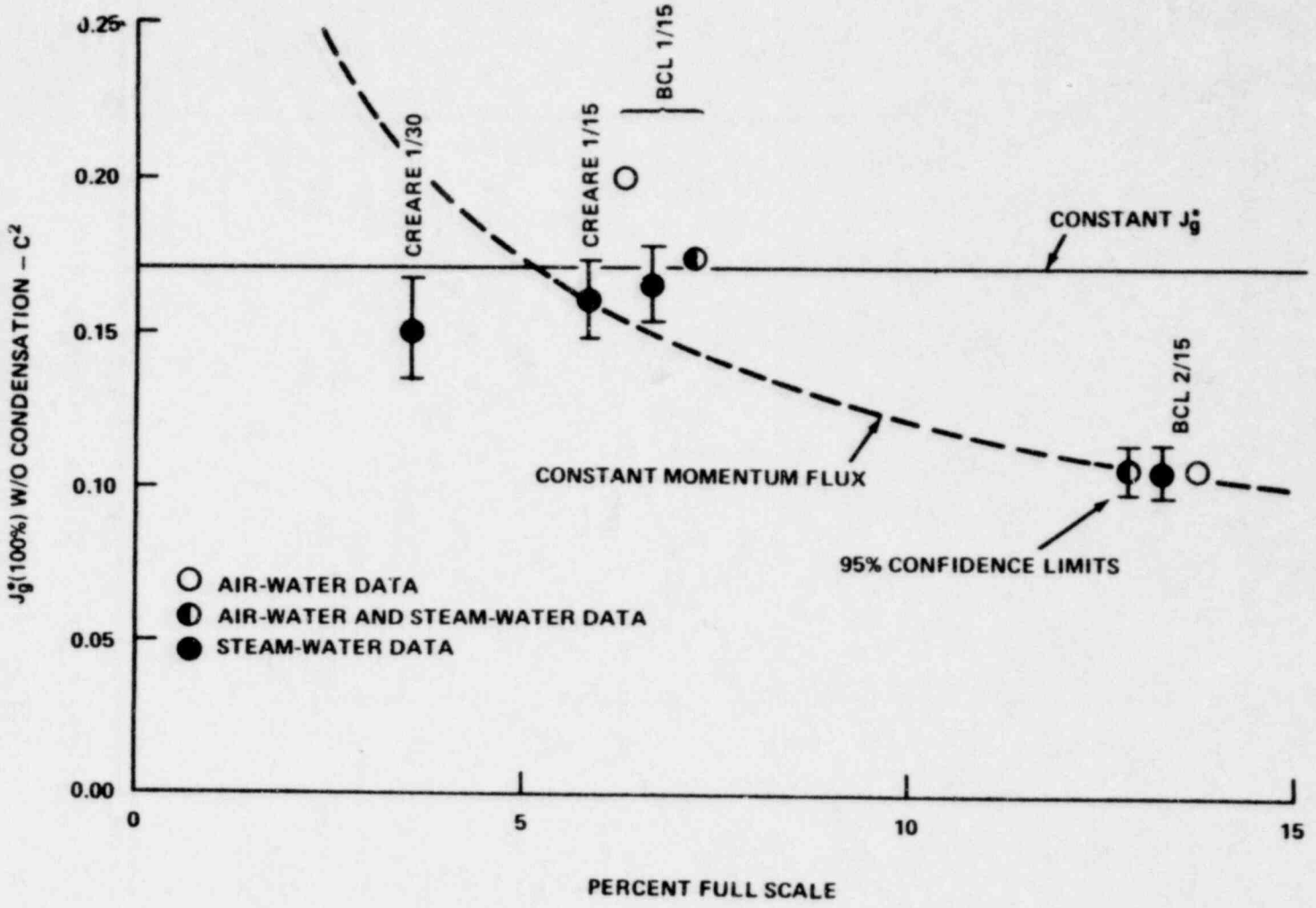


Figure 4 - Empirically Determined Gas Flow for 100% Bypass w/o Condensation as a Function of Scale Size

