Docket File

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

March 25, 1997

52-003

APPLICANT. Westinghouse Electric Corporation

FACILITY: AP600

SUBJECT: SUMMARY OF AP600 DESIGN REVIEW MEETING REGARDING THE PASSIVE CONTAINMENT COOLING SYSTEM (PCS) AND WGOTHIC COMPUTER CODE

On March 6, 1997, representatives of the U.S. Nuclear Regulatory Commission (NRC), Scientech, Inc. (NRC consultant), and Westinghouse Electric Corporation (Westinghouse) met in Rockville, Maryland, to discuss (1) the recently revised WCAP-14845 (Scaling Report), (2) WCAP-14812 (Phenomena and Identification Ranking Table (PIRT) report) and (3) the WGOTHIC computer code and PCS design issue closure process. Attachment 1 is a list of meeting participants.

Mr. D. Spencer of Westinghouse presented the revised Scaling Report (WCAP-14845, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents," February 1997). The presentation included an overview of the contents, the differences from previous reports, and the questions and discussion items addressed in the report. Mr. M. Loftus of Westinghouse presented information regarding the phenomena identification and ranking table (now in WCAP-14812, "Accident Specification and Phenomena Evaluation for AP600 Passive Containment Cooling System," December 1996). This presentation addressed key changes to the PIRT, the expert review process, and a proposal for closure. Westinghouse is in the process of resolving the comments from expert review, which was performed in January 1997. Attachment 2 is the Westinghouse handouts. The staff noted the PIRT report did not reflect the design changes due to post 72-hour actions, such as the PCS flow rate. Westinghouse stated that the analysis was still in progress and that, when the design was final, the report would be updated to reflect the design. The staff and Westinghouse discussed closure paths for resolving open items and discussion questions. The staff stated that they will work with Westinghouse to address the open issues in an expeditious manner, however, Westinghouse must propose its resolution or its approach for resolution. The staff and Westinghouse agreed on several actions (listed below).

Action items from the March 6, 1997, meeting:

1) Westinghouse and the staff will discuss additional staff comments on WCAP-14812 in a telephone conference on March 13, 1997.

2) Westinghouse and the staff will met in late-March to discuss Chapters 7 and 9 of WCAP-14407.

3) Westinghouse will investigate how to include the expert review comments and Westinghouse's resolution of the comments in WCAP-14812 (PIRT).

DF03

9703280425 970325
PDR ADOCK 05200003
A PDR

280066

NRC FILE CENTER COPY

4) Westinghouse will provide additional information for the PIRT rankings in WCAP-14812, including references to specific scaling Pi groups, a description (where relied upon) of the engineering judgement bases, and the references (where relied upon) to specific tests and types of data that were used to determine the rankings.

5) Westinghouse and the staff will met in April to discuss revisions to WCAP-14812. In preparation for the meeting, Westinghouse will provide proposed revisions to address the staff's questions and comments, including Actions (3) and (4) above, and the March 4, 1997, letter, for review.

6) Westinghouse informed the staff that they will submit a request to withdraw Chapter 13 (WGOTHIC Noding Studies in Support of the AP600 Evaluation Model) of WCAP-14407 from the design application. Included in this request, Westinghouse will provide an explanation for the request and identify any discussion items or questions that pertain to this chapter only.

If you have any questions, please contact me at (301) 415-8548.

original signed by:

Diane T. Jackson, Project Manager
Standardization Project Directorate
Division of Reactor Program Management
Office of Nuclear Reactor Regulation

Docket No. 52-003

Attachments: As stated

cc w/attachments:
See next page

DISTRIBUTION w/attachment:

| | | |
|---|---|---|
| Docket File | PDST R/F | TMartin |
| PUBLIC | MSlosson | TQuay |
| TKenyon | WHuffman | DJackson |
| JSebrosky | EThrom, O-8 H7 | |

DISTRIBUTION: w/o attachment:

| | | |
|---|---|---|
| SCollins/FMiraglia, O-12 G18 | RZimmerman, O-12 G18 | AThadani, O-12 G18 |
| JMoore, O-15 B18 | WDean, O-17 G21 | ACRS (11) |
| CBerlinger, O-8 H7 | JKudrick, O-8 H7 | GHolahan, O-8 E2 |

