SAFETY EVALUATION REPORT

FOR THE

BABCOCK AND WILCOX OWNERS GROUP

SMALL BREAK LOSS-OF-COOLANT ACCIDENT

EVALUATION MODEL, CRAFT2 (REV. 3)

(BAW-10092P, REV. 3 AND BAW-10154)

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I. BACKGROUND

Following the accident at TMI-2, the Bulletins and Orders Task Force was formed within the NRC Office of Nuclear Reactor Regulation. The Task Force was charged, in part, with reviewing the analytical predictions of feedwater transients and small break LOCAs to ensure the continued safe operation of all operating reactors, and with the determination of the acceptability of operator emergency guidelines. As a result of these reviews, the Task Force concluded that, while there were no apparent safety concerns, additional system verification of the small-break LOCA model (as required by II.4 of Appendix K to 10 CFR 50) was needed in certain areas. These improvements and concerns, as they applied to each LWR vendor's model, were documented in the various Task Force reports for each LWR vendor. The review of the B&W small-break LOCA model was documented in NUREG-0565, "Generic Evaluation of Small Break Loss-of-Coolant Accident Behavior in Babcock & Wilcox Designed 177-FA Operating Plants" (January 1980). The review of the reactor coolant pump model was documented in NUREG-0623, "Generic Assessment of Delayed Reactor Coolant Pump Trip During Small Break Loss-of-Coolant Accidents in Pressurized Water Reactors" (November 1979). On October 31, 1980, the NRC issued NUREG-0737, "Clarification of TMI Action Plan Requirements." Included in NUREG-0737 is the requirement for B&W licensees to review NUREG-0565 and -0623 and develop a program that addresses the NRC concerns therein. After a meeting between the 177-FA Owners Group and the NRC, the B&WOG instituted a Small-Break LOCA Methods Program to address the requirements of NUREG-0737, Section II.K.3.30, as they were identified by the staff in the meeting of December 16, 1980.

There were nine major areas of concern identified by the staff at the December 16, 1980 meeting. They are:

1. Condensation Heat Transfer and Noncondensable Gases
2. Non-Equilibrium Effects
3. Hot-Leg Phase Separation
4. Steam Generator Heat Transfer
5. Systems Verification and other Experimental Data
6. Flow Regimes
7. Core Steam Cooling
8. Metal Heat
9. Break Flow

Each of these concerns will be addressed in the body of this Safety Evaluation Report.

II. INTRODUCTION

The B&WOG has submitted two topical reports to the NRC in response to the NUREG-0737 (Reference 1) concerns. These are BAW-10092P, Revision 3 (Reference 2) and BAW-10154 (Reference 3). A third report, for core mixture level analysis (FOAM2, BAW-10155), was also submitted and reviewed elsewhere, see Section III.7 below.

BAW-10154 describes the features of B&W's small-break LOCA emergency core cooling system (ECCS) evaluation model and is applicable to all current B&W nuclear steam systems.

BAW-10092P Rev. 3 describes the CRAFT2 computer program. In particular Appendix I of the CRAFT2 report addresses the new features of the CRAFT2 models for small-break LOCA analyses.

At present, B&W's nuclear steam plants can be divided into three major categories:

1. 177-fuel assembly plants with lowered-loop arrangement.
2. 177-fuel assembly plants with raised-loop arrangement.
3. 205-fuel assembly plants

There are no significant design differences between the NSSs and ECCSs in each category. Table 1 lists the current B&W plants in each category. The plants in these categories are described as follows:

<u>Category 1</u> - The plants in this category are generally referred to as the Oconee type. They are characterized by their loop arrangement, in which the once-through steam generators are at a low elevation relative to the reactor vessel. These plants have eight internal vent valves and utilize the Mark B (15 x 15) fuel assembly.

<u>Category 2</u> - The design is essentially identical to Category 1 except that the steam generators are raised in relation to the reactor vessel. The pump suction leg is shorter for these plants due to the raised configuration of the steam generators. Also, there are only four vent valves in these plants. This reduction in the number of vent valves is factored into the model as a reduced vent valve flow area. The HPI system comprises low-head HPI pumps. There is only one plant of this design, Davis-Besse 1.

<u>Category 3</u> - These plants have the raised-loop arrangement of the Category 2 plants but are larger (more fuel assemblies) and have eight internal vent valves. The Category 3 plants employ the Mark C fuel assembly instead of the Mark B. Currently the only U.S. plant of this design is Bellefonte.

The small break LOCA evaluation model described in this report is applicable to all three plant categories.

The CRAFT2 computer program was developed by B&W to study the transient behavior of a Nuclear Steam Supply System undergoing a loss-of-coolant accident (LOCA). The program solves the conservation equations for mass and energy, the continuity equation, and the equation of state for water.

The CRAFT2 program permits the user to select the nodal representation that results in the best finite differencing of the fluid system to be analyzed. The program then solves the conservation equations for each node and the momentum equation for each flow path between nodes. CRAFT2 utilizes explicit solution techniques to analyze the transients. Components with different thermal-hydraulic characteristics must be simulated as different nodes.

Table 1 Category Classifications

Category	Plant Name	Docket No.	II.K.3.30 OR TACS
1	Oconee 1	50-269	45845
	Oconee 2	50-270	45846
	Oconee 3	50-287	45847
	Three Mile Island 1	50-289	48286
	Three Mile Island 2	50-320	-
	Crystal River 3	50-302	45815
	Arkansas Nuclear One	50-313	45803
	Rancho Seco	50-312	45859
	Midland 1	50-330	-
	Midland 2	50-329	-
2	Davis-Besse 1	50-346	45817
3	Bellefonte Unit 1	50-438	-
	Bellefonte Unit 2	50-439	-
	WNP-1	50-460	-
	WNP-2	50-513	-

CRAFT 2 contains flexible models of all major Nuclear Steam Supply System components. Various options as well as user input parameters enable the program to model the reactor core, reactor coolant pumps, steam generators, and connecting piping in any configuration and operating mode desired. The diversity of the models also allow the program to accurately model any thermal-hydraulic system containing similar components.

The CRAFT2 computer program has been previously reviewed by the NRC and was found to be in conformance with 10 CFR 50 Appendix K. The purpose of this report is to document the NRC review and findings of the new information provided by the B&WOG in response to item II.K.3.30 of NUREG-0737. This review is limited to those new models related to small-break LOCA Evaluation Model analyses and to information provided to justify the new models or to demonstrate the conservative aspects of CRAFT2 for these analyses, as discussed in Section III of this report.

With respect to LOCA analyses, a break is termed a "small-break" when its cross-sectional area is 0.5 ft^2 or less. Past experience with studies of small breaks has shown that the large break concepts of bypass and reflood do not apply to breaks of this size. A brief description of the behavior of small breaks will be valuable in understanding the evaluation technique. A small break accident involves a rather slow, non-violent system depressurization. Flow conditions within the reactor coolant system change gradually and smoothly. Temperature and pressure gradients between regions tend to be small. The lack of agitation allows partial phase separation of steam and water and, in some situations, countercurrent flow. Rather than the distinct blowdown and reflood phases associated with large breaks, small breaks have a smooth transition from a period of relatively high core flow to one of relatively quiescent conditions. During the early phase, heat transfer in the core is flow-controlled from natural circulation flow and is adequate to keep the cladding cool. Later, during the quiescent period, a two-phase froth level develops in the reactor inner vessel. The portion of the core that remains covered by this mixture is cooled by pool nucleate boiling, which is adequate to maintain the cladding temperature near that of the saturated fluid. If the entire core is not covered by the mixture, the portion above the froth level is cooled

by forced convection to steam. As the system depressurizes, injection flow increases, and gradually the core is recovered completely. The CRAFT2 code is used to predict the hydrodynamic behavior of the reactor coolant system. If CRAFT2 predicts that the core will be covered with liquid throughout the transient, no core heat-up is predicted, and therefore, no thermal analysis is required and compliance with 10 CFR 50.46 is ensured. Otherwise the FOAM computer program is used to determine the mixture height within the reactor core and the thermal response of the hottest fuel pin is calculated using the THETA computer program. The computer code interface and data transfer scheme is shown in Figure 1.

As appropriate, the NRC concerns regarding the B&W small-break LOCA Evaluation Model as identified in NUREG-0565 (Reference 4) and NUREG-0623 (Reference 5) are addressed in Section IV and V of this report.

The B&WOG has also responded to NRC questions concerning BAW-10092P Rev. 3 and BAW-10154 (Reference 6).

