Docket File

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

May 9, 1997

52-3

APPLICANT: Westinghouse Electric Corporation

FACILITY: AP600

SUBJECT: SUMMARY OF APRIL 17, AND 18, 1997, MEETING WITH WESTINGHOUSE TO DISCUSS THE PASSIVE CONTAINMENT COOLING SYSTEM AND WGOTHIC COMPUTER CODE FOR THE AP600 REACTOR DESIGN

The subject meeting was held on April 17, and 18, 1997, in the Rockville, Maryland, offices of the Nuclear Regulatory Commission (NRC) between representatives of Westinghouse, and the NRC staff. Attachment 1 is a list of meeting attendees. Attachments 2 and 3 are the handouts provided during the meeting by Westinghouse.

The purpose of the meeting was to discuss two reports: the Accident Specification and Phenomena Evaluation report (WCAP-14812), and the Scaling Analysis report (WCAP-14845). Prior to the meeting Westinghouse faxed attachments 4, 5, and 6 for the staff to review for the meeting. The attachments served as a proposal from Westinghouse to resolve issues associated with the review of WCAP-14812. The issues had previously been identified by the staff in a letter from T. R. Quay (NRC) to N. J. Liparulo (Westinghouse) dated March 4, 1997, "AP600 Passive Containment Cooling System (PCS) and WGOTHIC Computer Code Review."

Although the staff had not had a chance to review the attachments in detail it did provide some preliminary feedback to Westinghouse. In general, the staff believed that the attachments were responsive to the staff's concerns. Concerning the synopsis of the expert review (attachment 5) the staff believed that Westinghouse needed to provide more detail on: (1) what the experts were asked to do, (2) how differences of opinion between the experts on the ranking of phenomena were resolved, and (3) suggested that the letters from the peer reviewers be included in the report. The staff told Westinghouse that it would not provide any written comments on attachments 4, and 6 because: (1) it believed that Westinghouse was using the right approach, and (2) further comment would not be appropriate because these attachments lacked the technical detail necessary for the staff to provide detailed comments. The staff did agree to review attachment 5 in more detail to determine if any additional comments will be provided to Westinghouse.

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The Scaling Analysis report (WCAP-14845) was then discussed. The Advisory Committee for Reactor Safeguards (ACRS) consultants believed that the report did not address several key issues. The ACRS consultants believed that the distortions in the Large Scale Test (LST) facility relative to the actual AP600 design were not adequately treated in the report. Specifically, the ACRS consultants stated that the ratio of the heat flux to the size of the LST facility was much larger than the ratio of the heat flux to the actual size

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of the AP600 containment. Because of this distortion the ACRS consultants believed that Westinghouse could not conclude from the LST tests alone that stratification and the distribution of non-condensible gases in the full size AP600 containment would not be a problem.

The Westinghouse scaling report defines many dimensionless coefficients as "pi numbers." A more standard approach would call only the important scaling groups "pi numbers", which are defined in terms of the common dimensionless numbers, for example the Reynolds, Froude, and Grashof numbers, whenever possible. Westinghouse was asked to clarify their terminology in regard to "pi numbers."

The staff also provided to Westinghouse preliminary comments on the Scaling report. The staff committed to provide these preliminary comments and other comments in requests for additional information (RAIs) to Westinghouse by the end of April 25, 1997. The staff also agreed to assemble the ACRS consultants concerns into RAIs and issue them to Westinghouse by May 2, 1997.

A draft of this meeting summary was provided to Westinghouse to allow them the opportunity to ensure that the representations of their comments and discussions were correct.

original signed by:

Joseph M. Sebrosky, Project Manager
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Docket No. 52-003

Attachments: As stated

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## WESTINGHOUSE AP600 WGOTHIC
## MEETING ATTENDEES
## APRIL 17 AND 18, 1997

| NAME | ORGANIZATION |
|---|---|
| JOEL WOODCOCK | WESTINGHOUSE |
| DAN SPENCER | WESTINGHOUSE |
| BRUCE RARIG | WESTINGHOUSE |
| JIM GRESHAM | WESTINGHOUSE |
| MIKE LOFTUS (PART TIME) | WESTINGHOUSE |
| LOTHAR WOLF | NRC CONSULTANT |
| DAN PRELEWICZ | NRC CONSULTANT |
| BEN GITNICK | NRC CONSULTANT |
| NOVAK ZUBER | ACRS CONSULTANT |
| IVAN CATTON | ACRS CONSULTANT |
| PAUL BOEHNERT | ACRS STAFF |
| EDWARD THROM | NRC/NRR/DSSA/SCSB |
| KAZIMIERAS CAMPE (PART TIME) | NRC/NRR/DSSA/SASG |
| JOE SEBROSKY | NRC/NRR/DRPM/PDST |

Attachment 1

# Meeting on AP600 PCS PIRT

- o Meaning of Phenomena Ranking
- o Expert Review Synopsis *
- o Bases for Ranking **
  - Testing Results
  - Scaling Results
  - Sensitivity Studies
  - Expert Reviews
  - Engineering Judgement

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* faxed to NRC on 4/10

** faxed to NRC on 4/11

Attachment 2

## What Does Ranking Really Mean?

- The extent to which the phenomena affects containment Pressure versus time during time period of interest

- High or Medium
  - must be considered in Evaluation Model
  - either conservative or bounding manner

- Low
  - can use an available, best-estimate or realistic model in Evaluation Model
  - no need to bound realistic model as long as there is not a large uncertainty
  - not necessary to "fine-tune" or bound low ranked phenomena
  - phenomena may be neglected if effect is small enough or conservative to neglect them

Therefore, it is more important to distinguish between Medium and Low Ranked Phenomena than between Medium and High Ranked Phenomena

# Expert Review Summary

- Received Comments on Phenomena Identification and Ranking (see Appendix B faxed on 4/10/97)
  - external experts agreed with authors most of the time
  - internal experts had differing opinions

- Received Editorial Comments
  - clarifications
  - corrections
  - very little commonality between reviewers

- General Review Comment - latest version of report was significant improvement over preliminary version

- Common Review Comment - unclear basis for ranking many of the phenomena (authors addressed this with proposed "inserts" faxed 4/11/97)

- Authors to incorporate comments that significantly clarify or correct text, but also attempt to minimize changes to text

- Synopsis of Expert Review to be included as Appendix B (faxed 4/10/97)

## Table B-1 Summary of PIRT Expert Comments on Phenomena Ranking

| Phenomena | External Experts | | Internal Experts | | Revision 0 Ranking | Basis for Expert Ranking |
|---|---|---|---|---|---|---|
| | expert 1 | experts 2-4 | experts 5-7 | expert 8 | | |
| 1) Break Source | | | | | | |
| A-M&E | | | | | H,na,H,H,H | 1A |
| B-direct. | | | H,na,H,**L**,H | H,na,H,**L**,H | H,na,H,H,H | 1B |
| C-moment. | | | H,na,H,**L**,H | H,na,H,**L**,H | H,na,H,H,H | 1C |
| D-density | | | H,na,H,**L**,H | H,na,H,**L**,H | H,na,H,H,H | 1D |
| E - droplet flashing | | | | | H,H,na,na,na | |
| 2) Containment Volume | | | | | | |
| A - m/s | | | H,H,H,**L**,H | H,H,H,**L**,H | H,H,H,H,H | 2A |
| B-interc. flow | | | L,**L,L,L,L** | **H,L,L,L**,H | L,H,H,H,H | 2B |
| C-gas compliance | | | | | H,H,H,H,H | 2C |
| D-fog | | **H**,H,H,**L**,na | L,**L,L,L**,na | L,**L,L,L**,na | L,H,H,H, na | 2D |
| E-hydrogen release | | | | | L, L, L, L, na | |
| 3) Containment Solid Heat Sinks | | | | | | |
| A -film energy | | | (combine w/ condensation) | (combine w/ condensation) | L,M,H,H,M | 3A |
| B-vert. Film conduction | | | | | L, L, L, L, L | |
| C-horz. Film conduction | | | L,**L,L,L,L** | L,**L,L,L,L** | L,H,H,H,H | 3C |
| D-conduction | | | M,H,**L,L**,H | **H**,H,**L,L**,H | M,H,H,H,H | 3D |
| E - heat capacity | | | M,H,**L,L**,H | **H**,H,**L,L**,H | M,H,H,H,H | 3E |
| F-condensation | | | M,H,**L,L**,H | **H**,H,**L,L**,H | M,H,H,H,H | 3F |
| G-convection | | | L,**L,L,L**,L | L,**L,L,L**,L | L,M,M,M,L | 3G |
| H-radiation | | | L,**L,L,L**,L | L,**L,L,L**,L | L,M,M,M,L | 3H |
| 4) Initial Conditions | | | | | | |
| A-Temp. | | | **L**,M,H,**M**,H | **H**,M,**M,M**,H | M,M,H,H,H | |
| B- Humidity | | | **L**,M,H,**M**,H | **H**,M,**M,M**,H | M,M,H,H,H | |

| Phenomena | External Experts | | Internal Experts | | Revision 0 Ranking | Basis for Expert Ranking |
|---|---|---|---|---|---|---|
| | expert 1 | experts 2-4 | experts 5-7 | expert 8 | | |
| C- Pressure | | | **L**,M,H,**M**,H | **H**,M,**M**,**M**,H | M,M,H,H,H | 4A,B,C |
| 5) Break Pool | | | | | | |
| A-mixing | | | | | L,L,L,M,L | 5A |
| B-condensation | | | L,L,**L**,M,L | L,L,**L**,**L**,L | L,L,M,M,L | 5B |
| C-convection | | | | | L,L,L,L,L | |
| D-radiation | | | | | L,L,L,L,L | |
| E-conduction | | | L,L,L,**L**,L | L,L,L,**L**,L | L,L,L,M,L | 5E |
| F-flooding | | | L,L,L,**L**,L | L,L,L,**L**,L | L,L,L,M,L | 5F |
| 6-IRWST | | | | | L,L,L,L,L | 6B |
| 7) Steel Shell | | | | | | |
| A-convection | | | L,**L**,**L**,**L**,L | L,**L**,**L**,**L**,L | L,M,M,M,L | 7A |
| B-radiation | | | L,**L**,**L**,**L**,L | L,**L**,**L**,**L**,L | L,M,M,M,L | 7B |
| C-condensation | | | | **H**,H,H,H,H | L,H,H,H,H | 7C |
| D-film conduct. | | | | | L,L,L,L,L | |
| E-film energy | | | | | M,M,M,M,M | |
| F-shell conduct. | | | L,**H**,H,H,H | **H**,L,H,H,H | L,L,H,H,H | 7F |
| G - heat capacity | | | | **H**,**M**,**M**,L,H | L,H,H,L,H | 7G |
| H- convection | | | L,L,**L**,M,L | L,L,**L**,M,L | L,L,M,M,L | 7H |
| I-radiation to baffle | | | L,L,**L**,M,L | L,L,**L**,M,L | L,L,M,M,L | 7I |
| J-radiation to chimney | | | | | L,L,L,L,L | |
| K-radiation to fog/air | | | | | L,L,L,L,L | |
| L-film conduct. | | | | | na,na,L,L,L | 7L |
| M-film energy | | | | | na,na,M,M,L | 7M |
| N-evaporation | | | | | na,na,H,H,M | 7N |
| 8) PCS Cooling Water | | | | | | |
| A-flow rate | | | | | na,na,H,H,M | 8A |
| B-water temp. | | | | | na,na,M,M,L | 8B |

| Phenomena | External Experts | | Internal Experts | | Revision 0 Ranking | Basis for Expert Ranking |
|---|---|---|---|---|---|---|
| | expert 1 | experts 2-4 | experts 5-7 | expert 8 | | |
| C-film stability | | | | | na,na,H,H,L | 8C |
| D-film stripping | | | | | na,na,L,L,L | 8D |
| E-film drag | | | | | na,na,L,L,L | 8E |
| 9) Riser Annulus & Chimney Volume | | | | | | |
| A-nat. circ. | | | | L,L,**M,M**,M | L,L,H,H,M | 9A |
| B-vapor acceleration | | | | | na,na,L,L,L | 9B |
| C-fog | | | | | na,na,L,L,na | |
| D-flow stability | | | | | L,L,L,L,L | |
| 10) Baffle | | | | | | |
| A-convection to riser | | na,na,L,M,**L** | na,na,L,**L,L** | na,na,L,L,**L** | na,na,L,M,na | 10A |
| B-convection to downcomer | | | na,na,L,**L,L** | na,na,L,**L,L** | na,na,L,M,na | 10B |
| C-radiation | | na,na,L,L,**L** | na,na,L,L,**L** | na,na,L,L,**L** | na,na,L,L,na | 10C |
| D-conduction | na,na,L,**L**,na | | na,na,L,**L,L** | na,na,L,L,**L** | na,na,L,M,na | 10D |
| E-condensation | | | | | na,na,L,L,na | |
| F-heat capacity | | | | | na,na,L,L,na | |
| G-leaks | | | na,na,**L,L,L** | na,na,**L,L,L** | na,na,M,M,na | 10G |
| 11) Baffle Supports | | | | | | |
| A-convection | | | | | L,L,L,L,L | |
| B-radiation | | | | | L,L,L,L,L | |
| C-conduction | | | | | L,L,L,L,L | |
| D-heat capacity | | | | | L,L,L,L,L | |
| 12) Chimney Structure | | | | | | |
| A-conduction | | | | | L,L,L,L,L | |
| B-convection | | | | | L,L,L,L,L | |
| C-heat capacity | | | | | L,L,L,L,L | |
| D-condensation | | | | | L,L,L,L,L | |
| 13) Downcomer Annulus | | | | | | |

| Phenomena | External Experts | | Internal Experts | | Revision 0 Ranking | Basis for Expert Ranking |
|---|---|---|---|---|---|---|
| | expert 1 | experts 2-4 | experts 5-7 | expert 8 | | |
| A-nat. circ. | | | | L,L,**M,M**,M | L,L,H,H,M | 13A |
| B-flow stability | | | | | L,L,L,L,L | |
| 14) Shield Building | | | | | | |
| A-convection to downcomer | | | na,na,**L,L**,L | na,na,**L,L**,L | na,na,M,M,L | 14A |
| B-conduction | | | | | na,na,L,L,na | |
| C-convection to ambient | | | | | na,na,L,L,na | |
| D-radiation to ambient | | | | | na,na,L,L,na | |
| 15) External Atmosphere | | | | | | |
| A-temperature | | | | | na,na,L,L,L | |
| B-humidity | | | | | na,na,L,L,L | |
| C-recirculation | | | | | na,na,L,L,L | |
| D-pressure fluctuations | | | | | na,na,L,L,L | |
| | | | | | | |

