Westinghouse Electric
Company, LLC

Nuclear Systems

Box 355
Pittsburgh, Pennsylvania 15230-0355

DCP/NRC1484
Project 711

September 12, 2001

Document Control Desk
U. S. Nuclear Regulatory Commission
One White Flint North
11555 Rockville Pike
Rockville, MD 20852-2738

ATTENTION: Mr. Alan Rae, NRC, MS 12E15

SUBJECT: Transmittal of "Westinghouse Responses to Requests for Additional Information Related to Pre-Certification Review of the AP1000" (Proprietary and Non-Proprietary)

Dear Mr. Rae:

Attached please find the Westinghouse responses and related background information to Requests for Additional Information (RAIs) related to the pre-certification review of the AP1000. Attachment 1 contains the Westinghouse responses to the following AP1000 RAIs:

P016	P022	P027	P037
P017	P024	P030	P038
P018	P025	P031	P039
P020	P026	P034	P041
P021		P035	P046

Note that the responses to several RAIs contain information proprietary to Westinghouse. Attachment 2 contains the proprietary versions of these RAIs.

Attachments 3 and 4 contain proprietary and non-proprietary versions of a summary description of containment analysis results for the AP1000 performed with our updated WGOTHIC evaluation model. The evaluation model is constructed in accordance with methodology licensed for AP600, and is described in the attachment. Note that this model is not yet verified in accordance with Westinghouse Quality Assurance procedures.

D063

Add: Alan Rae
Andrzej Drozd

Westinghouse previously transmitted Revision K of the AP1000 Plant Parameters. Attachment 5 is Revision 0 of the AP1000 Plant Parameters. Revision 0 represents our baseline set of parameters for the AP1000 as we prepare our AP1000 Design Certification Application including Chapter 15 accident analyses. Please note that some of the information in Revision 0 of the plant parameters has been updated, and additional information is provided in the latest version of the plant parameters. Note that these changes are minor in nature, and do not significantly impact the determination of the issues set forth in the pre-certification review. Specifically, the determination of the applicability of the AP600 test data to the AP1000, and the applicability of the safety analysis codes for use in performing safety analysis for the AP1000.

Attachment 6 is the reviewer comments received by Westinghouse in development of the PIRT. These written comments are considered proprietary to Westinghouse.

Proprietary Submittal

The Westinghouse Electric Company proprietary information notice, application for withholding, and affidavit are also attached to the submittal letter as Attachment 7. Attachments 2, 3, 5, and 6 contain Westinghouse proprietary information consisting of trade secrets, commercial information or financial information which we consider privileged or confidential pursuant to 10CFR2.790. Therefore, it is requested that the Westinghouse proprietary information attached hereto be handled on a confidential basis and be withheld from public disclosures.

This material is for your internal use only and may be used for the purpose for which it is submitted. It should not be otherwise used, disclosed, duplicated, or disseminated, in whole or in part, to any other person or organization outside the Commission, the Office of Nuclear Reactor Regulation, the Office of Nuclear Regulatory Research and the necessary subcontractors that have signed a proprietary non-disclosure agreement with Westinghouse without the express written approval of Westinghouse.

Correspondence with respect to the application for withholding should reference AW-01-1482, and should be addressed to Hank A. Sepp, Manager of Regulatory and Licensing Engineering, Westinghouse Electric Company, P.O. Box 355, Pittsburgh, Pennsylvania, 15230-0355.

Please contact me if you have questions on this issue.

Very truly yours,

Michael M. Corletti

M. M. Corletti
Passive Plant Projects & Development

/Attachments

1. "Westinghouse Non-Proprietary Responses for Requests for Additional Information Regarding the AP1000 Pre-Certification Review" dated 9/12/2001
2. "Westinghouse Proprietary Responses for Requests for Additional Information Regarding the AP1000 Pre-Certification Review" dated 9/12/2001
3. "Containment Analysis Results for AP1000 Using Unverified WGOTHIC Evaluation Model" (Proprietary) dated 9/12/2001
4. "Containment Analysis Results for AP1000 Using Unverified WGOTHIC Evaluation Model" (Non-Proprietary) dated 9/12/2001
5. APP-GW-G0-002, Revision 0, "AP1000 Plant Parameters," dated 8/30/2001
6. "Expert Reviewer Comments Received by Westinghouse in the Development of AP1000 PIRT," dated 9/12/2001
7. Application for Withholding Proprietary Information from Public Disclosure

cc: H. A. Sepp, Westinghouse (w/o Attachment)

DCP/NRC1484

September 12, 2001

Attachment 7

Westinghouse Electric Corporation

Proprietary Information Notice

Application for Withholding

Affidavit

PROPRIETARY INFORMATION NOTICE

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

In order to conform to the requirements of 10 CFR 2.790 of the Commission's regulations concerning the protection of proprietary information so submitted to the NRC, the information which is proprietary in the proprietary versions is contained within brackets, and where the proprietary information has been deleted in the non-proprietary versions, only the brackets remain (the information that was contained within the brackets in the proprietary versions having been deleted). The justification for claiming the information so designated as proprietary is indicated in both versions by means of lower case letters (a) through (f) contained within parentheses located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters refer to the types of information Westinghouse customarily holds in confidence identified in Sections (4)(ii)(a) through (4)(ii)(f) of the affidavit accompanying this transmittal pursuant to 10 CFR 2.790(b)(1).

Westinghouse Electric Company, LLC

Box 355
Pittsburgh Pennsylvania 15230-0355

AW-01-1482

September 12, 2001

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555

ATTENTION: Mr. Samuel J. Collins

APPLICATION FOR WITHHOLDING PROPRIETARY
INFORMATION FROM PUBLIC DISCLOSURE

SUBJECT: Transmittal of Westinghouse Proprietary Class 2 Documents:

1) "Westinghouse Proprietary Responses to Requests for Additional Information Regarding the AP1000 Pre-Certification Review"
2) "Containment Analysis Results for AP1000 Using Unverified WGOTHIC Evaluation Model"
3) APP-GW-G0-002, Revision 0, "AP1000 Plant Parameters"
4) "Expert Review Comments Received by Westinghouse in the Development of AP1000 PIRT"

Dear Mr. Collins:

The application for withholding is submitted by Westinghouse Electric Company, LLC ("Westinghouse") pursuant to the provisions of paragraph (b)(1) of Section 2.790 of the Commission's regulations. It contains commercial strategic information proprietary to Westinghouse and customarily held in confidence.

The proprietary material for which withholding is being requested is identified in the proprietary version of the subject report. In conformance with 10CFR Section 2.790, Affidavit AW-01-1482 accompanies this application for withholding setting forth the basis on which the identified proprietary information may be withheld from public disclosure.

Accordingly, it is respectfully requested that the subject information which is proprietary to Westinghouse be withheld from public disclosure in accordance with 10CFR Section 2.790 of the Commission's regulations.

Correspondence with respect to this application for withholding or the accompanying affidavit should reference AW-01-1482 and should be addressed to the undersigned.

Very truly yours,

J. W. Winters, Manager
Passive Plant Projects & Development

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COMMONWEALTH OF PENNSYLVANIA:

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COUNTY OF ALLEGHENY:

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

James W. Winters, Manager
Passive Plant Projects & Development

Sworn to and subscribed
before me this 13th day
of September, 2001

Notary Public

Notarial Seal
Lorraine M. Piplica, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires Dec. 14, 2003
Member, Pennsylvania Association of Notaries

(1) I am Manager, Passive Plant Projects & Development, in the Nuclear Systems Division, of the Westinghouse Electric Company LLC ("Westinghouse"), and as such, I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing and rulemaking proceedings, and am authorized to apply for its withholding on behalf of the Westinghouse Electric Company, LLC.

(2) I am making this Affidavit in conformance with the provisions of 10CFR Section 2.790 of the Commission's regulations and in conjunction with the Westinghouse application for withholding accompanying this Affidavit.

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

(4) Pursuant to the provisions of paragraph (b)(4) of Section 2.790 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

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

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

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

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

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

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

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

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

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

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

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

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

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

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

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

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

(iii) The information is being transmitted to the Commission in confidence and, under the provisions of 10CFR Section 2.790, it is to be received in confidence by the Commission.

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

The proprietary information sought to be withheld in this submittal is that which is appropriately marked Proprietary Class 2 in the Westinghouse documents for submittal to the Commission: (1) "Westinghouse Proprietary Responses to Requests for Additional Information Regarding the AP1000 Pre-Certification Review", (2) "Containment Analysis Results for AP1000 Using Unverified WGOTHIC Evaluation Model", (3) APP-GW-G0-002, Revision 0, "AP1000 Plant Parameters", (4) "Expert Review Comments Received by Westinghouse in the Development of AP1000 PIRT."

This information is being transmitted by Westinghouse's letter and Application for Withholding Proprietary Information from Public Disclosure, being transmitted by Westinghouse Electric Company (W letter AW-01-1482) and to the Document Control Desk, Attention: Alan C. Rae, MS 12E15.

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

(a) Develop and verify Analytical Models

(b) Use computer codes to analyze postulated accident conditions.

Further this information has substantial commercial value as follows:

(a) Westinghouse plans to sell the use of similar information to its customers for purposes of meeting NRC requirements for Licensing Documentation.

(b) Westinghouse can sell support and defense of AP1000 Design Certification.

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

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

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

Further the deponent sayeth not.

Attachment 1

Westinghouse Non-Proprietary Responses to

Requests for Additional Information

Regarding the AP1000 Pre-Certification Review

REQUEST FOR ADDITIONAL INFORMATION

RAI: P016

Question:

WCAP-15612 states that long term cooling calculations are performed using WCOBRA/TRAC code initiated at the time of stable In-Containment Refueling Water Storage Tank (IRWST) injection using NOTRUMP code input for the reactor system conditions and WGOTHIC code for containment pressure. Justify that WGOTHIC predictions for containment pressure of AP1000 are conservative for the long term cooling evaluation. Compare WGOTHIC assumptions with the recommendations of Standard Review Plan 6.2.1.5 (NUREG-0800), "Minimum Containment Pressure Analysis for Emergency Core Cooling Performance Capability Studies" including Branch Technical Position CSB 6-1. Justify any deviations.