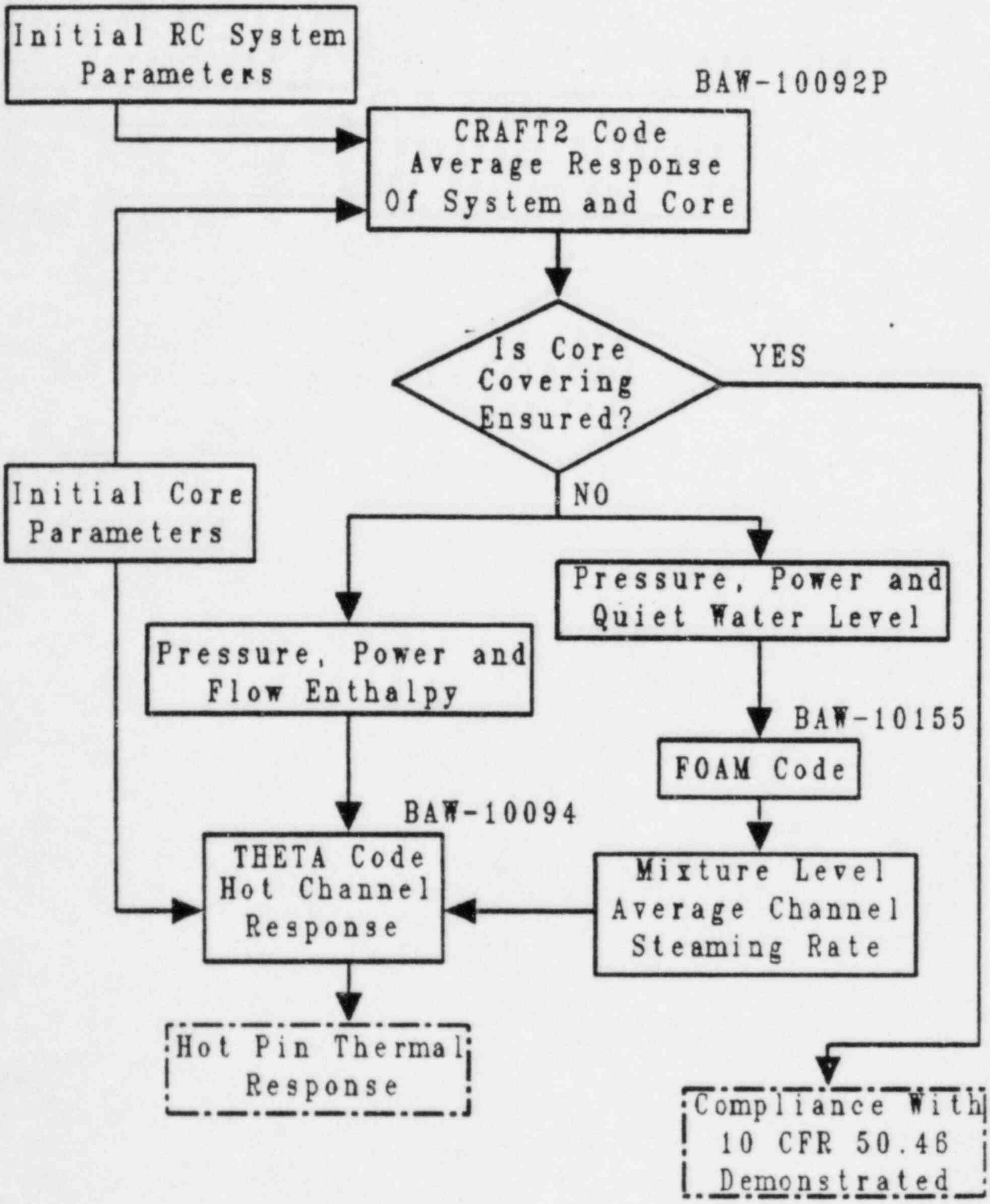
III. EVALUATION OF CRAFT2 SMALL-BREAK LOCA MODELS

The reviews of the revised CRAFT2 computer program models are provided in this section and are related to the nine major areas of concern expressed by the NRC, as mentioned earlier. The following guidelines were, in general, used for this review:

(a) Lower-than-actual energy removal from the primary system and minimization of cooling water injection into the primary system is judged to be conservative because higher fuel temperatures will result. Note that the lower-than-actual energy removal results in a higher pressure level and, therefore, increased break flow out of the primary system and decreased safety-injection flow into the system.

(b) Models not used for SBLOCA-EM analysis were not reviewed. Included are models for noncondensable gases (NCG), pressurizer spray, enthalpy adjustment, and downcomer bypass. It has been shown that

Figure 1. Small-Break LOCA Code Interface
Taken from BAW-10154



the effects of noncondensable gases is insignificant for SBLOCA-EM analysis.

(c) B&W experience and judgment was utilized for the selection and evaluation of tests or plant transients for code benchmarking, for the estimation of input values for the models, and for the estimation of parameter values when some pertinent test data missing.

(d) Future benchmarking will be performed as new test and plant transient results become available.

The following models have been incorporated into the CRAFT2 computer program, in response to NUREG-0737:

(a) Pressurizer Model

A non-equilibrium pressurizer model was added for SBLOCA-EM analyses. The model simulates pressurizer performance using two thermodynamic systems, one for stratified steam and one that contains either subcooled liquid or a two-phase mixture. Models are included for simulating pressurizer sprays, heaters, safety valves, and steam-mixture interface heat and mass transfer. Surge line flow is computed using a linear momentum balance, while relief valve performance is approximated via input mass flow rate versus pressure tables, the Moody model, or the HEM isentropic expansion model. The spray model and the heater model are not used for SBLOCA-EM analyses.

(b) Two-Phase Flow Model

Two-phase flows in vertical columns are modeled with the Lahey and Ohkawa drift-flux model correlation. Associated with the model is a logic to account for phase separation within the control volumes comprising drift flux columns.

The drift flux model accounts for phase slip by modifying the convective term in the mixture energy equation. The mixture mass and momentum conservation equations remain unchanged.

The drift flux model uses two equations to relate steam and liquid volumetric flux densities to the total volumetric flux density.

These equations model the composition of flow in the flow path based on the fluid flow conditions as well as the states of the bounding control volumes.

In the development of the basic drift flux model, it is assumed that control volumes comprising vertical columns contain a homogeneous mixture of steam and liquid. A drift flux level formulation option is provided for the accurate description of two-phase phenomena when sufficiently small control volumes are used.

(c) Two-Phase Pump Model

A new pump model was developed and accounts for two-phase flow degradation of the head and torque curves.

(d) Steam Generator Model

A detailed steam generator model was added to the CRAFT2 SBLOCA version. In this model, the steam generator is described by multiple axial regions, each of which contains one secondary volume and one or two primary volumes. Heat transfer between primary volumes and the corresponding secondary volume is calculated based on a regime-dependent correlation set and the results of an implicit tube calculation. This model contains all the features comprising the standard once-through steam generator (OTSG) and such special features as level rate-dependent auxiliary feedwater control, an aspirator model (OTSG), and a model that accounts for condensation of steam in the presence of noncondensables on the primary side of the steam generator.

The heat transfer contains logic that can be used to account for the degradation of condensation heat transfer on the primary side due to the presence of noncondensable gases. The model accumulates the noncondensable gases (NCG) from the following input sources:

- initial lbmoles of NCG in the system
- lbmoles of NCG/10^6 lbmoles of fill flow
- lbmoles of NCG/10^6 lbmoles of flood tank flow
- lbmoles of NCG released for each fuel pin rupture
- radiolytic NCG production in the core as a function of time and control volume density
- lbmoles of NCG from the Zr-H_2O reaction.

All of the sources are assumed to originate in the reactor vessel and are split between the two steam generators based on the ratio of hot leg nozzle flow rates. Inside the steam generator upper plenum, the NCGs are split between the two radial regions based on the ratio of the flow rates into each radial region. The NCGs are assumed to reside only in the steam generator upper plenum and in primary volumes undergoing condensation.

III.1 Condensation Heat Transfer and Noncondensable Gases

Two general concerns are identified in II.K.3.30: (1) the present condensation heat transfer models have not been adequately verified against applicable data, and (2) the effects of noncondensable gases have not been verified.

III.1.a. Steam Generator Model

The steam generator condensation heat transfer model used in CRAFT2 is for a flat plate in a saturated atmosphere without noncondensable gases being present. B&W has justified the use of this model by comparison to a more detailed solution for the heat transfer coefficient in a tubular geometry. Since

there was less than a 0.4% difference between the flat plate solution and the more complicated result for flow inside of the tubes, the flat plate solution is justified.

The flat plate solution can be used because the film thickness is small compared to the tube radius. This statement will be true for all conditions (where water is the fluid) where the flow is laminar. A substantial condensate film thickness resulting from long condensing lengths and large temperature differences will produce a turbulent flow regime, and the flat plate equation will underpredict the heat transfer coefficient, and is therefore conservative.

The condensation heat transfer coefficient is only used when the wall temperature is below the saturation temperature. When this event occurs, the location of the steam-water interface is determined, and the length used in the condensation heat transfer forumula is the length from the bottom of the upper tubesheet to the steam-water interface.

Babcock & Wilcox has performed experimental measurements of condensation heat transfer with noncondensable gases present in a prototypical OTSG tube. The results of this study were reported in Reference 7. An analysis of this data was reported in Reference 8. The analysis considers the diffusion of the vapor into solution in the condensate film. This model was in good agreement with the data. However, the model requires three interactive calculations to determine the heat transfer coefficient; thus, the implementation of this model in the CRAFT2 code would not be feasible. A user-input table of heat transfer multiplier is therefore provided as a means of accounting for degradation due to noncondensable gases.

B&W has not yet run any SBLOCA-EM calculations using this capability. B&W SBLOCA-EM analyses have demonstrated that the presence of noncondensable gases is negligible, i.e., the Core Flood Tanks do not empty and peak cladding temperatures are below the metal-water reaction temperatures. When such calculations are required, the input tables will be developed using the analytical model developed in Reference 8. The NRC will institute a review of this model at that time as a plant-specific issue.

Based on the observation from the Semiscale Mod-2A Natural Circulation Cooling test program (Reference 9), the staff finds that the B&W conclusion as to the negligible effect of noncondensable gases on condensation heat transfer is acceptable, provided that the Core Flood Tanks do not empty and that the peak cladding temperatures do not reach the onset of significant Zircalloy-water reaction.

