December 27, 1995

APPLICANT: Westinghouse Electric Corporation

PROJECT: AP600

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

On December 6 and 7, 1995, representatives of the U.S. Nuclear Regulatory Commission (NRC), Scientech, Inc. (NRC consultant), and Westinghouse Electric Corporation (Westinghouse) met in Rockville, Maryland to discuss design issues related to the AP600 passive containment cooling system (PCS) and the WGOTHIC computer code. Attachment 1 is a list of participants. Westinghouse submitted a non-proprietary version of Sections F and G of the presentation material via Westinghouse letter NTD-NRC-95-4609, dated December 11, 1995.

The purpose of this meeting was to discuss the status of the PCS review and WGOTHIC computer code validation review with NRC consultants from Scientech, Inc.. Brain McIntyre presented the meeting objectives and chronology of the PCS review to date. Joel Woodcock presented sections on PCS design overview, PIRT and methodology, PCS test and analysis, water coverage, WGOTHIC code, PCS evaluation model assumptions and results, open issues, and conclusions. Dan Spencer presented sections on scaling, separate effects testing, and integral effects testing. Non-prototypical features of the Large Scale test, changes from a best estimate approach to a bounding approach, the role of scaling, and regulatory compliance were among the topics that were discussed. Comments made during the discussion are included as Attachment 2.

Future meetings on PIRT and scaling, WGOTHIC, and the licensing calculations and applications report were suggested. Dates for these meetings will be scheduled at a later time. Attachment 3 is the non-proprietary presentation materials provided by Westinghouse.

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

Docket No. 52-003

Attachments: As stated

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Jack Dawson, O-8 H7

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

December 27, 1995

APPLICANT: Westinghouse Electric Corporation

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Diane T. Jackson

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

Docket No. 52-003

Attachments: As stated

cc w/attachments:
See next page

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College Park, MD 20742

WESTINGHOUSE/NRC MEETING
PASSIVE CONTAINMENT COOLING SYSTEM
DECEMBER 6 AND 7, 1995
MEETING PARTICIPANTS

NAME	ORGANIZATION
JOHN BUTLER	WESTINGHOUSE
JIM GRESHAM	WESTINGHOUSE
DAVID PAULSON	WESTINGHOUSE
BAMBANG NUGROHO	WESTINGHOUSE
BRAIN MCINTYRE	WESTINGHOUSE
RICK OFSTUN	WESTINGHOUSE
DAN SPENCER	WESTINGHOUSE
JOEL WOODCOCK	WESTINGHOUSE
KAZIMIERAS CAMPE (12/6)	NRC/NRR/DSSA/SASG
JACK DAWSON	NRC/NRR/DSSA/SCSB
DIANE JACKSON	NRC/NRR/DRPM/PDST
JACK KUDRICK (12/7)	NRC/NRR/DSSA/SCSB
JOE SEBROSKY (12/7)	NRC/NRR/DRPM/PDST
EDWARD THROM	NRC/NRR/DSSA/SCSB
KAZY ALMENAS	NRC CONSULTANT
BEN GITNICK	SCIENTECH, INC. (NRC CONSULTANT)
DAN PRELEWICZ	SCIENTECH, INC. (NRC CONSULTANT)
BOB TEDESCO	SCIENTECH, INC. (NRC CONSULTANT)
LOTHAR WOLF	NRC CONSULTANT

Attachment 1

Comments:

1. Westinghouse explained that the bounding approach for DBA analysis was taken in August 1995. Prior to this, the approach taken was more like a best estimate approach.

2. Dan Spencer stated that Westinghouse was working on revisions to the scaling and PIRT documentation to reflect a more traditional approach.

3. Scientech requested the WCAP or information that addressed SRP and regulatory compliance. Scientech was interested in the report on annulus fogging. Scientech would like copies of NTD-NRC-94-4100 Enclosures 1 and 2. Westinghouse stated that work was continuing for revisions to WCAP-14190 and the roadmap, which Scientech would like to review when available.

4. Scientech questioned the small to zero margin between the calculated peak pressure and the design pressure. Westinghouse stated that margin exists in the calculations because they bound all conditions.

5. In regards to the new bounding approach, Scientech requested Westinghouse to provide a list of important, current information. Westinghouse stated that Chapter 9 in the WGOTHIC code description and validation report (WCAP-14382) should be disregarded. Westinghouse also stated that none of the work is invalid because of the new bounding approach.

6. Westinghouse takes credit for the subcooling of the PCS flow, which they previously did not. This change may affect conservativisms in the water coverage fractions. Westinghouse stated that the film flow stability model was under review.

7. Dr. Wolf and Dr. Almenas noted that the term "scaling" did not represent the classical meaning of the term and led to misunderstandings of the work that Westinghouse was trying to accomplish. The term "scaling" was clarified. Westinghouse performed some aspects of a scaling analysis for the LST, but not a full scaling analysis. Westinghouse scaling analysis is used to identify and rank important processes and normalize the governing equations.

8. Westinghouse clarified that the Large Scale Test (LST) does not directly predict all responses as the AP600 plant would. The LST was used to validate models used in the WGOTHIC code. The code would be used to predict plant behavior.

9. Dr. Almenas was interested in reviewing a containment floor plan to examine how natural convection could be established.

10. Scientech was interested in trends from the Zuber-Staub equation.

11. Scientech was interested in reviewing the energy balance of the wetted containment surface in the LST (WCAP-14135).

Attachment 2

12. Dr. Wolf was interested in reviewing the full noding for the WGOTHIC code.

13. Dr. Wolf and Dr. Almenas noted that Westinghouse relied on data and tests that where either 20 to 30 years old or recent AP600 specific data. They would like to understand the reasons for choosing the AP600 supporting data and literature.

14. Dr. Wolf requested Westinghouse to provide a more rigorous qualification of EPRI's GOTHIC code.

WESTINGHOUSE

NON-PROPRIEATARY PRESENTATION MATERIALS

FOR THE DECEMBER 6 & 7, 1995 MEETING BETWEEN

WESTINGHOUSE AND THE NRC ON

PASSIVE CONTAINMENT COOLING SYSTEM

Attachment 3

PRESENTATION
TO
UNITED STATES
NUCLEAR REGULATORY COMMISSION

AP600 Passive Containment Cooling System (PCS) Code Validation & Test Analysis Program

Briefing for Scientech

Rockville, MD

December 6-7, 1995

Scientech Briefing Meeting on AP600 PCS

Agenda

December 6, 1995

Introduction	8:00 - 8:30
A. AP600 PCS Design Overview	8:30 - 9:30
B. PIRT and Methodology Summary	9:30 - 10:30
C. PCS Test and Analysis Program Outline	10:30 - 11:30
NRC morning wrap-up	11:30 - 12:00
Lunch	
AP600 Testing Program	
D. Scaling	1:00 - 2:00
E. Separate Effects Testing	2:00 - 3:00
F. Integral Effects Testing	3:00 - 4:00
NRC afternoon wrap-up	4:00 - 4:30

Scientech Briefing Meeting on AP600 PCS

Agenda December 7, 1995

Coffee		8:00 - 8:15
G.	Water Coverage	8:15 - 10:15
H.	WGOTHIC Code	10:15 - 11:15
NRC morning wrap-up		11:15 - 12:15
	Lunch	
I.	AP600 PCS Evaluation Model Key Assumptions and Results	1:00 - 2:00
J.	Steps to Closure of Remaining Open Items	2:00 - 3:00
K.	Conclusions	3:00 - 3:30
L.	Action Items and Summary	3:00 - 4:00
NRC afternoon wrap-up		4:00 - 4:30

INTRODUCTION

December 6, 1995

B. A. McIntyre, Manager
Advanced Plant Safety and Licensing

Westinghouse Electric Corporation

Meeting Purpose

Provide a high level briefing to NRC consultants for final stage of PCS DBA review

Objectives

1. Discuss NRC review plans and schedule, and NRC needs with respect to briefing meeting
2. Summarize AP600 PCS design, phenomena, and key licensing issues
3. Provide a broad overview of the AP600 PCS DBA test and analysis program
4. Give overview of major evaluation model elements and their bases
5. Discuss closure paths to address key PCS licensing issues
6. Provide cross references to existing reports supporting PCS DBA
7. Identify need for any additional meetings to aid in the review process.

AP600 PCS DBA Review Progress

- 1992 Baseline SSAR submitted
  - WGOTHIC V&V
  - SSAR Chapter 6.2 - PCS
- 1993 Testing Completed
- 1993-94 Confirmatory PCS test and analysis reports issued
  - Confirmatory LST - Phases 2 and 3
  - Phased phenomenological reports (Number = 16)
  - NRC issued DSER
  - NRC issued RAIs
  - WGOTHIC Final V&V
  - Draft SSAR incorporating existing reviews
- 1995 Progress on licensing issue identification and resolution
  - Licensing issues have been identified
  - Phased evaluation model documentation
  - Road maps to information for reviewers
  - Additional sensitivities
  - DSER responses
  - RAI responses
- 1996 Applications report to compile phased submittals
- 1996 Final SSAR Ch 6.2

Scientech Briefing Meeting on AP600 PCS

A. AP600 PCS DESIGN OVERVIEW

December 6, 1995

J. Woodcock, Principal Engineer
Containment and Radiological Analysis

Contact: John Butler
Phone: 412-374-5268

Westinghouse Electric Corporation

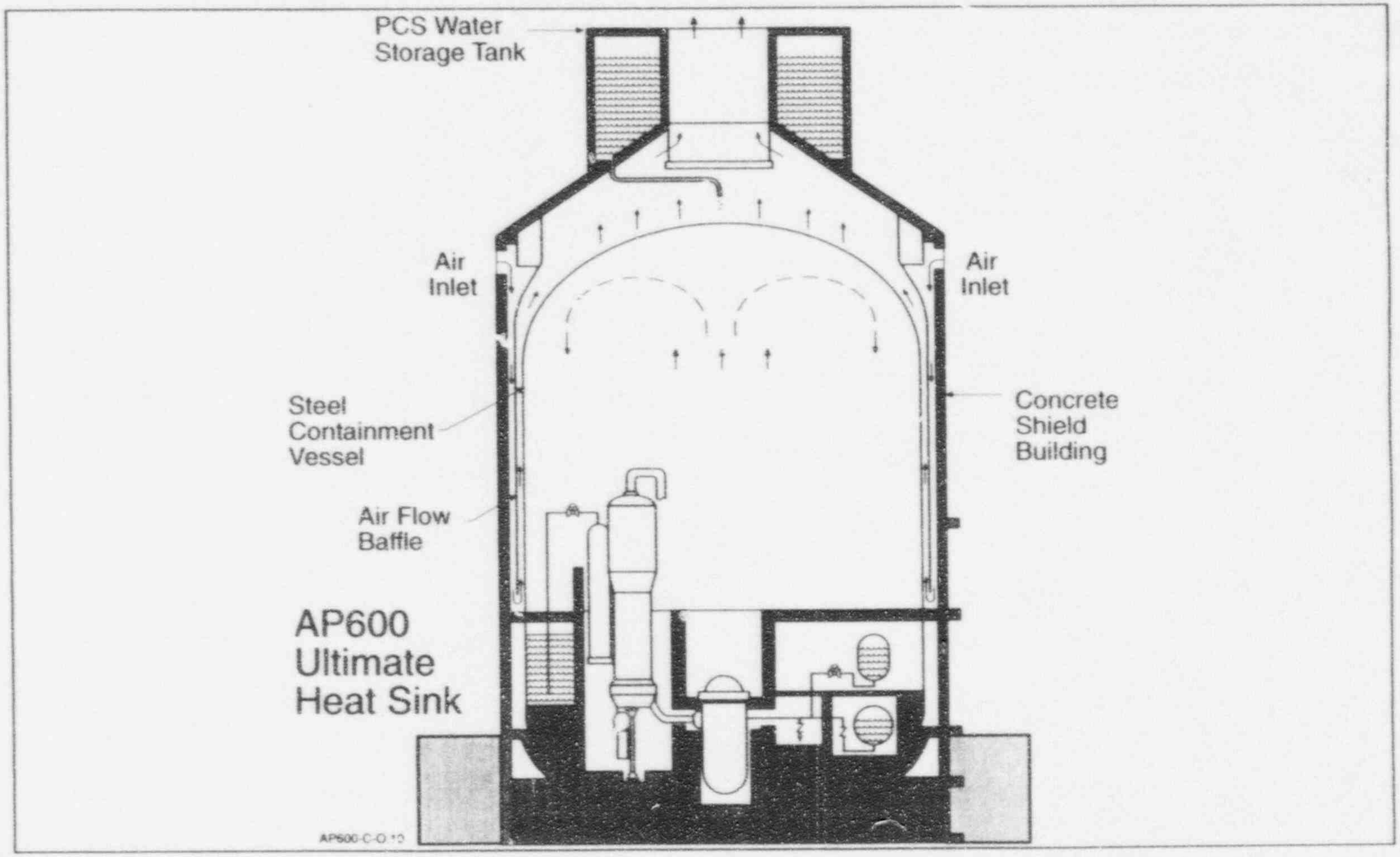
AP600 Plant Objectives

- **Safety**
  - Simple, dedicated, independent, passive safety systems
  - Substantial margin for design basis accidents
  - Core melt frequency < 10^{-5}/yr
- **Reliability**
  - Simplified design/operation/maintenance
  - 90% availability
  - 60 year design life
- **Economics**
  - 36 month construction schedule
  - No prototype required
  - Pre-engineered/pre-licensed standard design for U.S. sites

AP600 Key Design Features

- Simplified reactor coolant loop with canned motor pumps
- Low power density core
- Passive safety systems
- Simplified systems throughout the plant
- Microprocessor-based digital technology for I&C systems
- Control room design with electronic workstations for operator interface
- Plant arrangement based on integrated consideration for construction, operation, maintenance, safety and capital cost
- Use of modular construction

Containment Design Features



Passive Containment Cooling Design Features

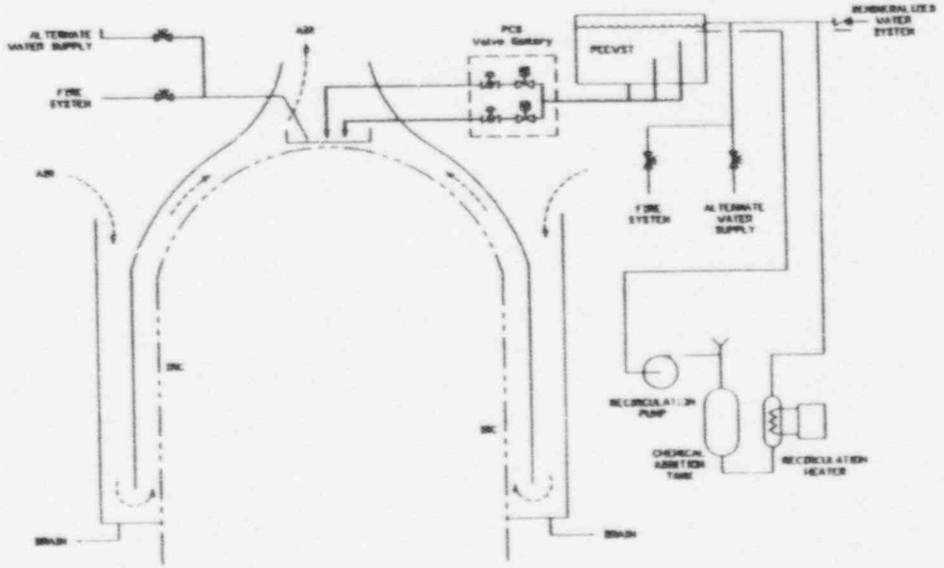
- Passive Containment Cooling Features Relative to Current Operating Plants
  - Increased containment volume to reactor power ratio
  - Increased steel surface area using modular design
  - Natural circulation flow path
  - Gravity-driven external cooling water delivery

- The only Active System Requirement Is a One-Time Valve Alignment To Begin PCS Water Delivery

- The Number of Required Safety-Grade Components Has Been Significantly Reduced

- Safety of the Plant has been Enhanced
  - System simplification
  - Reduced operator actions
  - High reliability
  - Minimum maintenance
  - Vessel material → increased safety factor

