BW

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JHT/90-133

September 5, 1990

Mrs. Valeria Wilson, Chief
Administration Section
Planning, Program and Management Support Branch
Program Management, Policy Development and
Analysis Staff
Office of Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission
Washington, D.C. 20555

Reference: 1. R. C. Jones to J. H. Taylor, Request for Additional Information on BAW-10168P, Revision 1, RSG LOCA, January 19, 1990.

2. J. H. Taylor to Valeria Wilson, JHT/90-37, March 12, 1990.

3. M. W. Hodges to J. H. Taylor, Request for Additional Information on BAW-10168P, RSG LOCA, December 1, 1988.

4. J. H. Taylor to Valeria Wilson, JHT/89-256, December 22, 1989.

Dear Mrs. Wilson:

Enclosed are revised responses to 2 of the questions that were previously answered by B&W Fuel Company. The first response is to question 1 of reference 1 and was previously answered in reference 2. The second response is to question 8 of reference 3 and was previously answered in reference 4. The responses are being revised to reflect the results of telephone conversations that have taken place between the NRC, INEL, and BWFC.

Very truly yours,

J. H. Taylor, Manager
Licensing Services

cc: Gene Hsii, NRC
R. C. Jones, NRC
R. B. Borsum
T. L. Baldwin

BWFC-1007 (2/88)
(BWNP 20032)

B&W Fuel Company

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BWFC-1016 (3/88)
(BWNP 20211A)

B&W Fuel Company — **LICENSING DOCUMENT APPROVAL**

File Point: 43-10168Q-08

Document Title: RSG-LOCA B&W Loss-of-Coolant Accident Evaluation Model for Recirculating Steam G.

Doc. No. 43-10168Q ____ -08 9/6/90
Rev. No./Date

☐ PSAR ☐ FSAR ☐ Topical Report ☐ Draft Tech. Spec. ☑ Documented Response to NRC Questions

Document Preparer [signature] Signature 9/6/90 Date

Document Preparer's Manager [signature] for J Cudlin Signature 9/6/90 Date

Document Reviewer JRB [signature] Signature 9/6/90 Date

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Is a list of source references required? ☐ Yes ☑ No

If yes, complete source references on reverse side of this form

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1. (a) Revision 1 of BAW-10168 stated that the ECC transport time, the time for the ECC to fa⁷ . to the lower plenum once it enters the downcomer, is neglected based on Upper Plenum Test ɪacility (UPTF) Test No. 5. However, the UPTF data showed an approximately 2 second delay from the time the ECC entered the downcomer to the time the lower plenum collapsed level began to increase. Therefore, clarify your reasoning for neglecting the ECC transport time in the REFLOD3B analysis and discuss the specific data from UPTF Test No. 5 that supports your position.

Response: In Section 4.3.6.5 of the EM topical report BAW-10168 it is stated that the time required for ECCS water to pass from the reactor vessel inlet to the lower plenum is neglected and refill begins at the end of blowdown. The time delay was neglected based on the consideration that in reality bypass of the ECC water occurs at the broken cold leg nozzle, that when the flow at this nozzle is directed toward the reactor vessel bypass no longer occurs, and that ECC water in transit across the downcomer would, therefore, not be ejected from the reactor coolant system. The water in transit across the downcomer at the end of blowdown would fall into the lower plenum during the first several seconds of refill essentially eliminating the transit time delay in question. These observations are supported by UPTF test 5A. Figure 1-1, the test vessel inventory for test 5A, shows that partial ECC retention starts much earlier than the end of blowdown and full retention precedes the end of blowdown by several seconds. Figure 1-2 provides the inventory for UPTF test 4A and demonstrates the same effects. Both of these figures and the sequence of events for test 5A (refer to Table 3-1 of Reference 1.2)

Begin ECC injection	= 24 s (Plot time)
Begin Opening Cold Leg Break	= 29 s
ECC Enters Downcomer	= 31 s
ECC Reaches Bottom of Downcomer	= 32.5 s

show a 1.5-second delay, in agreement with the question, from the first penetration of the downcomer until ECC water is observed in the lower parts of the test vessel. Under Revision 1 of the RSG LOCA evaluation model, that delay occurs as the ECCS first delivers water to the reactor vessel and should not be repeated during refill.

Although the position that transit liquid exists in the downcomer at the end of bypass, as defined in the BWFC RSG LOCA evaluation model, is correct and supportable by the experimental studies in this area, it does not necessarily agree with the requirements of Appendix K with respect to the bypass of ECCS water. To achieve a more explicit agreement with Appendix K requirements, BWFC will alter both the accounting for gravity time delay and the definition of end-of-bypass. A gravity time delay appropriate for the freefall of fluid from the bottom of the cold leg nozzle to the bottom of the active region of the core will be accounted for in the evaluation. The end of bypass will be defined in relation to the end-of-blowdown as a predecessor event using a correlation developed from the UPTF tests, but ECCS water will still be bypassed by the RELAP5/MOD2-B&W calculations until the end-of-blowdown. To adjust for the excess bypass, occurring over the last 2 or 3 seconds of blowdown, that amount of water will be reintroduced to the vessel in the REFLOD3B code at the beginning of refill.

