



Westinghouse
Electric Corporation

Energy Systems

Box 355
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AW-97-1083

February 28, 1997

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

ATTENTION: MR. T. R. QUAY

APPLICATION FOR WITHHOLDING PROPRIETARY
INFORMATION FROM PUBLIC DISCLOSURE

SUBJECT: WESTINGHOUSE RESPONSES TO NRC REQUESTS FOR ADDITIONAL
INFORMATION ON THE AP600

Dear Mr. Quay:

The application for withholding is submitted by Westinghouse Electric Corporation ("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-97-1083 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-97-1083 and should be addressed to the undersigned.

Very truly yours,

Brian A. McIntyre, Manager
Advanced Plant Safety and Licensing

jml

cc: Kevin Bohrer NRC OWFN - MS 12E20

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A PDR

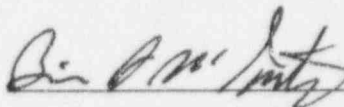
AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared Brian A. McIntyre, 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 Corporation ("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:



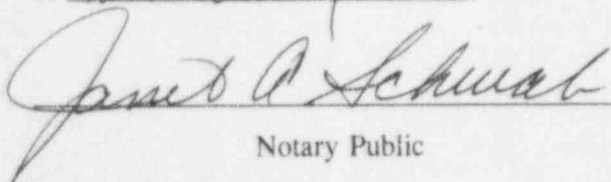
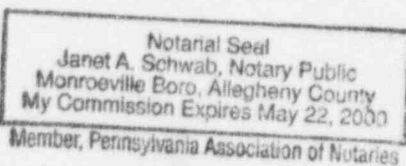
Brian A. McIntyre, Manager

Advanced Plant Safety and Licensing

Sworn to and subscribed

before me this 28 day

of February, 1997


Notary Public

- (1) I am Manager, Advanced Plant Safety And Licensing, in the Advanced Technology Business Area, of the Westinghouse Electric Corporation 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 Energy Systems Business Unit.
- (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 Energy Systems Business Unit 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.
- (v) Enclosed is Letter NSD-NRC-97-5006, February 28, 1997 being transmitted by Westinghouse Electric Corporation (W) letter and Application for Withholding Proprietary Information from Public Disclosure, Brian A. McIntyre (W), to Mr. T. R. Quay, Office of NRR. The proprietary information as submitted for use by Westinghouse Electric Corporation is in response to questions concerning the AP600 plant and the associated design certification application and is expected to be applicable in other licensee submittals in response to certain NRC requirements for

justification of licensing advanced nuclear power plant designs.

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

- (a) Demonstrate the design and safety of the AP600 Passive Safety Systems.
- (b) Establish applicable verification testing methods.
- (c) Design Advanced Nuclear Power Plants that meet NRC requirements.
- (d) Establish technical and licensing approaches for the AP600 that will ultimately result in a certified design.
- (e) Assist customers in obtaining NRC approval for future plants.

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 advanced plant licenses.
- (b) Westinghouse can sell support and defense of the technology to its customers in the licensing process.

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 advanced nuclear power designs 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 developing analytical methods and receiving NRC approval for those methods.

Further the deponent sayeth not.

Attachment A

49 Discussion Items and 3 Additional Items

Items for Discussion During 7/25/96 Telecon

on

"Scaling Analysis for AP600 Containment Pressure
During Design Basis Accidents"

Westinghouse has prepared Enclosure 1 to NSD-NRC-95-4752, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents". It is stated that this preliminary report supersedes WCAP-14190, "Scaling Analysis for the AP600 Passive Containment Cooling System" and incorporated NRC staff comments on the superseded report. Following are items for discussion on the subject report.

1. The superseded report, WCAP-14190, contained information comparing the dimensionless groups for AP600 with corresponding dimensionless groups for the LST. The dimensionless groups in the revised report do not relate the AP600 to any scaled integral test data. It will be necessary to provide a discussion of the significance of the magnitude of the pi groups and how this relates to scaling.
2. From the values given in Appendix B, it is not clear what value was used for the break enthalpy. Please specify the values used for $h_{brk,o}$, $Dh_{brk,o}$, $m_{brk,o}$, $m_{brk,g,o}$. Describe the basis for selection of each value. What, if any, is the difference between $Dh_{brk,o}$ and $Dh_{brk,g,o}$?
3. When equation 46 of Appendix A (Equation 2 in main body of report) is applied, m_{brk} is replaced by $m_{brk,g}$ (e.g. Equation 52). Also, $Z_{atmRstrm}$ is taken as being equal to ZR . Please explain.
4. On page A-1 it is stated that air can be approximated as an ideal gas due to high reduced temperature and low reduced pressure. The pressure condition given is $P_r = P/P_o < 0.05$ which is about 27.3 psia (P_o for air is 37.2 atm, or 547 psia). Please justify this assumption in light of the containment design pressure of 60 psia.
5. Please explain the following items regarding equation 18 on page 24. Why is the temperature $T_{bf,o}$ used in the second term on the right? The conductances are given as h_e and h_{ex} in the equation, but as $h_{e,in}$ and $h_{e,o}$ in the sentence following the equation. If $h_{e,o}$ is the conductance on the outside of the baffle, why are there film conductance and condensation contributions? Table 4-1 shows that these contributions are not included for the baffle.
6. On page 25 in the first sentence of 3.3.8, do you mean downcomer and not riser?
7. Section 3.3.9 states that radiation to the concrete chimney is conservatively neglected, but Table 4-1 shows a radiation contribution for the chimney. Which is correct?
8. In obtaining equations (30) and (31) from equations (25) and (24), respectively, d has been replaced by L . Please explain and state the value used for L .
9. In equations (29), (30) and (31) please explain how DP_{atm} and $P_{im,air}$ are evaluated, including all pressures used to obtain the differences.