Westinghouse Response:

WCAP-14601, Rev. 2, p. 5-9 presents the conservative basis for the AP600 WGOTHIC analysis of containment pressure during Chapter 15 long-term cooling (LTC) analyses. The same set of conservatisms will be employed for the AP1000 long-term cooling WGOTHIC analyses. In the following table the AP1000 set of conservative assumptions is listed and compared to the Standard Review Plan 6.2.1.5 / Branch Technical Position CSB 6-1 recommendations:

Branch Technical Position CSB 6-1 Guidance Compared to AP1000 Analysis Bases:

CSB 6-1 Subsection	CSB 6-1 Guidance	AP1000 Analysis Condition
B.1.a Initial Containment Internal Conditions	Use maximum containment gas temperature, minimum pressure, and maximum humidity for limiting normal operating conditions (for ice condenser plant designs)	[ ]a,c

REQUEST FOR ADDITIONAL INFORMATION

CSB 6-1 Subsection	CSB 6-1 Guidance	AP1000 Analysis Condition
B.1.b Initial Outside Containment Ambient Conditions	A reasonably low ambient temperature should be used.	[
B.1.c Containment Volume	The maximum containment net free volume should be used.	
B.1.d Purge Supply / Exhaust Systems	If purge operation is proposed during power operation, the purge system lines should be assumed to be initially open.	
B.2.a Spray and Fan Cooling Systems	All containment heat removal ESF systems operate at full capacity (maximum flow and minimum water temperature)	
B.2.b Containment Steam Mixing with Spilled ECCS Water	Effect of spilled subcooled ECCS water on calculated containment pressure should be considered	
B.2.b Containment Steam Mixing with Ice Melt Water	Effect of ice condenser melted water on the containment pressure calculation should be considered	]a,c

Modeling of the passive heat sinks in the WGOTHIC analysis of AP1000 long-term cooling cases is now discussed. The structural heat sinks present in the AP1000 containment have been identified through a detailed review of the plant design/layout drawings. [

]^{a,c}

Overall, the thermophysical properties utilized in the WGOTHIC calculation are well-established values for the various structural materials. One change is made to the containment integrity analysis properties. [The conductivities of material type 7 and type 8 in the WGOTHIC input are conservatively reduced by a factor of four for the baseline WGOTHIC evaluation model used to calculate maximum containment pressure and temperature (from 1.208 down to 0.302). For the long-term containment analysis, the thermal conductivity for these materials is assumed to be 1.208, consistent with the appropriate reference value.]^{a,c}

In performing AP1000 containment integrity analyses with WGOTHIC, the code heat and mass transfer predictions are penalized by multiplying the coefficients by a value less than one; these multipliers are set to 1.0 for the long-term cooling ECCS backpressure calculation to remove this penalty. Furthermore, all HTC = 5 (values) in the containment integrity analysis are reset to HTC = 1. The external containment surface is assumed to achieve the maximum wetting possible to maximize the heat transfer to the PCS water.

REQUEST FOR ADDITIONAL INFORMATION

RAI: P017

Question:

WCAP-15612 states that a constant containment pressure value of 29.5 psia will be used for long term cooling evaluations based on WGOTHIC calculations. Describe how the mass and energy inputs to WGOTHIC calculations for long term cooling were obtained. Describe the computer codes and methods that were used to obtain the mass and energy inputs. Discuss how these codes and methods have been made conservative for long term cooling analysis.

Westinghouse Response:

The containment pressure of 29.5 psia used in the AP1000 preliminary long-term cooling analysis presented in WCAP-15612 was obtained from a WGOTHIC calculation that used the scoping model with a single node above the operating deck and mass/energy releases from the AP1000 preliminary NOTRUMP analysis of the DEDVI line break. The assumptions in the WGOTHIC model were biased as per the RAI_P016 response to calculate a conservatively low pressure. This containment pressure was calculated solely for use in the WCAP-15612 case.

The AP1000 DCD long-term cooling analyses will use the same computer codes and calculational methods to calculate mass/energy releases as were used in the AP600 DCD long-term cooling (LTC) analyses (Reference 1, Section 5.2).

Large and small break LOCA events are analyzed in the short term using computer codes specifically designed for each break category. AP1000 large break LOCA events are analyzed by applying the WCOBRA/TRAC best-estimate methodology licensed for AP600 (Reference 2) to analyze the core response until total fuel rod quench is predicted. The small break LOCA events are analyzed using a NOTRUMP version specifically created and validated for AP600 and AP1000 (Reference 3) to perform an Appendix K analysis until the steady, continuous injection of water from the IRWST is established. The short-term ECCS analyses establish the boundary conditions for the long-term cooling analyses.

The containment mass and energy releases from the short-term analysis of an AP1000 LOCA transient are supplied to WGOTHIC (Reference 4). In addition, the mass and energy releases during the IRWST injection period are also be determined for the WGOTHIC LTC analysis. To accomplish this, first the drain rate of the IRWST is computed based on the minimum initial inventory condition when IRWST injection begins.

[

]a,c

A NOTRUMP model of the IRWST, and the passive safety system piping connecting it to the reactor vessel, is used to compute the draining of the IRWST during a double-ended DVI line break. This method is a simplified application of the NOTRUMP modeling which has been qualified for the AP600 and AP1000 during the code validation effort; [

]a,c

References:

1. WCAP-14601, Revision 2, "AP600 Accident Analyses – Evaluation Models," 1998.
2. Hochreiter, L. E., et al., "WCOBRA/TRAC Applicability to AP600 Large-Break Loss-of-Coolant Accident," WCAP-14171, Rev. 2, March 1998 (Proprietary).
3. Fittante, R. L., et al., "NOTRUMP Final Validation Report for AP600," WCAP-14807, Revision 5 (Proprietary), August 1998.
4. Forgie, A., et al., "WGOTHIC Application to AP600," WCAP-14407, Rev. 3, April 1998.
5. Andreychek, T. S., et al., "AP600 Low-Pressure Integral Systems Test at Oregon State University Test Analysis Report," WCAP-14292, Revision 1, September 1995.

Figure 1 IRWST Drain Rate Calculation Method for LTC M/E Releases

a,c

Figure 2 Small Break LOCA IRWST Drain Boiloff Calculation

REQUEST FOR ADDITIONAL INFORMATION

RAI: P018

Question:

The assumption of a low containment pressure during recovery from a small break LOCA may be conservative for predicting steam flow resistance within the reactor system during the time when the reactor system is being refilled by the passive emergency core cooling systems. A higher containment pressure may be conservative if this assumption leads to the prediction of a higher IRWST pool temperature when this water is calculated to flow into the reactor system. Provide a sensitivity study for AP1000 comparing assumptions for containment pressure during small break Loss of Coolant Accidents (LOCA) to demonstrate which assumptions are conservative.

Westinghouse Response:

For the cases performed in WCAP-15612 (Reference 1), heat addition to the IRWST is modeled for both ADS Stage 1-3 discharge and PRHR operation. A sensitivity study was performed and documented in Reference 1 with regards to the impact of increasing containment pressure on the Double-Ended DVI (DEDVI) line break. For this particular case, the major impact observed, was a much earlier occurrence of IRWST injection flow that serves to terminate inventory depletion.

Boiling of the fluid in the IRWST is typically not predicted to occur during the LOCA accidents such that an increase in containment pressure would not result in an increased injection temperature. In order to obtain boiling in the IRWST tank, a significant period of PRHR operation would have to occur which translates to a very small break LOCA.

References:

1. WCAP-15612, AP1000 Plant Description and Analysis Report, December 2000.

REQUEST FOR ADDITIONAL INFORMATION

RAI: P020

Question:

WCAP-14601, Rev. 2 Figure 5-6 states that for AP600, IRWST draining rates for LTC analysis are to be calculated using WGOTHIC or NOTRUMP. WCAP-15612 states that the MAAP code will be used to calculate IRWST draining rates for AP1000. Please submit the MAAP code for staff review with complete documentation. Include code manuals describing all equations with appropriate justification and assessment, user input instructions and guidelines. Include qualification of the code for AP1000 analysis by comparison with appropriate test data.

Westinghouse Response:

The MAAP code will not be used to calculate the IRWST draining rates for AP1000. This statement will be removed from the next revision of WCAP-15612. Westinghouse will continue to use the accepted AP600 code/methodology to calculate the IRWST draining rates for the AP1000 LTC analysis.

AP1000 PRE-CERTIFICATION REVIEW

REQUEST FOR ADDITIONAL INFORMATION

RAI: P021

Question:

The Rig of Safety Assessment (ROSA) test facility provided data of a different scale from that of the Simulatore per Experienze di Sicurezza (SPES) and Oregon State University (OSU) facilities. In particular, the ROSA facility provides additional data for ADS-4 discharge. The prediction of ADS-4 discharge has become more significant for AP1000 than for AP600 because of the higher power of the plant and the relative larger size of ADS-4 in relation to ADS Stages 1,2, and 3. Accordingly please provide comparisons of NOTRUMP predictions to test data from ROSA tests AP-CL-03, AP-PB-01, and AP-DV-01. Please provide plots showing comparisons with test data for reactor system pressure, core make-up tank (CMT) level, pressurizer level, accumulator level, ADS-4 mass flow rate, IRWST flow rate, and core collapsed level. Include fluid predictions in the ADS-4 lines upstream and downstream of the ADS-4.

Westinghouse Response:

The prediction of the ADS-4 discharge line is important for both the AP600 and AP1000. NOTRUMP predictions of ADS-4 performance were validated against SPES and OSU test facilities such that it was determined that NOTRUMP can provide conservative analytical results of small break LOCA. The scaling studies provided in Reference 1 demonstrate that these facilities are suitably scaled to the AP1000 plant to apply the code for conservative analysis of LOCA for AP1000, as detailed in Reference 2.

To further address the importance of the ADS-4 performance for AP1000, Westinghouse is proposing to perform confirmatory calculations of ADS-4 performance using WCOBRA-TRAC, as discussed in Reference 2. These additional analyses that were not performed for AP600 will provide further confirmation that NOTRUMP is sufficient to perform conservative Appendix K small break LOCA analyses for the purpose of predicting minimum core inventory and associated peak clad temperature for AP1000.

The ROSA facility was not used by Westinghouse to validate the NOTRUMP code for AP600, but rather was used as confirmatory tests by the NRC for the purposes of validating their independent analyses of the AP600 plant performance. Since it is shown that the SPES and OSU facilities are suitably scaled for AP1000, the ROSA experiments are not necessary for validating NOTRUMP predictions of ADS-4 performance for AP1000. Westinghouse does not have a NOTRUMP model of the ROSA facility. Such a model would require extensive code development, benchmarking and validation.

References:

1. WCAP-15613, "AP1000 PIRT and Scaling Assessment," dated March 2001.
2. WCAP-15644, "AP1000 Code Applicability Report," dated May 2001.

REQUEST FOR ADDITIONAL INFORMATION

RAI: P022

Question:

Please provide a scaling assessment of the ROSA facility as modified for AP600 with the AP1000 design.

Westinghouse Response:

A scaling assessment of the ROSA test facilitv as modified for AP600 has been performed for the AP1000 design. The ROSA scaling assessment is consistent with the approach taken in WCAP-15613 for the SPES and OSU test facilities. The results are summarized in the tables below and show that the ROSA facility is in general sufficiently scaled to AP1000. The one exception is the cold leg Froude number is distorted as the area of the cold leg is oversized in the ROSA facility relative to AP1000. This distortion may effect the flow regime in the cold leg and therefore the timing of the transition from single-phase to two-phase natural circulation through the PRHR heat exchanger. Note that the sump injection phase is not scaled as the ROSA facility did not simulate sump injection.

Table P022-1 provides the Summary of SBLOCA Top-Down Scaling Results for the ROSA facility, and is presented in the same form as that which is presented in WCAP-15613 for the SPES and OSU facilities. Table P022-2 provides the Summary of SBLOCA Bottoms-Up Scaling Results for the ROSA facility, and is presented in the same form as that which is presented in WCAP-15613 for the SPES and OSU facilities. Table P022-3 through P022-12 provides the scaling reference values used to perform the scaling calculations.