UPTF Tests and CCFL Correlation

The UPTF test facility simulates, at full scale, a 3900 MWt German PWR that closely represents a full scale US PWR (see Reference 1.3 for scaling details). Steady state and transient tests in the facility show that the reason for early partial delivery of the ECC water is strong multi-dimensional effects in the downcomer. To evaluate and quantify these effects, a series of steady state downcomer countercurrent flow tests were run and countercurrent flow limit (CCFL) correlations developed to fit the data. Details of these tests, the results, and the correlations are given in Reference 1.3. Equations 4 and 5 of reference 1.3 are both J^* (the Wallis parameter) CCFL correlations that have been fit to the data. The value of $J^*_{g',eff}$ determines the potential for ECCS bypass. If $J^*_{g',eff}$ is zero or negative the steam flow is insufficient to entrain liquid and bypass will not occur. If $J^*_{g',eff}$ is positive some entrainment will be occurring and for low values of $J^*_{g',eff}$ partial bypass is occurring. At present the RSG evaluation model does not intend to deal with partial bypass. Because the form of equation 4 may be somewhat more standard, and the report indicates that it does a slightly better job of fitting the data, this correlation has been selected for use in the RSG LOCA evaluation model.

$$J^{*\,1/2}_{g,eff} = \left[J^*_g - f * J^*_{g,cond} \right]^{1/2} = C + m * J^{*\,1/2}_f$$

where f, C, and m are correlation factors giving:

f = condensation efficiency,

C = effective dimensionless steam upflow at complete bypass, and

m = slope of steam flow/water flow relationship.

Curve 1 of Figure 1-3 compares the correlation to data for multiple loop ECCS injection conditions. The reference includes a different correlation of the same form for single loop injections (curve 2 of Figure 1-3), but those conditions would not be appropriate for application in the evaluation model. As can be seen in the figure the correlation is excellent.

As further support for the UPTF results, Izenson and Crowley at Creare (Reference 1.2), evaluated UPTF Test 5 and the earlier experiments in Creare test facilities at 1/15 and 1/5 scales. They concluded that the ECC bypass effects due to flashing are small at full scale compared to results of model tests and that the bypass rate observed in Test 5 appears to be the maximum achievable in the UPTF facility. Therefore, because the UPTF facility is geometrically similar to U.S. PWR designs, the correlation will be conservatively applicable to the determination of the end-of-bypass for the RSG LOCA evaluation model.

<u>Application within the Evaluation Model</u>

For application to the evaluation model, the current practice of bypassing all ECCS injection up to the calculation of end-of-blowdown (flow toward the vessel at the vessel side of the break) in RELAP5/MOD2-B&W is continued. The UPTF CCFL correlation is used after the blowdown calculations are complete to determine the time at which bypass should have ended. The ECC injection flow rate and the ECC subcooling in the correlation are replaced by the predicted liquid flow rate and subcooling of the water that is entering the downcomer from the intact loop cold legs. These values are more appropriate to use because they represent the state of the liquid entering the bypass region. In the UPTF steady state tests steam was not injected into the cold legs so that the liquid state at injection and in the downcomer were the same. The ECCS water bypassed between the end-of-bypass predicted by the CCFL correlation and the end-of-bypass predicted by RELAP5/MOD2-B&W is then added to the reactor vessel inventory at the end of blowdown and included in the initial REFLOD3B lower plenum inventory. Should the UPTF CCFL correlation not indicate the end-of-bypass prior to the end-of-blowdown then the end-of-bypass shall be taken as the end-of-blowdown and no additional or replacement water added to the initial conditions for the REFLOD3B code. Consequent to this the delivery of post blowdown ECCS water to the lower plenum is delayed by the time appropriate for the free fall of fluid from the bottom of the cold leg nozzle to the bottom of the active region of the core.

As an example, the CCFL correlation was applied using the downcomer steam flow rates and the system conditions from a LOCA limit case in the McGuire/Catawba LOCA analysis topical, BAW-10174. The calculated $J^*_{g',eff}$ and J^*_f values, after the accumulator injection began, are shown in Figure 1-4. In the figure, positive values indicate upward flow and negative values downward flow. The negative value of J^*_f, indicates that some penetration of the ECCS water into the lower plenum should have occurred as soon as the accumulators started injection (cold leg filling and other time delays set aside). The positive value of $J^*_{g',eff}$ prior to 19.5 seconds, however, indicates that the downcomer steam flow is sufficient to partially bypass the ECCS injection. After 19.5 seconds the ECCS should not have been bypassed. As the end-of-blowdown for this case was 21.2 seconds, the last 1.7 seconds of bypass was inappropriate.