10. In section 5.2.1, the blowdown liquid mass flow rate is given as 20,000 lbm/hr. Should this be 20,000 lbm/sec?
11. In Table 5-1 for the MSLB, the saturation temperature is given as 2348°F, the bulk steam density as 0.841 and the bulk air density as 0.732. Please correct these values or explain the basis for the values given.
12. In Table 5-2, the dry shell and evaporating shell areas should add to a total area of 52,600 ft². This constraint is not satisfied during the post-reflood and peak-pressure periods.
13. In section 5.2.3.1 a characteristic length of the liquid drops is calculated as 0.97 feet. Using a containment volume of 1.64×10^6 ft³ and total drop surface area of 9×10^7 ft² gives a characteristic length of 0.0193 feet. In Appendix B, page B-3, a characteristic length of 0.000869 feet is given, based upon a drop surface area of 2×10^9 ft². Which value is correct? Please explain the physical significance of this quantity.
14. Please explain how the conservation of mass for the drops is handled. The equation is given in Section 3.3.1, but doesn't appear again. Equation (7) shows a drop removal term and it is stated that the drops have a settling rate, but this term doesn't appear in equation (88).

Also, how is the surface area of the drops calculated. From the values given in Appendix B it appears that the total drop surface area is being held constant. Appendix B shows that during blowdown the temperature of the drops is increasing (dT/dt) at 30°F per second. How is this possible when the drops enter at saturation temperature?
15. In general, the reviewers are having difficulty relating the parameters in the "scaling equations" to the values of parameters in Appendix B. For example, the source drop scaling equations (67 and 68) list six pi groups, π_d , π_{source} , π_e , π_m , π_h and π_r . Appendix B lists four pi groups π_l , π_o , π_m and π_e .

Table 7-7 lists five RBC PI groups as drop related, $\pi_{radiation}$, $\pi_{convection}$, $\pi_{enthalpy}$, $\pi_{gas\ work}$, and $\pi_{liquid\ work}$. An additional PI group, π_{mass} appears in Appendix B.

On page 53 it is stated that τ is equal to the inverse of Ω_e , but the values given in Appendix B do not meet this constraint.
16. On page 36 it is stated that C is chosen to give P_o equal to 60 psia. Is this true for all phases of the DECLO LOCA? What value is used for $Dh_{brk,o}$?
17. Equations 54 and 55 contain a term rf^* . Since the fluid density is constant, why is this term needed?
18. There is a need for increased clarity in the nomenclature. All dimensionless numbers should be defined on page 35. The report must to be revised to use only one term for the same quantity and to avoid use of the same term for different quantities. As examples of problems with the present draft,

the quantities cv,d,o and cv,f,o appear to be the same; in equation 67, the term ad,o hasn't been defined; it appears to be the volume fraction of liquid droplets, but on page 35, ad,o is defined as the initial gas volume fraction. two different definitions are given for steam density on page 35; it is not clear whether $rbrk,g,o$ is the same as $retm,o$;

19. The pi-group designated pp in equation 71 and $ppool$ in equation 72 is dimensional; it should have $mbrk,g,o$ in the numerator.
20. Please explain the significance of the pi groups in the heat sink energy equations (Section 6.6). Values for these groups (e.g. in equation 67) are not given in Appendix B. Different factors are used to normalize the source drop, break pool, shell, baffle, chimney/shield building, heat sinks, etc. governing equations. This would appear to preclude any comparison of these pi groups between heat sinks.
21. The denominator of the left side of equation 66 has an error. The term $mbrk,g,o \cdot hbrk,g,o$ should be replaced by $md,o \cdot cv,f,o$.
22. What is the normalization used to define T^*d , T^*p , T^*hs , T^*sh , etc. The normalization for temperature differences is defined on page 35. However, both temperatures in the difference are functions of time, so it is not clear how the individual temperatures are normalized.
23. Section 9.3 refers to forced convection heat transfer, while Figure 11 which is cited in this section, is titled mixed convection heat transfer. Which is correct?

END

FROM DIANE JACKSON 4-15-96

Follow Up Items for Discussion During 8/1/96 Telecon on
"Scaling Analysis for AP600 Containment Pressure During DBAs"

Following are further questions and comments related to the 23 items discussed during the 7/25/96 telecon. Numbering corresponds to the original set of discussion items.

2. Shouldn't the last line of your response read: 10,300 lbm/sec and not 20,000? The value 20,000 is for liquid flow.
9. Please explain how $P_{stm,srf}$ is calculated. Page B-3 gives $P_{stm,srf}$ equal to P_{tot} for drops. Please explain.
13. The value calculated for A_{tot} in your response appears to be incorrect. A_{tot} is 1.67×10^8 using your input values. This affects the calculated value for characteristic length, by a factor of 2.
14. It is important to establish the effect of the assumption that the drop surface area remains constant throughout the transient. The best way to show this would be to integrate the scaling equations with and without the drop contribution and plot the pressure response for both cases.
15. In your response you mention 7 upper case Pi groups, but list six? Is there another?

