Westinghouse Non-Proprietary Class 3

WCAP-17721-NP
Revision 0

April 2013

Westinghouse Containment Analysis Methodology – PWR LOCA Mass and Energy Release Calculation Methodology

Westinghouse

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Westinghouse Containment Analysis Methodology – PWR LOCA Mass and Energy Release Calculation Methodology

WCAP-16608-P-A describes the Westinghouse containment analysis methodology. The GOTHIC generic BWR Mark I containment model is documented in Appendix A, and the BWR mass and energy release input calculation methodology is documented in Appendix B.

WCAP-16608, Appendix C was submitted for NRC review in July 2007; it described the PWR LOCA mass and energy (M&E) release input calculation methodology. Appendix C was withdrawn from NRC review in December 2009 after several issues were discovered with the LOCA M&E version of the WCOBRA-TRAC (WC/T) code. These issues have since been resolved and the LOCA M&E version of WC/T has been merged into the standard version of WC/T.

Westinghouse met with the NRC in August 2012 to discuss the best approach for submitting an updated version of WCAP-16608, Appendix C. After that meeting, Westinghouse decided it would be best to submit two separate topical reports instead of a single updated version of WCAP-16608 Appendix C – one for the current operating Westinghouse and CE NSSS plant designs and the other for the passive AP1000® plant design. Therefore, a new number was assigned to the topical report describing the LOCA M&E release calculation methodology for the current operating plants; it is now WCAP-17721-P.

Much of the information contained in this new topical report is the same as was previously presented in WCAP-16608, Appendix C. However, a couple of new sections have been added and a copy of the Westinghouse response to previous RAIs has been included as an appendix to the report. One of the new sections describes how the high ranked LOCA M&E phenomena identification and ranking table (PIRT) items are addressed in the WC/T model. The other new section provides benchmark comparisons and sample cases for application of the methodology to the ice condenser containment design analyses. Finally, the section that describes the WC/T code changes for the LOCA M&E calculations has been updated to explain how the M&E release output data files are generated when WC/T is running in the stand-alone mode.

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NOMENCLATURE

α	Void fraction
σ	Surface tension
μ	Viscosity
π	3.14159
ρ	Density
A	Area, Interfacial area for a single droplet
Cp	Specific heat
D	Diameter
DH	Hydraulic diameter
G	Mass flux
g	Gravitational constant
H_{fg}	Latent heat of vaporization
h	Heat transfer coefficient
k	Conductivity
N	Number of droplets
Nu	Nusselt number
P	Pressure
Pcrit	Critical pressure
Pr	Prandtl number
Re	Reynolds number
T	Temperature
Vr	Relative velocity
X	Quality

Subscripts

h	Homogeneous
l	Liquid
liq	Liquid
Sat	Saturation
vap	Vapor
v	Vapor

1 INTRODUCTION

The mass and energy release input data is the primary input for the calculation of the containment pressure and temperature. The mass and energy release input data for the containment response calculation can either be calculated by Westinghouse or provided by the customer. This topical report describes how Westinghouse calculates the mass and energy release input for the Pressurized Water Reactor (PWR) containment models for the various analyzed Loss of Cooling Accident (LOCA) event applications.

Traditionally, a LOCA event has been described in four phases: blowdown, refill, reflood, and post-reflood. Sometimes a fifth phase, long-term decay heat removal, is described after the post-reflood phase. The blowdown phase starts when the break occurs and ends when the Reactor Coolant System (RCS) pressure has equilibrated with the containment pressure. The only source of makeup water to the RCS during this phase is passive injection from the pressurized accumulator water tanks. During the refill phase, which begins just after blowdown, water from these tanks helps to partially refill the vessel prior to actuation of the active safety injection system. The reflood phase begins after the vessel water level reaches the bottom of the active fuel and continues until the core is quenched. The post-reflood phase starts after the core is quenched and continues until the remaining RCS and Steam Generator (SG) stored energy is released. If the break is located upstream of a SG (in a hot leg), the frothy two-phase mixture from the core will exit directly to containment during the early part of the post-reflood phase. Later, after the RCS metal has cooled down and the core decay heat rate decreases, the core will stop boiling and hot water will be released to the containment. If the break is located downstream of a steam generator (in a cold leg or pump suction leg), part of the frothy two-phase mixture from the core will be forced into the broken loop SG tubes during the early part of the post-reflood phase. Energy from the hot SG secondary fluid and metal will be transferred to the froth, causing it to become all steam. The steam exiting the steam generator outlet plenum will initially be super-heated but, as the steam generator secondary fluid cools from the bottom up, a two-phase mixture will begin to exit the outlet plenum. If the break is in the pump suction leg, the safety injection flow to that cold leg will mix with the steam and water coming from the intact loops and spill out the pump side of the break. If the break is in the cold leg, the safety injection line to that cold leg is assumed to be broken and spilling to containment; the steam and water coming from the intact loops will exit the vessel side of the cold leg.

1.1 CURRENT WESTINGHOUSE NSSS LOCA M&E RELEASE METHODOLOGY

The current Westinghouse LOCA mass and energy (M&E) release model methodology is documented in References 1 and 2. The model uses a series of three codes to calculate the mass and energy release input for the containment analysis. SATAN-VI (Reference 3) performs the blowdown phase M&E release calculations. SATAN-VI models the RCS thermal-hydraulic response with a detailed 1-D nodal network containing one lumped loop (to represent the intact loops) and one broken loop. WREFLOOD (Reference 4) covers the reflood phase of the LOCA event. WREFLOOD also performs the M&E release calculations from the end of blowdown to the time the broken loop SG pressure has equilibrated with the containment design pressure. WREFLOOD uses a simple flow resistance model to represent the RCS and calculates the heat transfer from the fuel as the core quenches. The FROTH code (Reference 2) calculates the heat transfer from the RCS metal and steam generators to the frothy two-phase mixture that exits the core during the post-reflood phase of the event. The WREFLOOD and FROTH codes have been updated and combined to create the REFLOOD10325 code (Reference 2). A third code, EPITOME, combines the

output M&E data files from SATAN-VI and REFLOOD10325. It then adjusts the break releases that were generated during the post-reflood phase of the transient to depressurize all of the steam generators to 14.7 psia at one hour. EPITOME calculates a conservative long-term steaming rate, based on the core decay heat rate, for the rest of the analysis, which is at least 24 hours after event initiation. All of the boil-off is assumed to exit out of the broken loop during the long-term steaming period.

Several simplifying assumptions were made while developing the current LOCA M&E release calculation methodology. These assumptions, which are listed below, were found to yield a conservative calculation of the containment pressure response.

1. The containment backpressure is assumed to remain at design pressure during the blowdown phase. Sensitivity studies documented in WCAP-10325-P-A (Reference 2) confirmed that this is a conservative assumption. The containment backpressure input value can be adjusted during the reflood, post-reflood, and long-term steaming phases.

2. The vessel is assumed to be refilled to the bottom of the active fuel at the end of the blowdown phase in accordance with NUREG-0800 Section 6.2.1.3 (Reference 5). This eliminates the calculation of the refill phase. Neglecting the refill phase eliminates the period of reduced break flow that would occur between the end of the blowdown and start of the reflood phase.

3. All of the post-blowdown RCS fluid, metal, and SG energy are assumed to be released to the containment within one hour after event initiation (i.e., the RCS and steam generators are assumed to depressurize to saturated conditions at 14.7 psia within 1 hour). There were several reasons for using this non-mechanistic method to calculate the SG and metal energy release rates.

    a. At the time the code was written, scalable test data for determining the heat transfer rate from the hot SG to the cooler two-phase RCS mixture was not yet available.

    b. Because the computer systems memory and processor speeds were not as advanced as they are today, the amount of thermal-hydraulic detail that could be put into the code (e.g., modeling conduction-limited heat conductors) was restricted.

    c. Because the sub-atmospheric containment design is required to be depressurized to atmospheric pressure within one hour of event initiation (Reference 5), it was determined that using the one hour time frame to remove all of the remaining RCS metal and SG energy would produce a conservative upper bound containment pressure response for evaluating the design of the sub-atmospheric, ice condenser, and large dry containment designs.

4. The flow split between the broken and un-broken RCS loops in the post-reflood calculation is assumed to be constant. The selected flow split maximizes the steam release to containment by reducing the amount of condensation via steam/water mixing in the intact loop(s).

This conservative LOCA M&E release calculation methodology has been applied in the design basis accident (DBA) analyses for all standard Westinghouse NSSS containment designs and this method will continue to be used, if requested by our customers.

1.2 CURRENT WESTINGHOUSE CE/ABB NSSS LOCA M&E METHODOLOGY

The CE/ABB LOCA M&E release model methodology is documented in References 6, 7, and 8. The model uses a series of three codes to calculate the mass and energy release input for the containment analysis. CEFLASH-4A (Reference 6) performs the blowdown phase M&E release calculations. CEFLASH-4A models the RCS thermal-hydraulic response with a detailed 1-D nodal network containing the two hot legs, the two steam generators, and the four cold legs. FLOOD3 (Reference 7) describes the reflood and post-reflood phases of the LOCA event and performs the M&E release calculations from the end of blowdown to the time the broken loop SG pressure has equilibrated with the containment design pressure. FLOOD3 uses a simple flow resistance model to represent the RCS and calculates the heat transfer from the fuel as the core quenches. A third code, CONTRANS (Reference 8), is used to calculate the long term boil-off and/or cooldown.

The simplifying assumptions noted above are implemented as follows for the current CE/ABB LOCA M&E release calculation methodology. These assumptions were found to yield a conservative calculation of the containment pressure response.

1. The containment pressure is calculated to increase during the blowdown phase, but is kept constant at slightly below the containment design pressure during the reflood and post-reflood phases.

2. The vessel is assumed to be refilled to the bottom of the active fuel at the end of the blowdown phase.

3. The long term boil-off and cooldown are calculated coincident with the containment response.

4. The reflood and post-reflood core exit flow split between the broken and un-broken RCS loops is calculated dynamically using hydraulic resistances in the RCS loops.

This conservative LOCA M&E release calculation methodology has been applied in the DBA analyses for all CE/ABB NSSS containment designs and this method will continue to be used, if requested by Westinghouse customers.

1.3 REASONS TO UPDATE THE LOCA M&E METHODOLOGY

Several developments have occurred since the time the current LOCA M&E release methodology was approved. First, the energy transfer from the hot steam generator secondary fluid to a cooler two-phase mixture flowing through the SG tubes was measured under representative large-LOCA, post-blowdown conditions in the FLECHT-SEASET tests (Reference 9). The two-phase mixtures, at various flow rates and void fractions, were forced into the SG test assembly to measure the transient heat transfer rates and fluid temperature distribution. The test data demonstrated that the SG quenched from the bottom up and that a complete SG cool down could take considerably more than one hour. Second, the computer processor speeds and memory have increased; this now allows the conduction limited heat transfer from the thick metal in the RCS vessel, piping, and SG inlet/outlet plenums to be modeled. This conduction limited thick metal takes considerably longer than one hour to cool down. Finally, proposed power

upratings and limitations in maintenance and operations have increased the need to obtain analysis margin for the containment.

Westinghouse has developed an improved LOCA M&E release calculation methodology, which is described in the sections that follow. This new methodology takes advantage of more realistic modeling capabilities and eliminates the need for some of the simplifying assumptions listed above. Westinghouse intends to offer this new method to its customers after it has been reviewed and approved by the NRC.

2 IMPORTANT PHENOMENA FOR MODELING LOCA M&E

A phenomena identification and ranking table (PIRT) for the Westinghouse LOCA M&E release calculation was developed and is documented in Reference 23. The LOCA M&E release PIRT is very similar to the LOCA PCT PIRT (Reference 29, Section 1.2.3) and includes many of the same phenomena.

The high ranked phenomena from the LOCA M&E release PIRT are shown in Table 2-1. The methods that are used in the WC/T LOCA M&E release model to address each of these high ranked phenomena are summarized in this section.

2.1 BREAK FLOW

Most of the initial RCS fluid mass and energy is released out of the break during the blowdown phase of the LOCA event; the larger the break size, the faster the release rate. The break flow rate is maximized by assuming a full double-ended pipe rupture. The break location is varied between the hot leg, cold leg, and pump suction leg. Most of the RCS fluid flashes into steam once it enters the containment. This causes a rapid increase in the containment pressure, resulting in what is known as the blowdown peak for the large dry, sub-atmospheric, and passive containment designs. The double-ended hot leg (DEHL) break location produces the highest steam release rate, and subsequently, the highest blowdown peak pressure.

The critical flow model is a high ranked phenomenon during the blowdown phase of the transient. Along with the break location, the critical flow model determines the system response and break flow rate during this phase of the LOCA event. The TRAC PF1 break flow model is used in WC/T. The WC/T break flow model predictions of the Marviken critical flow data are presented in Section 25-2 of Reference 10. The resulting cumulative distribution function is shown in Figure 25-2-10. The 50th percentile value of the measured/predicted break flow is about [

]^{a,c}.

The measured/predicted break flow rate is a function of the pipe length to diameter ratio (L/D); it is greater for small values of L/D (< 1), but decreases as L/D increases. The L/D for a large double-ended pipe break near the vessel is greater than 1.5. For these types of breaks, the TRAC PF1 break flow model will slightly over-predict the break flow rate.

The WC/T calculated DEHL and double-ended pump suction (DEPS) LOCA M&E releases were compared with those calculated using the previously approved LOCA M&E model (Reference 2), and were found to be very close over the blowdown period. [

]^{a,c} The SATAN-VI break flow correlations were compared with data from other test facilities and found to over-predict the data (see Section III of Reference 1).

Table 2-1 Summary of High Ranked Phenomena and Associated Data

Phenomena	Transient Phase	Source of Data
Break: Critical Flow	Blowdown	Marviken, LOFT
Fuel Rod: Stored Energy Release	Blowdown	Initial Stored Energy – Fuel Related Input Parameters Transient Aspects – LOFT, ORNL, G-1, G-2
Fuel Rod: Decay Heat	Reflood Long Term	ANS 1979 Decay Heat Standard
Core: Reflood Heat Transfer	Reflood	FLECHT, FLECHT SEASET, Semiscale, SCTF, CCTF,
Upper Plenum: Entrainment/De-entrainment, Condensation (UPI)	Reflood Long Term	CCTF, SCTF, UPTF
Hot Leg: Condensation	Long Term	UPTF
Hot Leg: Entrainment/De-entrainment	Reflood Long Term	CCTF, UPTF
Steam Generator: Heat Transfer (both primary and secondary, includes secondary stratification), Steam binding	Reflood Long Term	FLECHT SEASET, CCTF, UPTF
Cold Leg/Accumulator: Condensation	Reflood	W/EPRI 1/3 scale test, COSI
Downcomer: Condensation	Reflood	UPTF
Downcomer: Stored energy release (includes Hot Wall, saturated nucleate boiling, quenching)	Reflood	LOFT, CREARE, UPTF
Downcomer: Direct vessel injection	Reflood	UPTF, CCTF
Loop: Flow Split, losses, pump, PRHR	Reflood Long Term	UPTF, CCTF
ADS-4: Entrainment	Post-ADS-4	APEX

2.2 CORE STORED ENERGY RELEASE

Core stored energy is defined as the thermal energy in the fuel and cladding that is greater than a given reference temperature.

The core stored energy release is a high ranked phenomenon during the blowdown phase of the LOCA event. However, because the core stored energy is only a small fraction (< 5%) of the total energy released to containment during blowdown, this phenomenon is not as important for the LOCA M&E release calculation as it is for the LOCA PCT calculation.

The amount of core stored energy that is released during the blowdown phase depends on the break location. The flow through the core remains positive during the DEHL event, but can stagnate and reverse

direction during a DECL or DEPS LOCA event. This affects the heat transfer rate and the release of stored energy from the fuel during the blowdown phase.

Most of the core stored energy is released during the blowdown phase for a DEHL LOCA event. Because the core heat transfer rate is reduced when the flow rate stagnates, some of the initial core stored energy is retained in the fuel at the end of blowdown phase for the DECL and DEPS LOCA events. This is one reason why the calculated peak containment pressure is lower at the end of the blowdown phase for the DECL and DEPS LOCA events than it is for the DEHL LOCA event (see Figure 6-1).

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2.3 DECAY HEAT

The decay heat is a high ranked phenomenon during the reflood and long-term phases of the LOCA event. Decay heat from residual fissions and various fission products continues to be generated after the reactor is tripped. A higher decay heat rate will produce a higher break energy release and subsequently higher containment pressure and temperature.

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2.4 REFLOOD HEAT TRANSFER

Core heat transfer is a high ranked phenomenon during the reflood phase of the LOCA event. Because the flow rate through the core stagnates and/or reverses during the blowdown phase of the DECL and DEPS LOCA events, some of the original core stored energy remains after blowdown in these events. The remaining core stored energy (greater than the saturation temperature), along with the energy that is generated by residual fissions and fission product decay, is removed from the fuel during the reflood phase.

Forced reflood tests from five different facilities were simulated: FEBA, FLECHT Low Flood Rate, FLECHT skewed power, FLECHT-SEASET, and the G-2 loop. The FEBA reflood experiments had a different axial power shape as well as matching tests with and without the mid-plane spacer grid. The FLECHT-SEASET tests had reliable non-equilibrium vapor temperature data, axial void fraction or pressure drop data, as well as droplet diameter, velocity data, and heater rod temperature data. The G-2 reflood experiments had prototypical spacer grid geometry.

The WC/T code contains standard correlations that cover the various modes of heat transfer during the reflood phase. These correlations have been validated using scaled test data over the expected operating range for the various LOCA events. The WC/T heat transfer models have been tested over a wide range of fluid conditions, axial power shapes, bundle power, bundle array geometry, and fuel assembly designs. The WC/T calculated results for the tests described above are presented in Section 12 of Reference 10. A comparison of WC/T model results with the reflood heat transfer composite test results is presented in Section 13-5 of Reference 10.

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Reflood heat transfer was also present in the tests and simulations of SCTF, CCTF, and LOFT, which were described in Section 14 of Reference 10. The code calculated clad temperatures were conservatively predicted for these tests. [

]a,c This results in a conservatively higher calculated containment pressure response during the reflood phase and beyond.

2.5 UPPER PLENUM ENTRAINMENT/DE-ENTRAINMENT AND CONDENSATION

Entrainment/de-entrainment processes that determine the net entrainment of liquid from the upper plenum are high ranked phenomena during the reflood and long-term phases of the DECL and DEPS LOCA events. Entrained liquid drops from the core can be carried up into the upper plenum. Some of the entrained liquid drops will de-entrain on the structures within the upper plenum and form a pool above the upper core plate. The remainder of the entrained liquid drops will be swept into the hot legs and the SG tubes.

The entrainment of fluid at the quench front in the core was examined in tests performed under three different forced reflood conditions (FLECHT-SEASET, FLECHT Low Flooding Rate, and FLECHT Top Skewed Power). The FLECHT facility was full scale in height and represented the downcomer, core, and upper plenum of a reactor vessel. [

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The de-entrainment of fluid within the upper plenum initially tends to form a pool at the top of the upper core plate as it is held up by steam rising up through the core. The water from this pool would begin to drain down through the fuel assemblies after the core steaming rate decreases and the steam velocity through the upper core plate is reduced. The water would normally first start to drain down through the lower power fuel assemblies that are located on the periphery of the core because they would generate less steam than the average or higher power assemblies located near the center of the core. [

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The de-entrainment of fluid within the upper plenum and amount of fluid carried over to the hot legs was examined in tests performed at the Upper Plenum Test Facility (UPTF) and the Slab Core Test Facility (SCTF). The UPTF was full scale in both height and cross section and the SCTF represented a full scale radial slice of a PWR core. [

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For upper plenum injection (UPI) plants, cold water from the low pressure Emergency Core Cooling System (ECCS) pumps is injected directly into the upper plenum during the refill and reflood phases of the large LOCA event. This affects both the core reflood rate and the LOCA M&E release rate. The UPI flow will form a pool above the upper core plate and counter-current flow will affect the reflood rate. The cold water will also condense some of the steam that is generated by boiling in the core before it can enter the hot legs.

The qualification of WC/T for modeling large break LOCA events with UPI is documented in Reference 28. Modeling of steam condensation by the ECCS flow that is injected into the upper plenum is important for the LOCA M&E release calculation because this will significantly reduce the steam flow rate through the loops and out into containment. [

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2.6 HOT LEG CONDENSATION

Condensation in the hot legs during hot leg recirculation is a high ranked phenomenon during the long-term phase of the DECL and DEPS LOCA events. The transfer from cold-leg to hot-leg recirculation occurs several hours after the LOCA occurs. Condensation will reduce the steam release rate and this will decrease the calculated containment pressure. Hot leg recirculation is not modeled in the WC/T LOCA M&E release calculations.

2.7 HOT LEG ENTRAINMENT/DE-ENTRAINMENT

Hot leg entrainment and de-entrainment are high ranked phenomena during the reflood and long-term phases of the DECL and DEPS LOCA events. The liquid drops that are entrained in the flow from the vessel during the reflood and long-term phases can de-entrain and form a pool at the bottom of the hot legs or steam generator inlet plenums. The core reflood rate and steam generator heat release rate are affected by the amount of liquid that is able to flow into the steam generator tubes. Evaporation of the entrained liquid by the hot steam generator tubes causes the local pressure to increase and this steam binding effect decreases the core reflood rate.

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A slip multiplier is included in the WC/T code for potential use in the LOCA M&E application. The slip multiplier is applied to the calculation of the relative velocity between the vapor and liquid phases and provides a method to adjust the entrainment rate in the loops. The slip multiplier may be adjusted to a value between 0.0 and 1.0; the default value is 1.0. Using a slip multiplier value less than 1.0 in the hot leg could potentially allow more liquid to be carried out of the hot legs and into the steam generators. More liquid flowing through the steam generator is conservative for the LOCA M&E calculation because this would cause the steam generator to cool down faster.

Sensitivity cases were made varying the WC/T slip multiplier input values in the hot legs of the 4-loop plant model. The slip multipliers were varied between 0.10 and 1.0 for the DEPS LOCA case. Decreasing the hot leg slip multiplier input values in the WC/T LOCA M&E release calculation affected the broken loop void fraction, resulting in a higher liquid mass flow rate to that steam generator. However, there was essentially no difference in the calculated containment pressure response because the broken loop steam generator secondary fluid temperature was essentially equilibrated with the RCS steam temperature in all cases within the first 5 minutes after event initiation. Therefore, the containment response model is not sensitive to the WC/T slip multiplier input value, which has some effect on the hot leg entrainment, so the default value is used in the LOCA M&E release calculation.

2.8 STEAM GENERATOR HEAT TRANSFER

Steam generator heat transfer is a high ranked phenomenon during the reflood and long-term phases of the DECL and DEPS LOCA events. After the primary coolant energy is released during blowdown, the next largest source of energy for potential release to the containment is the fluid energy stored within the steam generators. The SG secondary fluid temperature is higher than the RCS temperature after blowdown, so the heat transfer will be reversed during the reflood and long-term phases of the DECL and DEPS LOCA events. The SG secondary fluid transfers energy to the two-phase flow passing through the SG tubes and cools from the bottom up. The FLECHT-SEASET tests (Reference 9) show the SG secondary coolant temperature stratifies during the long-term LOCA phase.

After the SGs have been isolated and the blowdown is over, the heat transfer rate from the SG secondary fluid to the outside of the SG tubes is primarily by natural convection. Heat is transferred from the SG secondary fluid to the upside SG tubes and to the SG secondary fluid from the downside SG tubes. The [ ]^{a,c} free convection heat transfer correlation is used, and has been previously accepted, for modeling heat transfer between the SG tubes and SG secondary fluid under these conditions.

The SG secondary fluid energy that is transferred to the SG tubes is released to the primary coolant by convection and evaporation of water drops in the two-phase flow that travels through the SG tubes. The heat transfer rate on the inside surface of the SG tubes is affected by the steam flow rate and amount of entrained liquid. [ ]^{a,c} The vaporization of entrained drops in the SG tubes will increase the pressure at the entrance to the SG tubes (steam binding). This could temporarily reduce the flow through the core and could reduce the core stored energy release rate for the DECL and DEPS LOCA events during the reflood phase. [ ]^{a,c}

As described in Section 3.1, an option was added to the WC/T code to improve the heat transfer modeling inside the SG tubes for the long-term LOCA M&E calculations. The interfacial heat and mass transfer and the [ ]^{a,c} nucleate boiling correlations in WC/T were modified to more accurately calculate the two-phase flow heat and mass transfer within the SG tubes. [ ]^{a,c}

WC/T model comparisons with the FLECHT-SEASET test data are presented in Section 3.2. [ ]^{a,c}

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2.9 COLD LEG/ACCUMULATOR CONDENSATION

Condensation in the cold legs, due to accumulator and safety injection, is a high ranked phenomenon during the reflood phase of the DECL and DEPS LOCA events. Condensation in the cold legs reduces the amount of steam that is released to containment through a break in the cold leg or pump suction leg, and thus reduces the containment pressure. [

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The cold leg break location could be modeled either upstream or downstream of the injection line; [ ]^{a,c}. If it is modeled downstream of the injection location (near the vessel), WC/T would calculate the condensation of some of the steam coming from the core and steam generator side of the break before releasing the mixture to containment. If it is modeled upstream of the injection location (near the pump discharge), most of the steam condensation would be calculated outside WC/T by the containment code. The containment response during blowdown should be about the same for both cold leg break locations. However, after blowdown, the containment pressure response for the case with the cold leg break located near the pump discharge would look like a pump suction break.

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2.10 DOWNCOMER CONDENSATION

Condensation in the downcomer, due to accumulator and safety injection, is a high ranked phenomenon during the reflood phase of the DECL or DEPS LOCA event. Condensation in the downcomer reduces the amount of steam released to containment through a break in the cold leg or pump suction leg, and thus reduces the containment pressure. [

]a,c This is conservative for the WC/T LOCA M&E release calculation because it yields a higher calculated post-blowdown containment pressure response.

2.11 DOWNCOMER STORED ENERGY RELEASE

The release of stored energy in the vessel downcomer is a high ranked phenomenon during the reflood phase of the DECL and DEPS LOCA events. The reason behind this high ranking is that the release of the vessel downcomer stored energy could cause the water that is refilling the downcomer to boil. This would reduce the effective downcomer driving head and entrain water out of the vessel through the broken loop

cold leg, which would slow the core reflood rate and core energy release rate. The reflood rate is very important for the LOCA peak clad temperature calculation, but not as important for the LOCA M&E release calculation because the core energy release rate is much less than the sum of the RCS metal stored energy and steam generator energy release rates during this time period.

Test 25, from the Upper Plenum Test Facility (UPTF), was used to investigate downcomer boiling and entrainment during the reflood phase, among other things. The test was divided into two phases, each with several parts. Phase A of the test started with the downcomer wall temperature approximately 144°F greater than the saturation temperature. The steam flow rate was varied between 30 and 15 kg/s per loop while the simulated ECC flow was maintained at 80 kg/s per loop.

Comparisons between WC/T predictions and measurements from UPTF Test 25 are presented in Sections 14-4-11 and 15-2-4 of Reference 10. [

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2.12 DIRECT VESSEL INJECTION

The phenomena associated with direct vessel injection are applicable to the passive plant design. This information will be provided in the AP1000® LOCA M&E topical report (WCAP-17722).

2.13 LOOP FLOW SPLIT

The loop flow split is a high ranked phenomenon during the reflood and long term phases of the DECL and DEPS LOCA events. The two-phase flow that exits the core must pass through a steam generator before it can exit a break in the pump suction or cold leg. The amount of flow to each loop affects the SG heat release and condensation rate in that loop, which affects the transient mass and energy release from the break to containment.

A flow resistance is modeled for each component in the WC/T LOCA M&E model. The resistance input values are adjusted to produce the correct pressure drop in each component at the specified steady state initial conditions.

After the LOCA occurs, the amount of flow that passes through each loop is primarily affected by the flow path resistance to the break location. Most of the two-phase flow coming out of the upper plenum will pass through the broken loop steam generator because this path offers the least resistance to a break in the pump suction or cold leg. The location of the cold leg break could affect the long-term containment pressure and temperature response because some of the broken loop steam flow can be condensed by safety injection if the break is located near the vessel instead of near the pump discharge. The rest of the two-phase flow coming out of the upper plenum will flow through the intact loop steam generators and continue on to the intact loop cold legs where most (if not all) of the steam can be condensed by safety injection.

The flow path resistance is significantly affected by loop seal plugging. Loop seal plugging occurs as a result of the eventual filling of the vessel; therefore, it is not practical to adjust model input values to try

to prevent loop seal plugging from occurring. As the downcomer fills and the overall liquid levels in the system reach the elevation of the nozzles, water from the safety injection system is able to flow into the intact loop pump suction legs. The loop seal plugging phenomenon is predicted to occur late in the WC/T LOCA M&E calculation (after 3000 seconds).

Loop seal plugging has no effect on the calculated peak containment pressure and temperature for a large dry containment because the peak typically occurs during the initial blowdown phase of the DEHL LOCA event. However, loop seal plugging can reduce the stored energy release rates from the intact loop steam generators during the long term decay heat removal phase of the transient. When a loop seal becomes plugged, the steam and entrained liquid droplets that exit the upper plenum can no longer vent through the affected loop. This prevents reverse heat transfer from the secondary fluid of the affected steam generator and reduces the rate of energy transfer to containment, which affects the calculated long term containment pressure and temperature response.

The containment peak pressure for plants with the ice condenser containment design is dependent on the capability of the spray system to condense the steam that is released to containment just after most of the ice melts. Typically, it takes several hours to melt most of the ice that is contained within the ice bays. An earlier time of ice melt yields a higher peak pressure. Therefore, loop seal plugging could affect the calculated peak containment pressure and temperature for the ice condenser containment design; however, as mentioned earlier, it is not practical to adjust model input values to try to prevent loop seal plugging from occurring.

The CE plant design has two cold legs and one hot leg in each reactor coolant loop. The diameter of the hot leg is much larger than the cold leg or pump suction leg.

The containment peak pressure for the CE plant design also occurs during the initial blowdown phase of the DEHL LOCA event. However, a second peak in the containment pressure is possible because the steam generators in the CE plant design are much larger than the typical Westinghouse plant design. Consequently, the amount of energy that is released from the broken loop steam generator to containment after the end of blowdown for a DECL or DEPS LOCA event is much larger. The second peak occurs during, or just after, the reflood phase, so the loop flow split, and its effect on the containment pressure response, is not affected by loop seal plugging. The magnitude of the second peak is determined by using the output from the DECL and DEPS LOCA M&E release cases in the corresponding containment response calculation.

2.14 ADS-4 OPERATION

The phenomena associated with Stage 4 of the Automatic Depressurization System (ADS-4) operation are applicable to the passive plant design. This information will be provided in the AP1000® LOCA M&E topical report (WCAP-17722).

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Figure 2-1 ECCS Temperature Sensitivity Break Flow Rate Comparison

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Figure 2-2 ECCS Temperature Sensitivity Break Energy Comparison

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Figure 2-3 ECCS Temperature Sensitivity Containment Pressure Comparison

3 WCOBRA/TRAC CODE UPDATES FOR LOCA M&E

3.1 OVERVIEW OF WC/T CODE MODIFICATIONS

The approved PWR ECCS evaluation model (Reference 10) uses the WCOBRA/TRAC (WC/T) code to calculate the RCS thermal-hydraulic response to a pipe rupture. The use of the code and model for these applications has been qualified by comparison with scalable test data covering the expected range of conditions and important phenomena. Therefore, when the input is properly biased, and the options are properly selected, the WC/T ECCS evaluation model can be used to produce the LOCA mass and energy release input data for the containment response calculations.

The heat transfer model in the WC/T ECCS evaluation model has been shown to over-predict the reverse SG heat transfer when compared with experimental data. Although this is conservative, a more realistic SG heat transfer option has been added to WC/T to improve the M&E release calculation.