DOCUMENT NAME: A:SCS3 6.MIN

To receive a copy of this document, indicate in the box: "C" = Copy without attachment/enclosure "E" = Copy with attachment/enclosure "N" = No copy

| OFFICE | PM:PDST:DRPM | SCSB:DSSA | D:PDST:DRPM | | |
|---|---|---|---|---|---|
| NAME | DTJackson:sg | CBerlinger CAB | TRQuay TRQ | | |
| DATE | 03/20/97 | 03/20/97 | 03/24/97 | | |

OFFICIAL RECORD COPY

cc: Mr. Nicholas J. Liparulo, Manager
Nuclear Safety and Regulatory Analysis
Nuclear and Advanced Technology Division
Westinghouse Electric Corporation
P.O. Box 355
Pittsburgh, PA 15230

Mr. B. A. McIntyre
Advanced Plant Safety & Licensing
Westinghouse Electric Corporation
Energy Systems Business Unit
Box 355
Pittsburgh, PA 15230

Ms. Cindy L. Haag
Advanced Plant Safety & Licensing
Westinghouse Electric Corporation
Energy Systems Business Unit
Box 355
Pittsburgh, PA 15230

Mr. M. D. Beaumont
Nuclear and Advanced Technology Division
Westinghouse Electric Corporation
One Montrose Metro
11921 Rockville Pike
Suite 250
Rockville, MD 20852

Mr. Sterling Franks
U.S. Department of Energy
NE-50
19901 Germantown Road
Germantown, MD 20874

Mr. S. M. Modro
Nuclear Systems Analysis Technologies
Lockheed Idaho Technologies Company
Post Office Box 1625
Idaho Falls, ID 83415

Mr. Charles Thompson, Nuclear Engineer
AP600 Certification
NE-50
19901 Germantown Road
Germantown, MD 20874

Mr. Frank A. Ross
U.S. Department of Energy, NE-42
Office of LWR Safety and Technology
19901 Germantown Road
Germantown, MD 20874

Mr. Ronald Simard, Director
Advanced Reactor Program
Nuclear Energy Institute
1776 Eye Street, N.W.
Suite 300
Washington, DC 20006-3706

Ms. Lynn Connor
Doc-Search Associates
Post Office Box 34
Cabin John, MD 20818

Mr. James E. Quinn, Projects Manager
LMR and SBWR Programs
GE Nuclear Energy
175 Curtner Avenue, M/C 165
San Jose, CA 95125

Mr. Robert H. Buchholz
GE Nuclear Energy
175 Curtner Avenue, MC-781
San Jose, CA 95125

Barton Z. Cowan, Esq.
Eckert Seamans Cherin & Mellott
600 Grant Street 42nd Floor
Pittsburgh, PA 15219

Mr. Ed Rodwell, Manager
PWR Design Certification
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94303

Mr. Ben Gitnick
Scientech, Inc.
11140 Rockville Pike
Suite 500
Rockville, MD 20850

WESTINGHOUSE/NRC MEETING

PASSIVE CONTAINMENT COOLING SYSTEM

MARCH 6, 1997

MEETING PARTICIPANTS

| NAME | ORGANIZATION |
|---|---|
| CARL BERLINGER | NRC/NRR/DSSA/SCSB |
| IVAN CATTON | ACRS |
| DIANE JACKSON | NRC/NRR/DRPM/PDST |
| JACK KUDRICK | NRC/NRR/DSSA/SCSB |
| TED QUAY | NRC/NRR/DRPM/PDST |
| EDWARD THROM | NRC/NRR/DSSA/SCSB |
| BEN GITNICK | SCIENTECH, INC./NRC CONSULTANT |
| DAN PRELEWICZ | SCIENTECH, INC./NRC CONSULTANT |
| JIM GRESHAM | WESTINGHOUSE |
| MIKE LOFTUS | WESTINGHOUSE |
| BRIAN MCINTYRE | WESTINGHOUSE |
| BRUCE RARIG | WESTINGHOUSE |
| DAN SPENCER | WESTINGHOUSE |
| JOEL WOODCOCK | WESTINGHOUSE |
| DONALD CHUNG | NUS/PUBLIC |
| JACK WHEELER | DOE/PUBLIC |