This new approach more clearly accounts for bypass and ECCS injection effects while retaining substantial conservatism. The early penetration of the ECCS into the lower plenum occurs because of three-dimensional effects not represented in one dimensional codes such as RELAP5/MOD2-B&W. Figure 1-5 compares the downcomer liquid flow rate, from the example above, as calculated by RELAP5/MOD2-B&W to that predicted by the UPTF CCFL correlation. Even with complete bypass, RELAP5 was causing liquid to flow up and out of the break while the correlation indicated that some liquid flow should be downward. This partial penetration of the ECCS water will not be credited in the evaluation model and forms a substantial conservatism. The direct consideration of the liquid fall time more clearly accounts for that consideration.

(b) The RSG LOCA EM defines the end-of bypass as the end-of-blowdown, which is defined as the time reverse flow is calculated at the vessel side break. While these definitions are appropriate for most situations, clarify how they allow the EM to handle the following situation: Reverse flow is calculated at the vessel side break due to steam condensation on the ECC injected into the intact cold leg causing a low pressure zone, which causes reverse steam flow up the downcomer so that the ECC is unable to penetrate the downcomer. In this situation, would a more appropriate definition of the end-of-bypass be one that is based on downflow in the downcomer, and one that includes the effects of countercurrent flow limitation phenomena?

Response: The situation described in the question has not occured in evaluation model calculations and is not expected to occur in reality because of multi-dimensional downcomer flow effects. As shown in the response to part "a" of this question the conditions in the downcomer toward the end of blowdown support first partial and then full penetration of ECCS water into the lower plenum several seconds prior to the end-of-blowdown. Even if the suggested scenario were to occur the ECCS liquid would not be being bypassed from the reactor coolant system and there would thus be no need to adjust the end-of-bypass definition. Notwithstanding these conclusions, BWFC agrees that a definition of the end-of-bypass based on countercurrent flow limits would be more appropriate and has adopted such an approach as outlined in the response to part "a" of this question.

In practice, the "end-of-blowdown" has been (and is) taken to be that time in the calculation at which it is both appropriate and acceptable to make the transition from the blowdown calculational technique to the reflood technique. This switch in methods and models is, of necessity, somewhat arbitrary, but it does recognize that the dominant physical processes being analyzed change at some point in the transient. In reality, the change is not so distinct or abrupt as it must be represented to be in the modeling. For example, experiments show that partial refilling of the lower plenum starts as soon as the accumulators begin injection. Furthermore, these experiments show that the lower plenum is full at the time that the containment and reactor coolant system pressures approach each other indicating that there should be no "refill period" and that reflooding of the heated core follows immediately. Thus, definitions of end-of-blowdown and end-of-bypass that comprise marked periods of refill prior to reflooding are inherently conservative and should be acceptable logic for switching the calculational technique.

Calculations performed to date by BWFC using its RELAP5 based evaluation model have not shown eratic or irregular occurences of end-of-blowdown as defined by the negative vessel side break flow criteria. However, in order to assure that the observations of the above paragraphs continue to apply, any occurence of end-of-blowdown that appears to have been caused by an eratic process and that appears to have shortened the blowdown period by more than four seconds will be rejected and the evaluation either continued or examined for possible corrective actions. The typical refill period for the plants covered by the BWFC evaluation model is 9 to 10 seconds.

Therefore, the clause above would be activated long before the refill period could be totally eliminated.

(c) If loop seal refill could occur as a result of ECC back flow into the loop seal during periods of steam upflow in the downcomer, is the RSG LOCA EM capable of calculating this phenomenon with RELAP5/MOD2-B&W? If not, justify why the EM should not be required to calculate this type of phenomena.

Response: The nonhomogeneous option of RELAP5/MOD2-B&W is used for evaluation model loop and the downcomer flow calculations. This allows countercurrent flow in the cold legs giving RELAP5/MOD2-B&W the capability of predicting ECC back flow towards the loop seal. If a seal were to form, the modelling of the cold legs, including the nonhomogeneous option, is sufficient to force the establishment of appropriate RCS conditions for the clearing of the seal. However, during blowdown the cold leg steam velocities in the intact loops are much higher than those at which countercurrent flow could occur. Thus, in practicality, backflow of the ECCS and loop seal formation does not occur. Some backflow has been observed experimentally in UPTF Test 5 (see Reference 1.1). These experiments, however, did not allow or model loop steam flow (the cold leg piping was closed off at the pump simulator) and are therefore inapplicable with respect to liquid backflow.