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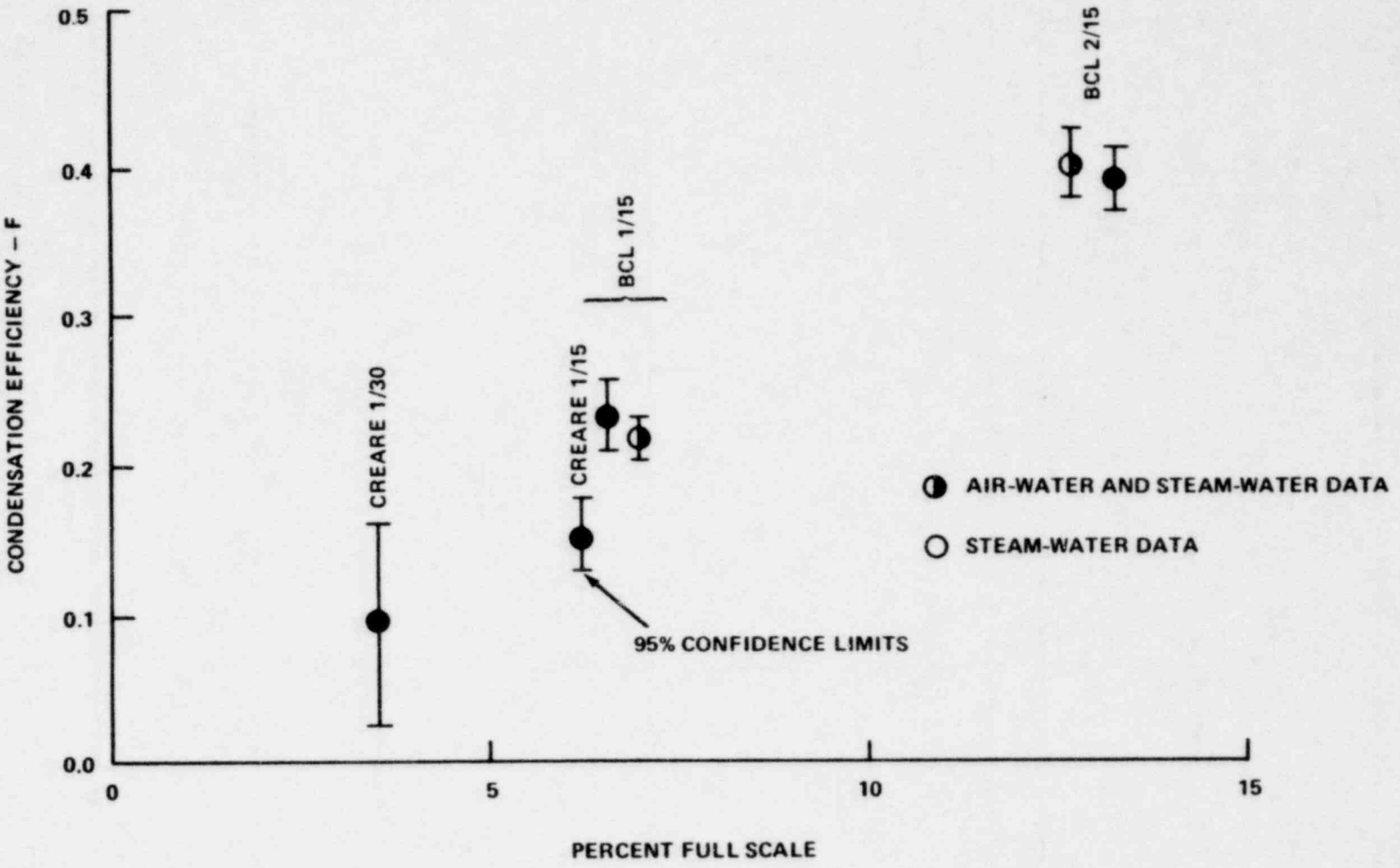