The WC/T ECCS evaluation model does not consider the metal energy of the SG inlet and outlet plenums, the steam separators and driers, and the secondary side shell. Modeling of this metal energy has been included as an option in WC/T for the M&E release calculation.

The containment response calculation can be performed in parallel with the LOCA M&E release calculation using the GOTHIC code (References 24 through 26). WC/T has been modified to allow it to run in parallel with GOTHIC.

3.1.1 Steam Generator Interface Heat/Mass Transfer Changes

The simulation of some of the experimental runs of the FLECHT-SEASET Steam Generator Separate Effects Tests (Reference 9) showed significant differences between the WC/T calculations and the FLECHT-SEASET test data. First, WC/T over-predicted the heat transfer from the secondary side for both high and low quality simulations. Second, WC/T did not calculate the significant temperature stratification seen in the experiments (see Figures 4 through 11 in Reference 11).

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Model Bases – Saturated Droplet Flow

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]^{a,c} According to several authors (References 12, 13, and 14), a reduction of the interfacial heat transfer coefficient between the droplets and the steam has been observed when the vapor is superheated. This is believed to occur because, for high evaporation rates, the vapor mass flux leaving the surface of the droplet boundary-layer act as a layer decreasing the overall heat transfer rate to the droplet by a "shielding" effect.

Webb and Chen (Reference 15) proposed a model to account for the vapor generation rate in case of superheated vapor in non-equilibrium conditions. The correlation is based on the two-region hypothesis. This hypothesis is that the vapor generation in the post-critical heat flux region is comprised of two mechanisms:

- A near-field evaporation term to model the active evaporation caused by liquid sputtering off of the heated wall in the vicinity of the CHF point.
- A far-field evaporation of entrained droplets by heat transfer from the superheated vapor. The near-field term is dominant near the CHF point. The far-field term is important further downstream.

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Model as Coded – Saturated Droplet Flow

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Scaling Considerations

The interfacial heat transfer correlation for the dispersed flow regime is verified through its use in the simulation of the FLECHT-SEASET steam generator tests described later in this section.

Subcooled Dispersed Droplet Flow

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Model as Coded – Subcooled Droplet Flow

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Scaling Considerations

The interfacial heat transfer correlation for the subcooled dispersed droplet flow is verified through its use in the simulation of the full height FLECHT-SEASET steam generator tests described later in this section.

Quench Front Simulation Model Basis

The SG FLECHT-SEASET experimental test results showed the appearance of a quench front inside the primary side tubes. The dispersed two-phase flow above the quench front provided enough heat transfer and precursory wall cooling so that the quench front advanced up the tubes with time. The abrupt drop in the temperature at a certain time was the proof of an active heat transfer process inside the tubes, and the axial stratification of the secondary side liquid temperature was its result.

The WC/T ECCS evaluation model code version was used to simulate these tests. [

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According to Collier (Reference 21, page 135), the heat transfer process in high quality flows is modeled by two main heat transfer regimes separated by the dryout phenomenon. The point of the dryout is also called the quench front. Downstream of the quench front, and before the dry saturated vapor region, there is a region characterized by a thin liquid film wetting the tube walls. The thickness of this film is often such that the effective thermal conductivity is able to prevent the liquid in contact with the wall from being superheated to a temperature which would allow bubble nucleation. The heat transfer process can no longer be called nucleate boiling because nucleation is suppressed. This region is called the two-phase forced convective region. According to Figure 4.14 in Reference 21, the heat transfer coefficient in this region increases as the film becomes thinner and, when the dryout occurs, there is an abrupt reduction in the value of this parameter.

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Model as Coded – Quench Front

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Code Validation

See Section 3.2.

3.1.2 Steam Generator Wall Heat Transfer Changes

The STGEN component of the WC/T ECCS Evaluation Model code version does not represent the metal wall of the SG inlet and outlet plenum, or the metal wall of the secondary side shell. For mass and energy release calculations, it is important to represent the metal mass of the steam generator inlet and outlet plenum and secondary side shell.

Model Basis

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Model as Coded

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3.2 COMPARISON TO FLECHT-SEASET STEAM GENERATOR TEST RESULTS

The FLECHT-SEASET Steam Generator Separate Effect tests (Reference 9) were conducted in 1982. The test facility consisted of a full height U-tube steam generator, boiler, accumulator, and containment tank. The steam generator tube height and dimensions in the test facility are typical of Westinghouse series 51 steam generators. A total of 32 of 33 U-tubes were used. The boiler and accumulator supplied steam and water to a mixing chamber, which generated a two-phase flow regime to supply the steam generator.

These experiments were conducted using high quality two-phase flows. Steam is the continuous phase with liquid dispersed within the steam flow. The two-phase flow in the steam generator hot leg and inlet plenum was generated by spraying liquid into passing steam.

The seven FLECHT-SEASET test cases that were selected for comparison are listed in Table 3-1. Test 22701 was selected as the reference case, test 23402 was a sensitivity to the flow rate (2X increase), test 22503 was a sensitivity to the RCS pressure (2X decrease), and tests 22920, 22314, 21806, and 21909 were sensitivities to the flow quality (1.0 through 0.1). The Reference 9 test data shows that increasing the flow rate (23402) or reducing the quality (22314, 21806, and 21909) causes the steam generator secondary side to cool faster.

The WC/T simulation model noding structure that was used to represent the FLECHT-SEASET tests is shown in Figure 3-1. [

]^{a,c} Therefore, the initiation and subsequent execution of the WC/T simulation is consistent with the FLECHT test procedure.

Figures 3-2 through 3-43 show a comparison of FLECHT-SEASET test data with results calculated using the standard WC/T ECCS evaluation model options (curves identified as WC/T Standard) and the LOCA M&E model options (curves identified as WC/T w/Interfacial HTX and SG HTX). The WC/T LOCA M&E model options typically show a marked improvement in the calculation of the steam generator outlet temperature and the calculation of the quench front. All cases under-predict the timing of the quench front, which is conservative for the LOCA M&E release calculations because it over-predicts the energy removal rate from the SG secondary side.

Figures 3-44 through 3-50 compare the SG secondary side temperatures. The values calculated using the WC/T LOCA M&E model options are typically lower than the test data.

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Table 3-1 FLECHT-SEASET Steam Generator Tests Initial Conditions

	R22701	R23402	R22503	R22314	R21806	R21909	R22920
Initial Pressure (kPa – abs)	290.9	331.9	166.9	290.9	297.9	304.9	294.2
Initial Temperature (K)	406	410	388	406	406	407	406
Initial Void Fraction	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Initial Secondary Pressure (MPa – abs)	5.86	5.86	5.86	5.86	5.86	5.86	5.86
Steam Flow Rate (kg/s)	0.179	0.358	0.178	0.112	0.045	0.045	0.225
Steam Temperature (K)	428	436	427	428	421	427	430
Steam Pressure (kPa – abs)	290.9	331.9	166.9	290.9	297.9	304.9	294.2
Water Flow Rate (kg/s)	0.045	0.090	0.045	0.114	0.181	0.384	0.0
Water Temperature (K)	395	399	375	400	401	402	N/A
Water Pressure (kPa – abs)	290.9	331.9	166.9	290.9	297.9	304.9	N/A
Outlet Pressure (kPa – abs)	269.9	269.9	131.9	269.9	269.9	269.9	272.1
Avg. Inlet Quality	0.8	0.8	0.8	0.5	0.2	0.1	1.0

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Figure 3-1 WC/T Simulation Model Noding Structure for SG FLECHT-SEASET Tests

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Figure 3-2 FLECHT-SEASET Test 22701 SG Outlet Temperature

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Figure 3-3 FLECHT-SEASET Test R22701 SG Tube Wall – 1 ft

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Figure 3-4 FLECHT-SEASET Test R22701 SG Tube Wall – 4 ft

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Figure 3-5 FLECHT-SEASET Test R22701 SG Tube Wall – 10 ft

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Figure 3-6 FLECHT-SEASET Test R22701 SG Heat Release Rate

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Figure 3-7 FLECHT-SEASET Test R22701 SG Exit Quality

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Figure 3-8 FLECHT-SEASET Test R23402 SG Outlet Temperature

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Figure 3-9 FLECHT-SEASET Test R23402 SG Tube Wall – 1 ft

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Figure 3-10 FLECHT-SEASET Test R23402 SG Tube Wall – 4 ft

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Figure 3-11 FLECHT-SEASET Test R23402 SG Tube Wall – 10 ft

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Figure 3-12 FLECHT-SEASET Test R23402 SG Heat Release Rate

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Figure 3-13 FLECHT-SEASET Test R23402 SG Exit Quality

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Figure 3-14 FLECHT-SEASET Test R22503 SG Outlet Temperature

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Figure 3-15 FLECHT-SEASET Test R22503 SG Tube Wall – 1 ft

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Figure 3-16 FLECHT-SEASET Test R22503 SG Tube Wall – 4 ft

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Figure 3-17 FLECHT-SEASET Test R22503 SG Tube Wall – 10 ft

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Figure 3-18 FLECHT-SEASET Test R22503 SG Heat Release Rate

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Figure 3-19 FLECHT-SEASET Test R22503 SG Exit Quality

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Figure 3-20 FLECHT-SEASET Test R22314 SG Outlet Temperature

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Figure 3-21 FLECHT-SEASET Test R22314 SG Tube Wall – 1 ft

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Figure 3-22 FLECHT-SEASET Test R22314 SG Tube Wall – 4 ft

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Figure 3-23 FLECHT-SEASET Test R22314 SG Tube Wall – 10 ft

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Figure 3-24 FLECHT-SEASET Test R22314 SG Heat Release Rate

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Figure 3-25 FLECHT-SEASET Test R22314 SG Exit Quality

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Figure 3-26 FLECHT-SEASET Test R21806 SG Outlet Temperature

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Figure 3-27 FLECHT-SEASET Test R21806 SG Tube Wall – 1 ft

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Figure 3-28 FLECHT-SEASET Test R21806 SG Tube Wall – 4 ft

a,c

Figure 3-29 FLECHT-SEASET Test R21806 SG Tube Wall – 10 ft

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Figure 3-30 FLECHT-SEASET Test R21806 SG Heat Release Rate

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Figure 3-31 FLECHT-SEASET Test R21806 SG Exit Quality

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Figure 3-32 FLECHT-SEASET Test R21909 SG Outlet Temperature

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Figure 3-33 FLECHT-SEASET Test R21909 SG Tube Wall – 1 ft

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Figure 3-34 FLECHT-SEASET Test R21909 SG Tube Wall – 4 ft

a,c

Figure 3-35 FLECHT-SEASET Test R21909 SG Tube Wall – 10 ft

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Figure 3-36 FLECHT-SEASET Test R21909 SG Heat Release Rate

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Figure 3-37 FLECHT-SEASET Test R21909 SG Exit Quality

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Figure 3-38 FLECHT-SEASET Test R22920 SG Outlet Temperature

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Figure 3-39 FLECHT-SEASET Test R22920 SG Tube Wall – 1 ft

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Figure 3-40 FLECHT-SEASET Test R22920 SG Tube Wall – 4 ft

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Figure 3-41 FLECHT-SEASET Test R22920 SG Tube Wall – 10 ft

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Figure 3-42 FLECHT-SEASET Test R22920 SG Heat Release Rate

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Figure 3-43 FLECHT-SEASET Test R22920 SG Exit Quality

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Figure 3-44 R22701 Steam Generator Secondary Fluid Temperatures

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Figure 3-45 R23402 Steam Generator Secondary Fluid Temperatures

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Figure 3-46 R22503 Steam Generator Secondary Fluid Temperatures

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Figure 3-47 R22314 Steam Generator Secondary Fluid Temperatures

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Figure 3-48 R21806 Steam Generator Secondary Fluid Temperatures

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Figure 3-49 R21909 Steam Generator Secondary Fluid Temperatures

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Figure 3-50 R22920 Steam Generator Secondary Fluid Temperatures

3.3 WC/T LOCA M&E RELEASE OUTPUT DATA

The WC/T LOCA M&E model output data provides input for a containment response model. The output data can be calculated by running the WC/T LOCA M&E model stand-alone or by executing WC/T in parallel with GOTHIC (see Section 3.4).

The WC/T LOCA M&E model output data is provided in a set of transient Mass – Energy release data tables. The mass-energy release data tables are provided for both ends of a double-ended guillotine break. The flow rate and enthalpy values that are provided in the data tables are written at user specified time intervals. These user specified time intervals may contain a large number of WC/T time step calculations. Therefore, the values provided in the data tables must be calculated such that the integrated WC/T mass and energy releases are conserved over each interval.

Code Implementation

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Figure 3-51 Calculation of Average M&E Release Rate in Specified Time Intervals

Model as Coded

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Code Validation

The WC/T LOCA M&E release output data files were verified by directly comparing the plots generated using the output data files with the WC/T time step data that is saved in the NSAPLOT output files.

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Figure 3-52 Implementation of the Containment Related Calculations in WC/T Logic

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Figure 3-53 Logic of the Containment Related Calculations in WC/T

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Figure 3-54 Containment Related Data Transfer to M&E Files or to GOTHIC

3.4 WCOBRA/TRAC RUNNING IN PARALLEL WITH GOTHIC

The containment pressure, temperature, and sump temperature response during a LOCA are dependent on the LOCA mass and energy releases. The LOCA mass and energy releases are dependent on the containment pressure and on the sump temperature when the RHR heat exchanger is in operation. Inter-process communication is available in GOTHIC by specifying read/write run-time from and to specified data files. WC/T was modified to incorporate in the code the read/write run-time files capability consistent with GOTHIC which allows WC/T to run in parallel with GOTHIC.

Code Implementation

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Model as Coded

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Code Validation

The interface transfer between WC/T and GOTHIC was validated by comparing the interface variable plots from the WC/T and GOTHIC sides. The results coincided identically.

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Figure 3-55 Schematic of the GOTHIC – WC/T Coupling

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Figure 3-56 Schematic of the GOTHIC – WC/T Parallel Execution

4 INPUT BIASING FOR THE CONTAINMENT DBA ANALYSES

As described in Section 1, several simplifying assumptions were made during the development of the currently approved LOCA M&E release methodology. Some of these assumptions are to be removed in the proposed new LOCA M&E release methodology as described below.

1. The new WC/T LOCA M&E release model can be coupled with a GOTHIC containment model to calculate the containment response into the post-reflood phase of the event. When running in this manner, it is not necessary to assume the containment backpressure remains at a constant value during blowdown or define conservative containment backpressure input values during the reflood and post-reflood phases. A conservative containment backpressure will continue to be used if the WC/T LOCA M&E model is not coupled to a containment response model. The SG fluid, metal, and RCS metal energy remaining at the end of the WC/T calculation will be released, along with the decay heat, in the long-term containment response calculation.

2. The assumption that the vessel is automatically refilled to the bottom of the fuel at the end of the blowdown phase (just prior to reflood) is conservative, but un-realistic. The new WC/T LOCA M&E release model will calculate the refill transient response.

3. The assumption that all the remaining post-blowdown energy in the metal and steam generators can be released to the containment within one hour is overly conservative. Now, with the advent of faster computers with more memory, the current non-mechanistic LOCA M&E model can be replaced with a more advanced model that includes an improved calculation of heat transfer from the RCS metal and steam generators into the post-reflood phase of the event.

4. It is not necessary to assume or force a fixed flow split between the broken and intact loops during the post-reflood phase. The new WC/T LOCA M&E release model will calculate the flow split based on the loop hydraulic resistances.

The proposed LOCA M&E release methodology was developed in a series of steps. In the first step of the process, a phenomena identification and ranking table (PIRT) was developed to identify the important phenomena that need to be considered in the calculation (Reference 23, updated in Section 2). Next, an appropriate code was selected for the LOCA M&E release model. The Westinghouse best-estimate LOCA ECCS evaluation model uses the WC/T code (Reference 10) to calculate the RCS thermal-hydraulic response to a large pipe rupture. The LOCA ECCS evaluation model PIRT (Reference 29, Section 1.2.3) is very similar to the LOCA M&E release model PIRT, so WC/T already contains models for most of the important M&E phenomena identified in the PIRT. The code and model have been qualified for large pipe rupture analyses by comparison with scalable test data covering the expected range of conditions and important phenomena. The LOCA ECCS evaluation model was modified to address the LOCA M&E PIRT items (see Sections 2 and 3). The changes to the WC/T code were validated by comparison with SG test data from FLECHT. Finally, the calculated transient response from the proposed WC/T LOCA M&E release methodology was compared with the calculated transient response from the current LOCA M&E release methodology (see Sections 5 and 6).

The LOCA mass and energy release model input for the containment design basis accident analyses is biased to maximize the initial mass and energy stored in the RCS and to calculate a conservatively rapid

release rate. NUREG-0800, Section 6.2.1.3 documents an acceptable practice for the calculation of the LOCA mass and energy release input data. This document specifies that the sources of energy available for release are to be based on 10 CFR Part 50, Appendix K, paragraph I.A. A comparison of the proposed Westinghouse methodology to the review guidance provided in NUREG-0800, Section 6.2.1.3 is shown in Table 4-1. ANS 56.4-1983 also provides guidance for developing conservative input for the mass and energy release calculation in accordance with the acceptable practice documented in NUREG-0800, Section 6.2.1.3. A comparison of the proposed Westinghouse methodology to the recommendations in ANS 56.4-1983 is shown in Table 4-2.

Table 4-1 NUREG-0800, Section 6.2.1.3 Review Guidance for LOCA M&E Release Calculations

	Sources of Energy, 10 CFR 50, Appendix K, I.A	Current Westinghouse Methodology	New Westinghouse Methodology
1	*Reactor Power* – The reactor should be assumed to have been operating continuously at a power level at least 1.02 times the licensed power level (to allow for instrumentation error), with the maximum peaking factor allowed by the technical specifications. An assumed power level lower than the level specified in this paragraph (but not less than the licensed power level) may be used provided the proposed alternative value has been demonstrated to account for uncertainties due to power level instrumentation error. A range of power distribution shapes and peaking factors representing power distributions that may occur over the core lifetime must be studied. The selected combination of power distribution shape and peaking factor should be the one that results in the most severe calculated consequences for the spectrum of postulated breaks and single failures that are analyzed.		
2	*Core Stored Energy* – The steady-state temperature distribution and stored energy in the fuel before the hypothetical accident shall be calculated for the burn-up that yields the highest calculated cladding temperature (or, optionally, the highest calculated stored energy.)		
3	*Fission Heat* – Fission heat shall be calculated using reactivity and reactor kinetics. Shutdown reactivities resulting from temperatures and voids shall be given their minimum plausible values, including allowance for uncertainties, for the range of power distribution shapes and peaking factors indicated to be studied above. Rod trip and insertion may be assumed if they are calculated to occur.		

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Table 4-1 (cont.) NUREG-0800, Section 6.2.1.3 Review Guidance for LOCA M&E Release Calculations

	Sources of Energy, 10 CFR 50, Appendix K, I.A	Current Westinghouse Methodology	New Westinghouse Methodology
4	*Decay of Actinides* – The heat from the radioactive decay of actinides, including neptunium and plutonium generated during operation, as well as isotopes of uranium, shall be calculated in accordance with fuel cycle calculations and known radioactive properties. The actinide decay heat chosen shall be that appropriate for the time in the fuel cycle that yields the highest calculated fuel temperature during the LOCA.		
5	*Fission Product Decay* – The heat generation rates from radioactive decay of fission products shall be assumed to be equal to 1.2 times the values for infinite operating time in the ANS Standard. The fraction of the locally generated gamma energy that is deposited in the fuel (including the cladding) may be different from 1.0; the value used shall be justified by a suitable calculation.		
6	*Metal-Water Reaction Rate* – The rate of energy release, hydrogen generation, and cladding oxidation from the metal-water reaction shall be calculated using the Baker-Just equation. The reaction shall be assumed not to be steam limited.		

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Table 4-1 (cont.) NUREG-0800, Section 6.2.1.3 Review Guidance for LOCA M&E Release Calculations

	Sources of Energy, 10 CFR 50, Appendix K, I.A	Current Westinghouse Methodology	New Westinghouse Methodology
7	*Reactor Internals Heat Transfer* – Heat transfer from piping, vessel walls, and non-fuel internal hardware shall be taken into account.		
8	*Fuel Rod Swelling and Rupture* – The calculation of fuel rod swelling and rupture should not be considered for M&E calculations		
9	*Break Size and Location* – Containment design basis calculations should be performed for a spectrum of possible pipe breaks, sizes, and locations to assure that the worst case has been identified.		

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Table 4-1 (cont.) NUREG-0800, Section 6.2.1.3 Review Guidance for LOCA M&E Release Calculations

Sources of Energy, 10 CFR 50, Appendix K, I.A		Current Westinghouse Methodology	New Westinghouse Methodology
10	*Calculations, Sub-compartment Analysis* – The analytical approach used to compute the mass and energy release profile will be accepted if both the computer program and volume noding of the piping system are similar to those of an approved emergency core cooling system (ECCS) analysis. An alternate approach, which is also acceptable, is to assume a constant blowdown profile using the initial conditions with an acceptable choked flow correlation.		
11	*Calculations, Initial Blowdown Phase* – The initial mass of water in the reactor coolant system should be based on the reactor coolant system volume calculated for the temperature and pressure conditions assuming that the reactor has been operating continuously at a power level at least 102% times the licensed power level (to allow for instrumentation error). An assumed power level lower than the level specified (but not less than the licensed power level) may be used provided the proposed alternative value has been demonstrated to account for uncertainties due to power level instrumentation error.		
12	*Calculations, Initial Blowdown Phase* – Mass release rates should be calculated using a model that has been demonstrated to be conservative by comparison to experimental data.		

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Table 4-1 NUREG-0800, Section 6.2.1.3 Review Guidance for LOCA M&E Release Calculations (cont.)

	Sources of Energy, 10 CFR 50, Appendix K, I.A	Current Westinghouse Methodology	New Westinghouse Methodology
13	*Calculations, Initial Blowdown Phase* – Calculations of heat transfer from surfaces exposed to the primary coolant should be based on nucleate boiling heat transfer. For surfaces exposed to steam, heat transfer calculations should be based on forced convection.		
14	*Calculations, Initial Blowdown Phase* – Calculations of heat transfer from the secondary coolant to the steam generator tubes should be based on natural convection for tubes immersed in water and condensing heat transfer for tubes exposed to steam.		
15	*Calculations, Core Reflood Phase* (cold leg breaks only) – The water remaining in the vessel should be assumed to be saturated. Justification should be provided for the refill period, which is the time from the end of blowdown to the time when the emergency core cooling system (ECCS) refills the vessel lower plenum. An acceptable approach is to assume a water level at the bottom of the active core at the end of blowdown so there is no refill time.		

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Table 4-1 (cont.) NUREG-0800, Section 6.2.1.3 Review Guidance for LOCA M&E Release Calculations

Sources of Energy, 10 CFR 50, Appendix K, I.A		Current Westinghouse Methodology	New Westinghouse Methodology
16	*Calculations, Core Reflood Phase* (cold leg breaks only) – The flooding rate should be based on the ECCS operating condition from the beginning of flooding the core until the time that the core is completely quenched. The carryout fraction should be based on the FLECHT emergency core heat transfer experiments and liquid entrainment should occur until the water level is 2 feet from the top of the core. The carryout rate fraction that is acceptable is 0.05 to the 18 inch level and linearly increasing to 0.80 at the 24 inch level and held constant at 0.8 until the quench front is 2 feet from the top of the core. Above this level, 0.05 may be used.		
17	*Calculations, Core Reflood Phase* (cold leg breaks only) – The assumption of steam quenching should be justified by comparison to applicable experimental data. Liquid entrainment should consider the effect of the carryout rate fraction of the increased core inlet temperature caused by the steam quenching assumed to occur from mixing with the ECCS water.		

a,c

Table 4-1 (cont.) NUREG-0800, Section 6.2.1.3 Review Guidance for LOCA M&E Release Calculations

	Sources of Energy, 10 CFR 50, Appendix K, I.A	Current Westinghouse Methodology	New Westinghouse Methodology
18	*Calculations, Core Reflood Phase* (cold leg breaks only) – The steam leaving the steam generators should be assumed to be superheated to the temperature of the secondary coolant.		
19	*Calculations, PWR Post-Reflood Phase* – All remaining energy in the primary and the secondary systems should be removed.		

a,c

Table 4-1 (cont.) NUREG-0800, Section 6.2.1.3 Review Guidance for LOCA M&E Release Calculations

	Sources of Energy, 10 CFR 50, Appendix K, I.A	Current Westinghouse Methodology	New Westinghouse Methodology
20	*Calculations, PWR Post-Reflood Phase* – Steam quenching should be justified by comparison with applicable experimental data. The results of post-reflood analytical models should be compared to applicable experimental data.		
21	*Calculations, PWR Decay Heat Phase* – The dissipation of core decay heat should be considered during this phase of the accident. The fission product decay energy model is acceptable if it is equal to or more conservative than the decay energy model given in Branch Technical Position ASB 9-2 in SRP 9.2.5.		

a,c

Table 4-1 (cont.) NUREG-0800, Section 6.2.1.3 Review Guidance for LOCA M&E Release Calculations

Sources of Energy, 10 CFR 50, Appendix K, I.A		Current Westinghouse Methodology	New Westinghouse Methodology
22	*Calculations, PWR Decay Heat Phase* – Steam from the decay heat boiling in the core should be assumed to flow to the containment by a path which produces the minimum amount of mixing with the ECCS injection water.		

a,c

Table 4-2 ANS 56.4-1983 Recommendations

Recommendation		Current Westinghouse Methodology	New Westinghouse Methodology
1	*3.2.1.1 Reactor Coolant System Water and Metal* – The increase in the reactor coolant system volume resulting from the pressure and temperature expansion to conditions at the initial power level defined in 3.2.2.2 shall be included. Stored energy in all reactor coolant system pressure boundary and internals metal thermally in contact with the reactor coolant system water shall be included.		
2	*3.2.1.2 Steam Generator Secondary Water and Meta*l – Maximizing the steam generator secondary water inventory and metal energy is conservative. The secondary volume resulting from the pressure and temperature conditions at the initial power level defining 3.2.2.2 shall be included.		
3	*3.2.1.3 Core Stored Energy* – The core stored energy and the steady-state core-temperature distribution, adjusted for uncertainties, shall be consistent with the initial conditions and consistent with the time of fuel cycle life required in 3.2.2.1.		

a,c

Table 4-2 ANS 56.4-1983 Recommendations (cont.)

	Recommendation	Current Westinghouse Methodology	New Westinghouse Methodology
4	*3.2.1.4 Fission Heat* – Fission heat shall be conservatively calculated. Shutdown reactivities resulting from temperature and voids shall assume minimum plausible values including allowances for uncertainties; all data shall be based on their minimum values consistent with the fuel parameters which yield the maximum core stored energy. Rod trip and insertion may be assumed at the time appropriate for the transient being analyzed.		
5	*3.2.1.5 Decay of Actinides* – The heat from the radioactive decay of actinides, including neptunium and plutonium as well as isotopes of uranium generated during operation, shall be calculated in accordance with fuel cycle calculations and shall be appropriate for the time in the fuel cycle that yields the highest calculated core stored energy. The decay heat shall be the values given in American National Standard for Decay Heat Power in Light Water Reactors, ANSI/ANS-5.1-1979 for end-of-life operation time.		
6	*3.2.1.6 Fission Product Decay* – The heat generation rates from radioactive decay of fission products shall be assumed to be equal to at least the values given in ANSI/ANS-5.1-1979 for end-of-life operation time.		

a,c

Table 4-2 (cont.) ANS 56.4-1983 Recommendations

a,c

Recommendation		Current Westinghouse Methodology	New Westinghouse Methodology
7	*3.2.1.7 Metal-Water Reaction Rate* – The amount of metal-water reaction shall be calculated according to 10 CFR 50.44 and assumed to occur uniformly over a period less than 2 minutes following the end of reactor vessel blowdown.		
8	*3.2.1.8 Main Steam Lines* – Steam flow to the turbine until the main steam isolation valves or turbine stop valves are calculated to close may be included. Flow to the turbine shall be minimized. Delays and valve closure times shall be conservatively short. In lieu of this calculation, flow to the turbine may be conservatively terminated at break initiation.		
9	*3.2.1.9 Main Feedwater Line* – Main feedwater flow shall be included and shall be maximized. Delays and valve closure times used to determine the termination of flow shall be conservatively long.		
10	*3.2.1.10 Auxiliary Feedwater System* – Auxiliary feedwater flow to the steam generators may be included in the analysis if it can be determined that the system is both available and actuated. Flow rates shall be minimized. Delays in actuating the auxiliary feedwater system shall be conservatively long. Alternatively, auxiliary feedwater (AFW) flow may be conservatively assumed to be zero.		

Table 4-2 (cont.) ANS 56.4-1983 Recommendations

	Recommendation	Current Westinghouse Methodology	New Westinghouse Methodology
11	*3.2.1.11 ECCS Flow* – Flow from the ECCS shall be included. Flows and delay times shall be chosen in accordance with the single active failure consideration which results in the highest peak primary containment pressure.		
12	*3.2.1.12 Safety Injection Tank Nitrogen Expansion* – Nitrogen release to the primary containment from the safety injection tanks after the tanks have emptied shall be included in the calculation. Core heat transfer shall be included if appropriate.		
13	*3.2.2.1 Time of Life* – The time of life of the core shall be that producing the maximum energy from the combination of core stored energy and decay heat assuming power level as required in 3.2.2.2.		
14	*3.2.2.2 Power Level* – The initial power level shall be at least as high as the licensed power level plus uncertainties such as instrumentation error (typically 102 percent of the licensed power level).		

a,c

Table 4-2 ANS 56.4-1983 Recommendations (cont.)

a,c

	Recommendation	Current Westinghouse Methodology	New Westinghouse Methodology
15	*3.2.2.3 Core Inlet Temperature* – The initial core inlet temperature shall be the normal operating temperature consistent with the initial power level adjusted upward for uncertainties such as instrumentation error. The uncertainties shall be biased to result in maximizing energy releases through the break for the entire transient.		
16	*3.2.2.4 Reactor Coolant System Pressure* – The initial reactor coolant system pressure shall be at least as high as the normal operating pressure consistent with the initial power level plus uncertainties such as instrumentation error.		
17	*3.2.2.5 Steam Generator Pressure* – The initial steam generator pressure shall be at least as high as the normal operating pressure consistent with the initial power level plus uncertainties such as instrumentation error.		
18	*3.2.2.6 Reactor Coolant System Pressurizer Level* – The initial reactor coolant system pressurizer level shall be at least as high as the maximum normal operating level plus uncertainties such as instrumentation error.		

Table 4-2 (cont.) ANS 56.4-1983 Recommendations

a,c

	Recommendation	Current Westinghouse Methodology	New Westinghouse Methodology
19	*3.2.2.7 Steam Generator Water Level* – The initial steam generator water level shall be at least as high as the normal operating level consistent with the initial power level plus uncertainties such as instrumentation error.		
20	*3.2.2.8 Core Parameters* – Initial core parameters (including physics parameters, fuel properties, and gas conductivity) shall be chosen to maximize core stored energy.		
21	*3.2.2.9 Safety Injection Tanks* – The initial safety injection tank water level and temperature and nitrogen pressure shall be based on normal operating values. Uncertainties shall be biased in the direction which leads to the maximum primary containment pressure.		

Table 4-2 (cont.) ANS 56.4-1983 Recommendations

a,c

Recommendation		Current Westinghouse Methodology	New Westinghouse Methodology
22	*3.2.3 Single Active Failures* – In determining the mass and energy releases following a reactor coolant system break, the most restrictive single active failure shall be considered. The possibility that the highest peak primary containment pressure may occur for the situation where no active failure has occurred shall not be overlooked. No more than one single active failure in the safety systems, (including primary containment heat removal system; see 4.2.5) required to mitigate the consequences of the event, need to be considered.		
23	*3.2.3.2 Single Passive Failures* – Passive failures normally need not be considered.		
24	*3.2.3.3 Non-emergency Power* – The loss of non-emergency power shall be postulated if it results in circumstances (for example, delayed primary containment cooling or safety injection) which lead to higher primary containment pressures.		
25	*3.2.4.1 Nodalization* – Geometric nodalization for the various periods of the reactor coolant system break analysis need not be the same. Since low quality at the break node is conservative during blowdown because it leads to high flow rates, the reactor coolant system shall be modeled with sufficient detail so that the quality at the break location shall not be over predicted.		

