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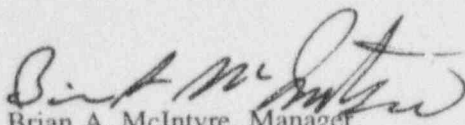
ATTENTION: MR. T. R. QUAY

SUBJECT: AP600 PCS DESIGN BASIS ACCIDENT "ROADMAPS"

Dear Mr. Quay:

The attachment to this letter provides several tables which were developed to assist the ongoing review of the AP600 Passive Containment Cooling System design basis analyses. The tables outline the PCS DBA methodology and have been revised to reflect items discussed in recent meetings between Westinghouse and the Containment Systems and Severe Accident Branch. This document was prepared in response to an NRC staff request and is intended to assist the review currently underway by the Containment Systems and Severe Accident Branch.

Please contact me on (412) 374-4334 if you have any questions concerning this transmittal.


Brian A. McIntyre, Manager
Advanced Plant Safety and Licensing

/nja

Attachment

cc: D. Jackson, NRC
J. Kudrick, NRC
E. Throm, NRC
N. J. Liparulo, Westinghouse (w/o enclosures/attachments)

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Table 1: PIRT Application to Evaluation Model: Inside Containment - All Phases

Module	PIRT Phenomena	Ranking for Containment	AP600 BCs or Phenomena Models	Test Bases	Report Submitted to NRC	Report Conclusions	Applicability of LST with Respect to Phenomena	Validation of Modeling Method and/or WGOETHIC	Use of Validation Results in this Evaluation Model	How Uncertainty is Handled
I. Volume	A. Multi-component Compressible Gasses	H	Gas constituents in the governing equations	All tests analyzed with WGOETHIC	Complete NTD-NRC-94-4260 Enclosure 1: GOTHIC Technical Manual describes governing equations Enclosure 2: GOTHIC User's Manual describes how to invoke various gasses Enclosure 3: GOTHIC Qualification Report provides large database of tests with air, hydrogen, and helium NTD-NRC-95-4462 EPRI Report RA-93-10, GOTHIC Design Review, Final Report WCAP-14382 validates WGOETHIC with separate effects, integral tests with steam and air, and helium	Effects of multicomponent compressible gasses are correctly included in governing equations	LST includes air and steam, and helium	WGOETHIC has been validated with the LST	Governing equations in WGOETHIC are a valid representation of compressible, multicomponent gas behavior Maximum Technical Specification pressure used in conjunction with 0% relative humidity.	Bounded
	B. Buoyancy	H	Buoyancy forces are included in the lumped parameter junction governing equations	LST internal buoyant flows <i>Hugon tests</i> <i>Siegel & Nistic tests</i>	Complete WCAP-14326, Separate effects test WCAP-14382, for integral tests	Lumped modeling overmixes noncondensibles above operating deck thereby reducing heat removal from vessel when PCS is dominant Distributed parameter modeling shows good agreement with 550 node LST model. Modeling of buoyancy and entrainment is acceptable.	Steam injection point elevation and direction effects tests were performed LST has prototypical buoyancy driving forces and covered the range of Froude numbers for LOCA	WGOETHIC has been validated with the LST	Mixing and stratification resulting from buoyancy-driven flow will be studied in the WGOETHIC. Applications WCAP See boxes for line IVA.	Sensitivity to mixing will be provided in applications WCAP Bounded

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	C. Flow Field Stability or Stratification	L	Mixing within the containment upper regions and mixing between the upper and lower portions of the containment	LST	NTD-NRC-95-4459, Stratification and Mixing Effects on AP600 Passive Containment Cooling System DBA WGOETHIC Applications Document ACRS T/H Subcommittee Meeting, March 29-30, 1995 (to be documented in letter report)	Blowdown is the same as standard plants. Long-term LOCA is driven by buoyant plume and LST covers range for AP600. MSLB is well mixed due to high velocity jet. Distributed parameter modeling shows good agreement with 550 node LST model. Modeling of buoyancy and entrainment is acceptable.	Upper and lower regions of containment represented in the LST	WGOETHIC model has been validated with the LST	Mixing and stratification resulting from buoyancy-driven flow will be studied in the WGOETHIC Applications WCAP. See boxes for line IVA	Sensitivity to mixing and break size will be provided in applications WCAP Bounded
II. Surface	A. Liquid Film Heat Transfer	M	Thermal conductivity of liquid film for film temperature drop	Chun & Seban Wisconsin Condensation Tests	Complete NTD-NRC-94-4100, Enclosure 2 "Liquid Film Model Validations" WCAP-14382 §2	The Chun and Seban data provides a basis for film thermal conductivity.	Internal and external liquid film effects are represented in the LST	All validation performed with WGOETHIC includes the small effect of film temperature drop	Nominal wavy-laminar and turbulent Chun and Seban correlations used as appropriate	Negligible effect since resistance across film is small part of total resistance
	B. Liquid Film Stability/Coverage	L	Condensation on the interior surface of containment	LST Wisconsin Condensation Tests	WCAP-13307 I.K. Huhtinemi, "Condensation in the Presence of Noncondensable Gas: Effect of Surface Orientation," Ph.D. Thesis, Univ. Wisconsin, 1992	Internal films are stable since containment shell slope is in excess of 1'. Droplet formation improves mass transfer	Prototypical surfaces included in the LST Separate effects studied in Wisconsin Condensation Tests	WGOETHIC model has been validated with the LST	Shell slopes modeled with WGOETHIC exceed 1' Condensate on containment is returned to the IRWST Benefits of droplet formation neglected	Bounded
	C. Liquid Film Enthalpy Transport	M	Liquid film energy conservation equation	LST Wisconsin Condensation Tests	Complete WCAP-14382 §2.4, 2.5 show equations for liquid film WCAP-14190	Subcooling is negligible compared to energy transported to liquid field	Prototypical surfaces included in the LST Separate effects studied in Wisconsin Condensation Tests	WGOETHIC model has been validated via the LST and Wisconsin Condensation Tests	Temperature profile through film considered in solution	Negligible, film is at or near saturation temperature

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	D. Free Convection Heat Transfer	L	McAdams Flat Plate Correlation Mixed Convection	LST	WCAP-14190 page 2-7 WCAP-14326 page 4-1 WCAP-14382 §8	Convective heat transfer is not significant in comparison to mass transfer	Prototypical internals Range of validation defined in WCAP-14382 §9.2	WGOthic model has been validated with the LST	<i>A conservative bias of 0.741 times the nominal correlation is used</i>	<i>Bounded by conservative bias</i>
	E. Forced Convection Heat Transfer	L	Lumped - Not modeled Distributed - flat plate forced convection, mixed convection	LST	WCAP-14190 page 2-7 WCAP-14326 page 4-1 WCAP-14382 §8	Convective heat transfer is not significant in comparison to mass transfer	Prototypical internals Range of validation defined in WCAP-14382 §9.2	WGOthic model has been validated with the LST	Lumped - Forced convection heat transfer not considered Distributed - Nominal flat plate correlation	Lumped - Bounded by neglecting forced convection Distributed - Bounded by code uncertainty
	F. Radiation Heat Transfer	L	Not modeled	LST	WCAP-14190 page 2-8	Temperature differences within containment are small enough that radiative heat transfer is low	Prototypical internals and temperature driving forces modeled in LST	WGOthic modeling of LST neglected radiative heat transfer	Not modeled	Bounded
	G. Free Convection Mass Transfer	H	Lumped - Heat and mass transfer analogy based on McAdams flat plate heat transfer correlation Distributed - Heat and mass transfer analogy using the mixed convection correlation	LST Wisconsin Condensation Tests	WCAP-14190 page 2-8 WCAP-14326 §3.8, 3.9, 4.3 WCAP-14382 §4.3, 8.2	Mass transfer conservatively biased mean=0.983 $\sigma=0.187$	Prototypical internals and temperature driving forces modeled in LST Range of validation defined in WCAP-14382 §9.2	LST internal data as a separate effect Wisconsin Condensation Tests	<i>A conservative bias of 0.741 times the nominal correlation is used</i>	<i>Bounded by conservative bias</i>
	H. Forced Convection Mass Transfer	L	Lumped - Not modeled Distributed - Heat and mass transfer analogy based on flat plate forced convection in the mixed convection correlation	LST Wisconsin Condensation Tests	WCAP-14190 page 2-8 WCAP-14326 §3.8	Mass transfer conservatively biased mean=0.968 $\sigma=0.203$	Prototypical internals and Froude numbers modeled in LST Range of validation defined in WCAP-14382 §9.2	Lumped - Validated WCAP-14382 §8 Dominant only during first seconds of LOCA transient Distributed - Dominant only during first seconds of transient	Lumped - Not modeled Distributed - Mixed convection correlation combining free and forced convection with a conservative bias	<i>Bounded by neglecting forced convection</i>

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III. Solids	A. 1-D Transient Conduction Heat Transfer	H	GOTHIC conductors used to model internal heat sinks include a 1-D conduction solution	CVTR LST with internal heat sinks	NTD-NRC-94-4260 "GOTHIC Containment Analysis Package, Version 3.4e, Volumes I-III," Volume 1, §6 describes the 1-D conduction solution used. WCAP-14382 provides validation with LST	Use of Uchida with 1-D conductor for internal heat sinks is conservative and consistent with SRP guidelines	Internal LST heat sinks are modeled using GOTHIC conductors with Uchida for condensation	WCAP-14382 shows validation results with internal heat sinks modeled with Uchida	SRP guidelines are an acceptable approach. Conservatively bounded material properties are used for AP600 internal conductors. Surface area and volume of internal heat sinks are conservatively underestimated.	Bounded