The effects of noncondensable gases on natural circulation flow are discussed in Section III.3, below.

III.1.b Pressurizer Model

The effects of condensation and noncondensable gases were also reviewed for the new non-equilibrium pressurizer model in CRAFT2. The model uses an overall heat transfer coefficient, U_i, a steam-mixture interface area, A_i, and a multiplier, f_c, to determine the condensed mass. Heat transfer through the liquid is assumed to be predominately a condensation process. The variable area, A_i, is calculated based on the actual pressurizer geometry, and is the heat transfer area at the interface.

A value of 1.0 is input for f_c, which requires an equivalent mass transfer (condensate) for all heat transferred across the interface. The value of unity prevents desuperheating or an accumulation of a mist (quality) in the steam space. The use of unity for f_c is a reasonable assumption since mass and energy is conserved and superheat temperatures would not be expected to be significantly altered in the steam region. This assumption corresponds to the isentropic compression of an open system in which mass is removed from the remaining mass.

The accumulation of noncondensables in the pressurizer is judged by B&W to be negligible due to the surge line configuration. Also, the condensation heat transfer across the liquid-steam interface is very small compared to the condensation heat transfer at metal surface interfaces. Additionally, the conservative conduction model assumed for heat transfer at the liquid-steam interface

is conduction limited, adding to the conservatism in accounting for the presence of noncondensables in the pressurizer. Therefore, a more mechanistic accounting for noncondensables in the pressurizer would have little, if any, impact on the results predicted by the B&W SBLOCA Evaluation Model.

The condensation model for the pressurizer is acceptable. Validation of the pressurizer model is discussed in Section III.5, below.

Accumulation of noncondensable gases in the pressurizer is not expected. The design of the surge line would limit the flow of gases to the pressurizer for breaks other than in the pressurizer itself. For breaks in the pressurizer, it is expected that noncondensable gases will exit the system through the break. Reference 10 and Appendix C to BAW-10154 provide additional details concerning the surge line design and evaluation.

III.2 Nonequilibrium Effects

The general concern identified in II.K.3.30 is the validation of the procedures used to model the physical phenomena resulting from subcooled water injection. Particular effects of concern include the effects of node size, injection location, and the localized pressure. Note that these can affect the injection mass flow rate. This concern is primarily directed at Core Flood Tank (CFT) injection into the reactor coolant system.

III.2.a Core Flood Tank (CFT) Model

The magnitude of system depressurization resulting from CFT injection is dependent upon control volume fluid content and control volume size. The selection of the ECC injection location can cause gross disturbances in the system response following CFT actuation. A sensitivity analysis performed by B&W confirms that the gross pressure disturbance is a function of modeling techniques. Reference 11 and Appendix D to BAW-10154 provide the results of these studies.

Results from LOFT Test L3-1 have shown that a minimal pressure disturbance will occur upon CFT actuation. CFT injection into a steam environment results in

the injection of a substantial amount of CFT liquid causing a rapid core recovery, which is non-conservative for transients similar to that of LOFT Test L3-1. To maintain a conservative position for all SBLOCA transients, including those outside the representation of L3-1, the B&W CFT model injects into a liquid environment to minimize pressure disturbance. This conservatism is valid for all SBLOCAs of interest, including those during which a greater pressure disturbance may occur.

The CFT model used by B&W is acceptable for SBLOCA-EM analyses.

III.2.b Pressurizer Model

The two-region, nonequilibrium pressurizer model uses two homogeneous regions, of variable size, to model the mixture-steam interface. Constant heat transfer coefficients are used to account for condensation on the pressurizer walls. Together with the assumption of constant mixture temperature, coupled with the assumption of conduction limited heat transfer at the interface, this is found to be a conservative and acceptable pressurizer model for SBLOCA-EM analyses.

III.3 Hot Leg Phase Separation

II.K.3.30 recommends the use of an adequately conservative phase separation model because entrapment in the candy cane of the separated vapor could interrupt natural circulation. Of additional concern are the hot leg model accounting of temperature distribution as the hot leg is refilling, the energy exchange with the walls, and the condensing rates at the liquid-vapor interface.

The interruption and re-establishment of natural circulation is dependent upon the mixture height in the hot leg relative to the bottom elevation of the U-bend piping. The SBLOCA-EM U-bend noding scheme accounts for the bottom elevation of the U-bend piping. Natural circulation will be interrupted when the mixture level falls below the bottom elevation of the U-bend node and is sustained above this elevation. Thus, the model accounts for spillover prior to sustained recirculation, when the hot leg is refilling.

Two drift flux models are available. One of these correlations is a simpler model developed by Kelly, Dougall, and Cantineau. This model was used in B&W's successful prediction of the LOFT L3-6 test (Reference 12). The second is a more sophisticated drift flux model developed by Lahey and Ohkawa. This second correlation (Lahey and Ohkawa) has been shown to demonstrate better agreement to level swell test data and as a result is the model currently used for SBLOCA-EM calculations.

The level formation model is used with the drift flux model to provide for phase separation. Phase separation begins in the uppermost node containing liquid and proceeds down from node to node as phase separation progresses. To accommodate phase separation, the upper stratified node calculation combines the Wilson bubble rise correlation with the drift flux model to determine the bubble escape velocity from the mixture and, hence, the mixture elevation in the node. The phase distribution in each of the lower nodes is assumed to be homogeneous.

The drift flux model/level formation model is used on the primary and secondary sides of the steam generators. Elsewhere in the system, the Wilson bubble rise correlation is used to model two-phase behavior. The Wilson bubble rise model is suitable for vertical columns in which low flow or fluid stagnation exists. Each vertical region of the system under Wilson bubble rise consideration is modeled as a single control volume. B&W experience demonstrates that one vertical node and one U-bend node together with the Wilson bubble rise correlation is sufficient to model spillover and the interruption of natural circulation. The Wilson bubble rise model is acceptable for two-phase low flow calculations in the hot leg for SBLOCA-EM.

B&W experience has demonstrated that using the Wilson bubble rise model in the hot leg for two-phase flow (low flows) and for phase separation yields more conservative results than the drift flux model/level formation option. Phase separation is predicted to occur more quickly, interrupting natural circulation sooner and delaying the re-establishment of natural circulation.

The drift flux models have been benchmarked to applicable data. Section III.5, below, provides additional information concerning verification of the drift flux model.

Heat transfer from the liquid in the U-bend node to the reactor coolant system metal is modeled. Condensation of steam in the U-bend node is modeled if the metal surface temperature is less than the fluid saturation temperature. A conservative condensation heat transfer coefficient of 1.98 BTU/ft^2-hr-°F is used.

It has been demonstrated that the effect of noncondensable gases is negligible on the condensation heat transfer in the steam generator. The other potential impact of noncondensable gases for a SBLOCA-EM analysis is the interruption of natural circulation as a result of a sufficiently large volume of gases in the hot leg U-bend.

In NUREG-0565 (Reference 4) the NRC staff reported the results of the B&W licensees evaluation of the effects of noncondensable gases.

There are nine sources of noncondensable gas which are already in, or could potentially be introduced into, the primary system. These are:

(1) dissolved hydrogen in the primary coolant;
(2) dissolved nitrogen in the CFT water;
(3) dissolved air in the borated water storage tank;
(4) hydrogen releases from zirconium-water reaction;
(5) free nitrogen used to pressurize core flood tanks;
(6) hydrogen released from radiolytic decomposition of injected water;
(7) fission and fill gas in reactor fuel;
(8) hydrogen gas (free and dissolved in the makeup tank); and
(9) pressurizer steam space gas.

With the exception of the source due to radiolytic decomposition (item 6), B&W accounted for each of these sources in their analysis. Because the CFT actuation pressure is approximately 450 psig below the secondary system relief valve

setpoint, the steam generators will be heat sources rather than sinks for any breaks which depressurize to the CFT setpoints and natural circulation would not be a requirement for decay heat removal. Therefore, gas sources from the CFT were not included in the analyses. The licensees have also concluded that for all small breaks considered in the design bases, peak cladding temperatures are low enough that fission gas sources due to cladding rupture or oxidation sources are negligible. Therefore, it was concluded that gas from sources identified as items (1), (3), (8), and (9), along with fission and fill gases assuming one percent failed fuel in the core, are available to the primary system.

If it is conservatively assumed that all the gas comes out of solution, that no noncondensable gas is lost through the break, and that the amount of water injected by the high pressure injection system from the borated water storage tank is 64,000 lbm (which corresponds to 1500 seconds of injection), then the B&W estimate for noncondensable gas in the primary system is 780 standard cubic feet. At a system pressure of 1050 psig (the secondary side relief valve setpoint), this volume would occupy 22.4 cubic feet.

In order to inhibit natural circulation at pressures representative of small breaks requiring secondary system heat removal, the gas would have to fill the U-bends at the top of the hot legs. These bends have a volume of 125 cubic feet. Thus, the conclusion drawn by the licensees is that the maximum amount of noncondensable gas calculated to be available is approximately a factor of five less than the amount needed to inhibit natural circulation. This analysis conservatively assumed that no gas accumulated in the upper head or plenum of the reactor vessel, which is considered the more likely location for gas accumulation. Thus, no reduction in natural circulation flow is predicted by the licensees due to noncondensible gas accumulation. However, as pointed out previously, B&W has neglected any gas source due to radiolytic decomposition of the water.