Table 4-2 (cont.) ANS 56.4-1983 Recommendations

a,c

	Recommendation	Current Westinghouse Methodology	New Westinghouse Methodology
26	*3.2.4.2 Thermodynamic Conditions* – The thermodynamic state conditions for steam and water shall be described using real gas equations or industry accepted steam table in such a manner that the resultant steam and water temperature and partial steam pressure are within one percent of that which would result from use of the 1967 ASME Steam Tables with appropriate interpolation.		
27	*3.2.4.3 Flow Modeling* – The following effects may be taken into account in the flow modeling: 1) temporal change in momentum, 2) momentum convection, 3) forces due to wall friction, 4) forces due to fluid pressure, 5) forces due to gravity, 6) forces due to geometric head loss effects. If an uncertainty in a pressure loss exists, the pressure loss shall be conservatively minimized.		

Table 4-2 (cont.) ANS 56.4-1983 Recommendations

	Recommendation	Current Westinghouse Methodology	New Westinghouse Methodology
28	*3.2.4.4 Pump Characteristics* – The characteristics of the reactor coolant system pumps shall be derived from a dynamic model that includes momentum transfer between the fluid and the impeller with variable pump speed as a function of time. The pump model for the subcooled and two-phase region shall be verified by applicable subcooled and two-phase performance data. In lieu of a full dynamic pump model, any model which can be shown to be conservative by comparison with the test data or by comparison with a full dynamic pump model may be used.		
29	*3.2.4.5.1 Break Sizes* – For reactor coolant system analysis, a spectrum of possible pipe breaks shall be considered. This spectrum shall include instantaneous double-ended breaks ranging in cross-sectional area up to and including that of the largest pipe in the reactor coolant system. The break shall be defined by its location, type, and area.		

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Table 4-2 ANS 56.4-1983 Recommendations (cont.)

a,c

	Recommendation	Current Westinghouse Methodology	New Westinghouse Methodology
30	*3.2.4.5.2 Break Flow Model* – Empirical critical break flow models developed from test data may be utilized during the periods of applicability, for example, subcooled, saturated, or two-phase critical flow. Acceptable critical break flow models, when the fluid conditions are subcooled immediately upstream of the break, include the Zaloudek and Henry-Fauske models. During the period when fluid conditions immediately upstream of the break are saturated or two-phase, an acceptable model is the Moody critical flow model. The critical break flow correlations may be modified to allow for a smooth transition between subcooled and saturated flow regions. Other critical flow models may be used if justified by analysis or experimental data. The discharge coefficient applied to the critical flow correlation shall be selected to adequately bound experimental data.		
31	*3.2.4.5.3 ECCS Spillage* – In generating mass and energy release source terms from spillage for primary containment peak pressure determination, the quality shall be selected based on the partial pressure of steam in containment to maximize primary containment pressurization. For the determination of the maximum primary containment sump temperature for calculation of available NPSH, assumptions on generating mass and energy release and spillage source terms shall be biased toward maximizing the sump temperature.		

Table 4-2 (cont.) ANS 56.4-1983 Recommendations

	Recommendation	Current Westinghouse Methodology	New Westinghouse Methodology
32	*3.2.4.6.1 PWR Backpressure* – For blowdown period analysis, the primary containment backpressure is unimportant because the break flow is critical virtually throughout the blowdown period. During the reflood and post-reflood periods, the primary containment backpressure affects the resistance to the flow (steam binding) in the reactor coolant loop and, therefore, affects the rate of mass and energy release. The mass and energy releases calculation shall be coupled to the primary containment pressure calculation or a conservatively high backpressure (constant or time dependent function) shall be used.		
33	*3.2.4.7 Heat Transfer Correlations* – Heat transfer correlations shall be based on experimental data or chosen to predict conservatively high primary containment pressure.		

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Table 4-2 (cont.) **ANS 56.4-1983 Recommendations**

a,c

	Recommendation	Current Westinghouse Methodology	New Westinghouse Methodology
34	*3.2.4.8 Core Modeling* – Fission heat may be calculated using a core averaged point kinetics model which considers delayed neutrons and reactivity feedback. Shutdown reactivities resulting from temperatures and voids shall be given their minimum plausible values, including allowances for uncertainties for the range of power distribution shapes and peaking factors which result in the maximum core stored energy. Rod trip and insertion may be assumed if they are calculated to occur. Reactivity effects shall be consistent with the time of life which leads to the maximum core stored energy. For core thermal hydraulic calculations, the core shall be modeled with sufficient detail so as not to under-predict core-to-reactor coolant heat transfer. Initial core stored energy shall be maximized.		
35	*3.2.4.9 Modeling of Metal Walls* – Heat transfer from metal walls to coolant shall be calculated so as not to under-predict the rate of heat transfer relative to experimental data or the solution of the one-dimensional, time dependent heat conduction equation.		

Table 4-2 (cont.) ANS 56.4-1983 Recommendations

	Recommendation	Current Westinghouse Methodology	New Westinghouse Methodology
36	*3.2.4.10 Modeling of Auxiliary Flows* – Flows from the safety injection tanks and safety injection pumps shall be calculated assuming backpressures less than or equal to the actual pressure at the injection point. The flows shall be based on expected pump performance values. Uncertainties shall be biased in such a way as to maximize primary containment pressure. A single active failure shall be included if conservative as discussed in 3.2.3. Flows from the auxiliary feedwater system may be assumed if they are calculated to occur or they may be conservatively omitted. If flows are assumed, they shall be based on expected pump performance values. Uncertainties shall be biased to minimize flow since this is conservative. A single active failure shall be included if conservative as discussed in 3.2.3.		

a,c

Table 4-2 (cont.) ANS 56.4-1983 Recommendations

	Recommendation	Current Westinghouse Methodology	New Westinghouse Methodology
37	*3.2.4.11 Post-blowdown Modeling* – The reflood of the core following blowdown shall be calculated using a gravity-feed model which considers the pressure distribution around the primary loop. Entrainment of reflood water in the core shall be based on carry-out rate fractions based on the FLECHT or other test data. Parameters which determine the carryout rate fractions, such as core inlet temperature, linear heat rate, core pressure, core height, and core inlet velocity shall be modeled in such a way as to maximize the carryout rate fraction. The height of water in the core at which the core is reflooded shall be based on experimental data or the reflood height may be assumed to be two feet below the top of the active core. If credit for condensing of steam by ECCS water is taken, it shall be justified with experimental data.		

a,c

4.1 BIASING FOR PEAK PRESSURE/TEMPERATURE

The following changes must be made to bias a WC/T ECCS evaluation model input deck to calculate conservative LOCA M&E releases for the peak containment pressure and temperature calculation:
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[

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The following is a list of items that are not included in the LOCA M&E release calculation:
[

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4.2 BIASING FOR LONG-TERM EQ APPLICATION

The WC/T LOCA M&E model is used to calculate the break releases until both sides of the break reach saturation, i.e., there is no superheated steam release or until after the containment peak pressure is predicted to occur (whichever is longer). The DEPS and DECL cases are typically run out to at least one hour to cover the transfer to sump recirculation. The energy remaining in the RCS metal, the SG fluid, and the SG metal at the end of the WC/T calculation is inventoried and released during the long-term boil-off calculation.

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4.3 BIASING FOR MINIMUM NPSHA APPLICATION

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5 BENCHMARK COMPARISONS

This section compares the DEPS and DEHL LOCA M&E releases calculated with a modified WC/T ECCS evaluation model to benchmark results calculated with the currently approved LOCA M&E release calculation methodology. The containment response comparison is also included.

5.1 LOCA M&E MODEL DESCRIPTION

An existing WC/T 4-loop plant ECCS evaluation model was modified and used for the DEPS and DEHL LOCA benchmark comparison cases. [

]^{a,c} The steady state loop noding diagram for the modified WC/T ECCS evaluation model is shown in Figure 5-1. The modified WC/T steam generator noding diagram is shown in Figure 5-2.

The accumulator pressure, temperature, and water volume, along with the SI flow rate and temperature were modified to match the SATAN-VI benchmark model. [

]^{a,c} The initial RCS pressure, pressurizer level, and fluid and metal temperatures were adjusted to match the SATAN-VI benchmark model. [

]^{a,c} A 60 second steady state case was used to adjust the SG secondary side pressure and steam/feed flow rates to maintain the desired RCS operating conditions.

The initial stored mass and energy from the modified WC/T ECCS evaluation model are compared with the SATAN-VI benchmark model in Table 5-1. The WC/T model has a slightly higher initial RCS fluid mass and energy, but a substantially higher initial SG fluid mass and energy than SATAN-VI. [

]^{a,c} The WC/T model SG metal energy is also substantially higher than SATAN-VI. All of the initial RCS fluid energy and a small part of the RCS metal, SG metal, and SG fluid energy is released during the LOCA blowdown phase. The rest of the RCS metal, SG metal, and SG fluid energy is released later during the post-reflood and long-term decay heat removal phases of the event.

Table 5-1 Initial Steady State Mass and Energy Comparison

	WC/T Model	SATAN-VI Model
RCS Fluid Mass	574,100 lbm	567,400 lbm
RCS Fluid Energy	345 MBtu	341 MBtu
RCS Metal Energy	171 MBtu	169 MBtu
SG Secondary Fluid Mass	564,100 lbm	546,500 lbm
SG Secondary Fluid Energy	326 MBtu	309 MBtu
SG Secondary Metal Energy	127 MBtu	119 MBtu

a,c

Figure 5-1 WC/T Steady State Noding Diagram (4-Loop Plant)

a,c

Figure 5-2 WC/T Steam Generator Noding Structure for LOCA M&E

5.2 CONTAINMENT MODEL DESCRIPTION

The GOTHIC containment model input is based on the COCO containment model from the benchmark analysis case. This model represents a PWR large dry containment with a net free volume of 2.76×10^6 ft^3. Twenty passive heat sinks are modeled. The active containment heat removal system includes 2 spray pumps, 5 service water cooled fan coolers, and 2 RHR cooling loops; however, only one electrical train of active containment heat removal is assumed to be in operation. This leaves only 1 spray pump, 2 fan coolers, and 1 RHR pump in service. The low-head RHR pump switches from the injection mode to the sump recirculation mode after the RWST reaches the low-2 level setpoint. The spray pump continues to draw from the RWST until the level reaches the low-3 setpoint. After this, the spray pump suction is transferred from the RWST to the sump to provide recirculation spray.

The GOTHIC containment model was developed following a methodology which is based on previously approved topical reports. The containment model noding diagram is shown in Figure 5-3 and the key containment model input is given in Tables 5-2 and 5-3. [

]^{a,c} The fan cooler heat removal rate is input as a function of the containment saturation temperature as shown in Figure 5-4. [
]^{a,c}

The GOTHIC containment model runs in parallel with the WC/T LOCA M&E release model to calculate the containment response during the blowdown, refill, reflood, and post-reflood phase of the LOCA event. The GOTHIC containment model is used to calculate both the M&E releases and containment response for the long-term decay heat removal phase.

Table 5-2 Key Containment Model Input Values	
Description	**GOTHIC Model**
Containment Data	
Noding Structure	Single lumped
Volume	2,758,000 ft^3
Height	100 ft
Pool Area	27,580 ft^2
Heat Sink Geometry – See Table 5-3	
Heat Transfer Coefficients – LOCA	Tagami+Uchida
Initial Conditions	
Initial Pressure	15.7 psia
Initial Temperature	120°F
Initial Humidity	20%RH
Boundary Conditions	
Break Flow Phase Separation	Liquid released as drops during blowdown phase
Accumulator Nitrogen Release	Modeled for LOCA
Fan Cooler Initiation	29.7 psia with a 60 second delay
Fan Cooler Heat Removal Rate (Btu/s)	See Figure 5-4
Spray Flow Initiation	44.7 psia with a 30 second delay
Spray Flow Rate	359 lbm/s per pump
Spray Flow Termination	Low-3 RWST Level (5,000 ft^3 remaining)
LOCA Sump Recirculation Modeling	
Transfer to ECCS Recirculation	Low-2 RWST Level (24,530 ft^3 remaining)
RHR Flow Rate	1,000 gpm
RHR Heat Exchanger UA (Btu/hr-F)	Code calculated for the HX type using flow area, D_h and HTA
CCW Flow Rate	5,000 gpm
CCW Heat Exchanger UA (Btu/hr-F)	Code calculated for the HX type using flow area, D_h and HTA
Other CCW Heat Loads	6.8 MBtu/hr
Service Water Flow Rate	690.6 lbm/s
Service Water Temperature	1,000°F

Table 5-3 Heat Sink Geometry

	Area (ft^2)	Sides	Paint (in)	SS Steel (in)	CS Steel (in)	Air (in)	Concrete (in)	Total (in)
Containment Cylinder	72,740	1	0.01		0.2496	0.017	9	9.2766
Containment Dome	17,550	1	0.01		0.2496	0.017	9	9.2766
Unlined Concrete	16,000	1					9	9
SS Lined Concrete	848	1		0.498		0.017	9	9.515
Unlined Concrete	4,803	1					12	12
CS Lined Concrete	7,702	1	0.01		0.9192	0.017	9	9.9462
Painted Steel Lining	422.3	1	0.01		0.75			0.76
Unlined Concrete	69,540	1					9	9
CS Lined Concrete	3,852	1	0.01		0.048	0.017	9	9.075
CS Lined Concrete	1,571	1	0.01		0.852	0.017	9	9.879
SS Lined Concrete	2,129	1		0.828		0.017	9	9.845
Misc. Steel Plate	19,790	1	0.01		0.5			0.51
Misc. Steel Plate	94,670	1	0.01		0.25			0.26
Polar Crane	14,090	1	0.01		0.912			0.922
Misc. Steel Plate	21,880	1	0.01		0.48			0.49
Misc. Steel Plate	22,530	1	0.01		0.18			0.19
Cable/Conduit Trays	27,095	1	0.01		0.125			0.135
Supports	6,385	1	0.01		0.098			0.108
Misc. Steel Plate	69,860	1	0.01		0.188			0.198
Lined Concrete	9,291	1		0.198		0.017	9	9.215

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Figure 5-3 GOTHIC Containment Model Noding Diagram

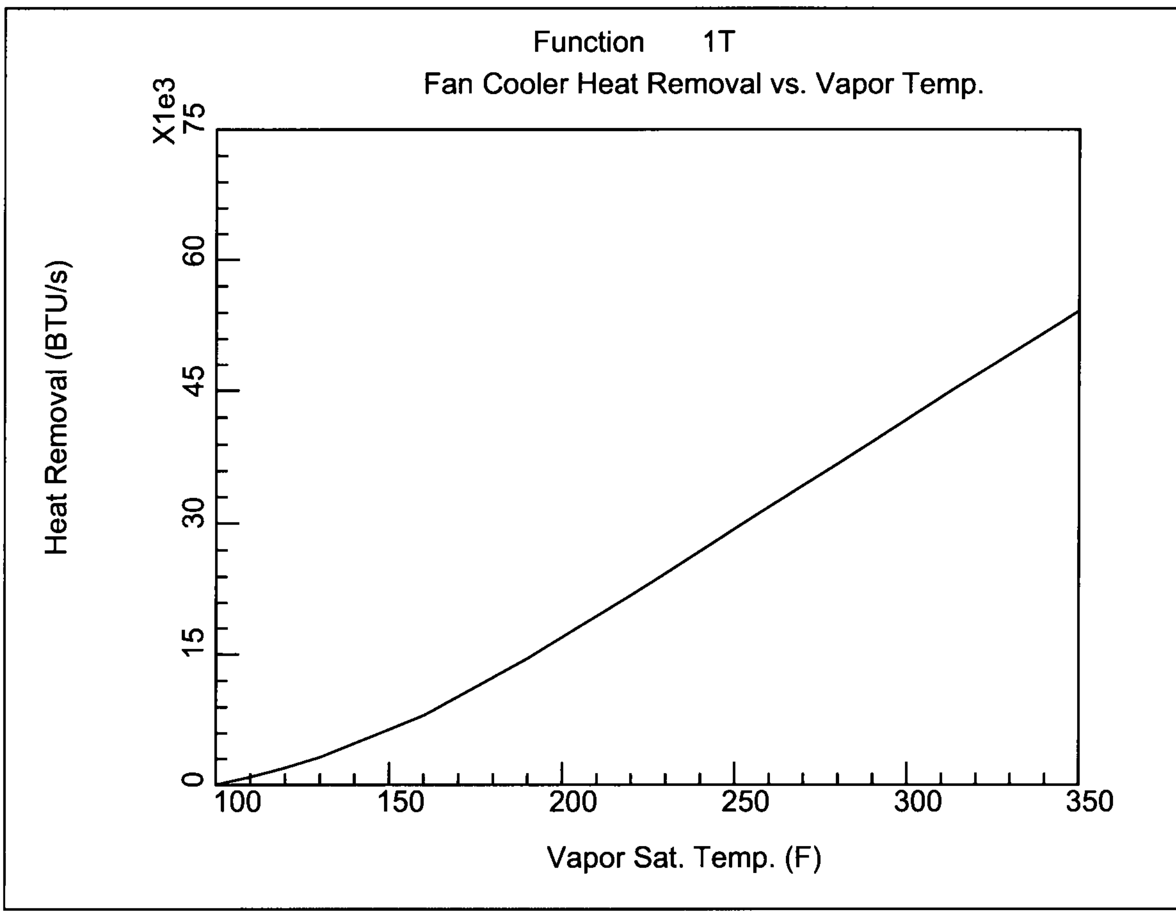

Figure 5-4 Fan Cooler Heat Removal Curve

5.3 DEPS LOCA BENCHMARK CASE RESULTS COMPARISON

The DEPS break is located in the pressurizer loop in both the WC/T and SATAN-VI models. [

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The WC/T DEPS LOCA case was run for at least 2,500 seconds to allow the M&E release and containment response results to be compared with the WCAP-10325-P-A (Reference 2) benchmark case through sump recirculation. The integrated blowdown break mass and energy release comparison is shown in Figures 5-5 and 5-6. The WC/T model calculates a similar blowdown break mass and energy release. The integrated long-term mass and energy release comparison is shown in Figure 5-7 and 5-8. The integrated long-term mass release comparison shows a difference starting at about 1,100 seconds because the benchmark model simulates a transfer to recirculation at that time; recirculation did not start until later (about 1,400 seconds) in the WC/T model. The WC/T model calculates a lower long-term break energy release than the benchmark model. The lower long-term break energy release rate is due to the improved modeling of the SG quench and RCS metal heat removal in the WC/T model. The effect of the lower metal and SG energy release rates on the GOTHIC calculated containment pressure and temperature is shown in Figures 5-9 through 5-14. The blowdown peak pressure and temperature are about the same because the energy release rate is the same. However, because the WC/T long-term energy release rate is much lower, the long-term peak containment pressure and temperature are more than 10 psi and 30°F lower than those predicted using the current WCAP-10325-P-A LOCA M&E release model.

