Effects of Internal Containment Stratification and Mixing on AP600 Passive Containment Coolirg System Design Basis Analysis Evaluation Models

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EXECUTIVE SUMMARY

This report provides a summary of the strategy for developing an evaluation model for passive containment cooling system design basis analysis and a framework for assessing the success of the methodology.

The physics of passive cooling in the AP600 plant are described for both loss-of-coolant-accident (LOCA) and main steam line break, and a sound, straightforward approach to developing and justifying the evaluation models relative to stratification and mixing is discussed.

Westinghouse has explored and is developing a detailed model to calculate the pressure transient during the early, peak-pressure stage of postulated design basis analysis LOCA, and a practical, more coarsely noded model for examining the 24-hour criterion for LOCA is being prepared in parallel. A comparison of the coarser model to results from the detailed model, in addition to the scheduled large-scale test (LST) validation, will provide a basis for the acceptability of the coarser calculation through 24 hours. An evaluation model approach for steam line break is currently under development. The characteristics of these evaluation models are described in this report.

A matrix of accident phases versus important phenomena identified by the phenomena identification and ranking table (PIRT) is provided. The well-understood characteristics of the evaluation models allow the use of these matrices to assess the acceptability of passive containment cooling system design basis analysis methodology.

An understanding of the evaluation model approach and its bases enhances a focused review and audit in the most significant areas with regard to containment pressure analyses.

1.0 INTRODUCTION

During the AP600 design program in early 1994, it became apparent that there was a need to establish a phenomenological report on the effects of stratification and mixing on heat removal inside containment during design basis analyses (DBA). The intent was to identify nondimensional groups and scaling considerations relative to stratification and mixing. That objective has been met with the preliminary and final passive containment cooling system (PCS) scaling reports.[1,2] The purpose of this report is to extend the scaling results in order to examine the AP600 PCS evaluation models with respect to mixing and stratification.

In the preliminary scaling report, the phenomena of jet entrainment, wall boundary layer entrainment, and mixing were discussed in some detail. In the final scaling report it was shown that mass transfer is the governing phenomenon. It can therefore be concluded that analysis methods should be assessed relative to parameters that are important to mass transfer. Mixing and stratification inside containment affect mass transfer to the internal containment surfaces; both the PCS and internal heat sinks play an important role. This report provides the following overview relative to mixing and stratification:

- Summary of phenomena related to PCS DBA
- Outline of the evaluation model strategy
- Applicability of the large scale tests (LSTs) for code validation
- Framework for assessing DBA methods

An understanding of the evaluation model approach and its bases enhances a focused review and audit calculation effort in the most important areas relative to containment heat removal.

2.0 CONTAINMENT DESIGN BASIS ANALYSIS REQUIREMENTS

An evaluation model, of the combination of the WGOTHIC computer code and the input, is defined during code validation for the purpose of calculating the containment response to the PCS design basis accidents - LOCA and main steam line break. Examples of the evaluation model definition are shown in Table 2-1.

The containment DBA criteria establish the goal for analyses. The AP600 PCS evaluation model is being used to assess the following criteria:

$P_{peak} \leq P_{design}$ [45 psig (60 psia)]

$P_{24\ hours} \leq 50\%\ P_{design}$

$T(t)_{DBA} \leq T(t)_{Equipment\ Qualification}$

It is necessary to show that the above criteria are met with sufficient margins while accounting for the effects of mixing and stratification.

A re-analysis of the limiting PCS design basis transients is scheduled for May 1995 (Preliminary SSAR Markups). The balance [illegible] report will provide an overview of the evaluation model strategy that will be followed for the S[illegible]bmittals. The pressure transient from the June 30, 1994, PCS analysis[3] is shown in Figure 2-1, and will be used for discussions in this report for reference.

Two evaluation models are being developed for the PCS—one for short-term pressure peaks and one for long term pressure reduction. A distributed parameter WGOTHIC model will be used for peak pressure calculations for LOCA. The LOCA calculation will be carried beyond the second peak through approximately 1000 seconds, during which time the pressure most closely approaches the P_{peak} criterion. A relatively coarsely noded lumped parameter WGOTHIC model will be used to calculate the entire transient through 24 hours. Subsequent portions of this report define the bases of the choice of these PCS evaluation models.

Table 2-1
Passive Containment Cooling System
Design Basis Analysis Evaluation Model

Evaluation Model Part	Aspect	Examples *(In baseline GOTHIC unless noted)*
Code	Models/Correlations	Momentum equation types Pressure drop correlations Flow paths (junctions) ***In WGOTHIC upgrade:*** Heat and mass transfer correlations Liquid film governing equations Wall-to-wall radiation
	Noding Definitions and Junctions	Lumped parameter node Distributed parameter node Flow junctions Boundary conditions
	Governing Equations/Solution Techniques	Matrix solver Time step control Stability criteria Convergence criteria
Input	Design Data	Geometry Flow areas Volumes Protection system configuration
	Noding Selection	Type (lumped/distributed parameter) Size Number Locations Connections
	Accident Boundary Conditions	Mass and energy releases Equipment assumptions
	Initial Conditions	Pressure Temperature Humidity Ambient conditions
	Model/Correlation Selection and Input	Uchida condensation correlation Friction factors ***In WGOTHIC upgrade:*** Channel correlations for external heat and mass transfer Flat plate correlations for internal shell heat and mass transfer