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IV Inter-Module	A. Convection	L	Governing χ for lumped p. volumes connects with junctions and node-to-node connections for distributed parameter	LST	NTD-NRC-95-4459, Stratification and Mixing Effects on AP600 Passive Containment Cooling System DBA WCAP-14382 §5.3 WCGOTHIC Applications Document WCAP-14190 §9	Fr scaling shows MSLB expected to be well mixed. Flow area restriction in evaluation model limits steam access to below deck during short MSLB releases Lumped - Overmixing penalizes heat and mass transfer when PCS is dominant (LOCA longterm) Distributed - 375 node LST is sufficiently accurate with bias slight bias towards overmixing - can bias mixing with flow areas LOCA blowdown pressurizes SG compartment sufficiently to drive flow throughout lower compartments. Natural circulation develops post-blowdown	Applicable to above deck circulation and heat and mass transfer correlation validation LST has been used to develop rationale for bounding approach on mixing	Mixing biased toward worst case for each accident. A sensitivity using nominal flow area in the AP600 will be provided in the Applications WCAP to quantify conservative bias	Restrict mixing between upper and lower regions of containment when mixing is a benefit (LOCA second peak)	Rounded by bounding mixing in conservative direction for each accident

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	B. Conduction	H	Clines include 1-D conduction model used for conduction through containment shell	Comparison to theoretical solutions	Complete. WCAP-14382 §2.5 shows the governing equation and discretization for 1-D conduction	The 1-D conduction model is correctly programmed into WGOETHIC.	1-D conduction used to model heat transfer through the LST shell, which neglects the additional heat removal by azimuthal conduction from dry to wet surfaces.	WCAP-14382 §4.1 contains validation of the 1-D conduction equations in Cline subroutine	1-D conduction equation is part of the Cline subroutines used for heat transfer through the shell. Effects of degradation of inorganic zinc paint are included in material properties. Conservative material properties used. Using 1-D conduction conservatively neglects azimuthal conduction from dry to wet stripes.	Bounded
	C. Form and Friction Losses	L	Inter-compartment losses	Standard experimentally based loss coefficients	WCAP-14382 §6.0 describes methods used to model LST	Use of standard loss coefficients through grating is validated	Simplified representation of lower compartments	See IVA.	Restrict mixing between upper and lower regions of containment when mixing is a benefit. Increase mixing when it is a penalty. (See IVA.)	Bound effects of mixing.

Date last modified: August 28, 1995

Table 2: PIRT Application to Evaluation Model. Outside Containment - LOCA - All Phases

PIRT Phenomenon	Ranking for Baseline External Flow Path	AP600 BCs or Phenomena Models	Test Bases	Report Submitted to NRC	Report Conclusions	Applicability of LST with Respect to Phenomenon	Validation of Modeling Method and/or WOOTHC	Use of Validation Results in Evaluation Model	How Uncertainty is Handled
I. Outside Volumes									
A. Multi-component compressible gases	H	Gas constituents in the governing equations	All tests analyzed with WOOTHC	<p>Complete NTD-NRC-94-4080 Enclosure 1: GOETHC Technical Manual" describes the governing equations</p> <p>Enclosure 2: GOETHC User's Manual describes how to invoke various gases</p> <p>Enclosure 3: GOETHC Qualification Report provides a large database of tests with air, hydrogen, and helium.</p> <p>NTD-NRC-95-4462 EPRI Report RA-95-16, GOETHC Design Review, Final Report</p> <p>WCAP-14382 validates WOOTHC with separate effects and integral tests with steam, air, and helium gases</p> <p>"Revisions will be made to correct typographical errors."</p> <p>"Westinghouse will expedite revised documentation which addresses Peer Review results."</p>	Effects of multi-component compressible gases are correctly included in governing equations.	LST includes air, steam, and helium.	WCAP-14382 provides validation of external annulus modeling methods	<p>Governing equations in WOOTHC are a valid representation of compressible, multi-component gas behavior.</p> <p>Maximum Test Spec value of environment temperature is used as the boundary condition in WOOTHC models.</p>	Included in code uncertainty. Bounded.
B. Buoyancy	H	Buoyancy forces are included in the lumped parameter junction governing equations	<p>LST without fan running</p> <p>Hughes tests</p> <p>Schubert and Hughes tests</p> <p>Slagel and Norris tests</p>	<p>Complete WCAP-14382 § 2.2 identifies the relevant priority test LST with fan off to support external annulus modeling</p> <p>WCAP-14326 § 3.1, 3.3</p> <p>NTD-NRC-94-4083 WNRG PCS Meeting</p> <p>To be issued: As part of the Applications Report, Document the sensitivity to Kloss (uniform and nonuniform) and nominal delay time will be confirmed using the final evaluation model.</p>	<p>The external annulus predictions provide comparisons to reasonable agreement with LST and accelerated accumulation can be accommodated in the DBA.</p> <p>External separate effects with buoyancy driven flows are validated.</p> <p>Whole capability to Kloss (uniform and nonuniform) has been shown.</p>	<p>All 7 baseline and 7 confirmatory LST in the HWSE program were run with the fan off.</p> <p>The LST priority test 214.1 (fan off) has been used for validation.</p>	<p>WCAP-14382 has been validated with LST 214.1 with natural convection driving the annulus flows in WCAP-14382 §§ 6, 7, 8.</p>	<p>The external annulus is modeled with pressure boundary conditions at the inlet and outlet, such that the imposed ΔP is 5 equal to the external density head driving force. Thus, the initial annulus air flow is conservatively established at a slightly negative value (directed downward in the annulus).</p> <p>The momentum equation is solved, balancing the buoyancy driving head with the unrecoverable losses through the annulus.</p>	<p>Nominal loss coefficient is used.</p> <p>Whole sensitivity to loss coefficient.</p> <p>Conservative initial air flow bounds postulated annulus flow start-up concerns.</p>

PIRT Phenomenon	Ranking for Baseline External Flow Path	AP600 BCs or Phenomena Models	Test Bases	Report Submitted to NRC	Report Conclusions	Applicability of LST with Respect to Phenomenon	Validation of Modelling Method and/or WOOTHC	Use of Validation Results in Evaluation Model	How Uncertainty is Handled
C. Flow field stability or stratification	L	External flow path is a 1D hydrostatic model	<ul style="list-style-type: none"> LST near External flow path at P test External and Diagonal Stage and Nozzle Height 	<p>Complete NTD-NRC 95-4414 RAI 95-102 response. WCAP 14150, Section 7.2 and 7.3 provide momentum and energy scaling for justification. WCAP 14382, §9 provides validation using 1D flow path for annulus.</p> <p>To be issued: Applications Support Document, sensitivity to cross-junction and nonuniformity and numerical delay time. See block on flow above for loss coefficient study results.</p>	<p>Potential for local recirculation → downcomer inlet to affect total air flow at AP600 operating conditions is negligible since there is minimal energy or momentum in the downcomer.</p> <p>Small sensitivity to fully large Nusselt effects.</p>	N/A	<p>The downcomer flow area is large to act as a reservoir with which pressures can equilibrate providing a relatively uniform inlet for the annulus. Use of 1D flow path is justifiable. Since heat transfer and momentum in the downcomer, relative to the inlet, is so small that the possibility of downcomer instabilities is insignificant. Flow is primarily one-dimensional in nature, therefore, use of 1D flow path is justifiable.</p> <p>Since fully developed turbulent flow develops in annulus, where the buffer heats up, there is potential for hot-buffa-induced flow instability to impact liquid air start-up of annulus air flow.</p>	External flow path is modelled as 1D lumped parameters	Negligible effect
		Fog in annulus		Complete NTD-NRC 94-4190, Enclosure 1 "Radiation Heat Transfer Through Fog in the PCCS Air Gap"	Justification for neglecting effect of fog in annulus shows effect of radiation captures by fog in AP600 has a negligible effect on the annulus air temperature and overestimates the heat transfer to the buffer.	Database consistent with AP600 expectations for external annulus conditions.	Effect of fog neglected in WOOTHC models	Negligible effect on answers	Negligible effect
		Effect of wind induced recirculation and stratified atmosphere is neglected	Literature	Complete NTD-NRC 94-4196 "AP600 Containment Plume Investigation"	Quantification of potential for recirculation of effluent and thermally stratified atmosphere to affect cooling robes gave bounding recirculation factor, and a resulting sensitivity showed no significant containment pressure effect.	LST was run in no-wind (-5 mph) conditions	External pressure boundary condition is unadjusted for these effects	Assumption of no recirculation due to these effects has negligible impact on pressure prediction	Negligible effect
		Effect of wind induced turbulence is neglected	Wind tunnel tests	Complete NTD-NRC 95-4467 "Analysis of AP600 Wind Tunnel Testing for PCS Heat Removal"	Oscillating flows for worst case can with least positive mean wind coefficient slightly increase heat removal rates from containment. Less severe turbulence with more positive wind coefficients show significant increases in heat removal.	Not applicable	External pressure boundary condition is unadjusted for these effects	Assumption of no wind is bounding for pressure prediction	Bounded