B&W endorses the conclusions in NUREG-0565 concerning noncondensable gases. In addition, the B&W position regarding the radiolytic decomposition of the injected

water is that this additional source of noncondensable gas does not alter the conclusions in NUREG-0565. Acceptance and reference to this Safety Evaluation Report by B&W and by the B&WOG affirms the conclusion regarding the insignificant effect of noncondensable gases for a SBLOCA-EM analysis.

III.4 Steam Generator Heat Transfer

II.K.3.30 expresses the general concern that the modeling of the steam generator secondary side conditions are oversimplified and too dependent on user-specified input, which could be used to dictate the desired transient result.

Specific concerns regarding the steam generator model were the heat transfer correlations and the effects of auxiliary feedwater (AFW) on the transient response. In response to this concern, B&W has developed a more mechanistic steam generator model with multiple heat transfer correlations and more realistic AFW interaction based on actual OTSG characteristics. The model includes the correlations of Dittus-Boelter for subcooled and superheated forced convection, Chen for saturated nucleate boiling, modified Chen for subcooled nucleate boiling, McAdams for natural convections, Nusselt's condensation correlation as given by Kreith, and Drew's correlation for a falling film for AFW heat transfer. Acceptability of the new steam generator model for SBLOCA has been demonstrated through noding sensitivity studies, the benchmark of Semiscale Mod-2A natural circulation test S-NC-2, and the benchmark of a Loss of Offsite Power (LOOP) event at Unit 1 of the ANO-1. Additional information concerning verification of the new steam generator model is provided in Section III.5, below.

III.5 Systems Verification and Other Experimental Verification

II.K.3.30 expresses the general concern that predicted overall system performance is not adequately verified against applicable data. Verification of overall performance would test detailed code models, for example those for condensation heat transfer and the vent valves. Also tested would be integral effects, such as interruption and restart of natural circulation. In addition, sensitivity studies for integral tests could be used to determine the importance of various modeling features.

III.5.a Vent Valve Model and Countercurrent Flow Model

The B&W NSSS design incorporates vent valves. The vent valve is a flapper-type valve which allow steam generated in the reactor core during a cold-leg LOCA to be vented from the reactor vessel upper plenum region directly to the downcomer, and then out the break. The vent valve design precludes the need for loop seal clearing and unacceptable core uncovery, and therefore mitigates the consequences of a LOCA. Prototypical, sealed model tests of the vent valve have been performed by B&W to determine the vent valve flow characteristics (Reference 13).

The composition of flow in the cold leg during pump suction and pump discharge breaks plays a major role in governing the consequences of an SBLOCA. A higher quality effects the volumetric discharge out the break which tends to reduce the rate of mass inventory depletion while simultaneously reducing the specific energy of the system. The net effect is an increase in the depressurization rate and, therefore, an increase in the HPI delivery.

In the current SBLOCA EM, reactor vessel vent valves are modeled using a simple pipe momentum equation oriented so that flow from the upper plenum to the downcomer is in the positive direction. The forward flow loss factor, which is input to the model, is based on experimental data and corresponds to a fully open vent valve configuration. A very large reverse flow loss factor is used to preclude flow from the downcomer to the upper plenum. The modeling of vent valve dynamics and flow characteristics as a function of opening angle has not been included in the SBLOCA EM due to the small pressure differentials required to open the valves and hold them in a full open configuration.

As required by design and periodically verified by testing, the vent valves will reach a full open configuration when acted on by a force no greater than the equivalent of a 0.25 psi pressure differential between the upper plenum and the downcomer (Reference 14, for example).

In SBLOCA evaluation model cases, steam passes through the vent valves and flows through the cold leg to the break location. Simultaneously, liquid, which overflows the pump suction or is injected by the HPI, will flow in the direction

towards the vessel. This countercurrent flow phenomenon is represented in the SBLOCA-EM by providing two horizontal flow paths joining adjacent cold leg volumes at different elevations.

The ability of the CRAFT2 code to predict countercurrent flow using the "double path" modeling scheme described above has been verified by predictions of LOFT and Semiscale tests. The phenomenon of countercurrent flow in horizontal and sloping pipes is not unique to the B&W NSSS configuration. It has occurred in LOFT and Semiscale SBLOCAs during the draining of the hot leg piping to the vessel.

The ability of the current SBLOCA model to predict steam migration in the cold leg has been verified indirectly by predictions of LOFT and Semiscale experiments. Precise predictions of this phenomenon are not judged by B&W to be necessary for providing an appropriate representation of the overall SBLOCA scenario.

Recently completed analyses performed by the NRC with the RELAP5/MOD2 computer program have been qualitatively compared to the B&W CRAFT2 results for a 0.01 square feet cold-leg break (Reference 15). While this study was not intended to be a direct audit analysis, input assumptions were selected to explore the effects of natural circulation, reactor system repressurization, and boiler-condenser heat transfer including the effectiveness of Auxiliary Feedwater (AFW) spray on the upper OTSG tube elevations.

The RELAP5/MOD2 analyses indicated that although AFW wetting effectiveness can influence the primary system response, the general trends are unaffected. The analyses demonstrate that repressurization can occur during a small break LOCA at a B&W lowered-loop plant. Figure 2 provides a comparison of the RELAP5 results to a similar CRAFT2 analysis. This confirms the B&W CRAFT2 results for a similar size break. The timing of the operator action to raise the secondary system water level to 95% was found not to be critical. Some boiler-condenser heat transfer was found to occur with the level at 50% of the operating range, which terminated the increase in the reactor system pressure before the level was raised to 95%. Finally none of the conditions examined led to core uncovery or heat-up.

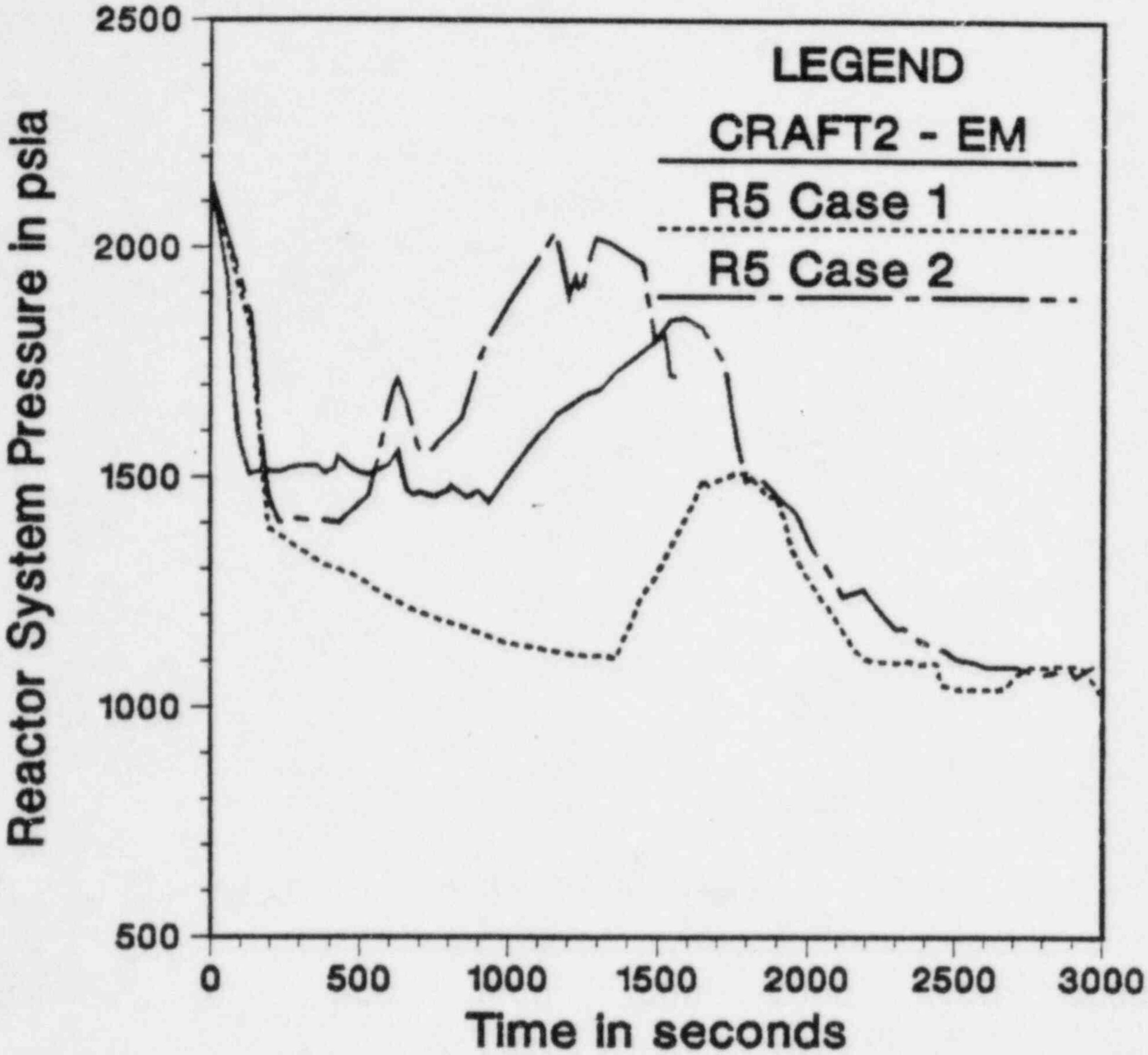


Figure 2. Comparison of CRAFT2 to RELAP5. RELAP5/MOD2 sensitivity study on percentage of steam generator tubes wetted by AFW.