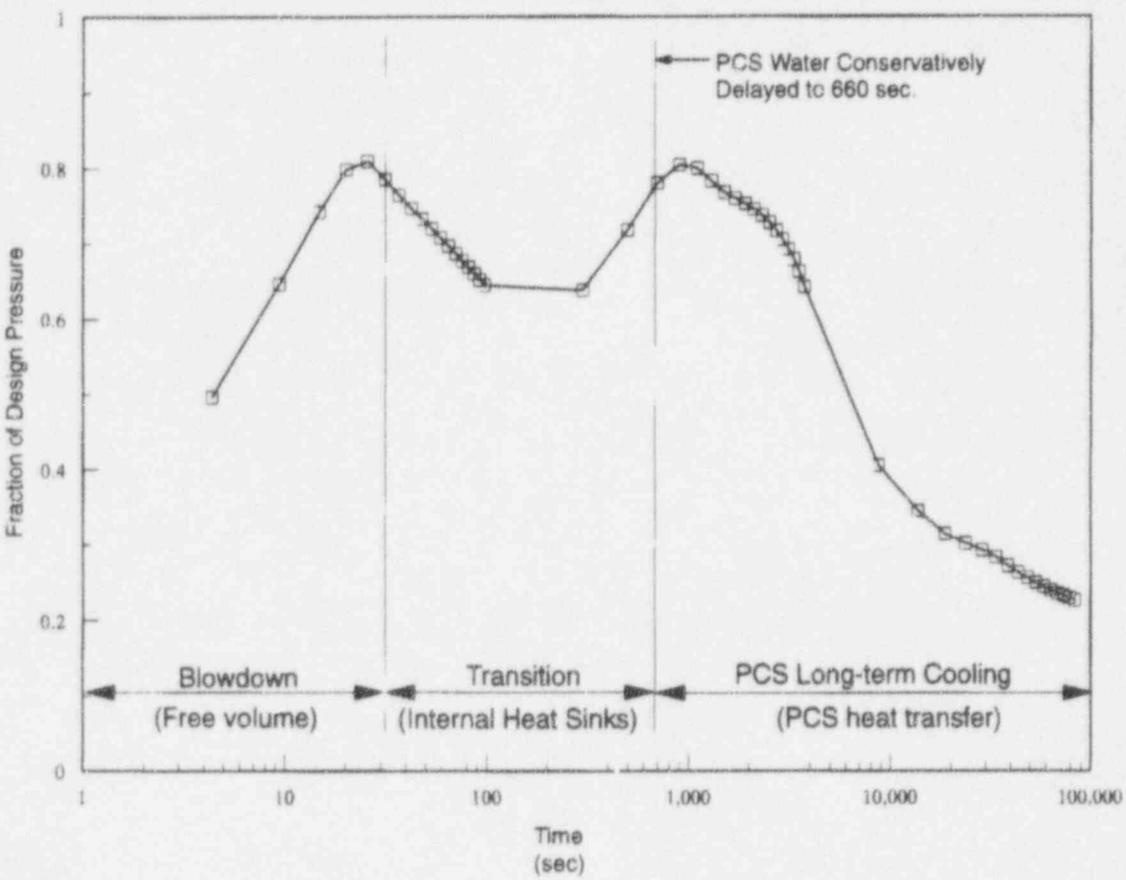

Figure 2-1 AP600 PCS LOCA Design Basis Analysis Pressure Transient (from Reference 3)

3.0 MIXING EFFECTS ON AP600 CONTAINMENT PERFORMANCE

The final scaling report[2] concluded that mass transfer is the dominant phenomenon governing heat transfer through the containment shell. The degree of mixing within the AP600 containment affects mass transfer. The dominant phenomena affecting mixing are different during each accident/phase, for example LOCA blowdown, LOCA long-term cooling, and steam line break. The amount of steam and noncondensible mixing predicted by WGOTHIC affects mass transfer rates calculated by the evaluation model due to the strong effect noncondensibles have on condensation mass transfer. The following discussion of the effects of mixing in AP600 and the influence of the evaluation model on mixing predictions provides a basis for assessing the evaluation model.

3.1 AP600 Design Characteristics with Respect to Mixing

The AP600 design is conducive to mixing. Table 3-1 provides a comparison of parameters related to mixing between the regions above and below the operating deck; the comparison is made with a current 4 loop Westinghouse plant for which design data is readily available; therefore, relative values are used in this comparison. The AP600 relative flow area through the deck, or deck porosity, will be similar to that in a standard plant, so the resistance to mixing between regions below and above deck is similar. The AP600 containment will have more area through the deck relative to the volume to be mixed, so that similar driving forces through the operating deck would have even more propensity to mix the entire containment volume than in current operating plants.

The AP600 design also has compartments below deck with relatively open interconnections. Table 3-2 summarizes these AP600 design features. As can be seen, the AP600 has even greater propensity for mixing than standard Westinghouse operating plants. These characteristics are considered in the input to the PCS evaluation model related to flow paths.

3.2 Mixing Effects on Mass Transfer

Plumes and jets entering a containment atmosphere and entrainment into wall boundary layers provide sufficient driving forces to move steam to the containment wall, so that mass transfer is limited by the ability of steam to diffuse through the boundary layer to the containment wall at a given elevation. Mass transfer is affected primarily by the bulk-to-film steam partial pressure difference near the condensing surface. It is also affected to some extent by velocity near the condensing surface, as is the case with high kinetic energy such as that which occurs with the high velocity steam jet released in steam line breaks.

Mass transfer surfaces can be considered in two categories—the PCS (containment shell) and the internal heat sinks (primarily below the operating deck). The heat removal by internal heat sinks is dominant during steam line break and the early phase of a LOCA, and heat removal by the PCS becomes dominant in the long-term cooling after a LOCA.[2] For a main steam line break (MSLB), the PCS heat sink is not dominant during the early limiting portions of the transient. Steam line releases, typically less than 500 seconds in duration, are limited by steam line and feedwater isolation and steam generator dryout. Longer term cooling and depressurization of the containment is provided by the PCS; however, since there are no long-term steam line releases, long-term containment response is bounded by the long-term LOCA. The following discussion shows how these physical processes can be related in a matrix for assessing the evaluation model.

Table 3-1 AP600 Design Characteristics Relative to Mixing Comparison of AP600 to Standard Large Dry Containment		
Parameter	**Current Plant (4 loop)**	**AP600**
Containment Free Volume (ft^3)	3.1 x 10^6	1.7 x 10^6
Containment Plan View Cross Sectional Area at Deck Elevation (ft^2)	15,400	13,300
Approximate Flow Area Between Lower Compartments and Above Deck Volume (ft^2)	~2,800	~1,900
Flow Area Relative to: Deck area	~18%	~14%
Flow Area Relative to: Free volume (ft^2/ft^3)	~0.9 x 10-3	~1.1 x 10-3

Table 3-2 "Porosity" within and from Lower Compartments in AP600		
Mixing Location	**AP600 Design Features Relative to Operating Plants**	**Expected Mixing Effect**
Within Lower Compartments	• Valve and CMT rooms have stairwells with large openings instead of closed doors • Lower compartments not sectioned off into small rooms; compartments are larger and more open	• Large, open, well connected lower compartments are conducive to mixing
From Lower Compartments to Open Volume	• Accumulator room is small open volume with stairwell open to volume above deck • CMT room is 30% of containment volume, with operating deck grating and stairwells, so compartment is very open to flow communication • SG (loop) compartments are open with grating at top and doorway at bottom	• Flow paths from lower compartments to open volume above deck are conducive to mixing

A stratified fluid can be defined as a volume of fluid with negligible horizontal density, temperature, or concentration gradients. A stratified volume may have vertical gradients or may be vertically well-mixed. The physics of a buoyant plume entering a large volume lead to a stratified fluid and any resulting axial gradient will have a higher concentration of the lighter fluid at the top (for example, richer steam concentrations at the top). Since there are negligible horizontal gradients in a stratified fluid, the distribution of steam and noncondensibles in containment can be represented by the axial steam density gradient, $\partial\rho/\partial z$. This definition is convenient for discussing the effects of mixing on heat removal by the two categories of heat transfer surfaces: the internal heat sinks located below the operating deck, and the PCS above the operating deck.

For low Froude numbers, there is negligible momentum introduced by the break flow, velocities are low, and mass transfer is dominated by free convection. For high Froude numbers developed during steam line breaks, the momentum leads to mixing throughout containment and to higher velocities along the walls, which enhances mass transfer due to mixed (free and forced) convection. Thus, for high Froude number jets, the effects of velocity must also be considered.

Therefore, the assessment of an evaluation model for inside containment can be reduced to examining models relative to how they affect $\partial\rho/\partial z$, and velocities near the containment shell and how these parameters affect mass transfer rates to solid surfaces as a function of time during a transient.

3.3 Mixing in the AP600—Loss-of-Coolant Accident (LOCA)

The postulated LOCA is a double-ended guillotine break of a primary system reactor coolant pipe, which releases significant quantities of high temperature, high-pressure steam and water inside the steam generator compartment. As shown in Figure 3-1 the steam that pressurizes containment circulates and condenses on the internal containment walls. Heat is ultimately removed from containment by evaporation of PCS liquid film to air flowing through the external PCS flow path. The focus of mixing discussions is on how the steam circulates and mixes with noncondensibles within containment.