Table P022-1 Summary of SBLOCA Top-Down Scaling Results – ROSA Test Facility

Phase of SBLOCA Transient	Important PIRT Phenomena Addressed	Scaling Ratio	Scaling Ratio Description or Remarks	Phase of SBLOCA Transient: Natural Circulation		ADS		ADS-IRWST Transition		IRWST Injection		Sump Injection		Is Scaling Ratio Acceptable or Distorted?
				ROSA AP600	ROSA AP1000	ROSA AP600	ROSA AP1000	ROSA AP600	ROSA AP1000	ROSA AP600	ROSA AP1000	ROSA AP600	ROSA AP1000	
Blowdown	- Core Decay Heat - Break Flow (Critical)	Blowdown Phase Scaling was not performed.	Blowdown is similar to conventional PWR.											
Natural Circulation	- Core Decay Heat - PRHR Circulation	$\pi_R = \left[X_e\left(\frac{\Delta\rho}{\rho_g}\right)\right]_R$	Core exit quality	[ ]^{a,c}	[ ]^{a,c}									Acceptable
ADS Depressurization	- Core Decay Heat - ADS 1-3 Flow (Critical)	$\omega_R = \left[\frac{\dot{m}_{\substack{core\\steam}} \cdot h_g}{(V\,\Delta P)_{\substack{RCS\\steam\ vol.}}}\right]_R$	Fractional rate of change of RCS pressure due to steam addition via core decay heat			[ ]^{a,c}	[ ]^{a,c}							Acceptable
		$\omega_R = \left[\frac{\dot{m}_{\substack{ADS\\steam}} \cdot h_g}{(V\,\Delta P)_{\substack{RCS\\steam\ vol.}}}\right]_R$	Fractional rate of change of RCS pressure due to steam removal via ADS vent			[ ]^{a,c}	[ ]^{a,c}							Acceptable
ADS-IRWST Transition • CMT Injection	- Reactor Vessel Inventory - Core Decay Heat	$\omega_R = \left[\frac{\dot{m}_{CMT}}{(\rho_f \Delta V)_{vessel}}\right]_R$	Fractional rate of change of vessel inventory due to inventory replenishment via CMT injection					[ ]^{a,c}	[ ]^{a,c}					Acceptable for AP1000
		$\omega_R = \left[\frac{\dot{m}_{core}}{(\rho_f \Delta V)_{vessel}}\right]_R$	Fractional rate of change of vessel inventory due to inventory depletion via core decay heat					[ ]^{a,c}	[ ]^{a,c}					Acceptable
• IRWST Injection	- Reactor Vessel Inventory - Core Decay Heat	$\omega_R = \left[\frac{\dot{m}_{IRWST}}{(\rho_f \Delta V)_{vessel}}\right]_R$	Fractional rate of change of vessel inventory due to inventory replenishment via IRWST injection					[ ]^{a,c}	[ ]^{a,c}					Acceptable for AP1000
		$\omega_R = \left[\frac{\dot{m}_{core}}{(\rho_f \Delta V)_{vessel}}\right]_R$	Fractional rate of change of vessel inventory due to inventory depletion via core decay heat					[ ]	[ ]^{a,c}					Acceptable

Table P022-1 Summary of SBLOCA Top-Down Scaling Results – ROSA Test Facility (cont.)

Phase of SBLOCA Transient	Important PIRT Phenomena Addressed	Scaling Ratio	Scaling Ratio Description or Remarks	Phase of SBLOCA Transient: Natural Circulation		ADS		ADS-IRWST Transition		IRWST Injection		Sump Injection		Is Scaling Ratio Acceptable or Distorted?
				ROSA AP600	ROSA AP1000	ROSA AP600	ROSA AP1000	ROSA AP600	ROSA AP1000	ROSA AP600	ROSA AP1000	ROSA AP600	ROSA AP1000	
ADS-IRWST Transition (cont.)	- ADS-4 Flow	$\omega_R = \left[\frac{(\dot{m}\cdot h_g)_{\substack{ADS-4\\critical}}}{(V\,\Delta P)_{\substack{RCS\\steam\ vol.}}}\right]_R$	Fractional rate of change of RCS pressure due to ADS-4 critical flow steam vent					[ ]^{a,c}	[ ]^{a,c}					Acceptable
		$\omega_R = \left[\frac{(\dot{m}\cdot h_g)_{\substack{ADS-4\\non-critical}}}{(V\,\Delta P)_{\substack{RCS\\steam\ vol.}}}\right]_R$	Fractional rate of change of RCS pressure due to ADS-4 non-critical flow steam vent					[ ]^{a,c}	[ ]^{a,c}					Acceptable
		$\omega_R = \left[\frac{(\dot{m}\cdot h_g)_{\substack{core\\steam}}}{(V\,\Delta P)_{\substack{RCS\\steam\ vol.}}}\right]_R$	Fractional rate of change of RCS pressure due to steam generation via core decay heat					[ ]^{a,c}	[ ]^{a,c}					Acceptable
IRWST Injection	- Core Decay Heat - IRWST Level - ADS-4 Flow - IRWST Temperature	$\pi_R = [X_e]_R$	Core exit quality							[ ]^{a,c}	[ ]^{a,c}			Acceptable
Sump Injection			ROSA facility did not simulate sump injection									See Remarks		

Table P022-2 Summary of SBLOCA Bottom-Up Scaling Results – ROSA Test Facility

Phase of SBLOCA Transient	Important PIRT Phenomena Addressed	Scaling Ratio	Scaling Ratio Description or Remarks	Phase of SBLOCA Transient: Natural Circulation		ADS		ADS-IRWST Transition		IRWST Injection		Sump Injection		Is Scaling Ratio Acceptable or Distorted?
				ROSA AP600	ROSA AP1000	ROSA AP600	ROSA AP1000	ROSA AP600	ROSA AP1000	ROSA AP600	ROSA AP1000	ROSA AP600	ROSA AP1000	
Blowdown		Blowdown Phase Scaling was not performed.	Blowdown is similar to conventional PWR.											
Natural Circulation	- CMT Balance Line Flow Composition - Phase Separation CL-CMT Balance Line T-Junction	$\pi_R = [(Fr)_{CL}]_R$ $\pi_R = \left[\left(\left(\frac{d_{CL}}{d_{CMT\ balance\ line}}\right)^2\right)^{-0.8}\right]_R$	Cold leg Froude number Phase separation CL-CMT balance line T-junction	$[\ ]^{a,c}$ $[\ ]^{a,c}$	$[\ ]^{a,c}$ $[\ ]^{a,c}$									Distorted Acceptable
ADS Depressurization	- Surge Line Pressure Drop		See Section 4.1.2.3.2 of WCAP-15613 for surge line pressure drop											
ADS-IRWST Transition	- Hot Leg Flow Pattern Transition - Hot Leg Entrainment - Countercurrent Flow in Surge Line - Pressurizer Draining	$\pi_R = [(Fr)_{HL}]_R$ $\pi_R = \left[\frac{U_g \cdot d^{1/2}}{Lg^2}\right]_R$ $\pi_R = [K^*]_R$	Hot leg Froude number Hot leg – ADS-4 entrainment number Surge line Kutateladze number See Section 4.1.2.4.2 of WCAP-15613 for pressurizer draining					$[\ ]^{a,c}$ $[0.9]^{a,c}$ $[\ ]^{a,c}$	$[\ ]^{a,c}$ $[\ ]^{a,c}$ $[\ ]^{a,c}$					Acceptable Acceptable Acceptable
IRWST Injection														
Sump Injection			ROSA facility did not simulate sump injection											

Table P022-3 Top-Down Scaling Reference Values: Natural Circulation

a,c

Parameter		Units	AP600	AP1000	OSU	SPES	ROSA	Remarks
RCS Pressure	p	psia						Secondary side pressure as reference
Density of liquid	ρ_f	lbm/ft^3						Thermodynamic property of saturated liquid
Density of gas	ρ_g	lbm/ft^3						Thermodynamic property of saturated vapor
Enthalpy difference	H_fg	BTU/lbm						Thermodynamic property at saturation
Elevation difference	z_prhr-z_c	ft						Elevation difference between midpoints of PRHR HX and reactor core[1]
Resistance of PRHR outlet/area squared	R_out	ft^-4						Resistance from PRHR HX outlet to SG plus 1/2 PRHR HX resistance
Resistance of PRHR inlet/area squared	R_in	ft^-4						Resistance from hot leg to PRHR HX plus 1/2 PRHR HX resistance
Core power ratio		N/A						Core power relative to AP600

Notes:

1. For scaling purposes, gas-liquid interfaces considered to be located at midpoints of PRHR HX and reactor core.

Test/Plant Scaling Ratio	Core exit quality-density
OSU/AP600	
OSU/AP1000	
SPES/AP600	
SPES/AP1000	
ROSA/AP600	
ROSA/AP1000	

a,c

Table P022-4 Top-Down Scaling Reference Values: ADS Depressurization

a,c

Parameter		Units	AP600	AP1000	OSU	SPES	ROSA	Remarks
Pressure @ ADS inlet, intial	p	psia						RCS pressure at start of depressurization; use secondary side pressure as reference
Pressure @ end of ADS phase	p	psia						RCS pressure at end of depressurization
Density of gas	ρ_g	lbm/ft^3						Thermodynamic property of saturated vapor
Enthalpy of gas	H_g	BTU/lbm						Thermodynamic property of saturated vapor
Enthalpy difference	H_fg	BTU/lbm						Thermodynamic property at saturation
Core power ratio		N/A						Core power ratio relative to AP600
Area of ADS-1/2/3	A_ads123	in^2						Total ADS-1/2/3 critical flow area
Volume of RCS steam ratio		N/A						Ratio of total RCS volume ratio relative to AP600[1,2] used as boundary value
Ratio of specific heat	γ_stm	N/A						Ratio of specific heats of steam vapor

Notes:

1. Actual volume ratio for SPES ~ 1/402. However 1/395 value for ideal scaling used as within few percent of actual.
2. Ideal volume ratio for OSU is 1/192. Actual is ~1/183.