Case 1 100 %

Case 2 0 %

B&W test data shows 6 to 10% wetting, as reflected in CRAFT2 results.

This qualitative assessment between CRAFT2 and RELAP5/MOD2, which employs a dynamic model for the vent valve as well as current state-of-the-art models for flow and heat transfer, provides suitable justification for the acceptance of the CRAFT2 models, and the B&W nodal representation used for SBLOCA-EM analyses.

Details concerning the nodal studies performed by B&W are documented in BAW-10154. Additional justification for the B&W SBLOCA-EM models are discussed below.

III.5.b Pressurizer and Surge Line Model

The nonequilibrium pressurizer model and surge line model have been evaluated against the ANO-1 Loss of Offsite Power (LOOP) event (Reference 16), the NPD surge tank insurge experiment (Reference 17), and the Syracuse University surge tank tests (also Reference 17).

These evaluations demonstrate that the models for the pressurizer and the surge line are acceptable.

III.5.c Steam Generator and AFW Models

The benchmark analyses for the AFW model are provided in Reference 18. Included in these studies is the LOOP test at TMI-2, and the LOOP events which occurred at Davis-Besse 1 and at ANO-1.

The natural circulation experiment during the hot functional tests at Oconee-1 provided AFW model development data (Reference 19). One of the Oconee-1 steam generators was heavily instrumented during the hot functional test program to obtain the data needed to develop the AFW model. Additional data to support the AFW models was also obtained from a flow-visualization test program performed by B&W (Reference 20).

The auxiliary feedwater model developed for use in the CRAFT2 computer program is based on experimental data and has been adequately verified against both separate and integral test data. The AFW model is acceptable for use in SBLOCA-EM analyses.

The steam generator heat transfer models have been assessed against the Alliance Research Center loss-of-feedwater test (Reference 21). The CRAFT2 SBLOCA model analysis compared favorably with the test data.

The steam generator heat transfer models were also assessed with the Semiscale Mod-2A natural circulation test S-NC-2, and is documented in BAW-10154, Appendix G. The purpose of this analysis was to demonstrate that the revised CRAFT2 computer program can track the various modes of natural circulation observed during a small-break LOCA.

During this analysis only the single- and two-phase natural circulation modes were predicted. The reflux condenser mode of natural circulation was not considered here since the relevant phenomenon was not applicable to a B&W NSS. The single- and two-phase modes of natural circulation were obtained by draining discrete amounts of liquid out of the reactor vessel lower plenum, allowing sufficient time for steady-state conditions to be achieved between drains. The overall loop natural circulation mass flow rate varied considerably depending on system mass inventory. The variation in loop mass flow rate with inventory was a result of the transition from single-phase to two-phase natural circulation.

Initially, the draining simply lowered the vessel liquid level to the top of the hot leg with no significant voiding in the loop. Consequently, there was little change in loop mass flow rate. Further draining caused the loop mass flow rate to increase sharply and eventually peak. This increase in flow was caused by increased voiding in the upflow portion of the steam generator, which increased the overall loop density gradient. The peak in flow occurred as steam bubbles in the upflow side eventually spilled over into the downflow side of the steam generator, causing a reduction in overall loop density gradient between the upflow and downflow sides in the steam generator.

The results of the post-test predictions of test S-NC-2 show that the CRAFT2 computer code compared reasonably well with the data. CRAFT2 predicted the same general trends as were found in the test. For most of the data points,

the results calculated by CRAFT2 were within the uncertainties of the measurements. This analysis demonstrates that the upgraded CRAFT2 code is capable of predicting the single- and two-phase natural circulation modes observed during the small-break LOCA transient.

B&W considers Semiscale Test S-NC-2 to be a suitable benchmark because it exhibits relevant SBLOCA phenomena. Results of the benchmark analysis demonstrate the adequacy of various analytical correlations in the evaluation model to simulate SBLOCA phenomena as they occurred during the Semiscale test. The commonality of SBLOCA behavior between reactor designs justifies the usefulness of S-NC-2 as a benchmark. Consequently, B&W concluded that the performance of the evaluation model will be consistent and that the evaluation model will adequately simulate SBLOCA performance of a B&W NSSS as plant-specific features are added to the modeling scheme such as the OTSG and vent valves.

The key issue is modes of natural circulation, governed by fluid conditions in typical PWR loops. The Semiscale facility is not scaled directly to the B&W configuration. Nonetheless, the physics of natural circulation are presumably independent of the design. Interruptions in flow, boiler-condenser heat transfer, vent valve effects, etc., may change the sequence and duration of certain events. Nonetheless, S-NC-2, as well as other benchmark analyses, confirm that CRAFT2 can adequately predict the key physical processes associated with natural circulation in commercial PWRs.

Additional comments related to Integral Systems Tests (IST) for geometries which are representative of the B&W design are provided in Section III.5.g., below.

III.5.d Two-Phase Flow and Phase-Separation Models

The benchmark analyses for the Wilson bubble rise model are provided in Reference 17. The GE/Hitachi and Westinghouse level swell experiments were used to assess the Wilson bubble rise model. The application of the Wilson bubble rise model, as part of the drift flux model, was assessed against the Mitsubishi

Atomic tests for drift flux modeling assessment. Additional verification of these models was obtained by comparing CRAFT2 to the LOFT L3-6 test (Reference 12).

The purpose of these investigations was to demonstrate that the revised CRAFT2 computer program, more specifically the new steam generator model, can adequately predict the phase-separation in the hot leg and the mixture level in the steam generator and to account for bubble formation and the interruption and re-establishment of natural circulation.

Nodalization studies for the hot leg and steam generator were performed by B&W, and provided in BAW-10154, to determine the proper nodal model for their representation.

The use of the Wilson bubble rise model and the Lahey and Ohkawa drift flux model, coupled with the nodal representations for the hot leg and steam generator, are acceptable for use in SBLOCA-EM analyses.

III.5.e Core Heat Transfer Model

The small break core heat transfer model employed by B&W was compared for steady-state conditions to six tests performed at the Oak Ridge National Laboratory (ORNL). These tests were designed to evaluate the steam cooling capability within a core in which the fluid level was allowed to fall below the top of the active core region and stabilize at an intermediate location. Core cooling under these conditions would be accomplished through pool boiling below the swell or fluid level, and by steam cooling above the swell level. The comparisons were made for that portion of the core above the swell level.

The comparison of the ORNL heat transfer test to B&W techniques indicates that utilization of the Dittus-Boelter correlation as the sole determination of heat transfer is acceptable for determining compliance to 10 CFR 50.46, no core uncovery. For the low flow tests, which are most representative of B&W SBLOCA conditions, the combined convective and radiant heat transfer from the ORNL

tests was higher than the Dittus-Boelter prediction when cladding temperatures exceed 1000F. For all tests, the predicted heat transfer was conservative, relative to the ORNL test data, for cladding temperatures above 1400F. Due to the conservatism of the Dittus-Boelter heat transfer correlation at high cladding temperatures, the present heat transfer model is acceptable for licensing calculations.

If the CRAFT2 analysis indicates core uncovery, a more detailed mixture level and heat-up analysis is performed with FOAM and THETA.

Appendix A of BAW-10154 provides a detailed description of the B&W studies and comparison to the ORNL data.

III.5.f Integral System Benchmarks

In addition to the ANO-1 LOOP event, the Semiscale S-NC-2 test, and the LOFT L3-6 test, previously discussed, additional integral system benchmarks have been performed. These include LOFT test L3-1 (Reference 22) and Semiscale test S-07-10D (Reference 23).

The LOFT L3-1, L3-6, and Semiscale S-07-10D analyses were performed prior to the submittal of the CRAFT2 computer program documentation under review. B&W was requested to provide a discussion on the suitability of these comparisons for verification. The following information was given concerning these analyses.

The code versions used to benchmark LOFT L3-1, LOFT L3-6, and Semiscale S-07-10D are characteristic of the code presently under review. Upgrades to these earlier versions include a two-phase pump model, a non-equilibrium pressurizer model, and an improved steam generator model. These upgrades are expected to have a negligible impact on the previous results of these specific benchmark analyses.

Inclusion of the updated two-phase pump model will not affect the results of the benchmark simulations. This is an appropriate conclusion since the RCS pumps were tripped at the initiation of each test with the exception of L3-6.

Thus, two-phase pump performance, for the benchmark cases other than L3-6, was not experienced in the tests. For LOFT Test L3-6, two-phase pump flow degradation parameters were used which were characteristic of the upgraded two-phase pump model.

The inclusion of the non-equilibrium pressurizer model will have little or no effect on the earlier results. This conclusion was reached after investigating the hydrodynamic behavior of the pressurizer during the transients used to benchmark the SBLOCA-EM. LOFT L3-1, LOFT L3-6, and Semiscale S-07-10D are transients in which the pressurizer emptied in a very short time and non-equilibrium modeling in the pressurizer is of little consequence.

The updated steam generator model would also have been inconsequential to the benchmarks. In the LOFT L3-6 benchmark, secondary steam generator conditions were controlled to the actual test data. In Semiscale S-07-10D and LOFT L3-1, the primary and secondary systems were decoupled during most of the transient. Therefore, steam generator performance predicted in the earlier code version is representative of expected results for the version under review.