PHST Phenomenon	Ranking for Blowing External Flow Path	AP600 BCs or Phenomena Models	Test Bases	Report Submitted to NRC	Fig.: Inclusions	Applicability of LST with Respect to Phenomenon	Validation of Modelling Method and/or WOOTHC	User of Validation Results in Evaluation Model	How Uncertainty is Handled
E. Bubble Surface									
A. Liquid film heat transfer	M	Thermal conductivity of liquid film for film temperature drop.	Chen and Suban	Complete NTD-NRC-94-4100, Enclosure 2 "Liquid Film Model Validation" WCAP-14362 §2 Scaling supplement will document consistent definition of resistances inside to outside shell	The Chen and Suban data provides a basis for film thermal conductivity. The liquid film temperature drop is small	Internal and external liquid film effects are represented in the LST.	All validation performed with WOOTHC includes the small effect of film temperature drop.	Nominal Chen and Suban correlation is used, accounting for wavy laminar and turbulent liquid films.	Negligible effect since resistance across film is small part of total resistance.
B. Liquid film stability/coverage	H	Shell water coverage fractions and applied flow rate	<ul style="list-style-type: none"> Full scale, cold 1/8 sector tests Hot LST measured coverage Weatherhouse for plate evaporation tests Vendor age/contamination information needs 	<p>Complete WCAP-12665 §3.1 NTD-NRC-94-4247 Method for Determining Film Flow Coverage for the AP600 Passive Containment Cooling System</p> <p>NTD-NRC-94-4296 "Supplemental Information on AP600 PCS Film Flow Coverage Methodology," including sensitivity to 3/4 and 1/2 of bounding SSAR coverage showing well away from any cliffs in performance.</p> <p>SSAR 2.0v = "Arbitrary May Aug 6.2.1.1.3 assumptions with coverage" assumptions.</p> <p>NTD-NRC-94-4089 WNRPC PCS Modeling Weak sensitivity to PCS flow rate, water coverage fraction, PCS time delay was shown.</p> <p>To be tested: Vendor report on effects of age and contamination.</p> <p>Note: An independent review by an industry expert is also planned.</p>	<p>Treats with water onto surfaces up to 248°C showed that the plate wet without delay, even quenching a hot plate with cold water. Evaporating films do not become unstable, even with total film dryout.</p> <p>Water coverage on dome and sidewalls as a function of time is used to bound (Figure 2) cold, full scale data and heated data from LST. The model has been validated with cold and heated tests, and bounds test data.</p> <p>Model adequately conservatively accounts for effects of aging by using a scale factor on the wetting angle for a new surface. Aging increases the porosity of the surface and thus increases wetting. Surface contaminants will be minimal based on inspection and cleaning criteria. Sensitivity using approximately 3/4 and 1/2 each of bounding SSAR coverage values show that the AP600 pressure response is relatively insensitive to further reductions in coverage below the bounding minimum evaluation model values.</p>	<p>Heated LST data has been used to assess heat flux effect on coverage fraction.</p> <p>Measured coverage fractions on the LST were used as input boundary conditions in the WOOTHC validation and to validate cooling rate prediction models with test data.</p>	<p>Water coverage is an input boundary condition in the WOOTHC code. A "top-to-bottom stack" of films is used to model each of the wetted and dry portions of the external shell. Coverage fractions are used to determine the maximum value of potentially wetted shell heat transfer surface area input to the WOOTHC codes model. Coverage for the "area at top and mid levels is assumed to be 40% to bound full scale cold test data, where the film is thick enough that film stability does not limit coverage.</p> <p>The wetted cross sectional area of the balance of the wetted portion where film stability limits coverage is obtained from 26.17 hrs in Table 4 of NTD-NRC-94-4247, where 100% dome coverage values show that film stability does not limit dome coverage. The Table 4 values have not been adjusted to account for the reduced evaporation associated with the assumed 40% coverage on the dome. Therefore, the coverage fraction assumed in the DBA bounds at times during the PCS DBA.</p> <p>Weak sensitivity to the input water coverage shows that minor perturbations in this assumption do not impact pressure predictions.</p>	<p>The validated conservative water coverage model is used to calculate input boundary conditions for the PCS DBA Evaluation Model.</p> <p>Bounding minimum water coverage fractions are used</p>	Bounded

PIPT Phenomenon	Ranking for Basic Channel Flow Path	AP600 BCs or Phenomena Models	Test Bases	Report Submitted to NRC	Report Conclusions	Applicability of LST with Respect to Phenomenon	Validation of Modelling Method and/or WOOTHC	Use of Validation Results in Evaluation Model	How Uncertainty is Handled
		Shelf wetting time delay	<ul style="list-style-type: none"> - Full scale, cold 1/3 section tests 	<p>NTD-NRC-98-4083 WMRC PCS Meeting</p> <p>A review-The discussion in the boxes to the right will be provided in the applications report.</p>	<p>Mixed sensitivity to PCS flow rate, water coverage fraction, PCS time delay was shown.</p>	<p>LST 219.1 has water onto hot surface and thermocouple readings show the surface heat flux during the high flow portion of the non-prototypical outflow flow.</p> <p>Videos of a shutdown LST with a somewhat higher flow rate show water behavior applied to 240F surface. The observations showed that the advancing film front stopped as it was boiled away, and readily flowed down as wide stripes after the surface fell below the Leidenfrost temperature.</p>	<p>Input Boundary Condition delay time produces a conservative result.</p> <p>Earlier water application does not adversely impact air flow initiation because there is a wet improvement in due to evaporative cooling.</p> <p>The effect on annulus air temperature and vapor content of water applied to the surface is explicitly modeled in WOOTHC-10 annulus calculation. A sensitivity based on actual channeling with water wetting will be provided in the Applications report.</p>	<p>Since the outer surface temperature does not increase significantly as wet but until after water reaches the containment shell surface in real time, cold tests are acceptable to determine delay times. Delay time to wet the external surface is conservatively bounded by using time to reach steady state coverage in channel from the cold full scale test. This conservative delay time thus neglects integrated heat removal during about 10.8 minutes of actual water application during the period when steady state film coverage is developing when surface temperature has not significantly increased.</p> <p>Time delay used bounds all postulated effects</p>	Bounded
C. Liquid film subcooling	M	Liquid film energy conservation equation	Large Scale Tests	<p>Complete</p> <p>WCAP-14382 §2.4, 2.5 show equations for liquid film</p>	<p>Inclusion of convective term in energy equation accounts for liquid film subcooling effect on LST dome heat fluxes.</p>	<p>LST covers range of liquid film subcooling expected for AP600.</p> <p>Although a majority of the LST have higher fractions of energy removed by subcooling than AP600, the LST is valid for developing a bounding approach for AP600 validation of physics and phenomena since a scalable liquid film wetting transport model is used.</p>	<p>WCAP-14382, p. 8.6 discusses validation of LST heat flux distribution predictions over the dome.</p>	<p>WOOTHC uses an appropriate set of governing equations for liquid film. Subcooling accounts for a small fraction (~5%) of the AP600 heat removal.</p>	Negligible effect since mechanism accounts for only small fraction of AP600 heat removal
D. Free convection heat transfer	L	Mixed convection correlation which reduces to the McAdams correlation, at high GrPr ^{0.7} , with characteristic length in Gr number based on channel diameter	<ul style="list-style-type: none"> - Hight tests - Eckert and Dittus tests - Sieder and Nusselt tests - Westinghouse LST - dry external heat transfer 	<p>Complete</p> <p>WCAP-14190</p> <p>Qualifies AP600 fraction of heat removed by convective heat transfer.</p> <p>NTD-NRC-95-4397</p> <p>Supporting information for the Use of Forced Convection in the AP600 PCS Annulus</p> <p>WCAP-1-325 separate effects tests validation</p>	<p>Free convective heat transfer can be neglected in the AP600 rise accounts for a small fraction of total heat transfer.</p> <p>See also-based convection heat transfer</p> <p>The mixed convection correlation predicts the data with a conservative margin bias of 2.4%.</p>	<p>Once the outer shell heats up to at least 25° above ambient, the AP600 annulus operates in forced convection.</p> <p>LST includes tests with and without film on, covering the annulus from mixed free convection through forced convection dominated regime.</p>	<p>Mixed convection correlation provides good agreement with annulus conditions in the LST.</p> <p>A conservative bias of 0.89 times the nominal correlation is used.</p>	<p>Mixed convection correlation reduces to forced convection at high GrPr^{0.7} consistent with expectation for AP600 annulus conditions.</p>	Negligible effect Bounded