Test/Plant Scaling Ratio	Fractional rate of change of RCS pressure due to steam addition via core decay heat	Fractional rate of change of RCS pressure due to steam removal via ADS vent
OSU/AP600		
OSU/AP1000		
SPES/AP600		
SPES/AP1000		
ROSA/AP600		
ROSA/AP1000		

a,c

Table P022-5 Top-Down Scaling Reference Values: CMT Injection

a,c

Parameter		Units	AP600	AP1000	OSU	SPES	ROSA	Remarks
Pressure ratio		N/A						Pressure similitude approx. exists
Density ratio		N/A						Property similitude approx. exists
Enthalpy ratio		N/A						Property similitude approx. exists
Elevation difference	zcmt-zdvi	ft						Elevation difference between top of CMT and DVI elevation (downcomer liquid level at or below DVI elev.during transition phase)
Resistance of CMT-DVI path/areasquared	R_cmt-dvi	ft^-4						Resistance associated with double ended DVI break (one injection path only)
Volume of vessel liquid	V_ves liq	ft^3						Total vessel volume represents boundary value
Core Power ratio		N/A						Core power relative to AP600

Test/Plant Scaling Ratio	Fractional rate of change of vessel inventory due to CMT injection	Fractional rate of change of vessel inventory due to core decay heat
OSU/AP600		
OSU/AP1000		
SPES/AP600		
SPES/AP1000		
ROSA/AP600		
ROSA/AP1000		

a,c

Table P022-6 Top-Down Scaling Reference Values: IRWST Injection

a,c

Parameter		Units	AP600	AP1000	OSU	SPES	ROSA	Remarks
Pressure ratio		N/A						Pressure similitude approx. exists
Density ratio		N/A						Property similitude approx. exists
Enthalpy ratio		N/A						Property similitude approx. exists
Elevation difference	zirwst-zdvi	ft						Elevation diff. between IRWST intial liquid level and DVI elev. (downcomer liquid level at or below DVI elev.during transition phase)
Elevation difference	zpzr-zhl	ft						Elevation difference between top pressurizer and hot leg with void fraction of ~0.5[1]
Resistance of IRWST DVIpath/area squared	R_dvi	ft^-4						Resistance associated with double ended DVI break (one injection path only)
Volume of vessel liquid	V_ves liq	ft^3						Total vessel volume represents boundary value
Core Power ratio		N/A						Core power relative to AP600

Notes:

1. Simple estimate of collapsed liquid level held up above core when IRWST injection initiates.

Test/Plant Scaling Ratio	**Fractional rate of change of vessel inventory due to IRWST injection**	**Fractional rate of change of vessel inventory due to core decay heat**
OSU/AP600		
OSU/AP1000		
SPES/AP600		
SPES/AP1000		
ROSA/AP600		
ROSA/AP1000		

a,c

Table P022-7 Top-Down Scaling Reference Values: ADS-4 Depressurization a,c

Parameter		Units	AP600	AP1000	OSU	SPES	ROSA	Remarks
RCS pressure @ ADS-4 inlet	p	psia						Pressure similitude approx. exists
Pressure @ ADS-4 discharge	p	Psia						Pressure similitude approx. exists
Density of gas @ ADS-4 inlet	ρ_gout	lbm/ft^3						Density of saturated steam
Density of gas @ ADS-4 outlet	ρ_gin	lbm/ft^3						Density of saturated steam
Average density	ρ_gave	lbm/ft^3						Average of inlet and outlet density
Ratio of RCS stm Vol		N/A						Represents volume of pressurizer, SGs, upper head/plenum, and loop piping[1]
Area of ADS-4 inlet	A_ads4in	ft^2						Total area, ADS-4 inlet (hot leg connection)
Area of ADS-4 outlet	A_ads4out	ft^2						Total area, ADS-4 discharge to containment
Resistance of ADS-4 vent path	R_ads4	ft^-4						Resistance of ADS-4 paths in parallel; all ADS-4 vent paths available[2]
Ratio of ADS-4 area		N/A						Represents minimum area for critical flow
Ratio of specific heat		N/A						Rato of specific heat of steam
Core Power ratio		N/A						Core power relative to AP600
Enthalpy ratio		N/A						Property similitude approx. exists

Notes:

1. RCS volume is largely voided except for core, lower plenum,and downcomer during transition phase.
2. ADS-123 path is not very effective during transition phase due to assumed failures, liquid hold-up in the pressurizer/surge line, and ADS-123 discharge in IRWST is covered by several feet of water (until IRWST drains sufficiently). ADS-123 becomes more effective after transition phase when ADS-123 vent path liquid is cleared or drained.

Test/Plant Scaling Ratio	Fractional rate of change of RCS pressure due to ADS-4 critical flow	Fractional rate of change of RCS pressure due to core decay heat	Fractional rate of change of RCS pressure due to ADS-4 non-critical flow
OSU/AP600			
OSU/AP1000			
SPES/AP600			
SPES/AP1000			
ROSA/AP600			
ROSA/AP1000			

a,c

Table P022-8 Top-Down Scaling Reference Values: IRWST Injection

a,c

Paramete r		Units	AP600	AP1000	OSU	SPES	ROSA	Remarks
RCS Pressure	p	psia						RCS is fully depressurized
Density of liquid	ρ_f	lbm/ft^3						Thermodynamic property of saturated liquid
Density of gas	ρ_g	lbm/ft^3						Thermodynamic property of saturated vapor
Enthalpy difference	H_fg	BTU/lbm						Thermodynamic property at saturation
Enthalpy subcooling	H_sub	BTU/lbm						Difference between saturated - subcooled
Elevation difference	z_s-z_cout	ft						Elevation difference between initial IRWST Liquid level and core outlet
Resistance of DVI paths/area squared	R_dvi	ft^-4						Resistance of IRWST injection path for DE DVI break; one flow path intact; Other flow path is broken near DVI nozzle Therefore not included in resistance
Resistance of ADS paths/area squared	R_ads	ft^-4						Resistance of ADS-4 flow paths in parallel With ADS-123 flow paths; failure of one ADS-1 and one ADS-3 flow path
Core power ratio		N/A						Core power relative to AP600

Test/Plant Scaling Ratio	Core exit quality
OSU/AP600	
OSU/AP1000	
SPES/AP600	
SPES/AP1000	
ROSA/AP600	
ROSA/AP1000	

a,c

Table P022-9 Bottom-Up Scaling Reference Values: Cold Leg Flow Pattern

a,c

Parameter		Units	AP600	AP1000	OSU	SPES	ROSA	Remarks
RCS Pressure	P	Psia						Secondary side pressure as reference
Density of liquid	ρ_f	Lbm/ft^3						Thermodynamic property of saturated liquid
Density of gas	ρ_g	Lbm/ft^3						Thermodynamic property of saturated vapor
Enthalpy	H_fg	BTU/lbm						Thermodynamic property at saturation
Core power ratio		N/A						Core power relative to AP600
Cold Leg diameter	d_cl	In						Inside diameter of cold leg

Test/Plant Scaling Ratio	Cold Leg Froude Number (a,c)
OSU/AP600	
OSU/AP1000	
SPES/AP600	
SPES/AP1000	
ROSA/AP600	
ROSA/AP1000	

Table P022-10 Bottom-Up Scaling Reference Values: Phase Separation at Cold Leg-CMT Balance Line Tee

a,c

Parameter		Units	AP600	AP1000	OSU	SPES	ROSA	Remarks
Cold Leg diameter	d_cl	in						Inside diameter of cold leg
CMT BL diameter	d_cmt bl	in						Inside diameter of cold leg balance line

Test/Plant Scaling Ratio	Phase Separation
OSU/AP600	
OSU/AP1000	
SPES/AP600	
SPES/AP1000	
ROSA/AP600	
ROSA/AP1000	

a,c

Table P022-11 Bottom-Up Scaling Reference Values: Hot Leg Flow Pattern

a,c

Parameter		Units		AP600	AP1000	OSU	SPES	ROSA	Remarks
Core Power ratio		N/A							Core power relative to AP600
Hot leg diameter	d_hl	in.							Inside diameter of hot leg

Test/Plant Scaling Ratio	Hot Leg Froude Number
OSU/AP600	
OSU/AP1000	
SPES/AP600	
SPES/AP1000	
ROSA/AP600	
ROSA/AP1000	

a,c

Table P022-12 Bottom-Up Scaling Reference Values: Entrainment from Hot Leg into ADS-4

a,c

Paramete r		Units		AP600	AP1000	OSU	SPES	ROSA	Remarks
Core Power ratio		N/A							Core power relative to AP600
Hot leg diameter	d_hl	in.							Inside diameter of hot leg
ADS-4 inlet diameter	d_ads-4	in.							ADS-4 inlet pipe connected to top of hot leg

Test/Plant Scaling Ratio	Entrainment Onset Correlation
OSU/AP600	
OSU/AP1000	
SPES/AP600	
SPES/AP1000	
ROSA/AP600	
ROSA/AP1000	

a,c

REQUEST FOR ADDITIONAL INFORMATION

RAI: P024

Question:

Page 2-25 of WCAP-15613 describes Dr. Hochreiter's suggestion that the Phenomena Identification and Ranking Table (PIRT) ranking for Direct Vessel Injection (DVI) pressure drop be raised from "Medium" for all phases of Small Break LOCA (SBLOCA). It is still ranked "Medium" by Westinghouse. Justify that the DVI pressure drop is adequately scaled in the integral system test data so that its effect on SBLOCA can be determined.

Westinghouse Response:

DVI line pressure drop is included in the safety analysis models and in the top-down integral effect test scaling of the ADS-IRWST transition, IRWST injection, and Sump injection phases of a SBLOCA. Refer to Section 4 of WCAP-15613. Injection via the DVI line is not of high importance during the blowdown and natural circulation phases of a SBLOCA.

DVI line pressure drop is scaled with respect to its influence on CMT and IRWST injection relative to reactor vessel inventory recovery during the ADS-IRWST transition phase. The DVI line pressure drop influence is embodied in the DVI resistance terms {i.e $(\Sigma R/A^2)_{CMT-DVI}$ and $(\Sigma R/A^2)_{IRWST-DVI}$} that can be seen in scaling equations 4-54 and 4-69 of WCAP-15613.

DVI line pressure drop is scaled with respect to its influence on IRWST and sump injection relative to core exit quality during the IRWST and Sump injection phases. The DVI line pressure drop influence is embodied in the DVI resistance terms {i.e $(\Sigma R/A^2)_{DVI}$} that can be seen in scaling equations 4-117 and 4-144 of WCAP-15613.

Thus, the AP1000 scaling analysis addresses the influence of the DVI line pressure drop during phases of the SBLOCA when DVI line pressure drop is important.

REQUEST FOR ADDITIONAL INFORMATION

RAI: P025

Question:

Page 2-25 of WCAP-15613 describes Dr. Bajorek's suggestion that the PIRT ranking for pressurizer inventory be "High" during the ADS blowdown and IRWST injection phase. It is currently ranked "Medium" by Westinghouse. Justify that pressurizer inventory is adequately scaled in the integral system test data so that its effect on SBLOCA can be determined.

Westinghouse Response:

The pressurizer inventory is not a significant source to provide reactor vessel inventory recovery for a SBLOCA. The CMTs (short term) and IRWST (long term) are primarily relied upon to provide vessel inventory recovery during a SBLOCA. The pressurizer volume is small (2100 ft^3) relative to the IRWST (~80,000 ft^3).

During the AP600 review, the gravity head associated with the inventory in the pressurizer was found to be of some importance as it may influence the backpressure (i.e. reactor vessel upper head/plenum pressure) to IRWST injection. Therefore, the gravity head associated with the inventory in the pressurizer was included in the AP1000 reactor vessel inventory scaling for the ADS-IRWST transition phase. Referring to Section 4 of WCAP-15613, the pressurizer gravity head $\{\rho_f g(z_{PZR}-z_{HL})\}$ is included in scaling equation 4-69 to scale its effect on reactor vessel inventory.

Thus, the pressurizer gravity head associated with pressurizer inventory has been addressed in the AP1000 scaling evaluation.