In summary, the analytical models affecting the system hydrodynamic predictions (i.e., leak discharge, drift flux, bubble rise) are modeled identically in the code version under review and the versions applied in LOFT L3-6, L3-1, and Semiscale S-07-10D. These tests were selected as the best available benchmarks, and they represent key PWR phenomena during a SBLOCA for a cold leg pump discharge (CLPD) break. Accurately predicting the system hydrodynamic behavior in these tests is considered partial but substantive justification for the B&W SBLOCA-EM.

The CRAFT2 code version under review was benchmarked against the Semiscale Natural Circulation Test S-NC-2 to demonstrate the analytical capability of the upgraded CRAFT2 code in tracking various modes (single- and two-phase) of natural circulation observed during an SBLOCA. The results of the analyses show that the upgraded CRAFT2 code was capable of reasonably predicting the various modes of natural circulation.

The CRAFT2 computer code was benchmarked against a loss of offsite power (LOOP) transient at Arkansas Nuclear One, Unit 1 (ANO-1). The analysis was performed in part to demonstrate the capability of the code to correctly predict the steam generator response during a B&W plant transient. The results showed that the upgraded CRAFT2 model was quite capable of predicting the system response during the ANO-1 LOOP event.

The verification and assessment program presented by B&W in support of the CRAFT2 computer program is judged to be acceptable in demonstrating that CRAFT2 can predict the major phenomena associated with a SBLOCA. These are the interruption and re-establishment of natural circulation, phase separation in the hot-leg, and steam generator condensation heat transfer.

While the integral system tests (LOFT and Semiscale) are not representative of the B&W NSSS design, the CRAFT2 comparisons to plant transients and tests, most notably the ANO-1 LOOP event, provide reasonable assurance that CRAFT2 can predict the pressurizer response, the steam generator response, and natural circulation (single-phase) for the B&W NSSS design.

III.5.g B&W Integral System Test Program

The B&W Integral System Test (IST) program (Reference 24) is intended to supply data for the verification of the B&W version of the best-estimate computer program RELAP5/MOD2 for B&W NSSS specific geometries. The IST program is not intended to provide integral test data for verification of the CRAFT2 SBLOCA-EM computer program.

B&W and the B&WOG have indicated (Reference 6) that the RELAP5 code may, in the future, become a component of the ECCS Evaluation Model but until that takes place, ECCS evaluations for licensing will be performed with the then current, approved Evaluation Model as required by 10 CFR 50.46.

The B&WOG position on the use of ITS data for verification of the CRAFT2 computer program is documented in Reference 25.

The NRC position concerning the IST program, in particular this MIST test facility, is that completion of the MIST program is not needed to approve computer programs and evaluation models to resolve the II.K.3.30 issue. However, the MIST program must be done to confirm the conclusion that CRAFT2 provides a conservative representation of SBLOCA behavior in B&W PWRs.

It is the intention of the B&WOG to use RELAP5/MOD2 for best estimate long term transient predictions. Future transient response predictions for ATOG and the Generic Technical Bases Document will be based on RELAP5/MOD2. It is realized that present ATOG guidance in the area of SBLOCA is based on experience gained through CRAFT2 licensing analyses. In order to affirm the validity of present guidance in the light of new best estimate codes and availability of IST data, the B&WOG is evaluating the benefits and effort required to perform a confirmation of the CRAFT2 model capabilities in one of three ways: (1) benchmark of CRAFT2 to an OTIS test, (2) comparison between predictions of the same transient performed in a best estimate mode using CRAFT2 and a verified RELAP5/MOD2 or (3) comparison between predictions of the same transient performed in an Appendix K type calculation using CRAFT2 and a verified RELAP5/MOD2. The latter two alternatives are considered for post MIST evaluation when the "verification" process of RELAP5 has been established.

B&W has made a long standing commitment to continually review experimental data and code predictions of these data by both B&W and other organizations, as they apply to the CRAFT2 evaluation model or portions of it (see Section 7 of BAW-10154). The MIST program (IST) is one such source of new information. This commitment, along with the commitment to affirm the validity of present ATOG guidance, is taken to be a commitment by B&W and the B&WOG to perform one of the comparisons noted above to demonstrate that CRAFT2 does provide a conservative representation of SBLOCA behavior in a B&W PWR.

The B&WOG also recognizes that test facilities other than MIST are currently performing tests that may be applicable to a B&W-designed NSS. They have not yet received sufficient information from either the University of Maryland or SRI-II Program to adequately assess the benefits they believe will be derived from each of these programs. The B&WOG will follow the test programs for each

of these facilities with the intention of determining the usefulness of the data generated to address scaling issues. However, the B&WOG currently has no firm plans to benchmark data from either of these facilities.

The B&W IST program is being monitored and supported by the NRC. The program is intended to support the development of the best-estimate analysis computer program RELAP5/MOD2. The effort is considered by the NRC staff to be confirmatory with respect to the licensing analysis computer program CRAFT2. It is the position of B&W and the B&WOG that the CRAFT2 (Revision 3) computer program, as an evaluation model for SBLOCA analyses, is conservative with respect to the criteria for ECCS analysis for compliance with 10 CFR 50.46. With respect to the requirement of 10 CFR 50 Appendix K, the CRAFT2 computer program conforms to the Evaluation Model criteria.

The NRC will continue to be involved in the IST program, and will continue to monitor other experimental programs related to the B&W NSSS design. B&W has committed to the continual comparison of relevant test data for the evaluation model and portions of it, as stated in BAW-10154. Any information on future comparisons will be documented and supplied to the NRC.

III.6 Flow Regimes

II.K.3.30 expresses concern about the general ability of codes to properly predict the two-phase-with-noncondensable-gas flow regimes that might exist in loop piping. The modeling of the flow phenomena needs to be verified or else justification needs to be given of why the models used are conservative for all breaks without modeling the phenomena explicitly.

CRAFT2 is an evaluation model code and is not intended for detailed best-estimate calculations. Thus, detailed calculations of flow regimes are not performed. Countercurrent flow is accounted for through the modeling techniques of parallel flow paths and flow regime dependent drift flux models. Of primary importance in transient analyses and predictions are macroscopic, or global, behavior such as RCS pressure and temperature, natural circulation,

heat transfer, and inventory. It has been demonstrated through benchmark analyses that the CRAFT2 code and modeling techniques can predict SBLOCA system characteristics and transient phenomena. For a discussion on noncondensable gas modeling refer to Section III.1, above.

LOFT Test L3-6 exhibited two-phase flow and phase separation and is thus applicable to the verification of the evaluation model. The drift-flux model used in the LOFT Test L3-6 analysis is characteristic of the models in the code version under review. The drift-flux model used in the LOFT Test L3-6 analysis was based on recommendations by Kelly, Dougall, and Cantineau.. The same model has been incorporated into the CRAFT2 code. Additionally, a second drift-flux model based on recommendations by Ohkawa and Lahey has been included in CRAFT2. Based on a better representation of level swell test data, the Ohkawa and Lahey model will be used for SBLOCA-EM calculations.

The flow regimes encountered in the LOFT and Semiscale SBLOCA experiments are indicative of those to be expected in actual plant transients. The duration, extent, and timing of events in the tests may not coincide with prototypical behavior, primarily owing to scaling limitations. Nonetheless, the test phenomena are representative, and, so long as the test geometries and conditions are within the range of the formulations used in the evaluation model, the tests present valid benchmarks.

The countercurrent flow parallel path modeling technique and the flow regime dependent drift flux model are acceptable for SBLOCA-EM analyses.

III.7 Core Steam Cooling

II.K.3.30 expresses concern regarding the capability to predict core level and core heat transfer because the comparisons with experimental results are not challenging to the code models.

The heat transfer models available in CRAFT2 for an SBLOCA analysis can be categorized as follows: (1) fuel pin surface heat transfer, (2) steam generator

primary to secondary heat transfer, and (3) primary metal (i.e., structural metal) heat transfer.

The fuel pin surface heat transfer model is described in the CRAFT2 topical report BAW-10092, Rev. 3. The heat transfer coefficient at the pin surface is calculated for five regimes: subcooled forced convection, nucleate boiling, transition boiling, film boiling, and superheat forced convection. These regimes are modeled by the correlations of Dittus-Boelter for subcooled and superheat forced convection; Thom for pre-CHF boiling; McDonough, Milich, and King for transition boiling; and Dougall-Rohsenow/Groeneveld/and Morgan for film boiling. These correlations are used in the applicable regimes. Of these regimes, for low flow condition, the superheat forced convection is of primary interest to an SBLOCA when a portion of the core is uncovered.

As indicated previously the detailed core level analysis is performed with the FOAM2 (Reference 26) computer program if the CRAFT2 analysis indicates core uncovery for a SBLOCA-EM analysis. The actual hot pin heat-up analysis is then performed with the THETA computer program (Reference 27).

The review of the FOAM2 computer program is being performed by the Core Performance Branch, Division of Systems Integration. A preliminary assessment indicates that, with some additional justification, the FOAM2 level swell and pin temperature calculations are conservatively evaluated for SBLOCA-EM analyses.

The CRAFT2 model is acceptable for determining if core uncovery will occur and is judged to be conservative for SBLOCA-EM analyses.

III.8 Metal Heat

II.K.3.30 expresses concern that metal heat should be appropriately accounted for.

All metal mass is simulated in the SBLOCA-EM calculations. Since the outside walls are considered adiabatic, all energy is conservatively retained in the system.