Attachment 1

# Scaling Analysis for AP600 Containment Pressure during Design Basis Accidents WCAP-14845

A Presentation to the U.S. Nuclear Regulatory Commisssion
Containment Systems Branch

By D. R. Spencer
Westinghouse Electric Corporation
Nuclear Service Division

March 6, 1994

Attachment 2

## Purpose of Presentation

WCAP-14845 was issued to resolve NRC comments/questions on the August 1996 Scaling Analysis.

- Describe Relationship of WCAP-14845 to August 1996 Scaling Analysis
- Discuss Resolution of Discussion Items, Additional Items, Open Items, RAI's and Where Addressed in WCAP-14845

# Relationship of WCAP-14845 to August 1996 Scaling Analysis

The NRC review of WCAP-14845 can be facilitated by understanding the relationship of WCAP-14845 to the August 1996 Scaling Analysis. WCAP-14845 is a significantly revised Scaling Analysis that includes new, reorganized, revised, and some largely unchanged information relative to the August Scaling Analysis.

New Material

Mass and energy transfer scaling, rate of change equation validation, and LST scaling was added for completeness.

Reorganized/Revised/Unchanged

For completeness and clarity:

Much of the material was significantly augmented, rearranged, or revised

Appendix A of the August Scaling Analysis was integrated into the body of WCAP-14845

The need for Appendix B was eliminated by clearly defining all parameters and pi groups.

The labels for the LOCA time phases were changed to: Blowdown, Refill, Peak Pressure, and Long Term for consistency with the PIRT (WCAP-14811).

Status and Cross Reference

Presented on the following WCAP-14845 Table of Contents

## WCAP-14845 Table of Contents

| | |
|---|---|
| Revised = | Substantially revised from August Scaling |
| New = | Not included in August Scaling |
| Renormalized = | Different normalization plus revision from August Scaling |
| (blank) = | Only minor changes from August Scaling |

| | | |
|---|---|---|
| 7.0 Heat Sink Analysis and Equations for Scaling | Revised | 3.3.3. 5.2.3 |
| 7.1 Drop Analysis and Scaling Equations | Revised | 5.2.3.1 |
| 7.1.1 Drop Conductance | Revised | 6.6.1 |
| 7.1.2 Drop Mass Transfer | New | |
| 7.1.3 Drop Energy Transfer | Renormalized | 6.6.1 |
| 7.1.4 Drop Effect on Pressure | New | |
| 7.2 Break Pool Analysis and Scaling Equations | Revised | 5.2.3.2 |
| 7.2.1 Pool Conductance | Revised | 6.6.2 |
| 7.2.2 Pool Mass Transfer | New | |
| 7.2.3 Pool Energy Transfer | Renormalized | 6.6.2 |
| 7.2.4 Pool Effect on Pressure | New | |
| 7.3 IRWST Analysis | | 3.3.3 |
| 7.4 Liquid Film Analysis | Revised | 3.3.4 |
| 7.5 Internal Solid Heat Sinks Analysis and Scaling Equations | Revised | 3.3.5 |
| 7.5.1 Heat Sink Conductance | Revised | 6.6.3 |
| 7.5.2 Heat Sink Mass Transfer | New | |
| 7.5.3 Heat Sink Energy Transfer | Renormalized | 6.6.3 |
| 7.5.4 Heat Sink Effect on Pressure | New | |
| 7.5.5 Steel Thermal Model | Revised | 5.2.3.3 |
| 7.5.6 Concrete Thermal Model | Revised | 5.2.3.3 |
| 7.5.7 Steel Jacketed Concrete Thermal Model | Revised | 5.2.3.3 |
| 7.6 Shell Analysis and Scaling Equations | Revised | 3.3.6 |
| 7.6.1 Shell Conductance | Revised | 6.6.4 |
| 7.6.2 Shell Mass Transfer | New | |
| 7.6.3 Shell Energy Transfer | Renormalized | 6.6.4 |
| 7.6.4 Shell Effect on Pressure | New | |
| 7.6.5 Shell Energy Equation Solution | Revised | 5.2.3.4 |
| 7.6.6 Weir and Water Coverage Timing | New | |
| 7.7 Baffle Analysis and Scaling Equations | Revised | 3.3.6 |
| 7.7.1 Baffle Conductance | New | |
| 7.7.3 Baffle Energy Transfer | Renormalized | 6.6.5 |
| 7.7.4 Baffle Energy Equation Solution | New | |
| 7.8 Shield Building Analysis and Scaling Equations | | 3.3.8 |
| 7.9 Chimney Analysis and Scaling Equations | Revised | 3.3.9 |
| 7.9.1 Chimney Conductance | Revised | 6.6.6 |
| 7.9.2 Chimney Mass Transfer | New | |
| 7.9.3 Chimney Energy Transfer | Renormalized | 6.6.6 |
| 7.9.4 Chimney Energy Equation Solution | New | |