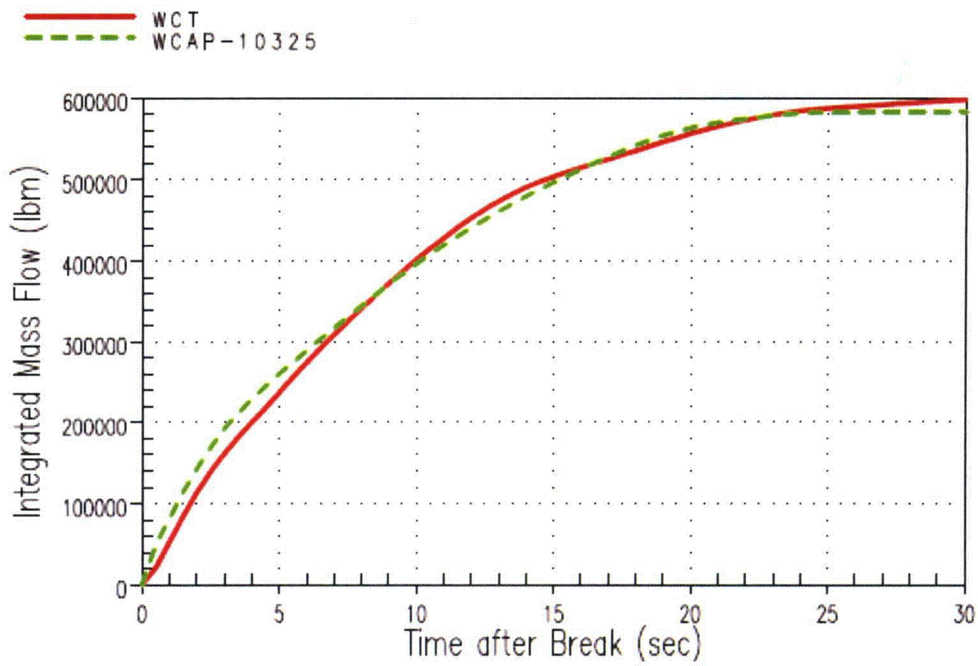

Figure 5-5 Integrated Blowdown Break Mass Release Comparison

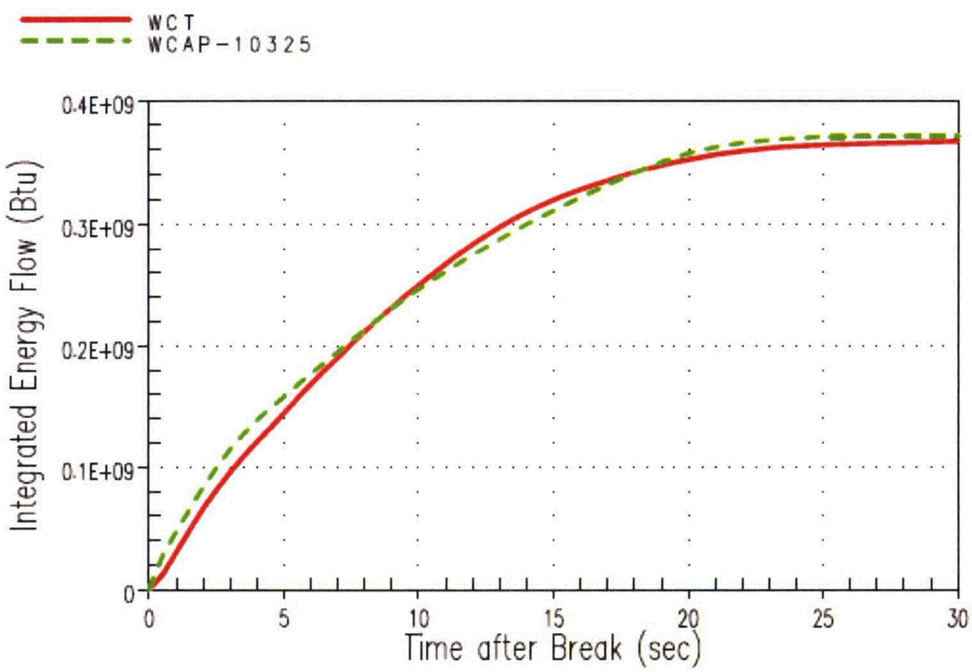

Figure 5-6 Integrated Blowdown Break Energy Release Comparison

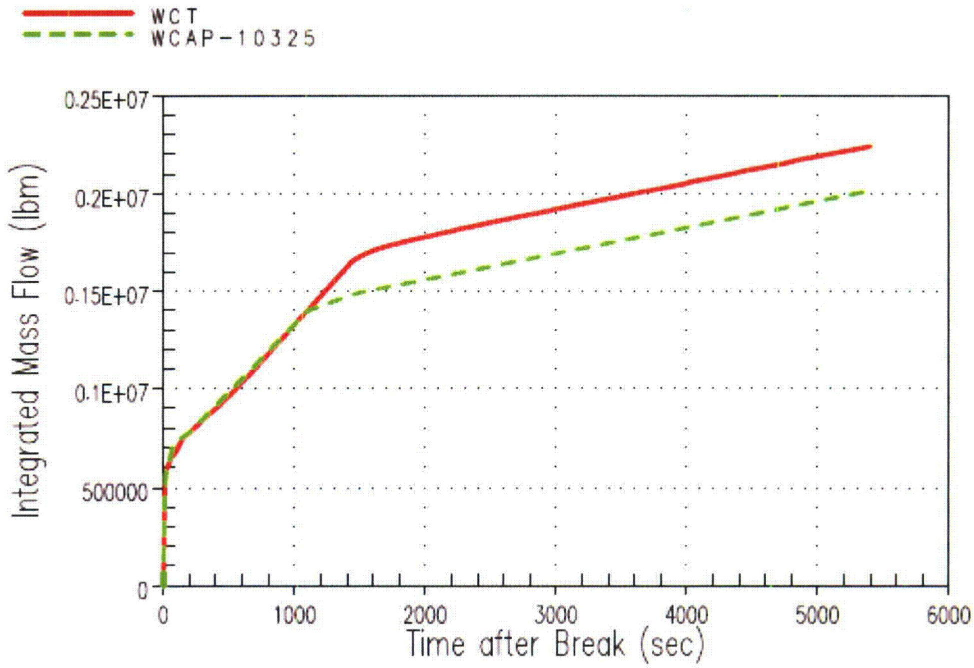

Figure 5-7 Integrated Long-term Break Mass Release Comparison

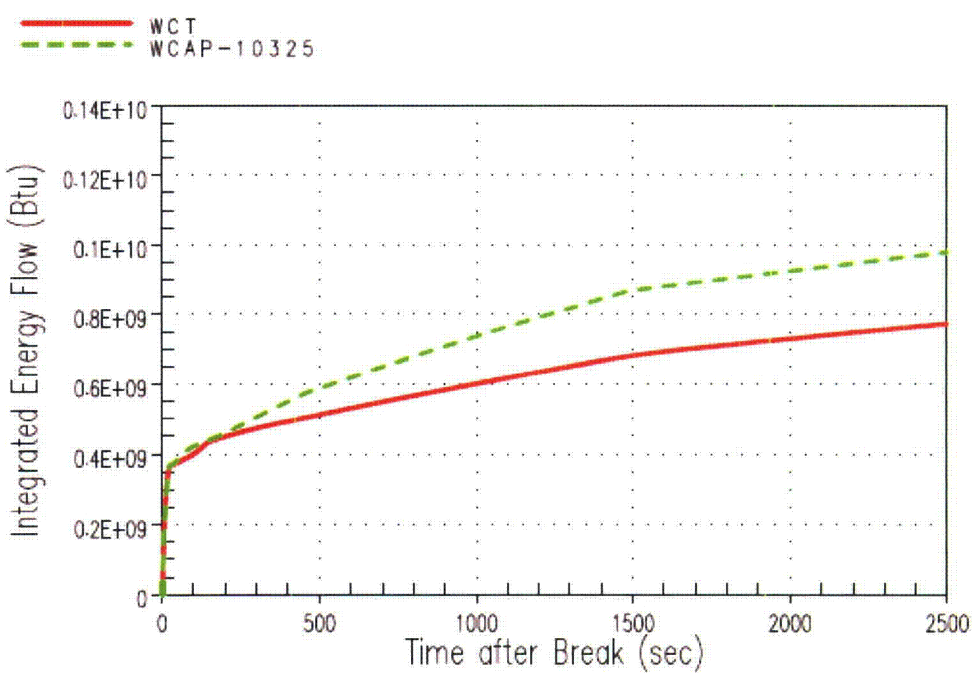

Figure 5-8 Integrated Long-term Break Energy Release Comparison

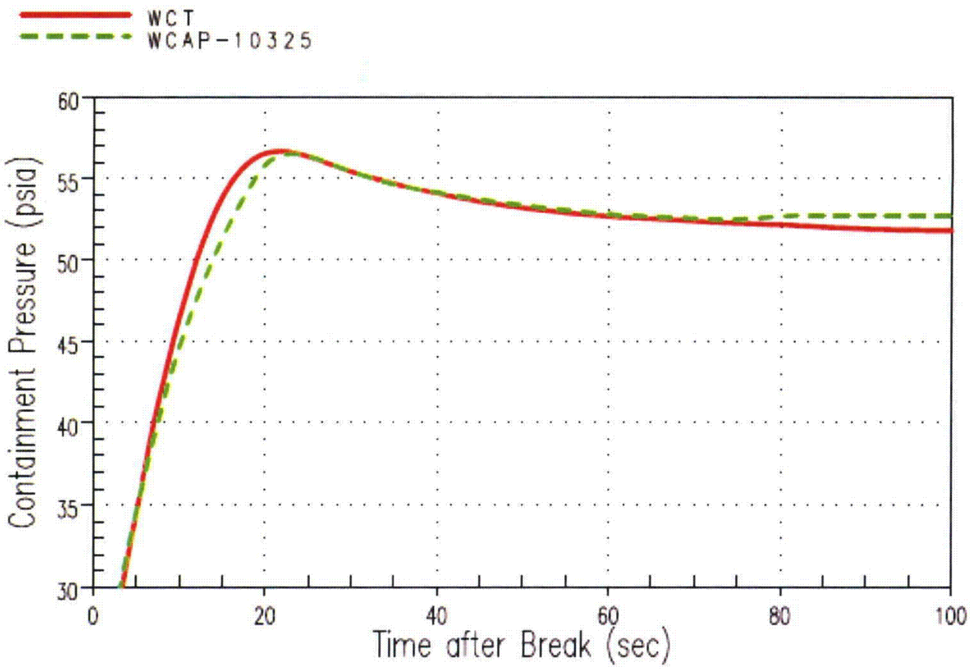

Figure 5-9 Blowdown Containment Pressure Comparison

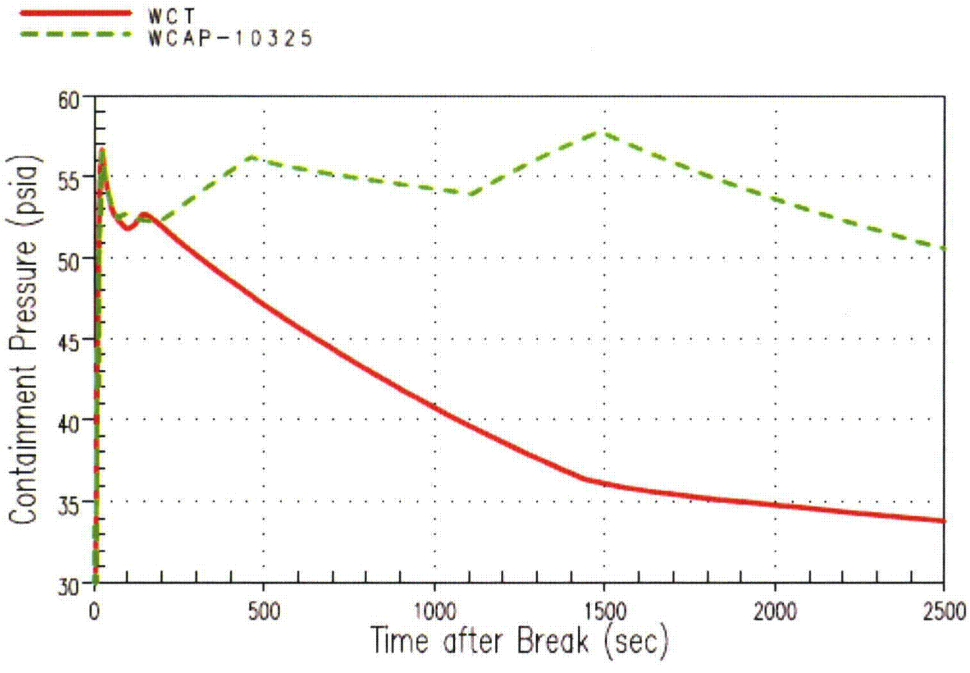

Figure 5-10 Long-term Containment Pressure Comparison

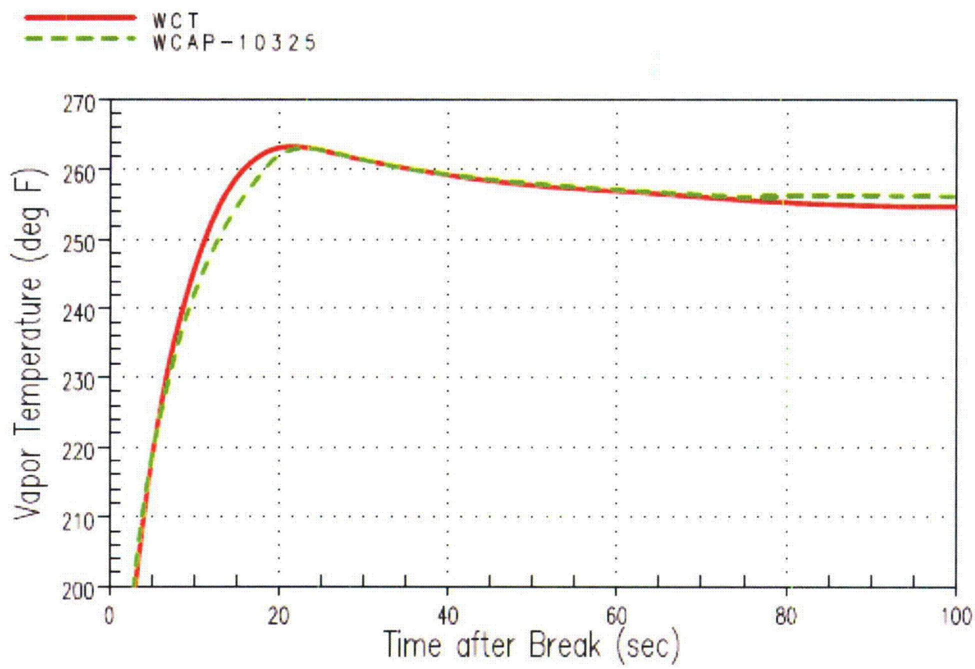

Figure 5-11 Blowdown Containment Vapor Temperature Comparison

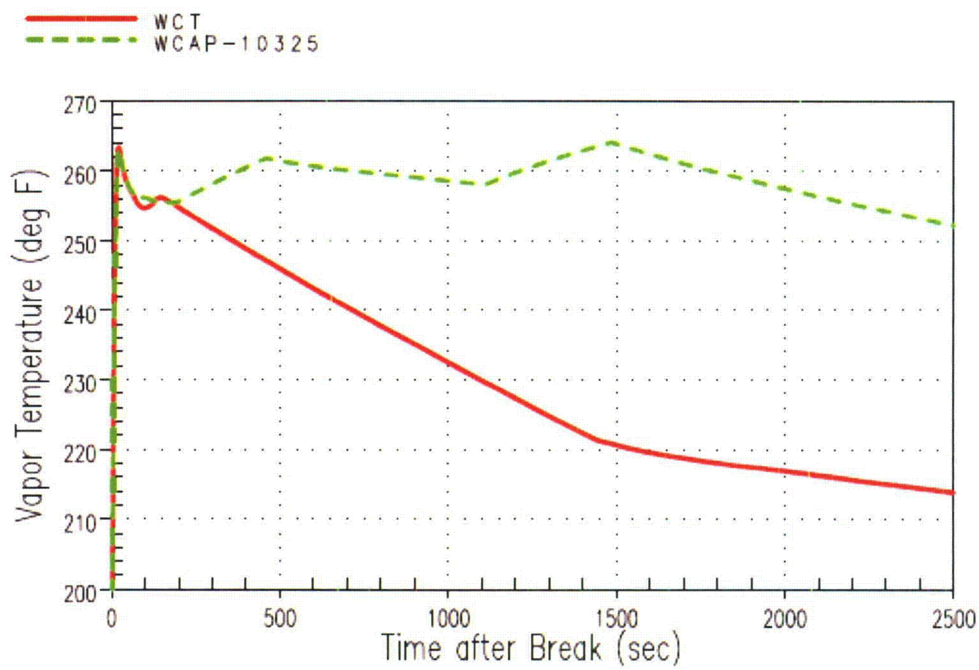

Figure 5-12 Long-term Containment Vapor Temperature Comparison

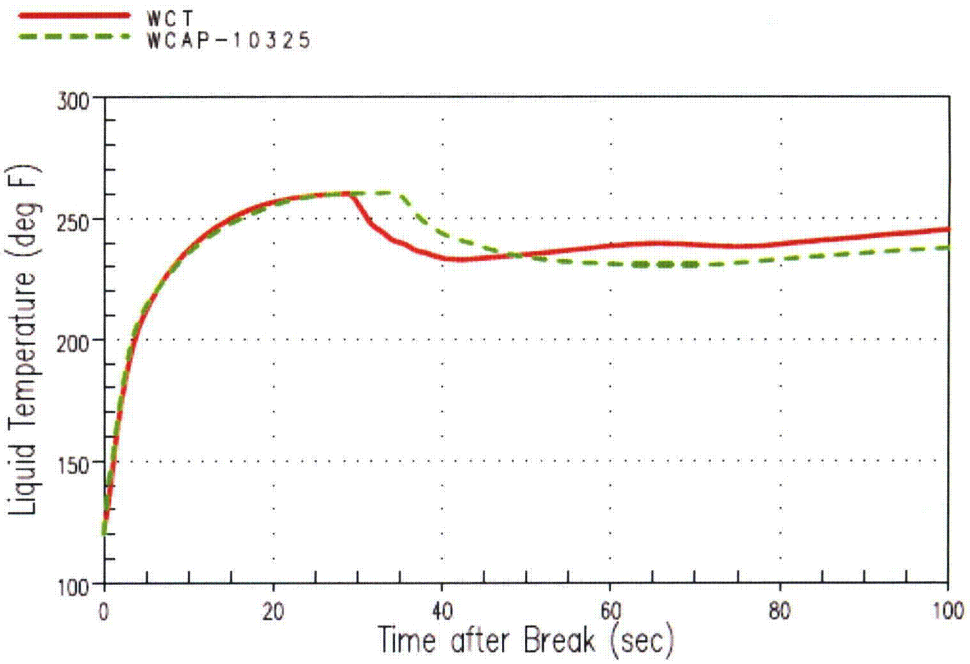

Figure 5-13 Blowdown Containment Sump Temperature Comparison

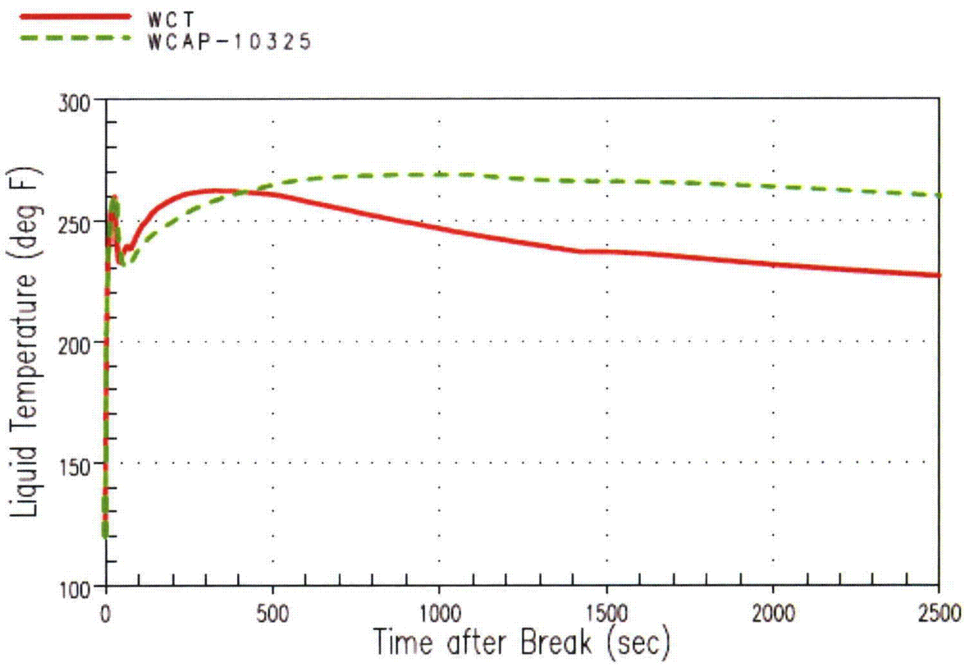

Figure 5-14 Long-term Containment Sump Temperature Comparison

5.4 DEHL LOCA BENCHMARK CASE RESULTS COMPARISON

The DEHL break is located in the pressurizer loop in both the WC/T and SATAN-VI models. [

]a,c

The WC/T DEHL LOCA case was run for at least 25 seconds to allow the M&E release and containment response results to be compared with the WCAP-10325-P-A benchmark case. The integrated break mass and energy release comparison is shown in Figures 5-15 and 5-16. The WC/T model calculates a similar blowdown break mass and energy release. The containment response comparison is shown in Figures 5-17 through 5-19. The blowdown peak pressure and temperature are about the same because the energy release rate is nearly the same.

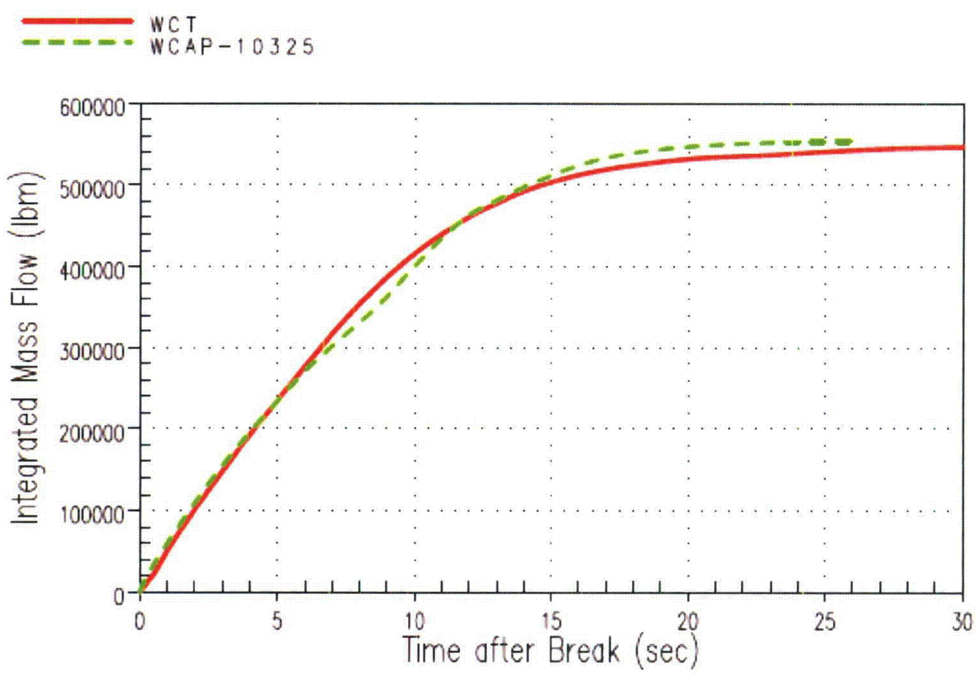

Figure 5-15 Integrated Break Flow Rate Comparison

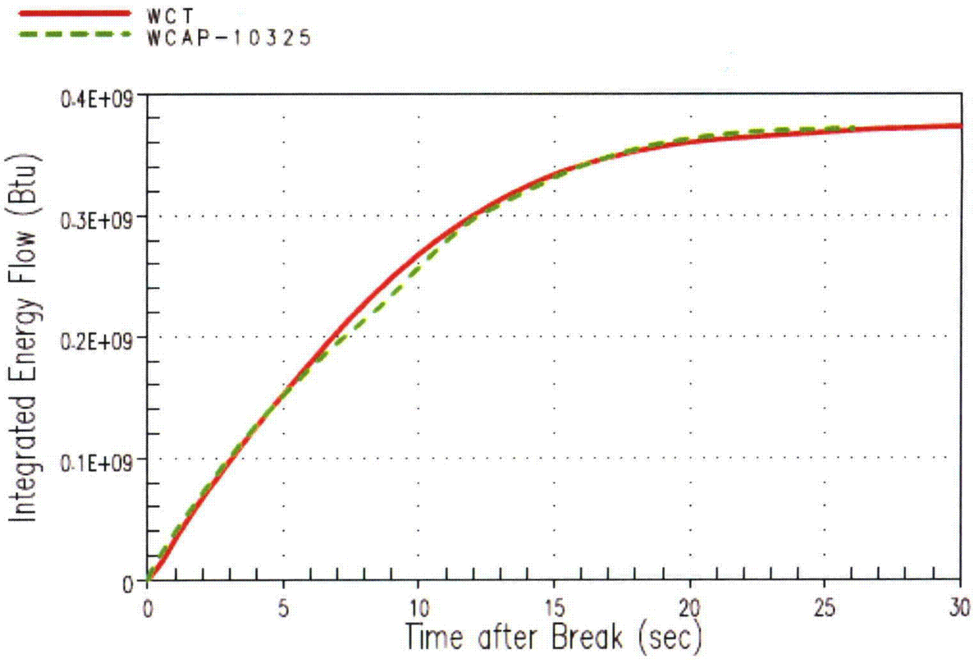

Figure 5-16 Integrated Break Energy Release Rate Comparison

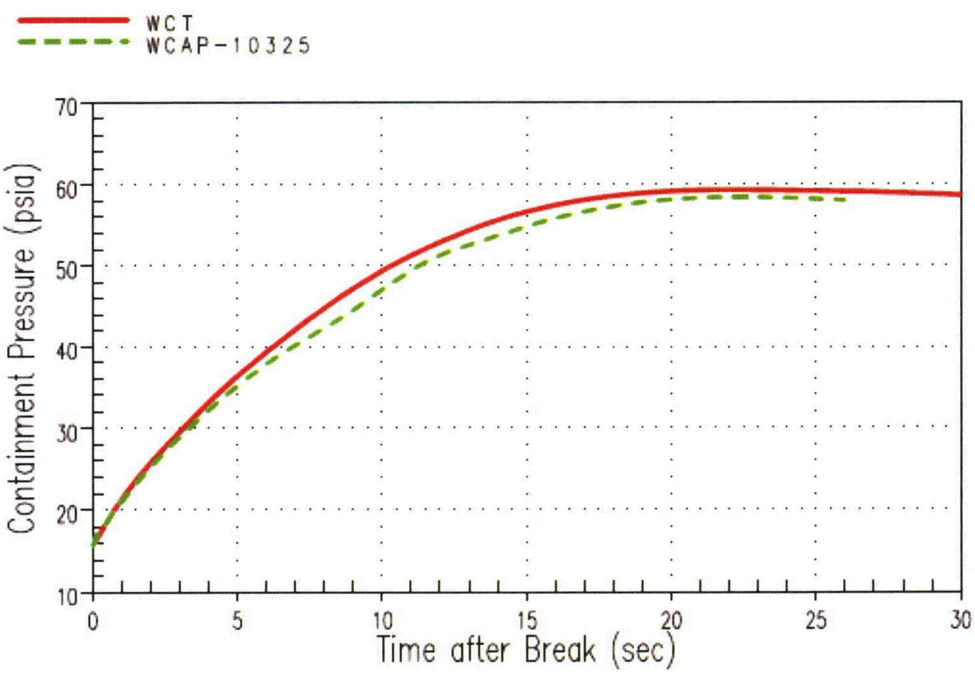

Figure 5-17 Containment Pressure Comparison

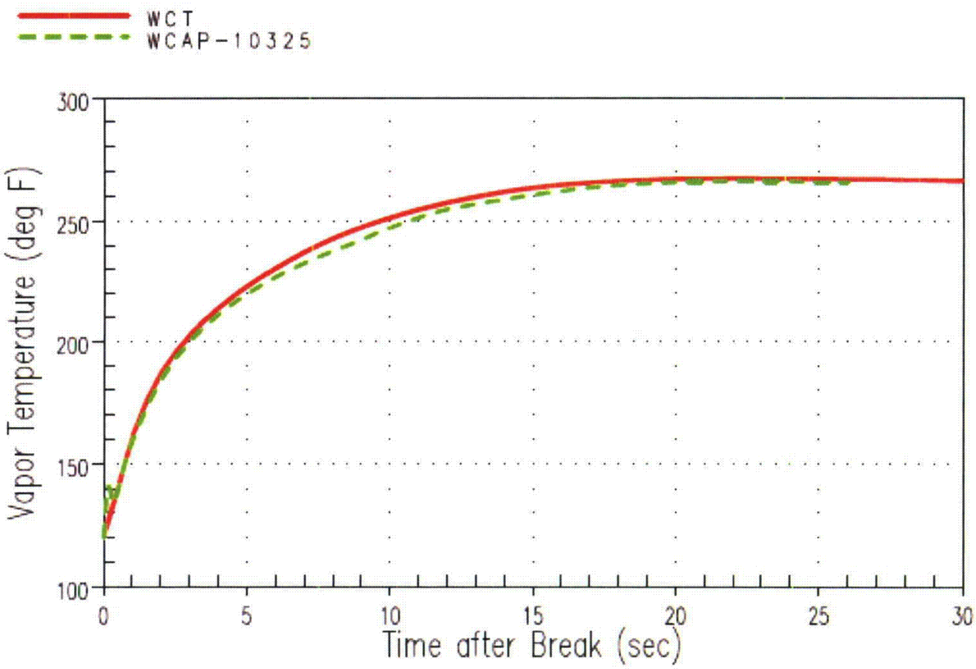

Figure 5-18 Containment Temperature Comparison

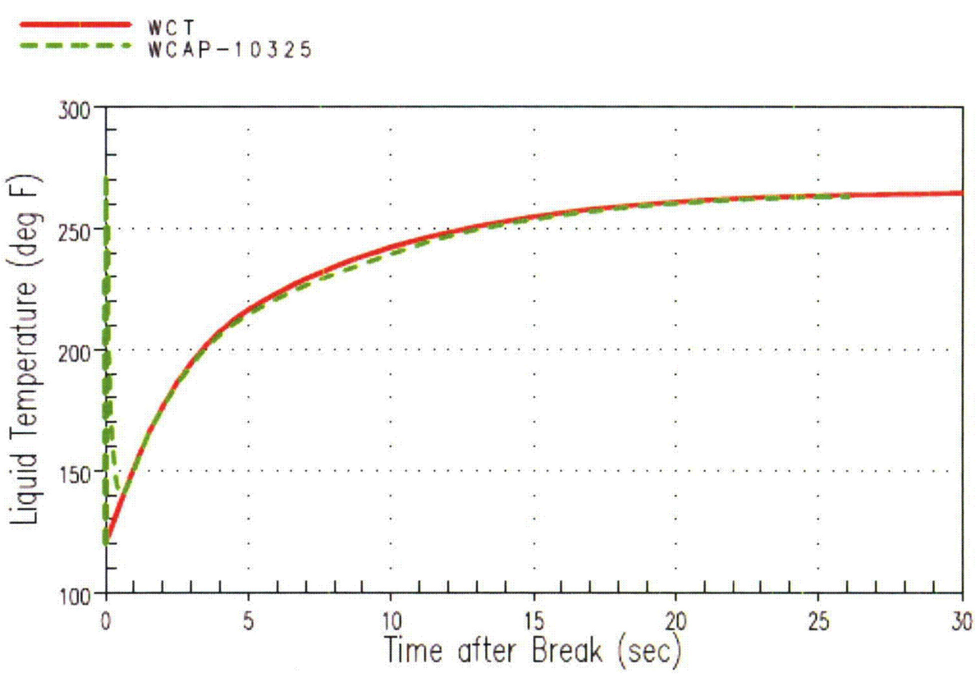

Figure 5-19 Containment Sump Temperature Comparison

6 SAMPLE CASES

The WC/T LOCA M&E release and containment model described in Section 5 was used to produce sample transient cases for the containment peak pressure/temperature application, the long-term equipment qualification (EQ) application, and the minimum net positive suction head available (NPSHa) application. This section provides the results from these sample cases.

6.1 PEAK CONTAINMENT PRESSURE/TEMPERATURE

LOCA M&E releases for the peak containment pressure/temperature application were generated for the DEPS, DEHL, and DECL LOCA events. [

]a,c

The containment pressure, temperature, and sump temperature for the three cases are compared in Figures 6-1 through 6-6. The peak pressure and temperature occur during blowdown for all three cases; the DEHL case peak pressure is highest, but the DECL case pressure peaks first and is slightly higher than the DEPS case. The containment pressure for the DEPS case increases between 100 and 200 seconds as steam produced during the core reflood process, along with energy from the broken loop steam generator, is added to the containment. In the long-term, the containment pressure and temperature remain higher for the DECL and DEPS cases due to the addition of the SG secondary energy to the break flow from the SG side of the break.

The blowdown break mass flow and energy release rates are compared in Figures 6-7 and 6-8. The DECL break flow and energy release rates are much higher than the others during the first 2 seconds. This explains why the containment pressure peaks first for the DECL case. Figure 6-9 compares the average blowdown break enthalpy. The average break enthalpy for the DEHL case is higher than the others because the release is mostly steam; this causes the initial containment pressure for this case to be higher than the others.