PIST Phenomenon	Ranking for Strength External Flow Path	AF900 BCs or Phenomena Models	Test Bases	Report Submitted to NRC	Report Conclusions	Applicability of LST with Respect to Phenomenon	Validation of Modelling Method and/or WGOITHC	Use of Validation Results in Evaluation Model	How Uncertainty is Handled
E. Forced convective heat transfer	L	Mixed convection correlation which reduces to the Colburn correlation at low Gr_{fl} ^{2,7}	<ul style="list-style-type: none"> Hugert tests Edman and Duggals tests Stagel and North tests Woolinghouse STC dry flat plate tests Woolinghouse LST - dry external heat transfer 	<p>Complete</p> <p>WCAP-14190</p> <p>Overlaid AP900 fraction of heat removed by convective heat transfer.</p> <p>WCAP-14326, §3.1, 3.2, 3.3, 3.4, 3.5, and 4.1 shows validation of the correlations with separate effects tests</p>	<p>Forced convective heat transfer dominates in AP900 near annulus for a small fraction of total heat transferred.</p> <p>The mixed convection correlation is biased 2.4% conservative about the mean over the range, with a relatively large scatter due to large measurement uncertainty with small ΔT.</p> <p>$\mu = -0.875$ $\sigma = -0.238$</p>	<p>Dry LST has dominant annulus heat removal by convection</p> <p>The LST and separate effects tests cover the range of AP900 Raynold's numbers.</p>	<p>WCAP-14382, §3.2.1, 4.2 provide summaries of the validation.</p> <p>Although the comparisons with data show high scatter, it is attributable to high instrument uncertainty with small ΔT. The lack of any trend in the mean over the range indicates the correlation is reasonable as a basis for mass transfer validation, covering ΔT an order of magnitude higher, shows much less scatter.</p>	<p>Nominal annulation (with inherent conservative bias) used in WGOITHC.</p> <p>A conservative bias of 0.80 times the nominal correlation is used.</p> <p>Convective heat transfer is not a dominant significant heat removal mechanism for AP900 DBA.</p>	<p>Unboundedly (scatter) is incorporated as an element of ends uncertainty.</p> <p>Bounded</p>
F. Radiation heat transfer	L	Well-to-wall radiant heat transfer	<ul style="list-style-type: none"> Woolinghouse STC dry flat plate tests Dry LST 	<p>Complete</p> <p>WCAP-14382, §2.5 describes the radiant heat transfer model used in Climate</p>	<p>Dry external vessel heat transfer is validated.</p>	<p>Varying fractions of dry shell surface are included for all wet tests. The dry LST causes transfer a large fraction of heat by radiation to the bundle.</p>	<p>WCAP-14382 §7 shows selection of LST and §6 shows validation results.</p>	<p>Conservative property values are used in AP900 DBA.</p>	<p>Bounded</p>
G. Free convection mass transfer		Empirical correlation for the Sherwood number, which is derived by dimensional analysis using the Reynolds analogy and Colburn factors.	<ul style="list-style-type: none"> Gilliland and Sherwood evaporation tests Woolinghouse STC flat plate evaporation tests University of Wisconsin condensation tests 	<p>Complete</p> <p>See free-annulation heat transfer</p> <p>NTD-NRC-95-4397</p> <p>Supporting information for the Use of Forced Convection in the AP900 PCS Annulus</p> <p>WCAP-14326 separate effects tests validation</p>	<p>See free-annulation heat transfer</p> <p>The annulus is dominated by forced convection mass transfer once the outer shell heats up to at least 2F above ambient during the transient.</p>	<p>See free-annulation heat transfer</p> <p>LST includes tests with and without fan on, covering the annulus from mixed convection through forced convection dominated regimes.</p>	<p>See free-annulation heat transfer</p> <p>WCAP-14382 summarizes WGOITHC separate effects validation results (§3.2.1, 4.4)</p>	<p>See free-annulation heat transfer</p> <p>A conservative bias of 0.80 times the nominal correlation is used.</p>	<p>Significant effect</p> <p>Bounded</p>
H. Forced convection mass transfer	H	Empirical correlation for the Sherwood number, which is derived by dimensional analysis using the Reynolds analogy and Colburn factors. Application of a correction for mass transfer rate gives the AP900 forced convection mass transfer correlation	<ul style="list-style-type: none"> Gilliland and Sherwood evaporation tests Woolinghouse STC flat plate evaporation tests University of Wisconsin condensation tests 	<p>Complete</p> <p>NTD-NRC-95-4397</p> <p>"Supporting information for the Use of Forced Convection in the AP900 PCS Annulus"</p> <p>Complete.</p> <p>WCAP-14326 gives correlation (§2.0, 2.1), entrance effect used for separate effect test (§2.2), and correlation validation with tests (§3.6, 3.7).</p>	<p>AP900 shown to operate in forced convection dominant regime.</p> <p>Correlation is biased 6.4% conservative with reasonable scatter over the range $\mu = -0.086$ $\sigma = -0.138$</p> <p>Once the outer shell heats up to at least 2F above ambient, the AP900 annulus operates in forced convection.</p>	<p>LST covers range of AP900 Gr_{fl}2, including tests without the fan running.</p> <p>LST includes tests with and without fan on, covering the annulus from mixed convection through forced convection dominated regimes.</p> <p>WCAP-14382</p> <p>LST includes tests which cover range of AP900 subcooling. Predictions of total evaporation (§-8.3) and wet heat flux (§-8-6) validate models in an integral setting.</p>	<p>WCAP-14382 summarizes WGOITHC separate effects validation results (§3.2.1, 4.4)</p>	<p>Forced convection correlation, modified for mixed convection effects to allow transient startup, is appropriate for AP900.</p> <p>A conservative bias of 0.80 times the nominal correlation is used.</p> <p>Nominal annulation (with inherent conservative bias) used in WGOITHC.</p>	<p>Included in ends uncertainty</p> <p>Unboundedly (scatter) is incorporated as an element of ends uncertainty.</p> <p>Bounded</p>

PIRT Phenomenon	Ranking for Analysis External Flow Path	AFR900 BC's or Phenomena Models	Test Status	Report Submitted to NRC	Report Conclusions	Applicability of LST with Respect to Phenomenon	Validation of Modelling Method and/or WOOTHC	Use of Validation Results in Evaluation Model	How Uncertainty is Handled
III. Module Excludes									
A. 1D transient conduction heat transfer	H	GOETHC conductors used to model a few external concrete heat sinks, using the GOETHC 1D conduction solution	CVTR	NTD-NRC 94-4280 "GOETHC Containment Analysis Package, Version 3.4a, Volumes I-III," Volume 1, §6 describes the 1D conduction solution used. WCAP-14382 provides validation with LST	Use of Uchida for heat sinks is conservative and consistent with SRP guidelines.	Not applicable	GOETHC Qualification Report shows validation for the GOETHC 1D conductor.	Conservatively bounded material properties are used for AFR900 external conductors. Surface area and volume of heat sinks are conservatively underestimated.	Bounded
IV. Inter-Module									
A. Connection	M	Governing equations for lumped parameter volumes connected with junctions	LST without the fan operating	External flow rate and ΔT comparisons between WOOTHC and LST have been presented at several meetings. These will be provided in a letter report. NTD-NRC 94-4280 Sensitivities to external Kloss, both uniform and non-uniform, as well as sensitivity to air inlet blockages up to 50%, were provided at the March 17, 1994 NRC PCS meeting. As part of the Applications report, these sensitivities will be confirmed with analysis using the final Evaluation Model.	For tests without the fan operating, relative insensitivity to loss coefficient, since the system is self-correcting. The highly non-linear relation of evaporation rate with surface temperature results in increased evaporative cooling with only moderate surface temperature increases. The 1D conduction model is correctly programmed into WOOTHC.	LST without the fan operating are applicable for validation of natural convective flows through the annulus with the 1D annulus flow model.	For tests without the fan operating, external flow rate and ΔT is predicted well.	A 1D lumped parameter model is used with an input nominal loss coefficient in WOOTHC analyses. Boundary driven flows are balanced by the form and friction losses.	Negligible effect due to weak sensitivity to external Kloss
B. Conduction	H	Clines include 1D conduction model used for conduction through containment shell	Comparison to theoretical solutions	Complete. WCAP-14382 §2.5 shows the governing equation and discretization for 1D conduction, as well as model validation.		1D conduction used to model heat transfer through the LST shell, which neglects the additional heat removal by axial conduction from dry to wet surfaces.	WCAP-14382, §4.1 contains validation of the 1D conduction equations used in Cline subroutines.	1D conduction equation is part of the Cline subroutines used for heat transfer through the shell. Using 1D conduction conservatively neglects axial conduction from dry to wet stripes. Conservative material properties are used. Effects of degradation variations of inorganic zinc paint are included in material properties.	Conservatively bounded material properties are used for AFR900 containment shell

Table 1: PIRT Application to Evaluation

Module	PIRT Phenomena	Ranking for Containment	AP600 BCs or Phenomena Models	Test Bases	Report Submitted to NRC
I. Volume	A. Multi-component Compressible Gases	H	Gas constituents in the governing equations	All tests analyzed with WGOETHIC	Complete NTD-NRC-94-4260 Enclosure 1: GOTHIC Technical Manual describes governing equations Enclosure 2: GOTHIC User's Manual describes how to invoke various gases Enclosure 3: GOTHIC Qualification Report provides large database of tests with air, hydrogen, and helium NTD-NRC-95-4462 EPRI Report RA-93-10, GOTHIC Design Review, Final Report WCAP-14382 validates WGOETHIC with separate effects, integral tests with steam and air, and helium
	B. Buoyancy	H	Buoyancy forces are included in the lumped parameter junction governing equations	LST internal buoyant flows Hugot tests Siegel & Norris tests	Complete WCAP-14326, Separate effects test WCAP-14382, for integral tests

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Model: Inside Containment - All phases