# Discussion Items, Additional Items, Open Items, RAI's

The transmittal of WCAP-14845 (NSD-NRC-97-5006, 2/28/97) included the following items:

Responses to 49 discussion items raised by the NRC on the August Scaling Analysis are presented and incorporated into WCAP-14845.

Responses to 3 additional items raised by the NRC on the August Scaling Analysis are presented and incorporated into WCAP-14845.

Responses are provided to Open Items 425 and 3202.

RAI's 480.330, 480.379, and 480.380 were revised consistent with the latest PIRT (WCAP-14811) and scaling analysis (WCAP-14845).

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-96-4762, "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 hbrk,o, Dhbrk,o, mbrk,o, mbrk,g,o. Describe the basis for selection of each value. What, if any, is the difference between Dhbrk,o and Dhbrk,g,o?

3. When equation 46 of Appendix A (Equation 2 in main body of report) is applied, mbrk is replaced by mbrk,g (e.g. Equation 52). Also, ZatmRatm 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 Pr = P/Pc < 0.05 which is about 27.3 psia (Pc 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 19 on page 24. Why is the temperature Tbf,o used in the second term on the right? The conductances are given as he and hex in the equation, but as he,in and he,o in the sentence following the equation. If he,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 DPatm and Pim,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 2349oF, the bulk steam density as 0.641 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 x 106 ft3 and total drop surface area of 9 x 107 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 x 109 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 (66).

    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 3oF 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, pd, psource, pe, pm, ph and pr. Appendix B lists four pi groups pi-r, pi-c, pi-m and pi-e.

    Table 7-7 lists five RPC PI groups as drop related, pradiation, pconvection, penthalpy, pgas work, and pliquid work. An additional PI group, pmass appears in Appendix B.

    On page 53 it is stated that Tau is equal to the inverse of Omega-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 Po equal to 60 psia. Is this true for all phases of the DECLG LOCA? What value is used for Dhbrk,o?

17. Equations 54 and 56 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, ao 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 ratm,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 * hbrk,g,o should be replaced by md,o * 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

**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 Pstm,srf is calculated. Page B-3 gives Pstm,srf equal to Ptot for drops. Please explain.

13. The value calculated for Atot in your response appears to be incorrect. Atot is 1.67x108 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 to (is this the same as tsys?) in terms of Vo. How is Vo calculated? and where are numerical values given in Appendix B? Why is there no value of tsys 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, rdc, rri, rch and renv 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 t 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?

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 $RT_o$ 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 $k_{g,o}$ for condensation and evaporation mass transfer given in Table 9-1. That is, how is $k_{g,o}$ 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 $H/d_o$?

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 $d_o$ 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.