Diverse and Redundant PCS Tank Water Sources

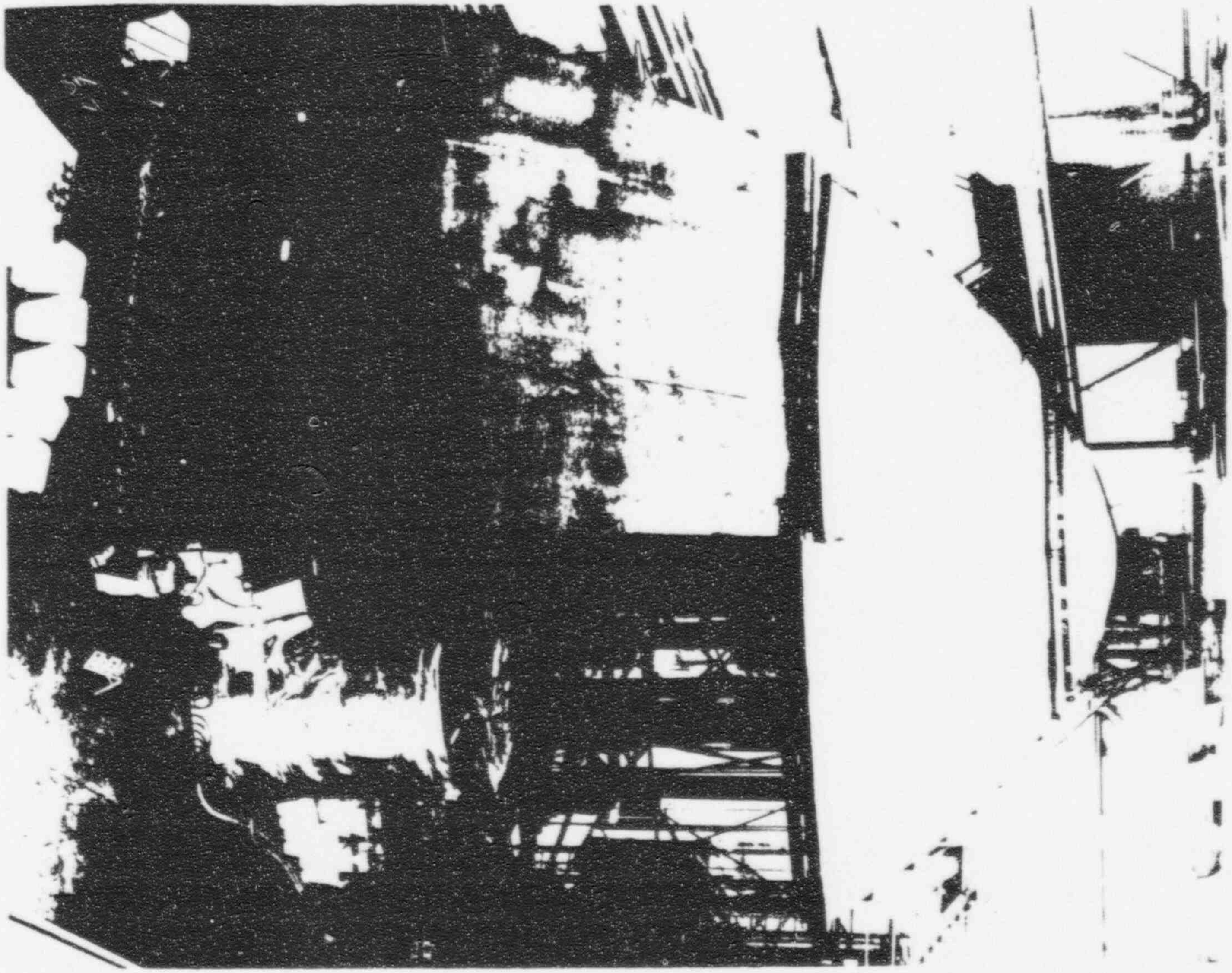


PCS Water Distribution System

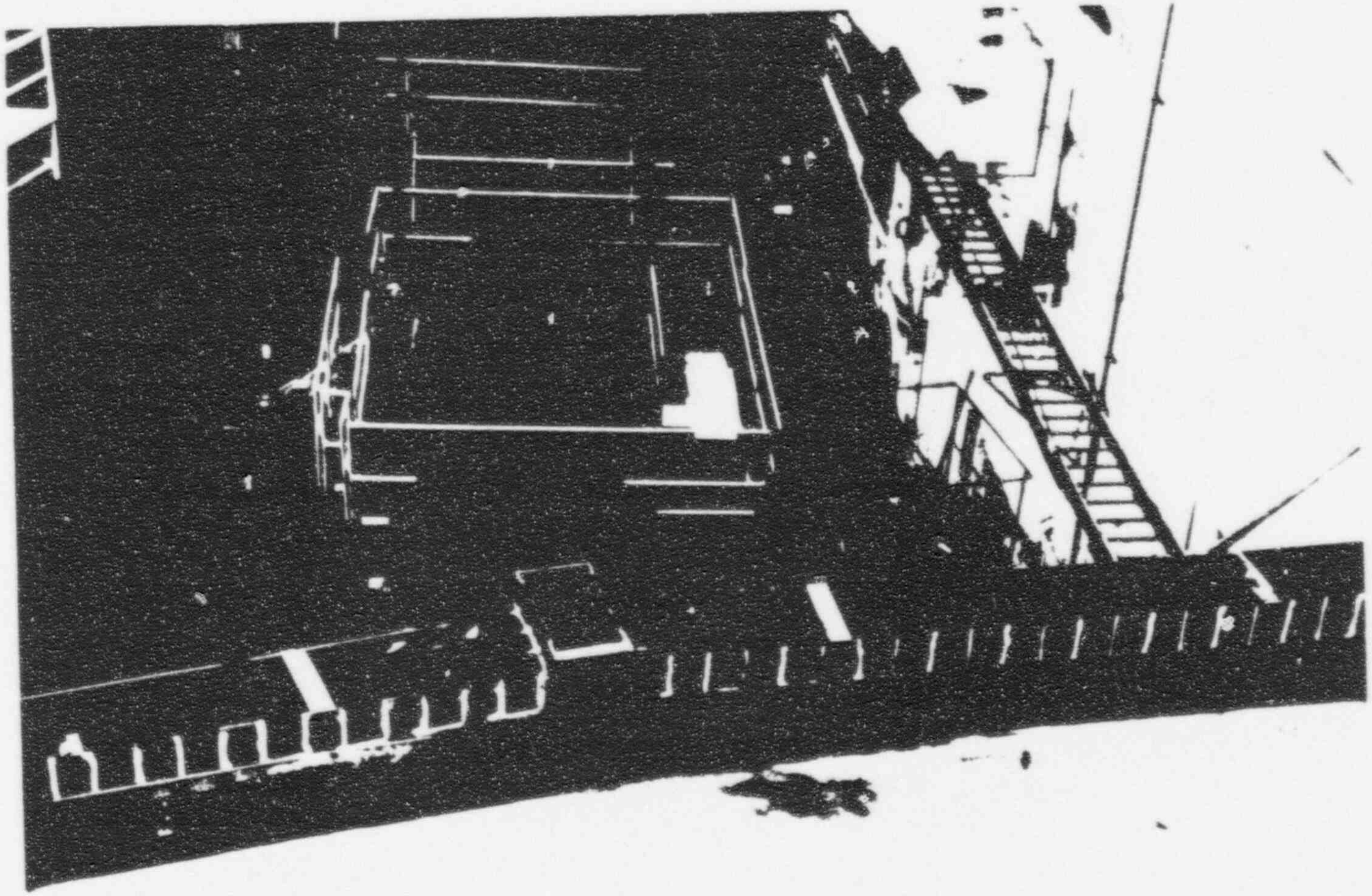
AP600

- Designed to distribute water over the outer containment shell
    - Bucket at center of dome with slots to initially distribute water
    - Two weirs on the dome (25 and 50 foot radii) to redistribute where area diverges
- Geometry of weirs designed to accommodate seismic conditions
- Large conduits feed dammed water into weirs and multiple "V" slots redistribute the water

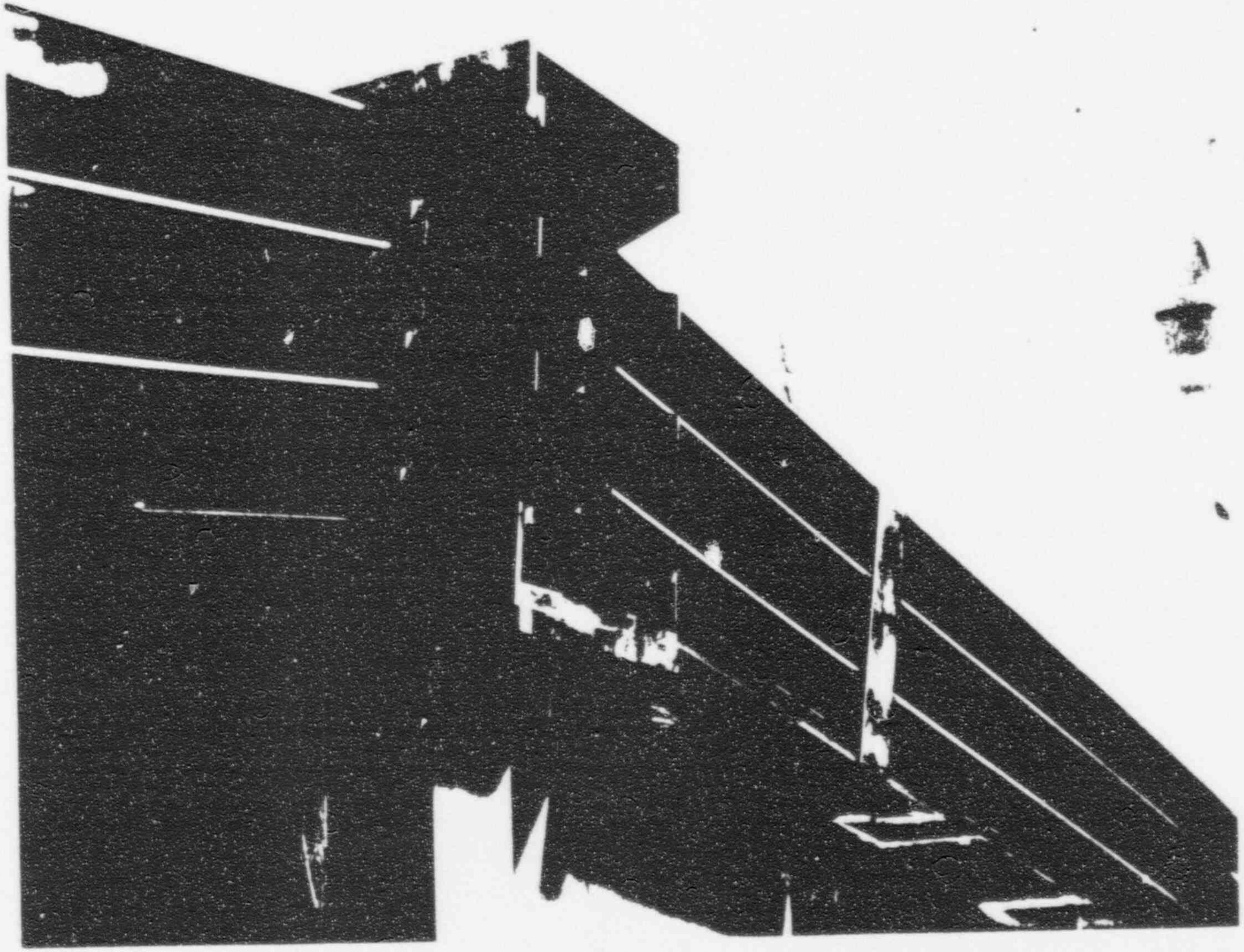
Full Scale Water Distribution Tests



Full Scale Water Distribution Tests



Full Scale Water Distribution Tests



Comparison of AP600 to Standard Westinghouse 2-Loop Plant

Plant Feature	*AP600*	*Standard 2-Loop Plant*
NSSS Thermal Power Rating (volume/power)	1940 MWt (0.88 ft.^{3}/kW)	1880 MWt (0.69 ft.^{3}/kW)
Containment Penetrations	40	93
Containment Diameter	130 ft.	109 ft.
Containment Net Free Volume	1,700,000 ft.^{3}	1,300,000 ft.^{3}
Exposed Mass Available for Heat Sinks		
Total internal concrete mass	14,734,000 lbm	14,343,000 lbm
Total internal steel mass	7,754,000 lbm	1,930,000 lbm
Long-Term Heat Removal	Passive cooling	Active systems - sprays - fan coolers

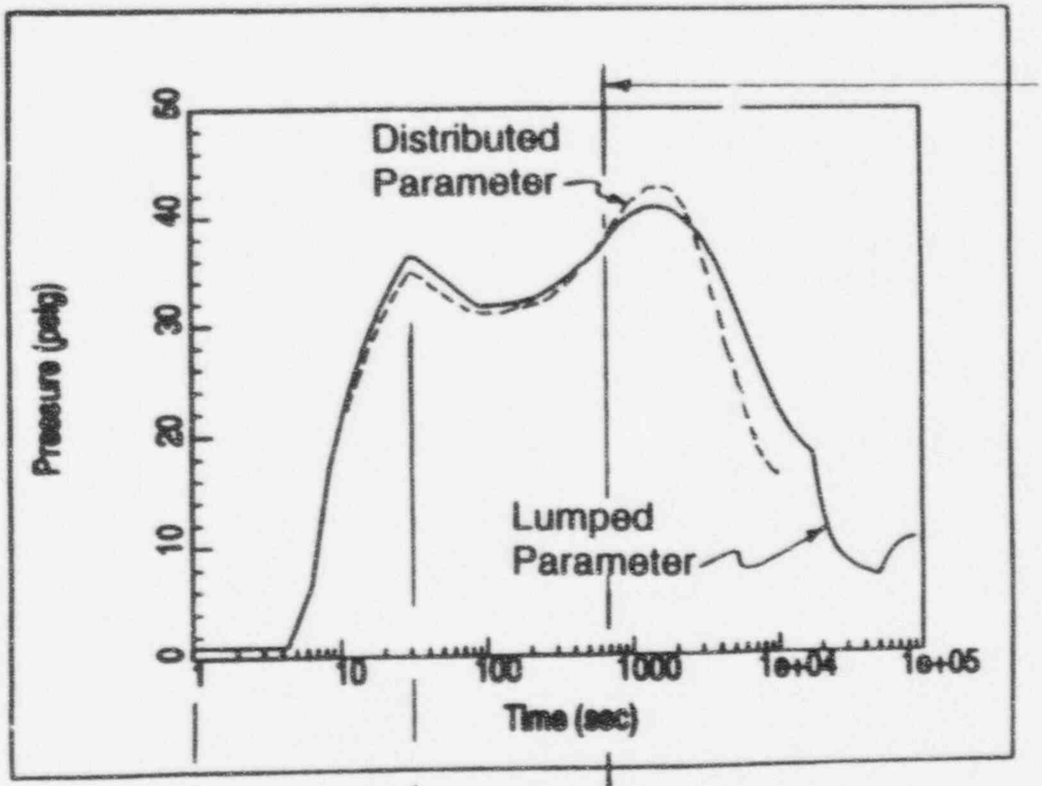
AP600 PCS DBA Shows Criteria Are Met

- July 1995 Preliminary/Draft Markups for SSAR Section 6.2

- Important Phenomena Bounded for Each Accident/Phase
  - LOCA peak pressure criterion met using distributed parameter to allow biasing of steam distribution
  - LOCA 24 hour pressure criterion met using bounding, highly mixed lumped parameter model
  - MSLB uses lumped parameter which has reduced steam access to below-deck heat sinks

AP600 PCS Response to LOCA Can Be Divided Into 3 Phases

From Preliminary Draft Markups of July 1995



PCS Water Conservatively Delayed to 660 seconds

Blowdown | Transition | PCS Long-term Cooling

Dominant Pressurization Mitigation Mechanisms

(Free Volume) (Internal Heat Sinks) (PCS heat transfer)

Criteria Addressed in the SSAR

- Containment design basis analysis (DBA) criteria

  $P_{peak} \leq$ 45 psig (60 psia)

  $P_{24\ hours} \leq 50\%\ P_{design}$

  $\Delta P_{subcompartment} \leq$ internal wall structural capability

  $T(t)_{DBA} \leq T(t)_{equipment\ qualification}$

  $P_{min} \geq$ minimum pressure capability

Summary of DBA Evaluation Model Development Process

- Important phenomena which must be considered were established using PIRT process
- An evaluation model was developed which includes models that bound important phenomena
- Bounding values were established for initial and boundary conditions
  - Worst case initial conditions
  - Conservative mass and energy releases
  - Conservative minimum water coverage

The evaluation model provides a conservative bound for all important phenomena

Status of Licensing interaction

- Documentation providing the bases for review of the evaluation model approach has been provided
- Bounding approach for correlation bias and mixing/stratification developed, discussed and submitted to NRC staff
- Sensitivities and documentation to confirm the bounding evaluation model approach have been performed
- Additional calculations are underway to support bounding approach
- Documentation of noding convergence study underway
- Responses are being provided to priority PCS RAIs

Conclusions

- AP600 PCS Design is a Simple, Robust Design which Provides:
  - Containment performance which is similar to existing operating plants
  - Margin to limits

- A bounding PCS DBA evaluation model has been established

Westinghouse Reports Issued to NRC on PCS DBA

Report Number	Report Title	Date Issued
NTD-NRC-94-4100, Enclosure 1	Radiation Heat Transfer Through Fog in the PCCS Air Gap	April 1994
NTD-NRC-94-4100, Enclosure 2	Liquid Film Model Validation	April 1994
NTD-NRC-94-4166	AP600 Containment Plume Investigation	June 1994
NTD-NRC-94-4174	AP600 PCS Design Basis Analysis (DBA) and Margin Assessment	June 1994
NTD-NRC-94-	AP600 Integrated Structure for Technical Issue Resolution (ISTIR) for Passive Containment Cooling System	July 1994
NTD-NRC-94-4247	Method for Determining Film Flow Coverage for the AP600 Passive Containment Cooling System	July 1994
NTD-NRC-94-4260	Enclosure 1: GOTHIC Containment Analysis Package, Version 3.4e, Volume 1: Technical Manual Enclosure 2: GOTHIC Containment Analysis Package, Version 3.4e, Volume 2: User's Manual (EPRI Proprietary) Enclosure 3: GOTHIC Containment Analysis Package, Version 3.4e, Volume 3: Qualification Report (EPRI Proprietary)	August 1994
NTD-NRC-94-4271	WGOTHIC Lumped Parameter LST Input Definition and Input Deck	August 1994
NTD-NRC-94-4286	Supplemental Information on AP600 PCS Film Flow Coverage Methodology	August 1994
NTD-NRC-94-4287	Experimental Basis for the Convective Heat Transfer Correlations Selected for Modeling Heat Transfer from the AP600 Containment Vessel	August 1994
NTD-NRC-94-4327	Experimental Basis for the Mass Transfer Correlations Selected for Modeling Condensation and Evaporation on the AP600 Containment Vessel	October 1994
NTD-NRC-94-4318 WCAP-14190	Scaling Analysis for AP600 Passive Containment Cooling System	October 1994
NTD-NRC-95-4397	Supporting Information for the Use of Forced Convection in the AP600 PCS Annulus	February 1995
NTD-NSA-CRA-95-096	Blind Pre-test Prediction (NRC declined to receive this document.)	April 1995

Report Number	Report Title	Date Issued
NTD-NRC-95-4428 WCAP-14326	Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations	April 1995
NTD-NRC-95-4459	Stratification and Mixing Effects on AP600 Passive Containment Cooling System DBA	May 1995
NTD-NRC-95-4463	Large-Scale Test Data Evaluation	May 1995
NTD-NRC-95-4462	EPRI Report RA-93-10, GOTHIC Design Review, Final Report	May 1995
NTD-NRC-95-4489 (WCAP-14382)	WGOTHIC Code Description and Validation	May 1995
NTD-NRC-95-4467 (PCS-T2C-059)	Analysis of PCS Wind Tunnel Testing for PCS Heat Removal	June 1995
NTD-NRC-95-4504	Proposed Draft/Markups of SSAR Sections 6.2 and 6.4 Enclosure 1: Markups of 6.2	July 1995
NTD-NRC-95-4545	AP600 PCS Design Basis Accident Roadmaps	August 1995
NTD-NRC-95-4558	Rationale for use of SATAN Computer Code for AP600	September 1995
NTD-NRC-95-4561	Scaling Role in AP600 PCS DBA Analysis	September 1995
NTD-NRC-95-4563	GOTHIC Version 4.0 Documentation Enclosure 1: Qualification Report Enclosure 2: Technical Manual Enclosure 3: User Manual	September 1995
NTD-NRC-95-4570	Bases for AP600 PCS DBA Mass Transfer Correlation Biases	September 1995
NTD-NRC-95-4577	Updated GOTHIC Documentation	October 1995
NTD-NRC-95-4595	AP600 WGOTHIC Comparison to GOTHIC	November 1995
NTD-NRC-95-4589	AP600 Containment Analysis for LOCA Blowdown	November 1995
NTD-NRC-95-4596	AP600 WGOTHIC Deck Flow Area Sensitivity	November 1995
NTD-NRC-95-**xxxx**	LOCA Break Spectrum for PCS DBA	December 1995
NTD-NRC-95-**xxxx**	Key Elements of the AP600 WGOTHIC PCS DBA Approach	December 1995

Report Number	**Report Title**	**Date Issued**
NTD-NRC-95-**xxxx**	Prioritization of PCS RAIs	December 1995

Scientech Briefing Meeting on AP600 PCS

B. Phenomena Identification and Ranking Table and Methodology Summary

December 6, 1995

J. Woodcock, Principal Engineer
Containment and Radiological Analysis

Contact: John Butler
Phone: 412-374-5268

PIRT and Methodology Summary

Outline

- PIRT Objectives and Process
- PIRT Results
- Methods used to Address Important PIRT Phenomena
- Conclusions

PIRT Objectives and Process

- Objective

  - Provide documentation of the bases for identification and prioritization of phenomena related to containment pressure mitigation

- Process

  - Partition containment spatially and temporally
  - Identify phenomena which can affect containment pressure response
  - Rank the phenomena relative to significance for pressure mitigation
  - Document bases for ranking of phenomena
  - Show how important phenomena are addressed in the PCS DBA evaluation model

PCS Post-Wetting PIRT For AP600 LOCA

PCS POST-WETTING PHENOMENA IDENTIFICATION AND RANKING TABLE FOR AP600 LOCA

Component	Phenomena	Ranking		
		internal	riser	downcomer
Module Volume	Multi-component compressible gasses	H	H	L
	Buoyancy	H	H	M
	Jet-plume mixing/entrainment	H	L	L
	Steam source superheating	M	-	-
	Flow field stability/stratification	L	L	L
Module Surface	Liquid film heat transfer	M	M	-
	Liquid film stability/coverage	L	H*	-
	Liquid film subcooling	M	M	-
	Free convection heat transfer	L	L	L
	Forced convection heat transfer	L	L	L
	Radiation heat transfer	L	L	L
	Free convection mass transfer	H	-	-
	Forced convection mass transfer	L	H	-
Module Solids	1-D transient conduction heat transfer	H	H	L
	2-or 3-D conduction	L	L	L
Inter-Module	Convection	L	M	L
	Conduction	H	H	L
	Form and friction losses	L	H	M

*Liquid film stability is analyzed separately and the results are imposed on the model.