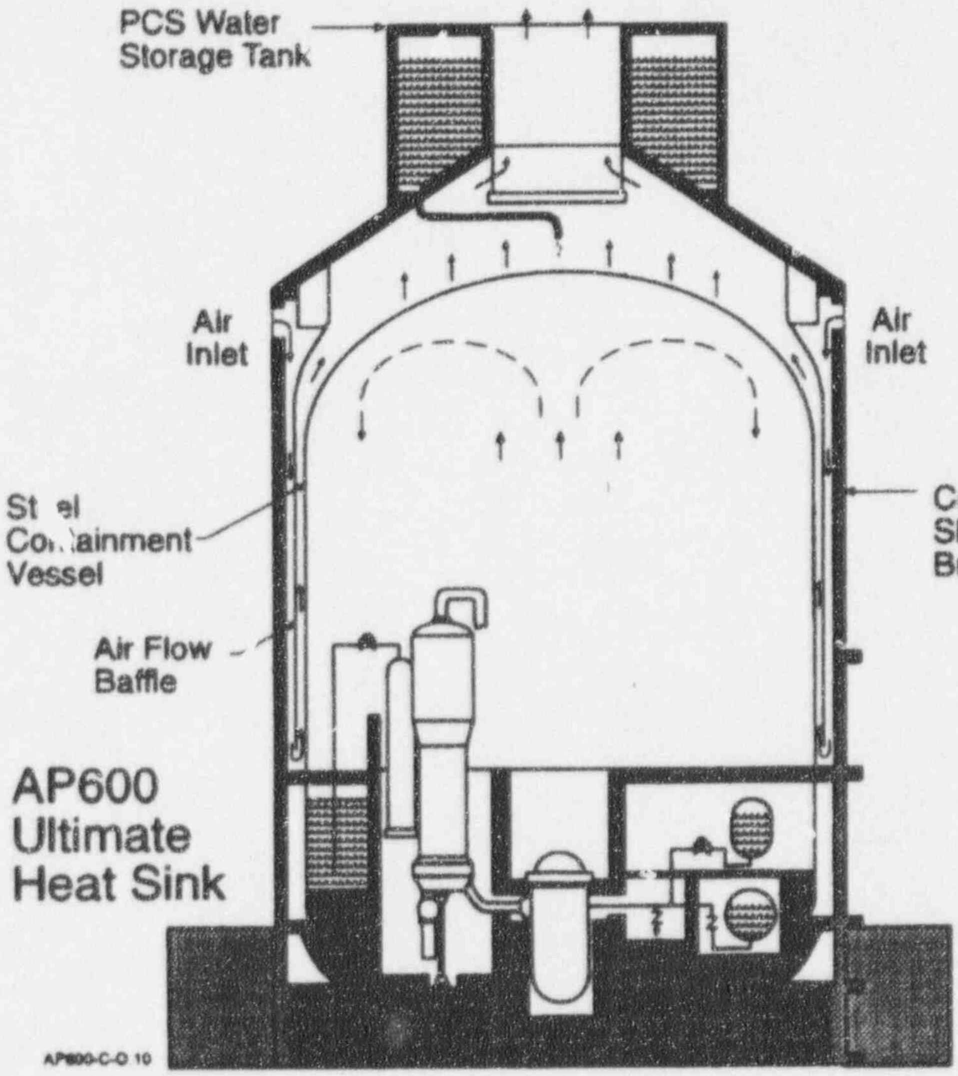

Figure 3-1 AP600 Passive Containment Cooling System Arrangement

Mixing inside the AP600 during a LOCA is dominated during blowdown by pressure-driven flows, and during long-term cooling by large-scale natural circulation driven by density head differences in adjacent compartments. During long-term cooling, additional mixing within the open volume above the operating deck occurs because of entrainment into the steam-rich plume rising from the steam generator compartment.

During blowdown, the steam generator compartment pressurizes by about 2 psi relative to adjacent compartments, forcing flow out of all openings from that compartment. This can be seen in Figure 3-2 where the pressure difference between the steam generator and adjacent compartments is shown as a function of time through blowdown. The evaluation model should be assessed relative to its ability to predict containment pressure under blowdown conditions of pressure-driven flow.

Because of the pressure-driven flow during blowdown, lower compartments become filled with relatively high steam concentrations. This leads to mixing during the transition to long term as the hotter, lighter steam rises and is replaced by cooler, drier gases from the boundary layers on condensing surfaces. During blowdown, the containment pressure is governed by volume pressurization. During the transition to long-term cooling, internal heat sinks, which are primarily below the operating deck, begin to absorb energy and reduce pressure.

As the transient progresses to long term, cooler, drier gases fall down along the walls and fill the bottom of containment up to a level at which they can be entrained into the break room. A quasi-steady flow field is reached relatively quickly, and is shown qualitatively in Figure 3-3.

Evaluations of larger scale containment test data (NUPEC M-4-3,[4] HDR[5,6,7]) have shown qualitatively that mixing within containment is strongly affected by the elevation of the steam injection. When steam is introduced at a low elevation, mixing occurs due to large-scale circulation driven by the density head in compartments adjacent to the break room. There is also a degree of mixing within the volume above the operating deck where the gases exit the steam generator compartment, since the rising plume entrains gases above the operating deck. While the NUPEC and HDR tests are in many ways dissimilar to AP600, these general mixing phenomena are expected to be qualitatively similar for AP600. Since the Froude number for a LOCA is very low, there is effectively no mixing due to momentum in the long term. The evaluation model should be assessed by its ability to model the longer term LOCA containment mixing phenomena of density head circulation and plume entrainment.

3.4 Mixing in the AP600—Main Steam Line Break (MSLB)

The limiting portion of the MSLB scenario is short (less than 600 seconds) since the accident is terminated by the main steam isolation valve and feed water isolation. Since the PCS