The effect of metal heat is of particular concern in the modeling of the hot leg because the vapor phase separation, natural circulation interruption, and re-establishment would be affected. Metal heat is also of concern in the modeling of the pressurizer because of the effect of the heat transfer on the pressurizer response to insurges and draining.

The metal heat modeling in the hot leg is described in BAW-10192 (CRAFT2). The heat transfer coefficient to the froth is calculated from the Jens-Lottes correlation or an input constant. The input steam heat transfer coefficient is held constant. The total heat transfer coefficient is the steam and froth contributions. Heat flow from the primary metal is deposited in the control volume fluid.

The metal heat modeling in the pressurizer is described in section 1.2.13, Appendix I of BAW-10192 (CRAFT2). It includes two variable area slabs of uniform thickness associated with both regions of the two-node pressuizer model. Heat flow from the primary metal is deposited in the fluid of each pressurizer region. If only one region exists, then the heat flow is deposited in the region which is present.

The treatment of metal heat, including the modeling for the hot leg and the pressurizer, is acceptable for SBLOCA-EM analyses.

III.9 Break Flow

II.K.3.30 expresses concern regarding the break flow representation used for SBLOCA-EM analysis. The concerns include accounting for the break geometry (F/L), location (hot leg, cold leg, top or bottom of pipe), and the upstream thermodynamic state and flow regime.

The upstream thermodynamic state and flow regime, two-phase conditions, provide the properties and state of the fluid flowing through the break.

The B&W SBLOCA Evaluation Model utilizes the orifice equation for subcooled discharge and the Moody correlation for saturated/two-phase discharge. A discharge coefficient of 1.0 is applied to both models. This configuration has been demonstrated to be conservative in Appendix B of BAW-10154, and is acceptable for SBLOCA-EM analyses.

In demonstrating conformance to 10 CFR 50.46 criteria, the actual break size analyses are only important with respect to demonstrating ECCS performance. To date, B&W SBLOCA-EM analyses have demonstrated conformance to 10 CFR 50.46 criteria for the full range spectrum of SBLOCA transients. The full range spectrum has demonstrated the acceptability of the B&W ECCS design (HPI, LPI, and CFT) to maintain core cooling.

Item II.K.3.31 of NUREG-0737 requires confirmatory analyses with the revised SBLOCA-EM to show that the criteria to 10 CFR 50.46 criteria are still met. Analyses of the full SBLOCA spectrum are not necessarily required. The analyses must demonstrate that the previous SBLOCA-EM analyses are conservative, or new analyses will be required. Therefore, it is necessary to choose a break spectrum for analysis that will bound previous analyses concerns.

The proposed break spectrum to be analyzed with the revised SBLOCA-EM is currently under consideration as a specific response to NUREG-0737, Item II.K.3.31.

IV. Concerns in NUREG-0565

NUREG-0565, Section 4.1.1.1, identifies concerns regarding the B&W small-break evaluation model:

Concern No. 1

Following postulated small break loss-of-coolant accidents, a primary mechanism for heat removal is natural circulation. The staff is concerned about the ability of the computer programs to correctly predict the various modes of natural circulation and the interruption of natural circulation, if it occurs.

Experimental data for the verification of methods for two-phase natural circulation are currently not available.

Response

In response to this concern, the CRAFT2 code was upgraded. Included in this modification are a non-equilibrium pressurizer model, an upgraded two-phase flow model, pump model, and a new steam generator model.

To demonstrate the ability of the upgraded CRAFT2 code to predict the various modes of natural circulation observed during a small break, a post-test analysis of the Semiscale Mod-2A Natural Circulation Test S-NC-2 was performed. This was a natural circulation test exhibiting single-and two-phase natural circulation modes. CRAFT2 predicted the same general trend as found in the test. The results calculated, for most data points, were within the uncertainties of the measurements. This analysis demonstrated that the upgraded CRAFT2 code is capable of predicting various modes of natural circulation observed during the small-break LOCA transient and the transition from one mode to another.

In addition, a benchmark of the small-break model against a B&W plant transient was performed. The high-pressure reactor trip incident at Arkansas Nuclear One (ANO-1) on June 24, 1980, was the selected transient. The results calculated by the upgraded CRAFT2 code were compared with the transient data to analyze the adequacy of the new steam generator and pressurizer models. It was demonstrated that the upgraded CRAFT2 code is capable of predicting the natural circulation mode observed during the B&W plant transient.

Concern No. 2

The experimental verification of small break analysis methods with systems data is currently limited. The available small-break data from Semiscale Test S-02-6, although containing a number of deficiencies, is the best information now available. The analytical methods used to predict the results of this test

do not correctly predict the overall system depressurization rate, and the depressurization rate following core flood tank injection. These are significant parameters in that they affect the injection rate of the core flood tank fluid. Analyses by B&W of Semiscale Test S-07-10B and LOFT Test L3-1, have been submitted by B&W and are currently being evaluated by the staff.

Response

In addition to the pre-test predictions of Semiscale Test S-07-10B and LOFT Test L3-1, B&W has also performed the post-test evaluation of these tests as requested in the "Letter to All Babcock & Wilcox Licensees" from R. W. Reid, Chief Operating Branch No. 4, Division of Licensing, February 24, 1981.

The post-test evaluation of LOFT Test L3-1 was submitted to the NRC in June 1981. It was concluded in this analysis that using initial and boundary conditions consistent with the actual test, the results calculated by CRAFT2 are in good agreement with the test data, thus confirming that CRAFT2 is capable of predicting small-break LOCA transient phenomena.

B&W and the B&WOG are also committed to the MIST integral test facility program (the IST program) to provide additional data to confirm that CRAFT2 provides a conservative representation of SBLOCA behavior in a B&W PWR.

Concern No. 3

The appropriateness of the pressurizer model for analyses of small breaks at various locations is a potential concern. The equilibrium pressurizer model assumed in the B&W analyses gives somewhat different results from hand calculations assuming non-equilibrium conditions. These modeling differences may be significant for various postulated breaks. Also, the representation of flooding in the surge line could affect draining of the pressurizer. A flooding check is not made for the surge line in the computer program.

Response

In response to this concern, a non-equilibrium pressurizer model was developed and incorporated in CRAFT2. The model simulates pressurizer performance using a steam region and a liquid region. Heat and mass transfer between the two regions is controlled by steam-mixture interface parameters.

The second part of the concern regarding the addition of flooding in the surge line was also assessed. The result of this evaluation is shown in BAW-10154, Appendix C. It is demonstrated in the report that, based on the geometry of the pressurizer surge line, countercurrent flow within the surge line cannot exist to any significant degree. Consequently, the flow in the B&W pressurizer surge line will be in the only one direction. There is no need to add a flooding check to the surge line.

Concern No. 4

The calculation of core level and core heat transfer are important features of the small break model. Limited experimental data are currently available to justify these models. Although the current comparisons have been satisfactory, the experiments are not challenging to the codes. More experimental data must be obtained for further code verification.

Response

In response to this concern, previous studies contained in BAW-10064 showing analytical and experimental agreement of the core mixture level evaluation technique are referenced. These comparisons show that the level evaluation technique employed by the B&W model is capable of predicting the core mixture level.

In order to provide the analytical and experimental agreement of the core heat transfer evaluation method, the small break core heat transfer model employed by B&W was compared for steady-state conditions to several tests performed at Oak Ridge National Laboratory (ORNL). These tests were designed to evaluate

the steam cooling capability within the core in which the fluid level was allowed to fall below the top of the active core region and stabilized at an intermediate location. These comparisons demonstrated that the use of the Dittus-Boelter correlation as the sole determinant of heat transfer is acceptable for evaluating compliance with 10 CFR 50.46, no core uncovery. Consequently, the present heat transfer model is acceptable for licensing evaluation. If CRAFT2 predicts core uncovery, additional core mixture level and heat-up analyses are performed.

Concern No. 5

The number of nodes used to represent the primary system for small break LOCA analyses should be sufficiently detailed to model the flashing of hot fluid in various locations. This modeling detail is necessary since the calculated system pressure during the decompression process is controlled by the flashing of the hottest fluid existing at any time in the model. The assumption of thermal equilibrium requires that the fluid combined in a single node be represented by the average fluid properties. If fluid from several adjacent regions is combined in one node, the calculated system process during a portion of the transient may be lower than could occur if the smaller regions of hot fluid flashed and maintained the system at the corresponding saturation pressure. Thus, the modeling detail could have a significant effect on the calculated times for various events, such as ECCS actuation.

Response

As a result of the Small-Break LOCA Methods Program developed to address the requirements of NUREG-0737, Section II.K.3.30, significant code modifications and revisions were made to the existing small-break LOCA evaluation model. Because of these modifications and revisions of the existing evaluation model, it was necessary to perform noding sensitivity studies to develop the base noding scheme which demonstrates convergence with respect to spatial detail. To accomplish this goal noding studies were performed by B&W.

A noding sensitivity study was performed to develop a converged steam generator model for 177- and 205-FA plants. These studies were conducted using a break that relies on the steam generator for RCS depressurization. The spatial detail for modeling the steam generator was increased to the code's capacity to assess the impact of additional spatial detail on the transient response. Based on these studies, the steam generator models that adequately accounted for all the phenomena were chosen as the appropriate models for 177- and 205-FA plants.

To ensure that the effects of local flashing were accounted for, noding sensitivity studies of the upper plenum and upper head of the reactor vessel were performed for 177- and 205-FA plants. The converged steam generator models were used for these studies. Based on these studies, a converged model was developed for the upper head and upper plenum of 177- and 205-FA plants by evaluating the results of various degrees of spatial detail in these regions.