PCS PIRT For AP600 MSLB

PCS PHENOMENA IDENTIFICATION AND RANKING TABLE FOR AP600 MSLB

Component	Phenomena	Ranking
		internal
Module Volume	Multi-component compressible gasses	H
	Buoyancy	L
	Jet-plume mixing/entrainment	H
	Steam source superheating	M
	Flow field stability/stratification	H
Module Surface	Liquid film heat transfer	M
	Liquid film stability/coverage	L
	Liquid film subcooling	M
	Free convection heat transfer	L
	Forced convection heat transfer	L
	Radiation heat transfer	L
	Free convection mass transfer	L
	Forced convection mass transfer	H
Module Solids	One-dimensional transient condition heat transfer	H
	Two or three-dimensional conduction	L
Inter-Module	Convection	L
	Conduction	L
	Form and friction losses	L

PIRT Results Summary

- PIRT provides a framework to show how phenomena are bounded in the evaluation model
- For each PIRT phenomenon, a road map has been provided
  - Ranking
  - AP600 boundary condition or phenomenological model
  - Test bases
  - Relevant report and conclusions
  - Applicability of LST
  - Validation basis
  - How validation results are used in evaluation model
  - How uncertainty is bounded

Evaluation Model Methods to Address Important PIRT Phenomena

LOCA and MSLB - Internal

- Module Volume

Compressible gasses, buoyancy, jet-plume mixing/entrainment, flow field stability, and stratification influence the degree of mixing and stratification, all of which affect internal heat sink efficiency by affecting steam concentration and velocity distributions.

The effect of steam concentration distribution is bounded by biasing the evaluation model to reduce heat sink efficiency for each accident/phase.

The effects of velocities are bounded by assuming free convection internal to containment, neglecting significant forced convection enhancement which results from highly kinetic steam releases.

Evaluation Model Methods to Address Important PIRT Phenomena

LOCA and MSLB - Internal

- Module Surface

Mass transfer is the dominant mode of containment heat removal

Free convection is conservatively assumed.

The condensation correlation is biased to bound separate effects test data.

Evaluation Model Methods to Address Important PIRT Phenomena

LOCA and MSLB - Internal

- Module solids / Inter-Module

Conduction into the internal heat sinks and through the containment shell affects the temperature of the surface onto which steam condenses.

> The volume and area of internal heat sinks is conservatively underestimated.

Evaluation Model Methods to Address Important PIRT Phenomena

LOCA - External

- Module Volume

Compressible gases, buoyancy affect flow through the external annulus.

The downcomer contributes insignificantly to energy and momentum in the external annulus flow path.

Buoyancy-driven flows through the external annulus are explicitly calculated to provide input to the bounding heat and mass transfer correlations.

Evaluation Model Methods to Address Important PIRT Phenomena

LOCA - External

- Module Surface

Liquid film stability and coverage affects the area over which evaporation occurs.

Film coverage is addressed with bounding minimum water coverage for input boundary condition for the evaluation model.

Forced convection mass transfer is the dominant heat removal mechanism in the external annulus.

The evaporation correlation is biased to bound separate effects test data.

Evaluation Model Methods to Address Important PIRT Phenomena

LOCA - External

- Module Solids / Inter-Module

Conduction is bounded as discussed for internal containment.

Flow through the external annulus results from the balance of form and friction losses with the buoyancy induced by heating the annulus riser air. Higher losses reduce annulus flow.

> A nominal loss coefficient is assumed for the external annulus based on pressure loss coefficient tests. PCS performance is not sensitive to relatively large variations in the external loss coefficient, so there is negligible impact on pressure calculations.

Conclusions

- The Phenomena Identification and Ranking Table (PIRT) aids the review of the bases for identification and prioritization of phenomena related to containment pressure mitigation

- The PIRT has assisted the development and discussion of how the important phenomena are addressed in the PCS DBA evaluation model

C. AP600 PCS TEST AND ANALYSIS PROGRAM OUTLINE

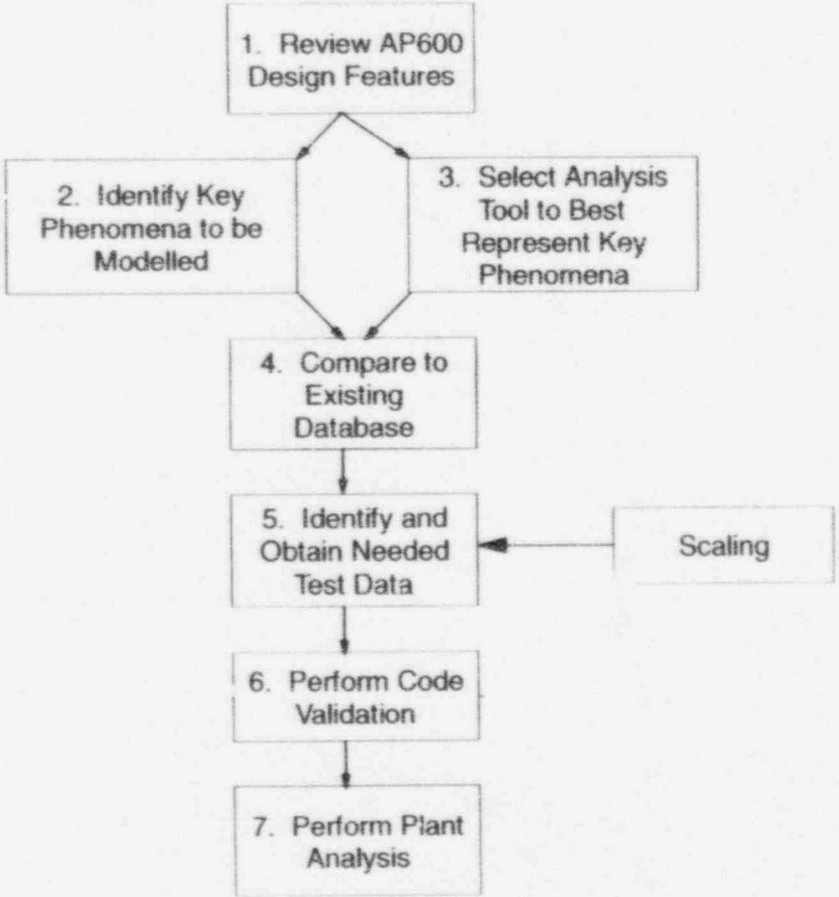
December 6, 1995

J. Woodcock, Principal Engineer
Containment and Radiological Analysis

Contact: John Butler
Phone: 412-374-5268

Westinghouse Electric Corporation

AP600 PCS Test and Analysis Program



1. Review AP600 Design Features

2. Identify Key Phenomena to be Modelled

3. Select Analysis Tool to Best Represent Key Phenomena

4. Compare to Existing Database

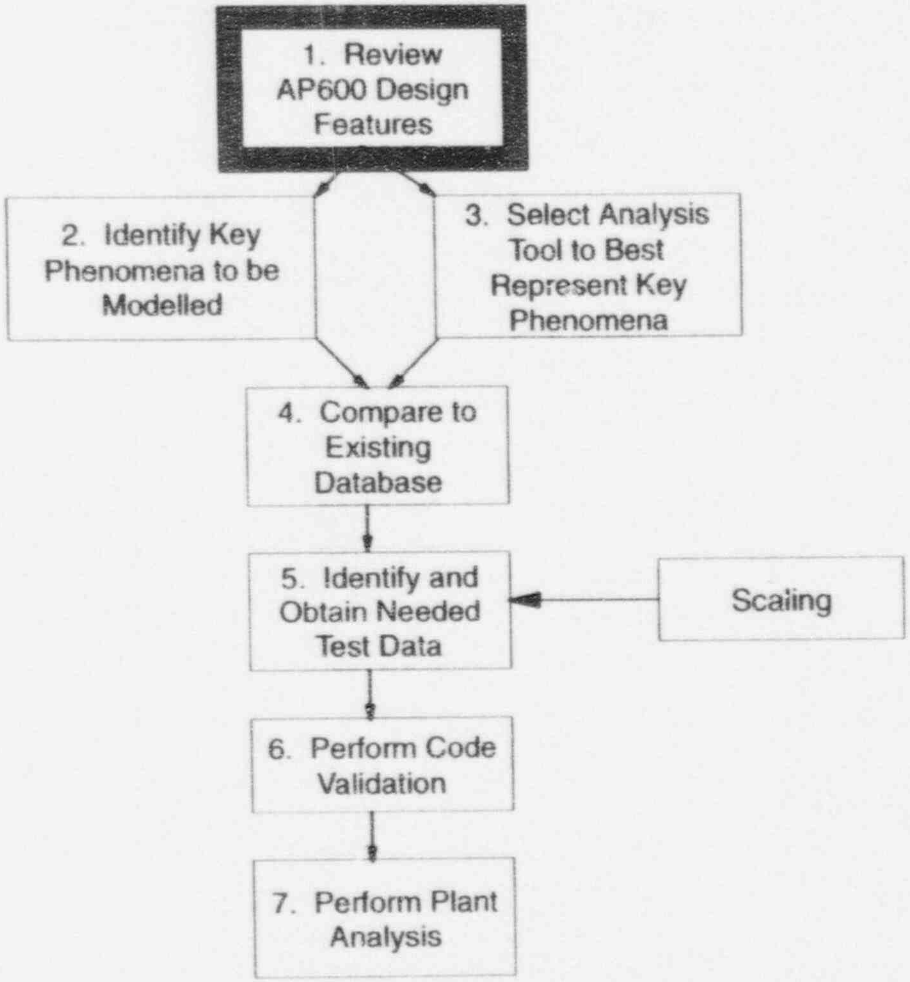
5. Identify and Obtain Needed Test Data

Scaling

6. Perform Code Validation

7. Perform Plant Analysis

Block 1. Review Ap600 Containment Design Features



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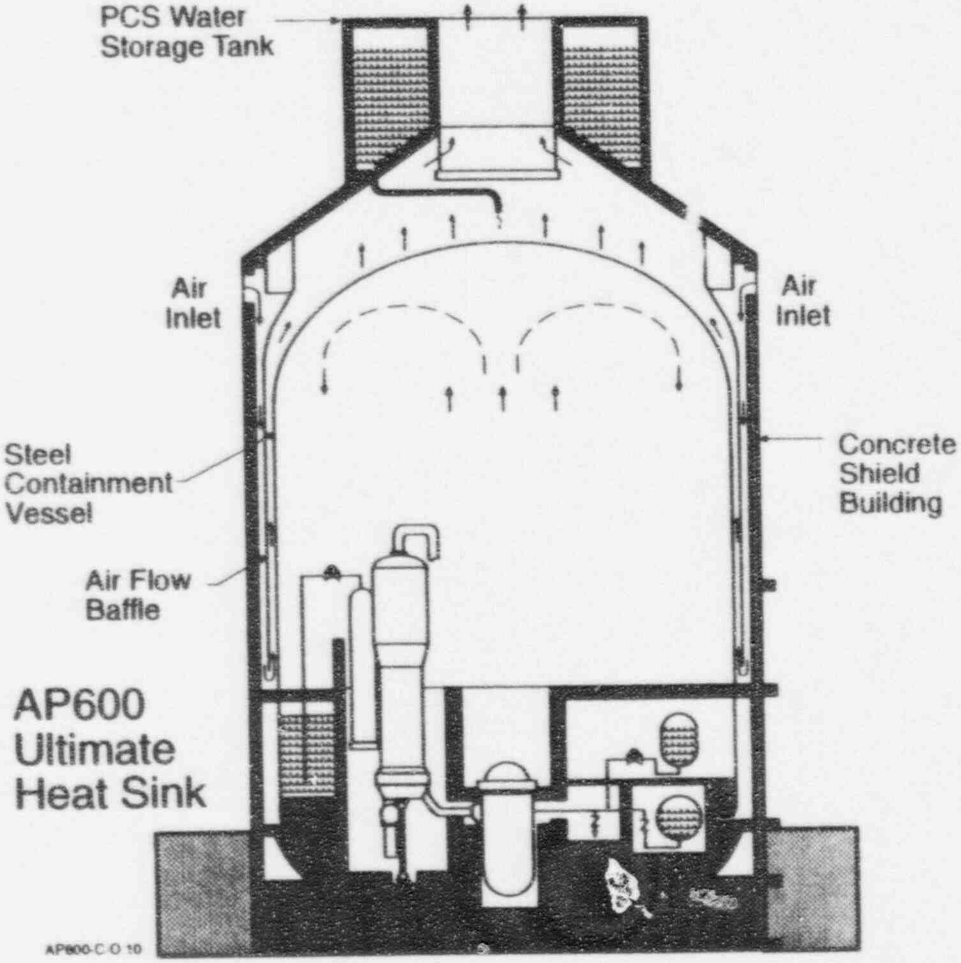
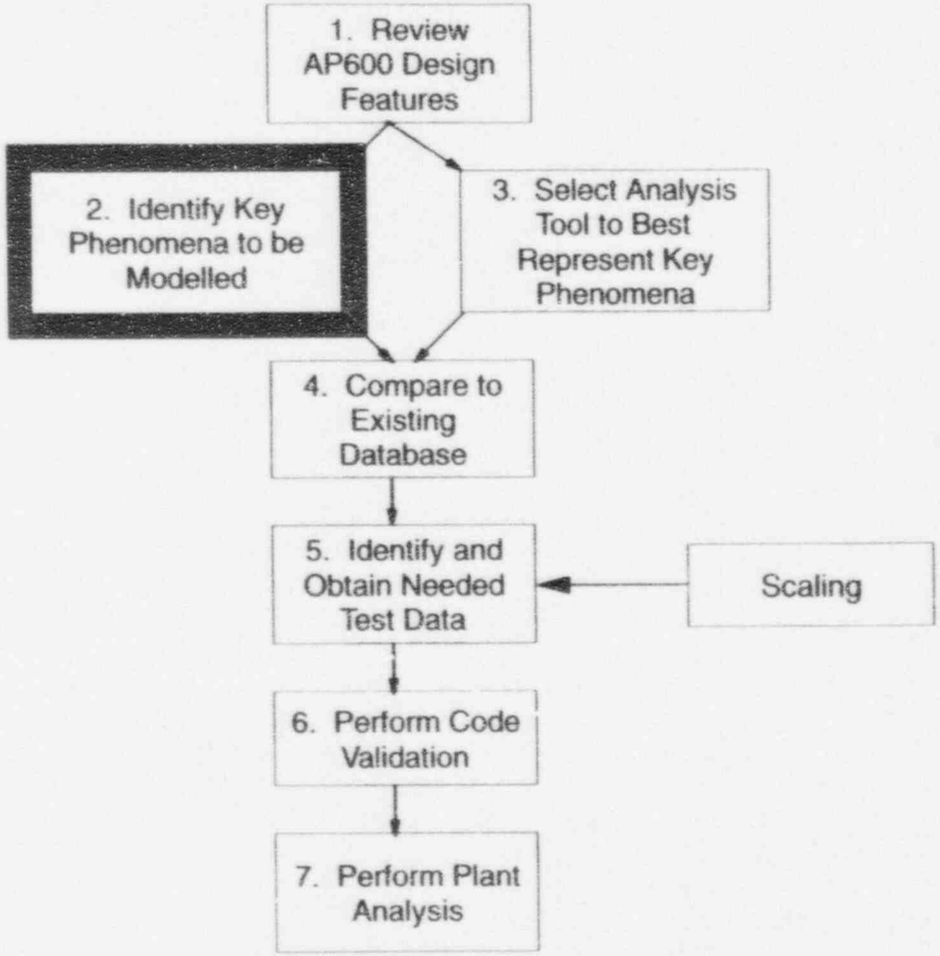


AP600 Ultimate Heat Sink

Block 2. Identify Key Phenomena to be Modelled

AP600



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Block 2. Identify Key Phenomena To Be Modeled

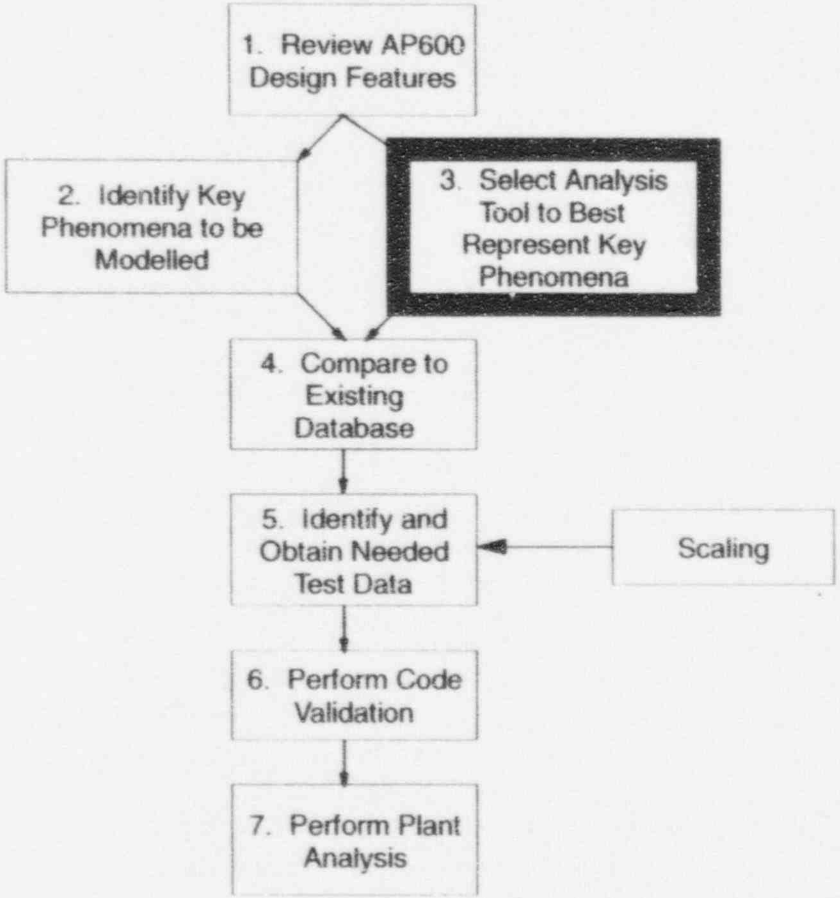
- Volume and momentum-related
    - noncondensible distributions and stratification
    - jets and buoyant plumes
    - wall boundary layer entrainment
    - wind effects on PCS flow
    - friction and form losses in external flow path

- Surface-related
    - liquid film heat transfer, coverage, and stability
    - liquid film subcooling
    - free and forced convective heat transfer
    - free and forced convective mass transfer with noncondensables
    - radiation heat transfer

- Transient conduction heat transfer

- A Phenomena Identification and Ranking Table (PIRT) has been completed for PCS design basis analysis