1.) blanks in table signify agreement with the Revision 0 ranking

2.) underlines and bold signify differences with the Revision 0 ranking and differences are explained in following notes

# Phenomena Ranking Based on Scaling Results

Quantitative Criteria for judging pi values in AP600 Containment Scaling Report (WCAP-14845)

- Low ranking = 0.0 - 0.10 pi values
- Medium ranking = 0.11 - 0.20 pi values
- High ranking = > 0.21 pi values

**Scaling Results (from WCAP-14845)**

| PIRT Phenomena | Scaling Pi Group | LOCA Blowdown | LOCA Refill | LOCA Peak Pressure | LOCA Long Term | MSLB Blowdown |
|---|---|---|---|---|---|---|
| 1A) M&E releases | Pi (p, g, brk, work) (table 8-5) | 1 | 0 | 1 | 1 | 1 |
| 1E) Droplet/liquid flashing | Pi (p,work,d) (table 8-5) | 0.05 | -0.04 | 0.01 | 0 | n/a |
| 2C) Gas compliance | Pi (p, t) (table 8-5) | 0.76 | 0.76 | 0.77 | 0.76 | 0.76 |
| 3A) Liquid film energy transport on heat sinks | Pi (e, f, st+cc+jc) (table 8-4) | 0 | -0.08 | -0.07 | -0.03 | -0.01 |
| 3F) Condensation on solid heat sinks | Pi (p, work, st+cc+jc) (table 8-5) | -0.08 | -1.95 | -0.94 | -0.29 | -0.64 |
| 3G) Conv. plus rad. containment to sinks | Pi (p, q, st+cc+jc) (table 8-5) | -0.01 | -0.33 | -0.12 | -0.02 | -0.13 |
| 3H) Radiation | (approx. 1/2 of 3G) | | | | | |
| 5B) Break pool condens./evaporation | Pi (p, work,p) (table 8-5) | 0.04 | 0 | 0.03 | 0.07 | n/a |
| 5C) Break pool conv. (plus radiation) w/cont | Pi (p, q, p) (table 8-5) | 0 | 0 | 0 | 0 | 0 |
| 5D) Break pool radiation | (approx 1/2 of 5C) | | | | | |
| 7AB) Convection (plus | Pi (p, q, es+ss+ds) | 0 | -0.1 | -0.08 | -0.08 | -0.07 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| radiation) to inside shell | (table 8-5) | | | | | | | | | |
| 7C) Condensation on inside shell | Pi (p,work,es+ss+ds) (table 8-5) | -0.02 | | -0.61 | | -0.47 | | -1.04 | | -0.37 |
| 7E) Film energy on inside shell | Pi (e, f, ss+es+ds) (table 8-4) | 0 | | -0.02 | | -0.02 | | -0.11 | | 0 |
| 7G) Heat capacity of shell | Pi (Sumqin-Sumqout) (table 8-4) | -0.02 | | -0.62 | | -0.44 | | -0.02 | | -0.33 |
| 7H) Convection (plus radiation) riser | Pi (e,q,esx+dxs) (table 8-4) | 0 | | 0 | | 0 | | -0.06 | | 0 |
| 7I) Radiation (plus convection) to baffle | Pi (e, q, bf) | 0 | | 0 | | 0 | | -0.02 | | 0 |
| 7J) Radiation to chimney | Pi (e, q, ch) (table 8-4) | 0 | | 0 | | 0 | | 0 | | na |
| 7K) Radiation from containment shell | Pi (e, q, esx + dxs) (table 8-4) | 0 | | 0 | | -0.02 | | -0.06 | | 0 |
| 7N) Evaporation from shell to riser | Pi (e, fg, esx) (table 8-4) | na | | na | | -0.02 | | -0.81 | | na |
| 8B) PCS water temperature | Pi (e, g, ssx) | na | | na | | -0.01 | | -0.08 | | na |
| | Note: Phenomena ranking basis from scaling: Low is 0-0.10, Medium is 0.11 to 0.20, High is >0.21 | | | | | | | | | |

# U.S. NRC Reactor Containment Branch - Westinghouse Working Meeting to Resolve Containment Pressure Scaling Issues

## April 18, 1997

Presented by D. R. Spencer
Westinghouse Electric Corporation
Nuclear Service Division

Attachment 3

**Meeting Purpose:**

A working meeting to resolve issues needed to reach closure on the AP600 Containment Pressure scaling analysis

**PCS Scaling Closure Plan:**

Discuss NRC issues to reach understanding on resolution.

Revise Scaling Analysis (WCAP-14845) accordingly and issue Rev. 1.

**Outline of the AP600 Containment Pressure Scaling Process**

- Equation Development
- Pi Group Values
- Validation of Scaling Equations and LST
- Results Summary

## Equation Development

Governing Equations

- Rate of change equations were developed for mass, energy, momentum, and pressure inside containment, and for mass, energy, and momentum outside containment, using the component level PIRT for guidance.
- The containment atmosphere was coupled to the shell and internal heat sinks (solids, drops, and pools) by energy transfer conductances.
- The outside of the shell was coupled to the PCS air flow path by energy transfer conductances.
- The inside and outside of the shell were coupled using integral equations for transient conduction.

Constitutive relationships for heat and mass transfer were selected and included in the rate of change equations.

## Equation Development (Continued)

Non-dimensionalize and normalize

- An initial value and a dimensionless character were substituted for each variable and parameter in the rate of change equations.
- The equations were normalized by the break source term and each resulting term separated into groups of dimensioned initial values and dimensionless characters.
- The dimensioned initial values are the pi groups for mass, energy, momentum, and pressure.

Energy transfer conductances were normalized to the containment shell conductance.

## PI Group Values

Bounding containment pressure and temperature histories were selected for the LOCA and MSLB design basis accidents. The histories were separated into time phases consistent with the PIRT.

For each time phase, initial conditions were specified

- for the containment gas by the state defined by the pressure and temperature histories, and
- for the heat sinks by integrating the heat flux to the heat sink over the time phase using integral equations.

Pi groups were evaluated for each component at the beginning of each time phase, except that blowdown used an average blowdown phase pressure.

All component level pi groups are of order unity or less and represent the magnitude of the transfer process relative to that of the break source.

## Validation of Scaling Equations and LST

The constitutive equations were validated by comparison to data from separate effects and integral effects tests. The tests covered the AP600 range of independent, dimensionless variables.

The scaling rate of change equations were validated by comparison to results of integral effects tests.

The integral effects tests were scaled to AP600

- The AP600 phenomena that were well scaled in the LST were identified
- Distortions were identified
- How the distortions are addressed was identified.

## Results Summary

The relative magnitude of AP600 transport processes and components were quantified.

The pi group values were used to confirm the PIRT rankings.

The important dimensionless groups and their range were identified for AP600 operation.

The SET's and IET were validated for modeling AP600.

Test distortions and work-arounds were identified.

## Proposed Inserts for Section 4.4 of PCS PIRT Report (WCAP-14812)

### 4.4 Bases for Ranking

The criteria for ranking phenomena based upon the scaling analysis results was as follows:

Low - 0 to 0.10
Medium - 0.11 to 0.20
High - > 0.21

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| Dept. Containment Systems | Phone # 412-374-4256 |
| Fax # 301-415-2002 | Fax # 412-374-5099 |

### 4.4.1A Break Source Mass and Energy Release

The expert review shown in Appendix B provided a ranking of High for all time periods except for the refill period, when there were no mass and energy (M&E) releases and therefore ranked as Not Applicable. The scaling results (section 8.5 of reference 20) provided pressure scaling π values ($\pi_{p, g, brk,work}$) of 1.0 for all time periods except for refill when there were no releases. The WGOTHIC sensitivity study (case # 7 in section 10 of reference 5) calculated a shift in the peak pressure to the blowdown period for LOCA with a 0.53 psi decrease in the peak pressure (3.4 psi decrease in second peak) using the nominal M&E releases instead of the DBA assumptions. This information supports a ranking of H, na, H, H, H for the break source M&E releases.

### 4.4.1B Break Source Direction and Elevation

The expert review shown in Appendix B provided a ranking of High for all time periods except for the refill period when there were no M&E releases and during the long-term period when the M&E releases were very small. The LST steam concentration measurement results (section 2.4 of reference 37) for tests 222.2B and 222.4B showed that direction and elevation can be important for containment pressure due to their affect on circulation and stratification within containment.

Sensitivities were performed to assess the effect of circulation and stratification on calculated pressure for LOCA and MSLB. For the LOCA, sensitivities (section 9.3.2.4 of WCAP-14407) show that the internal solid internal heat sinks are thermally saturated well before the time of peak pressure and the maximum calculated change in pressure is 0.5 psi. For the MSLB, jet direction is not a

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significant parameter since the jet kinetic energy is insufficient to drive circulation through the containment (section 9.2.2 of WCAP-14407). The LOCA releases are at the elevation of primary piping in the steam generator compartment. The MSLB elevations are the steamline above the operating deck (section 9.4.1.1 of WCAP-14407) and the steamline in the CMT room (section 9.4.1.2 of WCAP-9.4.1.2). The steamline break in the CMT room was shown to yield more effective heat sink utilization and provided a pressure benefit of 1.7 psi.

This information supports a ranking of High for blowdown and peak pressure periods, a ranking of Low for long term, and Not Applicable for refill when there is no break source.

### 4.4.1C Break Source Momentum

The expert review shown in Appendix B provided a ranking of High for all time periods, except for refill period when there were no M&E releases, and during the long-term period when the M&E releases were very small. The LST results (section 2.4 of reference 37) for tests 201.1, 202.1, and 203.1 compared to tests 201.2, 202.2, and 203.2 showed that the velocity (momentum) can be important on containment pressure due its affect on mixing and stratification within the containment. See item 4.4.1B for summary of relevant sensitivities. This information supports a ranking of High for the blowdown and peak pressure periods, a ranking of Low for long term, and Not Applicable for refill when there is no break source.

### 4.4.1D Break Source Density

The expert review shown in Appendix B supports the ranking of this phenomena as High for all time periods, except for refill period when there were no M&E releases and during the long-term LOCA period when the M&E releases were very small.

### 4.4.1E Droplet/Liquid Flashing

The expert review provided in Appendix B provided a ranking of High for blowdown and refill and Not Applicable for other periods. Droplet/liquid flashing can increase peak containment pressure by adding steam mass. However, the scaling results (section 8.5 of reference 20) showed that the drops were not very important with pressure scaling $\pi$ values ($\pi_{p,\,work,\,d}$) less than 0.05 for all time periods. These values support a ranking of Low for all time periods, and of Not Applicable for MSLB when there are no drops.

### 4.4.2A Circulation/Stratification in Containment Volume

The expert review shown in Appendix B provided a ranking of High for all time periods, except for refill when there were no M&E releases and during the long-term period when the releases were very small. The LST results (section 2.4 of reference 37) for tests 222.2B and 222.4B showed that circulation and stratification within the containment can strongly influence mass transfer rates. LST tests have been evaluated (section 9.2 of reference 5) to support a specific evaluation of the effect of stratification on containment pressure for various postulated scenarios. While circulation and stratification can strongly influence steam concentration distributions, sensitivities (see item 4.4.1B) show that the internal heat sinks saturate well before peak pressure, so peak pressure is not sensitive to effects of circulation and stratification. The steam concentration distributions continue to affect the PCS heat removal throughout the transient. This information supports a ranking of High for all time periods.

### 4.4.2B Intercompartmental Flow in Containment Volume

The internal and external experts provided differing opinions on the ranking for this phenomena as described in Appendix B. Sensitivity studies show that the details of the flow path (location, elevation, loss coefficient) are not very important by comparing the blowdown response for one-node and multi-node models (section 8 of WCAP-14407).

Evaluations and sensitivities (table 9-1 in section 9 of WCAP-14407, Rev 1) were performed for various assumed circulation patterns which lead to a range of steam concentration transients in the various compartments during a LOCA. Since internal heat sinks saturate well before the time of peak pressure (figure 10-4 in WCAP-14845), the effects of varying the rate of heat removal by internal heat sinks did not significantly affect peak pressure or long term pressure for the LOCA (section 9.3.2.4 of WCAP-14407).

Since the MSLB transient is essentially over before the PCS becomes effective, internal heat sink condensation rates are more important for MSLB than for LOCA.

Note that intercompartmental flow must be modeled to avoid artificially pressurizing the break compartment even though the details of flow paths do not dominate the pressure response. This information supports a ranking of L, H, H, H, H for intercompartmental flow.

### 4.4.2C Containment Volume Gas Compliance

The expert review shown in Appendix B provided a ranking of High for all time periods. The scaling results (section 8.5 of reference 20) provided pressure scaling π values ($\pi_{p,\tau}$) of approximately 0.76 for all time periods. This information supports a ranking of High for all time periods.

### 4.4.2D Fog in the Containment Volume

The internal experts agreed that fog in the containment has a Low importance ranking for all LOCA time periods, however the external experts provided a ranking of High except for the long term LOCA period as shown in Appendix B. This information supports a ranking of L, H, H, H, na.

### 4.4.2E Hydrogen Release

The experts agreed that the hydrogen release was of Low importance for the LOCA transient and Not Applicable for the MSLB. The LST results (section 2.5 of reference 37) for tests 217.1, 218.1, and 219.1 showed that the addition of helium into the simulated containment vessel well beyond DBA concentrations (up to 20% by volume) affected the heat removal rate as predicted by the non-condensable partial pressure in the mass transfer correlation. This information supports a ranking of Low importance for all time periods of the LOCA transient and Not Applicable for MSLB.

### 4.4.3A Liquid Film Energy Transport on Containment Heat Sinks

The experts provided differing opinions on the ranking of this phenomena as shown in Appendix B *(based in part upon preliminary scaling results)*. The scaling results (section 8.4 of reference 20) confirmed that the liquid film energy transport on the containment heat sinks was of Low importance for all time periods with energy scaling π values ($\pi_{e,f,st} + \pi_{e,f,cc} + \pi_{e,f,jc}$) between 0.0 and 0.08 for all phases of the transient.

### 4.4.3B Vertical Film Conduction on solid heat sinks

The experts all agreed that the conduction through vertical films on the solid heat sinks was of Low importance for all time periods as shown in Appendix B. The UW Condensation tests (section 3 of reference 29) and Chun and Seban data indicate that the effect of a condensate film on the heat transfer rates was negligible over the range of parameters tested due to the very small film thickness. This information supports a importance ranking of Low for all time periods.