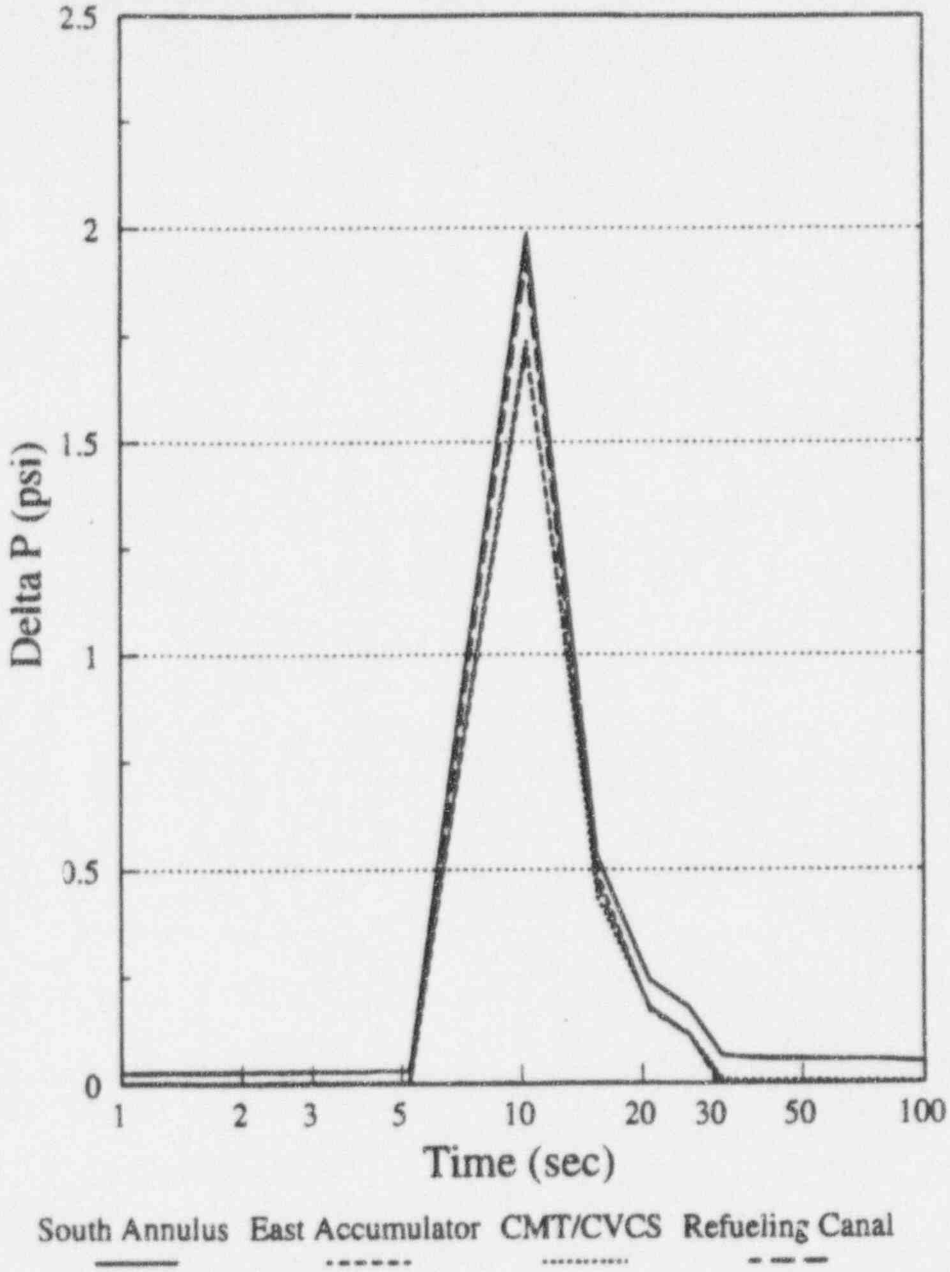

Figure 3-2 AP600 LOCA Break (Steam Generator) Compartment Relative Pressurization

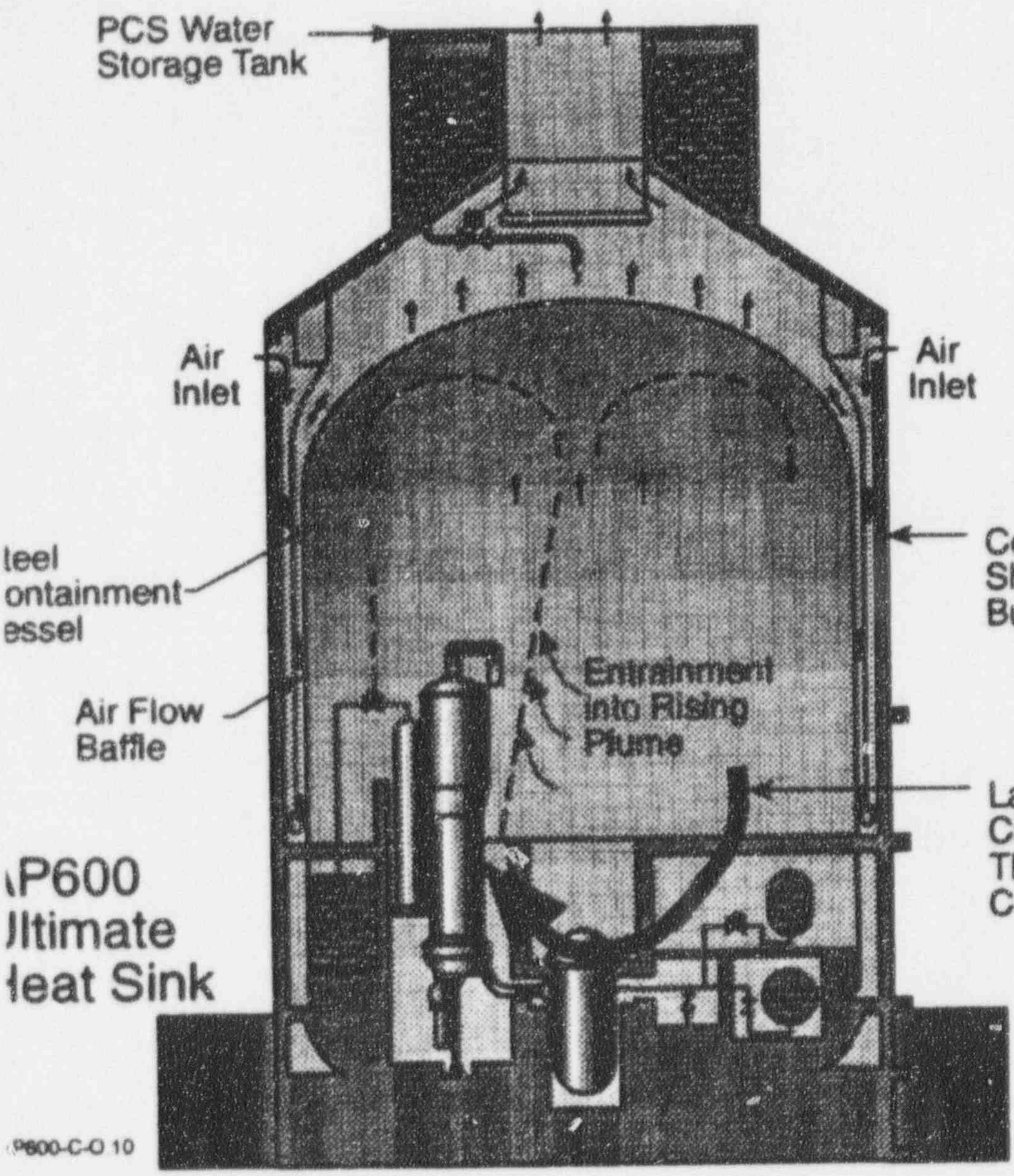

Figure 3-3 AP600 PCS Containment Vessel - Steam/Noncondensible Mixing Mechanisms during Long-Term LOCA

external water is not assumed to be available until 660 seconds, the PCS has no influence on MSLB performance. The high Froude numbers associated with MSLB indicate that the break results in very high kinetic energy into containment. In addition, the limiting steam line breaks occur at the elevation of the main steam line at the top of the steam generator, resulting in very high momentum flow introduced into the containment, tending to drive the containment to a well-mixed condition.

The LST tests with 3-inch steam delivery pipe achieve Froude numbers representative of an MSLB. The data show mixing throughout the test vessel. Thus, for the MSLB, the AP600 is expected to be well mixed throughout containment, both above and below deck. Test data evaluations based on the LST are being performed to confirm the expected mixing. These will be factored into the development of an evaluation model for MSLB which can be assessed according to the framework provided herein.

4.0 EVALUATION MODEL ABILITY TO PREDICT AP600 PERFORMANCE

The following section summarizes the modeling capabilities of the WGOTHIC transient momentum equation formulations and the effects of the formulation and noding on the ability of the evaluation model to predict AP600 performance. A discussion of the two momentum formulations as they will be applied to AP600 DBA is given, followed by the effects of relative heat removal by the internal heat sinks versus the PCS as the transient progresses. Model validation for blowdown calculations is also discussed.