Additional Discussion Items

24. Section 7.1 makes reference to conductance pi values defined in Section 6.5. Should this refer to Section 6.6 and not 6.5? Have these values all been re-normalized relative to the shell conductance? Please give the equations used to calculate each of the numbers in Table 7-1. Can these values be directly compared?
25. While there are indications that the set of scaling equations were integrated to determine a pressure response, e.g. top of page 48 describes integration approach for heat sinks, no results are presented. Will a plot similar to Figure 6-1 of WCAP-14190 be included in the final version of the report? Including this plot will permit evaluation of the reasonableness of the scaling model.
26. Equation 51 gives t_o (is this the same as t_{sys} ?) in terms of V_o . How is V_o calculated? and where are numerical values given in Appendix B? Why is there no value of t_{sys} calculated for the reflood period (Table 7-7)?
27. Since all of the Pi groups in Table 7-7 are related to the RPC equation, for any given period the magnitude of the Pi group value should be directly comparable. If so, this means that the drops are contributing about 1/10 the pressure reduction of the steel heat sinks and about as much as the concrete heat sinks during the blowdown period. Is this interpretation correct? Can the numerical values of Pi groups be directly compared between different periods?
28. The buoyancy term (equation 102) is stated to be in terms of "thermal center"

differences. It is difficult to tell from Figure 8, just how H1, H2, H3 and H4 are defined. However, the densities, ρ_{dc} , ρ_{ri} , ρ_{ch} and ρ_{nv} are calculated based upon exit temperatures. If H2 - H3 is the riser height, then using a density based upon exit temperature will overestimate the buoyancy force by about a factor of about 2, since the average density should be used. Please explain how your approach accounts for the variation in density along each segment of the flowpath.

29. It would seem that mevap and mcond should be consistent with the shell and chimney/shield building energy terms in the RPC equations (equations 81 and 92, respectively). Is this what is meant by "selecting a parametric value that is known to be consistent with evaporation limits"?
30. What is the physical explanation for the numerical value of the time constant τ for the peak pressure being less than one-third the value of any of the other LOCA phases? Also, why is the riser Reynolds number so much larger during this phase?
31. In section 4.2.3, would reference to the Eckert and Diaguila flow regime map be appropriate to support or validate the use of forced convection for this buoyancy driven flow?
32. In section 9.3, quantify "significantly greater scatter." Factor of two, order of magnitude? Can a specific reference be made? A similar plot of forced convection data only?

Items Needed to Complete Scaling Report

Item 1

The information developed needs to be used to identify the important phenomena in a quantitative way. Calculated values for the rate of pressure change equation pi groups should be listed for each phase of the accident and the importance of the phenomena they represent categorized based upon the magnitude of the pi group values. For all of the high or medium importance phenomena, the report should address how the phenomena is bounded for the range of parameters applicable to AP600. This could be done by reference to more detailed reports. A table similar to 2-1 but with the "how" instead of the "effect."

Results of integrating the scaling equations for the AP600 should be presented in the form of a plot of calculated pressure versus time. This is an essential zero-th order check which shows that the model is giving reasonable results. Both LOCA and MSLB should be presented. This should help validate the "magnitude" and "timing" of the AP600 pressure response.

Item 2

The scaling methodology should be applied to the LST to show that the approach correctly identifies important phenomena and yields a reasonable prediction of the steady-state pressure when compared to measured data. Representative tests should be selected to

demonstrate each of the important phenomena for both LOCA and MSLB conditions.

Item 3

Rate of pressure change equation pi group values should be calculated and presented for the LST. This would show the non prototypicality of the LST as a scaled test for AP600 but it would also show areas where test data are applicable.

**Additional Discussion Items on "Scaling Analysis for AP600 Containment
Pressure During Design Basis Accidents"**

33. In Table 9-1 the pi-groups p_{cond} and p_{evap} are defined. How do these pi-groups relate to the pi-groups defined earlier in the report? Specifically, what is the relationship of p_{cond} and p_{evap} to the pi-groups in the RPC and/or energy equations for the heat sinks?
34. Equations for p_{cond} and p_{evap} are given in Table 9-1 and also in equation (83). However, the definitions do not appear to be compatible. Please explain the relationship between these pi-groups.
- Also, the term RT_0 appears in the definitions in Table 9-1 without the compressibility term, Z , implying that air only was assumed. Please explain.
35. Please explain how the Sherwood number is extracted from the definitions of k_g for condensation and evaporation mass transfer given in Table 9-1. That is, how is k_g related to the data shown in Figure 9? How is the value of the length scale, L , introduced to obtain the Sherwood number?
36. Presumably the data points shown plotted in Figure 10 are from the LST. This should be stated explicitly (as is done in Figure 9).
37. On the evaporating shell, three parallel energy transfer mechanisms are being modeled, evaporation, forced convection and radiation to the baffle (Figure on page 23 and Section 9.3). The following items relate to the forced convection and evaporation terms:
- ° What is the source of the data shown plotted in Figure 11? Is any of the data for a wetted surface. How do you separate out the evaporative and convective components in the data comparison?
 - ° Does the scaling model account for water coverage fraction? How is the amount of coverage determined? Is the fraction allowed to change during the event? In what manner does it change?
38. Please explain what is meant by the statement in section 9.4, "with approximately 1/2 the Reynolds number dependence at the same Reynolds number".
39. At the bottom of page 65, the dependence of friction on the Reynolds number is stated to be -0.20 (the usual Blasius formula is -0.25) presumably for pipe friction but not form losses. Why is the loss coefficient expected to be of the form $C Re^{-0.10}$? Is this being used because the form losses (1/2 of the total) are assumed to be independent of Reynolds number? Please justify the Reynolds number dependence of the total loss coefficient.
40. The shell coating roughness is given in microinches per inch? usually roughness is a dimensioned variable. What quantity is being used to non-dimensionalize the roughness?
41. In Table 9-2, what does the designation WDT represent?
42. Petersen gave equation (119) for a stably stratified volume. He states (p. 102 of your Ref. 27) that "Because the recirculation patterns which result after breakdown of stratification are three-dimensional, for enclosures the breakdown of stratification will be modified somewhat." How does this fact impact the applicability to an enclosed containment?
43. Please explain the statement on the top of page 70 which states that equation (121) is equally valid for AP600 and the LST jets with similar z_{trans}/d . What is the relationship between z_{trans}/d and equation (121)?