References

1.1 2D/3D Program Upper Plenum Test Facility Quick-Look Report, Test No. 5, Downcomer Separate Effect Test, U9 316/87/17, KWU, October 1987.

1.2 M.G. Izenson and C. J. Crowley, Scaling of Flashing Transient Behavior to Full Scale : Evaluation of UPTF Test 5A, TM-1277, Creare Inc., September 1988.

1.3 2D/3D Program Draft Report, Summary of Results from the UPTF Downcomer Separate Effects Tests, Comparison to Previous Scaled tests, and Application To U.S. Pressurized Water Reactors, MPR Associates, Inc., December 1989.

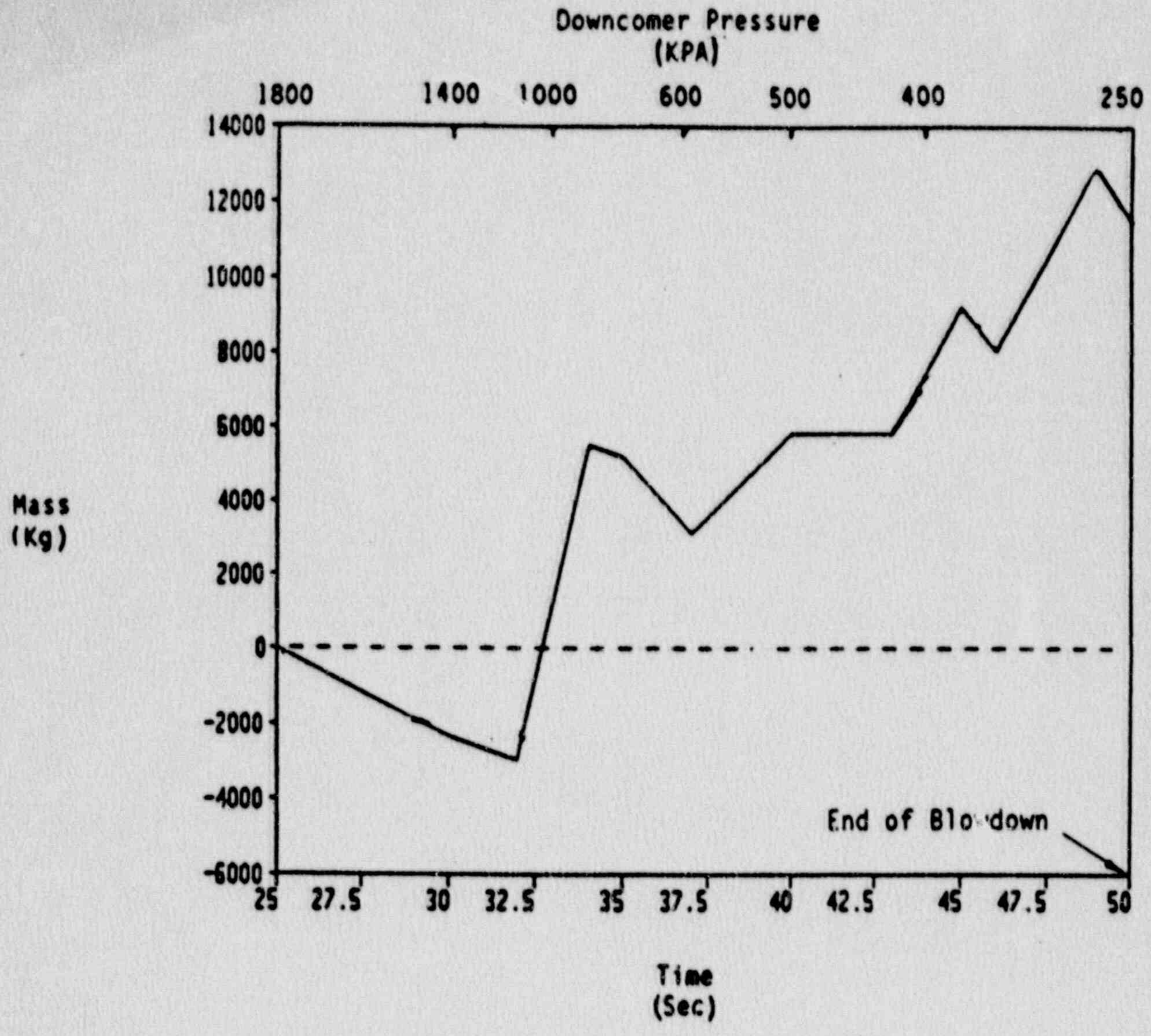

Figure 1-1 Test Vessel Inventory For UPTF Test 5 - Phase A[1-3]