**Responses to 49 Discussion Items**

1. WCAP-14845. Section 10.2 presents a scaled comparison of AP600 and the LST.

2. The mass flow rate, $\dot{m}_{g,brk,o}$ and enthalpy difference, $\Delta h_{g,brk,o}$ 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, $m_{g,brk}$ is the same parameter as $m_{brk}$ 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. $\Delta P_{stm}$ 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, $\rho_f$ is effectively constant, $\rho_f^*$ 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. $V_o$ = 1.741x10$^6$ 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. 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

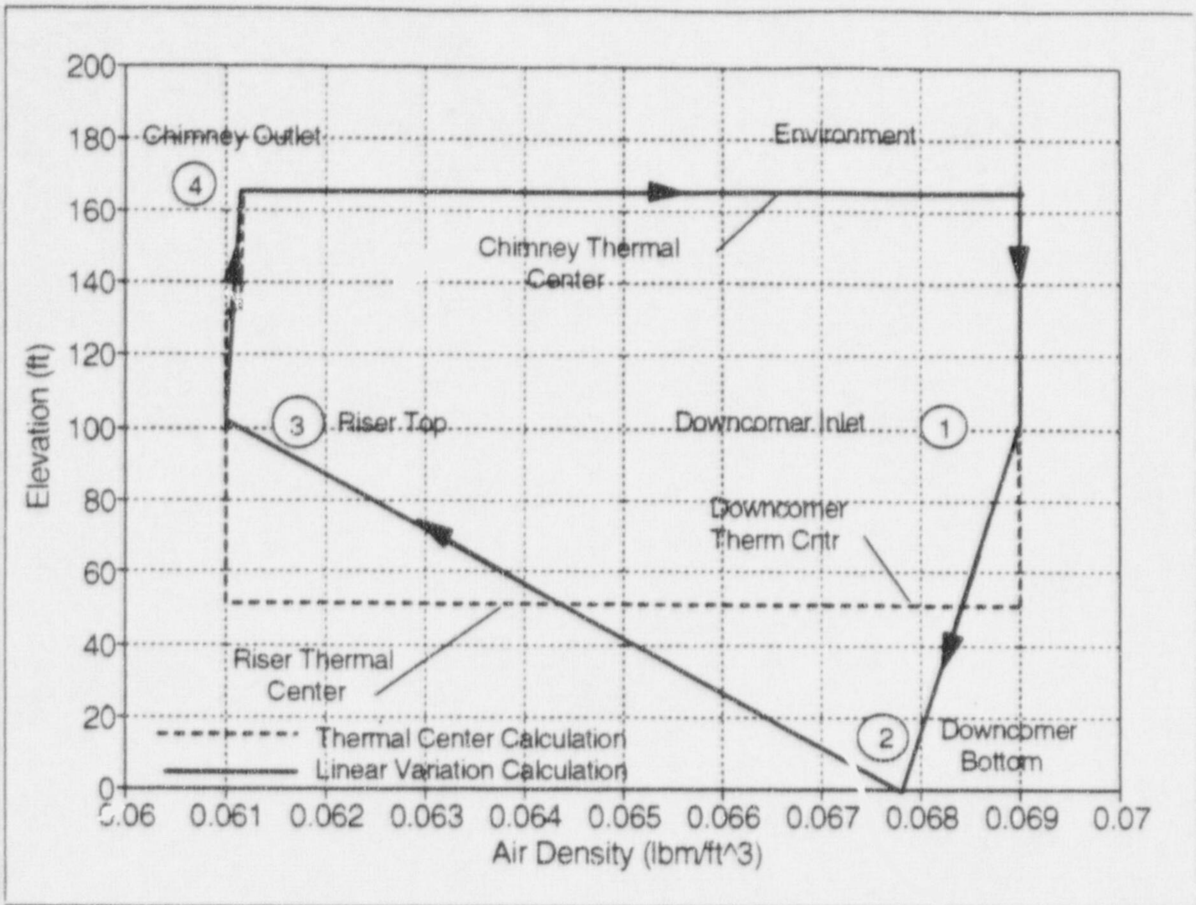


**Figure 1** Buoyancy Calculation for the AP600 PCS Air Flow Path Comparing Distributed and Thermal Center Approaches

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 date.