REQUEST FOR ADDITIONAL INFORMATION

RAI: P026

Question:

Please provide all comments from the committee of experts that reviewed the PIRT for AP1000 and discuss how these comments were resolved.

Westinghouse Response:

The written comments from the PIRT experts are contained in Attachment 6 to Westinghouse letter DCP/NRC1484. As stated in WCAP-15613, comments were resolved by modifying the PIRT, or changing the plant design or operating characteristics.

Dr. Bajorek suggested that the PIRTs be re-evaluated after the scoping analyses were completed. Results from the scoping analyses were factored into the PIRTs.

The bases for not incorporating certain review comments in the AP1000 PIRTs are listed below.

LB-LOCA PIRT

Dr. Hochreiter suggested that CMT phenomena should be added to the PIRT. His thinking was that if the accumulators were to empty before the core was quenched, then the CMT injection would be more important. Internal LB-LOCA scoping analyses for the AP1000 indicated that the core would quench before CMT injection occurred. The results from this internal scoping analysis are expected to be confirmed with the formal LB-LOCA analysis. Since the core is predicted to quench before CMT injection, there is no need to add CMT phenomena to the LB-LOCA PIRT.

SB-LOCA PIRT

Dr. Hochreiter suggested that during the ADS Blowdown and IRWST Injection Cooling phase, the vessel/core resistance should be increased from 'L' to either 'M' or 'H'. Westinghouse did increase the importance of vessel/core resistance during the IRWST Injection Cooling and Sump Injection phases when sub-critical flow exists, but not during the ADS blowdown phase. The vessel/core resistance does not limit the ADS critical flow rate or RCS depressurization during the ADS blowdown phase, and therefore its current ranking is considered appropriate.

Dr. Hochreiter suggested that the DVI line pressure drop be increased from 'M' to 'H'. This suggestion was based on the preliminary AP1000 design in which the CMT volume was the same as the AP600. However, the AP1000 DVI line resistance was subsequently reduced and the AP1000 CMT volume was increased to provide a comparable injection to AP600. This eliminated the need to increase the importance of the DVI line pressure drop.

Dr. Bajorek suggested that we add Post-CHF Heat Transfer and 3D Power Distribution with 'H' rankings for the ADS Blowdown and IRWST Injection phases if the core was predicted to uncover. The SB-LOCA scoping analyses for the AP1000 did not predict core uncovery, so Westinghouse did not add these phenomena.

Dr. Hochreiter suggested the pressurizer surge line pressure drop phenomena be increased from 'L' to 'M' during the IRWST Injection Phase since the AP1000 pressurizer surge line is the same size, but the steaming rate is much higher than AP600. (Note that the AP600 and AP1000 employ an 18-inch surge line which is larger than conventional plants). During the IRWST injection phase, the dominant paths for venting steam is the ADS-4 vent paths. The ADS1-2-3 vent path (including the pressurizer surge line) is not important or dominant for steam venting during this phase of a SBLOCA transient. As a result, Westinghouse increased the size of the ADS-4 vent paths for AP1000 to handle the additional decay steaming. Therefore, Westinghouse did not increase the importance of the pressurizer surge line pressure drop during IRWST injection.

Dr. Hochreiter suggested a new phenomena (Hot Leg Pressure Drop) be added to the PIRT. The hot leg pressure drop is primarily dependent on the flow pattern and entrainment, which are already considered as important phenomena during the IRWST and Sump Injection Phases. Since these phenomena are already ranked 'H', and since the hot leg pressure drop depends on them, Westinghouse did not feel it was necessary to add the new Hot Leg Pressure Drop phenomena to the list.

NON-LOCA PIRT

Westinghouse discussed the comments on this PIRT with Dr. Hochreiter. A summary of the resolution of differences is provided below.

Dr. Hochreiter suggested that the flashing in the upper head phenomena be considered 'L' for the Feedwater Malfunction, Excessive Increase in Secondary Steam Flow, and Inadvertent Operation of the PRHR transients due to the higher core exit temperature.

It is not expected that flashing in the upper head would occur during AP1000 design basis feedwater malfunctions, excessive increases in secondary steam flow and inadvertent operation of the PRHR. The full power design vessel outlet temperature for the AP1000 can be in the range of 610 to 620 degrees F. The saturation pressure corresponding to this temperature range is ~1750 psia. The change in RCS pressure during these types of transients is expected to be less than a ~200 psi deviation from the nominal pressure of 2250. The AP1000 reactor vessel upper head temperature design conditions is typically at T_{AVG}. Even if the upper head temperature is assumed to be equal to the vessel outlet temperature, it is not expected that these events will approach the point at which flashing occurs in the upper head. Therefore, this comment was not incorporated.

Due to the smaller pressurizer volume-to-power ratio, Dr. Hochreiter suggested that the pressurizer fluid level phenomena should increase in rank from 'M' to 'H' for the Steamline Break event. Dr. Hochreiter states "For the AP1000, a steam line break is like having a double steam line break in a typical Westinghouse four-loop plant since there are two very large generators not four." Therefore no change to the PIRT was incorporated.

The AP600 steam line break for core response shows the pressurizer rapidly emptying within 15 seconds of the start of the event. So if the AP1000 does empty sooner it will only be by a few seconds. This is not significantly more important for the AP1000 than the AP600. With regard to the size of the steam line break, the AP1000 and the AP600 have integral flow restrictors with areas of 1.4 ft^2. The additional mass in the steam generators will extend the duration of the blowdown but not significantly change the cooldown rate of the RCS. Therefore no change was required.

Dr. Hochreiter suggested that the pressurizer level phenomena should increase in rank from 'L' to 'M' for the Loss of forced RCS Flow and Locked or Broken RCP Shaft events.

Scoping analyses of the complete loss of forced RCS flow have been completed for AP1000 and are presented in Section 3.2 of WCAP-15612. These analyses indicate general phenomena as observed on the AP600 and operating plants. The peak RCS pressure observed for the AP1000 is higher than that observed in the AP600. However the pressurizer insurge was not great enough to open the pressurizer safety valves and there is still a large margin to filling the pressurizer for this event. Thus the pressurizer volume-to-power ratio appears to be adequate for this class of events.

Dr. Hochreiter suggested that the AP1000 Feed Line Break rankings for Vessel Mixing, Reactivity Feedback, and Pressurizer Fluid Level should be similar to the Steam Line Break ranking. The cooldown associated with a break of the larger feed line would be more severe in the AP1000 than the AP600.

The feed line break flow rate from the steam generator is restricted at the feed ring and/or nozzle. In either case, the limiting feed line break flow area is less than the area of the main steam line flow restrictor. Therefore, the maximum RCS cooldown rate would be limited by the MSLB event, not a feed line break event. So therefore no change was incorporated.

Containment PIRT

The experts found that none of the changes required for AP1000 would alter the relative ranking of phenomena from the original AP600 containment PIRT.

AP1000 PRE-CERTIFICATION REVIEW

REQUEST FOR ADDITIONAL INFORMATION

RAI: P027

Question:

Reactor vessel mixing is highly ranked in safety significance in the PIRT for feedwater malfunction, main steam line break (MSLB), inadvertent Passive Residual Heat Removal (PRHR), and startup of an inactive loop (SUIL). In evaluating these events for operating plants, Westinghouse has utilized data from scale mixing tests for the Indian Point Unit 2, vessel and data from a 3-loop European experiment. The loop and vessel design for AP1000 will be different from that of these tests. Provide and justify values for reactor vessel mixing that will be used for AP1000.

Westinghouse Response:

When performing various transient analyses, Westinghouse procedures dictate that a conservative assumption with regards to vessel inlet mixing be assumed. For most events, either perfect mixing or no mixing is assumed, depending on which assumption is conservative. For events where such an assumption is grossly over-conservative, Westinghouse assumes a design mixing assumption. The reactor vessel design mixing correlation developed for LOFTRAN is based on data from scale mixing tests for the Indian Point Unit 2 four-loop reactor vessel. The data was used to develop correlations to predict vessel mixing for two-loop, three-loop, and four-loop plants. The following equation is used to determine the flow distribution of the coolant entering the core:

a, c

REQUEST FOR ADDITIONAL INFORMATION

a, c

REQUEST FOR ADDITIONAL INFORMATION

RAI: P030

Question:

Reactor coolant pump performance is listed as "High" in the PIRT for transient and accident evaluation. Discuss the source and quality of reactor coolant pump data that will be utilized in analysis of transients and accidents for AP1000. Consider the four quadrant homologous relationships, pump coastdown, two phase degradation and the loss coefficients for locked rotor and sheared shaft evaluations. Please provide this data for use in NRC audit calculations using RELAP5 code.

Westinghouse Response:

APP-GW-G0-002, Revision 0 provides the requested AP1000 reactor coolant pump design data in Section 9.2. The AP1000 reactor coolant pump hydraulics are scaled from hydraulics designed by Westinghouse for the APWR (Tsuruga 3&4 project). The homologous curve information has been derived from model testing of the APWR hydraulics.

REQUEST FOR ADDITIONAL INFORMATION

RAI: P031

Question:

Westinghouse proposes to use the VIPRE computer code for AP1000 DNBR evaluations. The NRC staff approval for the use of VIPRE is contained in a letter from Thomas Essig, NRC, to Hank Sepp, Westinghouse, January 19, 1999. In the safety evaluation attached to that letter the NRC staff listed 4 conditions for Westinghouse use of VIPRE. Discuss how these conditions will be met for AP1000.

Westinghouse Response:

Westinghouse application of the VIPRE-01 (VIPRE) code for AP1000 DNBR calculations is in full compliance with the conditions listed in the Safety Evaluation Report (SER) for WCAP-14565. The compliance to each SER condition is described below.

1. The WRB-2M DNB correlation will be the primary correlation used for DNB analysis. The WRB-2 or W-3 will be used wherever the WRB-2M correlation is not applicable. The RTDP (Revised Thermal Design Procedure), is the primary methodology used for DNB analyses. All the DNB correlations and hot channel factors have been previously approved by the NRC for RFA (Robust Fuel Assembly) fuel and reactor cores similar to the AP1000. The DNBR Design Limits will be calculated with VIPRE based on RTDP, WRB-2M and the RFA.

2. The reactor core boundary conditions such as core inlet flow and temperature, power, power shape, and nuclear peaking factors will be justified for the VIPRE calculations.

3. The WRB-2M DNB correlation with a DNBR limit of 1.14 will be the primary correlation used for DNB analysis. The WRB-2 DNB correlation with a DNBR limit of 1.17 will be used wherever the WRB-2M correlation is not applicable.

4. VIPRE will be used for CHF predictions in replacement of the THINC code. Westinghouse does not plan to use VIPRE to replace the FACTRAN code to evaluate fuel performance beyond-CHF conditions in the AP1000 safety analyses.

REQUEST FOR ADDITIONAL INFORMATION

RAI: P034

Question:

WCAP-15612 contains analyses of design basis transients and accidents for AP1000. Since WCAP-15612 was issued, the design of AP1000 has changed, principally by the addition of steam generators of a new and larger design. Please provide re-analyses of the transients and accidents including SBLOCA in WCAP-15612. These results will be utilized in comparisons to audit calculations by the NRC staff using RELAP5. The redesigned steam generators will be a part of the RELAP5 model.