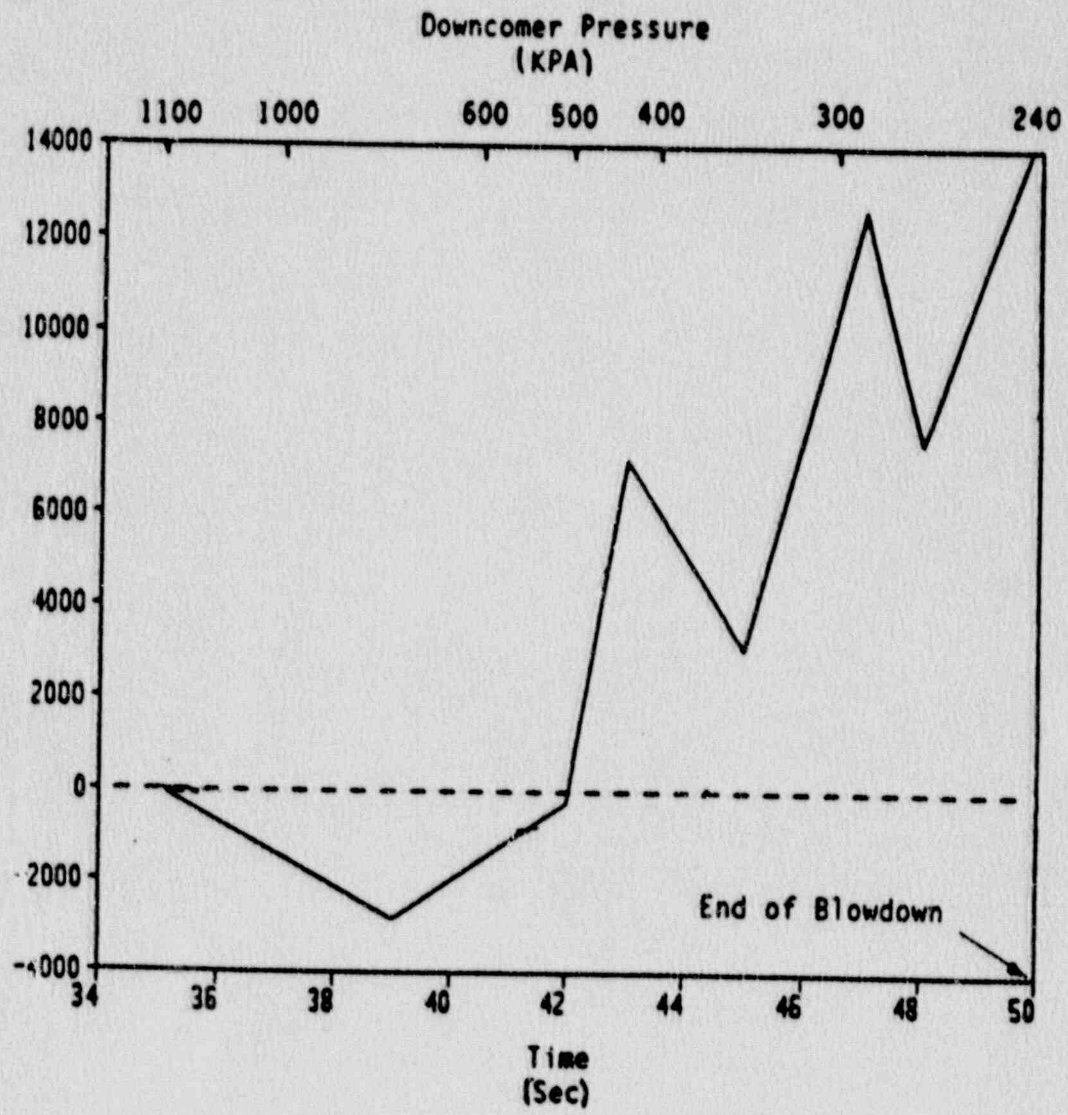

Figure 1-2 Test Vessel Inventory For UPTF Test 4 - Phase A[1-3]