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 $0.97 < Z_{stm} < 1.0$, where the minimum value corresponds to 40 psia of saturated steam. The assumption that $Z_{stm} = 1.0$ 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:

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

can be rearranged in the dimensionless form:

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

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:

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

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 Scaling 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 Blassius 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 $\varepsilon/d = 0.0001$ 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) : $nC_2R_0^{\,n-1} = mC_3R_0^{\,m-1}$. 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 $Fr_v$ 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.

## 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.

**Responses to 3 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.

**Open Items 425 and 3202**

OITS 425. ACRS Meeting on PCS Testing (3/16/94) The Subcommittee recommended that W evaluate the potential for stalling/restart of the air flow around containment, for the case of high ambient temperature conditions.

Response:

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. 21.6.5-14 Westinghouse needs to justify the use of correlations outside their range and discuss the impact of these correlations on AP600 licensing calculations

Response:

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.

Question 480.330 Revision 1

Re: (WGOTHIC MODELS AND PHENOMENA)DOWNCOMER
Does WEC consider that the effects of the downcomer are negligible, and if so how has this been demonstrated? How can the effects of a downcomer be quantified without experimental validation?

Response:

The effects of the downcomer on AP600 are quantified by the PIRT (Reference 480.330-1) and scaling analysis (Reference 480.330-2), and shown to be of low to moderate importance. The effect of the downcomer on AP600 is small, but is not negligible. The downcomer is modeled in the evaluation model.

The lack of a downcomer in the LST has no effect on the data that were used to validate phenomenological models or on the use of the LST pressure as a comparison to the evaluation model. This is true because the LST is not used as a transient representation of AP600. The data collected from the LST at numerous locations for heat and mass transfer to the riser provide measurements of heat flux, shell surface temperature, air temperature, and air steam partial pressure that are used to validate the heat and mass transfer correlations. This separate effects approach is not affected by the presence or absence of a downcomer.

The downcomer in the AP600 evaluation model is modeled as a channel operating with mixed convection thermal interactions with the shield building and baffle. The scaling analysis energy pi group for heat transfer from the baffle to the downcomer, $\pi_{e,q,bfs}$ in Table 8 showed the energy transfer to the downcomer to be minor. The buoyancy contribution of the downcomer to the net PCS air flow path buoyancy is shown by the value of $\pi_{mv,dc}$ in Table 9-1 to be minor. The phenomena that occur in the downcomer were addressed in the PIRT and were all ranked low to moderate importance. Because the PIRT and scaling analysis showed the downcomer and its associated phenomena to be minor, it is sufficient to model the downcomer using ordinary analytical models.

References:

480.330-1 M. Loftus, J. Woodcock, D. Spencer, "Accident Specification and Phenomena Evaluation for AP600 Passive Containment Cooling System", WCAP-14811, December 1996, Westinghouse Electric Coproration.

480.330-2 D. R. Spencer, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents," WCAP-14845, February 1997, Westinghouse Electric Corporation

SSAR Revision: NONE

Question 480.379 Revision 1

Re: (The following questions are based on the WEC March 29-30, 1995 ACRS Presentation on Scaling). Where does the "U" in the correlations come from when the main steam line break (MSLB) is being analyzed? How were equations derived, what assumption were used?

Response:

The containment rate of pressure change equation is derived from the energy equation for the containment gas. The energy equation for the containment gas is derived from the energy equation for a control volume which relates the internal energy, u, to the enthalpy fluxes and heat fluxes through the control surface. The derivation of the energy and rate of pressure change equations for the scaling analysis are presented in Section 6 of the scaling report (480.379-1).

References:

480.379-1 D. R. Spencer, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents," WCAP-14845, February, 1997, Westinghouse Electric Corporation.

SSAR Revision: NONE

Question 480.380 Revision 1

Re: The following questions are based on the WEC March 29-30, 1995 ACRS Presentation on Scaling. The Large-Scale Test air-annulus was scaled by matching Reynolds (Re) numbers. This tends to result in higher heat transfer and more vigorous in-containment convection than might be expected in the AP600. It would seem that scaling to the following form would be more appropriate:

integral (q dA / v)

What are the ramifications?