[

]a,c

[

]a,c

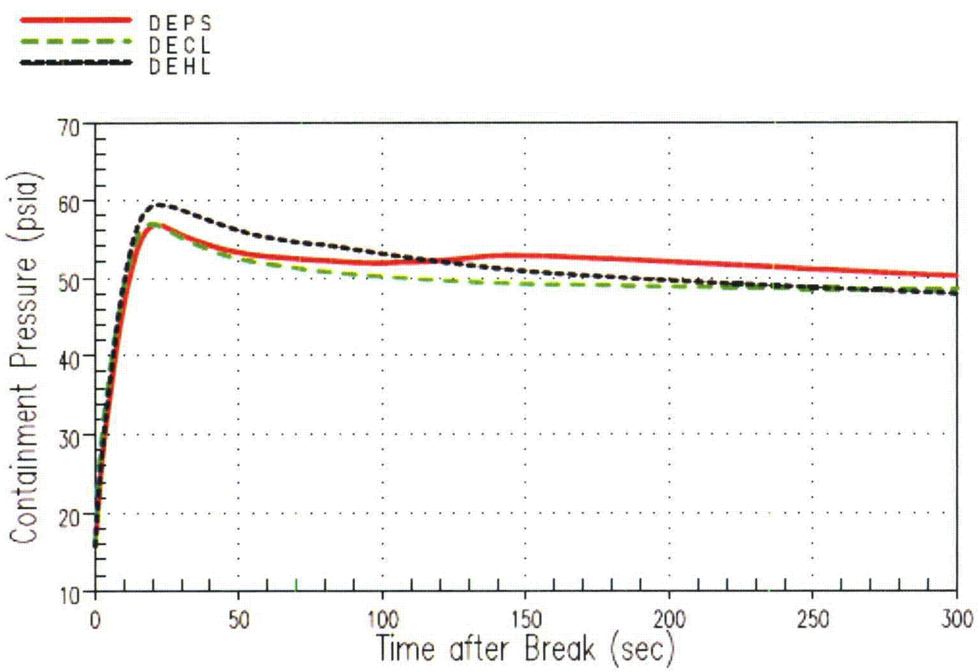

Figure 6-1 Peak Containment Pressure Comparison

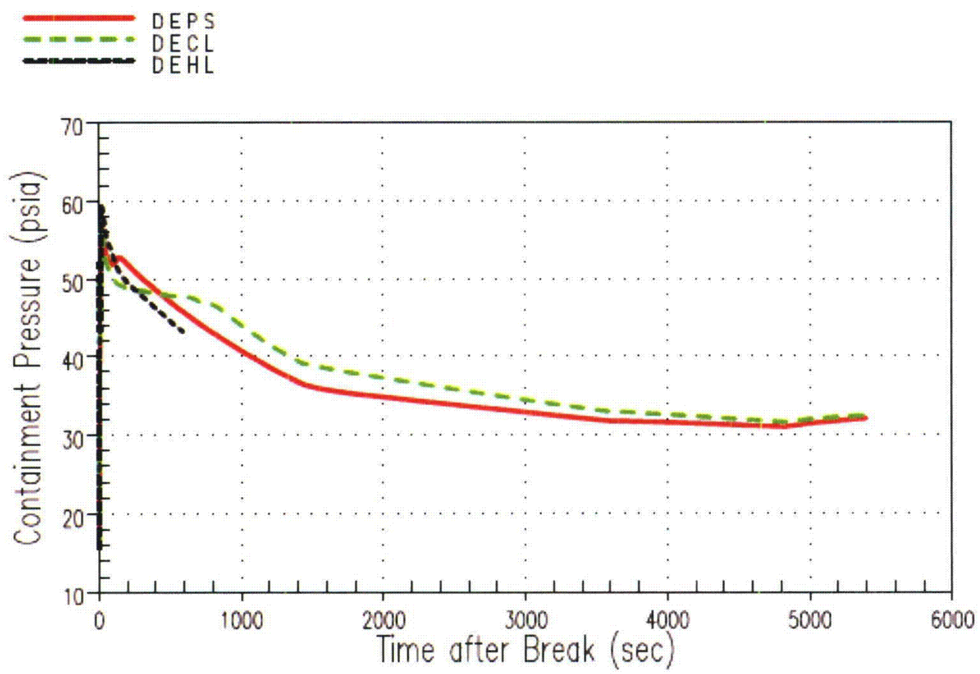

Figure 6-2 Long-term Containment Pressure Comparison

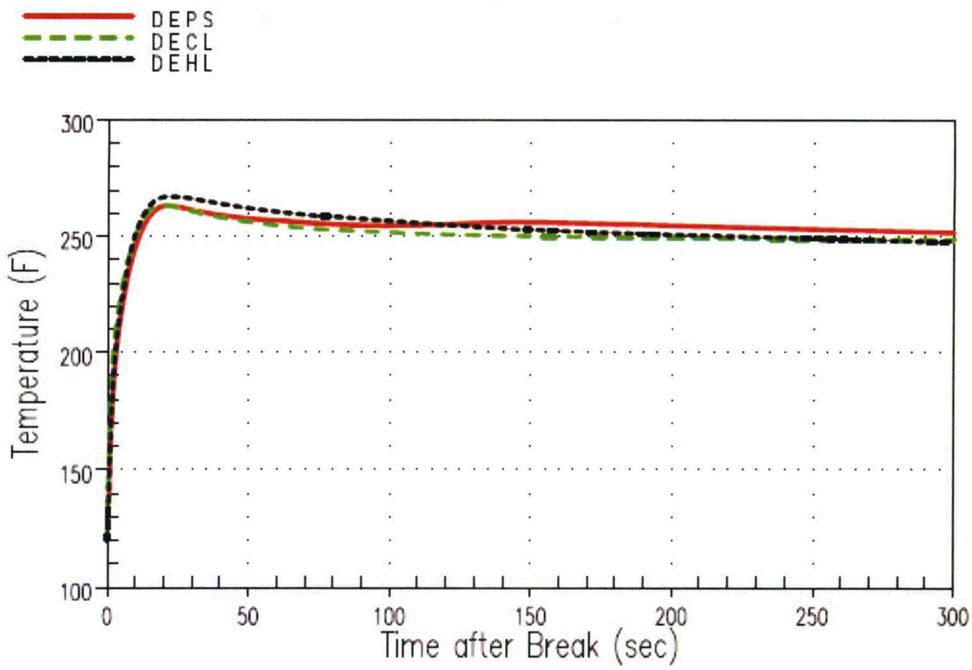

Figure 6-3 Peak Containment Temperature Comparison

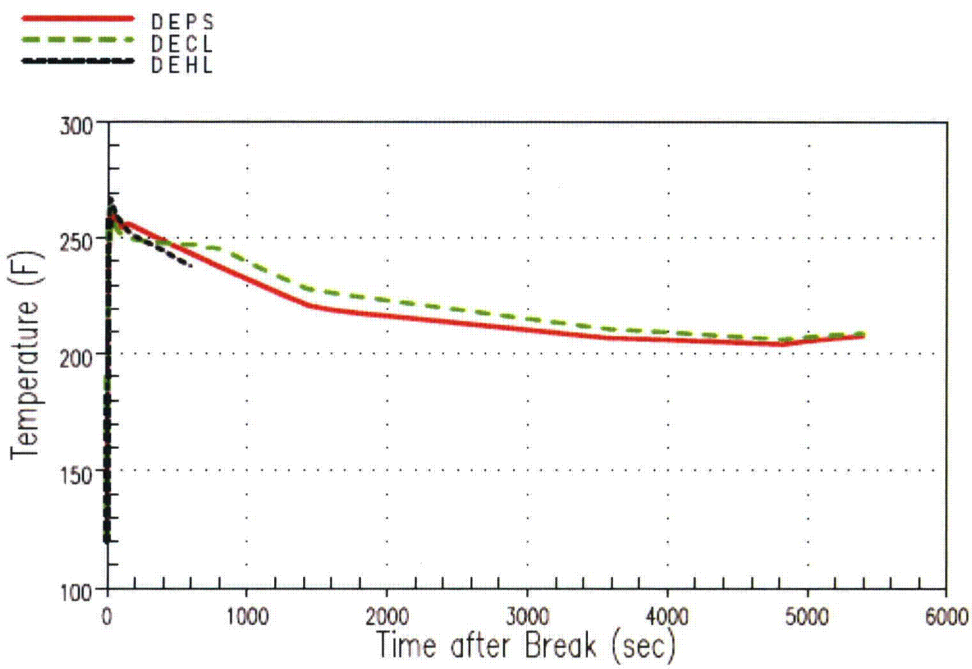

Figure 6-4 Long-term Containment Temperature Comparison

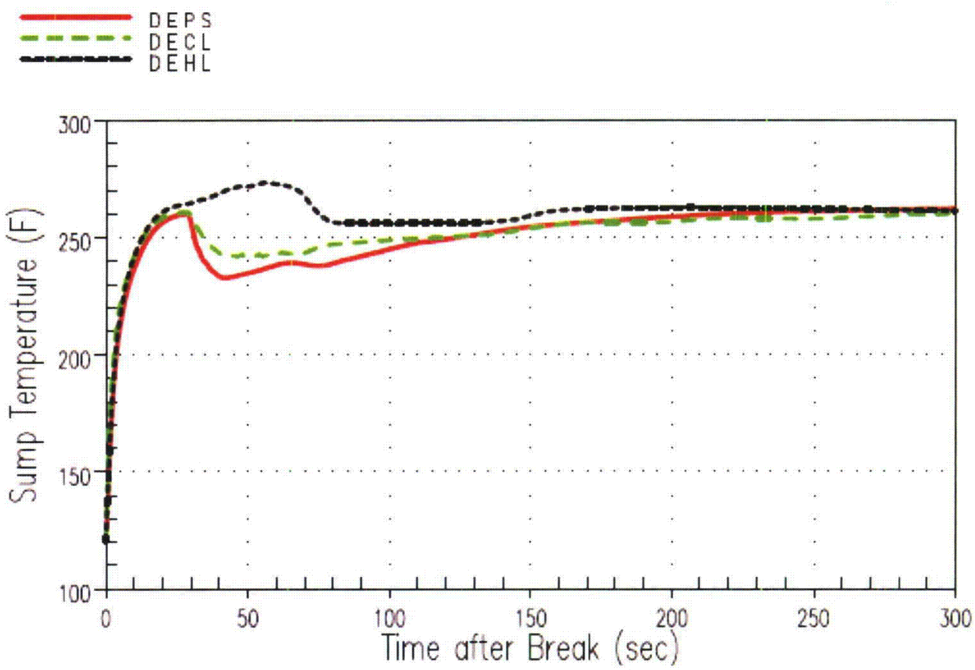

Figure 6-5 Peak Sump Temperature Comparison

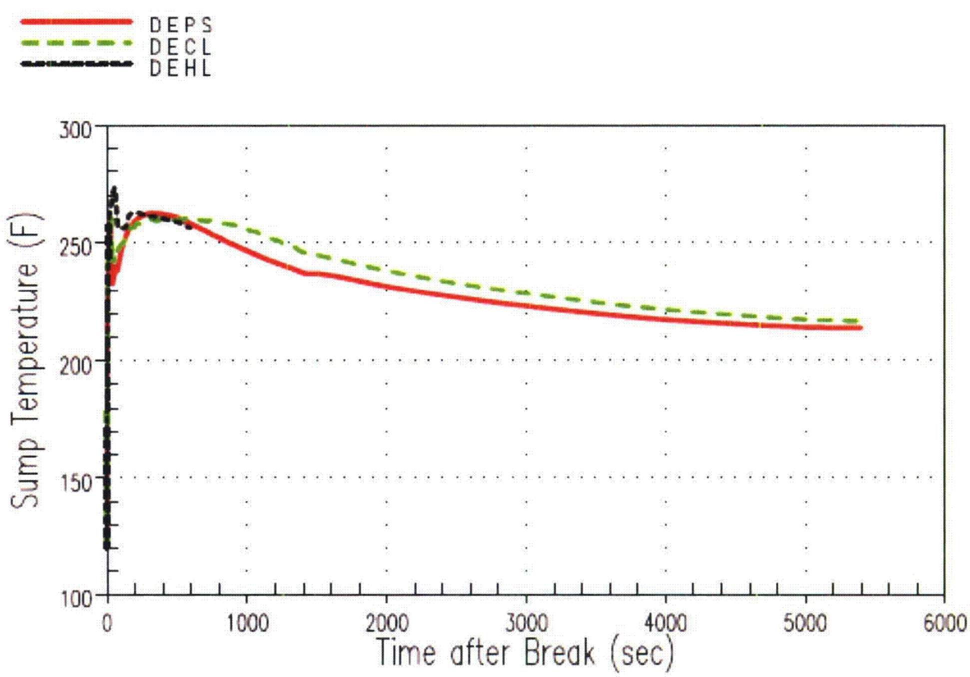

Figure 6-6 Long-term Sump Temperature Comparison

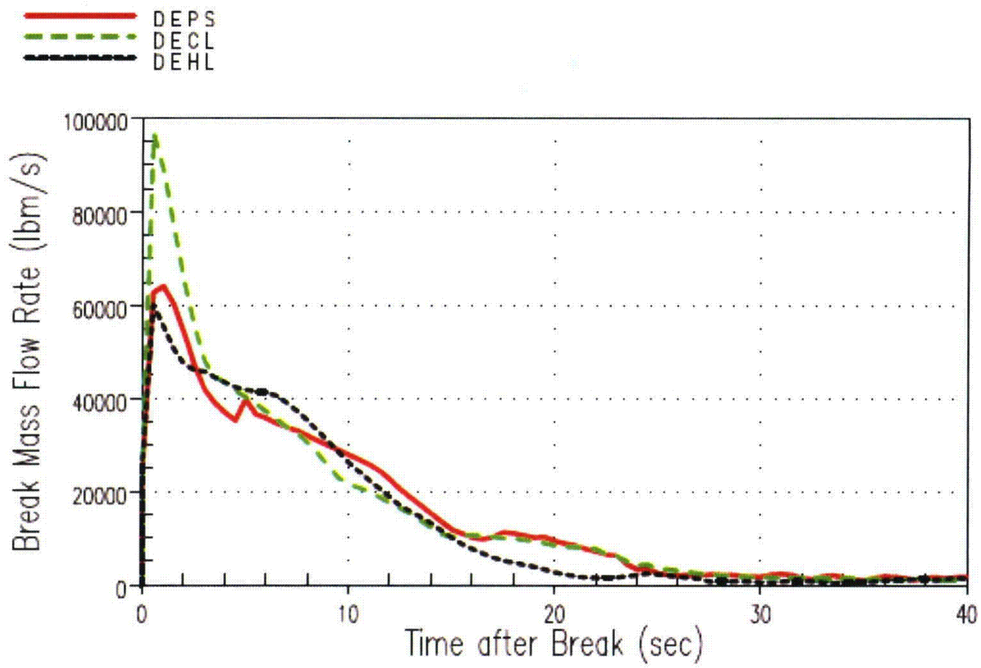

Figure 6-7 Blowdown Break Mass Flow Rate Comparison

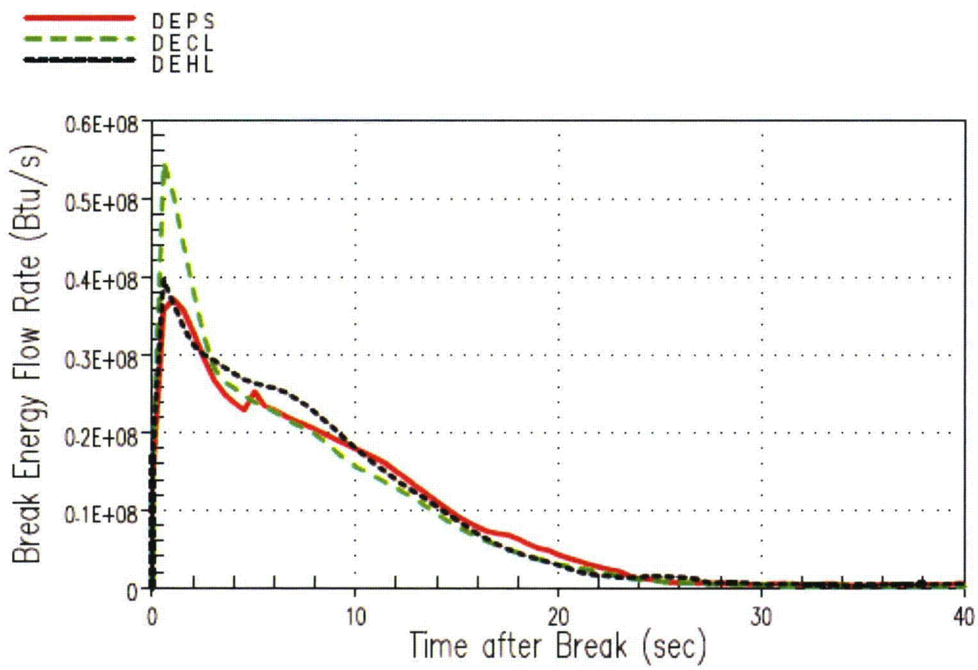

Figure 6-8 Blowdown Break Energy Flow Rate Comparison

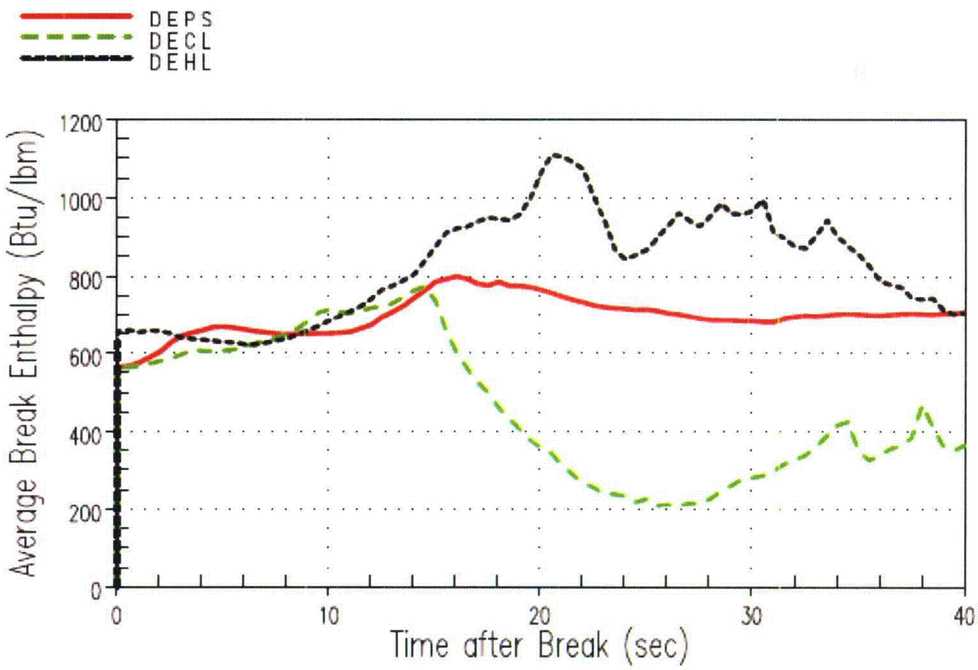

Figure 6-9 Blowdown Break Enthalpy Comparison

6.2 LONG-TERM EQ

As described in Section 4.2, the long-term LOCA steam release rate is maximized for the long-term EQ analysis. This increases the calculated containment pressure and temperature.

The long-term EQ mass and energy releases for the DEPS LOCA are shown in Figures 6-10 and 6-11. The recirculation flow rate was held constant at approximately 1,000 gpm. The steam mass and energy release rate decreased as the core decay, SG fluid, SG metal, and RCS metal energy release rates decreased. The containment pressure, temperature, and sump temperature response are shown in Figures 6-12 through 6-14. The containment pressure and temperatures decreased as the steam mass and energy release rate decreased.

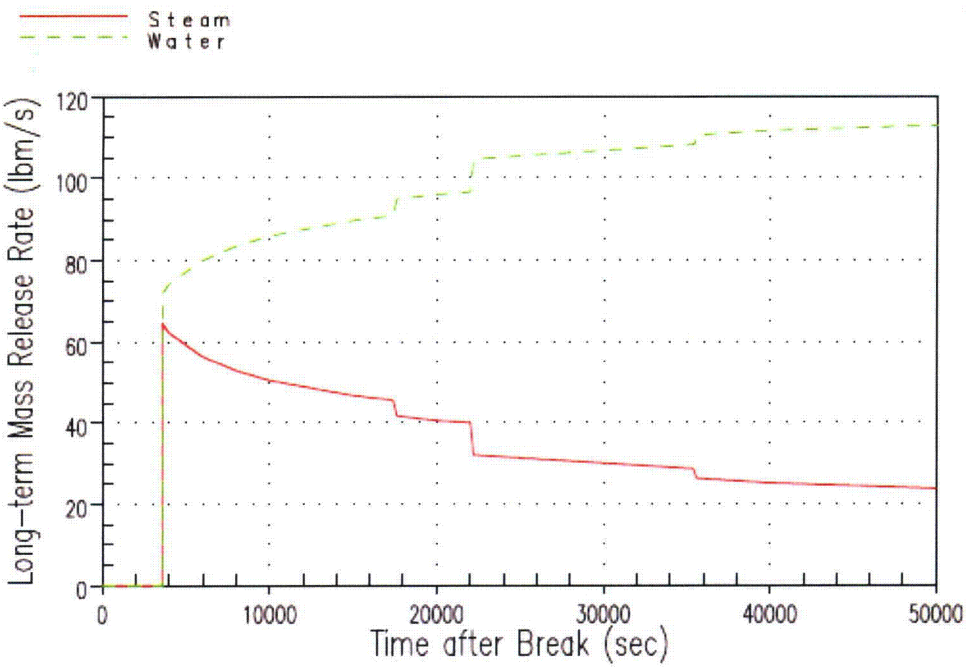

Figure 6-10 Long-term EQ Break Flow Rate

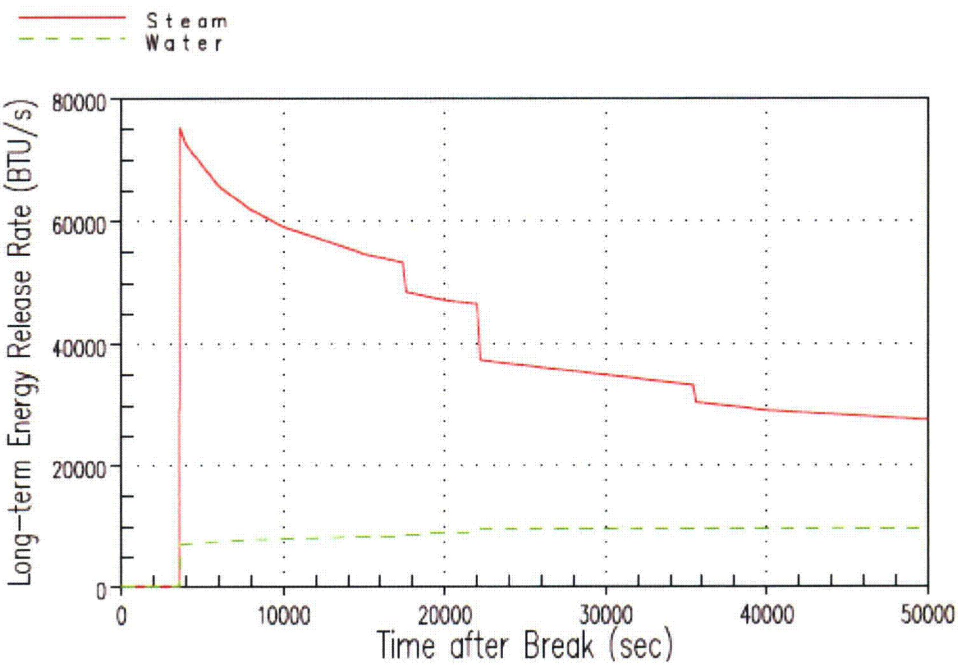

Figure 6-11 Long-term EQ Break Energy Flow Rate

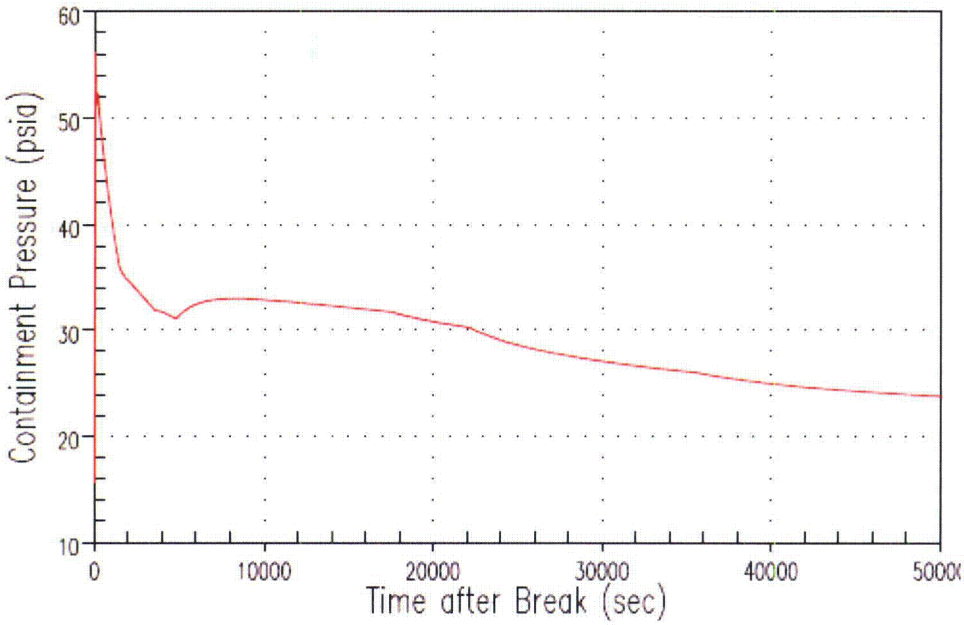

Figure 6-12 Long-term EQ Containment Pressure

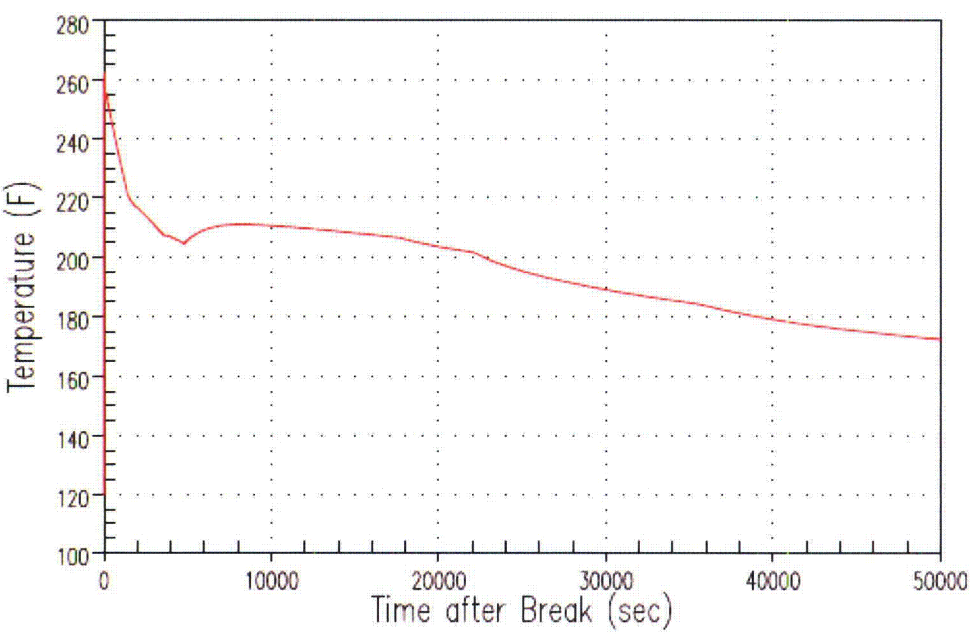

Figure 6-13 Long-term EQ Containment Temperature

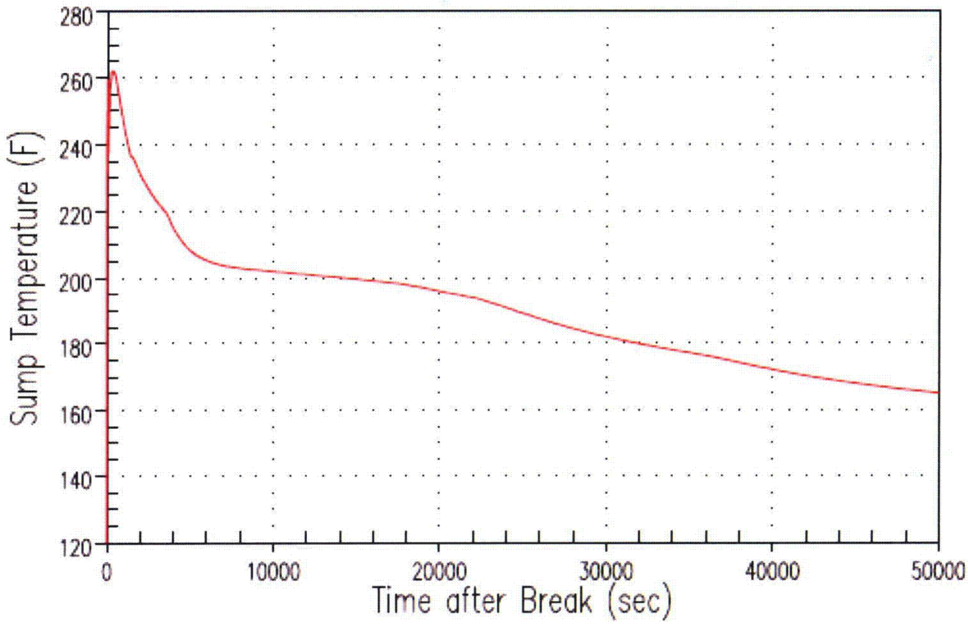

Figure 6-14 Long-term EQ Containment Sump Temperature

6.3 MINIMUM NPSHA

As described in Section 4.3, the LOCA steam release rate is minimized for the minimum NPSHa analysis. This reduces the containment backpressure and increases the containment sump temperature.

The minimum NPSHa mass and energy releases for the DEPS LOCA are shown in Figures 6-15 and 6-16. The recirculation flow rate was held constant at approximately 1,000 gpm. The steam mass flow rate was lower and the liquid mass flow rate was higher when compared with the long-term EQ sample case results. The energy release rate decreased as the core decay, SG fluid, SG metal, and RCS metal energy release rates decreased. The containment pressure, temperature, and sump temperature response are shown in Figures 6-17 through 6-19. The containment pressure and temperature were slightly lower and the sump temperature was higher when compared with the long-term EQ sample case results.

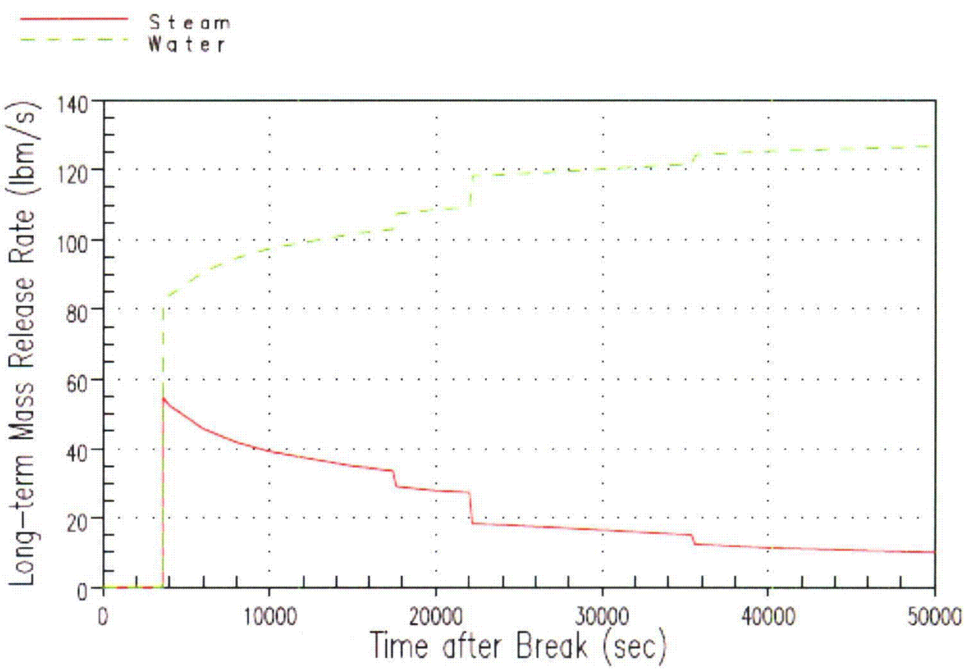

Figure 6-15 Minimum NPSHa Break Flow Rate

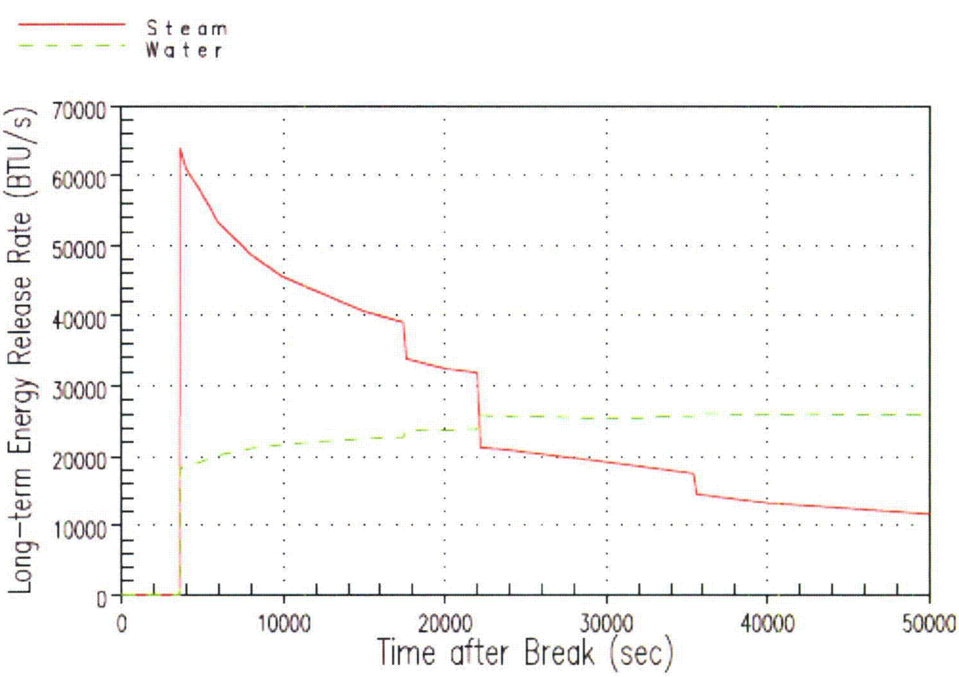

Figure 6-16 Minimum NPSHa Break Energy Flow Rate

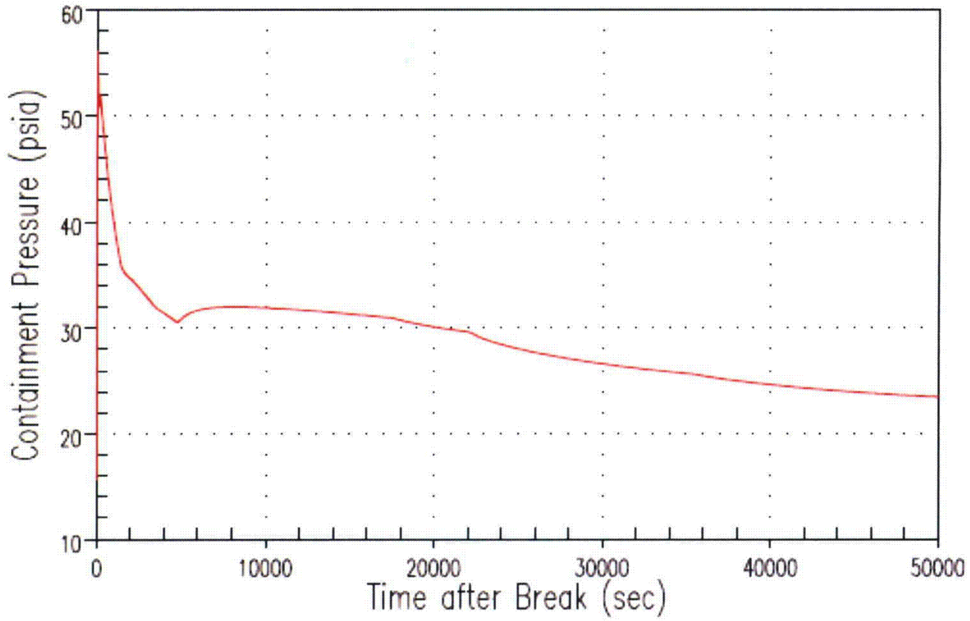

Figure 6-17 Minimum NPSHa Containment Pressure

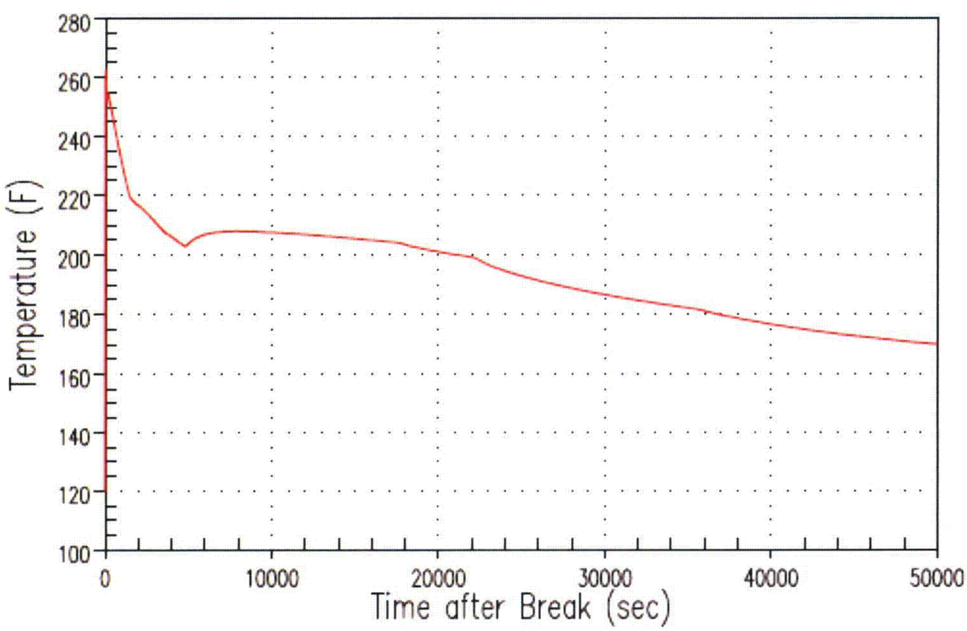

Figure 6-18 Minimum NPSHa Containment Temperature

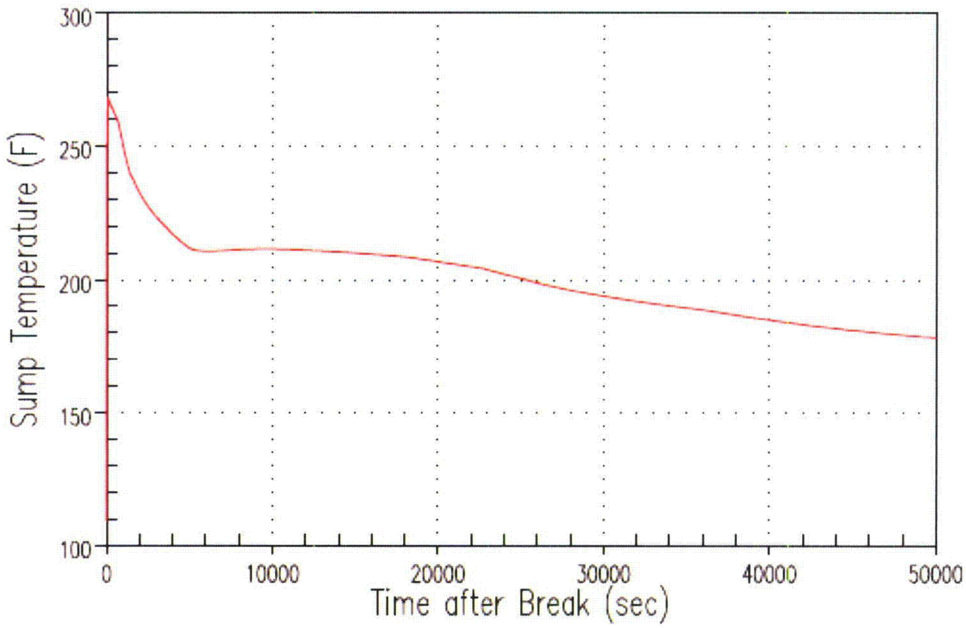

Figure 6-19 Minimum NPSHa Containment Sump Temperature

7 BENCHMARK COMPARISONS – ICE CONDENSER

This section compares the DEPS LOCA M&E releases calculated with a modified WC/T ECCS evaluation model to benchmark results calculated with the currently approved LOCA M&E release calculation methodology. The containment response comparison is also included.

7.1 LOCA M&E MODEL DESCRIPTION

An existing WC/T 4-loop plant ECCS evaluation model was modified and used for the DEPS LOCA benchmark comparison cases. [

]^{a,c} The steady state loop noding diagram for the modified WC/T ECCS evaluation model is shown in Figure 7-1. The modified WC/T steam generator noding diagram is shown in Figure 5-2.

The accumulator pressure, temperature, and water volume, along with the SI flow rate and temperature were modified to match the SATAN-VI benchmark model. [

]^{a,c} The initial RCS pressure, pressurizer level, and fluid and metal temperatures were adjusted to match the SATAN-VI benchmark model. [

]^{a,c} A 60 second steady state case was used to adjust the SG secondary side pressure and steam/feed flow rates to maintain the desired RCS operating conditions.

The initial stored mass and energy from the modified WC/T ECCS evaluation model are compared with the SATAN-VI benchmark model in Table 7-1. The WC/T model has a slightly lower initial RCS fluid mass and energy, but a substantially higher initial SG fluid mass and energy than SATAN-VI. The WC/T model SG and RCS metal energies are also substantially higher than SATAN-VI. The difference in the RCS metal energy is primarily due to the difference in vessel metal energy between the two models. All of the initial RCS fluid energy and a small part of the RCS metal, SG metal, and SG fluid energy is released during the LOCA blowdown phase. The rest of the RCS metal, SG metal, and SG fluid energy is released later during the post-reflood and long-term decay heat removal phases of the event.