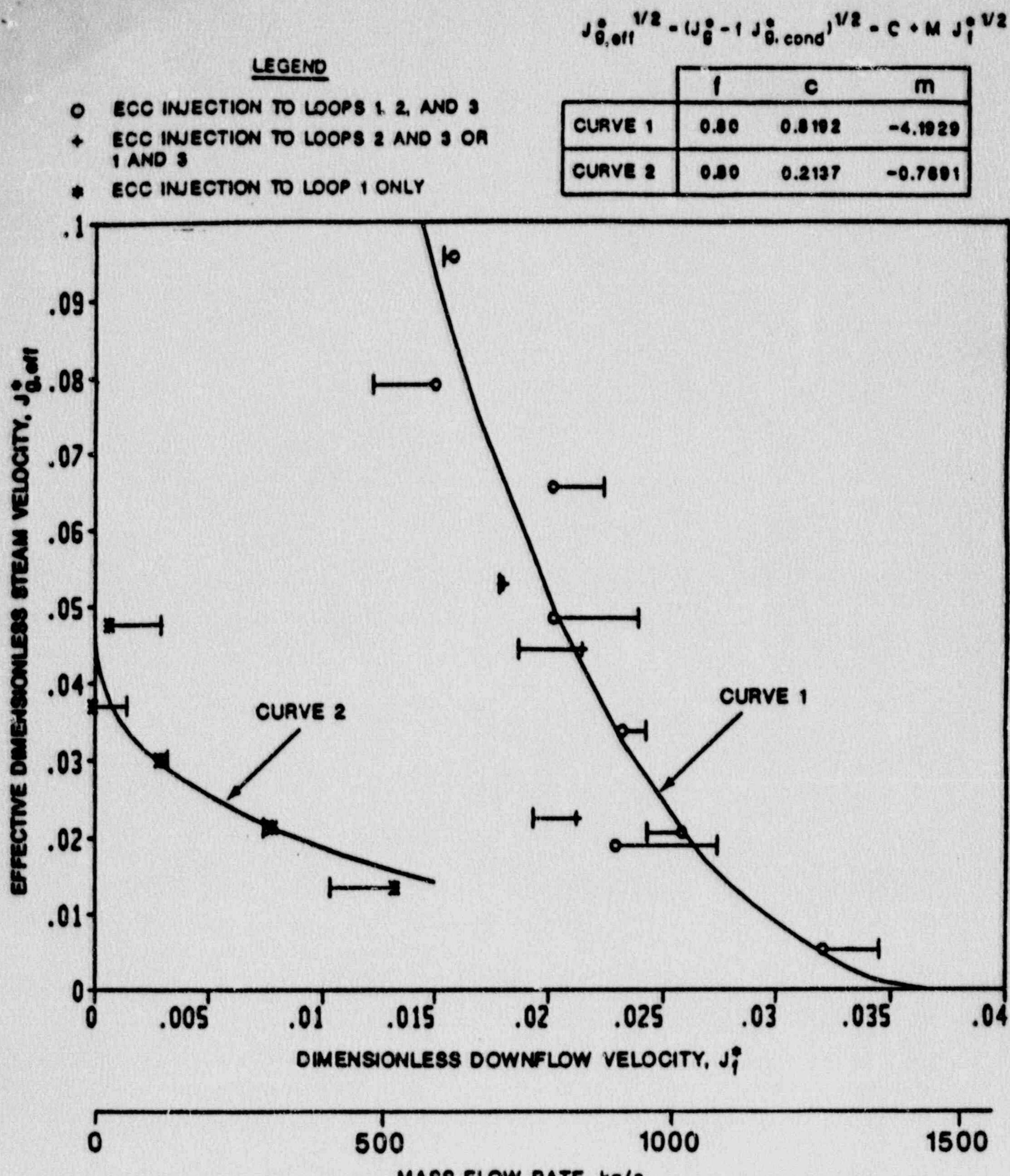

Figure 1-3 UPTF Steady-State Counter-Current Flow Tests Dimensionless Steam And Liquid Velocities Correlated With Equation 4 Given In Reference 1-3