AP600 PCS Test and Analysis Program



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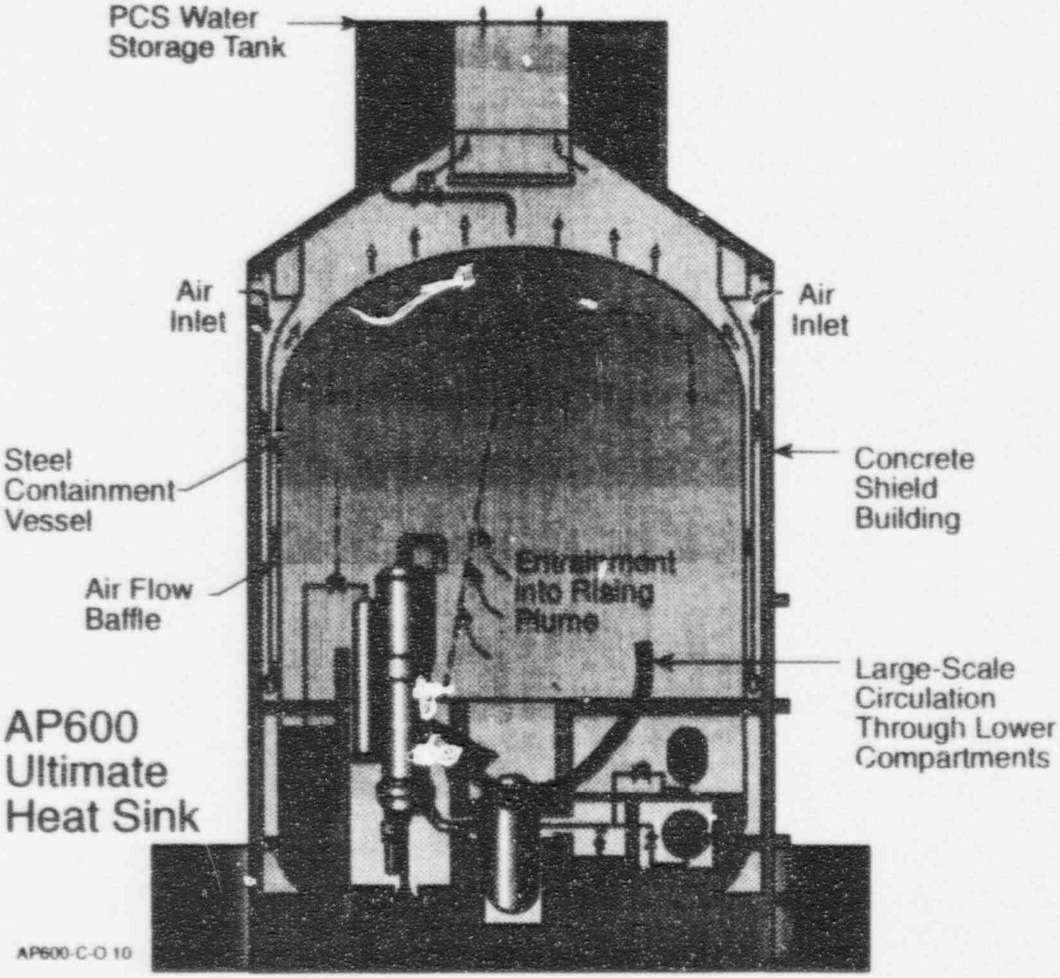
Block 3. Select Analysis Tool To Best Represent Key Phenomena

GOTHIC Was Selected over other Available Codes because of Its:

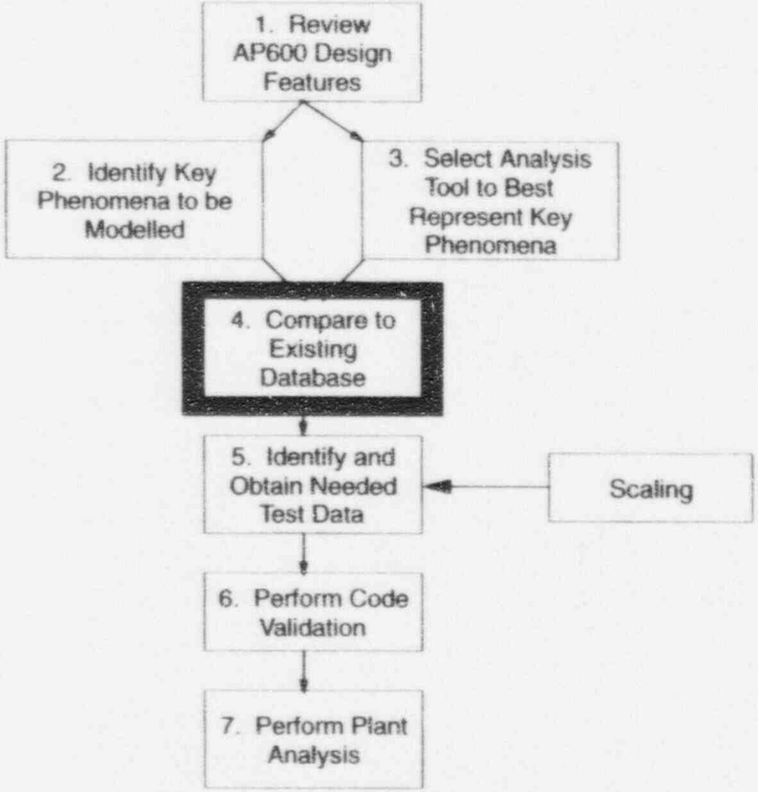
- State-of-the-art, two-phase flow models with noncondensibles
  - Multiple fields
    - Drop
    - Liquid
    - Vapor and Noncondensibles
  - Governing equations
    - Node-network (lumped parameter)
    - Distributed parameter (finite difference)
- Capability to model AP600 key phenomena
- Existing validation for complex containment analysis

WGOTHIC Has Capability To Address Circulation and Mixing



AP600 Ultimate Heat Sink

Block 4. Compare to Existing Database



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Block 4. Compare To Existing Database

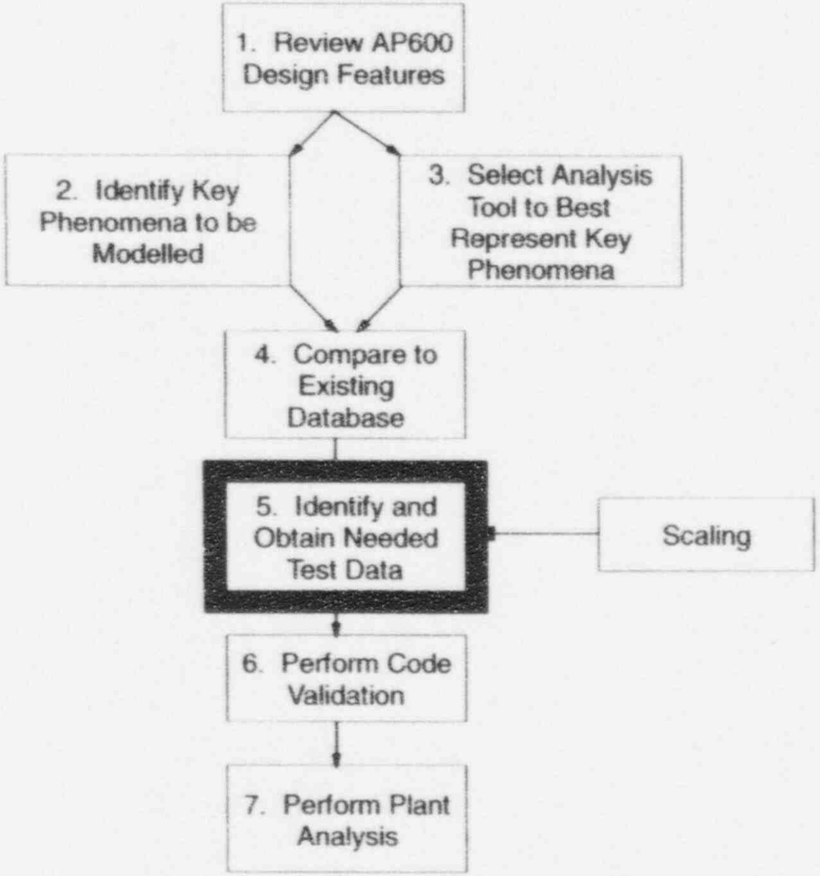
Containment Process	AP600 Uniqueness WRT W Plants	Containment Validation Does It Exist	AP600-Specific Validation Needed	Comments
Evaporative Liquid Film Cooling	Yes	No	Yes	Performed PCS tests, 1/8-scale tests, heated plate tests to develop data, literature
Condensation, with Noncondensables	No	Yes, not AP600-specific	Yes	CVTR, U. of Wisconsin, literature
Air Cooling of Steel Shell	Yes	No	Yes	Performed a large-scale test to simulate air passage
Radiant Heat Transfer from Steel Containment Vessel	No	Yes	Yes	Used prototypic surfaces in tests of external cooling capability
Internal Circulation Patterns in Containment	No	Yes, not AP600-specific	Yes	Performed a large-scale test to simulate containment
Effect of Hydrogen on Containment Heat Transfer	No	Yes, not AP600-specific	Yes (severe accident)	Performed large-scale tests which included helium to simulate hydrogen
Liquid Film Distribution on Containment	Yes	No	Yes	Performed film flow experiments to investigate the water distribution • Flat plate tests • Large-scale film flow tests
Friction and Form Losses in External Flow Path	Yes	No	Yes	Performed external flow path pressure drop tests
Effects of Buildings and Wind Velocity on Air Flow Over Steel Shell	Yes	No	Yes	Performed wind tunnel tests with building and site effects

Block 4. Compare to Existing Database

- Data Needs were Identified
  - Literature Separate Effects
  - Westinghouse Separate Effects
  - Westinghouse Integral Tests

- Data Sources have been Evaluated for Completeness and Applicability to AP600

Block 5. Identify and Obtain Needed Test Data



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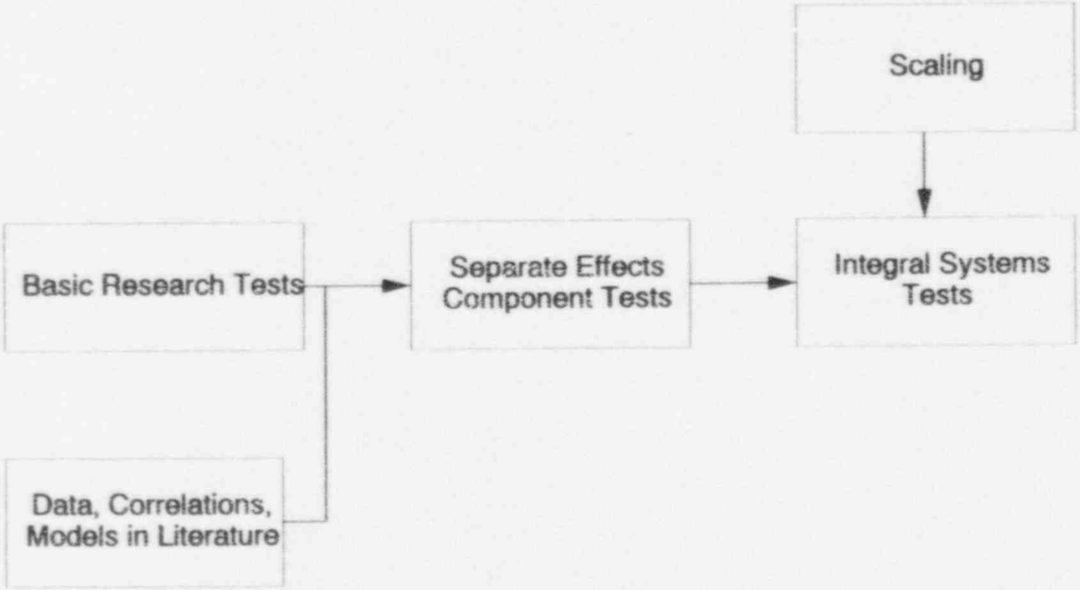


- Identify and capture phenomena on small scale

- Examine phenomena on larger scale, hardware, geometry more AP600 specific
- Develop boundary conditions for plant analysis

- Verify range of phenomena to be captured
- Show applicability of tests to full scale

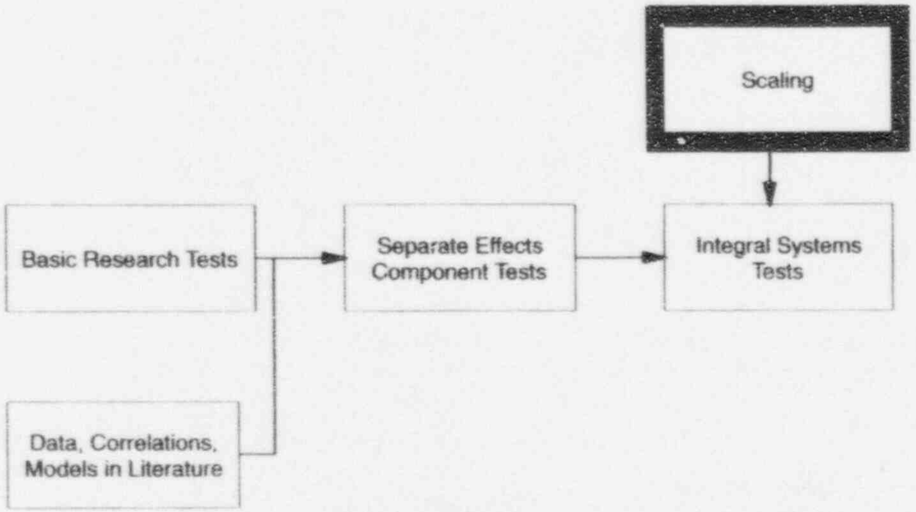
- Examine the interrealtionship of different phenomena at different scales

Block 5. Identify and Obtain Needed Test Data

- Basic Research Tests and Literature Test Data Have Been Combined with Separate Effects Tests to Develop Phenomenological Models

- The Integral PCS Large Scale Test (LST) Has Been Completed and Data Used as Basis for Code Validation and Evaluation Model Development

Scaling Evaluation of AP600 PCS and LST



Scaling

Basic Research Tests

Separate Effects Component Tests

Integral Systems Tests

Data, Correlations, Models in Literature

- Identify and capture phenomena on small scale

- Examine phenomena on larger scale, hardware, geometry more AP600 specific
- Develop boundary conditions for plant analysis

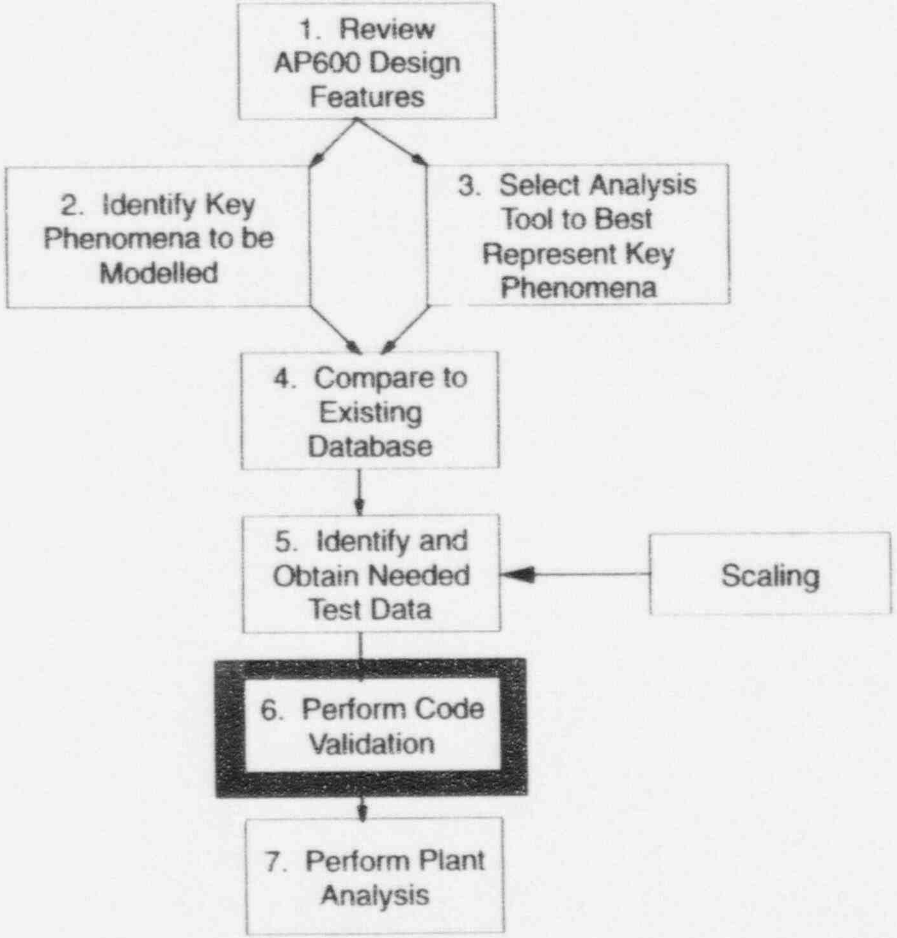
- Verify range of phenomena to be captured
- Show applicability of tests to full scale

- Examine the interrelationship of different phenomena at different scales

Block 5. Identify and Obtain Needed Test Data

- Scaling of AP600 and the Integral PCS Test Has Been Performed
  - Phenomena for AP600 are identified (PIRT-validated)
  - Dominant heat removal mechanisms are identified
  - Atypicalities in the LST and the effects of scale are identified

Block 6. Perform Code Validation



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Scaling

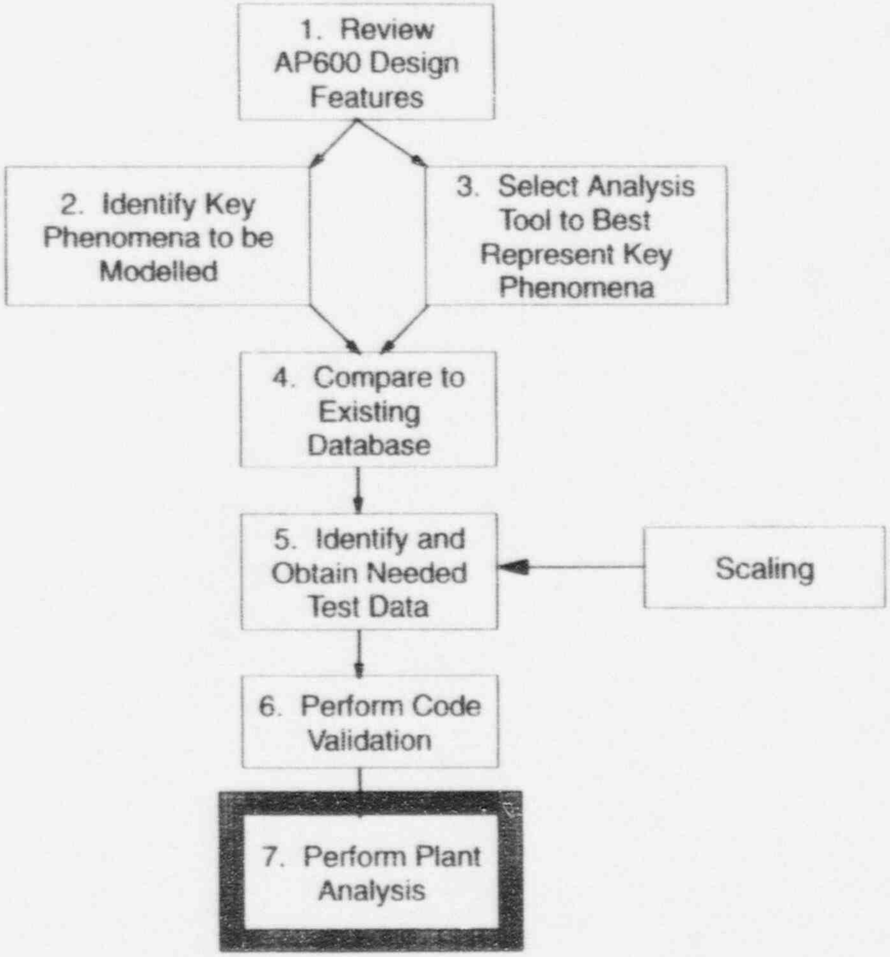
6. Perform Code Validation

7. Perform Plant Analysis

Block 6. Perform Code Validation

- Code Validation Has Been Completed
- WGOTHIC Calculations Have Been Completed for Separate Effects Tests to Verify Models
- WGOTHIC Comparisons to the LST Support Predictive Capability and Bounding PCS Evaluation Models