44. In Table 10-1 why is H so low for the MSLB? How is H selected in this case? At a minimum isn't this the height above the break? Does it make sense to apply these relationships for such large values of H/d?
45. How are the source diameters listed in Table 10-1 defined? In section 10.3 it is stated that for the MSLB, the steam source is a 3 inch ID pipe. This is not consistent with the 9.01 feet given for d, in Table 10-1.
46. In section 10.2.1 it is stated that the jet and volumetric Froude numbers differ by a factor of 1000 for the DECLG, yet Figure 12 shows a much smaller difference. Please explain.
47. Please explain the labels in Figures 12 and 13, i.e. Unstable, Mixed, 90% Buoyant, etc.
48. Please explain how the percentage of jet height that is buoyant is calculated.
49. On page 76 it is stated that during the DECLG LOCA the above deck atmosphere remains weakly stratified. The earlier analysis and discussion in Section 10.3.1 suggests that the atmosphere is stably stratified in this case. Please explain.

Attachment B

Responses to 49 Discussion Items and 3 Additional Items

Responses to Informal NRC Discussion Items

1. WCAP-14845, Section 10.2 presents a scaled comparison of AP600 and the LST.
2. The mass flow rate, $\dot{m}_{g,brk,0}$ and enthalpy difference, $\Delta h_{g,brk,0}$ used to normalize the mass, energy, and pressure equations are defined in WCAP-14845 Section 6.2 and values are specified in Table 6-3 for each time phase.
3. Appendix A of the August Scaling Analysis was largely replaced by WCAP-14845 Section 5. Relationships for individual gasses and for gas mixtures were developed in both. Since only gas was considered, the subscript g that is used in other sections where both gas and liquid are present, was omitted. Consequently, in WCAP-14845, $\dot{m}_{g,brk}$ is the same parameter as \dot{m}_{brk} in Section 5.

The relationship between ZR , $Z_{stm}R_{stm}$, and $Z_{air}R_{air}$ is developed for Equation 55 in Section 5 of WCAP-14845.

4. The basis for the low air reduced pressure that justifies treating air as an ideal gas is provided in WCAP-14845 Section 5.1. Since the maximum partial pressure of air is 19.7 psia, the reduced pressure is $Pr = 19.7/547 = 0.036$. Consequently, the deviation from ideal gas behavior for air is acceptably small.
5. The baffle temperature and conductance discrepancies were corrected and the revisions presented in WCAP-14845 Section 7.7.
6. The inadvertent reference to the riser should have been to the "downcomer". The corrected text is presented in WCAP-14845 Section 7.8.
7. Radiation was not included in the chimney calculation as noted in WCAP-14845 Section 7.9.
8. The parameter L has been replaced in WCAP-14845, Equation 13 by the channel hydraulic diameter, d_h and in Equation 14 by the drop diameter, d .
9. ΔP_{stm} is defined in WCAP-14845 following Equation 8, and $P_{lm,air}$ is defined following Equation 9. The bulk steam and air partial pressures used in these parameters are presented in Table 6-3. The surface values of air and steam partial pressure differ for each heat sink, depending upon the time phase, and are not presented. They are, however, defined by the saturation pressure of each heat sink surface, the temperature of which is tracked as explained in Section 7.
10. WCAP-14845 shows the (average) LOCA blowdown liquid mass flow rate is 7,777 lbm/sec. The break liquid flow rate was determined from Figure 3-2, and is the sum of the drop and pool flow rates presented in Table 6-3.
11. The MSLB saturation temperature, bulk steam density, and bulk air density were revised and are shown correctly in WCAP-14845, Table 6-3.

12. The evaporating, subcooled, and dry shell areas are presented in WCAP-14845, Table 8-1 and all add to 52,662 for each time phase.

13. The drop characteristic length was calculated in Section 7.1 to be 0.0242 ft, or 0.29 in. The characteristic length is the ratio of containment volume to drop surface area. The characteristic length is a measure of the coupling distance between the liquid surface and the surrounding gas. It can also be visualized more simply in this case as a smooth liquid surface with an overlying gas layer 0.29 inches thick. The very small length value indicates strongly coupled components (gas and drops).

14. The drop conservation of mass Equation 97 of WCAP-14845, includes terms for the source rate, the flashing rate, and the evaporation rate. The source is assumed to occur only during blowdown at the rate given in Table 6-2. The flashing and evaporation rates are calculated and discussed in Section 7.1. A drop removal term is not included in the equation since it was desired to maximize the effect of the drops on containment pressure.