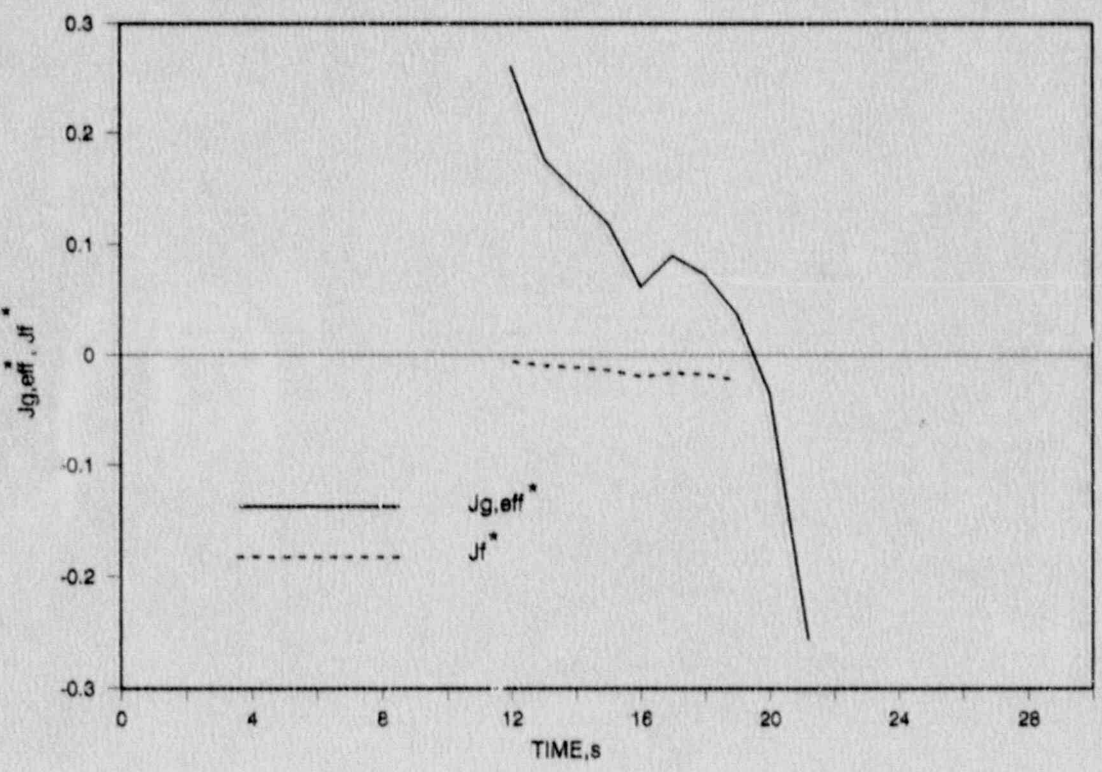

FIGURE 1-4. DIMENSIONLESS DOWNCOMER VELOCITIES CALCULATED USING THE CCFL CORRELATION.

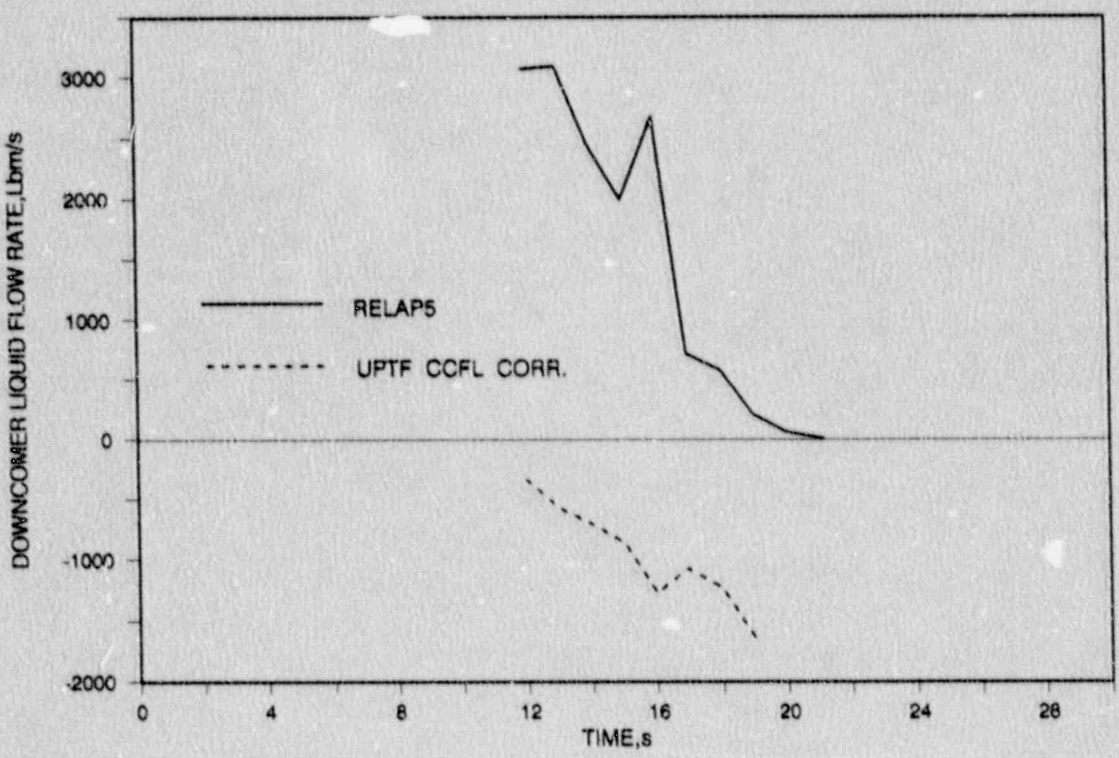

FIGURE 1-5. DOWNCOMER LIQUID FLOW RATES FOR A PLANT CASE.

8. Question: Sections 4.3.2.9 and 4.3.[illegible]0 of Volume I and Section 4.3.1.9 of Volume II referenced B&W report BAW-10091 to show that the effects of heat transfer from primary piping, vessels, and internals and secondary to primary heat transfer were minimal for LBLOCA and SBLOCA, respectively. Because this report was for B&W plants, provide additional information or analysis to justify the applicability of the conclusions of the report to the plants listed in Table 1-1, Volume I. Also, what are the criteria used to determine whether or not to model a metal mass?