### 4.4.3C Horizontal Film Conduction on solid heat sinks

The internal experts concluded that conduction through the horizontal film on the solid heat sinks was of Low importance for all time periods since the film would reach the saturation temperature very quickly. However, the external experts concluded that this phenomena was of High importance for all time periods except for the short LOCA blowdown period on the basis that the horizontal film can become thick enough to retard heat transfer into horizontal surfaces. Based upon this information, this phenomena was ranked Low for the LOCA blowdown period and High for other time periods.

### 4.4.3D Internal Heat Sink Conduction

The experts provided differing opinions on the ranking for this phenomena as shown in Appendix B except for the LOCA refill period and the MSLB blowdown period which were both ranked as High. Based on this information , this phenomena was ranked as Medium for LOCA blowdown and long term, and High for other time periods.

### 4.4.3E Heat Capacity of Solid Heat Sinks

The experts provided differing opinions on the ranking for this phenomena as shown in Appendix B except for the LOCA refill period and the MSLB blowdown period which were both ranked as High. WGOTHIC sensitivity studies (in section 9.3.2 of reference 5) have shown that neglecting internal heat sinks increases the containment pressure about 3psi during blowdown (a 10% uncertainity in heat sink capacity may cause only a 10% change in pressure or approximately 0.3psi). Furthermore, the energy removal (heat capacity) via the internal heat sinks significantly decreases after blowdown (figure 9-13 of reference 5). Based on this information, this phenomena was ranked as Medium for LOCA blowdown and long term, and High for other time periods.

### 4.4.3F Condensation on Solid Heat Sinks

The experts had differing opinions on the ranking for this phenomena as shown in Appendix B except for the LOCA refill period and the MSLB blowdown period which were both ranked as High. The scaling results (section 8.5 of reference 20) provided pressure scaling π values ($\pi_{\text{p, work, st}} + \pi_{\text{p, work, cc}} + \pi_{\text{p, work, jc}}$) of 0.08, 1.95, 0.94, 0.29, and 0.64 for the respective 5 time periods. This information supports a ranking of M, H, H, M, H for condensation on the solid heat sinks.

### 4.4.3G Convection from Containment to Solid Heat Sinks

The external and internal experts had differing opinions on the ranking for this phenomena for the refill, peak pressure, and long-term LOCA periods as shown in Appendix B. However, the experts agreed on ranking for the blowdown periods for both LOCA and MSLB as being of Low importance. The scaling results (in section 8.5 of reference 20) provided pressure scaling π values ($\pi_{\text{p, q, st}} + \pi_{\text{p, q, cc}} + \pi_{\text{p, q, jc}}$) of 0.01, 0.33, 0.12, 0.02, and 0.15 for the five time periods. These π values, which include both convection and radiation heat transfer, are roughly 50% attributed to convection. This information supports a ranking of L, M, L, L, L for convection.

### 4.4.3H Radiation from containment to Solid Heat Sinks

The external and internal experts had differing opinions on the ranking for this phenomena for the refill, peak pressure, and long-term LOCA periods as shown in Appendix B. However, the experts agreed on ranking for the blowdown periods for both LOCA and MSLB as being of Low importance. The scaling results (section 8.5 of reference 20) provided the pressure scaling π values ($\pi_{\text{p, q, st}} + \pi_{\text{p, q, cc}} + \pi_{\text{p, q, jc}}$) of 0.01, 0.33, 0.12, 0.02, and 0.15 for the five time periods. These π values, which include both convection and radiation heat transfer, are roughly 50% attributed to radiation. This information supports a ranking of L, M, L, L, L for radiation.

### 4.4.4A Initial containment temperature

The experts had differing opinions on the ranking for this phenomena for the blowdown, peak pressure, and long-term LOCA periods as shown in Appendix B. However, the experts agreed on the ranking for LOCA refill period as Medium and for MSLB blowdown as High. The sensitivity results (in section 5.5 of reference 5) showed that a decrease in the initial temperature from 120F to 50F subsequently decreased the peak pressure by approximately 2.7 psi. This information supports a ranking of Medium for all time periods since the initial temperature affects both the initial time period as well as the subsequent time periods.

### 4.4.4B Initial containment humidity

The external and internal experts had differing opinions on the ranking for this phenomena for the blowdown, peak pressure, and long-term LOCA periods as shown in Appendix B. However, the experts agreed on the ranking for LOCA refill period as Medium and for MSLB blowdown as High. The sensitivity results (in section 5.6 of reference 5) showed that an increase in the initial humidity from 0% to 100% subsequently decreased the peak pressure by approximately 1.3 psi. This information supports a Medium ranking for all time periods since the initial humidity affects both the initial time period as well as the subsequent time periods.

### 4.4.4C Initial containment pressure

The external and internal experts had differing opinions on the ranking for this phenomena for the blowdown, peak pressure, and long-term LOCA periods as shown in Appendix B. However, the experts agreed on the ranking for LOCA refill period as Medium and for MSLB blowdown as High. The sensitivity results (in section 5.4 of reference 5) showed that a decrease in the initial pressure from 15.7psia to 11.7psia subsequently decreased the peak pressure by approximately 5.7psi, therefore, the actual affect on containment pressure was 1.7psi (5.7psi - 4psi). This information supports a Medium ranking for all time periods since the initial pressure affects both the initial time period as well as the subsequent periods.

### 4.4.5A Break pool mixing

The experts all agreed that the mixing in the break pool was of Low importance for all time periods except for the LOCA long-term which was ranked as Medium as shown in Appendix B. The scaling results (section 8.5 of reference 20) showed that the pool is not a significant source even though the pi group is biased to maximize the surface temperature by assuming it to be stratified. Also, there are no significant driving forces for mixing in the pool. This information supports a ranking of L, L, L, M, L for break pool mixing.

### 4.4.5B Break pool condensation/evaporation

The experts had differing opinions on the ranking of this phenomena as shown in Appendix B although all agreed that the condensation on the break pool was of Low importance for the LOCA blowdown and refill periods and the MSLB blowdown period. The scaling results (in section 8.5 of reference 20) showed that the $\pi$ values ($\pi_{\mathrm{p,\,work,\,p}}$) were less than 0.07 for the time periods of interest assuming the pool to be stratified. This information supports a ranking of L, L, L, M, L.

### 4.4.5C Convection between containment and break pool

The experts all agreed that the convection heat transfer between containment and break pool was of Low importance for all time periods as shown in Appendix B. The scaling results (section 8.5 of reference 20) provided $\pi$ values ($\pi_{p,q,p}$) of 0.0 for the time periods of interest. This information supports a ranking of Low for all time periods for the convection between the containment and the break pool.

### 4.4.5D Radiation between containment and break pool

The experts all agreed that the radiation heat transfer between containment and break pool was of Low importance for all time periods as shown in Appendix B. The scaling results (section 8.5 of reference 20) provided $\pi$ values ($\pi_{p,q,p}$) of 0.0 for all of the time periods. This information supports a ranking of Low for all time periods for the radiation between the containment and the break pool.

### 4.4.5E Conduction in break pool

The experts agreed that the conduction in the break pool was of Low importance for all time periods as shown in Appendix B except for the LOCA long-term period where the external experts ranked it as Medium. This information supports a ranking of L, L, L, M, L for conduction heat transfer in the pool.

### 4.4.5F Flooding in break pool

The experts agreed that the flooding in the break pool was of Low importance for all time periods as shown in Appendix B except for the LOCA long-term period where the external experts ranked it as Medium because of the potential to block flow paths. But since the heat sink area in the flooded compartments is only 11% (table 3-1 of WCAP-14812 for dead-ended jacketed concrete areas and stairwells) of the total heat sink area, the affect of flooding on heat sink utilization is small, and during the long-term period, the heat sinks are "depleted". (Flow path blockage affects circulation and is evaluated in WCAP-14407, section 9 as it relates to item 4.4.2B.) This information supports a ranking of Low for all time periods.

### 4.4.6 IRWST

The experts all agreed that the IRWST phenomena was of Low importance for all time periods as shown in Appendix B since the IRWST is somewhat isolated from the containment atmosphere.

### 4.4.7A Convection from containment to shell

The experts agreed that this phenomena was ranked as Low for the LOCA and MSLB blowdown periods, but the internal and external experts had differing opinions on the other time periods (Low vs Medium). The scaling results (section 8.5 of reference 20) provided π values ($\pi_{p,q,es} + \pi_{p,q,ss} + \pi_{p,q,ds}$) of 0.08 or less for the time periods of interest. These π values included both convection and radiation heat transfer. This information supports a Low ranking for all time periods for the convection between the containment volume and the shell.

### 4.4.7B Radiation from containment to shell

The experts agreed that this phenomena was ranked as Low for the LOCA and MSLB blowdown periods, but the internal and external experts had differing opinions on the other time periods (Low vs Medium). The scaling results (section 8.5 of reference 20) provided π values ($\pi_{p,q,es} + \pi_{p,q,ss} + \pi_{p,q,ds}$) of 0.08 or less for the time periods of interest. These π values included both convection and radiation heat transfer. This information supports a ranking of Low for all time periods for the radiation between the containment volume and the shell.

### 4.4.7C Condensation on containment shell

The experts agreed this phenomena should be ranked as High for the LOCA refill, peak pressure, and long term periods and for the MSLB blowdown period as shown in Appendix B. There was one differing opinion on the rank for the LOCA blowdown period (High vs Low). The scaling results (section 8.5 of reference 20) provided π values ($\pi_{p,work,es} + \pi_{p,work,ss} + \pi_{p,work,ds}$) of 0.02, 0.61, 0.47, 1.04, and 0.37 for the respective 5 time periods. This information supports a ranking of High for all time periods for the condensation on the containment shell

### 4.4.7D Inside Film Conduction

The experts all agreed that the film conduction on the inside of the containment shell was of Low importance for all time periods as shown in Appendix B. The scaling analyses (section 7.4 and table 8-2 of 20) for the heat transfer ~~resistances~~ conductances in

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series provides the following conductances:

condensation - 0.3~~6~~7-0.60
inner film conduction - 4.2
shell conduction - 1.0
outer film conduction 4.2
evaporation - 0.52

The film conductances are much greater (or resistances are much smaller) than for the other conductances. This information supports a ranking of Low for all time periods for the inside film conduction.

### 4.4.7E Film energy transport on inside of steel shell

The experts agreed that the film energy transport on the inside of the containment shell was of Medium importance for all time periods as shown in Appendix B. The scaling results (section 8.4 of reference 20) provided $\pi$ values ($\pi_{e,f,ss} + \pi_{e,f,es} + \pi_{e,f,ds}$) of between 0.0 and 0.11 for the 5 time periods of interest. Since the film energy transport on the solid heat sinks (item 3A) was ranked Low, this information supports a ranking of L, L, L, M, L for the inside film energy transport.

### 4.4.7F Conduction through containment shell

The experts had differing opinions on the ranking of this phenomena for LOCA blowdown and refill as shown in Appendix B, although all agreed that shell conductance was of High importance for the LOCA peak pressure and long-term periods as well as for MSLB blowdown period. As discussed for item 4.4.7D, the conductance for the shell is of the same magnitude as the evaporation and condensation based upon scaling analyses. This information supports a High ranking for all time periods.

### 4.4.7G Heat Capacity of Shell

The experts had differing opinions on the ranking of this phenomena as shown in Appendix B although all agreed that it should be ranked as Low for the LOCA long-term period and High for the MSLB blowdown period. The scaling results (section 8.4 of reference 20) showed the $\pi$ values ($\Sigma \pi_{q\,in} - \Sigma \pi_{q\,out}$) of 0.02 for the LOCA blowdown period, 0.64 for the LOCA refill period, 0.46 for the LOCA peak pressure period, 0.13 for the LOCA long-term period, and 0.38 for the MSLB blowdown period. The high scaling value at the start of the refill period shows that the heat capacity at the end of ~~for~~ blowdown is much more important than the calculated value of 0.02 would indicate. This information supports a ranking of H, H, H, L, H for the shell heat capacity.

### 4.4.7H Convection from shell to riser annulus

The internal experts agreed that the ranking of this phenomena should be Medium for the long-term period of the LOCA (external experts agreed it should be Medium for peak pressure) and Low during all other time periods as shown in Appendix B. The scaling results (section 8.4 of reference 20) showed the $\pi$ values ($\pi_{c,q,esx} + \pi_{e,q,dsx}$) of between 0.0 and 0.06 for all time periods. These $\pi$ values included both convection and radiation heat transfer. This information supports a ranking of L, L, L, M, L for convection from shell to riser annulus.

### 4.4.7I Radiation from shell to baffle

The internal experts agreed that the ranking of this phenomena should be Medium for the long-term period of the LOCA (external experts agreed it should be Medium for peak pressure) and Low during all other time periods as shown in Appendix B. The scaling results (section 8.4 of reference 20) showed the $\pi$ values ($\pi_{e,q,esx} + \pi_{c,q,dsx}$ and $\pi_{e,q,bf}$) of between 0.0 and 0.06 for all time periods. These $\pi$ values included both convection and radiation heat transfer. This information supports a ranking of L, L, L, M, L for radiation from shell to baffle.

### 4.4.7J Radiation from shell to chimney

The experts agreed that the ranking of this phenomena should be Low during all periods of the LOCA, and Low for the MSLB blowdown as shown in Appendix B. The scaling results (in section 8.4 of reference 20) provided $\pi$ values ($\pi_{e,q,esx} + \pi_{e,q,dsx}$ and $\pi_{e,q,ch}$) of between 0.0 and 0.06 for all time periods. These $\pi$ values included both convection and radiation heat transfer. This information supports a ranking of Low for all time periods.

### 4.4.7K Radiation from shell to fog/air mixture

The experts agreed that the ranking of this phenomena should be Low during all periods of the LOCA and for the MSLB blowdown as shown in Appendix B. The scaling results (section 8.4 of reference 20) provided $\pi$ values ($\pi_{e,q,esx} + \pi_{e,q,dsx}$) less than 0.06 for radiation from the shell, and thus will be less for radiation to the fog/air mixture. These $\pi$ values included both convection and radiation heat transfer. This information supports a ranking of Low for all time periods.

### 4.4.7L Outside film conduction

The experts agreed that the ranking of this phenomena should be Low during the peak pressure and long-term periods of the LOCA and Low for the MSLB blowdown as shown in Appendix B. As discussed for item 4.4.7D, the film conductance was much less important than either shell conductance, evaporation or condensation based upon the scaling analyses. This information supports a Low ranking for all time periods.