Westinghouse Response:

The purpose of the scoping analyses presented in WCAP-15612 are to provide the staff with information regarding the overall performance of the AP1000, and an indication that the phenomena, plant response, and overall safety margins are similar to those of the AP600. Although some of the design details associated with the AP1000 steam generator are changed from what was assumed in the scoping analyses, the phenomena, plant response, and overall safety margins for the AP1000 should be similar to what was presented in WCAP-15612. Detailed review of the AP1000 Chapter 15 accident analyses will be performed as part of the review of an application for Design Certification for the AP1000.

REQUEST FOR ADDITIONAL INFORMATION

RAI: P035

Question:

The PIRT for AP1000 has increased the importance of the following phenomena to high:

ADS-4 two phase flow pressure drop during IRWST injection

Upper plenum/hot leg entrainment during the post-ADS period

Pressurizer surge line countercurrent flow/flooding during the ADS-IRWST period

Provide reference to past review of the phenomena for AP600. What additional data confirmation will be used to justify NOTRUMP and WCOBRA/TRAC models describing these phenomena?

Westinghouse Response:

High ranked and most medium ranked phenomena identified in the PIRTs were scaled for AP600 and addressed in the NOTRUMP and WCOBRA/TRAC models. Validation of NOTRUMP against AP600 test data is contained in WCAP-14807. Validation of WCOBRA/TRAC (long term cooling) against AP600 test data is contained in WCAP-14776. Review and scaling of AP600 phenomena such as entrainment are contained in WCAP-14727. Pressurizer surge line CCFL was ranked medium during the ADS Blowdown phase for AP600; its ranking did not increase to high for AP1000. Pressurizer surge line CCFL is still ranked medium for the ADS Blowdown phases for AP1000 and increased from N/A to medium for the IRWST Injection phase for AP1000.

The scaling contained in WCAP-15613 indicates that for the most important phenomena (high-ranked), the AP600 test facilities are still valid for AP1000. Therefore, no additional validation is necessary for NOTRUMP or WCOBRA/TRAC (long term cooling).

To provide additional confirmation to justify NOTRUMP and WCOBRA/TRAC results, a special version of WCOBRA/TRAC, referred to as WCOBRA/TRAC-AP, with enhanced models for entrainment and two-phase flow regime will be used as a supplemental calculation during the ADS-IRWST transition for AP1000. Refer to WCAP-15644 for more details.

REQUEST FOR ADDITIONAL INFORMATION

RAI: P037

Question:

On page 3-30 of WCAP-15644 it is stated that: "Among the phenomena which are important to AP1000 performance during the ADS-4 IRWST initiation phase are those that deal with flow patterns in the hot legs and removal of liquid and vapor from the hot legs into the ADS-4 flow paths. The models and correlations that have been added to the large break LOCA (LBLOCA) version of WCOBRA/TRAC to calculate these phenomena for horizontal pipe flow are presented in Appendix A." These additions are revisions to the large break LOCA version of WCOBRA/TRAC that was approved by the NRC staff for AP600. Please describe all applications of these models in LBLOCA and other safety analyses for AP1000. Provide the appropriate justifications and verifications for staff review for all applications of these models.

Westinghouse Response:

The subject models referenced on page 3-30 of WCAP-15644 are used only for the ADS-4 IRWST initiation phase focused calculation that is performed in support of the NOTRUMP small break LOCA analysis of AP1000. These models have been added to the WCOBRA/TRAC computer code solely for use in the focused calculation; they are not used in the large break LOCA or long-term cooling analyses of AP1000. Those analyses are performed using the WCOBRA/TRAC modeling approved by the NRC staff for the AP600 Chapter 15 analyses.

The specific validation of the WCOBRA/TRAC model revisions for use in the AP1000 ADS-4 IRWST initiation phase focused calculation as described in WCAP-15644 and the response to RAI P038 will be submitted to the NRC staff to support an AP1000 Design Certification application.

REQUEST FOR ADDITIONAL INFORMATION

RAI: P038

Question:

To better address entrainment in the hot leg during the transition from ADS to IRWST injection and the importance of momentum flux, use of WCOBRA/TRAC is proposed for comparison with NOTRUMP results. Will any of this work be performed to support the Phase 2 code review? Describe the code verification program that will be used to qualify WCOBRA/TRAC for SBLOCA analyses including integral system test benchmarks such as SPES, OSU, and ROSA.

Westinghouse Response:

The validation of the WCOBRA/TRAC version that contains the enhanced modelling capability described in WCAP-15644 will be submitted for review as part of an AP1000 Design Certification application. A WCOBRA/TRAC calculation using enhanced modelling features is performed in support of the NOTRUMP analysis of the AP1000 small break LOCA only during the ADS-4 IRWST transition phase. This is the only portion of the small break LOCA transient for which the NOTRUMP capability to model some of the significant phenomena has been challenged. Therefore, WCOBRA/TRAC is only used for a focused calculation of the small break LOCA transient from the time of ADS-4 actuation through the time that IRWST injection begins, and it only needs to be validated against test data for the ADS-4 IRWST transition phase portion of the transient.

The pertinent single-effect benchmark for this application of WCOBRA/TRAC is validation of the horizontal flow regime predictions; this calculation is presented in WCAP-15644. The pertinent integral test simulation is OSU Test SB18, a simulated two-inch cold leg break, which provides the necessary data for validation of the ADS-4 IRWST transition phase portion of the transient. The OSU APEX facility is the integral test facility of choice for AP1000 ADS-4 IRWST transition phase LOCA validation purposes because its scaling is the best among the AP600 test facilities during this portion of the transient, as discussed in WCAP-15613 (Reference 1). A subsequent scaling investigation of the ROSA facility (Reference 2) indicates that it is an acceptable test facility for this portion of the AP1000 LOCA transient. However, OSU is still preferred for code validation purposes because some of its features (such as hot leg and cold leg geometries) are more prototypic for phenomena such as entrainment that are important in the low pressure ADS-4 IRWST transition phase portion of the transient. Test SB18 from the OSU test matrix provides the necessary data for validation of WCOBRA/TRAC for this application.

References:

1. WCAP-15613, "AP1000 PIRT and Scaling Assessment," February 2001.

2. Westinghouse response to AP1000 RAI P022

REQUEST FOR ADDITIONAL INFORMATION

RAI: P039

Question:

WCOBRA/TRAC methodology for small break LOCA is described on Page 3-25 of WCAP-15644 and is stated to involve starting the WCOBRA/TRAC calculation at the time of ADS-4 actuation. Discuss how this initiation process will be performed in the middle of an accident scenario. Justify that conservative inputs will be selected. In particular, describe the means of assuring the reactor vessel water mass used to initialize the WCOBRA/TRAC analysis will be conservative.

Westinghouse Response:

The WCOBRA/TRAC focused calculation is performed to predict the phenomena associated with mass distribution and/or mass removal from the RCS, particularly in the reactor vessel / hot legs / ADS-4 / surge line region, during the AP1000 ADS-4 transition phase of a small break LOCA event until IRWST injection begins. Consistency in approach will be maintained in the initiation of the focused calculation between the OSU Test SB18 validation simulation and the AP1000 DCD analysis.

Based on the validation performed (Reference 1) for AP600, the NOTRUMP code is concluded to provide an accurate, conservative calculation of AP600 and AP1000 small break LOCA performance prior to ADS-4 actuation. In particular, NOTRUMP predicts conservatively low reactor vessel collapsed liquid levels for the time that ADS-4 actuation is predicted to occur in the OSU Test SB18 simulation. In the initiation process, [

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References

1. Fittante, R. L., et al., "NOTRUMP Final Validation Report for AP600," WCAP-14807, Revision 5 (Proprietary), August 1998.

REQUEST FOR ADDITIONAL INFORMATION

RAI: P041

Question:

NOTRUMP permits various user input options that can effect analytical results. Among these are drift flux model selection in the fluid nodes, void distribution parameter in the fluid nodes, flooding model, accumulator isentropic exponent, special flow link type, flow composition type for each flow link, drift flux model selection for the flow links, void distribution parameter for the flow links, flooding model selection for the flow links, internally-calculated friction loss model for each non-critical flow link, heat link type selection, and user supplied externals. Please provide the option used to describe each major reactor system component for AP1000 and justify that the option used is appropriate.

Westinghouse Response:

The various models utilized in the AP1000 analysis are identical to those utilized in the AP600 analysis and the OSU and SPES integral facility simulations except where changes are necessary to reflect the plant design features. The validation of the NOTRUMP models utilized are documented in WCAP-14807, Revision 5 (Reference 1). The details of the model usage and methodology is currently being compiled in the form of Safeguards Engineering Standards that identify all models utilized for the AP600 and AP1000 plant designs. Westinghouse will provide the NOTRUMP Safeguards Engineering Standards under a separate transmittal.

References:

1. WCAP-14807, Revision 5, NOTRUMP Final Validation Report for AP600, August 1998, R. L. Fittante, et. al.

REQUEST FOR ADDITIONAL INFORMATION

RAI: P046

Question:

We understand that the design of AP1000 may be modified between the review of the analytical codes and methods for AP1000 (Phase 2) and the review of the safety analysis report for design certification (Phase 3). Calculational limits must be placed on use of the codes so that they will not be used outside of the range for which they have been qualified. One method for setting these limits is to compare the tested range of the phenomena given a high importance in the PIRT with the values calculated in future plant analyses. To aid in setting these limits, please compile a chart providing the tested range for each of the highly ranked phenomena in the PIRTs for SBLOCA and non-LOCA events. The phenomena ranked as high are summarized below:

<u>For Small Break LOCA</u>
ADS-1,2,3 and 4 flow
Break flow
Accumulator flow
Core decay heat
Cold leg phase separation
Two-phase frothing in the core
CMT stratification and steam condensation
CMT circulation
CMT balance line flow and pressure drop
Downcomer and lower plenum level
Hot leg entrainment
IRWST pool level and draining
Pressurizer flashing
Upper reactor vessel mixture level and entrainment
Sump gravity drain, level and temperature

<u>For Non-LOCA and Steam Generator Tube Rupture</u>
Critical flow
Reactor vessel mixing
Reactivity feedback
Reactor trip
Decay heat
Forced convection in the reactor core
Natural circulation and heat transfer in the reactor core
Reactor coolant pump coastdown
Pressurizer fluid level
Surge line pressure drop
Steam generator heat transfer and secondary conditions
CMT recirculation
Balance line pressure drop

REQUEST FOR ADDITIONAL INFORMATION

Balance line initial temperature distribution

Westinghouse Response:

Westinghouse does not anticipate significant changes to the AP1000 design. The core power of 3400 MWt represents an upper limit on the AP1000 core design that will be certified. The passive core cooling system configuration identified in our licensing submittals (Plant Description Report and PIRT and Scaling Report) that is critical to our scaling evaluations will not change substantively. If the safety analysis results differ significantly to those presented to-date such that new phenomena is identified, then the applicability of the test data and correlations used to support code validation/calculations may need to be re-established during Design Certification (Phase 3). Westinghouse expects that the safety analysis scoping studies presented in WCAP-15612 will be representative of the AP1000 safety analysis results. If this is not the case, the staff's conclusions from the pre-application review (i.e. Phase 2) can be revisited during Design Certification. Applicability of the test data and correlations to support safety analysis code validation/calculations is addressed via scaling. Scaling of specific high ranked PIRT phenomena impacted by possible future design changes will be assessed should AP1000 design features be modified.