The discussion and calculations in Section 7.1, and the pi group values in Section 8 for the drops shows that even with no fall-out, the drop effect on containment pressure is small. Since the drop surface area will reduce over time due to evaporation, fall-out, and agglomeration, even the "small" effect is overestimated.

15. Each pi group and time constant is clearly defined in WCAP-14845 and given a unique name by the use of subscripts. That name is used consistently when evaluating and referring to the pi group. The errors in the August Scaling Analysis were corrected and inconsistencies were eliminated in WCAP-14845.

16. The complicated reference value for pressure was eliminated in WCAP-14845. Pressure is simply referenced to the initial value during each time phase. The definition of the dimensionless total and steam partial pressures are presented in Section 6.3.2 and the reference values are presented in Table 6-3.

17. Since liquid density, ρ_l is effectively constant, ρ_l^* is always 1.0 and was eliminated from the equations in WCAP-14845.

18. The scaling analysis presented in WCAP-14845 has been clarified and inconsistencies removed. Nomenclature was clarified as much as possible, although the extensive number of parameters works against simplification.

19. The comment is correct. The dimensional pi-pool group was not useful and was eliminated.

20. The terms representing energy transfer between the heat sinks and containment gas were redefined and consistently normalized in WCAP-14845.

21. The comment is correct. The redefined drop pi groups are presented in WCAP-14845, Section 7.1.

22. Each temperature difference is normalized to the temperature difference between the bulk fluid and the surface at the initial conditions of each time phase.

23. WCAP-14845, Section 10.1.3 contains a revised discussion of forced convection heat transfer. The ambiguous reference to mixed convection data was eliminated.

24. The incorrect section reference was corrected in WCAP-14845. The conductances are normalized to the shell plus coating conductance. The conductance pi groups are clearly defined for each heat sink in Section 7 under a "... Conductance" subheading. Since the normalizing value is always shell conductance, the conductance pi values can be compared horizontally as well as vertically in Table 8-2.

25. It is necessary to integrate the heat input to heat sinks over time to predict surface temperatures that are used to evaluate the heat transfer rates, and hence the pi values, for each time phase. This integration process is described under the subheading "... Thermal Model" in WCAP-14845. The reasonableness of the scaling equations is verified by comparing predictions of the steady state and transient equations to LST measurements in Section 10.2.

26. The single time constant used in the containment mass, energy, and pressure scaling is defined in WCAP-14845, Equation 59. $V_o = 1.741 \times 10^6 \text{ ft}^3$ is the total gas volume inside containment, both above and below deck. During refill the break source flow stops, so the time constant, with flow rate in the denominator is undefined. However, Table 8-3 presents a time constant calculated using a reference break steam flow rate of 200 lbm/sec.

27. The reviewer's interpretation of the pi groups is correct. WCAP-14845, Table 8-5 shows the drops affect pressure the same as the steel heat sinks during blowdown and less than 1/10 as much after blowdown. Pi groups are normalized to different steam mass flow rates in each time phase, so cannot be compared between different time phases.

28. Figure 9-1 of WCAP-14845 clarifies the location of thermal centers. The discussion in Section 9.3.1 and Figure 9-2 show how the thermal centers are used with the density to calculate the buoyancy. The example calculation in WCAP-14845 is repeated below.

Figure 1 shows an example of a simplified PCS buoyancy calculation using density values calculated for the beginning of the long term time phase of the LOCA. The density variations over each leg of the air flow path are assumed to be linear. The net buoyancy is represented by the enclosed area. The buoyancy calculated using the thermal center approach is shown for comparison. For this case both the distributed density and thermal center approaches give the same result. Note that for this assumed case, the net buoyancy is not affected by the amount of heat transferred from the riser to the downcomer. (Moving point 2 along the horizontal axis does not change the area within triangle 1-2-3). However, moving point 2 does change the relative ratio of negative downcomer buoyancy to positive riser buoyancy. Moving the thermal centers of the downcomer and riser up to the 84 ft elevation, as was done for the AP600 scaling calculation, significantly reduces the net buoyancy.

29. The text in WCAP-14845, Section 9.3.1 was revised to be consistent with what was done: condensation on the chimney was part of a simultaneous solution for the PCS air flow path air and steam mass, energy, and momentum (including buoyancy).

30. The PCS air flow path time constant is the ratio of the air flow path volume to the volumetric flow rate. At the time when the peak pressure occurs, the shell temperature and evaporation rate are higher than at any other time, so the buoyancy induced volumetric air flow rate is highest.