4.1 WGOTHIC Momentum Formulation and Noding Effects on Mixing

The traditional single-node containment code and WGOTHIC formulations are compared and contrasted in Figure 4-1. The lumped parameter formulation in WGOTHIC differs from traditional single-node codes. In single-node codes, the entire open volume is represented as one node and there can be no resolution of velocities or noncondensible distributions within containment.

WGOTHIC provides analysis capabilities beyond those of containment codes used for operating plants. The following are definitions of key terms used in WGOTHIC discussions. For PCS DBA evaluations, compartments below deck are modeled in WGOTHIC as lumped parameter volumes in a node-network solution, which is referred to as the *lumped parameter formulation*. In this formulation, a transient momentum equation is solved[9, pp. 11-18 through 11-19] through the junctions joining nodes. For pressure and density head-driven flows that exist below deck, node-network solutions, such as the WGOTHIC lumped parameter formulation, are acceptable. The transient momentum equation for flow *junctions* linking the volumes provides a coarse representation of transient fluid velocities, and the discretization of the containment allows coarse representation of steam/air concentrations throughout containment.

Based on LST validation, an accurate representation of entrainment into a buoyant plume rising into an open volume requires a more detailed model than can be obtained with lumped parameter volumes. WGOTHIC includes a finite difference solution to the transient momentum equation within an open volume[9, pp 11-12 through 11-18] which, when taken with relatively large node sizes, is referred to as the *distributed parameter formulation*. The distributed parameter formulation is a user option to define a more detailed matrix of nodes within an open volume. Such a *subdivided volume* allows a better resolution of flow fields such as those arising from plume entrainment. Subdivided volumes can be connected to lumped parameter volumes below deck using junctions, as described below.

The WGOTHIC evaluation model predictions for AP600 have well-understood characteristics. The distributed parameter formulation of the momentum equation in WGOTHIC, in combination with sufficient nodes in critical locations, has been shown to provide a reasonably detailed resolution of velocity and noncondensible distributions within the LST.[8] Additional validation for MSLB is currently underway.

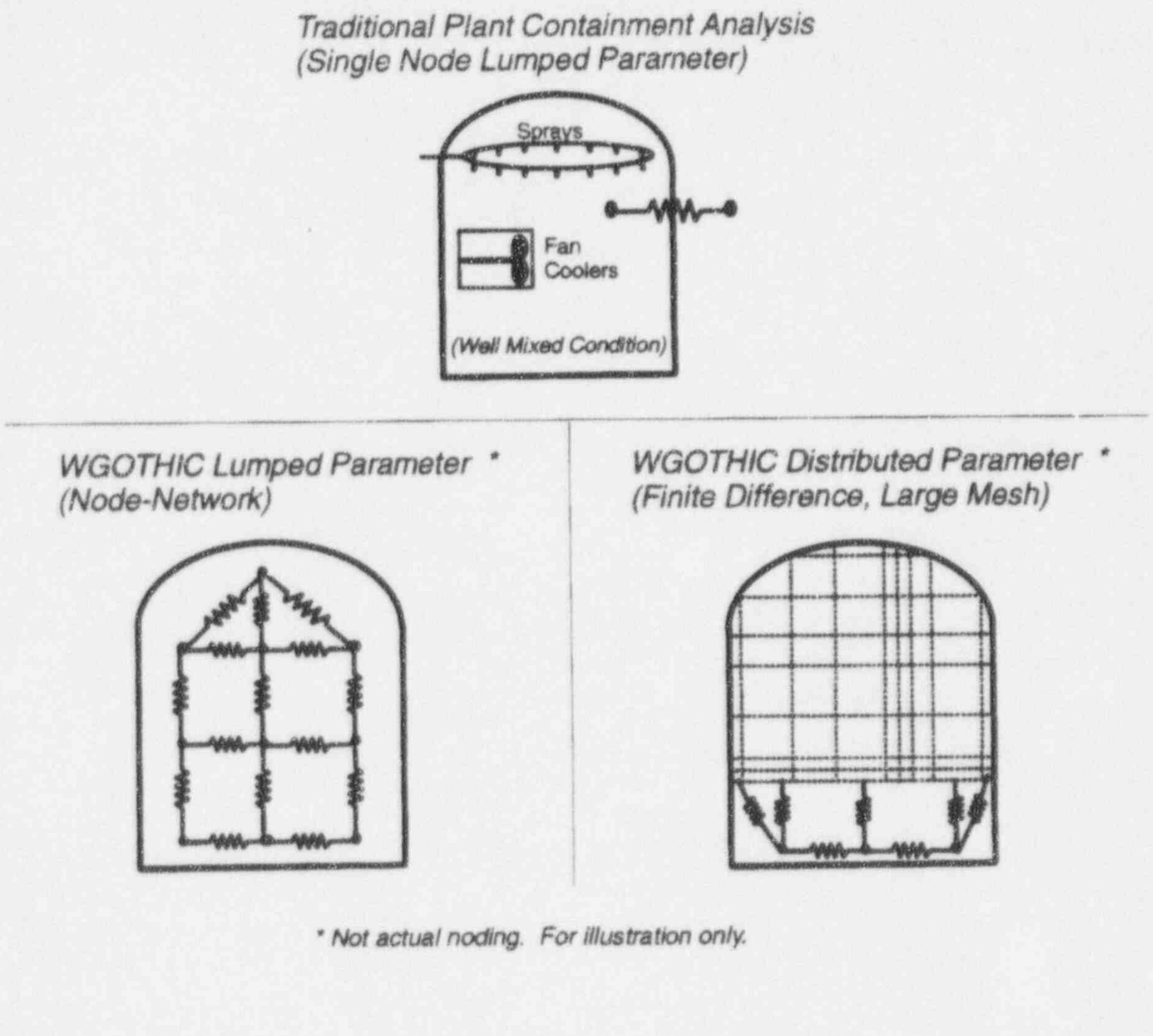

Figure 4-1 Comparison of Traditional Lumped Parameter Containment Codes to WGOTHIC Momentum Formulations

The distributed parameter model will be used to evaluate short term peak pressures of the LOCA. The distributed parameter model requires long compute times which make its use for evaluating the 24-hour pressure criterion impractical. Therefore, a less detailed lumped parameter model will be used to evaluate the 24-hour pressure criterion when containment pressure is well below the design pressure. Comparison of the results of distributed and lumped parameter models over the first 1000 seconds of a LOCA is expected to show that the lumped parameter model is a reasonable basis for evaluation of the AP600 long-term cooling. The following sections provide some background considerations which set the stage for an evaluation model assessment.

4.2 Heat Transfer Surfaces in Design Basis Analysis (DBA) Models

The axial steam density gradient can be examined relative to its effect on mass transfer to surfaces, the dominant process for pressure reduction. Surfaces on which mass transfer takes place can be divided into two categories, the heat sinks that are primarily located below the operating deck ("heat sinks"), and the interior PCS vessel surface that is above the operating deck ("PCS surface"). The dominant surfaces for heat removal are different depending on the postulated accident and the time in the transient.

In the postulated DBA LOCA, the final scaling report showed that pressure mitigation is dominated by volume pressurization and heat sinks below deck during the early parts of the transient. During the LOCA blowdown phase the PCS vessel surface can be considered simply as an externally adiabatic heat sink above deck, representing only a fraction of the total heat transfer surface area available.