DCP/NRC1484

September 12, 2001

Attachment 4

Containment Analysis Results for AP1000

Using Unverified WGOTHIC Evaluation Model

Westinghouse Non-Proprietary

Containment Analysis Results for AP1000

Using Unverified WGOTHIC Evaluation Model (Non-Proprietary)

In our response to the containment RAIs (Reference 1), Westinghouse agreed to provide AP1000 containment analysis results using an AP1000 Evaluation Model that is consistent with the approved AP600 Evaluation Model. Previous analyses were performed using a simplified WGOTHIC model with containment volume above the operating deck modeled as a single control volume to estimate the containment pressure response to design basis events; namely the main steam line break (MSLB), and the double-ended cold leg break (DECL LOCA).

The AP1000 Evaluation Model is based on the AP600 model with similar noding to the AP600 including multiple nodes above the operating deck. The compartment volumes, flow paths, and heat sinks are based on the latest AP1000 design data. A more detailed description of the changes to the AP600 Evaluation Model is included in Section 1 below.

Preliminary results have been calculated using the AP1000 Evaluation model, and the scoping mass and energy release rates. The MSLB pressure response is shown in Figure 1. These results show that the maximum pressure is 68.5 psia which is 5.5 psi less than the design pressure.

The LOCA results are shown in Figure 2. The peak pressure for this case is 70.6 psia which is 3.4 psi less than the design pressure.
In addition to the preliminary results, the following issues that were raised by the staff are explicitly addressed:

- AP1000 containment shell temperature prior to uniform water coverage
- AP1000 delay time prior to full PCS coverage
- Key dimensionless parameters as calculated by WGOTHIC

1. Changes to the AP600 Model Noding Structure for AP1000

A comparison of the AP600 and AP1000 containment model noding structures is shown in Figure 3 (the AP1000 is shown on the right side of Figure 3). The noding structure below the operating deck level (135.25-ft elevation) remains the same. An extra horizontal slice of volumes was added above the operating deck to account for the extra 25.5-ft of elevation in the cylindrical portion of the AP1000 structure.

a, c

2. AP1000 Containment Shell Temperature Prior to Uniform Water Coverage

The AP1000 containment is passively cooled by air and by applying a water film to the outside surface of the containment shell. In the case of a large pipe break inside containment, the containment pressure quickly reaches the setpoint for PCS activation. A valve is opened and PCS water is applied to the top of the dome section of the containment shell. The water spreads radially outward from the center of the dome and collects at a weir that provides uniform distribution around the circumference. A second weir is provided near the spring line to assure that the flow is uniform along the vertical section of the shell.

Because the mass and energy releases for the main steam line break are relatively short in duration, the PCS is not necessary to maintain the pressure below the design limit for this event. Figure 4 shows the containment pressure response for the MSLB case where the PCS operates, and for the case with air cooling only.

The double-ended cold leg break LOCA consists of an initial blowdown of the reactor coolant system, followed by a long term release of the reactor decay heat. For this case, it is necessary for the PCS to operate to maintain containment pressure below the design limit.

The AP600 containment evaluation model conservatively does not model any evaporation from the shell until after steady state water coverage has been established. The time to reach a steady state water coverage for AP600 was estimated using data from the Water Distribution Tests. At the minimum initial PCS flow rate of 440 gpm, this time was conservatively estimated to be 337 seconds. The external shell surface temperature at this time was estimated to be less than 200 F, so boiling at the leading edge of the advancing film did not need to be considered during the time steady state water coverage was developed on the AP600. This information is provided in Section 7 of WCAP-14407 (Reference 2).

For the AP1000, the containment design pressure is higher, resulting in a higher containment temperature during the blowdown portion of the LOCA transient. It is expected that the shell will heat up at a faster rate before the PCS water is applied. The following sections document the determination of the maximum external containment shell temperature before the PCS water is applied.

3. Water Application for AP1000

The initial PCS water flow rate is higher for AP1000, while the containment diameter and dome geometry are the same as AP600. The containment side wall is approximately 25 feet higher:

Since the water distribution system is the same for AP600 and AP1000, scaling the AP600 PCS flow delay time by the change in flow rate, yields:

$$t_{PCS\text{-}AP1000} = t_{PCS\text{-}AP600} * m_{PCS\text{-}AP600} / m_{PCS\text{-}AP1000}$$

where $t_{PCS\text{-}AP1000}$ is the time to reach steady coverage for AP1000
$t_{PCS\text{-}AP600}$ is the time to reach steady coverage for AP600 = 337 sec
$m_{PCS\text{-}AP600}$ is the initial flow for AP600 = 440 gpm
and $m_{PCS\text{-}AP1000}$ is the initial flow for AP1000 = 469 gpm

$$t_{PCS\text{-}AP1000} = 337 \text{ sec} * (440 \text{ gpm} / 469 \text{ gpm}) = 316.2 \text{ sec}$$

To account for the additional 25.5-ft fall height, the average velocity of the falling laminar film is calculated. From Reference 3, the average velocity and film thickness for a falling laminar film is:

$$v_{avg} = g * \delta^2 * \cos(\beta) / (3 * \nu)$$

where

$$\delta = (3 * \nu * Q / \{ g * \pi * D * \cos(\beta) \})^{1/3}$$

Q	is the film flow rate = 469 gpm = 1.04494 ft^3/s
G	is the gravitational constant (32.2 ft/s^2),
0.	is the surface angle relative to vertical (0° for cylindrical shell surface)
0.	is the kinematic viscosity (ft^2/s) (4.77E-06 @ 150°F, 3.41E-06 @ 200°F)
D	is the shell diameter (ft) = 130.2917 ft
0.	film thickness (ft)

δ @ 150°F = 0.001043 ft
δ @ 200°F = 0.000933 ft

v_{avg} @ 150°F = 2.45 ft/s
v_{avg} @ 200°F = 2.74 ft/s

Using an average film velocity of 2.5 ft/s, the film should take an additional 10 seconds to cover the 25.5 ft of shell height, yielding a total steady state coverage PCS flow delay time of approximately 326 seconds.

For the purpose of the scoping study, the PCS delay time for the AP1000 is conservatively maintained at the 337 second PCS flow delay time for the AP600.

4. Containment Shell Heat Up

To estimate the time to heat up the containment shell, consider a section of the shell that is exposed on the inside to a constant temperature of 270°F (typical for blowdown portion of LOCA) at a heat transfer coefficient typical for convection/condensation. To conservatively estimate the time to heat up the outer surface, assume that this surface is adiabatic. From Reference 4, Figure 5 can be used to determine the time to reach 212°F on the outer surface. From Figure 5,

$$\theta_o / \theta_i = (T - T_\infty) / (T_i - T_\infty)$$

where	T	is the target temperature of the outer surface, 212°F
	T_∞	is the containment atmosphere temperature, 270°F
and	T_i	is the shell initial temperature, 120°F

So,

$$\theta_o / \theta_i = (212 - 270) / (120 - 270) = 0.387$$

The Biot number is given by

$$Bi = h * L / k$$

where h is the heat transfer coefficient on the inside wall, Btu/hr-ft^2-°F
k is the thermal conductivity of the shell = 23.6 Btu/hr-ft-°F
and L is the shell thickness = 1.75 in = 0.1458 ft

The Fourier number is given by

$$Fo = \alpha * t / L^2$$

0. is the thermal diffusivity and is given by

$$\alpha = k / (\rho * c_p)$$

where ρ is the shell density = 490.7 lbm/ft^3
c_p is the shell specific heat = 0.107 Btu/lbm-°F
and t is the time to reach the target temperature

By assuming a heat transfer coefficient on the inside wall, the Biot number is calculated then used to determine the Fourier number and the time for the outer surface to reach 212°F.

h (Btu/hr-ft^2-°F)	1 / Bi	Fo	T (sec)
5	32.4	28	4762
10	16.2	18	3061
50	3.2	3.5	595.2
100	1.6	2.2	374.1

The inside heat transfer coefficient is likely in the range of 50 – 100 Btu/hr-ft^2-°F. Thus, the time for the outside wall to reach 212°F is between 374.1 and 595.2 sec.

From the WGOTHIC scoping analysis of the AP1000 containment following a DECL LOCA, the maximum shell temperature in the wetted area is shown in Figure 6. At the time that PCS water cooling is credited (337 sec), the maximum wall temperature is 180°F, which is consistent with the previous calculation. For the entire transient, the maximum wall temperature never exceeds the saturation temperature.

These results show that at the time PCS is credited, there is a large margin between the outer shell surface temperature and the saturation temperature at the time of water application, and that the maximum wall temperature in the wetted region never exceeds the saturation tempreature.

5. Key Dimensionless Parameters

The following table shows the dimensionless parameters that describe heat transfer in the air flow annulus that have been extracted for a WGOTHIC double-ended cold leg LOCA. The WGOTHIC model utilizes multiple nodes above the operating deck. The parameters are summarized in the table below for the downcomer region and the riser region. The table shows that the tests used to qualify WGOTHIC for AP600 cover the range of dimensionless parameters calculated for AP1000.

Comparison of Dimensionless Parameters for AP1000 and Test Data

Parameter	Composite of Test Data	AP1000 Range (est)	AP1000 WGOTHIC Calc (limiting location)
Riser			
Re	<120,000 (evap) <500,000 (dry)	<210,000	150,000
Gr	$<7.0\times10^{10}$ (evap) $<1.0\times10^{11}$ (dry)	$<1.5\times10^{9}$	1.1×10^{9}
Pr	0.72 – 0.9	0.72 – 0.9	0.8
Sc	~0.52	~0.52	0.55
Downcomer			
Re	<500,000	<190,000	103,000
Gr	$<1.0\times10^{11}$	$<2.1\times10^{10}$	5.2×10^{9}
Pr	~0.72	~0.72	0.72

References

1. Westinghouse letter DCP/NRC 1481 dated July 31, 2001.
2. WCAP 14407, AP1000 WGOTHIC Application Report, 2001
3. Bird, R.B, et al, Transport Phenomena, Wiley, 1960, pp 35-41.
4. Holman, J.P., Heat Transfer, McGraw-Hill, 1976, pg.109.