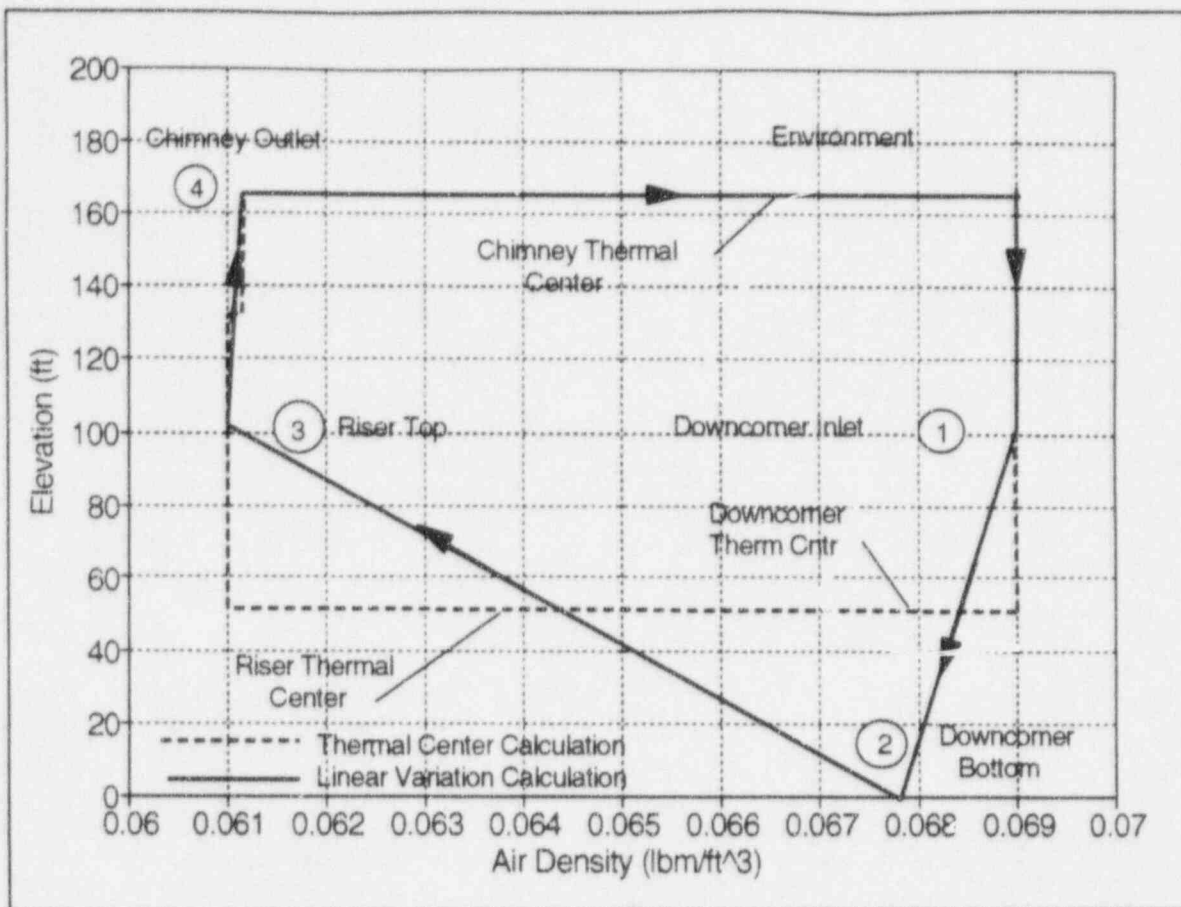


Figure 1 Buoyancy Calculation for the AP600 PCS Air Flow Path Comparing Distributed and Thermal Center Approaches

Consequently, the time constant is at its lowest value during the transient, and since the riser Reynolds number is proportional to the riser volumetric flow rate, the riser Reynolds number is at a maximum. The PCS air flow path time constants are presented in WCAP-14845, Section 9.1.

31. An Eckert and Metais flow regime map showing the boundaries between free, mixed, and forced convection flow is presented in WCAP-14845, Figure 4-1. The location of the downcomer, riser, and chimney operating points from the scaling analysis are shown on the map to help establish that the riser flow is forced convection.

32. A revised discussion of free and forced convection heat transfer and uncertainties are presented in WCAP-14845, Section 10.1.3. The forced convection data are no longer justified by comparison to mixed convection test data.

33. The mass transfer pi groups are defined in WCAP-14845, Section 7 for each heat sink: for example, Equation 122 for condensation and Equation 123 for evaporation. The relationships for condensation and evaporation mass transfer comparisons to test data are in terms of Sherwood number, defined in Section 4.3.1. Sherwood number comparisons to test data are presented in Section 10.1.1 and 10.1.2. The inconsistent definitions for the pi groups in the August Scaling Analysis was eliminated in WCAP-14845.

34. The definitions are clarified as noted in the response to discussion item (33).

The compressibility range in AP600 is $0.97 < Z_{\text{stm}} < 1.0$, where the minimum value corresponds to 40 psia of saturated steam. The assumption that $Z_{\text{stm}} = 1.0$ introduces an error of less than 3% in the equation of state, and permits steam to be modeled as an ideal gas. This is a significant simplification over the necessary steam table look-up required to quantify Z_{stm} , for only a small error in the equation of state. Although compressibility is neglected in this application of the equation of state, compressibility has been considered where it is more significant: the evaluation of the enthalpy rate of change with pressure in the development of the rate of pressure change equation presented in WCAP-14845, Sections 5 and 6.

35. Section 4.3.1 of WCAP-14845 presents the derivation of the Sherwood number relationships for free and forced convection that are compared to test data in Figures 10-1 and 10-2. The development follows.

The expression for the mass transfer coefficient for free convection condensation mass transfer:

$$k_{g,o} = \frac{0.13 D_{v,o}}{\bar{R} T_o (v^2/g)^{1/3}} \frac{P_o}{P_{\text{lm,air},o}} \left[\frac{\Delta \rho}{\rho} \right]^{1/3} Sc_o^{1/3}$$

can be rearranged in the dimensionless form:

$$\frac{k_{g,o} \bar{R} T_o (v^2/g)^{1/3} P_{\text{lm,air},o}}{D_{v,o} P_o} = 0.13 \left[\frac{\Delta \rho}{\rho} \right]^{1/3} Sc_o^{1/3}$$

The term $(v^2/g)^{1/3}$ represents length, so the right side of the equation is the Sherwood number plotted in Figure 10-1. Note that multiplying both sides of the equation by L , and dividing both sides by the term $(v^2/g)^{1/3}$ produces the more familiar form:

$$\frac{k_{g,o} \bar{R} T_o L P_{\text{lm,air},o}}{D_{v,o} P_o} = 0.13 \left[\frac{L^3}{(v^2/g)^{1/3}} \frac{\Delta \rho}{\rho} \right]^{1/3} Sc_o^{1/3} \quad \text{or} \quad Sh_L = 0.13 Gr_L^{1/3} Sc_o^{1/3}$$

The evaporation mass transfer relationships are developed similarly.