### 4.4.7M Outside film energy transport

The experts agreed that the ranking of this phenomena should be Medium during the peak pressure and long-term periods of the LOCA, and Low for the MSLB blowdown as shown in Appendix B.

### 4.4.7N Evaporation to riser annulus

The experts agreed that the ranking of this phenomena should be High during the peak pressure and long-term periods of the LOCA, and Medium for the MSLB blowdown as shown in Appendix B. The other time periods were judged to be Not Applicable. The LST results (section 2.1.2 of reference 37) for tests 202.2, 207.3, and 208.1 showed that the evaporation was much more important than convection and radiation. These tests confirm an importance ranking of High for the time periods when the shell is wet. Also, the scaling results (section 8.4 of reference 20) provided π values ($\pi_{e,fg,esx}$) of 0.02 for the peak pressure period and 0.81 for the long term period of the LOCA transient. The high scaling value at the start of the long term period (0.81) shows that the evaporation ~~for~~ at the end of the peak pressure period is much more important than the calculated value of 0.02 would indicate. This information supports a ranking of na, na, H, H, M for evaporation to riser annulus.

### 4.4.8A PCCWST water flow rate

The experts agreed that the ranking of this phenomena should be High during the peak pressure and long-term periods of the LOCA, and Low for the MSLB blowdown as shown in Appendix B. The LST results (section 2.1.2 of reference 37) for tests 202.2, 207.3, 208.1, 216.1A, 216.1B, 202.1, 202.2, 207.2, and 207.4 showed that water flow rate, which directly affects the evaporation rate, is important. These tests confirm an importance ranking of High for the time periods when the shell is wet. The sensitivity studies (section 7.5.2 of reference 5) showed that a 65% increase in the film flow rate decreased the peak containment pressure by only approximately 1 psi but this initial applied flow (440 gpm) was in excess of that which is evaporated. The flow coverage affected the long term pressure (figure 7-10 of reference 5) showing a relatively strong influence when coverage areas less than that available are considered. This information supports a ranking of na, na, H, H, M for the PCS water flow rate.

### 4.4.8B PCCWST water temperature

The experts agreed that the ranking of this phenomena should be Medium during the peak pressure and long-term periods of the LOCA, and Low for the MSLB blow-down as shown in Appendix B. The LST results (section 2.2 of reference 37) for tests 203.2 and 210.1 showed that the water film temperature had a smaller affect than the air temperature. These tests would suggest an importance ranking of Low for the time periods when the shell is wet. The scaling results (section 8.4 of reference 20) provided energy scaling π values ($\pi_{e,q,ssx}$) of 0.01 for peak pressure and 0.08 for long term which shows that the heat capacity (subcooling) of the water film was of Low importance. This information supports a ranking of na, na, M, M, L for PCS water temperature.

### 4.4.8C Water film stability and coverage

The experts agreed that the ranking of this phenomena should be High during the peak pressure and long-term periods of the LOCA, and Low for the MSLB blow-down as shown in Appendix B. The LST results (section 2.1.2 of reference 37) for tests 202.2, 207.3, 208.1, 216.1A, 216.1B, 202.1, 202.2, 207.2, and 207.4 showed that the water coverage, which directly affects the total evaporation heat removal rate, was important. These tests confirm an importance ranking of High for the time periods when the shell is fully wetted, i.e., during the peak pressure and long-term periods of the LOCA. Also, a sensitivity study (section 7.5.3 of reference 5) showed that a 50% reduction in water coverage (100% to 50%) resulted in a 1.85 psi increase in the peak containment pressure which is considered significant. See discussion for item 8A on the PCS water flow rate. This information supports a ranking of na, na, H, H, L for water coverage.

### 4.4.8D Film stripping

The experts agreed that the ranking of this phenomena should be Low during the peak pressure and long-term periods of the LOCA, and Low for the MSLB blowdown as shown in Appendix B. The Heated Flat Plate test results (section 3 of reference 23) for tests 13 through 21 showed that the water film was not adversely affected by the countercurrent air flow (5.9 fps to 38.7 fps). This information supports an importance ranking of Low for the time periods when the shell is wetted, i.e., during the peak pressure and long-term periods of the LOCA and the MSLB blowdown.

### 4.4.9A PCS natural circulation in riser annulus

The experts agreed that the natural circulation should be ranked Low for the blowdown and refill periods of the LOCA and Medium for MSLB, but should be either High or Medium rank for the peak pressure and long term periods of the LOCA as shown in Appendix B. The LST results (section 2.3 of reference 37) for tests 202.2, 204.1, 205.1, and 206.1 showed that the riser air velocity had a small affect on the containment pressure. But these tests had more water than AP600 plant and significant subcooling heat removal which would indicate that AP600 plant would be more sensitive. This information supports a ranking of L, L, M, M, M for the riser natural circulation.

### 4.4.13A PCS natural circulation in downcomer annulus

The experts agreed that the natural circulation flow in the downcomer annulus and riser annulus (item 4.4.9A) should be ranked the same since they constitute the same flow path. The scaling results (section 9.4 of WCAP-14845) shows that the downcomer contributes very little to energy or momentum. This information supports a ranking of L, L, L, L, L for the ~~riser~~ downcomer natural circulation.

### 4.4.14A Convection from shield building to downcomer

The experts agreed that convection from the shield building to downcomer annulus is of Low importance for the MSLB blowdown, however, the internal experts ranked it is as Low for the LOCA peak pressure and long term periods while the external experts ranked it Medium as shown in Appendix B. Since convection from the shell to the riser (item 7H) was ranked Low, the convection from the shield building, with a much lower surface temperature, can not be ranked higher. This information supports a ranking of na, na, L, L, L for the 5 time periods.

### 4.4.15A External temperature

The experts agreed that the external temperature is ranked Low for the peak pressure and long term periods of the LOCA and for the MSLB blowdown. The sensitivity study results (in section 5.7 of reference 5) showed that a large decrease in the initial temperature from 115F to 40F subsequently decreased the peak pressure by only approximately 0.1 psi due to the large time constant for the heat transfer through the shell. Over the longer term, the lower external temperatures provided a 2 psi benefit which is judged to be low relative to typical values of temperature uncertainties. This information supports a ranking of na, na, L, L, L.

### 4.4.15B External humidity

The experts agreed that the external temperature is ranked Low for the peak pressure and long term periods of the LOCA and for the MSLB blowdown. The sensitivity study results (in section 5.6 of reference 5) showed that a decrease in the initial humidity from 100% to 0% did not have any impact on the peak pressure since the ~~air in the~~ driving force for evaporation (partial pressure of steam at liquid-air interface) is large compared to humidity. This information supports a ranking of na, na, L, L, L.

**Scaling Results (from WCAP-14845)**

| PIRT Phenomena | Scaling Pi Group | LOCA Blowdown | LOCA Refill | LOCA Peak Pressure | LOCA Long Term | MSLB Blowdown |
|---|---|---|---|---|---|---|
| 1A) M&E releases | Pi (p, g, brk, work) (table 8-5) | 1 | 0 | 1 | 1 | 1 |
| 1E) Droplet/liquid flashing | Pi (p,work,d) (table 8-5) | 0.05 | -0.04 | 0.01 | 0 | n/a |
| 2C) Gas compliance | Pi (p, t) (table 8-5) | 0.76 | 0.76 | 0.77 | 0.76 | 0.76 |
| 3A) Liquid film energy transport on heat sinks | Pi (e, f, st+cc+jc) (table 8-4) | 0 | -0.08 | -0.07 | -0.03 | -0.01 |
| 3F) Condensation on solid heat sinks | Pi (p, work, st+cc+jc) (table 8-5) | -0.08 | -1.95 | -0.94 | -0.29 | -0.64 |
| 3G) Conv. plus rad. containment to sinks | Pi (p, q, st+cc+jc) (table 8-5) | -0.01 | -0.33 | -0.12 | -0.02 | -0.13 |
| 3H) Radiation | (approx. 1/2 of 3G) | | | | | |
| 5B) Break pool condens./evaporation | Pi (p, work,p) (table 8-5) | 0.04 | 0 | 0.03 | 0.07 | n/a |
| 5C) Break pool conv. (plus radiation) w/cont | Pi (p, q, p) (table 8-5) | 0 | 0 | 0 | 0 | 0 |
| 5D) Break pool radiation | (approx 1/2 of 5C) | | | | | |
| 7AB) Convection (plus | Pi (p, q, es+ss+ds) | 0 | -0.1 | -0.08 | -0.08 | -0.07 |

| | | | | | | |
|---|---|---|---|---|---|---|
| radiation) to inside shell | (table 8-5) | | | | | |
| 7C) Condensation on inside shell | Pi (p,work,es+ss+ds)<br>(table 8-5) | -0.02 | -0.61 | -0.47 | -1.04 | -0.37 |
| 7E) Film energy on inside shell | Pi (e, f, ss+es+ds)<br>(table 8-4) | 0 | -0.02 | -0.02 | -0.11 | 0 |
| 7G) Heat capacity of shell | Pi (Sumqin-Sumqout)<br>(table 8-4) | -0.02 | -0.62 | -0.44 | -0.02 | -0.38 |
| 7H) Convection (plus radiation) riser | Pi (e,q,esx+dxs)<br>(table 8-[illegible] | 0 | 0 | 0 | -0.06 | 0 |
| 7I) Radiation (plus convection) to baffle | Pi (e, q, bf) | 0 | 0 | 0 | -0.02 | 0 |
| 7J) Radiation to chimney | Pi (e, q, ch)<br>(table 8-4) | 0 | 0 | 0 | 0 | na |
| 7K) Radiation from containment shell | Pi (e, q, esx + dxs)<br>(table 8-4) | 0 | 0 | -0.02 | -0.06 | 0 |
| 7N) Evaporation from shell to riser | Pi (e, fg, esx)<br>(table 8-4) | na | na | -0.02 | -0.81 | na |
| 8B) PCS water temperature | Pi (e, g, ssx) | na | na | -0.01 | -0.08 | na |
| | Note: Phenomena ranking basis from scaling: Low is 0-0.10, Medium is 0.11 to 0.20, High is >0.21 | | | | | |

# Proposed Addition to WCAP-14812

## Appendix B

## Synopsis of Expert Review

An expert review was performed on the "Accident Specification and Phenomena Evaluation for AP600 Passive Containment Cooling System" report (WCAP-14812, Revision 0) issued in December, 1996. The experts consisted of personnel both external and internal to Westinghouse as listed below:

External Experts

- Per Peterson, UCLA
- Tom Fernandez, EPRI A&TRT
- Sol Levy, Levy & Associates (EPRI A&TRT)
- Doug Chapin, MPR Associates (EPRI A&TRT)

Internal experts

- Larry Hochreiter, Consulting Engineer
- Gene Piplica, AP600 Test Manager
- Larry Conway, PCS Patent Holder
- Terry Schulz, AP600 Systems Design Engineer

These personnel were considered experts based upon their knowledge of heat and mass transfer mechanisms and parameters related to these mechanisms, and their understanding of the AP600 containment design. The experts reviewed the Revision 0 report independently of each other and then two groups (EPRI A&TRT and Westinghouse) met with the objective of reaching consensus. The experts provided comments on the identification of phenomena and the ranking of the phenomena as well as editorial comments on the report text. The following four paragraphs provide a general overview from the expert review (four different reviewers).

> "In general, we found the organization of the material to be quite good. The PIRT itself is logically presented and most of the phenomena that can be expected to occur during PCS operation is included. Our major concern is the rationale given in the paragraphs following the PIRT that justify the

> selection of each ranking did not always accurately represent the basis for the selection. For many of the discussions, insufficient detail was provided to logically conclude the importance of the phenomena being discussed."
>
> "The revised documents are a significant improvement over the draft I reviewed in April, and at this point all of my comments are of an editorial or a simple technical nature. With the new structure of the PIRT, it is now much easier to conclude that all phenomena with the potential to influence the AP600 containment performance have been identified."
>
> "This version of the report is a significant improvement over the original version reviewed in March 1996. We believe the authors have made a valid effort to address most of our previous comments. In particular the report is much easier to follow and understand, is much better organized and more complete than the previous version. The authors added important new information which significantly strengthen the content. The report still has several structural and technical shortcomings. "
>
> "I don't think the report is organized as well as it should be to give the reader the confidence that we have an integrated program which will successfully provide the basis for licensing the AP600 containment."

The general consensus from the expert review was that the basis of the ranking was unclear. The specific expert review comments were filed in the Westinghouse calculation note system. The authors have incorporated the editorial comments where they were deemed to clarify or correct the text. The new phenomena identified by the experts, as shown below have been incorporated into the paragraphs describing closely-related phenomena.

1.) additional sources of mass and energy release such as ADS was added to the break source mass and energy release (item 1A)

2.) evaporation within containment as the pressure decreases and the heat sinks release their energy was added to break pool evaporation (item 5B)

3.) circumferential conduction in containment shell from the dry to wet exterior surfaces was added to shell conduction (item 7F)

4.) shield building heat capacity was added to conduction through shield building (item 14B)

The ranking of the phenomena by the experts is shown in Table B-1. The differences between the Revision 0 ranking and the expert ranking are highlighted. The blanks in the table indicate that the experts agreed with the authors on the Revision 0 ranking. As shown by this table, two groups of experts, each with three experts (total of six experts), achieved consensus on their ranking. The internal experts met to discuss their differences on ranking (relative to Revision 0) and attempted to achieve consensus on the ranking. Where consensus was not achieved due to differences in philosophy or viewpoint, the differing viewpoints were documented as shown at the end of Table B-1.

The phenomena ranking by the experts was used as one of the bases by the authors for ranking the phenomena. The authors blended the expert rankings with the other bases, which included test results, scaling analyses, hand-calculations, and sensitivity studies to reach closure. In some cases, not all sources for the ranking of phenomena were in agreement and these cases required some judgment by the authors. The specific ranking basis for each phenomena are provided in Section 4.4.