Table 7-1 Initial Steady State Mass and Energy Comparison

	WC/T Model	SATAN-VI Model
RCS Fluid Mass	754434 lbm	800993 lbm
RCS Fluid Energy	348 MBtu	355 MBtu
RCS Metal Energy	134 MBtu	112 MBtu
SG Secondary Fluid Mass	684850 lbm	552900 lbm
SG Secondary Fluid Energy	385 MBtu	323 MBtu
SG Secondary Metal Energy	85 MBtu	57 MBtu

a,c

Figure 7-1 WC/T Steady State Noding Diagram (4-Loop Ice Condenser Plant)

7.2 CONTAINMENT MODEL DESCRIPTION

The LOTIC1 computer code is used to model the ice condenser containment, and LOTIC1 is discussed in detail in WCAP-8354-P-A. [

]^{a,c} Active containment cooling consists of 2 spray pumps and 2 RHR cooling loops; however, only 1 electrical train of active containment heat removal is assumed to be in operation. This leaves only 1 spray pump and 1 RHR pump in service. The low-head RHR pump switches from the injection mode to the sump recirculation mode after the RWST reaches the low level setpoint. The spray pump continues to draw from the RWST until the level reaches the low-low setpoint. After this, the spray pump suction is transferred from the RWST to the sump to provide recirculation spray.

The LOTIC1 model was developed following the methodology documented in WCAP-8354-P-A. Key containment model input is given in Tables 7-2 and 7-3. The containment model contains two break streams, one each for the high enthalpy and spilling sides. Steam from both break streams is directed towards the ice compartment, and liquid is spilled to the sump. Also, accumulator nitrogen release is modeled in LOTIC1.

The LOTIC1 model is run standalone. Mass and energy releases from the WC/T LOCA M&E release calculation are used as input to the LOTIC1 model. [

]^{a,c}

Table 7-2 Key LOTIC1 Model Input Values

Description	LOTIC1 Model
Containment Data	
Noding Structure	5 lumped volumes
Volume	1.27×10^6 ft^3
Initial Ice Mass	2.26×10^6 lb$_m$
Heat Sink Geometry – See Table 4.2-2	
Heat Transfer Coefficients – LOCA	Tagami
Initial Conditions	
Initial Pressure	15.0 psia
Initial Temperature	80°F (UC), 100°F (LC and DE), 15°F (IC)
Initial Humidity	10 %RH (UC, LC, DE), 100%RH (IC)
Boundary Conditions	
Break Flow Phase Separation	Steam is directed to the ice condenser, liquid to sump
Accumulator Nitrogen Release	Modeled for LOCA
Spray Flow Initiation	234 seconds
Spray Flow Rate	4000 gpm
Spray Flow Termination	Low-low RWST Level (4,575 ft^3 remaining)
LOCA Sump Recirculation Modeling	
Transfer to ECCS Recirculation	Low RWST Level (20,921 ft^3 remaining)
RHR Flow Rate	3,674 gpm injection/3160 gpm after switchover completion
RHR Heat Exchanger UA	1.666 MBTU/hr-°F
CCW Flow Rate	5,000 gpm
CCW Heat Exchanger UA	6.076 MBTU/hr-°F
Service Water Flow Rate	5200 gpm (spray)/6315 gpm (CCW)
Service Water Temperature	88°F
Deck Fans	
Number of Fans in Operation	1
Flow Rate	40,000 CFM
Initiation Time	600 seconds

Table 7-3 Heat Sink Geometry

	Area (ft^2)	Paint (in)	SS Steel (in)	CS Steel (in)	Concrete (in)	Steel and Insulation (in)	Total (in)
Operating Deck Slab 1	4880				12.8		12.8
Operating Deck Slab 2	18280	0.066			16.8		18.866
Operating Deck Slab 3	760	0.066			18.0		18.066
Operating Deck Slab 4	3840		0.25		18		18.25
Containment Shell Slab 5	56331	0.012		0.948			0.960
Operating Deck, Crane Wall, Interior Concrete Slab 6	31963				17.16		17.16
Operating Deck Slab 7	2830	0.066			13.2		13.266
Operating Deck Slab 8	760	0.066			21.0		21.066
Interior Concrete/Stainless Steel Slab 9	2270		0.25		24.0		24.25
Floor Slab 10	15921	0.066			19.2		19.266
Misc. Steel Slab 11	28500	0.012			0.79		0.802
Ice Baskets Slab 12	149600			0.080			0.080
Lattice Frame Slab 13	75865			0.260			0.260
Lower Support Structure Slab 14	28760			0.704			0.704
Ice Condenser Floor Slab 15	3336	0.066			4.0		4.066
Containment Wall Panels and Shell Slab 16	19100			0.75		12.0	12.75
Crane Wall Panels and Crane Wall Slab 17	13055				12.0	12.0	24.0

7.3 DEPS LOCA BENCHMARK CASE RESULTS COMPARISON

The DEPS break is located in the pressurizer loop in both the WC/T and SATAN-VI models. [

]a,c

Figures 7-2 and 7-3 compare the integrated break mass and energy flow rates for WC/T and WCAP-10325-P-A. The integrated mass flow is less in the WCT run because of slight changes in SI flow rates due to pump performance assumptions (the flow change is ~10 lbm/s). The effect of this can also be seen in Figure 7-3. In the long term LOCA transient, the large majority of SI flow is spilled out of the pump side of the break, with flow to the core only making up for break flow from the steam generator side. Because of the mechanistic WC/T calculation, the overall steam flow to the lower compartment is reduced (Figure 7-4). The reduced steam flow rate causes the ice bed to melt out later for the WC/T containment response (7850 seconds vs. 3100 seconds), and the resulting peak pressure is reduced (Figure 7-5). Figures 7-6 and 7-7 indicate that the compartment temperatures are also reduced in the long term.

The sump temperature for the WC/T run (Figure 7-8) is generally higher than the WCAP-10325-P-A run. This is attributed to two factors. [

]a,c

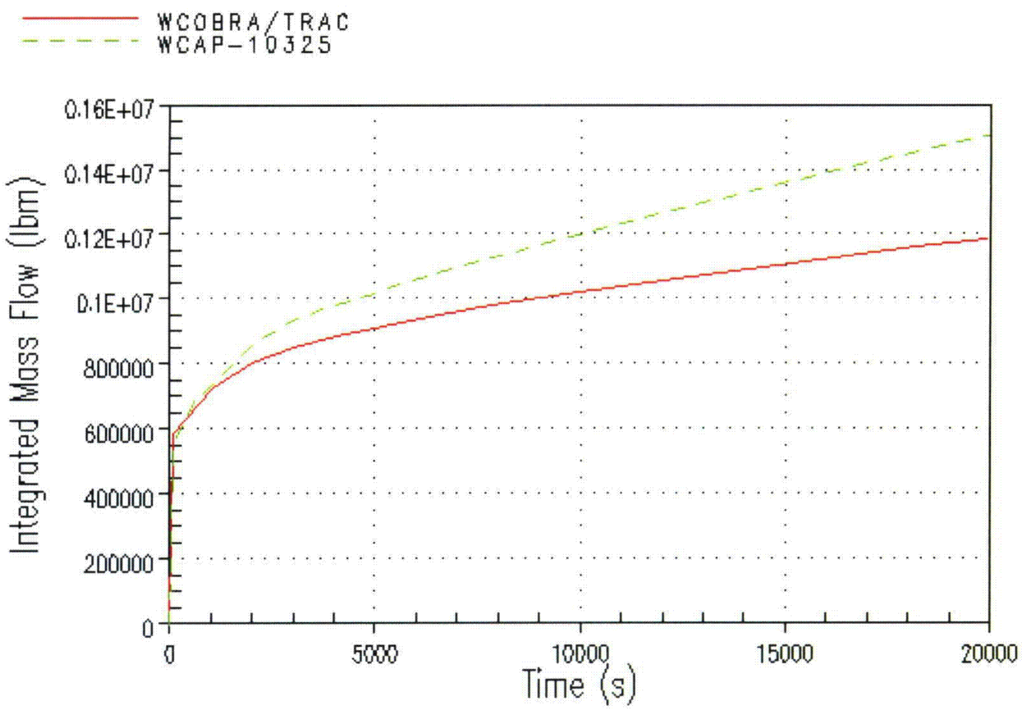

Figure 7-2 Integral Break Mass Comparison

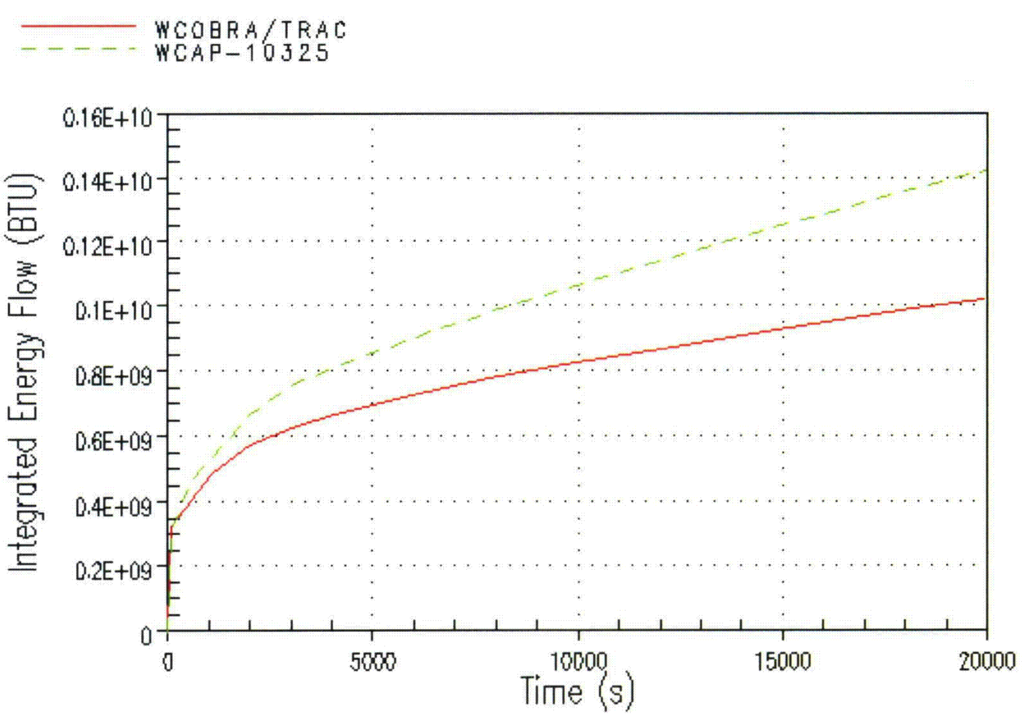

Figure 7-3 Integral Energy Comparison

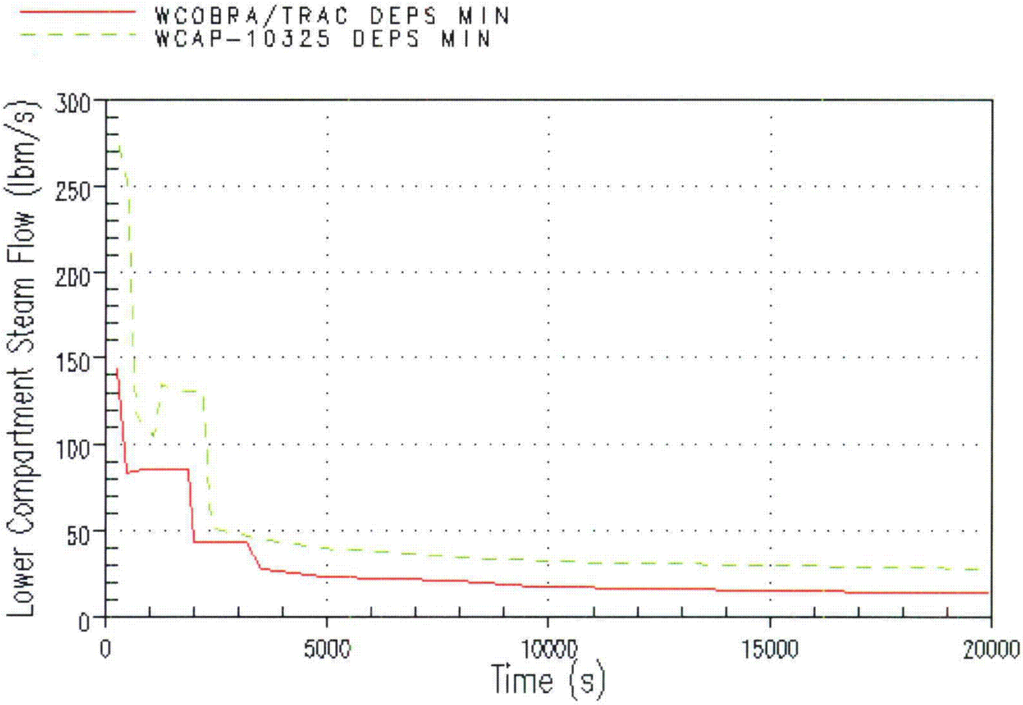

Figure 7-4 Lower Compartment Steam Flow Rate Comparison

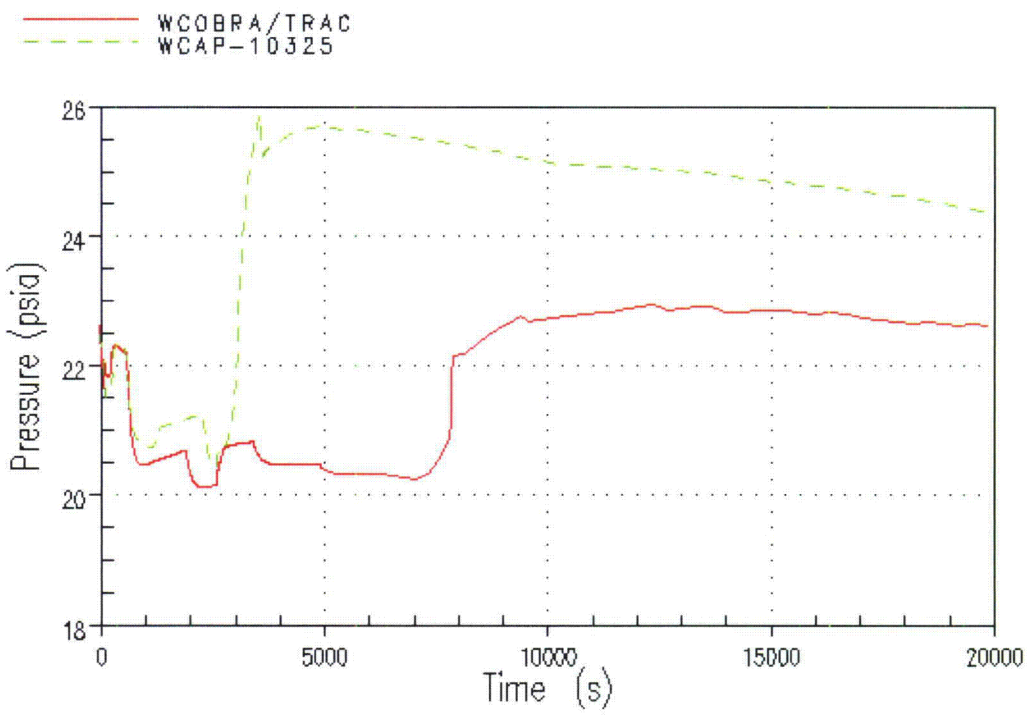

Figure 7-5 WC/T and WCAP-10325-P-A DEPS MIN Containment Pressure

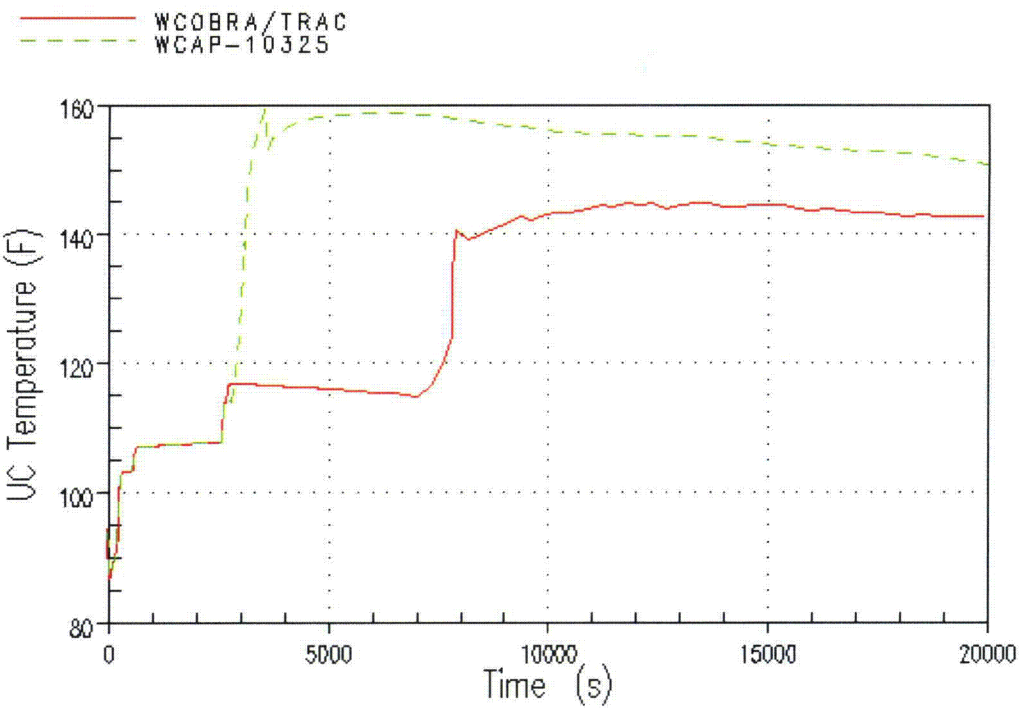

Figure 7-6 WC/T and WCAP-10325-P-A Upper Compartment Temperature

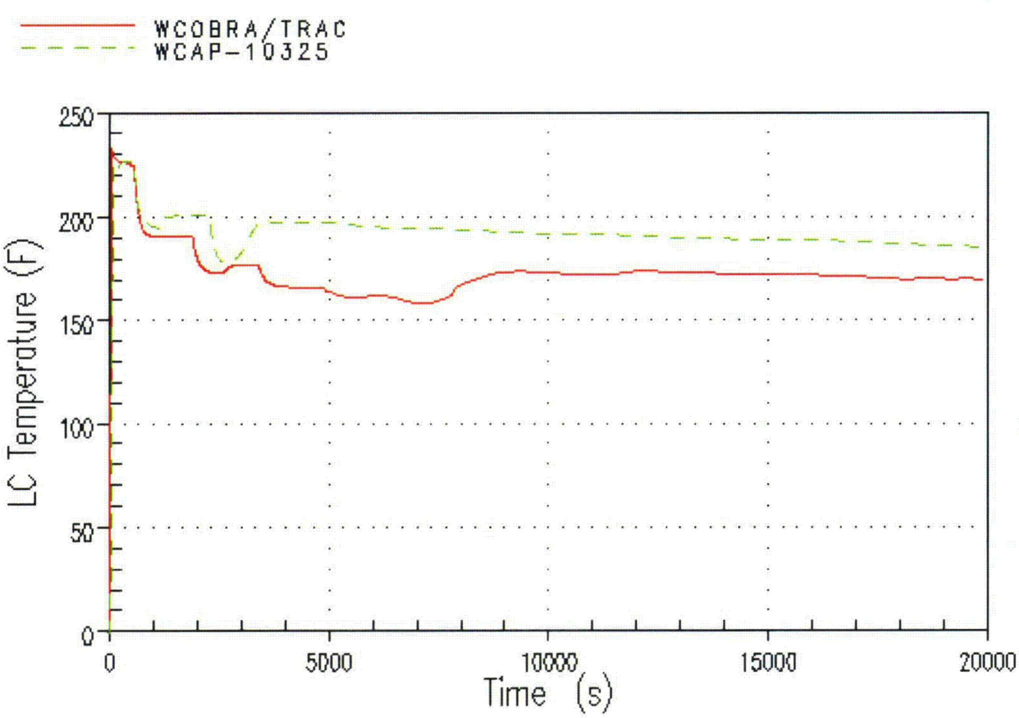

Figure 7-7 WC/T and WCAP-10325-P-A Lower Compartment Temperature

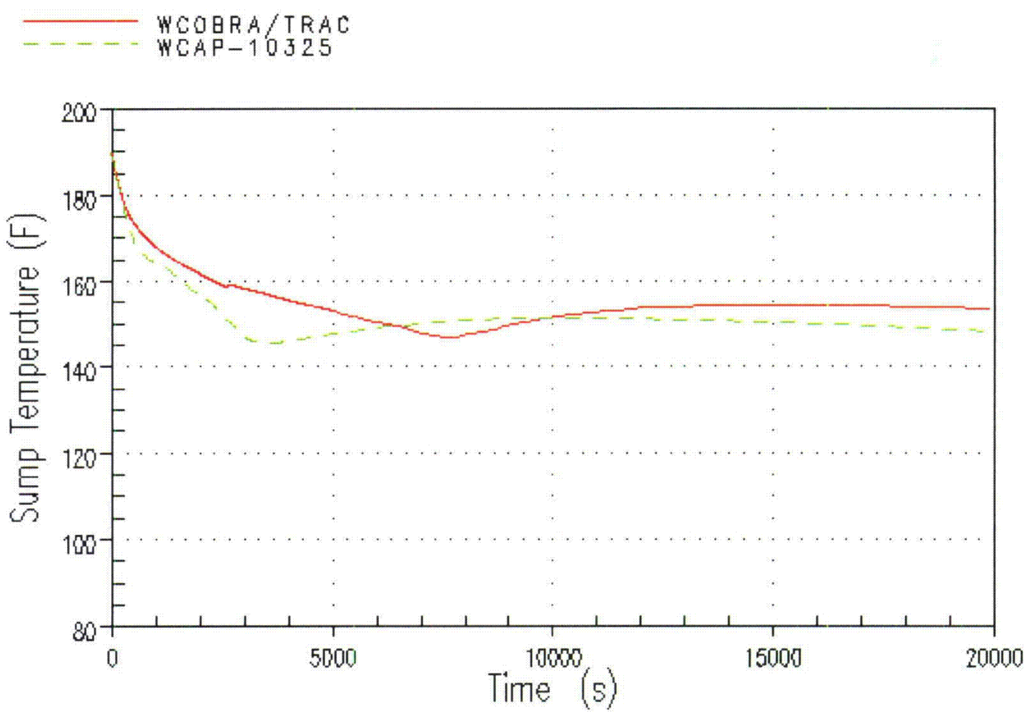

Figure 7-8 WC/T and WCAP-10325-P-A Sump Temperature

7.4 SAMPLE CASE – PEAK CONTAINMENT PRESSURE/TEMPERATURE

The WC/T LOCA M&E releases for the peak containment pressure/temperature application were generated for the DEPS and DECL LOCA events. The DEHL LOCA event was not included because it leads to little to no energy release from the steam generators, a major factor in the ice bed melt. [

]^{a,c}

The containment pressure, upper compartment temperature, lower compartment temperature, and sump temperature are compared in Figures 7-9 through 7-12. Both the DEPS and DECL cases display elevated pressure early during the blowdown phase, but containment pressure decreases as safety systems are activated. Pressure is higher for the DECL case from approximately 500 seconds to 3200 seconds because for the DECL case the intact steam generators receive more flow from the core exit and release more secondary energy to containment. At 600 seconds, the deck fan begins to drive flow through the ice bed, thus the pressure reduction in both cases. Pressure again begins to increase slightly as the safety injection system switches to recirculation. The reduction in pressure at 2000 seconds is attributed to loop seal plugging and a change to a new portion of mass and energy release data in the LOTIC1 containment code. The increase and decrease in pressure between 2600 seconds and 2700 seconds is due to an interruption in spray flow while switchover to sump recirculation is taking place. Pressure remains low until the ice bed melts out at approximately 7800 seconds for the DEPS case and 8700 seconds for the DECL case. Because the DEPS case melts the ice bed sooner, when the decay heat rate is higher, the resulting peak

pressure is higher than the DECL case. This also leads to higher upper compartment and lower compartment temperatures.

Figures 7-13 through 7-15 show the overall mass and energy release is similar for the DECL and DEPS cases, as well as the total average break enthalpy. For the DECL case, however, the high enthalpy side break flow (flow that travels through the broken loop steam generator) encounters cold leg safety injection prior to exiting the RCS. Condensation of steam from the high enthalpy side of the DECL break leads to a higher sump temperature. Relative to peak containment temperature and pressure, the DEPS break is limiting for the ice containment design.