Report Conclusions	Applicability of LST with Respect to Phenomena	Validation of Modeling Method and/or WGOthic	Use of Validation Results in this Evaluation Model	How Uncertainty is Handled
Effects of multicomponent compressible gasses are correctly included in governing equations	LST includes air and steam, and helium	WGOthic has been validated with the LST	Governing equations in WGOthic are a valid representation of compressible, multicomponent gas behavior Maximum Technical Specification pressure used in conjunction with 0% relative humidity.	Bounded
Lumped modeling overmixes noncondensibles above operating deck thereby reducing heat removal from vessel when PCS is dominant Distributed parameter modeling shows good agreement with 550 node LST model. Modeling of buoyancy and entrainment is acceptable.	Steam injection point elevation and direction effects tests were performed LST has prototypical buoyancy driving forces and covered the range of Froude numbers for LOCA	WGOthic has been validated with the LST	Mixing and stratification resulting from buoyancy driven flow will be studied in the WGOthic. Applications WCAP See boxes for line IV.A.	Sensitivity to mixing will be provided in applications WCAP Bounded

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Table 1: PIRT Application to Evaluation

Module	PIRT Phenomena	Ranking for Containment	AP600 BCs or Phenomena Models	Test Bases	Report Submitted to NRC
	C. Flow Field Stability or Stratification	L	Mixing within the containment upper regions and mixing between the upper and lower portions of the containment	LST	NTD-NRC-95-4459, Stratification and Mixing Effects on AP600 Passive Containment Cooling System DBA WGO THIC Applications Document ACRS T/H Subcommittee Meeting, March 29-30, 1995 (to be documented in letter report)
II. Surface	A. Liquid Film Heat Transfer	M	Thermal conductivity of liquid film for film temperature drop	Chun & Seban Wisconsin Condensation Tests	Complete NTD-NRC-94-4100, Enclosure 2 "Liquid Film Model Validations" WCAP-14382 §2
	B. Liquid Film Stability/Coverage	L	Condensation on the interior surface of containment	LST Wisconsin Condensation Tests	WCAP-13307 I.K. Huhtininemi, "Condensation in the Presence of Noncondensable Gas: Effect of Surface Orientation," Ph.D. Thesis Univ. Wisconsin, 1992
	C. Liquid Film Enthalpy Transport	M	Liquid film energy conservation equation	LST Wisconsin Condensation Tests	Complete WCAP-14382 §2.4, 2.5 show equations for liquid film WCAP-14190

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on Model: Inside Containment - All phases

Report Conclusions	Applicability of LST with Respect to Phenomena	Validation of Modeling Method and/or WGOthic	Use of Validation Results in this Evaluation Model	How Uncertainty is Handled
Blowdown is the same as standard plants. Long-term LOCA is driven by buoyant plume and LST covers range for AP600. MSLB is well mixed due to high velocity jet. Distributed parameter modeling shows good agreement with 550 node LST model. Modeling of buoyancy and entrainment is acceptable.	Upper and lower regions of containment represented in the LST	WGOthic model has been validated with the LST	Mixing and stratification resulting from buoyancy-driven flow will be studied in the WGOthic Applications WCAP See boxes for line IV.A	Sensitivity to mixing and break size will be provided in applications WCAP Bounded
The Chun and Seban data provides a basis for film thermal conductivity.	Internal and external liquid film effects are represented in the LST	All validation performed with WGOthic includes the small effect of film temperature drop	Nominal wavy-laminar and turbulent Chun and Seban correlations used as appropriate	Negligible effect since resistance across film is small part of total resistance
Internal films are stable since containment shell slope is in excess of 1'. Droplet formation improves mass transfer	Prototypical surfaces included in the LST Separate effects studied in Wisconsin Condensation Tests	WGOthic model has been validated with the LST	Shell slopes modeled with WGOthic exceed 1' Condensate on containment is returned to the IRWST Benefits of droplet formation neglected	Bounded
Subcooling is negligible compared to energy transported to liquid field	Prototypical surfaces included in the LST Separate effects studied in Wisconsin Condensation Tests	WGOthic model has been validated via the LST and Wisconsin Condensation Tests	Temperature profile through film considered in solution	Negligible, film is at or near saturation temperature

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Table 1: PIRT Application to Evaluation

Module	PIRT Phenomena	Ranking for Containment	AP600 BCs or Phenomena Models	Test Bases	Report Submitted to NRC
	D. Free Convection Heat Transfer	L	McAdams Flat Plate Correlation Mixed Convection	LST	WCAP-14190 page 2-7 WCAP-14326 page 4-1 WCAP-14382 §8
	E. Forced Convection Heat Transfer	L	Lumped - Not modeled Distributed - flat plate forced convection mixed convection	LST	WCAP-14190 page 2-7 WCAP-14326 page 4-1 WCAP-14382 §8
	F. Radiation Heat Transfer	L	Not modeled	LST	WCAP-14190 page 2-8
	G. Free Convection Mass Transfer	H	Lumped - Heat and mass transfer analogy based on McAdams flat plate heat transfer correlation Distributed - Heat and mass transfer analogy using the mixed convection correlation	LST Wisconsin Condensation Tests	WCAP-14190 page 2-8 WCAP-14326 §3.8, 3.9, 4 WCAP-14382 §4.3, 8.2
	H. Forced Convection Mass Transfer	L	Lumped - Not modeled Distributed - Heat and mass transfer analogy based on flat plate forced convection in the mixed convection correlation	LST Wisconsin Condensation Tests	WCAP-14190 page 2-8 WCAP-14326 §3.8

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on Model: Inside Containment - All phases

Report Conclusions	Applicability of LST with Respect to Phenomena	Validation of Modeling Method and/or WGOthic	Use of Validation Results in this Evaluation Model	How Uncertainty is Handled
Convective heat transfer is not significant in comparison to mass transfer	Prototypical internals Range of validation defined in WCAP- 14382 §9.2	WGOthic model has been validated with the LST	A conservative bias of 0.741 times the nominal correlation is used	Bounded by conservative bias
Convective heat transfer is not significant in comparison to mass transfer	Prototypical internals Range of validation defined in WCAP- 14382 §9.2	WGOthic model has been validated with the LST	Lumped - Forced convection heat transfer not considered Distributed - Nominal flat- plate correlation	Lumped - Bounded by neglecting forced convection Distributed - Bounded by code uncertainty
Temperature differences within containment are small enough that radiative heat transfer is low	Prototypical internals and temperature driving forces modeled in LST	WGOthic modeling of LST neglected radiative heat transfer	Not modeled	Bounded
Mass transfer conservatively biased mean=0.983 $\sigma=0.187$	Prototypical internals and temperature driving forces modeled in LST Range of validation defined in WCAP- 14382 §9.2	LST internal data as a separate effect Wisconsin Condensation Tests	A conservative bias of 0.741 times the nominal correlation is used	Bounded by conservative bias
Mass transfer conservatively biased mean=0.968 $\sigma=0.203$	Prototypical internals and Froude numbers modeled in LST Range of validation defined in WCAP- 14382 §9.2	Lumped - Validated WCAP- 14382 §8 Dominant only during first seconds of LOCA transient Distributed - Dominant only during first seconds of transient	Lumped - Not modeled Distributed - Mixed convection correlation combining free and forced convection with a conservative bias	Bounded by neglecting forced convection

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Table 1: PIRT Application to Evaluation

Module	PIRT Phenomena	Ranking for Containment	AP600 BCs or Phenomena Models	Test Bases	Report Submitted to NRC
III. Solids	A. 1-D Transient Conduction Heat Transfer	H	GOTHIC conductors used to model internal heat sinks include a 1-D conduction solution	CVTR LST with internal heat sinks	NTD-NRC-94-4260 "GOTHIC Containment Analysis Package, Version 3.4e, Volumes 1-111," Volume 1, §6 describes the 1-D conduction solution used. WCAP-14382 provides validation with LST

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Report Conclusions	Applicability of LST with Respect to Phenomena	Validation of Modeling Method and/or WGOTHIC	Use of Validation Results in this Evaluation Model	How Uncertainty is Handled
Use of Uchida with 1-D conductor for internal heat sinks is conservative and consistent with SRP guidelines	Internal LST heat sinks are modeled using GOTHIC conductors with Uchida for condensation	WCAP-14382 shows validation results with internal heat sinks modeled with Uchida	SRP guidelines are an acceptable approach. Conservatively bounded material properties are used for AP600 internal conductors. Surface area and volume of internal heat sinks are conservatively underestimated.	Bounded

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Table 1: PIRT Application to Evaluation

Module	PIRT Phenomena	Ranking for Containment	AP600 BCs or Phenomena Models	Test Bases	Report Submitted to NRC
IV. Inter-Module	A. Convection	L	Governing equations for lumped parameter volumes connected with junctions and node-to-node connections for distributed parameter	LST	NTD-NRC-95-4459, Stratification and Mixing Effects on AP600 Passive Containment Cooling System DBA WCAP-14382 §5.3 WGOTHIC Applications Document WCAP-14190 §9

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Model: Inside Containment - All phases

Report Conclusions	Applicability of LST with Respect to Phenomena	Validation of Modeling Method and/or WGOthic	Use of Validation Results in this Evaluation Model	How Uncertainty is Handled
<p><i>Fr scaling shows MSLB expected to be well mixed. Flow area restriction in evaluation model limits steam access to below deck during short MSLB releases</i></p> <p><i>Lumped - Overmixing penalizes heat and mass transfer when PCS is dominant (LOCA longterm)</i></p> <p><i>Distributed - 375 node LST is sufficiently accurate with has slight bias towards overmixing - can bias mixing with flow areas</i></p> <p><i>LOCA blowdown pressurizes SG compartment sufficiently to drive flow throughout lower compartments. Natural circulation develops post-blowdown</i></p>	<p><i>Applicable to above deck circulation and heat and mass transfer correlation validation</i></p> <p><i>LST has been used to develop rationale for bounding approach on mixing</i></p>	<p><i>Mixing biased toward worst case for each accident.</i></p> <p><i>A sensitivity using nominal flow area in the AP600 will be provided in the Applications WCAP to quantify conservative bias.</i></p>	<p><i>Restrict mixing between upper and lower regions of containment when mixing is a benefit (LOCA second peak)</i></p>	<p><i>Bounded by biasing mixing in conservative direction for each accident</i></p>