36. The evaporation test data points in Figure 10-2 are from the STC Flat Plate Test. The figure title was revised in WCAP-14845.

37. Figure 11 of the August Safety Analysis was mixed convection, not free convection or forced convection. The mixed convection correlation figure was replaced with discussions of the free convection and the forced convection correlations in WCAP-14845, Section 10.1.3.

The scaling model accounts for the water coverage fraction. The area of the evaporating, subcooled, and dry shell regions change during the transient. The determination of area is defined by Equation 135 and the discussion in Section 7.6.6. The resulting areas for the three shell regions are presented in Table 8-1 for each time phase. A maximum evaporation rate of 40 lbm/sec, consistent with WCAP-

14407, Section 7, is used.

38. What is meant is the slope, or exponent on the Reynolds number, is 1/2 that for friction at the riser Reynolds number corresponding to the peak containment pressure. This was clarified in Section 10.1.4, third paragraph of WCAP-14845.

39. The Blasius friction factor correlation is a reasonable approximation for low turbulent Reynolds numbers. However, at the riser Reynolds number corresponding to the peak containment pressure ($Re = 163,000$), the tangent to the $\epsilon/d = 0.0001$ curve on the Moody friction factor chart has a slope of -0.20 , hence the value used in the calculations.

Since form losses are known to be independent of Reynolds number at high Reynolds numbers ($K = C_1 Re^0$), and since the frictional losses are known to have only a weak dependence on Reynolds number at high Reynolds numbers ($fL/d = C_2 Re^n$, where $n = -0.20$), it is reasonable to expect the sum of the form and friction losses can also be approximated by a function of the form $K_{tot} = C_3 Re^m$. An approximating function can be defined as the tangent to the approximated function at some Reynolds number, R_0 . The values of C_3 and m in the approximating function can be determined as follows with the assumption:

1. The form, K , and friction losses, fL/d , are equal in magnitude at $Re = R_0$, so $C_1 = C_2 Re^n$,

and with the definition of the tangent:

2. The magnitudes of the approximated function, $(K+fL/d)$, and the approximating function, K_{tot} are equal at $Re = R_0$, so $K_{tot} = K + fL/d$, and

3. The slope of the approximating function dK_{tot}/dRe is equal to the slope of the approximated function $d(K+fL/d)/dRe$, at $Re = R_0$.

From assumption (1) : $C_2 = C_1/R_0^n$; from assumption (1) and definition (2): $C_3 = 2C_1/R_0^m$; and from definition (3) : $nC_2 R_0^{n-1} = mC_3 R_0^{m-1}$. Substituting the first and second expressions into the third to eliminate C_2 and C_3 results in the equation $m = n/2$. Since $n = -0.20$ at $Re = 163,000$, $m = -0.10$.

This discussion was included in Section 10.1.4 of WCAP-14845.

40. The roughness should have been stated as micro inches, not micro inches per inch, and was corrected in Section 10.1.4 of WCAP-14845.

41. WDT, an acronym for Water Distribution Test, is spelled out in Table 10-7 of WCAP-14845.

42. The stability criteria shows the containment atmosphere is stably stratified during most of the transient (after approximately 5 sec during a DECLG and 80 sec for the MSLB). It is considered unlikely that a more rigorously applicable stability criteria would permit the conclusion that the atmosphere is unstable during the majority of the transient time. Therefore it is necessary to address the consequences of stratified gas volumes in the AP600 evaluation model. The consequences of stratification are addressed in WCAP-14407, Section 9.

43. Equation 121 of the August Scaling Analysis is Equation 89 of WCAP-14845. The sentence was

rephrased in WCAP-14845 to state "Equation (89) is equally valid for AP600 and the LST with jets that are forced over most of the containment height."

Equation 89 was derived from Peterson's equations for entrainment into a forced jet, so for Equation 89 to be applicable, it is necessary that the jet be predominantly forced, or $Z_{trans} \approx H$. Peterson also examined a stability criterion for buoyant jets, and concluded that buoyant jets almost never break up stably stratified fluid volumes. Thus, the criteria for instability are a predominantly forced jet, and violation of Equation 89. This paragraph was added to Section 6.5.2 of WCAP-14845.

44. The MSLB values in Table 10-1 of the August Scaling Analysis are juxtaposed. They were corrected in WCAP-14845, Table 6-4 to read, first line: 74.8, 9.01, 1/8.3, and the second line: 2.46, 0.256, 1/9.61.

Figure 3 of Peterson, *I. J. of H & M. T., Vol 37*, shows stability data for $2 < H/d < 40$, which includes the range for both the LOCA and MSLB in both AP600 and the LST. Thus, we believe the relationships are valid for our values of H/d .

45. The values in Table 10-1 of the August Scaling Analysis are incorrectly listed and are corrected as noted in the response to Question 44.