## Table B-1 Summary of PIRT Expert Comments on Phenomena Ranking

| Phenomena | External Experts | | Internal Experts | | Revision 0 Ranking | Basis for Expert Ranking |
|---|---|---|---|---|---|---|
| | expert 1 | experts 2-4 | experts 5-7 | expert 8 | | |
| 1) Break Source | | | | | | |
| A-M&E | | | | | H,na,H,H,H | 1A |
| B-direct. | | | H,na,H,L,H | H,na,H,L,H | H,na,H,H,H | 1B |
| C-moment. | | | H,na,H,L,H | H,na,H,L,H | H,na,H,H,H | 1C |
| D-density | | | H,na,H,L,H | H,na,H,L,H | H,na,H,H,H | 1D |
| E - droplet flashing | | | | | H,H,na,na,na | |
| 2) Containment Volume | | | | | | |
| A - m/s | | | H,H,H,L,H | H,H,H,L,H | H,H,H,H,H | 2A |
| B-interc. flow | | | L,L,L,L,L | H,L,L,L,H | L,H,H,H,H | 2B |
| C-gas compliance | | | | | H,H,H,H,H | 2C |
| D-fog | | H,H,H,L,na | L,L,L,L,na | L,L,L,L,na | L,H,H,H, na | 2D |
| E-hydrogen release | | | | | L, L, L, L, na | |
| 3) Containment Solid Heat Sinks | | | | | | |
| A -film energy | | | (combine w/ condensation) | (combine w/ condensation) | L,M,H,H,M | 3A |
| B-vert. Film conduction | | | | | L, L, L, L, L | |
| C-horz. Film conduction | | | L,L,L,L,L | L,L,L,L,L | L,H,H,H,H | 3C |
| D-conduction | | | M,H,L,L,H | H,H,L,L,H | M,H,H,H,H | 3D |
| E - heat capacity | | | M,H,L,L,H | H,H,L,L,H | M,H,H,H,H | 3E |
| F-condensation | | | M,H,L,L,H | H,H,L,L,H | M,H,H,H,H | 3F |
| G-convection | | | L,L,L,L,L | L,L,L,L,L | L,M,M,M,L | 3G |
| H-radiation | | | L,L,L,L,L | L,L,L,L,L | L,M,M,M,L | 3H |
| 4) Initial Conditions | | | | | | |
| A-Temp. | | | L,M,H,M,H | H,M,M,M,H | M,M,H,H,H | |
| B- Humidity | | | L,M,H,M,H | H,M,M,M,H | M,M,H,H,H | |

| Phenomena | External Experts | | Internal Experts | | Revision 0 Ranking | Basis for Expert Ranking |
|---|---|---|---|---|---|---|
| | expert 1 | experts 2-4 | experts 5-7 | expert 8 | | |
| C-film stability | | | | | na,na,H,H,L | 8C |
| D-film stripping | | | | | na,na,L,L,L | 8D |
| E-film drag | | | | | na,na,L,L,L | 8E |
| 9) Riser Annulus & Chimney Volume | | | | | | |
| A-nat. circ. | | | | L,L,M,M,M | L,L,H,H,M | 9A |
| B-vapor acceleration | | | | | na,na,L,L,L | 9B |
| C-fog | | | | | na,na,L,L,na | |
| D-flow stability | | | | | L,L,L,L,L | |

| Phenomena | External Experts | | Internal Experts | | Revision 0 Ranking | Basis for Expert Ranking |
|---|---|---|---|---|---|---|
| | expert 1 | experts 2-4 | experts 5-7 | expert 8 | | |
| C- Pressure | | | L,M,H,M,H | H,M,M,M,H | M,M,H,H,H | 4A,B,C |
| 5) Break Pool | | | | | | |
| A-mixing | | | | | L,L,L,M,L | 5A |
| B-condensation | | | L,L,L,M,L | L,L,L,L,L | L,L,M,M,L | 5B |
| C-convection | | | | | L,L,L,L,L | |
| D-radiation | | | | | L,L,L,L,L | |
| E-conduction | | | L,L,L,L,L | L,L,L,L,L | L,L,L,M,L | 5E |
| F-flooding | | | L,L,L,L,L | L,L,L,L,L | L,L,L,M,L | 5F |
| 6-IRWST | | | | | L,L,L,L,L | 6B |
| 7) Steel Shell | | | | | | |
| A-convection | | | L,L,L,L,L | L,L,L,L,L | L,M,M,M,L | 7A |
| B-radiation | | | L,L,L,L,L | L,L,L,L,L | L,M,M,M,L | 7B |
| C-condensation | | | | H,H,H,H,H | L,H,H,H,H | 7C |
| D-film conduct. | | | | | L,L,L,L,L | |
| E-film energy | | | | | M,M,M,M,M | |
| F-shell conduct. | | | L,H,H,H,H | H,L,H,H,H | L,L,H,H,H | 7F |
| G - heat capacity | | | | H,M,M,L,H | L,H,H,L,H | 7G |
| H- convection | | | L,L,L,M,L | L,L,L,M,L | L,L,M,M,L | 7H |
| I-radiation to baffle | | | L,L,L,M,L | L,L,L,M,L | L,L,M,M,L | 7I |
| J-radiation to chimney | | | | | L,L,L,L,L | |
| K-radiation to fog/air | | | | | L,L,L,L,L | |
| L-film conduct. | | | | | na,na,L,L,L | 7L |
| M-film energy | | | | | na,na,M,M,L | 7M |
| N-evaporation | | | | | na,na,H,H,M | 7N |
| 8) PCS Cooling Water | | | | | | |
| A-flow rate | | | | | na,na,H,H,M | 8A |
| B-water temp. | | | | | na,na,M,M,L | 8B |

| Phenomena | External Experts | | Internal Experts | | Revision 0 Ranking | Basis for Expert Ranking |
|---|---|---|---|---|---|---|
| | expert 1 | experts 2-4 | experts 5-7 | expert 8 | | |
| C-film stability | | | | | na,na,H,H,L | 8C |
| D-film stripping | | | | | na,na,L,L,L | 8D |
| E-film drag | | | | | na,na,L,L,L | 8E |
| 9) Riser Annulus & Chimney Volume | | | | | | |
| A-nat. circ. | | | | L,L,M,M,M | L,L,H,H,M | 9A |
| B-vapor acceleration | | | | | na,na,L,L,L | 9B |
| C-fog | | | | | na,na,L,L,na | |
| D-flow stability | | | | | L,L,L,L,L | |
| 10) Baffle | | | | | | |
| A-convection to riser | | na,na,L,M,L | na,na,L,L,L | na,na,L,L,L | na,na,L,M,na | 10A |
| B-convection to downcomer | | | na,na,L,L,L | na,na,L,L,L | na,na,L,M,na | 10B |
| C-radiation | | na,na,L,L,L | na,na,L,L,L | na,na,L,L,L | na,na,L,L,na | 10C |
| D-conduction | na,na,L,L,na | | na,na,L,L,L | na,na,L,L,L | na,na,L,M,na | 10D |
| E-condensation | | | | | na,na,L,L,na | |
| F-heat capacity | | | | | na,na,L,L,na | |
| G-leaks | | | na,na,L,L,L | na,na,L,L,L | na,na,M,M,na | 10G |
| 11) Baffle Supports | | | | | | |
| A-convection | | | | | L,L,L,L,L | |
| B-radiation | | | | | L,L,L,L,L | |
| C-conduction | | | | | L,L,L,L,L | |
| D-heat capacity | | | | | L,L,L,L,L | |
| 12) Chimney Structure | | | | | | |
| A-conduction | | | | | L,L,L,L,L | |
| B-convection | | | | | L,L,L,L,L | |
| C-heat capacity | | | | | L,L,L,L,L | |
| D-condensation | | | | | L,L,L,L,L | |
| 13) Downcomer Annulus | | | | | | |

| Phenomena | External Experts | | Internal Experts | | Revision 0 Ranking | Basis for Expert Ranking |
|---|---|---|---|---|---|---|
| | expert 1 | experts 2-4 | experts 5-7 | expert 8 | | |
| C-film stability | | | | | na,na,H,H,L | 8C |
| D-film stripping | | | | | na,na,L,L,L | 8D |
| E-film drag | | | | | na,na,L,L,L | 8E |
| 9) Riser Annulus & Chimney Volume | | | | | | |
| A-nat. circ. | | | | L,L,**M,M**,M | L,L,H,H,M | 9A |
| B vapor acceleration | | | | | na,na,L,L,L | 9B |
| C-fog | | | | | na,na,L,L,na | |
| D-flow stability | | | | | L,L,L,L,L | |

| Phenomena | External Experts | | Internal Experts | | Revision 0 Ranking | Basis for Expert Ranking |
|---|---|---|---|---|---|---|
| | expert 1 | experts 2-4 | experts 5-7 | expert 8 | | |
| A-nat. circ. | | | | L,L,**M,M**,M | L,L,H,H,M | 13A |
| B-flow stability | | | | | L,L,L,L,L | |
| 14) Shield Building | | | | | | |
| A-convection to downcomer | | | na,na,**L,L**,L | na,na,**L,L**,L | na,na,M,M,L | 14A |
| B-conduction | | | | | na,na,L,L,na | |
| C-convection to ambient | | | | | na,na,L,L,na | |
| D-radiation to ambient | | | | | na,na,L,L,na | |
| 15) External Atmosphere | | | | | | |
| A-temperature | | | | | na,na,L,L,L | |
| B-humidity | | | | | na,na,L,L,L | |
| C-recirculation | | | | | na,na,L,L,L | |
| D-pressure fluctuations | | | | | na,na,L,L,L | |
| | | | | | | |

1.) blanks in table signify agreement with the Revision 0 ranking
2.) underlines and bold signify differences with the Revision 0 ranking and differences are explained in following notes

Notes on Expert Ranking Basis:

1A) Break source mass and energy represent the driving force (it is the boundary condition like decay heat for PXS analysis) for each time period and should be ranked High even through there is a significant reduction in the M&E release between blowdown and long term for the LOCA.

1B) Due to the significant reduction in mass and energy release during the long term period of LOCA, the break source direction has Low importance. It was also noted that the ADS stage 4 provides a controlled break release location and direction once they open.

1C) as above for break source momentum

1D) as above for break source density

2A) Due to the significant reduction in mass and energy release during the long term period of LOCA, the mixing and stratification effects within containment have Low importance. Discussions indicated that since not much energy is being released into containment relative to the state of the containment volume, that mixing/stratification effects would not have a major impact. Also, dP/dt is negative during the long term period (post peak pressure).

2B) Expert 8 stated that intercompartmental flow was of High importance for blowdown (LOCA and MSLB) since it establishes the "initial conditions" for the remainder of the transient, but of Low importance for the remaining time periods of LOCA. Other experts did not feel that this initial condition was important. All agreed that details of flow paths were not important during blowdown since volume compliance or energy stored in containment volume was dominant and the time constant for heat sinks is long compared to the 30 second LOCA blowdown. It was agreed that gas content (steam or air in item 2A) was important, but the rate at which it moves is not as important relative to the time to reach peak pressure.

2C) Experts agreed that containment free volume was a more accurate description of the energy storage capability of the containment. All experts felt that since the "compliance" consists of gas properties which are well defined, and free volume, which is a known design parameter, that most appropriately this item could be deleted entirely since it is not strictly a process. (It was also noted that the primary system volume does not appear in the PXS PIRT.)

2D) Experts agreed that fog was not a controlling factor on the containment pressure response during any time period of the LOCA and should be ranked of Low importance. Drops do not appear for the superheated MSLB event.

3A) Experts agreed that film energy was an element of the condensation process and should be combined into the discussion on condensation (items 3A, 3B should be included in 3F to be consistent with traditional definition of condensation which includes the film resistance along with mass transfer resistance).

3C) Expert 8 felt that the upper surface of horizontal films would thermally saturate very quickly, therefore horizontal films were considered to be of Low importance during the transient.

3D) Expert 8 stated that initially the heat sinks play an important role (in blowdown and refill) but they decrease in importance as the heat sinks become saturated (peak pressure and long term). Expert 8 felt that heat sinks are the only mitigating feature (besides containment volume), so it must be ranked High for blowdown. Experts 5-7 felt that the heat sinks were of Medium importance during blowdown.

3E) All experts agreed that the heat capacity of internal heat sinks should be rated same as conduction (3D).

3F) All experts agreed that condensation of internal heat sinks should be rated same as conduction (3D).

3G) All experts agreed that convection to heat sinks was less important than condensation.

3H) All experts agreed that radiation to heat sinks was less important than condensation.

4ABC) Experts agreed that the initial conditions increase in importance as the LOCA transient proceeds (from blowdown to peak pressure), is Medium importance for the long term; and is of High importance during the relatively long MSLB blowdown (600 seconds).

5ABEF) Experts felt that the break pool had much less importance than the solid heat sinks and that the phenomena should be ranked Low for all time periods, except for the mixing and condensation which should be ranked Medium during the long-term phase of the LOCA after the break pool fills with water. The effects of cold water spilling into the break pool and ADS4 actuation (during the long-term period) were considered.

However, expert 8 felt that condensation on the break pool should be ranked Low for the long-term period of the LOCA since the top of the pool is expected to be saturated.

6) The IRWST is too isolated to affect the containment pressure (recognize that liquid to core cooling is included in the M&E).

7AB) Experts felt that convection and radiation to the inside of the steel shell were much less important than condensation on the shell and should be ranked Low for all time periods. This is also consistent with solid heat sinks (items 3G and 3H).

7CFG) Experts felt that condensation on the shell was of Low importance during the short LOCA blowdown period (30 seconds) except for expert 8 who felt that since the shell has a very large surface area, high thermal conductivity and is rather thin, it should probably be the most important heat sink during blowdown.

All experts felt these phenomena were of High or Medium importance for all other time periods including the relatively long MSLB blowdown (600 seconds). The conduction through the film and heat capacity of the shell were ranked the same as condensation, except for the heat capacity which is "consumed" by the long term and is ranked Low.

7HI) Experts agreed that convection to the riser and radiation to the baffle during all periods should be of Low importance except for the long term which was ranked Medium due to the higher dry fraction and, hence higher temperature of the shell.

7LMN) These 3 phenomena were not applicable during the blowdown and refill periods since water coverage was not initiated. After water coverage started (peak pressure period), the experts agreed that film conduction was of less importance than the film energy (experts felt that a more appropriate name for this film energy was sensible heat); and that evaporation was of High importance for the peak pressure and long-term periods. For MSLB blowdown, film energy and evaporation were rated lower than the LOCA due to the timing (600 seconds for MSLB versus 1200 seconds for LOCA peak pressure).

8) Experts agreed with authors on ranking for each of the 5 phenomena for the PCS cooling water. It was recommended that authors include a full description of the phenomena and parameters affecting film stability and coverage.

9A) Experts agreed that natural circulation through the riser was of Low importance during the blowdown and refill periods of the LOCA since there was an insignificant amount of heat transfer from the shell; but was of High importance during the peak pressure and long-term periods when the heat transfer (especially evaporation - item 7N was highly important) was significant.