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Table 1: PIRT Application to Evaluation

Module	PIRT Phenomena	Ranking for Containment	AP600 BCs or Phenomena Models	Test Bases	Report Submitted to NRC
	B. Conduction	H	Climes include 1-D conduction model used for conduction through containment shell	Comparison to theoretical solutions	Complete. WCAP-14382 §2.5 shows the governing equation and discretization for 1-D conduction
	C. Form and Friction Losses	L	Inter-compartment losses	Standard experimentally based loss coefficients	WCAP-14382 §6.0 describes methods used to model LST

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n Model: Inside Containment - All phases

Report Conclusions	Applicability of LST with Respect to Phenomena	Validation of Modeling Method and/or WGOthic	Use of Validation Results in this Evaluation Model	How Uncertainty is Handled
The 1-D conduction model is correctly programmed into WGOthic	1-D conduction used to model heat transfer through the LST shell, which neglects the additional heat removal by azimuthal conduction from dry to wet surfaces.	WCAP-14382 §4.1 contains validation of the 1-D conduction equations in Clime subroutine	1-D conduction equation is part of the Clime subroutines used for heat transfer through the shell. Effects of degradation of inorganic zinc paint are included in material properties. Conservative material properties used. Using 1-D conduction conservatively neglects azimuthal conduction from dry to wet stripes.	Bounded
Use of standard loss coefficients through grating is validated	Simplified representation of lower compartments	See IVA.	Restrict mixing between upper and lower regions of containment when mixing is a benefit. Increase mixing when it is a penalty. (See IVA.)	Bound effects of mixing.

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Table 2: PIRT Application to Evaluation Model: Outside Containment - LOCA - All Phases

PIRT Phenomenon	Ranking for Riser ⁽⁴⁾ External Flow Path	AP600 BCs or Phenomena Models	Test Bases	Report Submitted to NRC	Report Conclusion
1. Module Volume					
A. Multi-component compressible gasses	H	Gas constituents in the governing equations	All tests analyzed with WGOTHIC	<p>Complete NTD-NRC-94-4260</p> <p>Enclosure 1: GOTHIC Technical Manual* describes the governing equations</p> <p>Enclosure 2: GOTHIC User's Manual describes how to invoke various gasses</p> <p>Enclosure 3: GOTHIC Qualification Report provides a large database of tests with air, hydrogen, and helium.</p> <p>NTD-NRC-95-4462</p> <p>EPRI Report RA-93-10, GOTHIC Design Review, Final Report</p> <p>WCAP-14382 validates WGOTHIC with separate effects and integral tests with steam, air, and helium gases.</p> <p>*Revision will be made to correct typographical errors.</p> <p><i>*Westinghouse will expedite revised documentation which addresses Peer Review results.</i></p>	Effects of multi-component gasses are included in governing equations.
B. Buoyancy	H	Buoyancy forces are included in the lumped parameter - junction governing equations	<ul style="list-style-type: none"> • LST without fan running • Hugot tests • Ecker and Diaguila tests • Siegel and Norris tests 	<p>Complete WCAP-14382 §7.2.2 identifies the relevant priority test LST with fan off to support external annulus modelling.</p> <p>WCAP-14326 § 3.1, 3.3</p> <p>NTD-NRC-94-4083</p> <p><u>W/NRC PCS Meeting</u></p> <p>To be issued: As part of the Applications Report, Document the sensitivity to Kloss (uniform and nonuniform) and nominal delay time will be confirmed using the final evaluation model.</p>	<p>The external predictions provide reasonable agreement with LST and a range of uncertainties are accommodated by DBA.</p> <p>External separation with buoyancy flows are valid.</p> <p>Weak sensitivity (uniform and nonuniform) has been shown.</p>

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	Applicability of LST with Respect to Phenomenon	Validation of Modelling Method and/or WGOthic	Use of Validation Results in Evaluation Model	How Uncertainty is Handled
possible ly ing	LST includes air, steam, and helium.	WCAP-14382 provides validation of external annulus modelling methods.	Governing equations in WGOthic are a valid representation of compressible, multi-component gas behavior. <i>Maximum Tech Spec value of environment temperature is used as the boundary condition in WGOthic models.</i>	Included in code uncertainty <i>Bounded</i>
ulus e ment eciated be the effects ven d. to Kloss uniform)	All 7 baseline and 7 confirmatory LST in the HWRF program were run with the fan off. The LST priority test 214.1 (fan off) has been used for validation.	WGOthic has been validated with LST 214.1 with natural convection driving the annulus flows in WCAP-14382 §5, 6, 7, 8.	The external annulus is modelled with pressure boundary conditions at the inlet and outlet, such that the imposed ΔP is \leq equal to the external density head <i>driving force</i> . Thus, the initial annulus air flow is conservatively established at a <i>slightly negative value (directed downward in the annulus)</i> . The momentum equation is solved, balancing the buoyancy driving head with the unrecoverable losses through the annulus.	Nominal loss coefficient is used. Weak sensitivity to loss coefficient. Conservative initial air flow bounds postulated annulus flow start-up concerns.

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PIRT Phenomenon	Ranking for Riser External Flow Path ⁽⁴⁾	AP600 BCs or Phenomena Models	Test Bases	Report Submitted to NRC	Report Conclusion
C. Flow field stability or stratification	L	External flow path is a 1D hydraulic model	<ul style="list-style-type: none"> • LST riser • External flow path ΔP test • Eckert and Diagonal • Siegel and Norris • Hugot 	<p>Complete NTD-NRC-95-4414 RAI 952.102 response: WCAP-14190, Section 7.2 and 7.3 provide momentum and energy scaling for justification.</p> <p>WCAP-14382, §8 provides validation using 1D flow path for annulus.</p> <p>To be issued: Applications Report Document sensitivity to Kloss (uniform and nonuniform) and nominal delay time. See block on line above for loss coefficient study results.</p>	<p>Potential for low recirculation at downcomer inlet; total air flow at operating conditions negligible since minimal energy momentum in the downcomer.</p> <p>Small sensitivity large Kloss effect</p>
	-	Fog in annulus	-	<p>Complete NTD-NRC-94-4100, Enclosure 1 "Radiation Heat Transfer Through Fog in the PCCS Air Gap"</p>	<p>Justification for effect of fog in since effect of capture by fog has a negligible the annulus air temperature and overestimates the transfer to the b</p>
	-	Effect of wind-induced recirculation and stratified atmosphere is neglected	Literature	<p>Complete NTD-NRC-94-4166 "AP600 Containment Plume Investigation"</p>	<p>Quantification of for recirculation and thermally stratified atmosphere to cooling rates governing recirculation fraction, and a sensitivity show significant containment pressure effect</p>
	-	Effect of wind-induced turbulence is neglected	Wind tunnel tests	<p>Complete. NTD-NRC-95-4467 "Analysis of AP600 Wind Tunnel Testing for PCS Heat Removal"</p>	<p>Oscillating flow case site with low positive mean wind coefficient slightly increase heat removal rates from containment. Less severe than more positive wind coefficients show significant increase in heat removal.</p>

	Applicability of LST with Respect to Phenomenon	Validation of Modelling Method and/or WGOthic	Use of Validation Results in Evaluation Model	How Uncertainty is Handled
to affect AP600 is are is fairly	N/A Successful modelling of the external annulus with a 1D flow path shows ability of 1D model to predict riser phenomena.	<i>The downcomer flow area is large to act as a reservoir within which pressures can equalize, providing a relatively uniform inlet for the annulus. Use of 1D flow path is justifiable</i> Since heat transfer and momentum in the downcomer, relative to the riser, is so small that the possibility of downcomer instabilities is insignificant. Flow is primarily one-dimensional in nature; therefore, use of 1D flow path is justifiable. <i>Since fully developed turbulent flow develops in annulus before the baffle heats up, there is no potential for hot-baffle-induced flow instability to impact impact on start-up of annulus air flow.</i>	External flow path is modelled as 1D lumped parameter ANSTEC APERTURE CARD Also Available on Aperture Card	Negligible effect Weak sensitivity to external loss coefficient shows pressure is not sensitive to postulated inhibitors to external flow.
neglecting annulus radiation AP600 effect on heat baffle	Database consistent with AP600 expectations for external annulus conditions.	Effect of fog neglected in WGOthic models	Negligible effect on answers	Negligible effect
potential effluent diffused effect on radiation resulting in no movement	LST was run in no-wind (<5 mph) conditions	External pressure boundary condition is unadjusted for these effects	Assumption of no recirculation due to these effects has negligible impact on pressure prediction	Negligible effect
for worst case and removal. Units with and cases in	Not applicable	External pressure boundary condition is unadjusted for these effects	Assumption of no wind is bounding for pressure prediction	Bounded