Response:

The scaling analysis (Reference 480.380-1, Sections 10.1.2 and 10.1.3) demonstrated that the Reynolds number is the appropriate dimensionless group to use to scale evaporation mass transfer and heat transfer to the riser.

References:

480.380-1 D. R. Spencer, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents," WCAP-14845, February, 1997, Westinghouse Electric Corporation

SSAR Revision: NONE

AP600 PCS PIRT

March 6, 1997

M.J.Loftus
412-374-5957

# AP600 PCS PIRT

- o PIRT Chronology
- o Some Key Changes/Impovements
- o Expert Review Process
- o Process to reach PIRT Closure

# PIRT Chronology

- o Pre-1996

  - Initial PIRT identified key containment phenomena for evaluation in separate effect tests and scaled testing (late 80's)

  - Interim PIRT's developed and published (e.g., joint scaling and PIRT report in 1994)

- o 1996

  - Preliminary (February) version of PIRT published consistent with available scaling analysis results

  - EPRI A&TRT reviewed PIRT

  - Revsied PIRT format provided in May at ACRS meeting

  - Efforts to address NRC comments on containment test analyses, model development, and documentation throughout the year

  - Scaling analyses revised in 1996 (issued February, 1997) and factored into December PIRT

- o Final Product - December, 1996 PIRT with bases for ranking

Some Key Changes/Improvements
Between February PIRT and December PIRT

- o Some report format changes, *for example*
  - Added chapter (2.0) on process
  - Added specific test objectives and overall test conclusions
  - Added paragraph for each phenomena on ranking
  - Added appendix summarizing sources for ranking bases (scaling, tests, sensivitivities, engineering judgement, first principles)

- o PIRT structure improved, *for example*
  - Included phenomena for both volumes and structures
  - Phenomena listed inside to outside

- o New phenomena added, *for example*
  - Break source mass and energy release
  - Intercompartmental flow in containment volume
  - Gas compliance in containment volume
  - Hydrogen release in containment volume
  - Heat capacity of heat sinks
  - Initial conditions of containment

## Some Key Changes/Improvements
## Between February PIRT and December PIRT
## (continued)

o Some rankings changed from Low to High for Long Term, *for example*

- Heat sink liquid film energy transport
- Heat sink horizontal film conduction
- Heat sink internal conduction
- Fog in the containment volume

For those phenomena that are related to or strongly affected by the condensation rate which was ranked High

o Some rankings changed from Medium to Low for Blowdown, *for example*

- Heat sink liquid film energy transport
- Convection from containment to heat sinks
- Radiation from containment to heat sinks

Based on available scaling analysis results and test results

Note: not a complete list of changes

## Expert Review Process

- o Supplements prior expert reviews and confirms that previous comments addressed
- o Performed in parallel with NRC review of WCAP-14811 in January, 1997
- o External Experts
  - Per Peterson, UCLA
  - Tom Fernadez, EPRI
  - Sol Levy, Levy & Associates (EPRI)
  - Doug Chapin, MPR Assocaites (EPRI)
- o Internal experts
  - Larry Hochreiter, Consulting Engineer
  - Gene Piplica, AP600 Test Manager
  - Larry Conway, PCS Patent Holder
  - Terry Schulz, AP600 Systems Design Engineer
- o Comments received on phenomena identification
- o Comments received on phenomena ranking

# PIRT Closure

- ~~To be~~ addressed ~~once~~ NRC ~~specific~~ comments/discussion items ~~are available~~

- Resolve Expert Review Comments

- Westinghouse and NRC to agree on specific changes to WCAP

- Proposed format is a working level PIRT closure meeting

- Suggested Ground Rules

    - only those items neccesary to make report correct are to be changed

    - minimize changes to WCAP

    - add supporting appendices as necessary

## Summary

- o PIRT has changed/improved since February, 1996

- o Westinghouse has received specific Expert Review comments on December, 1996 PIRT

- o Westinghouse has proposed "path to closure"

  - Obtain NRC specific comments/questions

  - W to provide responses on comments/questions

  - W/NRC working-level meeting on proposed responses