Finally a noding study was conducted for the hot leg to ensure that its spatial detail is sufficient to model any interruption in natural circulation flow due to the formation of a steam pocket in the top of the inverted U-bend in the hot legs.

Concern No. 6

During the recovery period from a small-break LOCA, the thermodyanmic equilibrium assumed in fluid control volumes could result in errors in the predicted system pressure. This could, in turn, introduce errors in both the break discharge and safety injection flow. The rate at which the water is refilling the system can affect steam condensation. If the condensation efficiency is less than 100%, system pressure would be higher than predicted.

Concern No. 7

The reduction in the primary system pressure determines the rate and amount of core flood tank water injected. Core reflooding is dependent on this flow. As discussed in NUREG-0611, the sensitivity analyses performed demonstrate the influence of core flood tank injection. The amount of steam present at the in-

jection location is the predominant factor that determines the core flood tank mass delivery. The results of an analysis will be influenced by the model and the modeling assumptions used to calculate the core flood tank flow. Additional studies will be required to obtain the necessary information to perform an Appendix K analysis. Additional work in this area is underway at EG&G Idaho since more recent experimental data, including LOFT Test L3-1, indicate less depressurization than Semiscale Test S-02-6.

Response (to Concerns 6 and 7)

These concern deal with the adequacy of the ECCS injection model used in small-break LOCA evaluations. During the NRC/B&W Owners Group meeting of December 16, 1980 these concerns were clarified. The concern addressed the possibility of a large pressure disturbance after CFT actuation due to the ECCS injection location. In order to respond to this concern, previous B&W small-break transient evaluations were reviewed to determine whether they exhibit the system disturbance of concern. The review of these previous analyses showed that the downcomer liquid volume remains high throughout the transient. As a result of this high liquid content, the use of the thermodynamic equilibrium assumption does not illustrate the system disturbance of concern. The system depessurization characteristics are not significantly altered. Thus, the ECC injection modeling employed in the B&W evaluation model provided an adequate representation of the actual phenomena and the system responses.

In NUREG-0565, Section 4.2.11, the staff expresses the following concern:

Concern

All sources of noncondensable gas generation in the RCS must be taken into consideration, including radiolytic decomposition, to determine the effect on the small-break transient. In addition, it was recommended that the licensees provide "confirmatory information to verify the predicted condensation heat transfer degradation" in responding to this concern.

Response

In response to this concern, all sources of noncondensable gas, including the radiolysis have been accounted for to assess the impact of noncondensables on the small-break transients. The condensation heat transfer degradation model used to assess the impact of noncondensables on SBLOCA transients has been developed by investigating the available literature of industry data including the B&W Single-Tube Condensation Test results at ARC.

V. Concerns in NUREG-0623

The following two concerns are identified in NUREG-0623:

Concern No. 1

In NUREG-0623, Section 4.2.2, the staff expressed a concern that the two-phase flow treatment in CRAFT2 is not adequate to calculate the distribution of liquid in the primary system during a small break with reactor coolant pumps operating.

Response

In response to this concern, the drift-flux model was developed and incorporated in the CRAFT2 code. The adequacy of the two-phase flow model was demonstrated by the successful prediction of the LOFT L3-6 test submitted to the NRC in April 1981.

Concern No. 2

In NUREG-0623, Section 4.3.5, the NRC raised a concern that the two-phase pump model currently used in the evaluation of small-break transients does not adequately model the degradation of pump head and hydraulic torque during two-phase operation.

Response

In response to this concern, a new pump model was developed and incorporated into CRAFT2. The new pump model will account for the degradation of pump head and torque in a two-phase environment.

VI. Conclusions

The Babcock and Wilcox Owners C[illegible], through Babcock and Wilcox, have modified the CRAFT2 small-break LOCA Evaluation Model computer program in response to NUREG-0737 TMI-2 Action Item II.K.3.30, "Revised Small-Break Loss-of-Coolant Accident Methods to Show Compliance with 10 CFR 50, Appendix K." These revisions are based on the NRC recommendations and concerns identified in NUREG-0565 and NUREG-0623.

The modifications to CRAFT2 include a nonequilibrium pressurizer model, a mechanistic steam generator model which incorporates a condensation heat transfer model, a drift flux/level formation model to account for two-phase flow and primary to secondary heat transfer, and a new pump model to account for two-phase flow degradation in the head and torque curves.

A noncondensable gas model, to account for the degradation in condensation heat transfer, was also added to the CRAFT2 computer program. The model is based on data obtained by B&W for an OTSG tube geometry. Past experiences by B&W have demonstrated that the amount of noncondensable gases occurring during a SBLOCA-EM evaluation are insufficient to significantly effect the calculation, and therefore noncondensable gases are not tracked by the CRAFT2 computer program. Recent testing at Semi-scale has also shown that, for the expected amounts of noncondensable gases occurring during a SBLOCA, the effect on the system transient are negligible. At this time the NRC has not reviewed, in detail, the noncondensable gas model.

B&W experiences with SBLOCA-EM evaluations have shown that the Core Flood Tanks (CFTs) do no empty and that the calculated peak cladding temperatures remain

below the metal-water reaction temperatures. Therefore these potential sources of noncondensable gases may be omitted.

B&W endorses the conclusions in NUREG-0565 concerning the amount of noncondensable gases which could accumulate in the primary system. This evaluation conservatively estimated the maximum volume of noncondensable gases from all potential sources, with the exception of the radiolytic decomposition of the safety injection water. The result of this evaluation was that the amount of noncondensable gases is not sufficient to block natural circuation in the hot leg U-bend, if all the noncondensable gases were conservatively assumed to accumulate at that location. In addition, the B&W position regarding the radiolytical decomposition of the injected water is that this additional source of noncondensable gas does not alter the conclusions in NUREG-0565.

The staff agrees with the B&W conclusion regarding the insignificant effect of noncondensable gases for a SBLOCA-EM analysis.

In support of the new models, and the CRAFT2 computer program in general, the B&WOG has performed an extensive verification and benchmark program. Separate effects tests as well as integral system test comparisons were provided. The verification and benchmark program demonstrate that the revised CRAFT2 computer program is capable of predicting those phenomena identified as being important to the SBLOCA-EM analysis. These are condensation heat transfer in the steam generator, hot leg phase separation, the interruption and re-establishment of natural circulation, single and two-phase natural circulation flow, countercurrent flow, nonequilibrium effects for Core Flood Tank injection, and core steam cooling heat transfer. For the most part the new models developed and implemented in CRAFT2 result in a conservative evaluation for SBLOCA-EM analysis. Other models, such as the two-phase pump degradation model, provided for a better, realistic representation of the effects.

The SBLOCA integral system tests used in this evaluation program, LOFT and Semiscale, do not represent the unique B&W NSSS design feature, such as the vent valves, the hot-leg U-bend and the once-through steam generator (OTSG).

However these comparisons are acceptable for demonstrating the capability of CRAFT2 to predict the SBLOCA phenomena of concern.

Additional support for the steam generator model and pressurizer model are based on B&W operating reactor data. These demonstrate the capability of CRAFT2 to model the pressurizer response, to model the steam generator heat transfer, and to model natural circulation (single phase) flow.

Recently completed studies by the NRC using the RELAP5/MOD2 computer program have shown similar response characteristics to CRAFT2 for a SBLOCA-EM calculation. Primary system repressurization for a lower-loop plant was observed, the interruption of natural circulation and re-establishment of natural circulation was observed, and boiler-condenser heat transfer was observed to occur at lower secondary side water levels than CRAFT2 would predict. The overall response was very similar to an equivalent CRAFT2 analysis. The RELAP5/MOD2 computer program employs a dynamic vent valve model as well as current state-of-the-art models for flow and heat transfer.

The verification and benchmark evaluation coupled with the RELAP5/MOD2 qualitative assessment provides suitable justification for the acceptance of the CRAFT2 computer program and the B&W system nodal models to be used for SBLOCA-EM calculation.

The B&W Integral System Test program (IST) will provide data concerning SBLOCA behavior for the B&W specific geometry. It is B&W's position that this program will not result in the identification of any new phenomena related to the B&W design which will alter the conclusion that the CRAFT2 SBLOCA-EM model is conservative and in compliance with 10 CFR 50 Appendix K. This statement is based on a review of the test results from the GERDA and OTIS test programs. GERDA has not been used for benchmark because no reactor coolant pumps were modeled and is not representative of US-B&W PWRs. B&W is currently evaluating the benefit, if any, from benchmarking CRAFT2 to OTIS test data. OTIS is more representative of US-B&W PWRs and can supply natural circulation verification data.

B&W and the NRC will continue to monitor the IST program results, as well as other experimental programs related to the B&W design, to confirm the acceptance of the CRAFT2 SBLOCA-EM computer program.

B&W has made a long standing commitment to continually review experimental data and code predictions of these data by both B&W and other organizations, as they apply to the CRAFT2 evaluation model or portions of it (see Section 7 of BAW-10154). The MIST program (IST) is one such source of new information.

The revised CRAFT2 computer program for small-break LOCA analysis to demonstrate compliance with 10 CFR 50.46 has been shown to be in conformance with the Evaluation Model criteria as specified in 10 CFR 50 Appendix K. The revised CRAFT2 computer program is acceptable for reference in future B&W ECCS licensing evaluations.

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