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PIRT Phenomenon	Ranking for Riser ⁽⁴⁾ External Flow Path	AP600 BCs or Phenomena Models	Test Bases	Report Submitted to NRC	Report Conclusion
II. Module Surface					
A. Liquid film heat transfer	M	Thermal conductivity of liquid film for film temperature drop.	Chun and Seban	Complete NTD-NRC-94-4100, Enclosure 2 "Liquid Film Model Validation" WCAP-14382 §2 Scaling supplement will document consistent definition of resistances inside to outside shell	The Chun and Seban data provides a film thermal conductivity. The liquid film temperature drop.
B. Liquid film stability/coverage	H	Shell water coverage fractions and applied flow rate	<ul style="list-style-type: none"> • Full scale, cold 1/8 sector tests • Hot LST measured coverage • Westinghouse flat plate evaporation tests • Vendor age/contamination information tests 	<p>Complete.</p> <p>WCAP-12665, §3.1</p> <p>NTD-NRC-94-4247 "Method for Determining Film Flow Coverage for the AP600 Passive Containment Cooling System"</p> <p>NTD-NRC-94-4286 "Supplemental Information on AP600 PCS Film Flow Coverage Methodology," including sensitivity to 3/4 and 1/2 of bounding SSAR coverages showing well away from any cliffs in performance.</p> <p>SSAR Rev. 4 Preliminary Markup 6.2.1.1.3 summarizes water coverage assumptions.</p> <p>NTD-NRC-94-4083 W/NRC PCS Meeting Weak sensitivity to PCS flow rate, water coverage fraction, PCS time delay was shown.</p> <p>To be issued: Vendor report on effects of age and contamination.</p> <p>Note: An independent review by an industry expert is also planned.</p>	<p>Tests with water on surfaces up to 2 ft showed that the film without delay, even quenching a hot surface with cold water. Evaporation films do not become unstable, even in film dryout.</p> <p>Water coverage on and sidewalls as a function of time was bounded (Figure 2) by scale data and data from LST. The model has been compared with cold and hot tests, and bounding data.</p> <p>Model adequately conservatively accounts for effects of age on the wetting angle of a new surface. As age increases the peeling of the surface and increases wetting. Surface contamination be minimal based on inspection and criteria. Sensitivity using approximations of 1/2 and 1/4 bounding SSAR values show that AP600 pressure is relatively insensitive to further reduction in coverage below bounding minimum evaluation model.</p>

	Applicability of LST with Respect to Phenomenon	Validation of Modelling Method and/or WGOthic	Use of Validation Results in Evaluation Model	How Uncertainty is Handled
an is for ivity. small.	Internal and external liquid film effects are represented in the LST.	All validation performed with WGOthic includes the small effect of film temperature drop.	Nominal Chun and Seban correlation is used, accounting for wavy laminar and turbulent liquid films.	Negligible effect since resistance across film is small part of total resistance.
to F ate wet ate with rating e n total dome used to old, full ated e alidated ed test ounts y ct-on or a g rity of us nts will on aning es ly 3/4 coverage the response itive to in e n values.	<p>Heated LST data has been used to assess heat flux effect on coverage fraction.</p> <p>Measured coverage fractions on the LST were used as input boundary conditions in the WGOthic validation runs to validate cooling rate prediction models with test data.</p>	<p>Water coverage is an input boundary condition to the WGOthic code. A "top-to-bottom stack" of climes is used to model each of the wetted and dry portions of the external shell. Coverage fractions are used to determine the maximum value of potentially wetted shell heat transfer surface area input to the WGOthic climes model. Coverage for the dome at top and mid levels is assumed to be 40% to bound full scale cold test data, where the film is thick enough that film stability does not limit coverage.</p> <p><i>The wetted cross sectional area of the balance of the wetted portion where film stability limits coverage is obtained from 26.17 hrs in Table 4 of NTD-NRC-94-4247, where 100% dome coverage values show that film stability does not limit dome coverage. The Table 4 values have not been adjusted to account for the reduced evaporation associated with the assumed 40% coverage on the dome. Therefore, the coverage fraction assumed in the DBA bounds all times during the PCS DBA.</i></p> <p><i>Weak sensitivity to the input water coverage shows that minor perturbations in this assumption do not impact pressure predictions.</i></p>	<p>The validated conservative water coverage model is used to calculate input boundary conditions for the PCS DBA Evaluation Model.</p> <p>Bounding minimum water coverage fractions are used</p> <p>ANSTEC APERTURE CARD</p> <p>Also Available on Aperture Card</p>	Bounded

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PIRT Phenomenon	Ranking for Riser ⁽⁴⁾ External Flow Path	AP600 BCs or Phenomena Models	Test Bases	Report Submitted to NRC	Report Conclusions
		Shell wetting time delay	• Full scale, cold 1/8 sector tests	NTD-NRC-94-4083 W/NRC PCS Meeting A written The discussion in the boxes to the right will be provided in the applications report.	Weak sensitivity to flow rate, water fraction, PCS level was shown.
C. Liquid film subcooling	M	Liquid film energy conservation equation	Large Scale Tests	Complete WCAP-14382 §2.4, 2.5 show equations for liquid film	Inclusion of convection term in energy accounts for liquid subcooling effects, dome heat flux
D. Free convection heat transfer	L	Mixed convection correlation which reduces to the McAdams correlation, at high $Gr/Re^{2.7}$, with characteristic length in Gr number based on channel diameter	• Hugot tests • Eckert and Diagonal tests • Siegel and Norris tests • Westinghouse LST - dry external heat transfer	Complete WCAP-14190 Quantifies AP600 fraction of heat removed by convective heat transfer. NTD-NRC-95-4397 Supporting Information for the Use of Forced Convection in the AP600 PCS Annulus WCAP-14326 separate effects tests validation	Free convection transfer can be included in the AP600 model accounts for a fraction of total heat transferred. See also forced convection tests The mixed convection correlation provides data with a conservative mean bias of 10%.

	Applicability of LST with Respect to Phenomenon	Validation of Modelling Method and/or WGOthic	Use of Validation Results in Evaluation Model	How Uncertainty is Handled
PCS coverage delay	<p>LST 219.1 has water onto hot surface and thermocouple temperatures show the surface readily rewets during the high flow portion of the non-prototypical oscillating flow.</p> <p>Videotapes of a shakedown LST with a somewhat higher flow rate show water behavior applied to 240F surface. The observations showed that the advancing film front sizzled as it was boiled away, and readily flowed down as wide stripes after the surface fell below the leidenfrost temperature.</p>	<p>Input Boundary Condition delay time produces a conservative result.</p> <p>Earlier water application does not adversely impact air flow initiation because there is would be a net improvement in due to evaporative cooling.</p> <p>The effect on annulus air temperature and vapor content of water applied to the surface is explicitly modeled in WGOthic 1D annulus calculation. A sensitivity based on actual chronology with earlier wetting will be provided in the Applications report.</p>	<p>Since the outer surface temperature does not increase significantly is not hot until after water reaches the containment shell surface in real time, cold tests are acceptable to determine delay times. Delay time to wet the external surface is conservatively bounded by using time to reach steady state coverage fractions from the cold full scale test. This conservative delay time thus neglects <i>integrated</i> heat removal during about 10.5 minutes of actual water application <i>during the period when steady state film coverage is developing.</i> when surface temperature has not significantly increased.</p> <p>Time delay used bounds all postulated effects</p>	<p>Bounded</p> <p>ANSTEC APERTURE CARD</p> <p>Also Available on Aperture Card</p>
Subcooled liquid film on LST	<p>LST covers range of liquid film subcooling expected for AP600.</p> <p>Although a majority of the LST have higher fractions of energy removed by subcooling than AP600, the LST is valid for <i>developing a bounding approach for AP600 validation of physics and phenomena</i> since a scalable liquid film enthalpy transport model is used.</p>	<p>WCAP-14382, p. 8-6 discusses validation of LST heat flux distribution predictions over the dome.</p>	<p>WGOthic uses an appropriate set of governing equations for liquid film. Subcooling accounts for a small fraction (~5%) of the AP600 heat removal.</p>	<p>Negligible effect since mechanism accounts for only small fraction of AP600 heat removal.</p>
Heat neglected in shell heat transfer Convection sets the conservative %.	<p>Once the outer shell heats up to at least 2F above ambient, the AP600 annulus operates in forced convection.</p> <p>LST includes tests with and without fan on, covering the annulus from mixed free convection through forced convection dominated regimes.</p>	<p>Mixed convection correlation provides good agreement with annulus conditions in the LST.</p>	<p>Mixed convection correlation reduces to forced convection at high low $Gr/Re^{2.7}$, consistent with expectation for AP600 annulus conditions.</p> <p>A conservative bias of 0.83 times the nominal correlation is used.</p>	<p>Negligible effect</p> <p>Bounded</p>