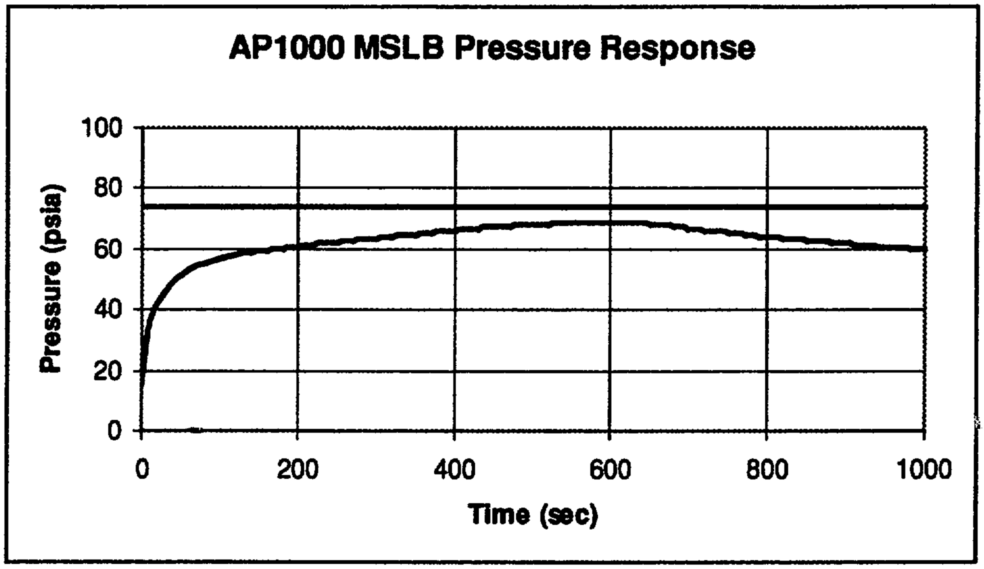

Figure 1: Main Steam Line Break Pressure Response – WGOTHIC MAD Model

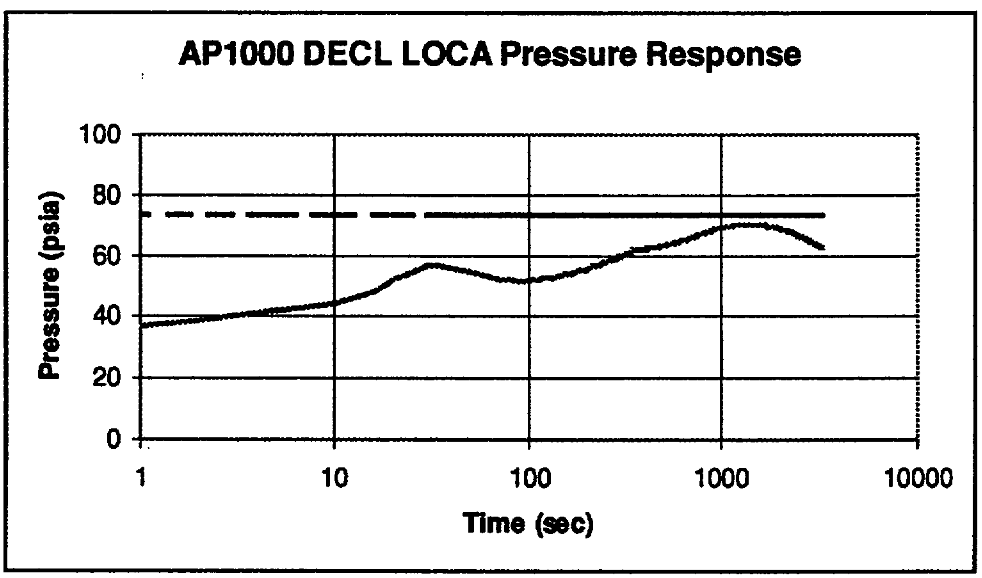

Figure 2: DECL LOCA Pressure Response – WGOTHIC MAD Model

Figure 3 – AP600 and AP1000 Noding Diagrams

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AP600

AP1000

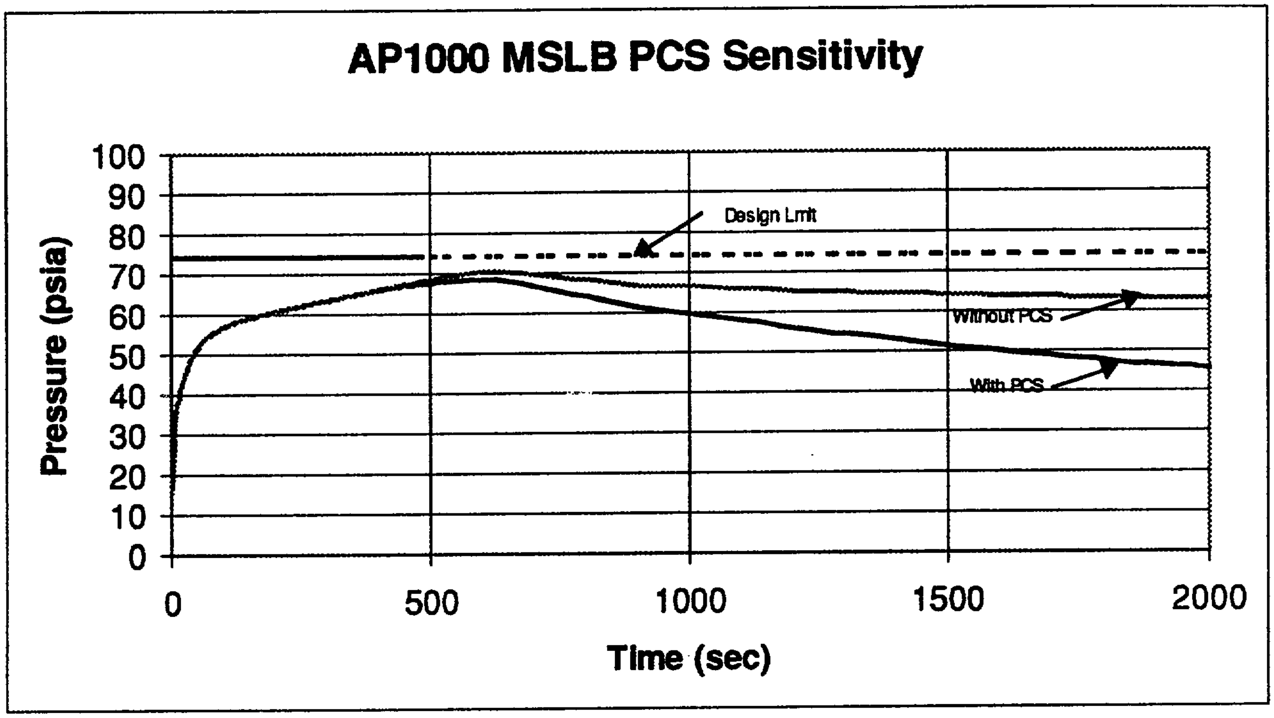

Figure 4: AP1000 WGOTHIC Main Steam Line Break PCS Sensitivity

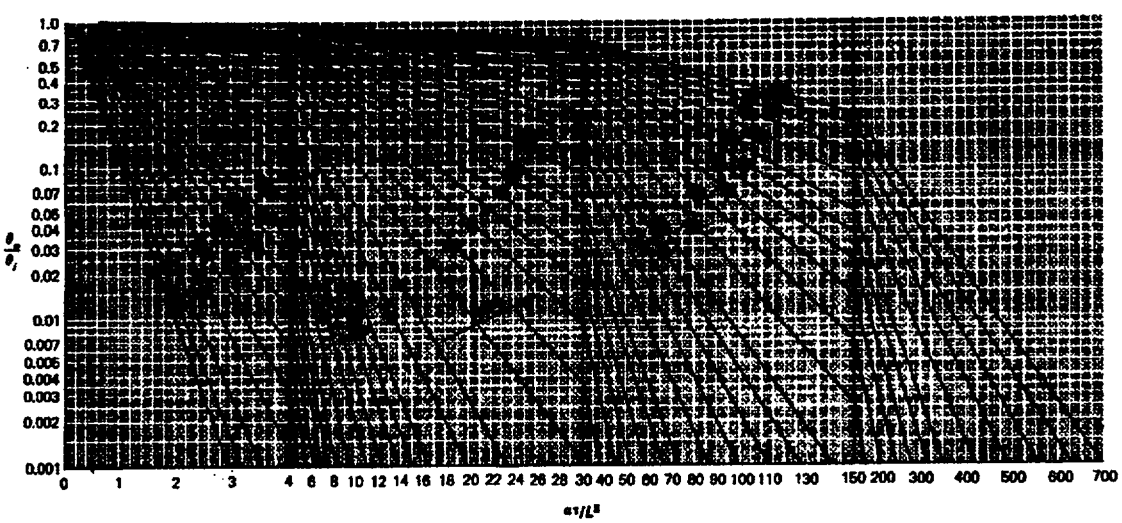

Figure 5: Midplane Temperature for an Infinite Plate of Thickness 2L

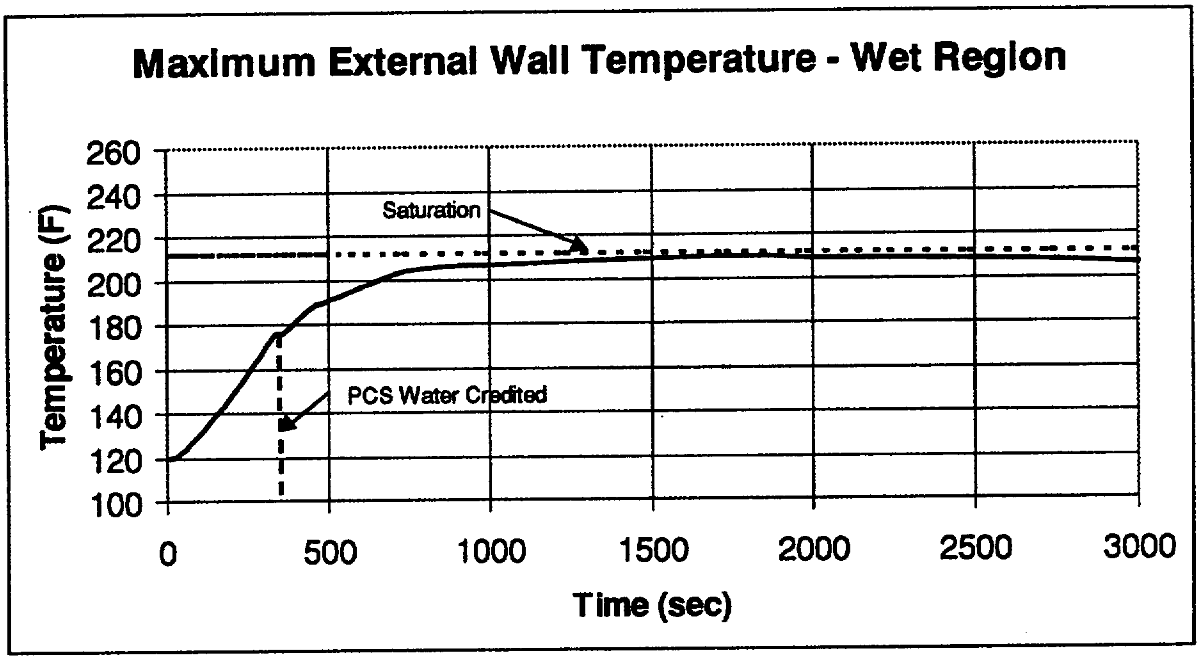

Figure 6: AP1000 WGOTHIC Maximum Containment Shell Temperature – LOCA