Figure 5 – Empirically Determined Condensation Efficiency as a Function of Scale Size

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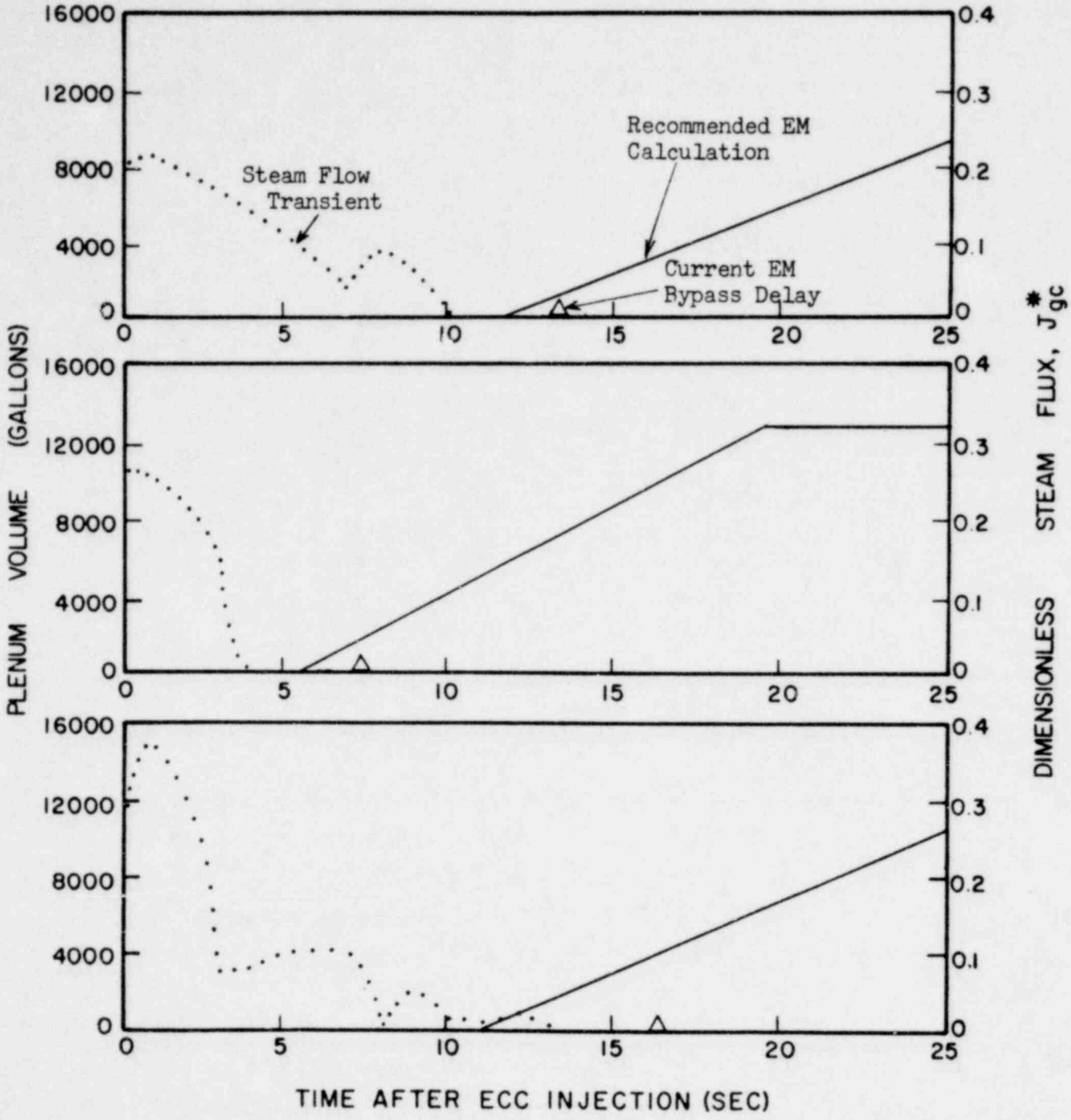