However, expert 8 felt that it was of Medium importance during the peak pressure and long-term periods since the LS tests did not show any sensitivity to velocity.

9B) Experts agreed that vapor acceleration (via water being evaporated from the shell) was not applicable during blowdown and refill since there was no water coverage; and was of Low importance during the other periods when there was water coverage.

10) Experts agreed that the baffle phenomena was not applicable during the blowdown and refill periods since there was insignificant heat transfer; and was of Low importance during the other periods when there was heat transfer. Leaks through the baffle are expected to be small but need to be quantified.

13A) Experts agreed that natural circulation through the downcomer annulus should be ranked the same as natural circulation through the riser annulus (item 9A).

14A) Experts agreed that convection from the shield building to the downcomer was not applicable during blowdown and refill since there was an insignificant amount of heat transfer from the shell; and was of Low importance during the other periods when there was limited transfer in the downcomer volume.

Basis for External Expert Ranking

2D) Since fluid issuing from the DBA break is postulated to act as the fog source (broad drop size spectrum) and since fog thermodynamic and thermal properties are significantly different from steam or a steam/air mixture we would expect this item to be ranked High for blowdown since these properties could significantly lower the containment pressure history. (authors note that this most likely refers to item 1E - droplet/liquid flashing)

During long term cooling, it seems possible that fog conditions might form in a region cooled slightly below the dew point. Thus, the ranking would be Low.

10AC) For MSLB, the text ranking is "Low" but is not consistent with the table 4-1 ranking of N/A. We believe the rank of Low is correct since the phenomena will occur but is not very important.

10D) The baffle is 1/8-in thick steel with a very small Biot number of 0.0004. Thus the baffle behaves as a lumped mass with negligible internal resistance for all time phases. A low Biot number says that conduction resistance is small compared to convection (and should be ranked as being low importance).

# Presentation to US NRC
April 17, 1997

## Preliminary Draft of Example Road Maps to Phenomena Implementation in the Evaluation Model

- Road map objectives
- Relevant additions to WCAP-14407 to address NRC review items
- List of examples included in informal transmittal of April 11, 1997.

## Road map objectives

**Phenomenon** - Phenomenon name and identifier from PIRT

**Ranking** - Ranking from the PIRT WCAP-14812 Rev. 0

### Relevant AP600 Boundary Conditions or Phenomena Models

Related input items (Boundary Conditions, option/correlation selection, input parameters) for the evaluation model and/or, if not "handled by the code," reference to a report that addresses the phenomenon.

### Method to Validate WGOTHIC and/or Establish Conservative Model using Scaled Test

Relevant scaled tests are identified in WCAP-14812, Section 4.4.x.y. Reference is made here to the report which justifies the modelling method or evaluates the phenomenon. Reference includes code qualification/validation for how code handles phenomenon, and/or report describing how input for code is used to account for phenomenon. Summary of validation - result or bias to be imposed.

### How Bounding Approach is Implemented in Evaluation Model

Summary of how results of validation are applied to evaluation model for the bounding methodology, and reference to WCAP-14407 Section 4.xx showing that the evaluation model code input related to the phenomenon is implemented as desired.

# References Used in the Example Road Maps

1. NTD-NRC-95-4563, "GOTHIC Version 4.0 Documentation, Enclosure 1: Qualification Report," September 21, 1995.

2. NTD-NRC-95-4563, "GOTHIC Version 4.0 Documentation, Enclosure 2: Technical Manual," September 21, 1995.

3. WCAP-14407, "WGOTHIC Application to AP600," Rev. 1 to address NRC review comments.

4. WCAP-14812, "Accident Specification and Phenomena Evaluation for AP600 Passive Containment Cooling System," Rev. 0, January 1997.

5. WCAP-14845, "Scaling Analysis for AP600 Containment Pressure During Design Basis Accidents," Rev. 0, February 1997.

6. NTD-NRC-95-4563, "GOTHIC Version 4.0 Documentation, Enclosure 3: User Manual," September 21, 1995.

7. WCAP-14382, "WGOTHIC Code Description and Validation," May 1995.

8. WCAP-14326, "Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations," Rev. 1.

9. R.P. Ofstun, et al., "Westinghouse-GOTHIC Modeling of NUPEC's Hydrogen Mixing and Distribution Test M-4-3," Third International Conference on Containment Design and Operation, Vol. 1, Session 8, October 19-21, 1994, Toronto, Ontario.

10. Adrian Bejan, Heat Transfer, p. 421, John Wiley & Sons, 1993,

# Relevant Rev. 1 Subsections of WCAP-14407
# For Road Map Discussions

NOTES:

1. It is proposed that the Road Maps be added as an Appendix in WCAP-14812 to allow the reader to see how phenomena are implemented in the evaluation model. It is also proposed to add the Road Maps to WCAP-14407 Section 4 to serve as an index by phenomena to supplement the existing Section 4 which is organized by geometry.

2. Pointers to specific subsections of reports are provided in the Road Maps. In the examples, section numbers are from the Rev. 0 reports. Rev. 1 subsections are identified as, e.g., "Ref. 3 Section 4.xx Rev. 1". These references will be updated to be consistent with section numbers in Rev. 1 of reports where applicable.

3. The following is a list of the new information, being added to WCAP-14407 to address NRC review comments, which is referenced in the example [illegible].

## Selected Section 4 Rev. 1 Added Information

Summary of implementation of

- bounding water coverage model (Tie between sections 4 and 7)

- circulation and stratification biases (summarize information in "Special Modeling Considerations" subsections already provided for each compartment)

Specification of break boundary condition properties and nodes
- LOCA, including Stage 4 ADS controlled release location
- MSLB

Internal heat sinks condensation, convection, radiation model bias, [illegible]

Summary figure of compartment arrangement with respect to pool level and compartment flooding levels versus time

## Selected Section 7 Rev. 1 Added Information

An explanation will be added to Section 7 Rev. 1 of the four elements or layers of conservatism with respect to containment pressure incorporated into the approach to determine water coverage area :

a) Conservative treatment of experimental data and associated uncertainties

b) Bouncing of experimental data and uncertainties, including full scale unheated and heated surfaces

c) Conservative physical modeling of evaporating film without credit for complete evaporation (use of evaporation-limited flow for calculations)

d) Margin between coverage determined by conservative water coverage model and water coverage necessary to keep LOCA peak pressure below design.

A description of the water film behavior at complete evaporation similar to LST [illegible]

## Selected Section 9 Rev. 1 Added Information

Revised Table 9-1 Rev. 1 which connects PIRT phenomena to evaluation model inputs.

Appendix A CMT room flow and circulation calculations

Appendix B Effects of stratification on CMT room heat sink utilization

Appendix C Additional information on AP600 containment circulation based on international database, and published lumped parameter limitations

## List of examples included in informal transmittal of April 11, 1997

The attachment contains proposed road maps for the following example phenomena:

- **Boundary and initial conditions**
  - 1A Mass and energy release of break source
  - 4A Initial temperature in containment

- **Properties and hardware quantities**
  - 2C Gas compliance in containment volume
  - 3D Internal conduction in containment solid heat sink
  - 3E Heat capacity of containment solid heat sinks
  - 7F Conduction heat transfer through containment shell
  - 7G Heat capacity of containment shell

- **Mass and heat transfer**
  - 3F Condensation on containment solid heat sinks
  - 7C Condensation on steel shell
  - 7N Evaporation on steel shell
  - 7A Convection to containment shell
  - 7H Convection from containment shell to riser annulus

- **Water coverage**
  - 8A Water flow rate from PCCWST to steel shell
  - 8C PCS water film stability and coverage

- **Circulation and stratification**
  - 2A Circulation and stratification in containment volume
  - 2B Intercompartment flow in containment volume
  - 1B Direction and elevation of break source
  - 1C Momentum of break source
  - 1D Density of break source

# Example Road Maps

# Boundary and Initial Conditions

## Phenomena - Mass and Energy Release of Break Source (item 1A in PIRT)

### Ranking

High for all phases, except N/A for Refill

### Relevant AP600 Boundary Conditions or Phenomena Models

Flow boundary conditions are input to the code as described in Ref. 6 Section 12.1.2 and 12.1.3. Flow boundary condition parameters are specified for LOCA mass and energy releases of superheated steam (LOCA and MSLB), subcooled liquid (LOCA), or steam/liquid mixture (LOCA) as described in Ref. 3 Section 4.xx Rev. 1. Mass and energy are input as time histories of mass flow rate and enthalpy.

### Method to Validate WGOTHIC and/or Establish Conservative Model Using Scaled Test

A spectrum of break sizes and locations is evaluated for the LOCA, and the Double Ended Cold Leg Guillotine break is determined to be the limiting LOCA for containment pressure.

A spectrum of MSLB transients is run, varying break size, initial power level, and single failure assumptions and those which are limiting with respect to pressure are presented in SSAR 6.2.1.1.3.

The flow boundary condition was used to represent superheated steam in WGOTHIC simulations of LST (Ref. 7, Section 6.1). Flow boundary condition used to represent steam/liquid mixture injection in BMC test D-16 (Ref. 1, Section 8.2). In both comparisons, the predicted pressure reasonably represents the measured pressure transient.

Subcooled liquid is verified to fill compartments at the appropriate rate by hand calculations Ref. 3 Section 4.xx).

### How Bounding Approach is Implemented in Evaluation Model

The boundary condition specifications used in validation for superheated steam and mixture releases formed the basis for the AP600 evaluation model method (Ref. 3, Section 4.xx Rev. 1).

LOCA: Available energy sources are considered and biased conservatively high

(SSAR 6.2.1.3.2) with respect to containment pressure. mass and energy releases are The Refill period of no releases is conservatively neglected, to maximize pressure. (Ref. 3, Section 4.5.2, Table 4-107, and Table 14-4; SSAR 6.2.1.3.) By neglecting the Refill period of no significant releases, the containment pressure at the beginning of the peak pressure phase is maximized.

MSLB: Secondary side energy releases are biased conservatively high, and a spectrum of break scenarios is studied to select limiting cases (SSAR 6.2.1.4) with respect to pressure and temperature.

Nodes to which the mass and energy boundary conditions are connected for LOCA and MSLB are shown in Ref. 3 Section 4.xx Rev. 1.

## Phenomena - Initial Temperature in Containment (item 4A in PIRT)

### Ranking

Medium for Blowdown and Refill, High for other phases of LOCA, High for MSLB

### Relevant AP600 Boundary Conditions or Phenomena Models

The initial internal temperatures are specified for each internal fluid volume and structure.

### Method to Validate WGOTHIC and/or Establish Conservative Model Using Scaled Test

Changing the initial containment volume temperature introduces two competing effects on calculated containment pressure: 1) the effect of initial temperature on noncondensible gas content and 2) the effect of initial temperature on the heat absorption capacity of internal heat sink structures. A sensitivity to initial temperature (Ref. 3, section 5.5) shows that the assumption of higher initial temperature leads to a higher containment peak pressure, although the reduced noncondensible inventory as a function of increased temperature decreases long term predicted pressure by about 2 psi.

The higher initial temperature is chosen to maximize peak pressure, and the resulting long term pressure response is conservative with respect to many other parameters used in the bounding approach, consistent with the criterion to show rapid pressure reduction over the long term.

### How Bounding Approach is Implemented in Evaluation Model

The maximum tech spec initial temperature is used in the evaluation model (Ref. 3, table 4-105) to initialize both containment fluids (gas, IRWST liquid) and internal solid heat sinks.

# Properties and Hardware Quantities

## Phenomena - Gas Compliance in Containment Volume (item 2C in PIRT)

### Ranking

High for all phases

### Relevant AP600 Boundary Conditions or Phenomena Models

Gas compliance affects energy storage in the internal volume. Gas compliance is a function of gas properties, volume of gas, and initial pressure and temperature. Standard gas constituents and properties are used in the governing equations, as shown in Ref 2, Section 10 for liquid water, steam, gas component, and steam and gas component mixture properties. The initial temperature and pressure for each volume and the volume of each computational cell are code inputs. The effects of liquid level on available gas volume, and thus on containment pressure, are tracked in the code using the mass and density of water delivered via the break mass releases (see also 5F Flooding in the pool). The models in WGOTHIC allow for thermal non-equilibrium between the air/vapor mixture and drops in the gas volume (Ref. 2 Section 2.2).

### Method to Validate WGOTHIC and/or Establish Conservative Model Using Scaled Test

The WGOTHIC lumped parameter model has been validated with the LST (Ref. 7, Section 8.2). Initial air pressure in the test matrix ranged from a vacuum (test 223.1) to 30.9 psia (test 224.1).

CSNI numerical benchmark problem discussed in Reference 1 Section 3 validates the calculation of pressure within an enclosed volume by comparison to an analytical solution. GOTHIC standard problems 2, 3, 5, and 14, described in Reference 1 Section 4 also provide validation of the constitutive equations for lumped volume pressurization.

### How Bounding Approach is Implemented in Evaluation Model

Governing equations in WGOTHIC are a valid representation of compressible, multi-component gas behavior in a volume in which steam and liquid are injected. The maximum Technical Specification values are used for initial pressure and temperature (Ref. 3, Section 5.4 and Table 4-105) in conjunction with a conservative initial containment volume (Ref. 3, Table 4-104). Liquid level is tracked using input for each below-deck volume as discussed under "5F Flooding in the pool". Therefore, uncertainties in input parameters which affect volume compliance are bounded with respect to the effect on containment pressure.

## Phenomena - Internal conduction in Containment Solid Heat Sinks (item 3D in PIRT)
## - Heat capacity of Containment Solid Heat Sinks (item 3E in PIRT)

### Ranking

Medium for Blowdown and High for all other phases of LOCA, High for MSLB

### Relevant AP600 Boundary Conditions or Phenomena Models

GOTHIC conductors used to model internal heat sinks include a 1-D conduction solution (Ref 2, section 6) using input material properties of density, specific heat, and thermal conductivity (See Ref. 3 Table 4-49). Conductor area and thickness are discussed under "3F Condensation on containment solid heat sinks," since they affect total condensation rates. The mesh of solid heat sink conductors is established based on the Biot number (See for example, Ref. 3 Table 4-50).

### Method to Validate WGOTHIC and/or Establish Conservative Model Using Scaled Test

Ref 1 section 4, GOTHIC standard problem 26 compares analytic solutions to the solution of the conduction equations used for internal heat sinks with specified temperature and heat flux boundary conditions. WGOTHIC does not modify the conduction equation used for containment solid heat sinks.

### How Bounding Approach is Implemented in Evaluation Model

Conservatively bounded material properties are used for AP600 internal conductors to maximize containment pressure (Ref. 3, section 4.3, Table 4-49 for internal heat sinks).