The PCS becomes the dominant heat removal surface during the LOCA long-term heat removal phase. During the same period, heat sinks below deck become saturated and eventually become heat sources.

Postulated steam line breaks are over in about 600 seconds, so that the PCS is not the dominant heat removal surface during the limiting portion of that transient, although the containment shell metal heat capacity does contribute to total heat removal.

4.3 Distributed Parameter Model for Peak Pressure Calculations

The distributed parameter evaluation model provides increased resolution to more accurately represent entrainment into a rising plume above the operating deck. Compartments below deck are modeled with lumped parameter nodes—one per compartment, and the Uchida condensation mass transfer coefficient is applied to all internal heat sinks.

For-long term heat removal, the LST has provided a database from which to establish a valid distributed parameter model.[8] The distributed parameter model has shown good agreement with LST measured noncondensible distributions, total pressure, and available velocity measurements as well as with other local test data from the extensive LST instrumentation. Noding studies have led to a final distributed parameter LST model. A corresponding AP600 distributed parameter model is being built.

4.4 Lumped Parameter Model for LOCA—Long-Term

For LOCA long-term containment cooling, the lumped parameter model of the LST has been shown to slightly over-predict the containment vessel pressure.[8] This results from two competing effects: over-mixing of noncondensibles in the vessel, and over-predicting the velocity. Both effects are caused by the tendency of lumped parameter models to over-entrain.

The impact of these competing effects on pressure in a lumped parameter model are as follows. In the long term, heat removal is dominated by the PCS. Over-mixing carries noncondensibles above the operating deck, and increased noncondensibles above the operating deck degrade mass transfer, thereby penalizing PCS heat removal. Therefore, over-mixing tends to *increase the predicted pressure* for long-term cooling.

Over-predicting velocity tends to over-predict heat and mass transfer using mixed free and forced convection correlations, and therefore tends to *decrease the predicted pressure*. The balance between mixing and velocity yields a slight net over-prediction of pressure for the LST.[8]

The AP600 internal mass transfer is expected to be dominated by free convection during a LOCA based on the relatively low Froude number. Forced convection effects will be neglected in the lumped parameter evaluation model, that is, the mixed convection correlation will be disabled by setting the forced convection component to zero, effectively eliminating the calculated velocities from consideration. Therefore, assessing the lumped parameter model will reduce to consideration of its ability to predict mixing.

The LST does not have a flow path into the simulated steam generator compartment (see Section 5.1), so that the tests show a rather steep axial steam density gradient that is not well represented by the LST lumped parameter model. The AP600 has sufficient flow area into the steam generator compartments to allow large-scale circulation, so that the plant is expected to be well mixed (see Section 3.3). Since the AP600 is expected to be well mixed and dominated by free convection, the use of the lumped parameter evaluation model, with free convection only, will provide a good representation of the AP600 conditions.

Validation of the use of the lumped parameter evaluation model will be based on comparisons to LST covering a range of conditions expected in the AP600. Comparisons between the lumped and distributed parameter results over the early limiting portion of the containment response transient will provide additional support for the use of the lumped parameter for long term depressurization.

4.5 Model Assessment for LOCA Blowdown

The lumped parameter model is being validated by comparison to CVTR tests, and by comparison to standard review plan methodology. During the AP600 blowdown (the first 30 seconds of the transient) containment pressure is governed by volume pressurization, with the second order effect of heat removal by internal heat sinks, including the containment shell heat capacity, similar to current operating plants. Since the AP600 design is at least as open to mixing as currently operating plants, the CVTR tests are equally applicable for AP600 blowdown methods validation.

For currently operating plants, the standard review plan allows, a single-node containment code using the Uchida correlation, based on CVTR test comparisons. A comparison will be provided between the WGOTHIC code and CVTR data using a single WGOTHIC node with Uchida specified for the total heat transfer coefficient. The WGOTHIC single-node results will be compared to results of a similar GOTHIC comparison to CVTR data.[10: Figure 15-4] The single-node/Uchida WGOTHIC model can therefore serve as a basis for comparison to validate the evaluation models during blowdown, while the external containment surface can be considered to be adiabatic.

To provide additional comparison to current plant methodology, the single-node/Uchida WGOTHIC will be run with AP600 blowdown mass and energy releases and compared to the evaluation models. The blowdown pressurization predicted by the evaluation model is expected to be similar to that of the single-node/Uchida case; therefore, the evaluation model is expected to be equivalent to models in the standard review plan for blowdown calculations. The AP600 is expected to perform equivalently to standard Westinghouse operating plants using approved methodology during blowdown.

4.6 Evaluation Model Assessment Matrix

A matrix of accident phases and important phenomena are shown in Table 4-1, along with an indication of the dominant heat sink surface for the accident phase and whether or not velocity plays a significant role. The framework of Table 4-1 can be used to systematically assess the evaluation model. In later sections, the matrix is applied specifically to the LOCA phases of interest.

Table 4-1 Matrix for Systematic Assessment of PCS Evaluation Model			
	Consideration for Accident/Phase		
Parameter Influencing Mass Transfer	LOCA (0-1500 seconds)	LOCA (>1500 seconds)	MSLB (0-600 seconds)
$\partial\rho/\partial z$	• Blowdown steam distributions lead to initially well mixed containment • Heat sinks below deck are dominant surface during transition	• For the low elevation break, large scale circulation leads to well mixed containment • PCS is dominant surface	• High-momentum jet leads to well mixed containment • Heat sinks below deck are dominant surface
Velocity	• Negligible effect (free convection dominated) after blowdown • Volume pressurization is dominant mechanism	• Negligible effect (free convection dominated)	• Significant effect (forced convection dominated)

5.0 WGOTHIC VERIFICATION AND VALIDATION WITH LST

The LST is a credible database for validation of WGOTHIC. This has been shown through a detailed scaling analysis.[2] The following provides a brief summary of the most important considerations for code validation—atypicalities identified in scaling analyses and the ranges of noncondensible concentrations in the above deck region near the PCS.

5.1 LST Scale Atypicalities

The scaling analysis identified two atypicalities in the LST facility relative to the AP600: a small yet higher fraction of cooling in the test due to sensible heating of the external liquid film; and the lack of a flow path into the simulated steam generator compartment in the LST. Since sensible heating of the liquid film is a relatively small fraction of the total heat removal in both AP600 (5 percent) and LST (5 to 20 percent), and a mechanistic (and therefore, scalable) model of the sensible film heating is included in WGOTHIC, this is not a significant atypicality for internal mass transfer. The effect of higher cooling rates in the LST database is simply to increase the range of condensation rates over which WGOTHIC is validated.

The lack of a flow path into the simulated LST steam generator compartment, shown in Figure 5-1, has two effects relative to code validation. The first is that the LST has a more emphasized axial gradient since there is no large scale circulation through the operating deck as shown in Figure 3-3 for the AP600. Mixing in the LST at low Froude numbers is therefore driven only by entrainment into the plume rising out of the simulated steam generator compartment, and not by a density head driven large-scale circulation through the below-deck regions. Since entrainment into a plume is one of the more difficult phenomena to model with a containment code, the LST provides a rather severe test for WGOTHIC validation.