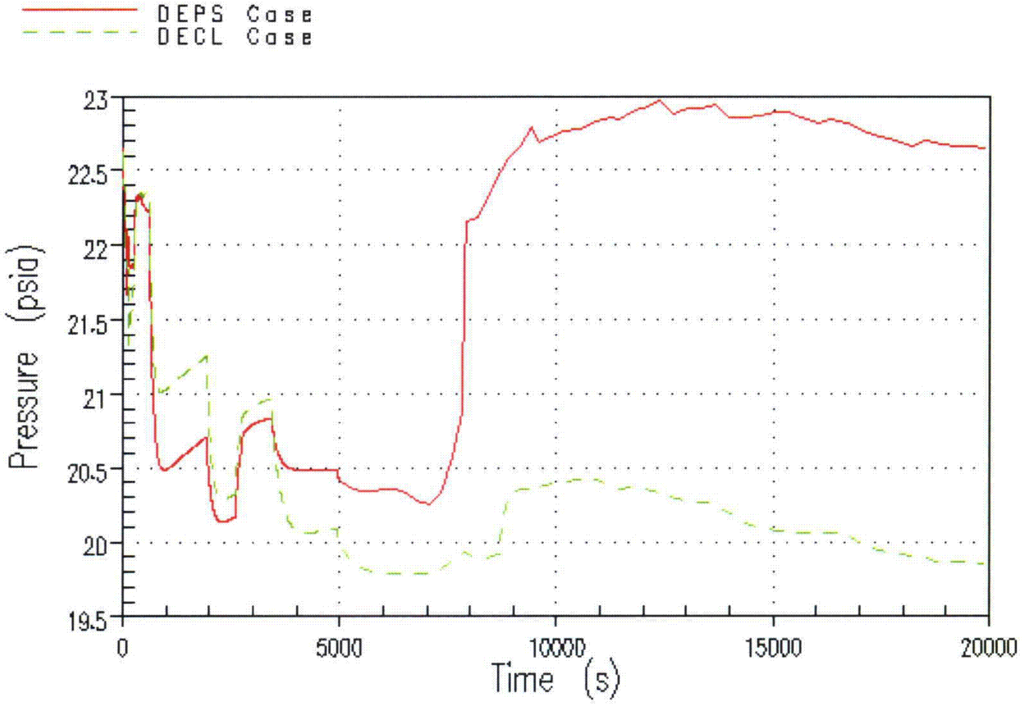

Figure 7-9 WC/T DEPS and DECL Containment Pressure

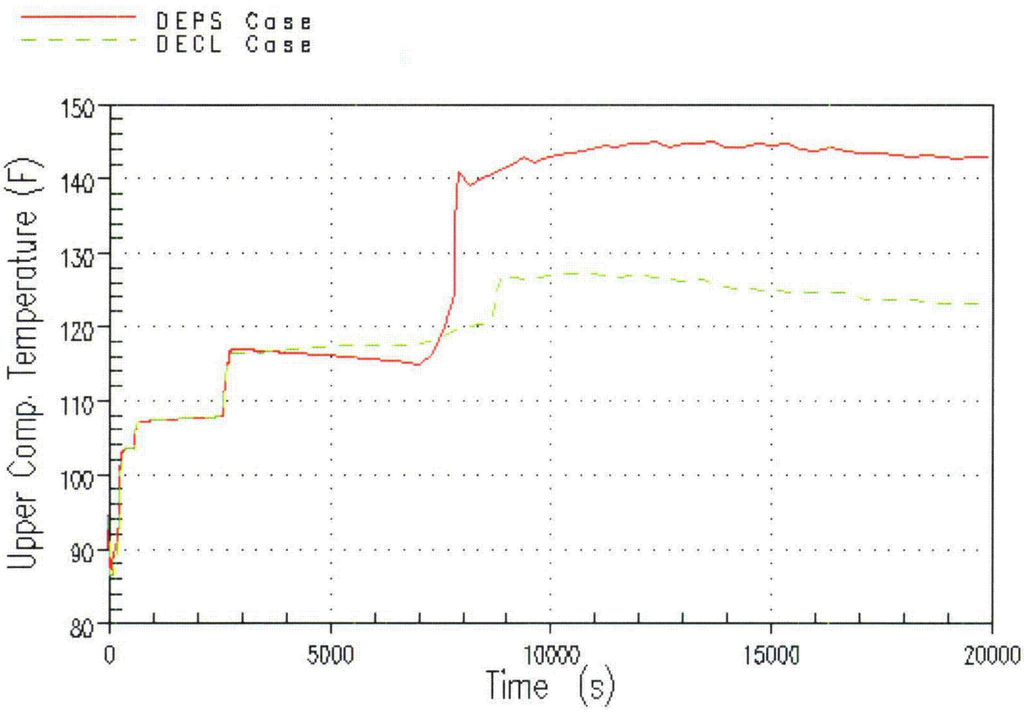

Figure 7-10 WC/T DEPS and DECL Upper Compartment Temperature

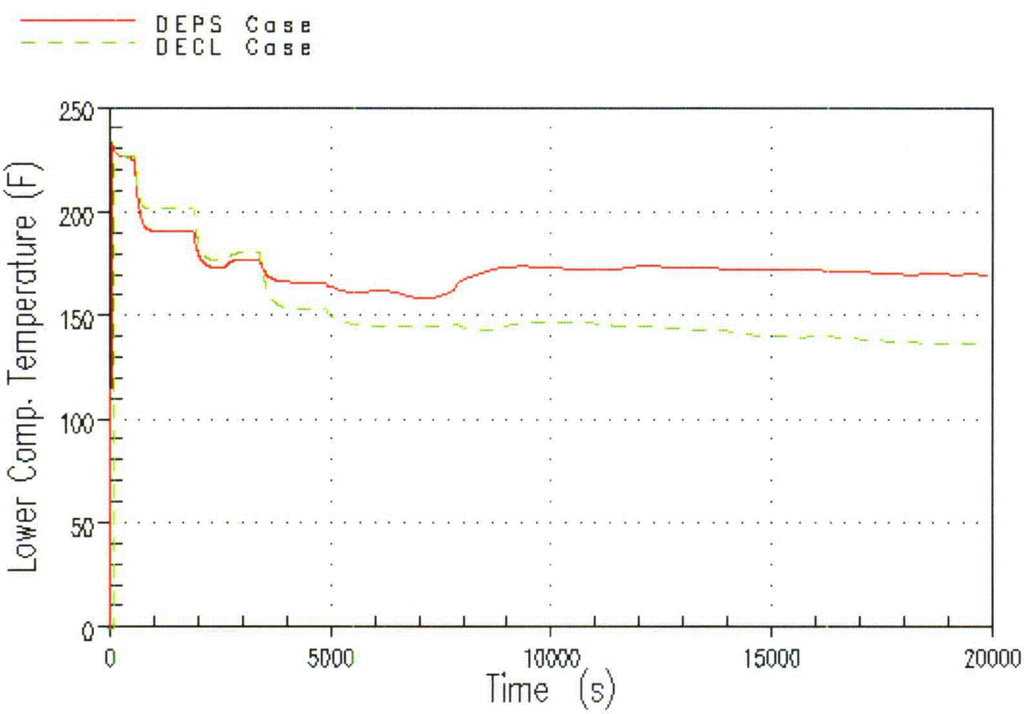

Figure 7-11 WC/T DEPS and DECL Lower Compartment Temperature

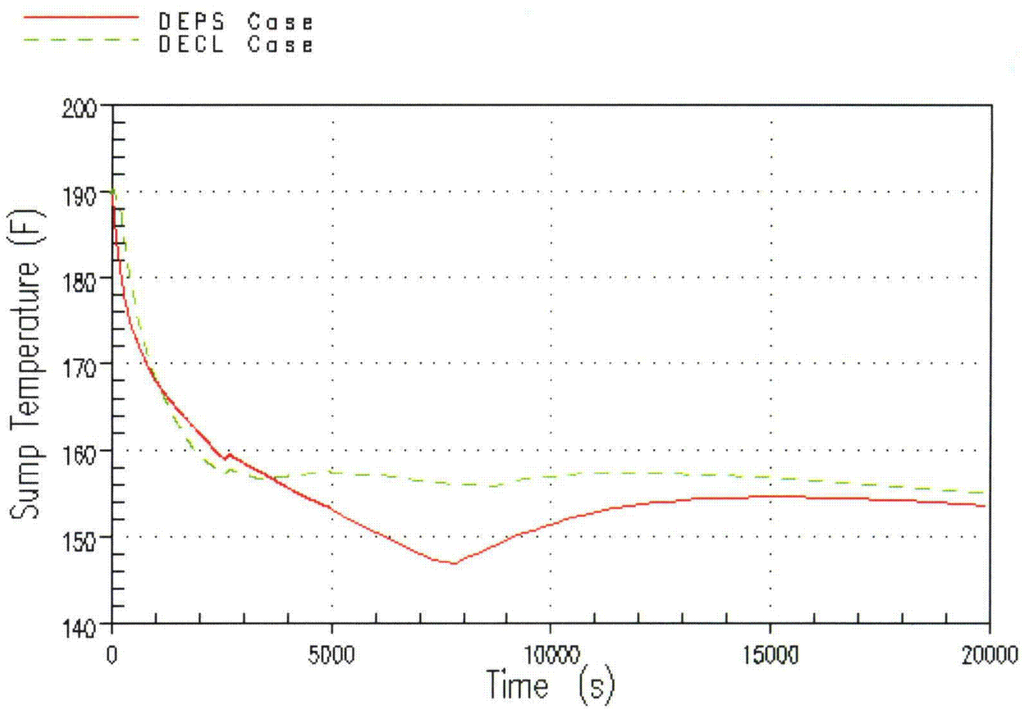

Figure 7-12 WC/T DEPS and DECL Sump Temperature

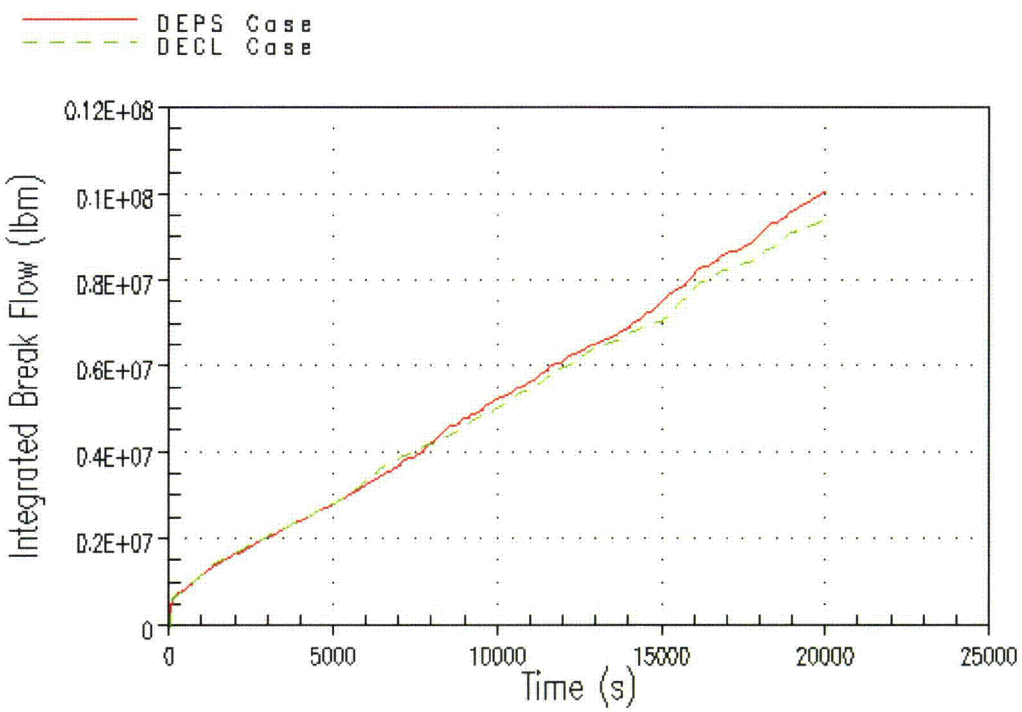

Figure 7-13 WC/T DEPS and DECL Integrated Break Flow

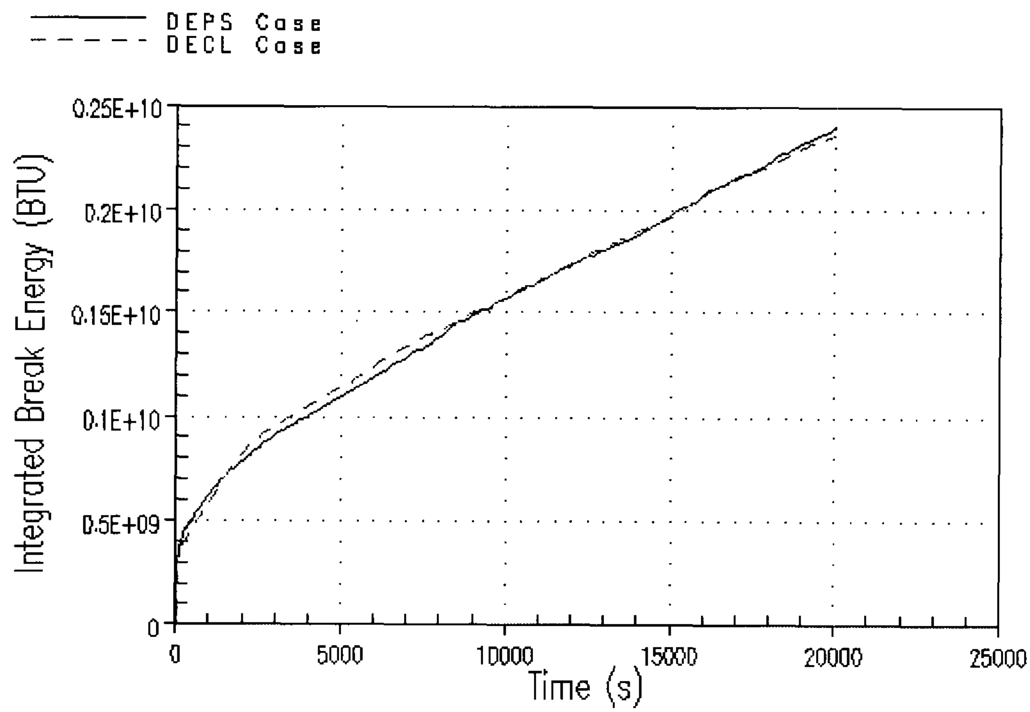

Figure 7-14 WC/T DEPS and DECL Integrated Energy Flow

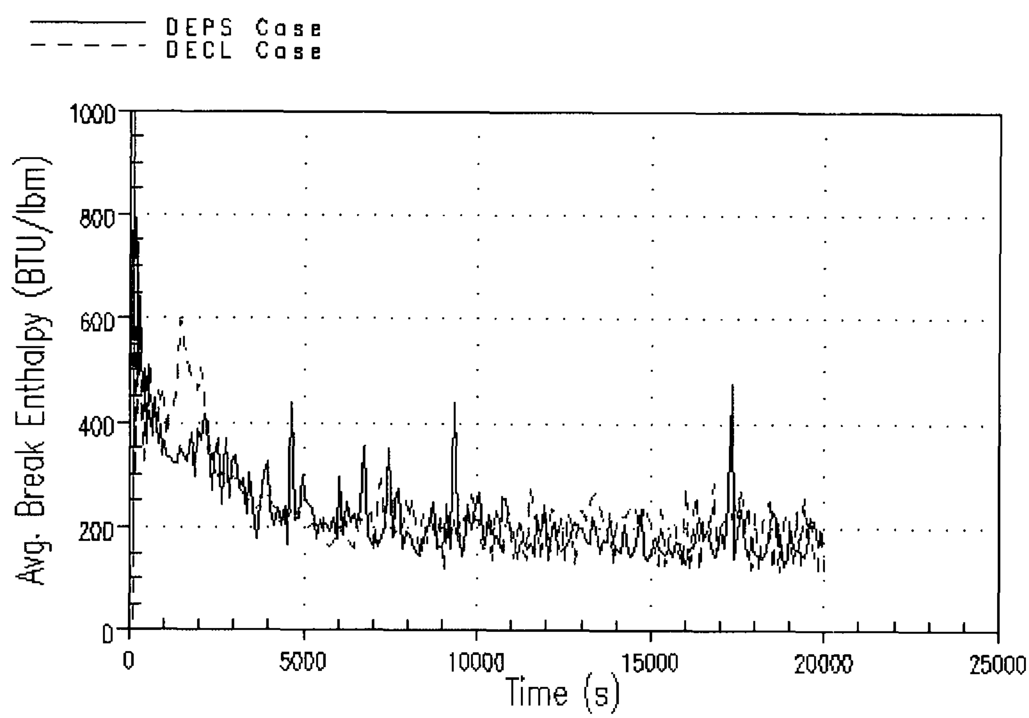

Figure 7-15 WC/T DEPS and DECL Average Break Enthalpy

8 CONCLUSIONS

The WC/T ECCS analysis model was modified, as described in this report, to allow it to produce LOCA M&E releases for the containment response calculations. Modifications were made to both the code and the input bias.

The WC/T code changes that were made for the LOCA M&E release calculations are transparent to, and do not affect, the ECCS analysis. The WC/T code was modified to better model the SG interface heat/mass transfer and SG metal heat transfer, and to allow it to run in parallel with GOTHIC. The SG modeling changes were validated by comparison with data from the FLECHT SEASET test facility. The modified WC/T code conservatively calculates the transfer rate of SG secondary side energy to the primary and can run in parallel with GOTHIC.

The WC/T ECCS evaluation model input was biased to produce conservative LOCA M&E releases in accordance with the acceptance criteria documented in NUREG-0800, Section 6.2.1.3 (Reference 27). The WC/T calculated LOCA M&E release data was compared with results from the currently approved model (Reference 2). The LOCA blowdown M&E releases were essentially the same; however, the WC/T post-reflood energy releases were lower than the currently approved model because the WC/T LOCA M&E release model uses mechanistic steam generator and metal heat release models.

Finally, sample transient results for the containment peak pressure, long-term EQ, and minimum NPSHa applications were produced. The results demonstrate that the WC/T LOCA M&E release model, combined with a long-term steaming release model, is capable of performing these types of calculations with analysis margins to the containment design limits.

Westinghouse intends to use this WC/T methodology to generate LOCA M&E releases for the Westinghouse NSSS Large Dry, Sub-Atmospheric, and Ice Condenser Containment Designs, and the CE/ABB NSSS Containment Designs.

9 REFERENCES

1. WCAP-8264-P-A, Rev. 1, "Westinghouse Mass and Energy Release Data for Containment Design," August 1975 (WCAP-8312-A, Rev. 2 is the non-proprietary version).

2. WCAP-10325-P-A, "Westinghouse LOCA Mass and Energy Release Model for Containment Design – March 1979 Version," May 1983 (WCAP-10326-A is the non-proprietary version).

3. WCAP-8302, "SATAN-VI Program: Comprehensive Space-Time Dependent Analysis of Loss-of-Coolant," F. Bordelon, et al., June 1974 (WCAP-8306 is the non-proprietary version).

4. WCAP-8170, "Calculational Model for Core Reflooding After a Loss of Coolant Accident (WREFLOOD Code)," G. Collier, et al., June 1974 (WCAP-8171 is the non-proprietary version).

5. NUREG-0800, Section 6.2.1.1.A, "PWR Dry Containments, Including Sub-atmospheric Containments," Rev. 3, March 2007.

6A. Citation of the Reference for C-E LOCA Mass & Energy Release Methodology:

   a. CENPD-132P, Volumes 1 and 2, "Calculative Methods for the C-E Large Break LOCA Evaluation Model," August 1974.

   b. CENPD-132P, Supplement 1, "Calculative Methods for the C-E Large Break LOCA Evaluation Model," February 1975.

   c. CENPD-132-P, Supplement 2-P, "Calculative Methods for the C-E Large Break LOCA Evaluation Model," July 1975.

   d. CENPD-132, Supplement 3-P, "Calculative Methods for the C-E Large Break LOCA Evaluation Model for C-E and W Designed NSSS," June 1985.

   e. CENPD-132, Supplement 4-P-A, "Calculative Methods for the C-E Large Break LOCA Evaluation Model," March 2001.

6B. Citation of the Reference for CEFLASH-4A Computer Code:

   a. CENPD-133P, "CEFLASH-4A, A FORTRAN-IV Digital Computer Program for Reactor Blowdown Analysis," August 1974.

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c. CENPD-133P, Supplement 4-P, "CEFLASH-4A, A FORTRAN-IV Digital Computer Program for Reactor Blowdown Analysis," April 1977.

d. CENPD-133P, Supplement 5, "CEFLASH-4A, A FORTRAN-IV Digital Computer Program for Reactor Blowdown Analysis," June 1985.

7. FLOOD3 is an extension of the NRC approved FLOOD-MOD2 code referenced in the NUREG-0800, Standard Review Plan. "FLOOD-MOD2 – A Code to Determine the Core Reflood Rate for a PWR Plant with Two Core Vessel Outlet Legs and Four Core Vessel Inlet Legs," Interim Report, Aerojet Nuclear Company, November 1972.

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9. WCAP-9724, Westinghouse Report No. 9, "PWR FLECHT SEASET Steam Generator Separate Effects Task Data Analysis and Evaluation Report," February, 1982.

10. WCAP-12945-P-A, Revision 1, "Code Qualification Document for Best Estimate LOCA Analysis," March 1998.

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21. "Convective Boiling and Condensation," J. G. Collier, McGraw Hill, 1982.

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10 NRC RAIS AND WESTINGHOUSE RESPONSES

Westinghouse

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Our ref: LTR-NRC-08-25

May 16, 2008

Subject: Response to NRC Request for Additional Information on WCAP-16608-P, Addendum 1, "Westinghouse Containment Analysis Methodology, Addendum 1 Appendix C, PWR LOCA Mass and Energy Release Input Calculation Methodology" (Proprietary/Non-Proprietary) dated May, 2008

Enclosed are five (5) copies of the proprietary and one (1) copy of the non-proprietary version of, "Response to NRC Request for Additional Infonnation on WCAP-16608-P, Addendum 1, 'Westinghouse Containment Analysis Methodology, Addendum 1 Appendix C, PWR LOCA Mass and Energy Release Input Calculation Methodology'."

Also enclosed is:

One (1) copy of the Application for Withholding, AW-08-2422 (Non-Proprietary) with Proprietary Infonnation Notice, and
One (1) copy of the Affidavit (Non-Proprietary).

This submittal contains proprietary information of Westinghouse Electric Company LLC. In conformance with the requirements of 10 CFR Section 2.390, as amended, of the Commission's regulations, we are enclosing with this submittal an Application for Withholding from Public Disclosure and an affidavit. The affidavit sets forth the basis on which the information identified as proprietary may be withheld from public disclosure by the Commission.

Correspondence with respect to this affidavit or Application for Withholding should reference AW-08-2422 and should be addressed to J. A. Gresham, Manager, Regulatory Compliance and Plant Licensing, Westinghouse Electric Company LLC, P.O. Box 355, Pittsburgh, Pennsylvania 15230-0355.

Very truly yours,

J. A. Gresham, Manager
Regulatory Compliance and Plant Licensing

Enclosures

cc: Jon Thompson (NRC O-7E1A)

Distribution for LTR-NRC-08-25

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RCPL Administrative Aide (ECE 4-7) 1L w/affidavit

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Our ref: AW-08-2422

May 16, 2008

APPLICATION FOR WITHHOLDING PROPRIETARY
INFORMATION FROM PUBLIC DISCLOSURE

Subject: LTR-NRC-08-25 P-Attachment, "Responses to NRC Request for Additional Information on WCAP-16608-P, Addendum 1, 'Westinghouse Containment Analysis Methodology, Addendum 1 Appendix C, PWR LOCA Mass and Energy Release Input Calculation Methodology," (Proprietary)

Reference: Letter from J. A. Gresham to U.S. NRC Document Control Desk, LTR-NRC-08-25, dated May 16, 2008

The Application for Withholding is submitted by Westinghouse Electric Company LLC (Westinghouse), pursuant to the provisions of Paragraph (b) (1) of Section 2.390 of the Commission's regulations. It contains commercial strategic information proprietary to Westinghouse and customarily held in confidence.

The proprietary material for which withholding is being requested is identified in the proprietary version of the subject report. In conformance with 10 CFR Section 2.390, Affidavit AW-08-2422 accompanies this Application for Withholding, setting forth the basis on which the identified proprietary information may be withheld from public disclosure.

Accordingly, it is respectfully requested that the subject information which is proprietary to Westinghouse be withheld from public disclosure in accordance with 10 CFR Section 2.390 of the Commission's regulations.

Correspondence with respect to this Application for Withholding or the accompanying affidavit should reference AW-08-2422 and should be addressed to J. A. Gresham, Manager, Regulatory Compliance and Plant Licensing, Westinghouse Electric Company LLC, P.O. Box 355, Pittsburgh, Pennsylvania 15230-0355.

Very truly yours,

J. A. Gresham, Manager
Regulatory Compliance and Plant Licensing

cc: Jon Thompson, NRC O-7E1A

Enclosures

AW-08-2422

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared J. A. Gresham, who, being by me duly sworn according to law, deposes and says that he is authorized to execute this Affidavit on behalf of Westinghouse Electric Company LLC (Westinghouse), and that the averments of fact set forth in this Affidavit are true and correct to the best of his knowledge, information, and belief:

J. A. Gresham, Manager
Regulatory Compliance and Plant Licensing

Sworn to and subscribed before me
this 16th day of May, 2008

Notary Public

COMMONWEALTH OF PENNSYLVANIA
Notarial Seal
Sharon L. Markle, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires Jan. 29, 2011
Member, Pennsylvania Association of Notaries

(1) I am Manager, Regulatory Compliance and Plant Licensing, in Nuclear Services, Westinghouse Electric Company LLC (Westinghouse), and as such, I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing and rule making proceedings, and am authorized to apply for its withholding on behalf of Westinghouse.

(2) I am making this Affidavit in conformance with the provisions of 10 CFR Section 2.390 of the Commission's regulations and in conjunction with the Westinghouse "Application for Withholding" accompanying this Affidavit.

(3) I have personal knowledge of the criteria and procedures utilized by Westinghouse in designating information as a trade secret, privileged or as confidential commercial or financial information.

(4) Pursuant to the provisions of paragraph (b)(4) of Section 2.390 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse.

(ii) The information is of a type customarily held in confidence by Westinghouse and not customarily disclosed to the public. Westinghouse has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application of that system and the substance of that system constitutes Westinghouse policy and provides the rational basis required.

Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of Westinghouse's

competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage, e.g., by optimization or improved marketability.

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

There are sound policy reasons behind the Westinghouse system which include the following:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

(b) It is information that is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

(c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

(d) Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Westinghouse of a competitive advantage.

(e) Unrestricted disclosure would jeopardize the position of prominence of Westinghouse in the world market, and thereby give a market advantage to the competition of those countries.

(f) The Westinghouse capacity to invest corporate assets in research and development depends upon the success in obtaining and maintaining a competitive advantage.

(iii) The information is being transmitted to the Commission in confidence and, under the provisions of 10 CFR Section 2.390, it is to be received in confidence by the Commission.

(iv) The information sought to be protected is not available in public sources or available information has not been previously employed in the same original manner or method to the best of our knowledge and belief.

(v) The proprietary information sought to be withheld in this submittal is that which is appropriately marked in LTR-NRC-08-25 P-Attachment, "Responses to NRC Request for Additional Information on WCAP-16608-P, Addendum 1, 'Westinghouse Containment Analysis Methodology, Addendum 1 Appendix C, PWR LOCA Mass and Energy Release Input Calculation Methodology,'" (Proprietary), for submittal to the Commission, being transmitted by Westinghouse letter (LTR-NRC-08-25) and Application for Withholding Proprietary Information from Public Disclosure, to the Document Control Desk. The proprietary information as submitted by Westinghouse is that associated with Westinghouse's request for NRC approval of WCAP-16608-P, Addendum 1, 'Westinghouse Containment Analysis Methodology, Addendum 1 Appendix C, PWR LOCA Mass and Energy Release Input Calculation Methodology."

This information is part of that which will enable Westinghouse to:

(a) Obtain NRC approval of WCAP-16608-P, Addendum 1, 'Westinghouse Containment Analysis Methodology, Addendum 1 Appendix C, PWR LOCA Mass and Energy Release Input Calculation Methodology."

Further this information has substantial commercial value as follows:

(a) Westinghouse plans to sell the use of this information to its customers for purposes of design basis containment licensing analyses.

(b) Westinghouse can sell support and defense of design basis containment licensing analyses.

(c) The information requested to be withheld reveals the distinguishing aspects of a methodology which was developed by Westinghouse.

Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar calculations and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

The development of the technology described in part by the information is the result of applying the results of many years of experience in an intensive Westinghouse effort and the expenditure of a considerable sum of money.

In order for competitors of Westinghouse to duplicate this information, similar technical programs would have to be performed and a significant manpower effort, having the requisite talent and experience, would have to be expended.

Further the deponent sayeth not.

Proprietary Information Notice

Transmitted herewith are proprietary and/or non-proprietary versions of documents furnished to the NRC in connection with requests for generic and/or plant-specific review and approval.

In order to conform to the requirements of 10 CFR 2.390 of the Commission's regulations concerning the protection of proprietary information so submitted to the NRC, the information which is proprietary in the proprietary versions is contained within brackets, and where the proprietary information has been deleted in the non-proprietary versions, only the brackets remain (the information that was contained within the brackets in the proprietary versions having been deleted). The justification for claiming the information so designated as proprietary is indicated in both versions by means of lower case letters (a) through (f) located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters refer to the types of information Westinghouse customarily holds in confidence identified in Sections (4)(ii)(a) through (4)(ii)(f) of the affidavit accompanying this transmittal pursuant to 10 CFR 2.390(b)(1).

Copyright Notice

LTR-NRC-08-25 NP-Attachment
TAC NO. MD6380

Response to NRC Request for Additional Information on WCAP-16608-P, ADDENDUM 1 REVISION 0, "WESTINGHOUSE CONTAINMENT ANALYSIS METHODOLOGY, ADDENDUM 1, APPENDIX C, PWR [PRESSURIZED WATER REACTOR] LOCA [LOSS-OF-COOLANT ACCIDENT] MASS AND ENERGY RELEASE INPUT CALCULATION METHODOLOGY"

May, 2008

Westinghouse Electric Company LLC
P.O. Box 355
Pittsburgh, PA 15230-0355

Westinghouse Non-Proprietary Class 3

REQUEST FOR ADDITIONAL INFORMATION (RAI)
BY THE OFFICE OF NUCLEAR REACTOR REGULATION
WCAP-16608-P, ADDENDUM 1, REVISION 0, "WESTINGHOUSE CONTAINMENT ANALYSIS METHODOLOGY, ADDENDUM 1, APPENDIX C, PWR [PRESSURIZED WATER REACTOR] LOCA [LOSS-OF-COOLANT ACCIDENT] MASS AND ENERGY RELEASE INPUT CALCULATION METHODOLOGY"
WESTINGHOUSE ELECTRIC COMPANY
PROJECT NO. 700

Westinghouse Response in Italics

1. Section C.3.1, Item 5: Please justify that a [ ]^{a,c} increase in volume due to thermal expansion is conservative. Refer to sentence: [

   ]^{a,c} Please explain (a) which vessel calculation is being referred to in this sentence, (b) why it is conservative to add the thermal expansion volume [ ]^{a,c}, and (c) whether guide tubes are part of the model.

   Westinghouse Response: Westinghouse is not requesting a change to the currently approved [ ]^{a,c} value that is used to account for the RCS volume increase due to thermal expansion [ ]^{a,c} and measurement uncertainty [ ]^{a,c} as documented in WCAP-10325-P-A, page 5-1. This meets the ANS 56.4-1983 requirement listed as item 1 in Table C.3-2.

   a. *The WC/T vessel volume input calculation is being described in this sentence. The WC/T vessel model consists of a number of sections. Each section contains several channels. The total vessel volume is the sum of the various channel volumes.*
   b. *[*

      ]^{a,c}
   c. *The metal structures and fluid volumes associated with the control rod guide tubes are modeled in the upper head and upper plenum sections of the WC/T vessel.*

2. Section C.3.1, Item 2: Please explain why a different set of [ ]^{a,c} flows is required [ ]^{a,c} for the pump suction and the hot leg breaks LOCA mass and energy (M&E) calculations and explain how these flows are calculated?

   Westinghouse Response: [

1

]^{a,c}

3. Section C.3.1, Item 16: Please justify that [ ]^{a,c} increase in steam generator (SG) secondary side volume due to thermal expansion and measurement uncertainty is conservative.

   Westinghouse Response: The percentage increase in SG secondary side volume due to thermal expansion and measurement uncertainty should not be any different than the RCS. The SG pressure is substantially lower and the temperature is slightly lower than the RCS.

4. Section C.3.3, for minimum net positive suction head available analysis. Please explain why is it conservative to [ ]^{a,c}

   Westinghouse Response: [

   ]^{a,c}

5. Section C.4.1, second paragraph, last sentence: Please further explain the 60 second steady-state case used to adjust the SG secondary side pressure and steam/feed flow rates to maintain the desired reactor coolant system operating conditions.

   Westinghouse Response: The WC/T ECCS evaluation model input must be initialized at hot full power steady state conditions. The LOCA transient analysis case is started from the end of the steady state case. Typically, the initial SG secondary pressure and steam/feed flow rates must be adjusted slightly to maintain the desired RCS steady state conditions. For example, the input SG secondary side steam and feed flow rates may have to be decreased if the RCS pressure and average temperature decrease during the steady state period.

6. Section C.3 Item 1: States that the LOCA Emergency Core Cooling System evaluation model PIRT [phenomena identification and ranking table] is very similar to the LOCA M&E release model PIRT, so WC/T [Westinghouse COBRA/TRAC] already contains models for most of the important M&E phenomena identified in the PIRT. Please explain what other phenomena besides the SG reverse heat transfer were required to be modeled in the WC/T code and how they were validated?

   Westinghouse Response: The SG metal energy must be considered in the LOCA mass and energy release calculation. Aside from the SG tubes, the SG metal energy was not modeled in the WC/T code calculation. The capability to model the primary and secondary SG metal was added to the code. This is described in Section C.2.3 of WCAP-16608-P, Addendum 1. The WC/T SG metal energy conduction model was validated by comparing the code calculated transient SG metal temperature response with the analytic solution for a step change in temperature at the conductor surface.

   Although not required by the PIRT, coupling the RCS and containment response eliminates the potential need for iteration during the post-blowdown phases of the LOCA event. The WC/T code was updated to allow it to exchange information with GOTHIC. This is described in Section C.2.4 of WCAP-16608-P, Addendum 1. This code change was validated by

comparing the interface variables sent by WC/T and received by GOTHIC over the course of a transient.

7. Table C.3-1, Item 7: Under the column titled "New Westinghouse Methodology" states an exception of not modeling heat transfer from reactor coolant system hot metal during the long term decay heat removal phase. Please provide the reasons for this exception and the appropriate justification as to why it is biasing for the M&E release for the containment analysis? Please note Item 19 under the new Westinghouse methodology which states that "...a long term decay heat boil-off model, which also accounts for the remaining energy in the primary metal ...." appears to be in contradiction to the statement in Item 7. Please reconcile these two statements.

   Westinghouse Response: The text in Table C.3-1 will be clarified; Westinghouse is not taking an exception to modeling the metal heat release during the long-term decay heat removal phase. [

   ]a,c

8. Table C.3-1, Item 10: Does the new Westinghouse methodology use the alternate approach given in Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, Appendix K, Section I.A, of assuming a constant blowdown profile using the initial conditions with an acceptable choked-flow correlation? What choked-flow correlation is used?

   Westinghouse Response: If a utility were to request Westinghouse to use the WC/T LOCA M&E release model to generate the break mass and energy releases for a short-term sub-compartment analysis, the input would be biased differently than for the containment peak pressure and temperature analysis. The short-term LOCA M&E release calculation input would be biased to maximize the initial break flow rate for the sub-compartment analyses. [

   ]a,c

   The TRAC PF1 break flow correlation is programmed into WC/T (see Section 4-8 of the CQD, WCAP-12945).

9. Table C.3-1, Item 15: Please provide references to experimental data reports used to validate the refill calculations.

   Westinghouse Response: The predictions of end of ECC bypass and subsequent refill have been validated by comparisons with full scale and scaled tests. These comparisons are provided in the WC/T CQD, WCAP-12945-P-A as follows:

   UPTF Test 6 (full scale) - Sections 14-4 and 15-1-9
   Creare tests (1/15-th and 1/5th scale) - Section 15-1-5

   The data references are provided in each of these sections. In addition, Section 25-6 provides a summary of the comparisons with data.

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10. Table C.3-2, Item 9: Please confirm that an evaluation was performed to verify that M&E added due to feedwater flow from the event initiation to feedwater isolation has no effect on the containment response.

Westinghouse Response: A loss of offsite power is assumed at the start of a LOCA event. The loss of offsite power causes the feedwater pumps to trip and the flow rate to coast down. An SI signal causes the feedwater control valve to start to close. The SI signal is generated fairly quickly in a large LOCA event. Therefore, following the design basis large LOCA event, the main feedwater flow would continue for only a short period of time. This time would depend on how long it takes for the pumped flow rate to coast down and the flow control valve to close.

*A sensitivity case was run during the initial WC/T LOCA M&E model development program to examine the containment response to modeling the feedwater flow coast down. WC/T uses the feedwater velocity as input to the feedwater FILL component. For the sensitivity case, the feedwater FILL velocity was ramped from 19.5 ft/s to 0.0 ft/s over the first 10 seconds of the transient. This added approximately 1100*5 = 5500 lbm of water and approximately 5500*450 = 2.5 MBTU of energy to each steam generator. This represents about 2% of the total energy in each steam generator.*

The transient fluid energy plots for an intact loop SG and the broken loop SG are shown in Figures 1 through 4. Both the intact loop and broken loop SG energy increase by approximately 1.5 MBTU shortly after trip in the base case (Figures 1 and 3). The SG energy for the sensitivity case increases by approximately 4 MBTU shortly after trip (Figures 2 and 4). As expected, this is about 2.5 MBTU higher for each SG than the base case. At the end of the transient, the total fluid energy remaining in the sensitivity case steam generators is about 18 MBTU greater than the base case steam generators. Therefore, the sensitivity case steam generators are cooling down slower than the base case steam generators.

The transient containment pressure, temperature and sump temperature are shown in Figures 5 through 7. The containment transient response is not impacted by modeling the feedwater flow coastdown. Therefore, after finding no impact on the containment peak pressure and temperature response, Westinghouse decided not to model the feedwater flow coastdown in the WC/T LOCA M&E release calculation.