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PIRT Phenomenon	Ranking for Riser ⁽⁺⁾ External Flow Path	AP600 BCs or Phenomena Models	Test Bases	Report Submitted to NRC	Report Conclusion
E. Forced convection heat transfer	L	Mixed convection correlation which reduces to the Colburn correlation at low Gr/Re ^{2.7}	<ul style="list-style-type: none"> • Hugot tests • Eckert and Diaguila tests • Siegel and Norris tests • Westinghouse STC dry flat plate tests • Westinghouse LST - dry external heat transfer 	<p>Complete WCAP-14190</p> <p>Quantifies AP600 fraction of heat removed by convective heat transfer.</p> <p>WCAP-14326, §3.1, 3.2, 3.3, 3.4, 3.5, and 4.1 shows validation of the correlations with separate effects tests</p>	<p>Forced convection heat transfer dominates AP600 riser. As a small fraction of heat transfer</p> <p>The mixed convection correlation is biased conservative at mean over the range. A relatively large uncertainty with $\mu = 0.976$ and $\sigma = 0.278$</p>
F. Radiation heat transfer	L	Wall-to-wall radiant heat transfer	<ul style="list-style-type: none"> • Westinghouse STC dry flat plate tests • Dry LST 	<p>Complete WCAP-14382, §2.5 describes the radiant heat transfer model used in Climes</p>	Dry external heat transfer is valid
G. Free convection mass transfer	-	Empirical correlation for the Sherwood number, which is derived by dimensional analysis using the Reynold's analogy and Colburn j factors.	<ul style="list-style-type: none"> • Gilliland and Sherwood evaporation tests • Westinghouse STC flat plate evaporation tests • University of Wisconsin condensation tests 	<p>Complete</p> <p>See free convection heat transfer</p> <p>NTD-NRC-95-4397</p> <p>Supporting Information for the Use of Forced Convection in the AP600 PCS Annulus</p> <p>WCAP-14326 separate effects tests validation</p>	<p>See free convection heat transfer</p> <p>The annulus is dominated by forced convection mass transfer. The outer shell heat transfer is at least 2F above during the transient</p>
H. Forced convection mass transfer	H	Empirical correlation for the Sherwood number, which is derived by dimensional analysis using the Reynold's analogy and Colburn j factors. <i>Application of a correction for mass transfer rate gives the AP600 forced convection mass transfer correlation</i>	<ul style="list-style-type: none"> • Gilliland and Sherwood evaporation tests • Westinghouse STC flat plate evaporation tests • University of Wisconsin condensation tests 	<p>Complete.</p> <p>NTD-NRC-95-4397</p> <p>"Supporting Information for the Use of Forced Convection in the AP600 PCS Annulus"</p> <p>Complete.</p> <p>WCAP-14326 gives correlation (§2.0, 2.1), entrance effect used for separate effect test (§2.2), and correlation validation with tests (§3.6, 3.7).</p>	<p>AP600 shown to be dominant in forced convection region</p> <p>Correlation is conservative with reasonable scatter in the range.</p> <p>$\mu = 0.936$ $\sigma = 0.139$</p> <p>Once the outer shell is up to at least ambient, the AP600 annulus operates in forced convection</p>

	Applicability of LST with Respect to Phenomenon	Validation of Modelling Method and/or WGOthic	Use of Validation Results in Evaluation Model	How Uncertainty is Handled
heat in rate for total ion d 2.4% the ge, with scatter ement all ΔT .	Dry LST has dominant annulus heat removal by convection <i>The LST and separate effects tests cover the range of AP600 Reynold's numbers.</i>	WCAP-14382, §3.2.1, 4.2 provide summaries of the validation. Although the comparisons with data show high scatter, it is attributable to high instrument uncertainty with small ΔT . The lack of any trend in the mean over the range indicates the correlation is reasonable as a basis for mass transfer analogy. Mass transfer validation, covering ΔT an order of magnitude higher, shows much less scatter.	Nominal correlation (with inherent conservative bias) used in WGOthic. <i>A conservative bias of 0.83 times the nominal correlation is used.</i> Convective heat transfer is not a dominant significant heat removal mechanism for AP600 DBA.	Uncertainty (scatter) is incorporated as an element of code uncertainty. <i>Bounded</i>
heat d.	Varying fractions of dry shell surface are included for all wet tests. The dry LST cases transfer a large fraction of heat by radiation to the baffle.	WCAP-14382 §7 shows selection of LST and §8 shows validation results.	Conservative property values are used in AP600 DBA.	Bounded
n heat minated on the go to at ambient ot.	See free convection heat transfer LST includes tests with and without fan on, covering the annulus from mixed convection through forced convection dominated regimes.	See free convection heat transfer WCAP-14382 summarizes WGOthic separate effects validation results (§3.2.1, 4.4)	See free convection heat transfer <i>A conservative bias of 0.83 times the nominal correlation is used.</i>	Negligible effect <i>Bounded</i>
perate n ed 6.4% over ell heats bove 00 in	LST covers range of AP600 Gr/Re2, including tests without the fan running LST includes tests with and without fan on, covering the annulus from mixed convection through forced convection dominated regimes. WCAP-14382 LST includes tests which cover range of AP600 subcooling; Predictions of total evaporation (p. 8-3) and wall heat flux (p. 8-6) validate models in an integral setting.	WCAP-14382 summarizes WGOthic separate effects validation results (§3.2.1, 4.4)	Forced convection correlation, modified for mixed convection effects to allow transient startup, is appropriate for AP600. <i>A conservative bias of 0.83 times the nominal correlation is used.</i> Nominal correlation (with inherent conservative bias) used in WGOthic.	Included in code uncertainty Uncertainty (scatter) is incorporated as an element of code uncertainty. <i>Bounded</i>

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PIRT Phenomenon	Ranking for Riser ⁽⁴⁾ External Flow Path	AP600 BCs or Phenomena Models	Test Bases	Report Submitted to NRC	Report Conclusions
III. Module Solids					
A. 1D transient conduction heat transfer	H	GOTHIC conductors used to model a few external concrete heat sinks, using the GOTHIC 1D conduction solution	CVTR	<p>NTD-NRC-94-4260 "GOTHIC Containment Analysis Package, Version 3.4e, Volumes I-III," Volume 1, §6 describes the 1D conduction solution used.</p> <p>WCAP-14382 provides validation with LST</p>	Use of Uchida heat sinks is consistent with guidelines.
IV. Inter-Module					
A. Convection	M	Governing equations for lumped parameter volumes connected with junctions	LST without the fan operating validate ability to calculate natural convective flows	<p>External flow rate and ΔT comparisons between WGOTHIC and LST have been presented at several meetings. These will be provided in a letter report.</p> <p>NTD-NRC-94-4083 Sensitivities to external Kloss, both uniform and non-uniform, as well as sensitivity to air inlet blockages up to 50% were provided at the March 17, 1994 NRC PCS meeting.</p> <p>As part of the Applications report, these sensitivities will be confirmed with <u>evaluated</u> using the final Evaluation Model.</p>	<p>For tests without fan operating, external flow rate and ΔT is well.</p> <p>Pressure response relatively insensitive to loss coefficient. The highly non-linear relation of evaporation rate with surface temperature results in increased evaporation cooling with only moderate surface temperature increase.</p>
B. Conduction	H	Climes include 1D conduction model used for conduction through containment shell	Comparison to theoretical solutions	<p>Complete.</p> <p>WCAP-14382 §2.5 shows the governing equation and discretization for 1D conduction, as well as model validation.</p>	The 1D conduction is correctly programmed into WGOTHIC.

	Applicability of LST with Respect to Phenomenon	Validation of Modelling Method and/or WGOthic	Use of Validation Results in Evaluation Model	How Uncertainty is Handled
heat e and p	Not applicable	GOTHIC Qualification Report shows validation for the GOTHIC 1D conductor.	Conservatively bounded material properties are used for AP600 external conductors Surface area and volume of heat sinks are conservatively underestimated.	Bounded ANSTEC APERTURE CARD Also Available on Aperture Card
the fan flow dicted	LST without the fan operating are applicable for validation of natural convective flows through the annulus with the 1D annulus flow model.	For tests without the fan operating, external flow rate and ΔT is predicted well.	A 1D lumped parameter model is used with an input nominal loss coefficient in WGOthic analyses. Buoyancy driven flows are balanced by the form and friction losses.	Negligible effect due to weak sensitivity to external Kloss
is e to nce the ecting, ear ation s in itive ases.	1D conduction used to model heat transfer through the LST shell, which neglects the additional heat removal by azimuthal conduction from dry to wet surfaces.	WCAP-14382, §4.1 contains validation of the 1D conduction equations used in Clime subroutines.	1D conduction equation is part of the Clime subroutines used for heat transfer through the shell. Using 1D conduction conservatively neglects azimuthal conduction from dry to wet stripes. Conservative material properties are used. Effects of degradation corrosion of inorganic zinc paint are included in material properties.	Conservatively bounded material properties are used for AP600 containment shell.

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PIRT Phenomenon	Ranking for Riser ⁽¹⁾ External Flow Path	AP600 BCs or Phenomena Models	Test Bases	Report Submitted to NRC	Report Conclusions
C. Form and friction losses	H	External flow path hydraulic resistance	Air flow path ΔP test, ~1/6 scale	<p>Complete See also the blocks on items I.C and IV.A. See also the line addressing item I.C. "External flow path is a 1D hydraulic model."</p> <p>NTD-NRC-94-4083 Sensitivities to external Kloss, both uniform and non-uniform, as well as sensitivity to air inlet blockages up to 50% were provided at the March 17, 1994 NRC PCS meeting.</p>	Loss coefficient external flow path

	Applicability of LST with Respect to Phenomenon	Validation of Modelling Method and/or WGOthic	Use of Validation Results in Evaluation Model	How Uncertainty is Handled
		LST - used constant loss coefficient for all predictions	Nominal loss coefficient used; lack of sensitivity	Negligible effect due to weak sensitivity to external Kloss

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