46. Figure 12 of the August Scaling Analysis is Figure 6-2 of WCAP-14845. Both figures show the ratio of jet Froude number to volumetric Froude number is consistently 1000. Note the left and right scales on the figure.

47. Figures 12 and 13 are Figures 6-2 and 6-3 of WCAP-14845. The following paragraphs of clarification were added to WCAP-14845.

Stable/unstable regions are distinguished by the AP600 values of Fr , presented in Table 6-4, calculated from Equation 89. Figures 6-2 and 6-3 show the AP600 transients are expected to operate predominantly in the stably stratified regime.

For entrainment calculations it is important to know whether the jet is buoyant or forced, since buoyant and forced jets entrain the surrounding fluid at different rates. A forced jet transitions to a buoyant plume after traveling some distance and dissipating some of its kinetic energy. Thus, the first criterion to examine is whether the jet remains forced over the full height of containment, that is, what is the jet Froude number for $Z_{trans} = H$? The values were calculated for AP600 with Equation 86 and presented in Table 6-4. Comparison to the transient Froude numbers in Figures 6-2 and 6-3 show this criteria is never satisfied. So the jet always transitions to a plume before reaching the top of containment.

The second criterion to consider is, since the jets cannot always be modeled as forced, can the jets be modeled as always buoyant? The strict answer is no, since Equation 86 always gives a finite value of Z_{trans} . However, if the jet is predominantly buoyant, say over 90% of the containment height, then it is reasonable to model the jet as buoyant over its full height. The value for Z_{trans} then is 10% of the height, and the corresponding jet Froude numbers are presented in Table 6-4. When compared to the AP600 jet Froude numbers, Figure 6-2 shows the DECLG jet height is 90% buoyant for the entire post-blowdown time. Figure 6-3 shows the MSLB jet height does not become 90% buoyant until the end of the transient. Prior to the end of the MSLB the jet transition height must be calculated as a

function of the jet Froude number and modeled as mixed (that is, part forced and the remainder buoyant) to accurately calculate entrainment..

48. The part of the jet height that is buoyant is $H - Z_{trans}$, where H is the containment height above the source, and Z_{trans} is the height of the forced jet calculated from Equation 86 of WCAP-14845.

49. The phrase "weakly stratified" is used as a qualitative measure of the vertical density gradient observed in the LST data for the LOCA configurations. Strongly stratified would be nearly pure air at the deck elevation and nearly pure steam at the dome, which was never observed in the LST. If the jet entrainment is high enough, the resulting fluid circulation can nearly eliminate vertical concentration gradients, resulting in a weakly stratified atmosphere.

"Stably stratified" is not related to whether the gradient is weak or strong, only that it is stable.

Responses to Additional Items

ITEM 1. Calculated values for the rate of pressure change equation pi groups are presented in Table 8-5 for each phase of the LOCA and for the MSLB. The magnitude of the pi group, relative to 1.0 represents the importance of the phenomena. The phenomena represented by the pi groups are identified by the subscripts on the pi groups and the definitions of the pi groups. How the high and medium ranked phenomena are bounded is presented in WCAP-14407, Section 2.

The mass, energy, and pressure rate of change equations were validated by comparison to LST data as described in Section 10.2. The comparisons show the rate of change calculations agree with the test measurements.

ITEM 2. The scaling methodology was applied to the LST in Section 10.2. The predictions and measurements presented in Table 10-10 showed good agreement for the dominant phenomena (condensation and evaporation). The steady-state scaling model predicts the total steady state LST energy transfer for 21 tests with an average deviation between predictions and measurements of less than 1% and a standard deviation of 13%. The scaling analysis shows the dominant phenomena inside containment during a MSLB are also dominant during a LOCA. Therefore test results are valid for both transients.

ITEM 3. Transient rate of pressure change equation prediction are presented and compared for the LST and scaling equations. Pi group values were also calculated and compared to LST measurements to validate the mass and energy rate of change equations at steady state. Since the pressure rate of change equation is a combination of the mass and energy equations with the equation of state, validation of the mass and energy equations also validates the pressure equation.

The scaled comparisons show the dominant phenomena in the LST represent those in AP600, and the test data validate the scaling equations.

Attachment C

Discussion of Open Items 425 and 3202

OITS 425. Stalling/restart of PCS air flow under high ambient conditions.

The shield building walls are 3 ft thick concrete. This thickness strongly damps the effect on the inside of the shield building of solar radiation, that cycles from day to night. Calculations (Schlichting, *Boundary Layer Theory*, 6th Edition, pp 85-86) show the wave length of a 24 hour thermal cycle propagating through concrete is 3.05 ft. Thus the peak temperature on the inside of the structure occurs in-phase with the peak in the outside surface temperature. However, the damping reduces the amplitude on the inside to less than 0.2% of the outside amplitude.

A much more immediate effect on the inside of the shield building is due to the ambient air that is drawn into the downcomer by the natural circulation induced by the warmer containment shell, and by the wind-positive PCS air flow path. The wind-positive behavior is such that the external wind induces a positive (down the downcomer and up the riser) air flow. Thus, the ambient air will always be in thermal communication with the inside of the shield. Consequently, the downcomer side of the shield will respond directly to the outside air, but not to the solar heat load.

OITS 3202. Use of correlations outside their range.

The range of correlations for the dominant phenomena, condensation, evaporation, and heat transfer are all used within the range of the data as shown in WCAP-14845, Sections 10.1.1, 10.1.2, and 10.1.3. All correlations used to represent significant AP600 phenomena have been validated over a range appropriate for AP600 operation.