Response: The LBLOCA and SBLOCA models contain primary metal slabs to properly simulate heat transfer from these metals. The study in BAW-10091 demonstrated that heat transfer from primary metals is not sensitive to conditions of surrounding fluids because the transfer rate quickly becomes conduction-limited. Furthermore, the amount of energy released from the primary metals and the steam generators for LBLOCA is small compared to core decay heat and flashing. Because the thicknesses of metal slabs in B&W, W and CE plants are comparable, the conclusions from the referenced study are applicable to the other designs. The primary metal model used in the evaluations contains all metal within or in contact with the reactor coolant system (RCS) water. Attached small piping, ECCS piping, instrument lines, and metal attached to the RCS metal are considered to have little impact on the LOCA results and are not included in the model.

The steam generators are important for both LBLOCA and SBLOCA as large reservoirs that act as either heat sources or as heat sinks. Within reasonable limits, the surface areas, metal thicknesses, and flow geometries within the steam generators do not have substantial impact on the results of either the LBLOCA or the SBLOCA. The energy of the pool of secondary coolant and the auxiliary feedwater, however, can have a profound effect on the transients.

For the LBLOCA, the secondary system acts as a heat source after the first several seconds of the transient. Although unimportant during blowdown, the energy transport can easily vaporize and superheat the venting fluids during reflooding. That, in turn, worsens the steam venting and retards the plant flooding rates. During this period, the primary-to-secondary temperature differential is large and there is ample heat transfer area such that the details of the steam generator do not control the process. The only requirement is for the model to recognize and account for a large reserve of energy within the secondary system. The B&W evaluation model reflood simulation does this by setting the steam generator heat transfer coefficient conservatively high so that all incoming primary side fluid is vaporized and superheated to the secondary saturation temperature. Therefore, dependency on modeling detail and nodalization is removed from the simulation.

Surface heat transfer coefficients for the primary metal and the steam generators are selected to be representative of the heat transfer regimes encountered. Although no attempt is made to incorporate conservatism per se, the calculations of heat transfer can not be made to produce more conservative conditions because of the large energy supply and the heat transfer from the steam generator secondary fluid described above. The selected film coefficients around the loop are: (1) For primary metal (not fuel) within the reactor vessel upstream of the top of the core, a film coefficient of 200 btu/hr-F-ft^2 is used for liquid regions and 20 btu/hr-F-ft^2 for steam blanked regions. The 200 btu/hr-F-ft^2 is reasonable to high for pool boiling in liquid under low flow conditions. The 20 btu/hr-F-ft^2 is reasonable for convection to vapor at low flows. (2) The film coefficient for the upperhead is set at 100 btu/hr-F-ft^2. The upperhead is a relatively stagnate steam only region and not a significant contributor to the solution.

100 btu/hr-F-ft^2 is quite high for a convection to vapor coefficient in this area. (3) A film coefficient of 1000 btu/hr-F-ft^2 is applied in the reactor coolant loops, hot and cold legs, and the steam generators, for both the thick metal and tube surfaces. These regions experience a relatively high velocity flow of mixed vapor and liquid droplets. The 1000 btu/hr-F-ft^2 is high for the flow film boiling regime expected.

Although of substantially lower importance than vapor superheating, the amount of tube plugging modeled should be higher than that applicable to the plants to be covered by the analysis. At 10 to 20 percent plugging, a difference of a few percent is not consequential, but differences of 5 percent or more will effect the results. The modelling within the B&W evaluation model for these parameters assures an appropriate and representative secondary inventory, sets a conservatively high reflooding secondary heat transfer coefficient, and employs a degree of tube plugging with selected margin.

For the smaller SBLOCAs, the steam generator acts as a heat sink. If the break flow cannot remove sufficient energy to keep the plant below the secondary pressure, the steam generator will absorb heat through steam condensation to maintain the primary system at a pressure near that of the secondary system. The available heat transfer area in the generator is large and the required heat transfer is small, so that the only substantial requirement on the modelling is to provide for the secondary side as a large reservoir of water. Of substantially lower importance is the action of the steam generators as heat sources for larger SBLOCAs and the flow restriction offered by tube plugging. The primary coolant flow rate through the steam generators is not high at any time that there is a potential for core uncovery, and only small frictional differential pressures result. The alteration of these pressure drops by a few percent because of the effect of tube plugging will not alter the static heads of liquid within the system. Similarly, because the flow through the steam generators is steam, at any time at which the core may be uncovered, the action of the steam generator as a heat source is to superheat the steam and not to vaporize entrained liquid. This effect should be modeled, but it does not have the importance of either the heat sink effect for SBLOCA or the heat source effect on reflooding for LBLOCA. The modelling within the B&W evaluation model for these parameters, is the same as that for the LBLOCA and assures appropriate and representative treatment.

The text within the evaluation model report that could be taken to mean that the secondary system is not important to the course of the LOCA transients will be modified to reflect the discussions in this response.