Block 7. Perform Plant PCS Analysis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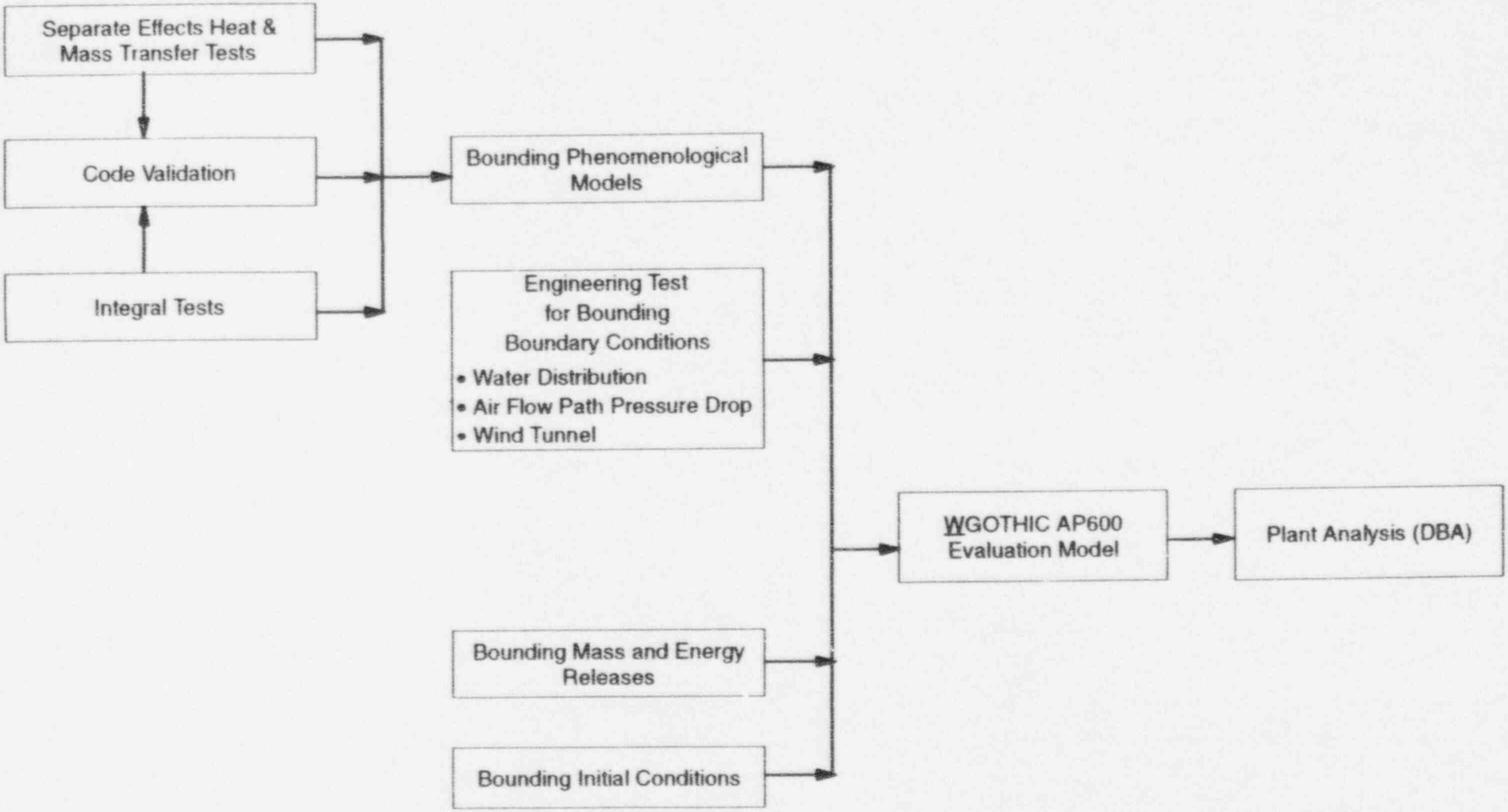
Application of Test & Analysis to Evaluation Model



Separate Effects Heat & Mass Transfer Tests

Code Validation

Integral Tests

Bounding Phenomenological Models

Engineering Test for Bounding Boundary Conditions

- Water Distribution
- Air Flow Path Pressure Drop
- Wind Tunnel

Bounding Mass and Energy Releases

Bounding Initial Conditions

WGOTHIC AP600 Evaluation Model

Plant Analysis (DBA)

Summary of Containment Design Criteria

10 CFR 50 App. A

Criterion 16 -- Containment design
"Reactor containment...shall...establish an essentially leak-tight barrier against the uncontrolled release of radioactivity to the environment and to assure that the containment design conditions important to safety are not exceeded for as long as postulated accident conditions require."

Criterion 38 -- Containment heat removal
"...The system safety function shall be to reduce rapidly, consistent with the functioning of other associated systems, the containment pressure and temperature following any loss-of-coolant accident and maintain them at acceptably low levels...for onsite...and offsite electric power system operation...assuming a single failure."

Summary of Containment Design Criteria (continued)

10 CFR 50 App. A (continued)

Criterion 50 -- Containment design basis
"The reactor containment structure, including access openings, penetrations, and the containment heat removal system shall be designed so that the containment structure and its internal compartments can accommodate, without exceeding the design leakage rate and with sufficient margin, the calculated pressure and temperature conditions resulting from any loss-of-coolant accident. This margin shall reflect consideration of

(1) the effects of potential energy sources which have not been included in the determination of the peak conditions, such as energy in steam generators and as required by § 50.44 energy from metal-water and other chemical reactions that may result from degradation but not total failure of emergency core cooling functioning,

(2) the limited experience and experimental data available for defining accident phenomena and containment responses, and

(3) the conservatism of the calculational model and input parameters.

Summary of Containment Design Criteria (continued)

10 CFR 52.47 (b)(2)(i)

"Certification...will be granted only if:

(A)(1) The performance of each safety feature of the design has been demonstrated through either analysis, appropriate test programs, experience, or a combination thereof;...

(3) Sufficient data exist on the safety features of the design to assess the analytical tools used for safety analyses over a sufficient range of normal operating conditions, transient conditions, and specified accident sequences..."

Containment Chapter 6.2 Safety Evaluation Criteria

- Containment Design Basis Analysis (DBA) Criteria

  $\mathbf{P_{peak} \leq 45\ psig\ (60\ psia)}$

  $\mathbf{P_{24\ hours} \leq 50\%\ P_{design}}$

  $\Delta P_{subcompartment} \leq$ internal wall structural capability

  $T(t)_{DBA} \leq T(t)_{equipment\ qualification}$

Note: $P_{yield} = 120$ psig

*SSAR 3.8.2.4.2.7 Pressure at minimum specified yield based on minimum specified material properties, reduced to consider 400°F effects.

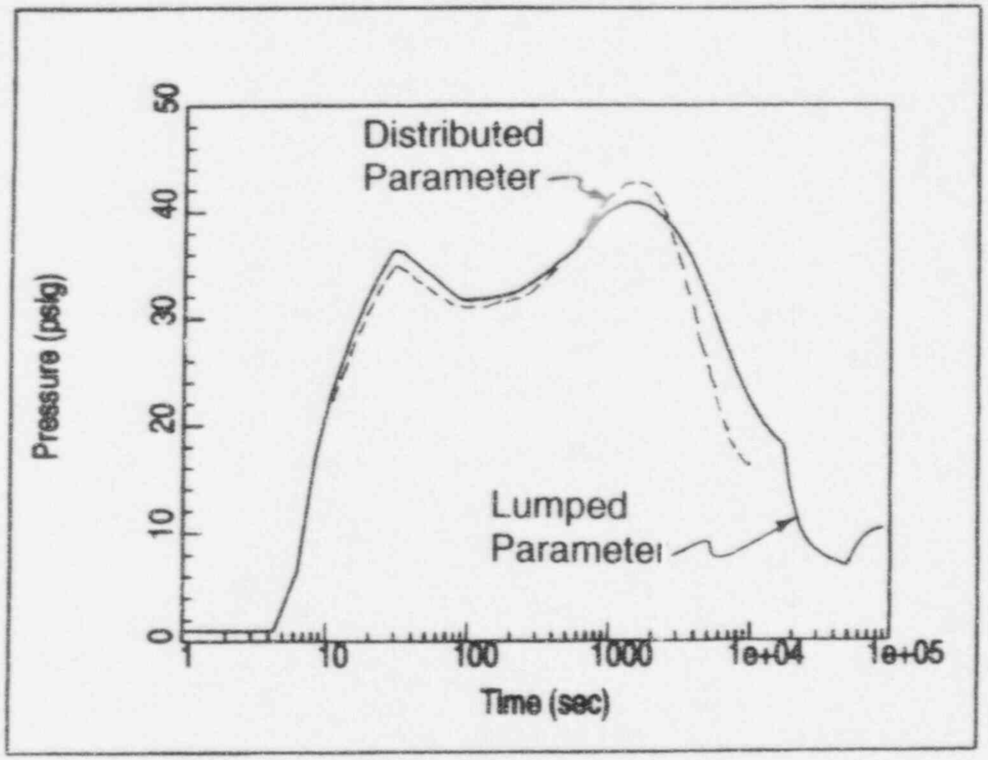
LOCA DBA Evaluation Model Approach

- Distributed parameter (more accurate) AP600 model is used to calculate pressure through the second peak when the pressure most nearly approaches design pressure

- Lumped parameter (faster running) AP600 model is used to calculate LOCA transient to evaluate 24 hour criterion

LOCA DBA Evaluation with Lumped and Distributed Parameter

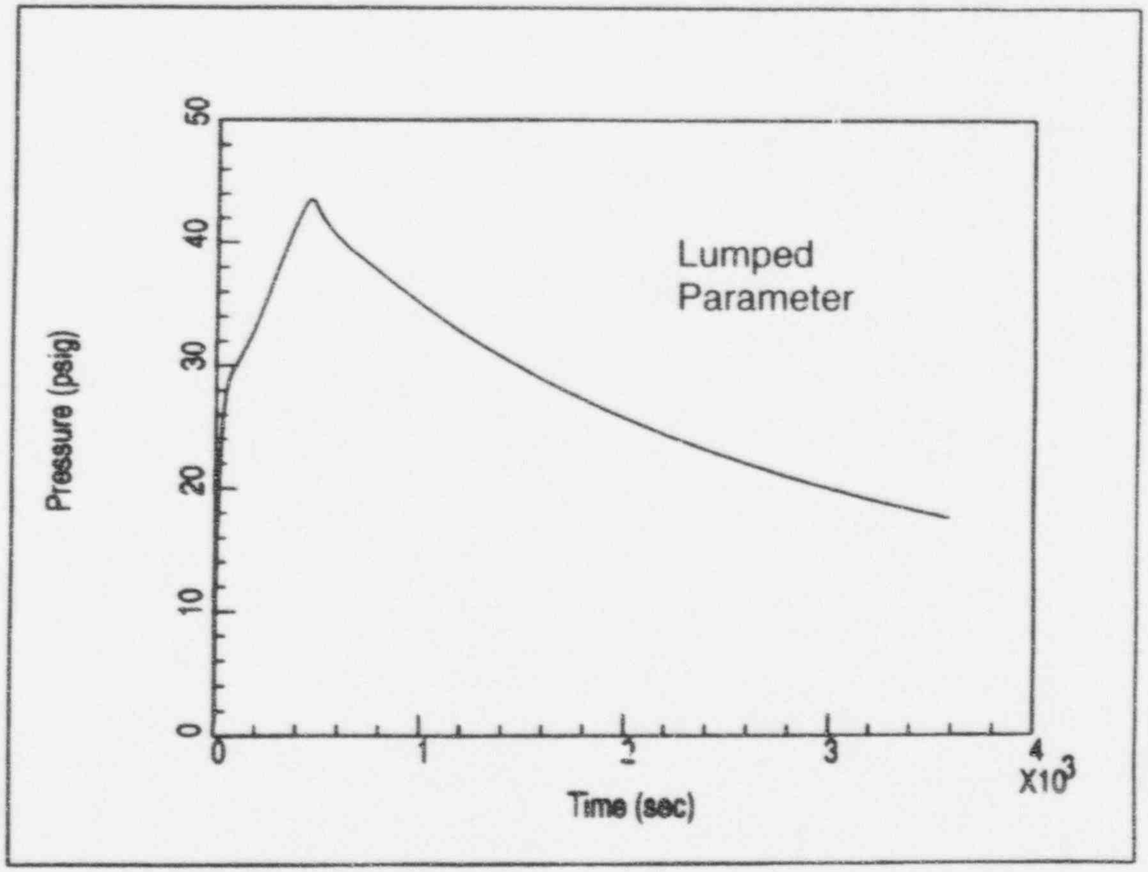
From Preliminary Draft Markups of July 1995



Postulated DBA Accident Scenarios are Being Addressed

From Preliminary Draft Markups of July 1995

MSLB



Evaluation Model

AP600

- Three LOCA Phases and the Main Steamline Break Are Considered
- The Dominant Phenomena Identified by the PIRT have been addressed
- The bases for a bounding evaluation model have been established
- Sensitivities have been performed to confirm the bounding analysis approach

Summary of PCS Analysis Approach

PCS Test and Analysis Program Has Been Structured To Meet Criteria of 10 CFR 50 App. A and 52.47

- The test program captures the key phenomena as identified in the PIRT and a scaling analysis supports use of LST facility and separate effects tests
- Sufficient data exist to assess the calculational model over the range of conditions for DBA
- Containment DBA approach includes sufficient margin to reflect consideration of:
    - Appropriate energy sources
    - Extent of experimental data available
    - Conservatism of calculational model and input parameters

Scientech Briefing Meeting on AP600 PCS

AP600 Testing Program

D. Scaling

December 6, 1995

D. R. Spencer, Principal Engineer
Containment and Radiological Analysis

Contact: John Butler
Phone: 412-374-5268

Westinghouse Electric Corporation

Outline

- Scaling Goals
- Scaling Approach
- Accident Specification
- The PIRT
- Results of Scaling
  - Containment Pressure
  - Energy Transfer Resistance
  - Internal Momentum
  - External PCS Air Momentum
- Scaling Conclusions: Evaluation Modeling Requirements

SCALING GOALS

- Scaling is used to identify the major transient modeling requirements for inclusion in the evaluation model
- Scaling provides an auditable basis to:
  - Organize the transport processes and interactions with components
  - Identify for inclusion in the evaluation model the major transient modeling requirements (components and processes)
  - Define similarity criteria for tests to support phenomenological model development
  - Provide support for, and input to, bounding models

SCALING APPROACH

- Utilized guidance for an Integrated Structure for Technical Issue Resolution (ISTIR) presented in NUREG/CR-5809
  - Define plant, accident, and success criteria
  - Develop equations and relationships, in terms of known parameters, for:
    - Containment pressure
    - Energy transfer resistance
    - Air flow path momentum
    - Intra-compartment momentum
    - Inter-compartment momentum
  - Nondimensionalize each term with reference parameters.
  - Normalize each term with an appropriate reference term.
  - Manipulate each term to:
    - Emphasize recognized dimensionless groups (Re, Gr, Pr, etc.).
    - Extract time constants and characteristic lengths.
  - Quantify each term, during each time phase, and rank importance.

ACCIDENT SPECIFICATION

PLANT:

The 2-loop Westinghouse AP600 with a passive containment cooling system. No active containment cooling systems are operational.

ACCIDENT:

A DECLG rupture is postulated to occur in a steam generator compartment. The reactor cooling system blows down, followed by the direct water injection from accumulators, core makeup tanks, and the IRWST.

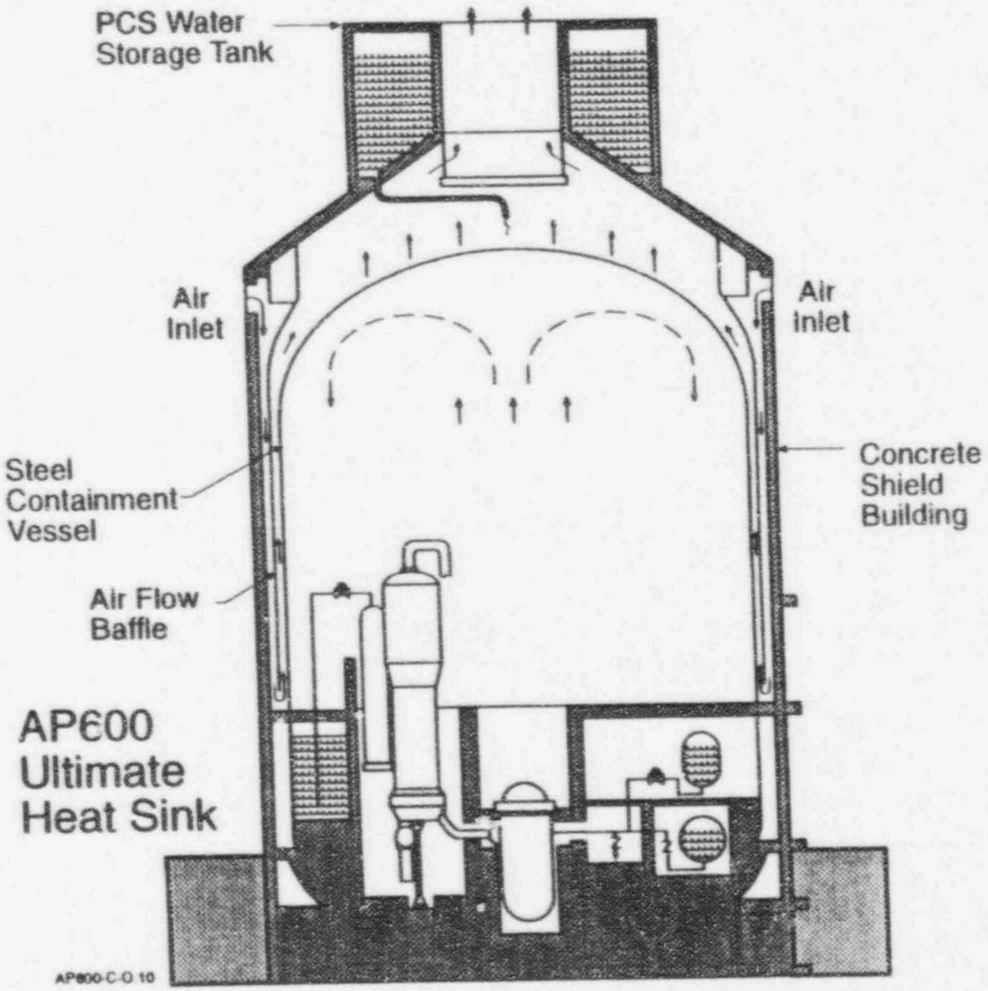
An MSLB is postulated to occur at the top of the steam generator. The reactor is at 30% power and the MSIV fails.