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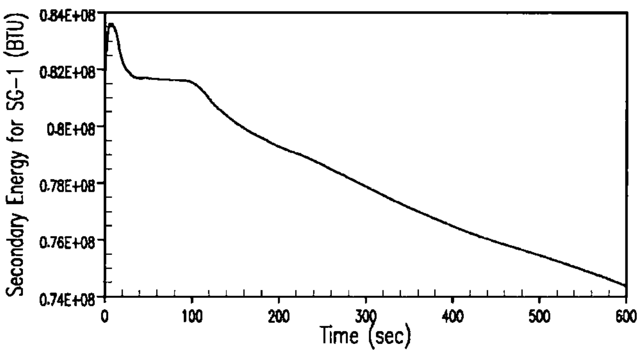

Figure 1 – Intact Loop SG Energy w/o Feedwater Coastdown

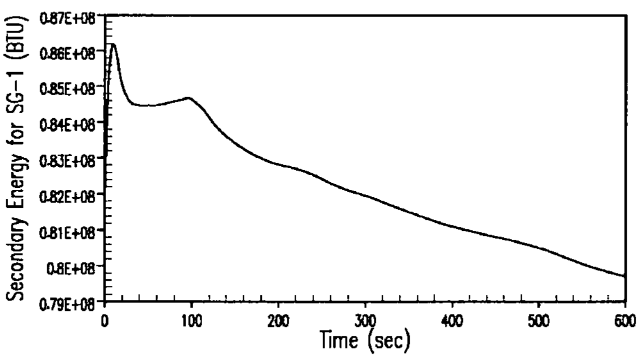

Figure 2 – Intact Loop SG Energy with Feedwater Coastdown

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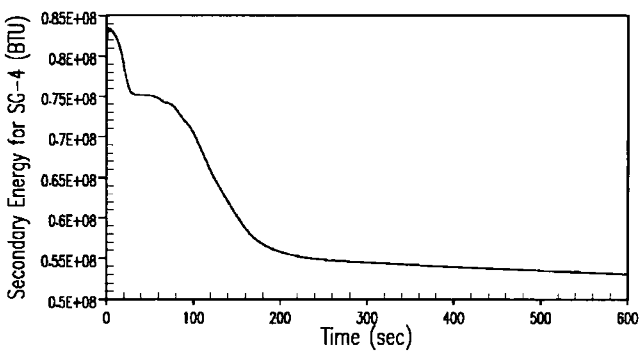

Figure 3 – Broken Loop SG Energy w/o Feedwater Coastdown

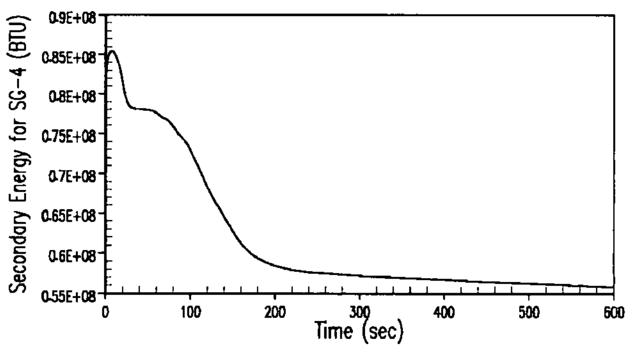

Figure 4 – Broken Loop SG Energy with Feedwater Coastdown

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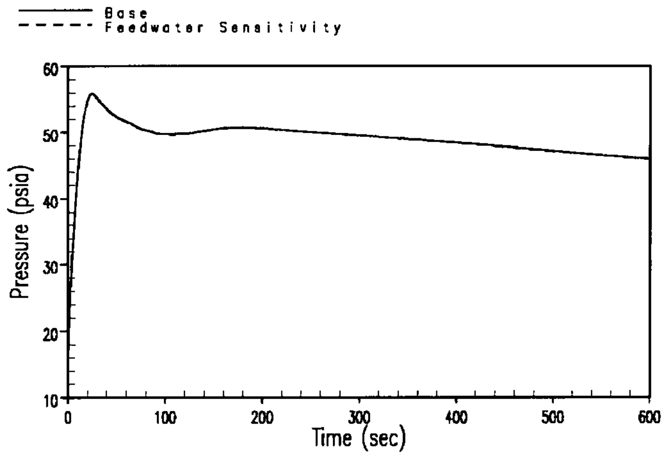

Figure 5 – Containment Pressure Comparison

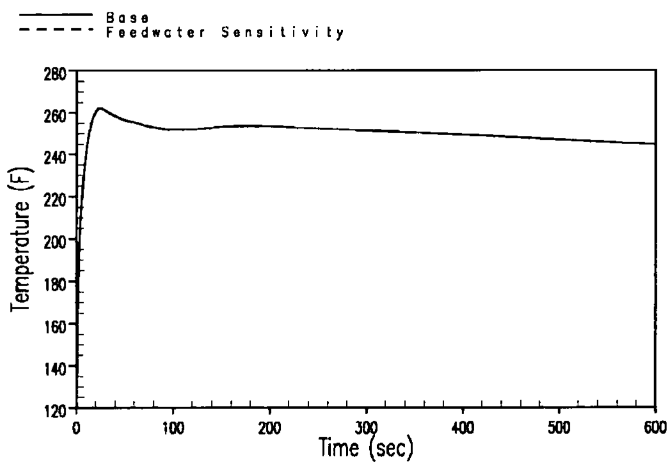

Figure 6 – Containment Temperature Comparison

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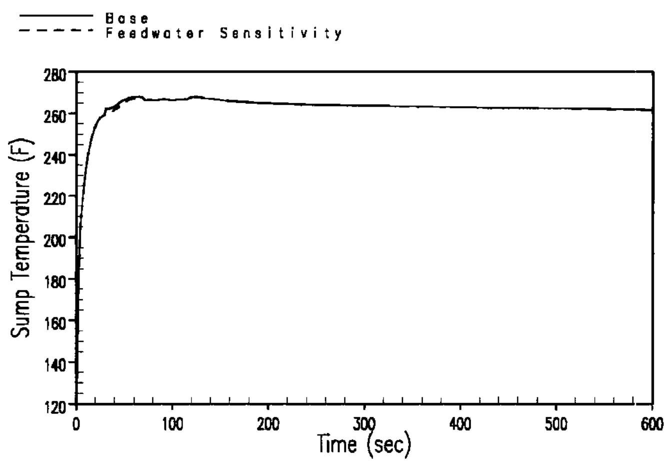

Figure 7 – Containment Sump Temperature Comparison

11. Table C.3-2, Item 25: Please justify that the proposed LOCA M&E release model nodalization [ ]^{a,c} is conservative for all phases of LOCA and meets the American Nuclear Society (ANS) 56.4-1983, Section 3.2.4.1 guidance.

    Westinghouse Response: The WC/T [ ]^{a,c} noding structure is much more detailed than what is used in the current approved LOCA M&E release model, particularly during the reflood and post-reflood phases.

    Nodalization studies performed with WC/T are summarized in Section 19-6 of the CQD, WCAP-12945-P-A. These include LOFT L2-5 (integral test, all phases of the transient), ORNL 3.08.6c (high pressure film boiling heat transfer test, blowdown phase conditions), G-2 Refill Test 743 (refill heat transfer test) and FLECHT-SEASET (reflood heat transfer test).

12. Table C.3-2, Item 33: Please justify that the use of same heat transfer correlation as used in the WC/T ECCS model is conservative for the LOCA M&E calculations and will predict high containment pressure.

    Westinghouse Response: The WC/T ECCS evaluation model uses a standard set of heat transfer correlations (McAdams, Dittus-Boelter, and Chen) to calculate the heat transfer to the RCS from the fuel, RCS metal, SG fluid (through the tubes), and SG metal (to the fluid). The correlations were assessed for a large number of separate and integral tests over a large range of scale and were found to be acceptable for calculating the heat transfer during the LOCA event.

    In order to address the over-prediction of the SG heat transfer as noted in Section C.2.1, the SG heat transfer model was modified and verified adequate for the LOCA M&E calculations as described in Section C.2.2.

13. Section C.3.2: It is not clear from the explanation given for the [ ]^{a,c} as to how this maximizes the long term containment pressure and temperature. Please explain further the contents of second paragraph of this section.

    Westinghouse Response: The long-term containment pressure and temperature increase as the steam mass release rate increases. [

    ]^{a,c}

14. Figure C.4.2-1: Please provide the GOTHIC input file electronic and hard copy for this containment model nodal diagram.

    Westinghouse Response: The GOTHIC containment model input file will be provided. This model was used to test the capability of the codes to run in parallel and to compare the calculated containment response with WC/T LOCA M&E input to the response with WCAP-10325 M&E input.

Note, Westinghouse intends to run the WC/T LOCA M&E release model in a stand-alone mode for plants that do not use GOTHIC for their containment DBA calculations. The following text changes (strikeouts and underlines indicate deletions and additions, respectively) will be made to help clarify this:

Page C-12, Section C.2.1 – The containment response for the M&E calculations is can be calculated with the GOTHIC code (Reference C-24 through C-26). In order to calculate the RCS thermal-hydraulics with WC/T and the containment calculations with GOTHIC, WC/T needs to be was modified to allow running the code in parallel with GOTHIC.

Page C-40, item 1 – The new WC/T LOCA M&E release model will can be coupled with a GOTHIC containment model to calculate the containment response into the post-reflood phase of the event. The SG fluid, metal, and RCS metal energy remaining at the end of the coupled WC/T+GOTHIC calculation will be released, along with the decay heat, in the long-term GOTHIC containment response calculation.

Page C-58, item 26 – The accepted GOTHIC code steam tables are used for the long term LOCA M&E release calculation.

Page C-61, item 32 – [

]a,c

Page C-68, Section C.3.2, second paragraph – The long-term decay heat boil-off calculation is performed in the GOTHIC containment response model.

Page C-68, Section C.3.3 – [

]a,c

Page C-91, Section C.5.2 – As described in Section C.3.2, the long-term LCOA steam release rate is maximized for the GOTHIC long-term EQ analysis.

Page C-94, Section C.5.3 – As described in Section C.3.3, the LOCA steam release rate is minimized for the GOTHIC minimum NPSHa analysis.

15. Section C.6, third paragraph, first sentence: Please specify what acceptance criteria and which NRC regulation are referred to in this sentence.

Westinghouse Response: The text will be modified as follows to clarify this sentence: The WC/T ECCS evaluation model input was biased to produce conservative LOCA M&E releases in accordance with the acceptance criteria documented in NUREG-0800, Section 6.2.1.3.

The standard review plan (SRP) provides guidance for the NRC safety review of various applications. The SRP for the LOCA mass and energy release calculations is provided in NUREG-0800, Section 6.2.1.3. This document lists the areas of review, acceptance criteria, and review procedures. The relevant requirements of the applicable NRC regulations are listed under the acceptance criteria section. Although compliance with the SRP specific acceptance criteria is not required, a comparison of both the new and old Westinghouse LOCA M&E release calculation methodology with the SRP acceptance criteria is provided in Table C.3-1 of WCAP-16608-P, Addendum 1.

16. Figure C.4.3-6: Please explain why the long term containment pressure WC/T curve deviates considerably from the WCAP-10325 curve.

    Westinghouse Response: The WCAP-10325 model performs a deterministic calculation of the LOCA mass and energy releases after blowdown. The remaining post-blowdown RCS and SG energy is assumed to be released in one hour. This assumption is very conservative based on comparisons with test data. The WC/T model performs a mechanistic calculation of the LOCA mass and energy releases. As shown in Figure C.4.3-4, the post-blowdown LOCA energy release rates calculated with the WC/T model are lower than those calculated with the WCAP-10325 model. The lower energy release rate yields a lower calculated long-term containment pressure and temperature.

17. Figure C.4.3-8: Please explain why the WC/T long term containment vapor temperature transient deviates considerably from the WCAP-10325 transient.

    Westinghouse Response: See the response to item 16.

The following RAI questions are requested to clarify the WCOBRA/TRAC (WC/T) model changes to address heat transfer in the steam generators, as described in Section C.2.2 of the topical report:

18. Regarding p C-14,
    a. Provide comparisons between the range of Westinghouse's intended use Unal's correlation and the parametric ranges given in Table 1 from Reference 16 of WCAP-16608 (which include pressure, mass flux, dryout quality, and heat flux). Also provide a comparison between the hydraulic diameters of the test sections from the data provided in Table 1 and the hydraulic diameters which Westinghouse intends to use with Unal's correlation.

    Westinghouse Response: Unal specifies the ranges for which his correlation fits the experimental data. There are three sets of data cited. The table below summarizes/combines all three sets of data.

	Unal
Pressure	*0.1 - 7 MPa*
Mass Flux	*7-100 kg/(m^{2}s)*
Dryout quality	*0.0-0.99*
Heat flux	*0.8 – 22.5 W/cm^2*

    Given the broad range of operating conditions, it is expected that any application of Unal's correlation for expected LOCA conditions would be appropriate.

    For a round tube, the hydraulic diameter is the same as the tube diameter. For the FLECHT tests (WCAP-8583), the ID of the SG tubes were 0.775 inches. For older PWR's, a typical outer diameter of the SG tubes is around 7/8" (with a wall thickness of 40 to 50 mils). Newer PWR's have a typical outer diameter of the SG tubes around 11/16" (with a wall thickness of 40 to 50 mils). Thus, the FLECHT tests represent the expected hydraulic diameters in PWRs.

Unal uses the experimental data from Unal Reference 18 to develop the model and then uses the experimental data from Unal References 12 and 13 to verify the model. Unal Reference 18 is for a 3x3 rod bundle experiment while Unal References 12 and 13 are for single tube experiments. The hydraulic diameter for the tests in Unal Reference 12 is 0.606." Unal Reference 13 could not be found. An article compiling the data from Unal Reference 13 ("Assessment of Post Critical Heat Flux Models with Lehigh Nonequilibrium Data", April 1986) does not contain the actual test dimensions.

For Unal Reference 18, the OD is 0.374" with a pitch of 0.496". This results in a hydraulic diameter of 0.464".

The overall range of hydraulic diameters (including the FLECHT tests) indicate the applicability of Unal's correlation to Westinghouse applications. The table below summarizes the hydraulic diameters.

	Hydraulic Diameter	*Notes*
Unal Reference 12	*0.606"*	*Round tube*
Unal Reference 13	*unknown*	
Unal Reference 18	*0.464"*	*Rod bundle*
Westinghouse	*0.835" or 0.6475"*	*Assuming 40 mil thick walls*
FLECHT	*0.775"*	*Round U- tubes*

b. Depending on the results from above, additional information may be required to justify the use of Unal's correlation. For example, if Westinghouse intends to use Unal's correlation at lower heat fluxes than those listed in Table 1 (i.e. in ranges where the radiative heat transfer may no longer be insignificant compared to the convective heat transfer) additional work may be needed to account for radiative heat transfer. Also, if Westinghouse intends to use the correlation over a small subset of the ranges given in Table 1, a further review of the correlation compared to only the data in the intended range may be necessary. Further considerations may be identified after the comparisons in part 'a' of this question have been addressed.

Westinghouse Response: Unal's correlation will be used within the parametric ranges outlined in his paper.

19. Regarding p C-15, a. Provide comments on Reference 20, with respect to Pasamehmetoglu's requirement that 'there are no non-condensable components in the steam environment.' Is this a correct assumption for the steam generator when this model will be used? If there are non-condensables in the steam generator at this time, justify the use of this correlation, or address the WC/T treatment of non-condensables.

Westinghouse Response: In reality, it is likely that there will be some non-condensable components in the steam environment. WC/T ignores the presence of non-condensable gas in the steam flow. For the post-blowdown LOCA M&E release calculations, the main concern is the transfer of heat from the SG tubes to the RCS steam/water/air mixture flowing through them. Ignoring the non-condensable gas would conservatively over predict the SG heat transfer rate and thus increase the energy release rate to containment. This is a conservative assumption since the presence of any non-condensable gas (e.g. air, N_2, H_2, He, etc.) in the steam results in a significant reduction in heat transfer during condensation.

Accumulation of non-condensable gases near the condensate film restricts the diffusion of vapor from the steam flow mixture to the liquid film on the droplet.

b. Provide the derivation for the dimensionless instantaneous cup temperature found on page C-15 from equation 4 of Pasamehmetoglu's paper. Define terms not defined by Pasamehmetoglu, specifically t_d, D_H, and Vr_{drop}.

Westinghouse Response: [

]^{a,c}

20. Regarding the Biasi correlation, will the parameters in the steam generator be within the ranges for the Biasi correlation?

    Westinghouse Response: The Biasi correlation has been developed based on Critical Heat Flux test data for tubes ranging from 0.12 inches to 1.47 inches (diameters) and tube lengths up to 20 feet. This range of test data covers typical geometry of steam generator tubes (see end of response to question 18). Also, the range of conditions in the test data cover the expected PWR steam generator conditions during reflood. There should be no scaling bias. [Reference: WCAP-12945-P-V1, Section 6.3-4]

21. The comparisons of the proposed revised WC/T results to the currently approved methods do not show the impact of the changes within WC/T. Regarding section C.4.3, provide the same plots with the addition of calculations from the unmodified version of WC/T (without the code updates). Include additional results to show the quench behavior at a few selected locations, and discuss the results comparing the modified WC/T model to the unmodified model for steam generator heat transfer.

    Westinghouse Response: A comparison of the LOCA mass and energy release results from the unmodified WC/T code with WCAP-10325 results was not included in the topical report; however, this was done as part of a feasibility assessment. The results were documented internally and presented in a paper that was published as part of the ICONE14 conference proceedings (ICONE14-89258). The unmodified WC/T RCS model does not include the improved SG noding structure, SG secondary metal, the interfacial heat and mass transfer model, or run in parallel with the GOTHIC containment model.

    The LOCA ECCS evaluation model input deck for a Westinghouse 4-loop, 3600 MWth PWR was used to test the feasibility of using WC/T for LOCA M&E calculations. The LOCA ECCS evaluation model input was biased to generate bounding LOCA M&E release data for the containment model. The system volume was increased to account for measurement uncertainty and thermal expansion. The WC/T STGEN component did not include metal, so the SG secondary water volume was increased to account for the SG secondary metal stored energy and uncertainty in the secondary volume. Additional RCS pipe volumes were

incorporated in the WC/T ECCS evaluation model to include the metal in the SG inlet and outlet plenums. The initial core thermal power, RCS pressure, and RCS temperatures were also increased to include uncertainties. After making these changes, a steady state restart point was created. The initial WC/T model mass and energy was compared with the benchmark LOCA M&E release model mass and energy on a component by component basis to verify the model initial conditions were equivalent before running the transient benchmark comparisons.

The mass and energy release output from the biased WC/T models was compared with the current LOCA M&E release model output for a double ended pump suction LOCA event. The integrated blowdown mass and energy release comparison for the 4-loop plant model is shown in Figures 8 and 9. The biased WC/T model calculated approximately the same blowdown break mass and energy release. The integrated long-term mass and energy release comparison is shown in Figure 10 and 11; the biased WC/T model calculated a lower long-term energy release. An investigation identified the cause of the difference. The calculated SG heat transfer in the biased WC/T model was lower than the non-mechanistic SG heat release from the current LOCA M&E release model; the WC/T SG model was cooling down from the bottom up and the secondary fluid had become stratified.

The mass and energy releases were fed into the corresponding GOTHIC containment model to determine the impact on the containment pressure. As can be seen in Figure 12, the blowdown peak pressure is the same, but because the biased WC/T long-term energy release is lower, the long-term peak containment pressure is at least 5 psi lower than that predicted using the current LOCA M&E release model.

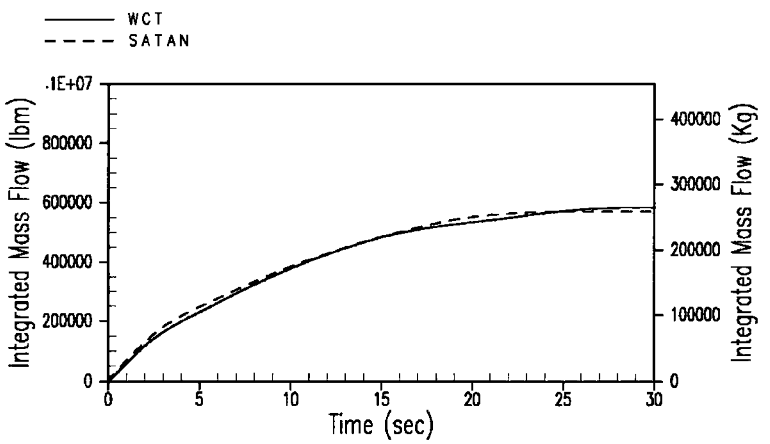

Figure 8 – Biased WCT Integrated Blowdown Mass Release Comparison

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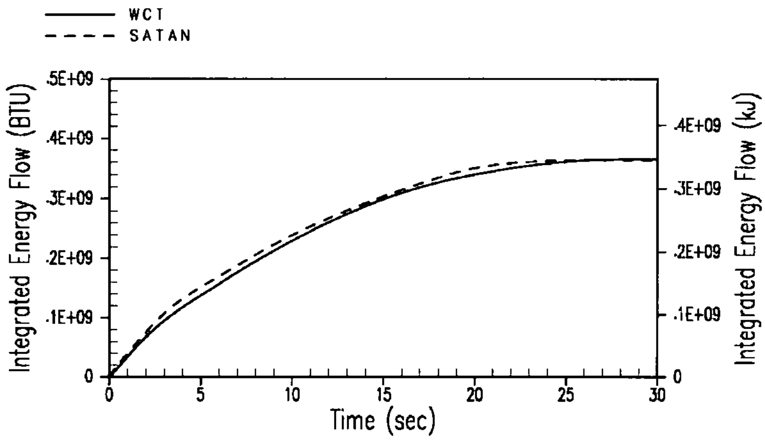

Figure 9 – Biased WCT Integrated Blowdown Energy Release Comparison

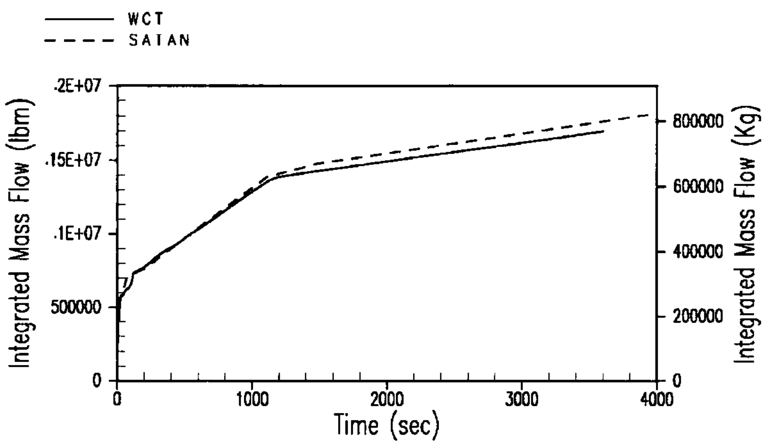

Figure 10 – Biased WCT Integrated Long-Term Mass Release Comparison

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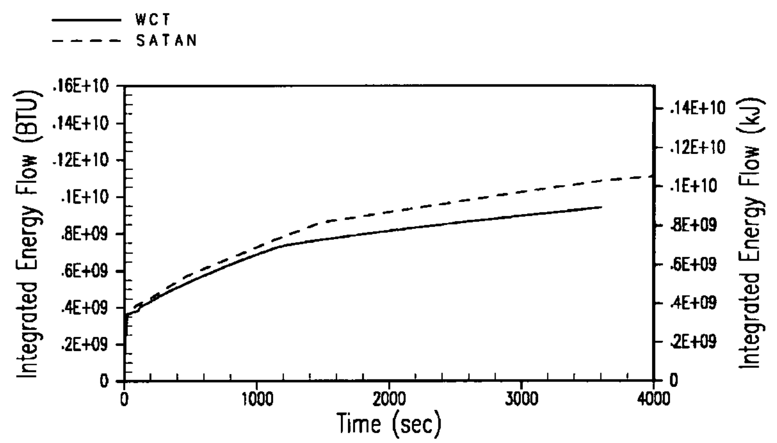

Figure 11 – Biased WCT Integrated Long-Term Energy Release Comparison

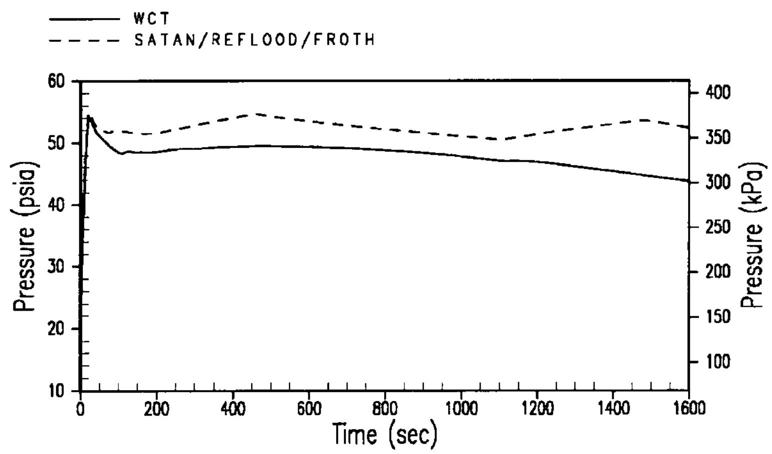

Figure 12 – Biased WCT Containment Pressure Response Comparison

The following RAI questions are requested in order to clarify the WCOBRA/TRAC (WC/T) to GOTHIC interface methodology, as described in Section C.2.4 of the topical report:

22. On page C-35, reference to Figure 3.2, which does not exist, should be changed to the correct Figure, C.2.4-2.

    Westinghouse Response: The text will be corrected in the final report.

23. The mass and energy averaging, described on page C-35, appears to under predict the values if a quantity is monotonically decreasing over the GOTHIC time step range. As presented, it seems that the average is based on the quantity at the end of the WC/T time step multiplied by the time step size instead of using the average quantity over the time step. Address the apparent under prediction of the mass and energy entering the containment, and include the process used to establish and justify the time step size in both WC/T and GOTHIC.

    Westinghouse Response: Figure C.2.4-2 on page C-39 will be corrected; the current figure does not show the calculation of the average break flow and enthalpy in WC/T and the transfer of the average values to GOTHIC. The modified Figure C.2.4-2 is shown on the next page. The highlighted text will be added. The text on page C-34 (Code Implementation-Output interfaces from WC/T to GOTHIC) will also be corrected to be consistent with the changes in Figure C.2.4-2. The mass and energy averaging that was implemented conserves mass and energy transfer across the interfaces from WC/T to GOTHIC.

    The time step size used in WC/T and GOTHIC is consistent with the time step size used in WC/T LOCA calculations and GOTHIC containment analysis calculations, respectively.

a,c

Figure C.2.4-2 Schematic of the GOTHIC – WC/T Parallel Execution

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24. The SI flow can come from GOTHIC (during recirculation) or come from WC/T to GOTHIC for RWT inventory calculations. Please describe the SI modeling in terms of how the flows are obtained in each code, and how the energy in the SI flow is modeled. Is there a period of time, for example during recirculation, when both codes are calculating the SI flow separately? If so, is this one of the verification parameters?

    Westinghouse Response: The SI flow rate is calculated in the WC/T SI FILL boundary conditions by interpolating an input SI velocity vs. RCS pressure table. The RWST temperature is input for the SI temperature in the WC/T LOCA M&E model. WC/T continues to calculate the SI flow rate and temperature until a non-zero recirculation flow rate is received from GOTHIC. At this point, the WC/T SI FILL boundary condition will use the recirculation flow rate and temperature specified by GOTHIC.

    GOTHIC models the RWST. The combined SI flow rate for all loops is passed from WC/T to GOTHIC. The SI and containment spray flow rates are subtracted from the RWST water volume.

    The recirculation flow rate is determined by GOTHIC after the RWST level reaches the setpoint to transfer to recirculation. A constant recirculation flow rate input value was used in the GOTHIC model for the topical report cases. The recirculation flow rate and calculated RHR heat exchanger outlet temperature are passed to WC/T.

    There is no period of time when both codes are calculating the SI flow rates separately.

The following RAI questions are requested to clarify the use of WC/T to obtain the mass and energy releases for the containment peak pressure LOCA analysis:

25. Address how uncertainties in the WC/T core heat transfer models are to be applied. Specifically, during core safety analysis the overall heat transfer coefficient in WC/T would be conservatively decreased due to uncertainties if there was not enough data to justify a more realistic heat transfer coefficient. This decrease in the heat transfer coefficient would be conservative for core safety analysis, as it would decrease core heat removal resulting in more energy remaining in the fuel. However, this decrease in the heat transfer coefficient would not be conservative for mass and energy (M&E) release, as it would decrease core heat removal resulting in less energy transferred into containment. Therefore, consider the uncertainties in the core heat transfer models in WC/T and provide the rationale for applying them to the containment M&E analysis.

    Westinghouse Response: Heat transfer uncertainties are not applied in the WC/T ECCS Evaluation Model. They are applied in the HOTSPOT code, which is a one-dimensional conduction model that uses WC/T calculated fluid conditions as boundary conditions.

    The WC/T ECCS evaluation model uses a standard set of heat transfer correlations (McAdams, Dittus-Boelter, and Chen) to calculate the heat transfer to the RCS from the fuel, RCS metal, SG fluid (through the tubes), and SG metal (to the fluid).The correlations were assessed for a large number of separate and integral tests over a large range of scale and were found to be acceptable for calculating the heat transfer during the LOCA event.

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The uncertainty in the core heat transfer correlations has not been considered for the new WC/T LOCA M&E calculation. Likewise, the uncertainty in the core heat transfer correlations is not considered in the currently approved LOCA mass and energy release methodology.

26. Provide justification of the break flow model in WC/T, with respect to its 20 percent uncertainty. Address the guidance provided in SRP 6.2.1.3, "Mass release rates should be calculated using a model that has been demonstrated to be conservative by comparison to experimental data."

    Westinghouse Response: The TRAC PF1 break flow correlation is programmed into WC/T (see Section 4-8 of the CQD, WCAP-12945-P-A). The WC/T break flow model predictions of the Marviken critical flow data are presented in Section 25-2 of the CQD. The resulting cumulative distribution function is shown in Figure 25-2-10. The 50th percentile value of measured/predicted break flow is about 1.0. Over 90% of the comparisons are within +/- 15%.

    The measured-to-predicted break flow is higher for small values of L/D (<1), but decreases as L/D increases. Most of the uncertainty occurs in the transition from subcooled to saturated flow conditions, which occurs early in the event (see Section 16-4 of the CQD, WCAP-12945-P-A). The L/D for a large double ended pipe break located near the vessel is greater than 1.5. Therefore, for these types of breaks, the TRAC PF1 break flow correlation will slightly over-predict the break flow.

    The WC/T calculated DEHL and DEPS LOCA M&E releases were compared with those calculated using the approved SATAN LOCA M&E model and were found to be very close over the blowdown period. The SATAN break flow correlations were compared with data from other test facilities and were found to over-predict the data (see WCAP-8264).

27. What sensitivity studies were performed to justify the level of detail necessary to adequately model the steam generator? Address both the FLECHT-SEASET model and the PWR model. Is the PWR model expected to be sensitive to the steam generator design, for example the tube design, or pre-heated sensors? If so, please describe the process to be used for other steam generator designs.

    Westinghouse Response: [

    ]^{a,c}

    The WC/T code was revised to improve the calculation of the SG tube quenching process. A standalone SG model was built to compare the revised WC/T code results with the FLECHT test data. A SG noding study was performed using the standalone FLECHT SG model and convergence was obtained when the SG was modeled with [ ]^{a,c} cells in the primary and [ ]^{a,c} cells in the secondary.

    The SG noding in the WC/T LOCA M&E plant model was increased to be similar to the noding structure used for the FLECHT model. The primary side was modeled with [ ]^{a,c} cells and the secondary side was modeled with [ ]^{a,c} cells.

    [ ]^{a,c}

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28. Does Westinghouse plan to use the revised steam generator interface mass/heat transfer exchange package for other accident analyses to be used to support licensing actions? Are there plans to incorporate the model into other computer programs for use in supporting licensing actions?

    Westinghouse Response: No, Westinghouse does not plan on incorporating the revised steam generator interface heat and mass transfer model into other computer programs.