At high Froude numbers, mixing is also driven by momentum introduced by the high velocity jet. The lack of a flow path into the simulated steam generator compartment provides additional resistance to mixing, and therefore causes the LST to conservatively under-represent mixing in the AP600 due to momentum. Even so, the LST still showed near perfect mixing at Froude numbers as low as the minimum that occurs during the limiting portions of an AP600 MSLB.

Based on the above discussions, the LST atypicalities relative to AP600 identified by the scaling analysis can readily be factored into the WGOTHIC code validation.

5.2 Range of Noncondensibles above Operating Deck

The LST database covers a wide range of internal conditions. The range of conditions includes a wide range of noncondensible concentrations above the operating deck, which compares favorably to the range of noncondensible concentrations expected in the AP600.[11]

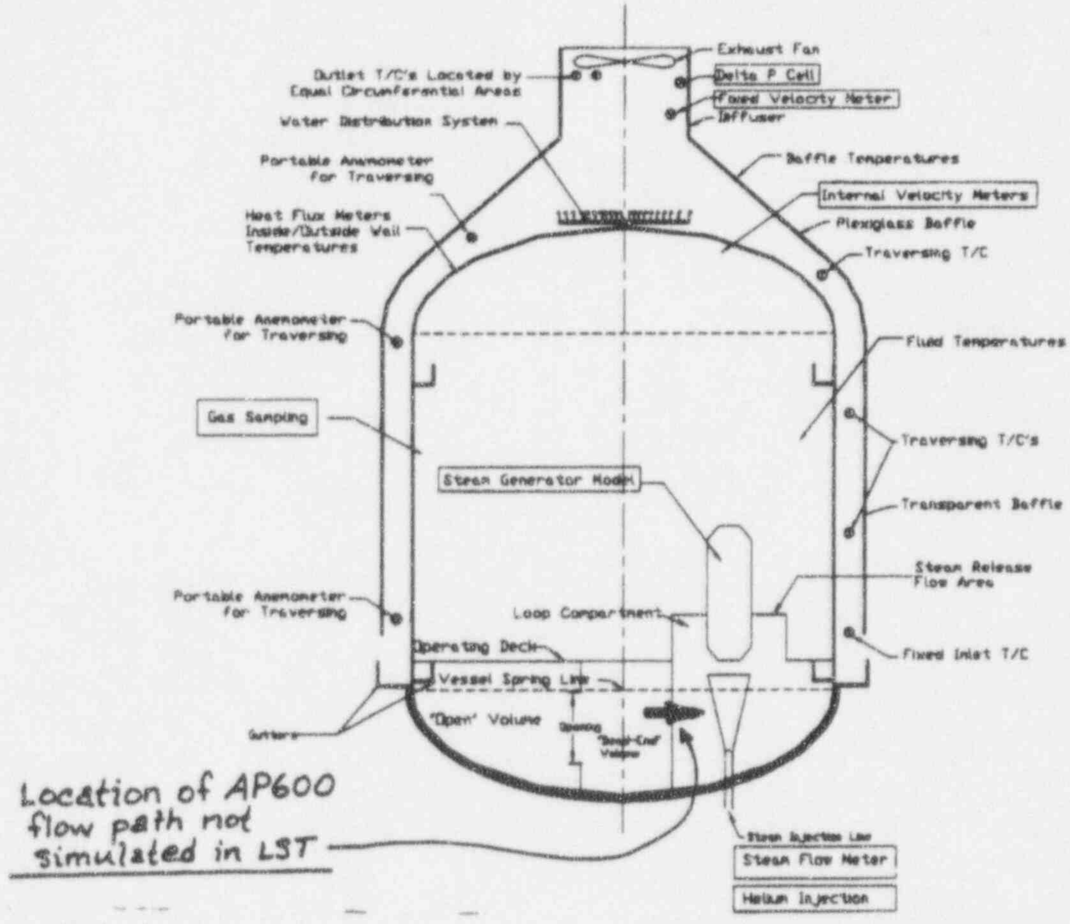

Figure 5-1 PCS Large Scale Test Configuration for Tests Applicable to WGOTHIC Validation for LOCA

5.3 Tests Selected for WGOTHIC Validation

The phenomena identification and ranking table (PIRT) developed in the scaling evaluation identifies the most important phenomena for predicting containment pressurization. Based on the PIRT and the considerations discussed above, LST runs have been selected that address code validation for the parameters with the largest effect on vessel pressure. The bases for selection of LST cases for code validation have been discussed with the NRC.[8]

Data from the entire LST database is also being used to examine such topics as:

- The validation of heat and mass transfer correlations in an integral setting
- The degree of mixing as a function of Froude number
- The effects of break elevation and orientation

Therefore, there is a sufficient database being utilized for WGOTHIC validation, as well as methodology and phenomena validation.

6.0 FRAMEWORK FOR PASSIVE CONTAINMENT COOLING SYSTEM EVALUATION MODELS

A detailed model of the LST has been constructed consisting of a relatively large number of nodes interior to containment, a distributed parameter momentum formulation, and the best available thermal-hydraulic correlations. The model has been developed through noding sensitivities and by incorporating mechanistic models for the dominant phenomena. The mechanistic models include boundary layer heat and mass transfer correlations with noding sufficient to define properties for use in the correlations. This model is referred to as the distributed parameter evaluation model.

The AP600 distributed parameter evaluation model will be used to calculate the LOCA peak containment pressure which occurs prior to approximately 1000 seconds. The phenomena in this model are well represented. A coarser noded, lumped parameter model will be used to calculate containment pressure through 24 hours, when the pressure is well below containment design. Thus, there will be two PCS DBA evaluation models as shown in Table 6-1.

Table 6-1
PCS Evaluation Models for AP600 DBA

	Accident/Phase		
	LOCA (0--1000 seconds)	**LOCA (1000 seconds -24 hours)**	**MSLB (0-600 seconds)**
PCS DBA Evaluation Model	Distributed Parameter	Lumped Parameter	(Currently under investigation)

Support for the acceptability of the evaluation model will be drawn from the areas of scaling, code validation and test comparisons, and uncertainty and margin assessments. The primary source of conservatism is in boundary and initial conditions as shown in Figure 6-1. The evaluation models have well-understood characteristics that can be assessed according to the matrix in Tables 5-1 and 6-1. A code uncertainty will also be appropriately considered. Tables 6-2 through 6-4 provide a more detailed breakdown of the considerations of dominant phenomena during a LOCA according to the approach outlined in Tables 5-1 and 6-1. A similar framework for evaluating MSLB is under development.