SUCCESS CRITERIA:

Prevent the peak containment pressure from exceeding its design pressure.

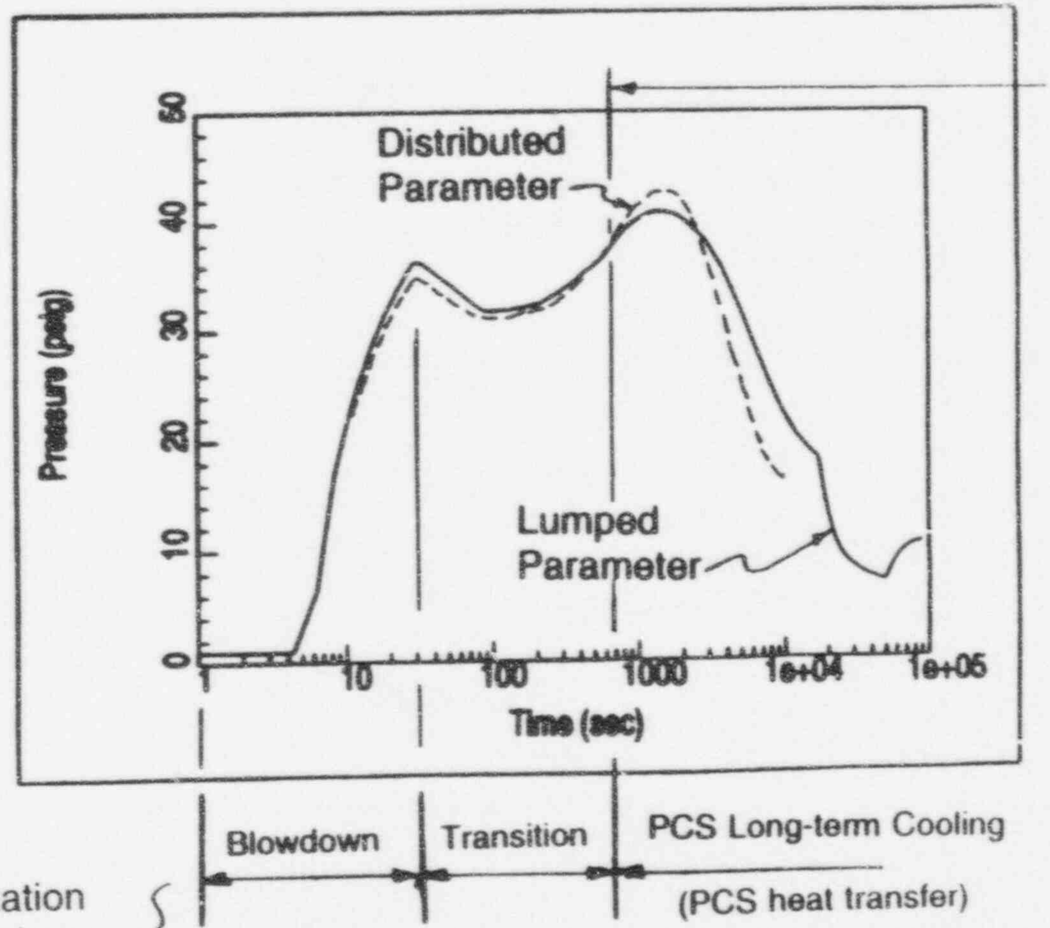
Reduce the containment pressure at 24 hours to less than half the design pressure.

AP600 Passive Containment Cooling System



AP600 PCS Response to LOCA Can Be Divided Into 3 Phases

From Preliminary Draft Markups of July 1995



PCS Water Conservatively Delayed to 660 seconds

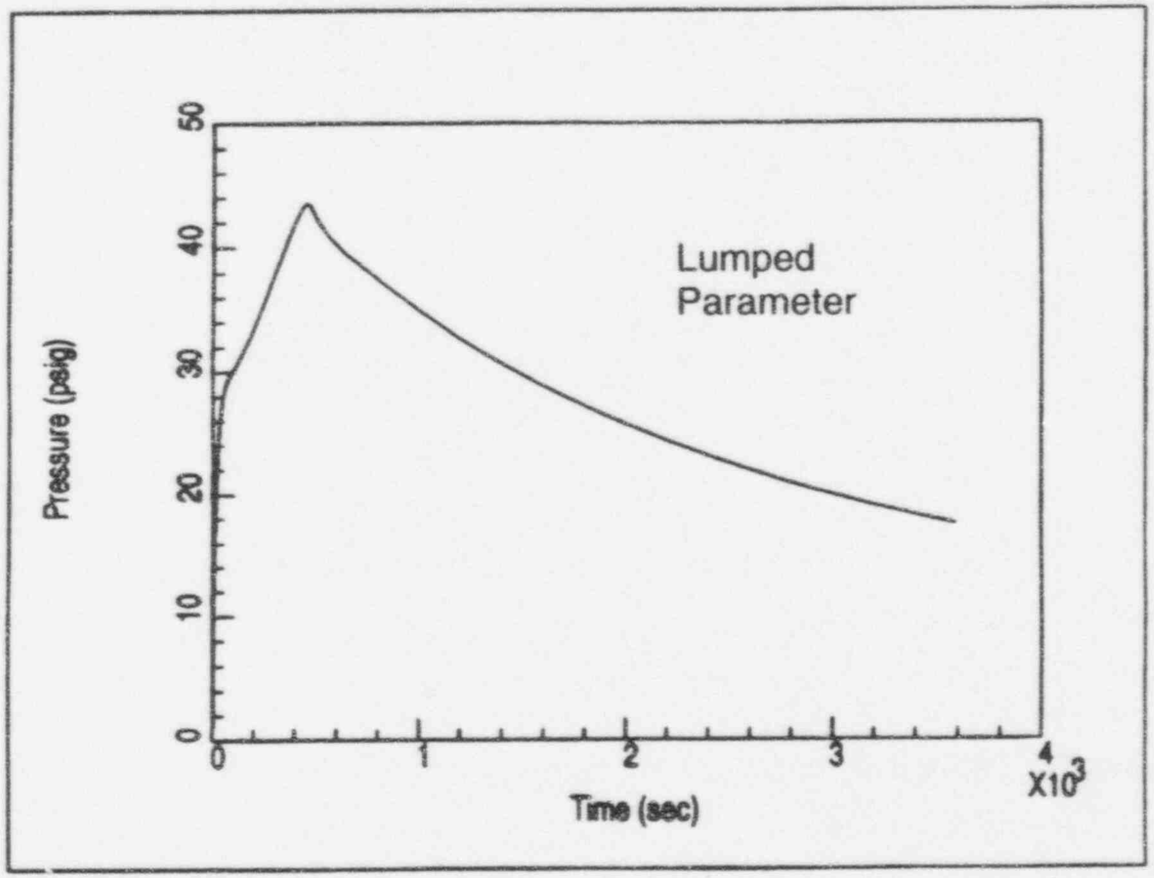
Blowdown | Transition | PCS Long-term Cooling

Dominant Pressurization Mitigation Mechanisms: (Free Volume) (Internal Heat Sinks) (PCS heat transfer)

Postulated DBA Accident Scenarios are Being Addressed

From Preliminary Draft Markups of July 1995

MSLB



The PIRT

The phenomena identification and ranking table (PIRT) was developed as follows:

- Components that must be considered were identified - gas, liquid, and solid
- Processes that can transport mass, momentum, and/or energy between components were specified
- Initial conditions and forcing functions were specified
- Spatial and temporal partitioning were utilized to facilitate organization:
  - Spatial: Inside / outside and subcooled / evaporating / dry
  - Temporal: Blowdown, refill, and evaporating.
- All interacting components and the transport processes by which they interact in a PIRT were identified
- The basis for ranking each interaction in the PIRT was documented

AP600 Components Involved in PCS Cooling

AP600 Components Involved in Passive Containment Cooling

Gasses	Liquids	Solids
Above Deck Volume	Internal Film (Subcooled)	Containment Shell (Sub)
Reactor Cavity	Internal Film (Evaporating)	Containment Shell (Evap)
Accumulator Room (2)	Internal Film (Dry)	Containment Shell (Dry)
Steam Generator Room (2)	External Film (Subcooled)	Internal Solid Heat Sinks
CMT/CVCS Room	External Film (Evaporating)	Baffle
Refueling Canal	Break Pool	Baffle Supports
IRWST	IRWST	Shield Building
Stairwell	Break Source Water	
Downcomer	PCS Cooling Water	
Riser		
Chimney		
Break Source Steam		
External Atmosphere		

Plausible Transport Processes

Plausible Transport Processes

Radiation (Transport Energy)

- Surface - Surface (solid or liquid)
- Surface - Dispersion (fog)
- Surface - Opaque Gas
- Opaque Gas - Opaque Gas
- Solar - Shield Building

Conduction (Transport Energy)

- Solids
- Liquid film
- Gas boundary layers
  - Free convection heat transfer
  - Forced convection heat transfer

Diffusion (Transport Mass, Energy)

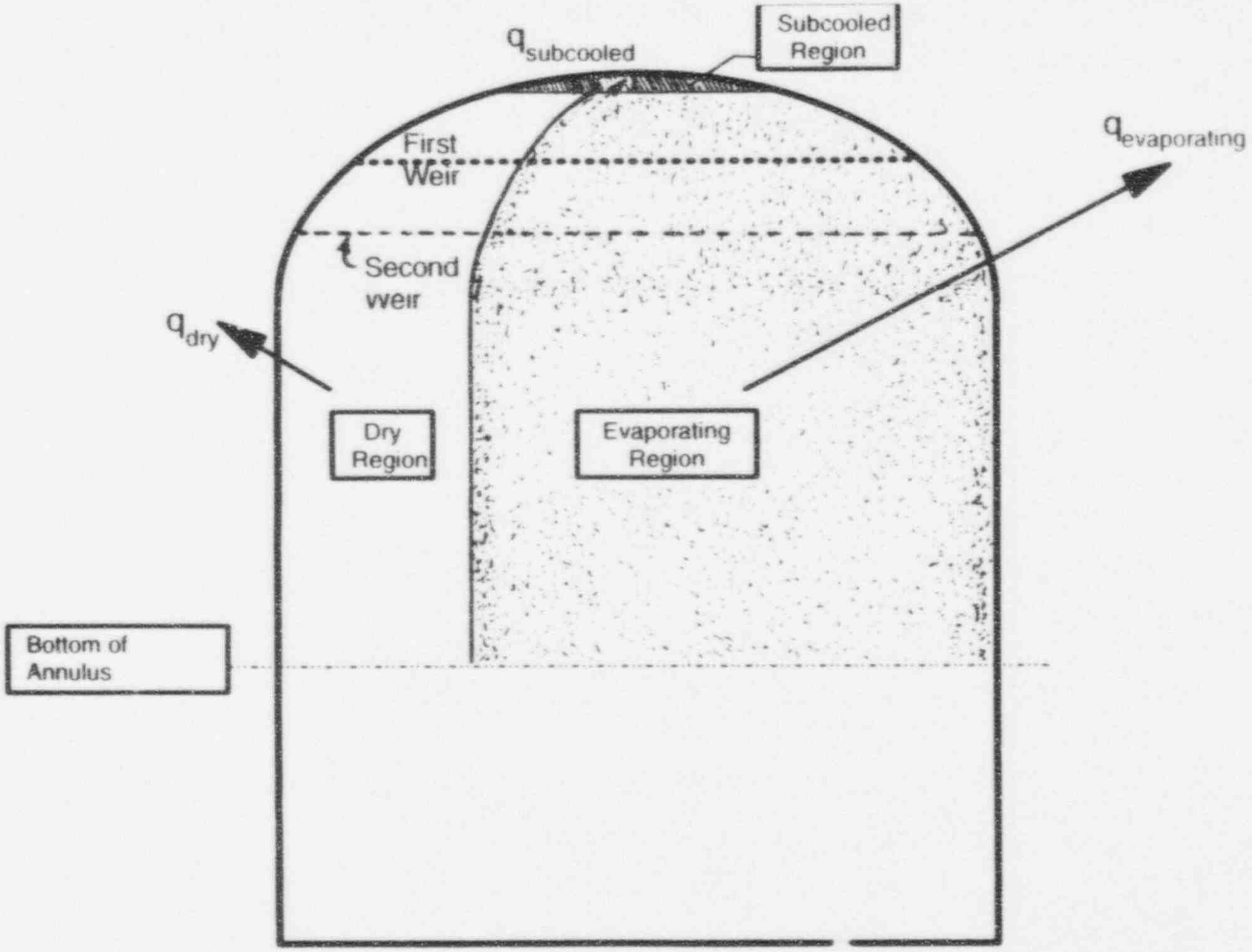
- Gas boundary layers
  - Free convection mass transfer
  - Free convection enthalpy transfer
  - Forced convection mass transfer
  - Forced convection enthalpy transfer

Convection (Mass, Momentum, Energy)

- Gas and liquid flow
  - Free and forced Convection
  - Jets, jet entrainment
  - Plumes, wall plume, plume entrainment

External Shell Partitioning For PCS Scaling

Schematic of Subcooled/Evaporating/Dry Partitioning of the AP600 Containment Shell for PCS Scaling



Results of Containment Pressure Scaling

The rate of pressure change equation developed for containment showed:

- The addition of steam mass and sensible heating of the atmosphere by a break source at a single location is the dominant cause of containment pressure increase

- Mass transfer is the dominant energy removal process
    - Condensation mass transfer is the dominant process for transferring energy from the containment atmosphere to the shell and heat sinks. Condensation has an order of magnitude greater effect on pressure than radiation or convection heat transfer
    - Evaporation of the PCS cooling water is the dominant process for transferring energy from the shell to the PCS air flow path. Radiation and convection have an order of magnitude lesser effect on pressure than evaporation
    - Inputs to mass transfer are properties, steam and air concentrations and velocity

- The absorption of a significant fraction of the source energy by the shell and internal heat sinks causes the containment pressure to decrease. The shell and steel heat sinks are effective for 1000 to 2000 seconds, and the concrete for 2000 to 4000 seconds

- The removal of energy from the shell by external energy transport processes causes the shell energy removal to exceed the source energy after 2000 to 3000 seconds

- The subcooled heat capacity of the PCS coolant is second order relative to the effect of evaporation on pressure

Results of Containment Pressure Scaling (continued)

Effect on Evaluation Model:

- Confirmed that mass transfer is the dominant heat removal mechanism. The mass transfer model was developed, validated, bounded, and included in the evaluation model.

- Velocity and air/steam concentration were identified as major parameters in the mass transfer model.
  - The effects of velocity are bounded by using free convection only (no forced or mixed convection) inside containment
  - The effects of air/steam concentration are bounded by biasing the effects of mixing and stratification

- The importance of internal heat sinks was identified. The heat sinks are included in the evaluation model and are bounded by conservative heat sink masses, areas, properties, and initial conditions.

- Combined with the bounding mass transfer correlations, heat sink effectiveness is bounded in the evaluation model.

Energy Transfer Resistance Scaling

- The steady-state energy transfer resistance from the containment atmosphere, through the shell, to the riser can be expressed in terms of an effective heat transfer coefficient. Scaling the condensation, internal film, shell, external film, and evaporation parts of the overall heat transfer coefficient showed the following:
  - The resistance through each liquid film is less than 2% of the total resistance
  - The shell, condensation, and evaporation each account for approximately 1/3 of the total resistance
- During the early portion of the transient (less than 2000 sec) the shell absorbs more energy than it rejects, so the resistances are increased towards the inside. Even then the liquid film is not significant.

Effect on Evaluation Model:

- The evaporation and condensation correlations are both bounded and the evaluation model uses bounding velocity and air/steam concentration inputs to the correlations.

Internal Momentum Scaling

The Froude numbers calculated for the above deck volume show that:

- During blowdown, momentum effects are more significant than buoyant effects. The gas is well mixed and heat transfer ranges from mixed to forced convection dominated.

- After blowdown, momentum effects are negligible compared to buoyant effects. The gas is stably stratified, with small vertical air/steam concentration gradients. Heat transfer is free convection.

Effect on Evaluation Model:

- Free convection heat and mass transfer is used for the shell, and Uchida is used for the internal heat sinks throughout the transients. Bounded mass transfer correlations are used with conservatively bounded input values of velocity and air/steam concentration.

External PCS Air Flow Path Scaling

- The flow through the PCS air flow path (downcomer, riser, and chimney) can be calculated by equating buoyant and drag forces
  - The buoyant forces result from temperature and molecular weight differences.
  - The drag forces are form and friction losses. The drag forces were measured on a 14 degree sector, 1/6 scale model.
- At steady-state, the downcomer buoyancy accounts for less than 6% of the net buoyant force, and is opposed to the riser and chimney buoyancy
- At startup, the shell time constant is on the order of 400 sec. compared to the baffle time constant of 2000 sec., so the air flow starts up and is well developed before the baffle temperature increases

Effect on Evaluation Model:

- The evaluation model includes the measured loss coefficients and calculates the heat transferred and mass evaporated to the riser.

Scaling Conclusions: Evaluation Model Requirements

- Scaling confirmed the significant modelling features necessary for consideration in the evaluation model:
  - Condensation mass transfer inside containment
  - Velocity and air/steam concentration fields inside containment
  - Evaporation mass transfer outside containment
  - PCS wetting and surface coverage
  - Effectiveness of internal heat sinks

    Break source momentum and direction
    Inter-compartment circulation
    Intra-compartment circulation

- Scaling confirmed the applicability of the AP600 PCS test database

Scientech Briefing Meeting on AP600 PCS

AP600 Testing Program

E. Separate Effects Testing

December 6, 1995

D. R. Spencer, Principal Engineer
Containment and Radiological Analysis

Contact: John Butler
Phone: 412-374-5268

Westinghouse Electric Corporation

Separate Effects Tests Have Been Completed

PHENOMENON	TEST EVALUATION	PURPOSE
Condensation	U of Wisconsin[1]	Model Validation
	W Large Scale[1]	Model Validation
	W Small Scale[2]	Early Insight
Evaporation	Gilliland and Sherwood[1]	Model Validation
	W Flat Plate[1]	Model Validation
	W Small Scale[2]	Early Insight
Convective Heat Transfer	Hugot[1]	Model Validation
	Eckert and Diaguila[1]	Model Validation
	Siegel and Norris[1]	Model Validation
	W Dry Flat Plate[1]	Model Validation
	W Dry Large Scale[1]	Model Validation
	W Dry Small Scale[2]	Early Insight
Water Coverage	W Water Dist System[3,4]	Model Validation
	W Large Scale Tests[3,4]	Model Validation
PCS Loss Coefficient	W 1/6 Scale Test	Model Input
Environmental Interaction	U of WO Wind Tunnel[5,6]	Model Validation

References

1. R. P. Ofstun, "Experimental Bassis for the AP600 Containment Vessel Heat and Mass Transfer Correlations", March 31, 1995, WCAP-14326, Westinghouse Electric Corporation, Proprietary Class 2.

2. J. Woodcock, D. R. Spencer, M. D. Kennedy, K. S. Howe, "Westinghouse-GOTHIC: A Computer Code for Analyses of Thermal Hydraulic Transients for Nucleatr Plant Containments and Auxiliary Buildings", July 1992, WCAP-13246, Westinghouse Electric Corporation, Proprietary Class 2.