Note that, although heat sinks may become heat sources as the containment pressure reduces over the long term, eliminating heat sinks from the model maximizes peak pressure (LOCA or MSLB). Therefore, the small effect of those conductors on long term pressure is neglected for comparison to the criterion requiring rapid pressure reduction after a design basis LOCA.

## Phenomena - Conduction heat transfer through Steel Shell (item 7F in PIRT) Heat capacity of Steel Shell (item 7G in PIRT)

### Ranking

7F Conduction:
Low for Blowdown and Refill, High for other phases of LOCA, High for MSLB

7G Heat capacity:
Low for Blowdown, High for Refill and Peak Pressure, Low for Long Term, and High for MSLB

### Relevant AP600 Boundary Conditions or Phenomena Models

Climes include 1D conduction model used for conduction through containment shell (Ref. 7, Section 2.5). Related inputs are shell and coating thicknesses, shell area, and shell and coating properties of thermal conductivity, heat capacity, and density. Input is also used to specify the numerical mesh through each conductor thickness based on the Biot number, as described in Ref. 3, as follows. Examining Ref. 3 Section 4.3, the Biot number, materials, and mesh for each conductor type are specified. Ref. 3 Section 4.4 describes each of the conductors which represent the containment shell, baffle, and shield building; for example, 4.4.1.2 gives, for the top clime in a wet stack, the following conductor types:

| Conductor | Conductor Type | Material/Mesh |
|---|---|---|
| First conductor - containment shell | 20 | Table 4-69 |
| Second conductor - baffle | 5 | Table 4-54 |
| Third conductor - shield building | 30 | Table 4-79 |

### Method to Validate WGOTHIC and/or Establish Conservative Model Using Scaled Test

Ref. 7, section 4.1 contains validation of the 1D conduction equations used in clime subroutines by comparison to theoretical solutions. Noding studies have been performed for the number of axial elevations, number of circumferential divisions, and radial conductor mesh (Ref. 3 Section 12.3.2.), showing that doubling the number of clime axial nodes, doubling the number of circumferential stacks, or doubling the number of conductor mesh points does not affect the calculated pressure transient in the evaluation model.

## Use of Validation Results and Bounding Evaluation Model

Using 1D conduction conservatively neglects the benefit to containment pressure of azimuthal conduction from dry to wet stripes. Conservative material properties (Ref. 3, Table 4.xx Rev. 1 ) for thermal conductivity, heat capacity, and density are used. Effects of degradation of inorganic zinc coating are included in material properties.

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**Note:**

For evaluations of transients beyond design basis, such as evaluations of 7-day cooling, a conservative assessment of the effects of azimuthal conduction (from hotter, dry stripes to cooler, wet stripes) may be credited in water coverage calculations (see 8C PCS cooling water film stability and coverage on steel shell).

# Mass and Heat Transfer

## Phenomena - Condensation on Containment Solid Heat Sinks (item 3F in PIRT)

### Ranking

Medium for Blowdown and High for all other phases of LOCA, High for MSLB

### Relevant AP600 Boundary Conditions or Phenomena Models

For internal heat sinks, the Direct Condensation option (Ref 2, section 8.1.2) with the user-selected Uchida condensation correlation, gives the condensation rate at the wall (from Ref 2, equation 8.19). The area and thickness of internal heat sinks affect the condensation mass flow rate and total condensation, respectively. A forcing function is used to shut off condensation to conductors in dead ended compartments at the end of blowdown (see for example, 4.2.1.4 for the reactor cavity).

### Method to Validate WGOTHIC and/or Establish Conservative Model Using Scaled Test

The use of the Uchida correlation on internal heat sinks is consistent with the Standard Review Plan. Uchida is a natural convection correlation, and thus neglects benefits of forced convection which would exist during high Froude number phases of LOCA blowdown and MSLB.

Surface area and thickness of containment internal solid heat sinks are conservatively underestimated by neglecting smaller equipment, such as cable trays and stairs, to maximize containment pressure.

Thermal gradients that could exist in a dead ended compartment due to unequal heat sink temperatures could drive natural circulation which would bring steam into the compartments (Ref. 9). Natural circulation into dead ended compartments is conservatively neglected for containment pressure calculations. Thus, condensation is only credited during blowdown, while steam is forced into dead ended compartments by pressurization. Condensation in dead ended compartments is shut off after blowdown (30 seconds), so no credit is taken for subsequent condensation of steam in those compartments.

### How Bounding Approach is Implemented in Evaluation Model

The conservative Uchida correlation is applied to all internal heat sinks, not including the PCS shell (item 7C).

Conservative values of surface area and volume (thickness) are used as discussed above.

A forcing function is used to set condensation heat transfer coefficient to zero after 30 seconds.

**Phenomena -**

**Condensation on Steel Shell (item 7C in PIRT)**
**Evaporation on Steel Shell (item 7N in PIRT)**

**Convection to Steel Shell (item 7A in PIRT)**
**Convection from Steel Shell to riser annulus (item 7H in PIRT)**

**Ranking**

| Phenomenon | LOCA | | | | MSLB |
|---|---|---|---|---|---|
| | Blowdown | Refill | Peak Pressure | Long Term | |
| 7C Condensation | L | H | H | H | H |
| 7N Evaporation | N/A | N/A | H | H | M |
| 7A Inside convection | L | M | M | M | L |
| 7H Outside convection | L | L | M | M | L |

**Relevant AP600 Boundary Conditions or Phenomena Models**

Total condensing or evaporating mass flow rate is equal to the product of the condensing or evaporating mass flux to/from wetted surfaces times the wetted area. The entire internal steel shell surface area is assumed to be wetted by condensation, which leads to a liquid film resistance to condensation heat transfer (see 7D Inside film conduction on steel shell). The external steel shell wetted surface area is determined using a conservative water coverage model (see 8C PCS water film stability and coverage) with respect to containment pressure. The correlations used for condensation and evaporation mass fluxes on the steel shell surfaces, as well as convective heat transfer correlations, are specified in Ref. 3, section 3.4. Related code inputs are described below.

**Method to Validate WGOTHIC and/or Establish Conservative Model Using Scaled Test**

# Water Coverage

## Phenomena - Water flow rate from PCCWST to Steel Shell (item 8A in PIRT)

### Ranking

Not applicable for Blowdown and Refill, High for other phases of LOCA, Medium for MSLB

### Relevant AP600 Boundary Conditions or Phenomena Models

Related inputs are the shell wetting time delay and applied PCS flow rate, both input as applied mass flow rate versus time in WGOTHIC clime input tables. The evaluation model input PCS flow rate is externally determined, by reducing delivered flow, to limit the flow applied to the evaluation model calculation. See 8C PCS water film stability and coverage for how the film stability is used to limit the applied PCS flow.

### Method to Validate WGOTHIC and/or Establish Conservative Model Using Scaled Test

- **Wetting Time Delay**

o The input boundary condition PCS flow delay time produces a conservative result compared to the actual water delivery chronology, by neglecting all heat removed by the film as it fills weirs and reaches a quasi-steady coverage down the side walls over a period of 337 seconds (based on an initial applied flow of 440 gpm). A WGOTHIC sensitivity based on actual chronology with earlier wetting to quantify a portion of the margin in the evaluation model time delay is described in section 7.5.2. The pressure margin associated with the assumption of delaying any applied water until after the time it takes to reach steady state coverage based on a hand calculation is described in Ref. 3 Section 7.5.4.

o A conservatively high estimate of the actual surface temperature when water begins to pour onto the vessel from the bucket at the top of containment (about 37 seconds based on an initial PCCWST delivered flow of 440 gpm) is 130F, and by the time quasi-steady water coverage is assumed to be achieved, the surface is conservatively estimated to be 190F (Ref. 3 Table 7-8), both of which are less than the surface temperatures shown to readily wet in tests discussed below. It should be noted that the AP600 shell surface temperatures are well away from the Leidenfrost temperature, the temperature at which stable film boiling begins (Ref. 10), which is about 570F.

- o LST 219.1 included water applied to a hot surface. The LST surface thermocouple measurements show that the surface readily wets adjacent, hotter, dry surfaces during the increasing flow portion of the small periodic variation in delivered flow which occurred over at least tens of seconds during the test, as shown in Figure 7.XX (new) in Ref. 3 Section 7.A.6. The effect of the relatively slow periodic flow variations extending over tens of seconds that were observed in the LST data is bounded by the use of the maximum flow during coverage measurements, to maximize the $Re_\Gamma$ at stability limit. Maximizing $Re_\Gamma$ at stability limit minimizes water coverage, and thus maximizes calculated pressure.

- o Videotapes of a shakedown LST with somewhat higher PCS flow rate shows the behavior of approximately 80F water when applied to a 240F surface. The observations showed that the advancing film front sizzled as it cooled the surface, and readily flowed down as wide stripes as the surface was cooled (Ref. 3 Section 7.3). Similar information is obtained from the STC wet flat plate tests.

**- Effect of water on air flow**

- o Early application of water to the containment dome does not adversely impact the initial air flow past the containment shell; rather, it improves the air flow. Steam generated from evaporating water would reduce the density of the vapor in the annulus early in time, increasing the density head difference between the annulus and downcomer. This increased density head will result in increased airflow from the downcomer into the annulus relative to that calculated by the evaluation model.

- o The effect on annulus air temperature and vapor content of water evaporated from the surface is explicitly modeled in the evaluation model annulus flow calculation.

- o Effects of shear between the air flow and falling water film are evaluated to be negligible in Ref. 4 Section 4.4.8D Film stripping and 4.4.8E Film drag.

**- Water Coverage Area**

- o See 8C PCS water film stability and coverage for how the effects of film stability and heat flux on containment pressure are addressed in the evaluation model.

## How Bounding Approach is Implemented in Evaluation Model

- Since the steel shell outer surface temperature does not increase significantly until after water reaches the containment shell surface in real time, the cold full-scale tests are representative for determining delay times associated with volume storage in the distribution system. With respect to containment pressure, the delay time to wet the external surface is conservatively bounded by assuming no water on the external surface during the time to reach steady-state coverage from the cold full-scale test. This conservative delay time thus neglects integrated heat removal during the early stages of actual water application during the period when steady-state film coverage is developing, which is conservative for containment pressure.

- The calculations assume application of a conservatively reduced amount of liquid to the PCS containment shell, which increases containment pressure. Thus, there is a conservative upper limit on the amount of water that can be evaporated by the evaluation model. The bounding water coverage model is used to calculate the amount of flow that could run off the PCS shell without being evaporated. The liquid flow used as an input to the WGOTHIC model for calculations is then evaluated as;

$$\dot{m}_{APPLIED} = \dot{m}_{PCS\ ACTUAL} - \dot{m}_{PREDICTED\ RUNOFF} \qquad (1)$$

  The equation given above defines the "evaporation-limited flow rate" and requires the applied PCS flow rate to be limited to only that which is predicted to be evaporated. Additional conservatism with respect to containment pressure exists since no credit is taken for the sensible heating of the liquid runoff. [ Note: Equation (1) was also provided in the draft response to RAI 480.874 and will be included in the amended text of Section 7.]

## Phenomena - PCS Cooling Water Film Stability and coverage on Steel Shell (item 8C in PIRT)

### Ranking

Not applicable for Blowdown and Refill, High for other phases of LOCA, Low for MSLB

### Relevant AP600 Boundary Conditions or Phenomena Models

Total evaporation cooling rate is equal to the product of the condensing or evaporating mass flux from wetted steel shell surfaces times the wetted area. Condensing and evaporating mass fluxes are described under 7C Condensation on steel shell and 7N Evaporation on steel shell. For condensation, the entire internal PCS surface area is assumed to be wetted, which leads to a liquid film resistance to condensation heat transfer (see 7D Inside film conduction on steel shell).

The effects of film stability on external coverage area is determined as follows. External coverage is modelled as quasi-steady coverage fraction by conservatively neglecting evaporative heat removal during the period that external water is reaching steady state (see 8A PCS water flow rate from the PCCWST for discussion of initial transient). External shell water coverage area is input to WGOTHIC by specifying the surface area input at each elevation for the dry and wet portions of the shell (Ref. 3 Section 4.4). If the calculation indicates complete evaporation of the applied water at any elevation, the code calculates the area that is wetted and separately calculates heat removal from the dry and wet regions for the clime where dryout is predicted. The applied PCS flow rate is input with mass flow rate versus time tables (see 8A PCS water flow rate from PCCWST to steel shell). The flow rate versus time tables are reduced to account for film stability effects, effectively limiting the amount of evaporative cooling which is credited in the evaluation model.

### Method to Validate WGOTHIC and/or Establish Conservative Model Using Scaled Test

o Conservatism with respect to containment pressure has been incorporated into the approach to determine water coverage area in four elements or layers to account for liquid film stability, including the effects of heated surface, as follows:

  a) Conservative treatment of experimental data and associated uncertainties

  b) Bounding of experimental data and uncertainties, including full scale unheated and heated surfaces

c) Conservative physical modeling of evaporating film without credit for 4 complete evaporation (use of evaporation-limited flow for calculations). A description of the water film behavior at complete evaporation similar to LST 213.1 will be provided in Section 7.

d) Margin between coverage determined by conservative water coverage model and water coverage necessary to keep LOCA peak pressure below design (Ref. 3, Section 7.7.5.3), established by delivered PCCWST flows.

o An inorganic zinc coating provides a surface which has relatively low wetting angles, as compared to the high wetting angles typical of polished copper surfaces in the literature (Ref. 3 Figure 7.A-1). Therefore, there is a weaker influence of heat flux on film stability for the coated surface than for polished metal surfaces (compare Ref. 3 Figure 7.A-3 to Figure 7.A-4).

o An external water coverage model (Ref. 3 Section 7.4) is developed. The water coverage model is validated (Ref. 3, Appendix 7.A) and used to bound full scale, 1/8 sector, partial sidewall tests to address effects of surface misalignments and flow distribution and coverage from the weirs, and heated LST water coverage data to address the effects of heat flux on film stability during evaporation, relative to containment pressure calculations.

o The water coverage model is used to calculate a maximum runoff flow rate at the bottom of the shell. This represents an upper limit on the evaluation model evaporative cooling. The water coverage model considers film stability, surface heat flux as a function of time, and evaporation from the film on the steel shell. The model does not credit the observed shape of completely evaporating films as the film flow rate goes to zero. (See sample runoff flow calculation in Ref. 3, Section 7.4.1)

o Water coverage area is an input boundary condition to the WGOTHIC code. A top-to-bottom stack of climes is used to model each of the wetted and dry portions of the external shell (Ref. 3, Section 4.4). To maximize calculated containment pressure, coverage for the dome at top and mid-levels bounds full-scale, cold test data, where the film is thick enough that film stability does not limit coverage, and no credit is taken for better spreading at weir delivery due to higher temperatures than tested. The wetted coverage of the evaporating sidewall where film stability limits coverage is obtained from the water coverage model. Coverage fractions input to the WGOTHIC model are sufficiently large to evaporate all the applied water, since film stability and coverage area are used to calculate the maximum runoff flow, as discussed above.