An assessment of the margins due to these code inputs has been provided previously.[3]

Table 6-2 Assessment of LOCA Blowdown (0-30 seconds)			
Topic	**Evaluation Model Characteristic Relative to Topic**	**Effect of Characteristic**	**Basis for Characteristic**
$\partial\rho/\partial z$	During blowdown, break compartment pressurizes Both distributed parameter and lumped parameter models use node-network below the operating deck	Blowdown pressurization will drive mixing throughout containment. Node-network solution will show steam is driven into lower compartments during blowdown	For the relatively high pressurization of the break compartment, a lumped parameter (node-network) formulation is applicable below deck. The evaluation models will provide a reasonable initial condition for transition and long term cooling. The Evaluation Model is expected to give results similar to SRP 6.2 methods (single node, Uchida). AP600 design is more conducive to mixing than standard plants.
Velocity	*Distributed Parameter* Use mixed convection for PCS and Uchida for internal heat sinks *Lumped Parameter* Use free convection for PCS and Uchida for internal heat sinks	Heat transfer to surfaces is not dominant during blowdown.	*Distributed Parameter* Low velocities effectively give free convection *Lumped Parameter* Predicted velocities are not utilized in heat/mass transfer correlations

Table 6-3 LOCA Transition (30-1500 seconds)			
Topic	**Evaluation Model Characteristics Relative to Topic**	**Effect of Characteristics**	**Basis for Characteristic**
$\partial\rho/\partial z$	*Distributed Parameter* model accurately represents $^{\partial\rho}/_{\partial z}$ *Lumped Parameter* model will overmix	*Distributed Parameter* will be used to calculate pressure through the second peak when the containment design pressure may be challenged. *Lumped Parameter* Mixing noncondensibles from below deck penalizes PCS heat transfer	*Distributed Parameter* methodology has been qualified for entrainment into buoyant plumes with LST comparisons *Lumped Parameter* LST validation shows lumped parameter model will overmix
Velocity	*Distributed Parameter* Use mixed convection as currently implemented *Lumped Parameter* Use free convection	*Distributed Parameter* Results in free convection effectively due to low predicted velocities. *Lumped Parameter* Neglects effects of high predicted velocities	*Distributed Parameter* Low Fr in AP600 leads to expectation of free convection during transition period. *Lumped Parameter* Same as distributed parameter

Table 6-4 LOCA Long Term PCS Cooling (> ~1500 seconds)			
Topic	Evaluation Model Characteristic Relative to Topic	Effect of Characteristic	Basis for Characteristic
$\partial\rho/\partial z$	*Distributed Parameter* Accurately represents expected $\partial\rho/\partial z$ *Lumped Parameter* Coarse noding increases predicted mixing	*Distributed Parameter* Accurate representation of expected AP600 gradients *Lumped Parameter* May drive somewhat more mixing than expected for AP600 For PCS, it is conservative to mix noncondensibles from below deck.	*Distributed Parameter* Model has been qualified with LST wherein buoyant plumes drive the internal flow field. *Lumped Parameter* AP600 is expected to be well mixed by large scale circulation >1500 seconds, PCS is dominant heat removal surface, and mixing noncondensibles from below deck suppresses mass transfer
Velocity	*Distributed Parameter* Accurately represents velocities, so use mixed convection as currently implemented *Lumped Parameter* Will neglect forced convection in the model	*Distributed Parameter* Effectively is free convection in code correlations, due to low velocity predicted for AP600 *Lumped Parameter* Conservatively neglects velocity effects	*Distributed Parameter* Low Fr in AP600 leads to expectation of low velocity *Lumped Parameter* Velocities are over-predicted by model, and neglecting forced convection is conservative based on LST results

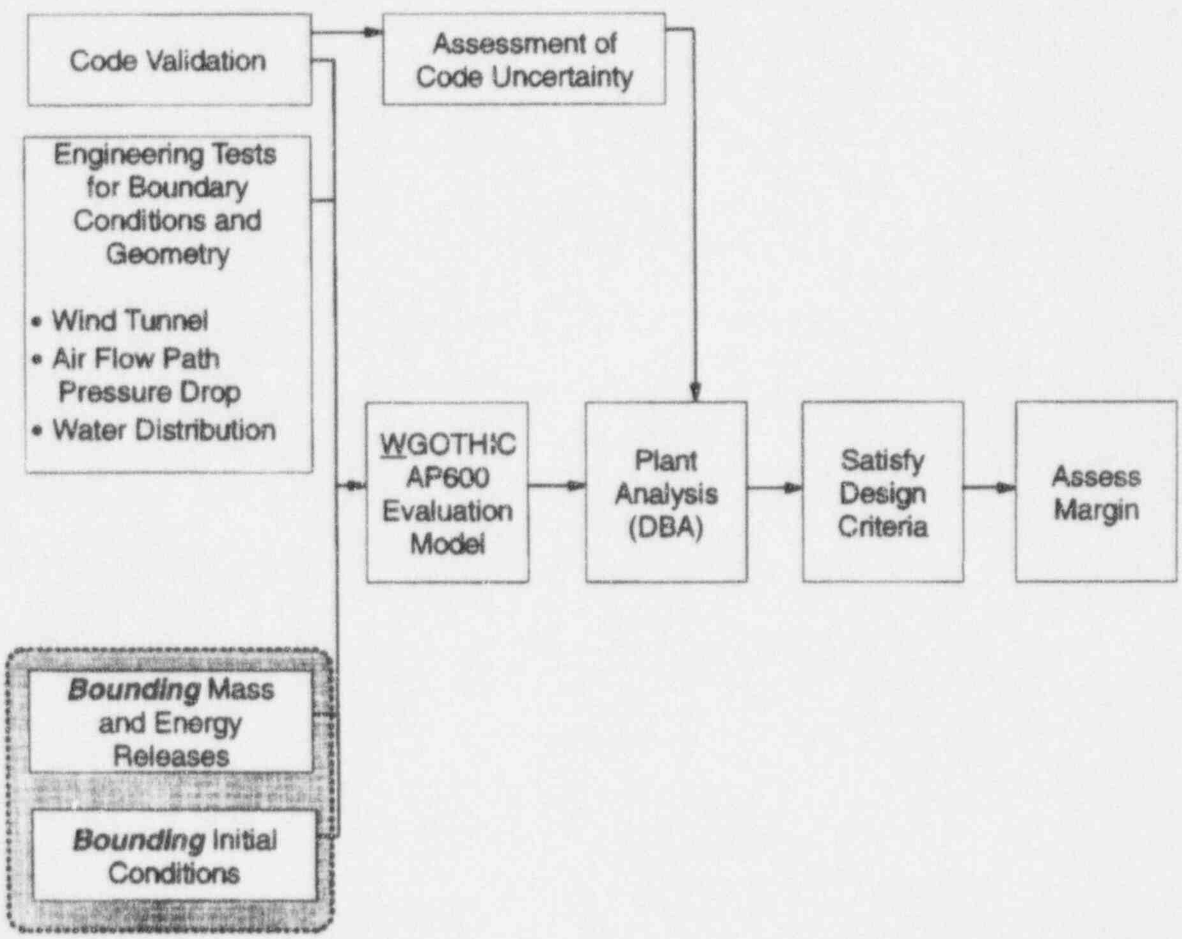

Figure 6-1 Principle Sources of Conservatism in AP600 PCS DBA Evaluation Models

7.0 CONCLUSIONS

The physics and modelling characteristics for the Passive Containment Cooling System Design Basis Analysis evaluation models have been described.

A sound, straightforward approach to developing and justifying the evaluation models relative to stratification and mixing has been discussed. Westinghouse has explored and is developing a relatively detailed model, the distributed parameter evaluation model, to calculate the pressure transient during the early stages of LOCA when the containment design pressure may be challenged. A practical lumped parameter evaluation model for examining the 24-hour criterion is also being prepared. Comparison of the lumped and distributed parameter model results will provide additional basis for the acceptability of the calculation at 24 hours.

A matrix of accident phases versus important phenomena has been provided. The well-understood characteristics of the evaluation models allows the use of these matrices to assess the acceptability of passive containment cooling system design basis analysis methodology. An appropriate strategy for use of WGOTHIC for steam line break is under development.

An understanding of the evaluation model approach and its basis will allow focused review and audit efforts in areas of most significance to containment pressure analyses.

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