Figure 6 - PWR ECC PENETRATION CALCULATIONS USING MODEL DEVELOPED FROM SMALL SCALE TESTS AND CONSERVATIVE SCALING ASSUMPTIONS

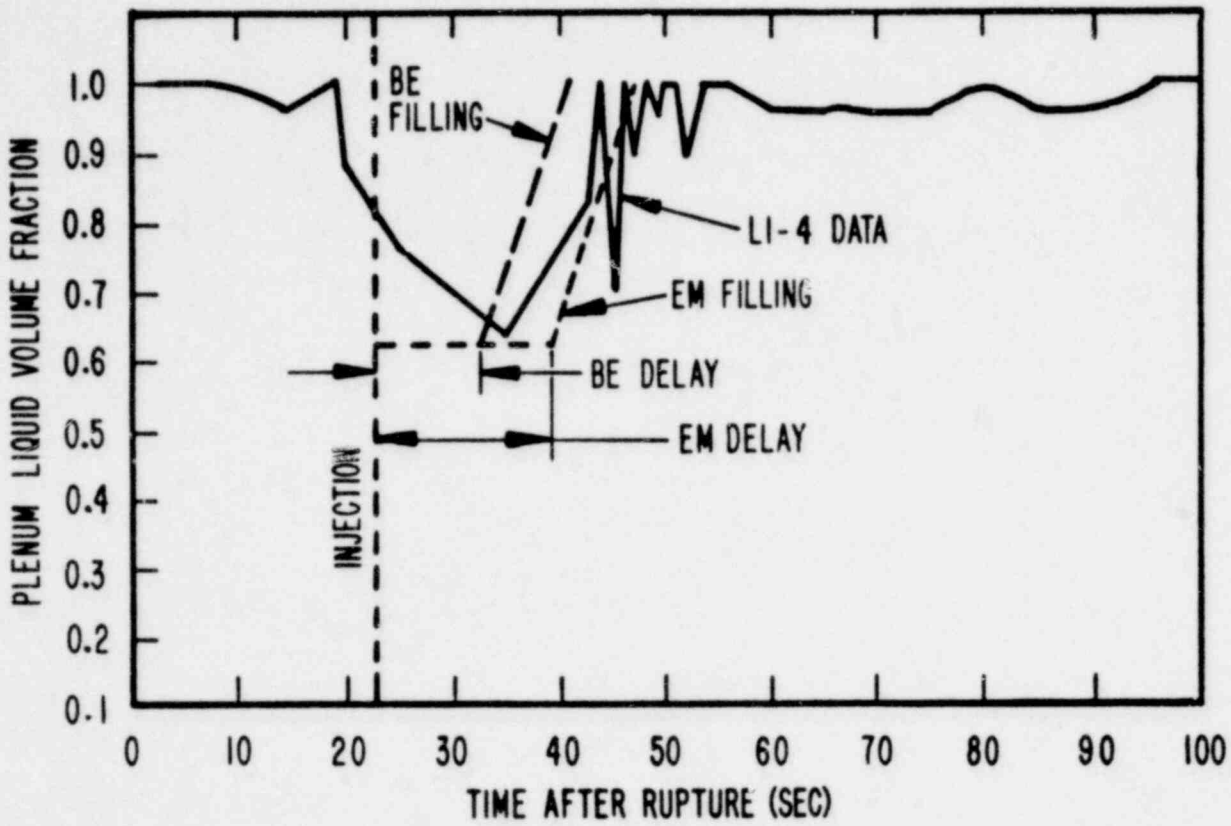


FIGURE 7 — COMPARISON OF TRANSIENT HOT WALL MODEL AGAINST LOFT TEST LI-4 DATA

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