- PCCWST delivered flow is based on the single failure assumption of the only active component of the PCS, failure of one of the two parallel PCCWST drain valves to open. Water coverage model runoff flow is subtracted from the PCCWST delivered flow, and the net flow is provided as WGOTHIC input applied PCS flow (Ref. 3 Figure 4-93).
- Aging increases the free energy of the surface and this increases the ability to wet the surface. Surface contaminants are addressed based on inspection and cleaning criteria established in the Reliability Assurance Program (SSAR Section 16.2).

**How Bounding Approach is Implemented In Evaluation Model**

- The conservative water coverage model is used to calculate input boundary conditions for the PCS DBA Evaluation Model as shown in the sample problem of Ref. 3 Section 7.4.
- Elements of the four layers of conservatism described above in the water coverage approach are identified in Ref. 3 Section 7.4.3.

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**Note:**

For evaluations of transients beyond design basis, such as evaluations of 7-day cooling, a conservatively low effect of azimuthal conduction (from hotter, dry stripes to cooler, wet stripes) may be credited in water coverage calculations (see 8C PCS cooling water film stability and coverage on steel shell) for long term containment pressure calculations. For the number and size of wet stripes at lower coverage fractions, 2D conduction into the side of the wet region would increase evaporation rates. Such 2D conduction can be conservatively estimated and accounted for in the calculation of evaporated water to maximize containment pressure.

# Circulation and Stratification

## Phenomena - Circulation and Stratification in Containment Volume (item 2A in PIRT)

### Ranking

High for all phases

### Relevant AP600 Boundary Conditions or Phenomena Models

Circulation within the containment upper regions and circulation between the upper and lower portions of the containment is examined in a phenomenological report (Ref. 3, Section 9). Methods are developed which bound the potential effects on the containment pressure calculation by selection of limiting scenarios and applying conservatism to bound the effects of stratification on containment pressure. Biases to maximize containment pressure for these effects by selection of scenarios to be modelled and by code input are summarized below.

### Method to Validate WGOTHIC and/or Establish Conservative Model Using Scaled Test

WGOTHIC lumped parameter model has been validated with the LST (Ref. 7, Section 8.2). In Ref. 3, the applicability and limitations of using WGOTHIC lumped parameter for internal circulation are identified in Appendix 9C and the effects of circulation and stratification on containment pressure are evaluated according to Table 9-1 Rev. 1, as summarized below, including the effects of drops (see also 2D Fog in containment volume).

### How Bounding Approach is Implemented in Evaluation Model

The evaluation model bounds effects of circulation and stratification on containment pressure as shown in Ref. 3 Table 9-1 Rev. 1. In summary, conservatism with respect to containment pressure calculations is applied to bound effects on containment pressure of stratification within compartments or regions, and limiting scenarios and break elevations are chosen to maximize pressure calculated for the LOCA and MSLB, as follows:

**Stratification biases (LOCA and MSLB):**

- Insulate upward-facing horizontal surfaces, including floors and non-grating operating deck.
- Take no credit for conduction to heat sinks in dead ended compartments after

blowdown.

**Limiting LOCA scenario:**

- The limiting LOCA scenario for containment pressure forms the DBA bases and is a buoyant plume rising from the steam generator compartment. A highly kinetic jet in the steam generator compartment or buoyant plume rising from postulated locations, other than the steam generator compartment, increases internal heat sink condensation rates. It should also be noted that since internal heat sinks effectively saturate well before the time of peak pressure, the calculated LOCA peak pressure is not sensitive to the break locations studied.

- For equipment qualification, the temperature of the break room for the LOCA is applied to all containment equipment, providing an upper bound of temperature distribution effects.

**Limiting MSLB scenario:**

- The limiting MSLB scenario for containment pressure is a release from the steam lines above the operating deck. The lumped parameter model is biased to conservatively underestimate circulation below the operating deck, by assuming the break node immediately above the operating deck. Test data shows that at least some circulation would be driven by the high kinetic energy during the MSLB. This approach minimizes the benefits on containment pressure of solid heat sinks below the operating deck, which are a dominant heat removal mechanism, since the PCS is actuated relatively late in the transient relative to MSLB peak pressure.

- The limiting MSLB scenario for containment equipment qualification is a release from the steam lines located in the CMT compartment, which leads to high condensation rates on equipment and higher local compartment temperatures than an above-deck release.

## Phenomena - Intercompartment Flow in Containment Volume (item 2B in PIRT)

### Ranking

Low for Blowdown, High for all other phases

### Relevant AP600 Boundary Conditions or Phenomena Models

Intercompartment flows are represented by junctions in the WGOTHIC lumped parameter model. The momentum conservation equations for junctions include the following terms (Ref. 2 Section 4.1) :

inertia
pressure gradient
gravity head (including the specific junction height within a volume, Section 4.4)
equipment source (not used for AP600)
momentum fluxes (not used for lumped parameter)
wall drag
interfacial drag

The effects on containment pressure of intercompartment flow (circulation between compartments), circulation within compartments or regions, as well as stratification are evaluated in a phenomena report (Ref. 3 Section 9). Justification for the methodology used in the specific application of the lumped parameter formulation of the WGOTHIC code to AP600 is provided in that report (see 2A Circulation and stratification in containment volume).

Junctions have input properties of flow areas, lengths, elevations, and loss coefficients. As the lower compartments fill with liquid from safeguards systems released through the break, liquid height (see 5F Flooding in break pool) is tracked via the pool area input, and flow paths are eliminated for gas circulation as they become submerged.

### Method to Validate WGOTHIC and/or Establish Conservative Model Using Scaled Test

In Ref. 3, the applicability and limitations of using WGOTHIC lumped parameter for internal circulation are identified in Appendix 9C, based on published comparisons to international databases. The applicability and limitations of the WGOTHIC lumped parameter formulation have been confirmed with comparisons to tests (Ref. 7, Section 8, for LST, and Ref 3. Appendix 9C for published international test experience). The effects on containment pressure of circulation and stratification are evaluated according to Table 9-1 Rev. 1, including the effects of drops (see also 2D Fog in containment volume). Results are summarized as follows.

For LOCA, the break source must pass through rooms with equipment and gratings which will dissipate some fraction of the momentum. An extreme range, between complete momentum dissipation and no dissipation has been considered. For postulated extreme scenarios wherein momentum is assumed to be dissipated within the break compartment and the break release is low in the containment, the lumped parameter is used within limitations developed from code validation with various scaled tests (Ref. 3 Appendix 9C) to perform sensitivities (Ref. 3 Section 9.3.2.4). The WGOTHIC lumped parameter model is used to assess the effects of a range of break locations on circulation patterns, and thus on a range of transient evolution of steam concentration in various compartments. Results show that the internal heat sinks are saturated well before the time of peak pressure for the cases analyzed. Thus, peak pressure is not sensitive to the range of circulation patterns studied. An undissipated jet, the other postulated extreme, has been evaluated to be less limiting with repect to pressure than the sensitivity cases (9.3.1.2).

For MSLB, the circulation to below-deck compartments is minimized in the evaluation model by the selection of WGOTHIC lumped parameter node to which the flow boundary condition is applied.

## How Bounding Approach is Implemented in Evaluation Model

For LOCA, the limiting circulation pattern with respect to containment pressure calculation is chosen by assuming the break to be a buoyant plume (momentum is dissipated) released in the affected steam generator compartment (Ref. 3 Section 4.xx Rev. 1), which minimizes the heat removal rate for internal heat sinks (primarily in the CMT room) due to the reduced steam concentration in the gases drawn through the CMT by entrainment into the steam generator by the chimney effect.

For MSLB, the flow boundary condition is applied to a node above the operating deck (Ref. 3, Section 4.xx Rev. 1) to limit the intercompartment flow into the below deck compartments. (See also 1C Momentum of break source).

See 2A Circulation and stratification in containment volume for summary of related modelling biases.

## Phenomena - Direction and Elevation of Break Source (item 1B in PIRT)

### Ranking

High for all phases, except N/A for Refill

### Relevant AP600 Boundary Conditions or Phenomena Models

The direction and elevation of the break source affects circulation and stratification within the AP600 containment, which affects the distribution of steam. The distribution of steam affects heat and mass transfer on containment solid heat sinks and the shell surface, and thus has the potential to affect containment pressure. WGOTHIC lumped parameter formulation artificially dissipates momentum, so break direction is not a parameter explicitly considered within the model. The range of break directions for a LOCA are evaluated by considering different directions which a jet could point and then different locations where the jet momentum (see also 1C Momentum of break source) could be dissipated. A limiting LOCA scenario for containment pressure is selected as discussed below.

The elevation of the break source is modelled by choosing an appropriate internal containment node to which the boundary condition (1A Mass and energy release of break source) is connected. The LOCA DECLG releases are relatively low in containment, in the steam generator compartment. LOCA DECLG sensitivities were performed assuming various lower compartment release locations (Ref. 3, Section 9.3.2.4). The effects of elevation are examined for the MSLB by sensitivities to a break at the steamline above the operating deck and a steamline break in the CMT compartment (Ref. 3 Section 9.4.1.1 and 9.4.1.2).

See 2A Circulation and stratification in containment volume for more detail and a summary of related modelling biases.

### Method to Validate WGOTHIC and/or Establish Conservative Model Using Scaled Test

The effects of break direction (LOCA) and elevation (LOCA and MSLB) on containment pressure are evaluated in the key phenomenon report addressing circulation and stratification for each accident phase (Ref. 3, Table 9-1 Rev. 1). The break direction for a MSLB is not relevant since the break kinetic energy is high enough to circulate within the break region regardless of break direction (compare LST 222.3 to 222.4). See 2A Circulation and stratification in containment volume for summary of additional related validation.

**How Bounding Approach is Implemented in Evaluation Model**

For the LOCA, a limiting containment pressure scenario has been defined with respect to break direction and elevation, and for the MSLB, the break elevation has been chosen to conservatively bound potential effects of stratification on the containment pressure calculation (Ref. 3, Table 9-1 Rev. 1). The evaluation model bounds the effects of break direction and elevation on containment pressure calculation (Ref. 3 Table 9-1 Rev. 1) by choosing limiting scenarios for the LOCA and MSLB, and choosing a bounding break node elevation for MSLB. See 2A Circulation and stratification in containment volume for summary of related modelling biases.

## Phenomena - Momentum of Break Source (item 1C in PIRT)

### Ranking

High for all phases, except N/A for Refill

### Relevant AP600 Boundary Conditions or Phenomena Models

Break source momentum affects circulation and stratification within the AP600 containment, which affects the distribution of steam. The distribution of steam affects heat and mass transfer on containment solid heat sinks and the shell surface, and thus has the potential to affect containment pressure. The WGOTHIC lumped parameter formulation artificially dissipates the momentum of the break flow boundary condition. The effects on containment pressure of break source momentum are evaluated in a phenomenological report (Ref. 3, Section 9).

### Method to Validate WGOTHIC and/or Establish Conservative Model Using Scaled Test

The phenomenological report on circulation and stratification evaluates the effects on containment pressure of momentum on circulation and stratification within the AP600 containment (Ref. 3, Table 9-1 Rev. 1)

In summary, for LOCA DECLG, the lumped parameter is used, within limitations developed from code validation with various scaled tests (Ref. 3 Appendix 9C), to perform sensitivities for a range of postulated extreme scenarios wherein post-blowdown momentum is assumed to be dissipated within various compartments, based on postulated break directions. For the blowdown portion, the break compartment pressurizes (Ref. 3 Section 9.3.1.1 Rev.1 ), and the lumped parameter (node-network) formulation is a reasonable tool to calculate the relative flows exiting the break compartment based on the resistance in the various flow paths.

For the MSLB, LST data (Ref. 3, 9.2) shows that the high kinetic energy drives circulation throughout the test vessel. Since the lumped parameter formulation artificially dissipates momentum in the break node, the evaluation model stratifies from the break elevation upwards. Therefore, the evaluation model bounds the effects of momentum by placing the break in a node immediately above the operating deck, which does not take credit for the kinetic-energy driven circulation below the operating deck.

See 2A Circulation and stratification in containment volume for more detail and a summary of related modelling biases.

**How Bounding Approach is Implemented in Evaluation Model**

For the LOCA, the effect of break source momentum on the containment pressure calculation is bounded by selecting the limiting scenario of a buoyant jet and by using only free convection on internal heat sink surfaces during the forced convection dominated blowdown.

For the MSLB, the effect of momentum on the containment pressure calculation is bounded by conservatively not crediting the full benefit of high kinetic energy (forcing the model to stratify between the above and below operating deck regions) and by using only free convection on internal heat sink surfaces (See 3F Condensation on containment solid heat sinks and 7C Condensation on steel shell) during the forced convection dominated MSLB. See 2A Circulation and stratification in containment volume for more detail and a summary of related modelling biases.

## Phenomena - Density of Break Source (item 1D in PIRT)

### Ranking

High for all phases, except N/A for Refill

### Relevant AP600 Boundary Conditions or Phenomena Models

The density of the break source affects circulation and stratification within the AP600 containment. The density of the break source is established by the WGOTHIC flow boundary condition parameters. Buoyancy driving forces are included in the WGOTHIC lumped parameter governing equations for junctions between computational cells. The effective density of the break source is affected by the amount of drops assumed (see 2D fog in containment volume).

### Method to Validate WGOTHIC and/or Establish Conservative Model Using Scaled Test

WGOTHIC lumped parameter model has been validated by comparisons with LST data (Ref. 7, Section 8.2). In Ref. 3, the effects of density on the containment pressure calculation are evaluated according to Table 9-1 Rev. 1.

### How Bounding Approach is Implemented in Evaluation Model

A road map of how parameters which influence circulation and stratification, including break source density, are evaluated is given in Ref. 3 Table 9-1 Rev. 1. Uncertainty is bounded by selection of a limiting scenario with respect to circulation and stratification effects on containment pressure. See 2A Circulation and stratification in containment volume for summary of related modelling biases.