3. Letter, N. J. Liparulo (Westinghouse) to R. W. Borchardt (U.S. NRC), "AP600 Passive Containment Cooling System Letter Reports" (Method for Determining Film Flow Coverage for the AP600 Passive Containment Cooling System), NTD-NRC-94-4247, DCP/NRC0172, Docket No.: STN-52-003, July 28, 1994.

4. Letter, N. J. Liparulo (Westinghouse) to R. W. Borchardt (US NRC), "Supplemental Information on AP600 PCS Film Flow Coverage Methodology," NTD-NRC-94-4286, August 31, 1994.

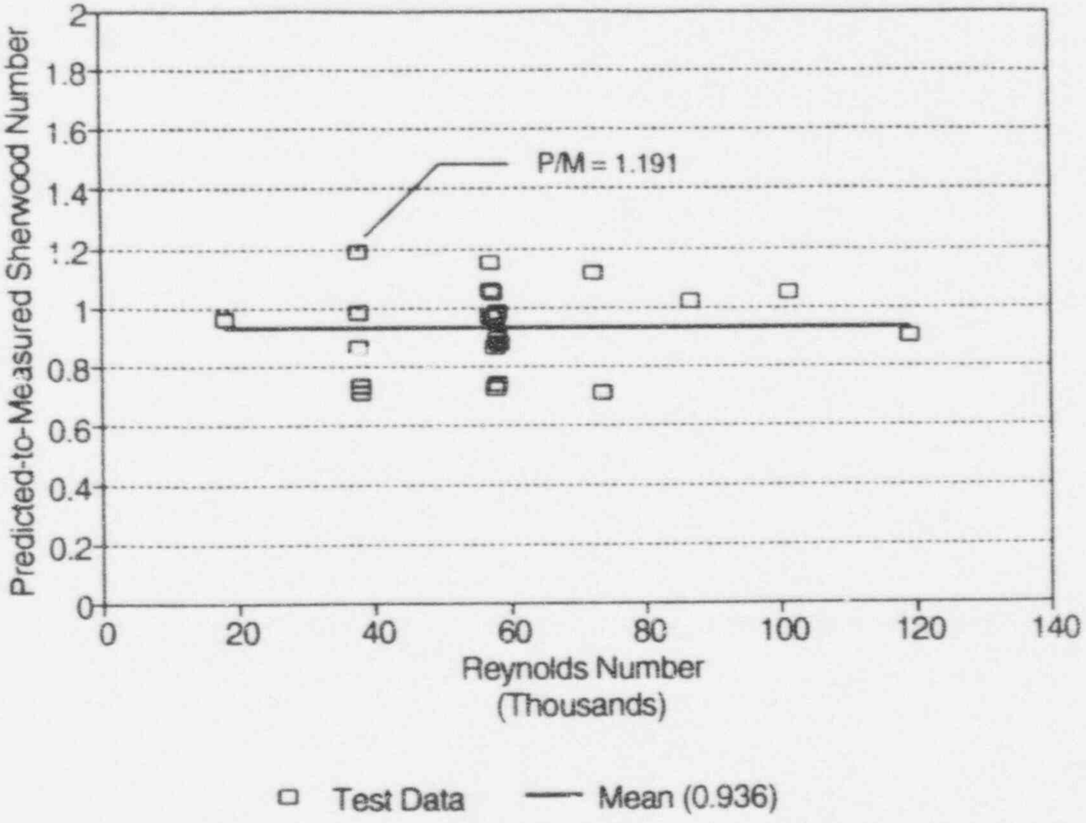
5. J. S. Narula, "Analysis of AP600 Wind Tunnel Testing for PCS Heat Removal", PCS-T2C-059, May 1995, NTD-NRC-95-4467, Westinghouse Proprietary Class 2.

6. Letter N. J. Liparulo (Westinghouse) to Document Control Desk (USNRC), NTD-NRC-94-4166, "AP600 Passive Containment Cooling System Letter Reports: AP600 Containment Plume Investigation", June 10, 1994.

Summary Conclusions From Separate Effects Tests

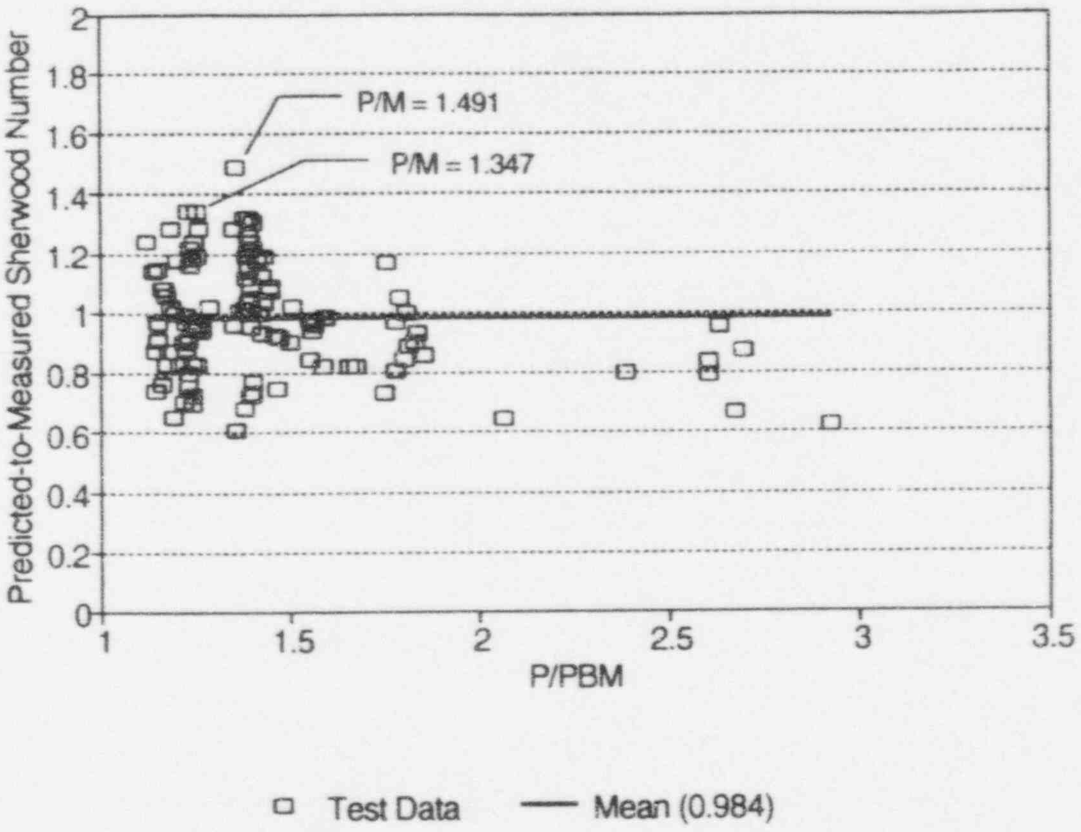
- Condensation and evaporation separate effects tests have been used to develop correlations biased to bound test data, using the bias factor, C = M/P. (See figures for condensation and evaporation.)
- Convective heat transfer tests show that the heat transfer correlations (a small contribution to heat removal) predict the data. The bias factor determined from mass transfer tests is applied to convective heat transfer.
- Water coverage tests have been used to develop a bounding water coverage input to the evaluation model.
- PCS loss coefficient test provides the basis for the external flow path loss coefficient.
- The wind tunnel tests have been used to confirm that it is conservative to assume no external wind in the evaluation model.

Evaporation Separate Effects Data



Predicted-to-Measured Sherwood Numbers for Evaporation as a Function of the Reynolds Number

Condensation Separate Effects Data



Predicted-to-Measured Sherwood Numbers for Condensation as a Function of Dimensionless Pressure

AP600 Testing Program

F. Integral Effects Testing

December 6, 1995

D. R. Spencer, Principal Engineer
Containment and Radiological Analysis

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Integral Effects Tests: (Large Scale Tests)

Outline

Objectives

Test Facility Description

Primary Test Variables

Instrumentation

Test Matrices

Observations

Conclusions

LST Overview

OBJECTIVES

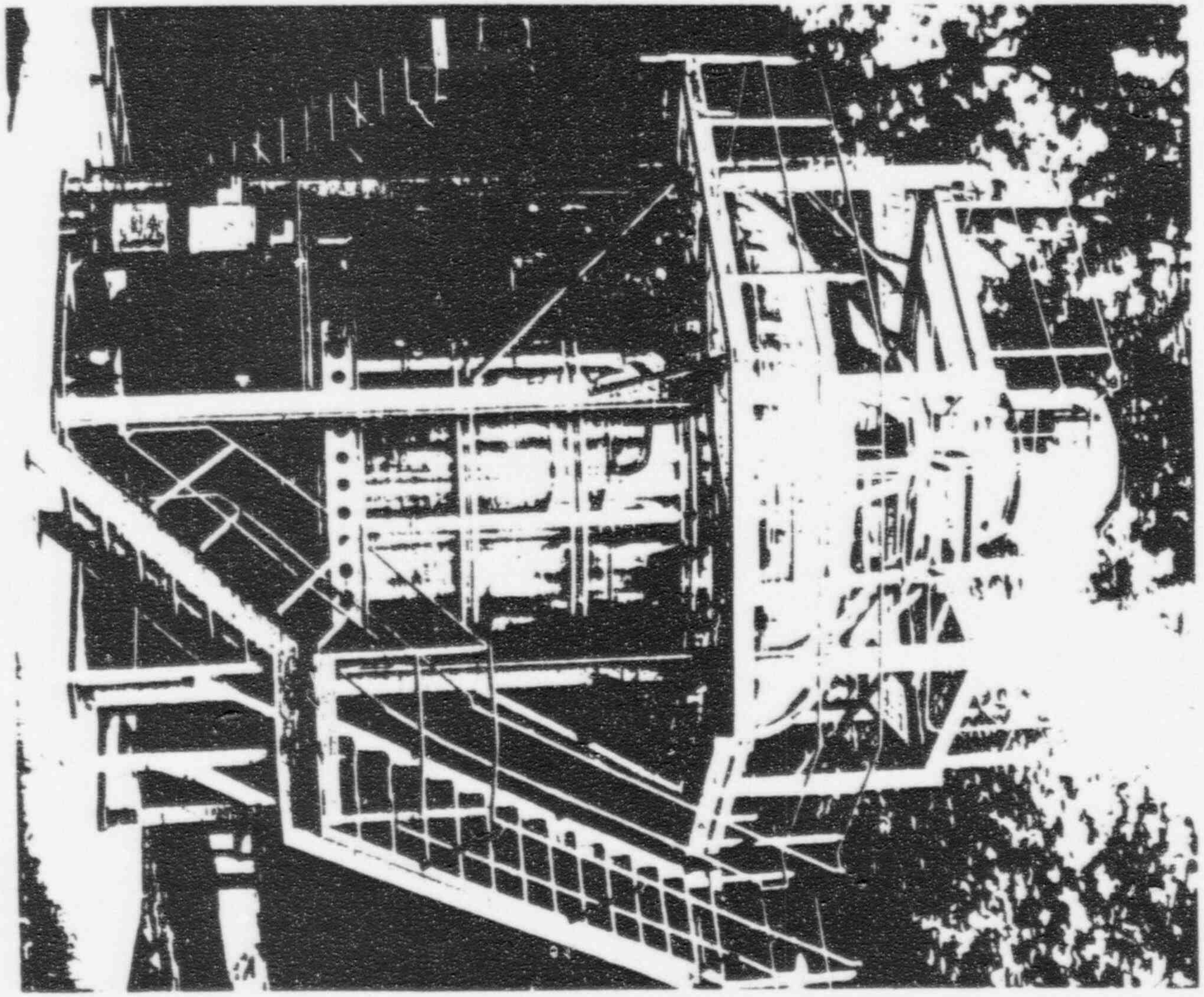
Examine, on a large scale integral test, the parameters that control containment heat and mass transfer:

- Steam condensation on the interior of the containment
- Water evaporation into the external riser air

The data are used for:

- Validation of containment analysis phenomenological models
- Validation of computer codes
- Development of Evaluation Model

Large Scale PCS Test Apparatus



TEST FACILITY

- 1/8th scale AP600 instrumented test vessel

- Instrumented to measure
  - Containment Pressure
  - Wall temperature and heat flux
  - Containment gas temperatures
  - Containment gas steam/air/helium concentrations
  - Containment gas velocities near walls
  - Riser air temperature
  - Riser air velocity
  - External water on and off
  - Internal condensation rate and distribution
  - Boundary and ambient conditions

- 400 channel data acquisition system, (26 channel per sec max)

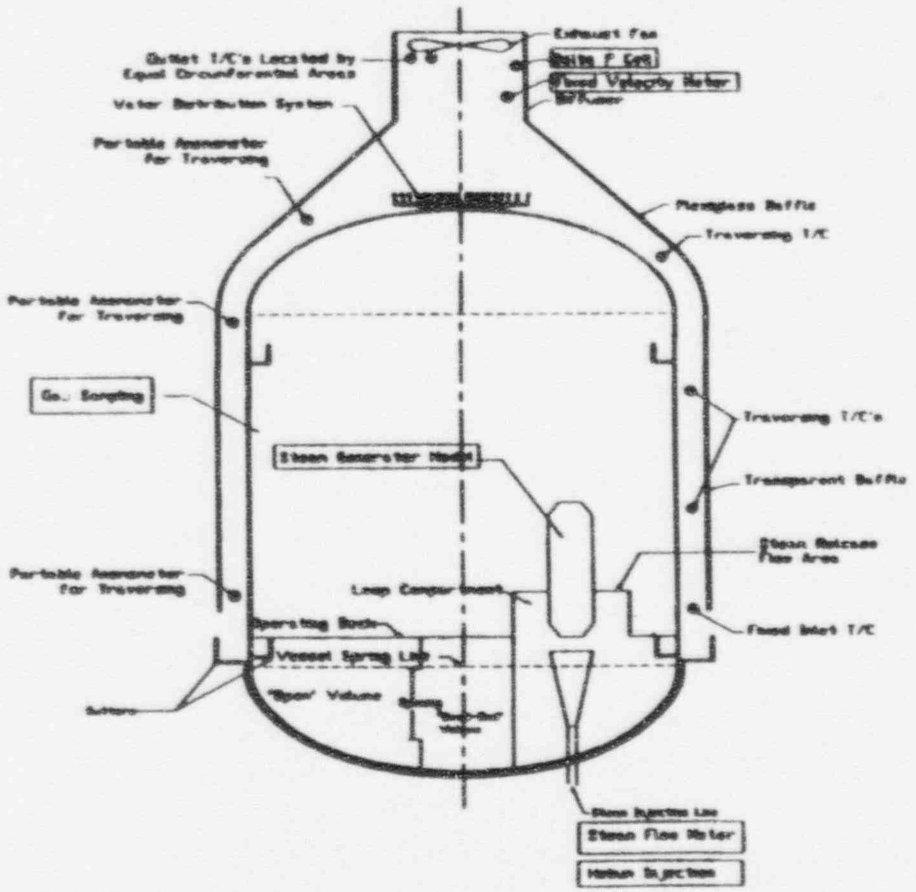
PRIMARY TEST VARIABLES

Values of the primary test variables

- 1.6 lbm/sec steady state and 6.0 lbm/sec peak transient steam supply system
- Natural convection air cooling to 16 ft/sec forced air
- 0 to 3.3 lbm/sec exterior water film supply
- 8 to 22 volume percent helium

LST Overview

Test Facility Configuration



LST Overview

Instrumentation and Measurement Locations

- Wall TC/Heat Flux and Fluid TC - See Figure
- Instrument Tree Fluid TC - See Figure
- Concentrations [ ]^{a,b,c} from wall: Dome [ ]^{a,b,c}, A at [ ]^{a,b,c}, E at [ ]^{a,b,c} F at [ ]^{a,b,c}
- Velocity sensors mounted in vertical plane, parallel to wall
  - 2.75" throat, [ ]^{a,b,c} from wall; E at [ ]^{a,b,c}, D at [ ]^{a,b,c}, Dome [ ]^{a,b,c}
  - 1.0" throat, [ ] from wall; Dome [ ]^{a,b,c}, A at [ ]^{a,b,c}

Water Source Location

- 8 at a radius of [ ]^{a,b,c}
- 56 at a radius of [ ]^{a,b,c}

LST Wall and Fluid TC Locations

a,b,c

Instrument Tree Fluid TC Locations

a,b,c

⊠ Fluid TC

LST Overview

BASELINE TESTS

Steady state heat transfer tests, simplified internals

- Steam flow rate
- Air flow rate
- Water coverage

PHASE 2 TESTS - EXTEND DATA BASE

Steady state and transient simulations, simulated internals

- Steam flow rate
- Air flow rate
- Water coverage
- Effect of light noncondensables
- Internal heat sinks
- Blind blowdown test

LST Overview

PRE-TESTS

- Cold helium distribution
- Video tape delayed water distribution
- Air flow vessel cold (~100°F)
- Establish water distribution control levels

PHASE 3 TESTS - FOLLOW-ON

Steady state and transient heat transfer, simulated internals

- Stepped blowdown steam discharge
- Alternate steam discharge (MSLB)
- Vacuum
- Pressurized vessel

LST Overview

PCCS BASELINE TEST MATRIX

TEST NUMBER	STEAM SUPPLY PRESSURE (PSIG)	WATER COVERAGE	ANNULUS AIR FLOW (FT/SEC)
BASELINE TEST NO INTERNALS:			
L-201.1	10	100%	9
L-202.1	30	100%	9
L-203.1	40	100%	9
L-207.1	30	75% QUADRANTS	9
L-207.2	30	75%	9
BASELINE TEST WITH INTERNALS (NO STEAM GENERATOR MODEL):			
L-201.2	10	100%	12
L-202.2	30	100%	12
L-203.2	40	100%	12
L-204.1	30	100%	16
L-205.1	30	100%	8
L-206.1	30	100%	FREE
L-207.3	30	75 QUADRANTS	12
L-208.1	30	50 QUADRANTS	12
L-207.4	30	75%	12
L-210.1	40	100%	12
L-211.1	40	100%	FREE

LST Overview

PCCS PHASE 2 TEST MATRIX

TEST NUMBER	STEAM CONTROL		AIR FLOW	WATER COVERAGE	LONG TERM HEAT SINKS	HELIUM	SAMPLING
	PRESSURE (PSIG)	FLOW (LB/SEC)	(FT/SEC)				
202.3	30	-	12	100 %	NO	NO	NO
203.3	40	-	12	100%	NO	NO	NO
212.1		0.25/0.5/0.75	12	75 % STRIPED	NO	NO	YES
213.1		0.25/0.5/0.75	12	25 % STRIPED	NO	NO	NO
214.1	-	1.	FREE/12	75 % STRIPED	NO	NO	NO
215.1	-	1.	FREE/12 1/2 AIR BLOCKAGE	75 % STRIPED	NO	NO	NO
216.1	-	0.5	12	75%/25 % QUADRANTS	NO	NO	NO
217.1	-	1.	12	75 % STRIPED	NO	17 MOLE %	YES
218.1	-	1	12	75 % STRIPED	YES	17 MOLE %	YES
219.1	-	0.2	12	DRY/50 % STRIPED	YES	17 MOLE %	YES
220.1 (Blind Test)	-	BLOWDOWN	12	75 % STRIPED	YES	NO	YES
221.1	-	BLOWDOWN	12	50 % STRIPED/DRY	YES	25 MOLE %	YES

LST Overview

PHASE 3 - PCCS FOLLOW-ON TEST MATRIX

TEST NUMBER	STEAM CONTROL		AIR FLOW	WATER COVERAGE	LONG TERM HEAT SINKS	HELIUM	SAMPLING	NOTES
	PRESSURE (PSIG)	FLOW (LB/SEC)	(FT/SEC)					
222.1	-	6/3/0.5	12	75 % STRIPED	YES	NO	YES	Diffuser under SG
222.2	-	6/3/0.5	12	75 % STRIPED	YES	NO	YES	Diffuser 6 feet above deck, pointed up
222.3	-	6/3/0.5	12	75 % STRIPED	YES	NO	YES	3" steam source, 6' above deck, jet pointed at near wall
222.4	-	6/3/0.5	12	75 % STRIPED	YES	NO	YES	3" steam source, 6' above deck, jet pointed up
223.1	-	2.0	12	100%	YES	NO	YES	Vacuum
224.1	-	0.25	12	100%	YES	NO	YES	2 atmospheres air pressure
224.2	-	0.5	12	100%	YES	NO	YES	2 atmospheres air pressure

LST Overview - Observations

Containment Pressure a primary function of:

- Steam source flow rate
- External water flow evaporation rate
- Steam and noncondensable partial pressures
- Internal gas velocities

Containment Pressure a secondary function of:

- External air flow rate
- 50% inlet blockage

LST Overview - Observations

Condensate:

- Approximately 95% of the condensate is collected from the vessel dome and sidewall
- 5% is collected from the open, closed, and steam generator areas
- Condensate approximately equally divided between dome and side wall
- No observable rainfall (below detection limits)

LST Overview - Observations

Internal Velocities and Air/Steam Concentrations

- Under post blowdown LOCA configurations velocities are low (0 to 5 ft/sec) and steam concentrations are high above deck
- Under MSLB configurations velocities are higher and air/steam concentrations are uniform above and below deck

External

- Vessel at 100°F shows strong turbulent upward air flow in annulus
- Dry vessel at 250°F wets readily

LST Overview - Conclusions

The LST measurements provided scalable data to validate

- The PIRT phenomena selection
- The convection heat and mass transfer models
- The subcooled heat transfer model
- The wetting model
- WGOTHIC

Scientech Briefing Meeting on AP600 PCS

G. WATER COVERAGE

December 7, 1995

J. Woodcock, Principal Engineer
Containment and Radiological Analysis

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Westinghouse Electric Corporation

Water Coverage

Objectives:

1. Describe the PCS test program to determine how wetting and film coverage change as a function of the film and surface properties
   - a. Film flowrate, distribution and temperature
   - b. Surface heat flux and temperature
   - c. Surface geometry (height, and angle of inclination)
   - d. Age of surface coating
   - e. Contamination of surface
   - f. Manufacturing tolerances

2. Show how transient and steady state film coverage for AP600 are predicted (phenomenological model development and validation)

3. Show how the bounding film coverage input is determined for the evaluation model

PCS Test Program

1. Water Film Formation Tests
2. Water Distribution Tests
3. STC Wet Flat Plate Tests
4. Small-Scale Tests
5. Large-Scale Tests

Water Film Formation Tests (WCAP-13884)

Purpose of Tests

1. To show the wettability of the selected exterior coating for the AP600 containment shell.
2. To characterize the general requirements for forming a water film over a large surface.

Apparatus

The test section is an 8-ft long, 4-ft wide steel plate on a pivoting frame. The plate was coated with the selected inorganic-zinc coating.

Results

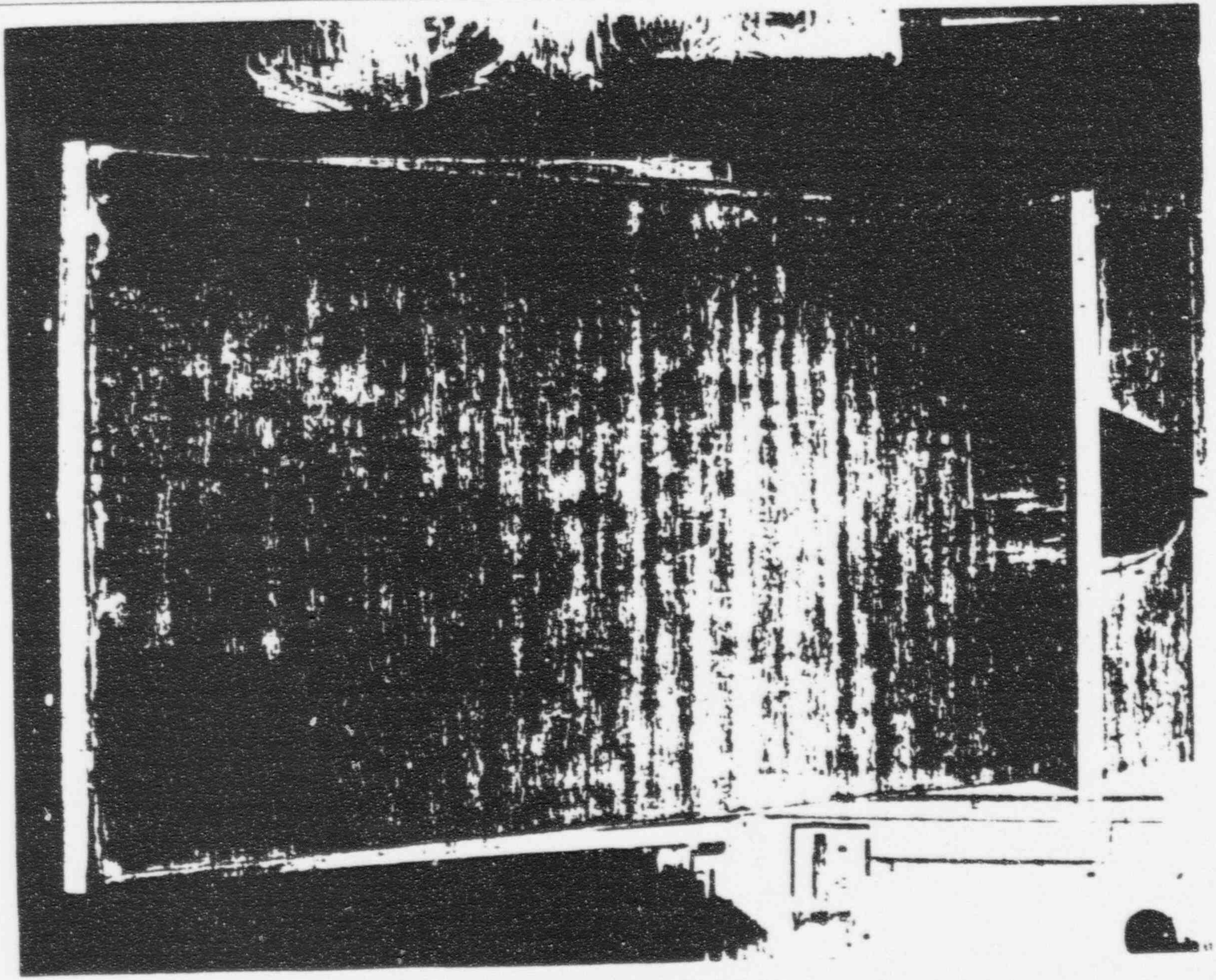
The selected coating wetted readily.

A point source flowrate of 1 gpm produced a 1-ft wide stripe, independent of the inclination angle.

No rivulet formation was observed even at high point source flow rates and with vertical orientation.

Various methods were tried to enhance the spreading across the entire width of the plate. Once formed, the film was stable, did not form into rivulets, and wetted the entire length of the plate.

Water Film Formation Tests



Water Distribution Tests (WCAP-13292, WCAP-13816, WCAP-13960)

Purpose of Tests

To provide a full-scale demonstration of the capability to distribute water on the steel containment dome outer surface and top of the containment sidewall with worst case manufacturing tolerances.

Apparatus

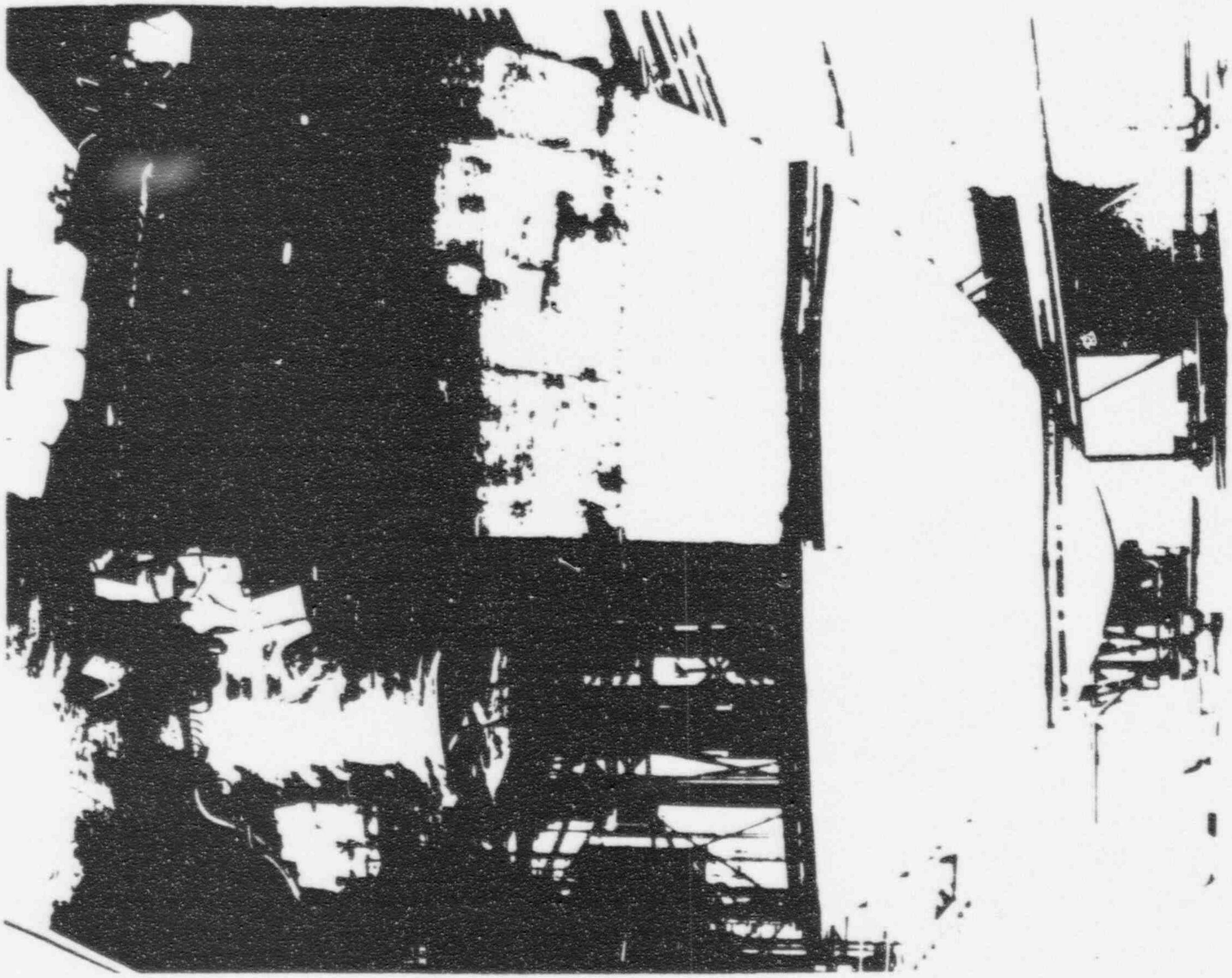
The test section is a 1/8 sector of the full-scale dome. The test section was built with maximum allowable weld tolerances between the steel plates and was coated with the selected inorganic zinc coating.

Results

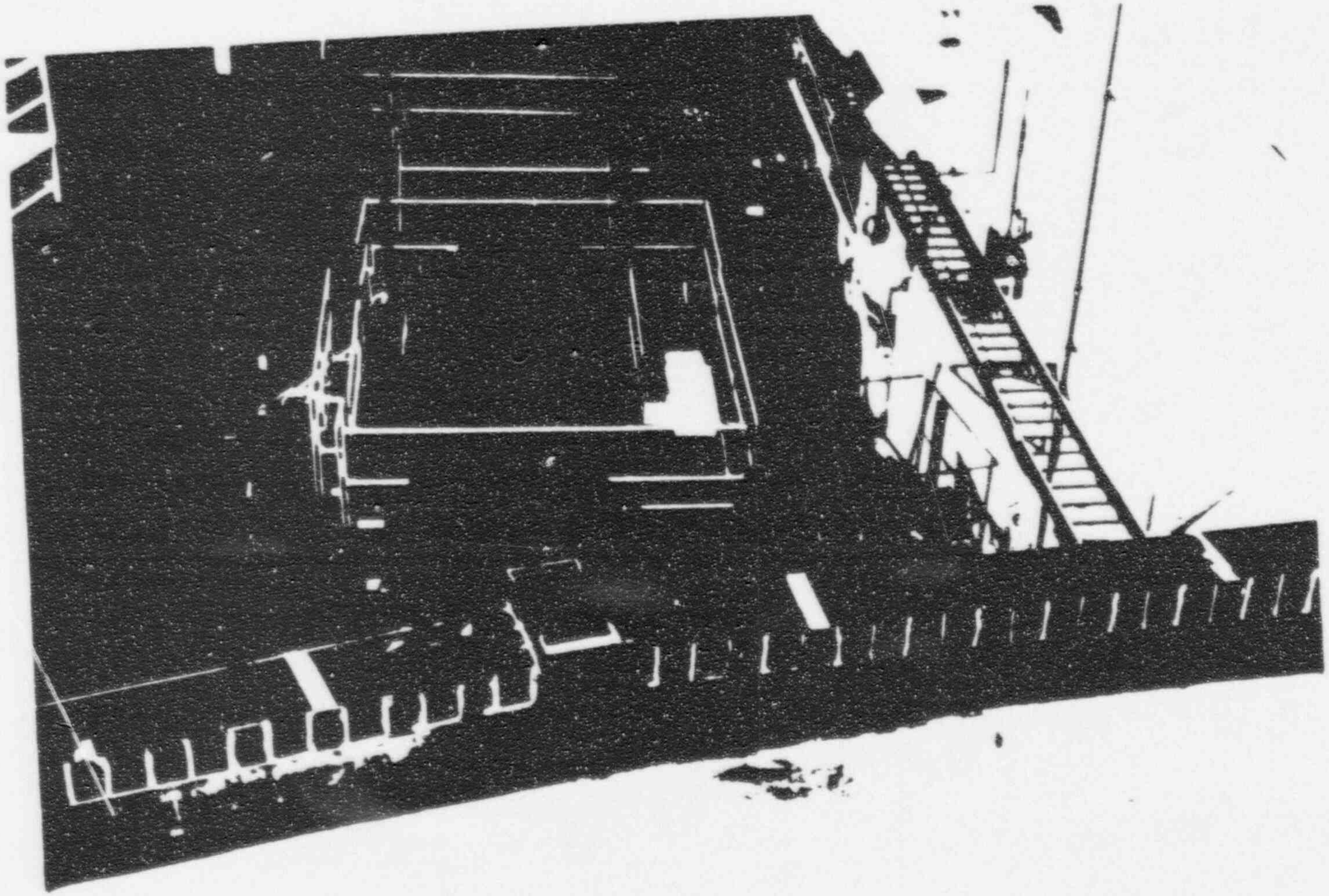
Time to fill weirs and reach a steady state coverage at 220 gpm equivalent flowrate was about 10 minutes.

The film coverage and thickness was measured as a function of flowrate at the springline on the full-scale test section.

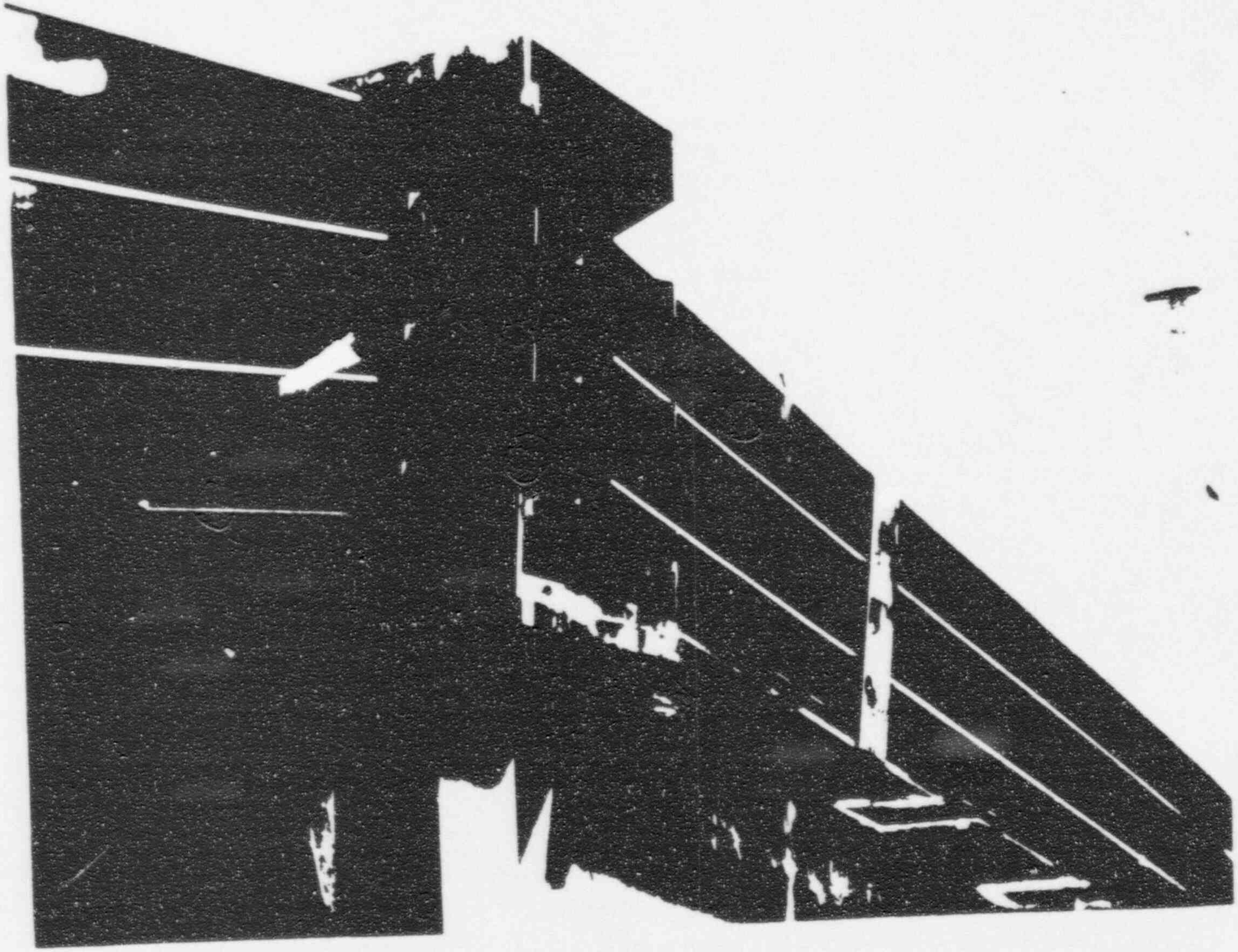
Full Scale Water Distribution Tests



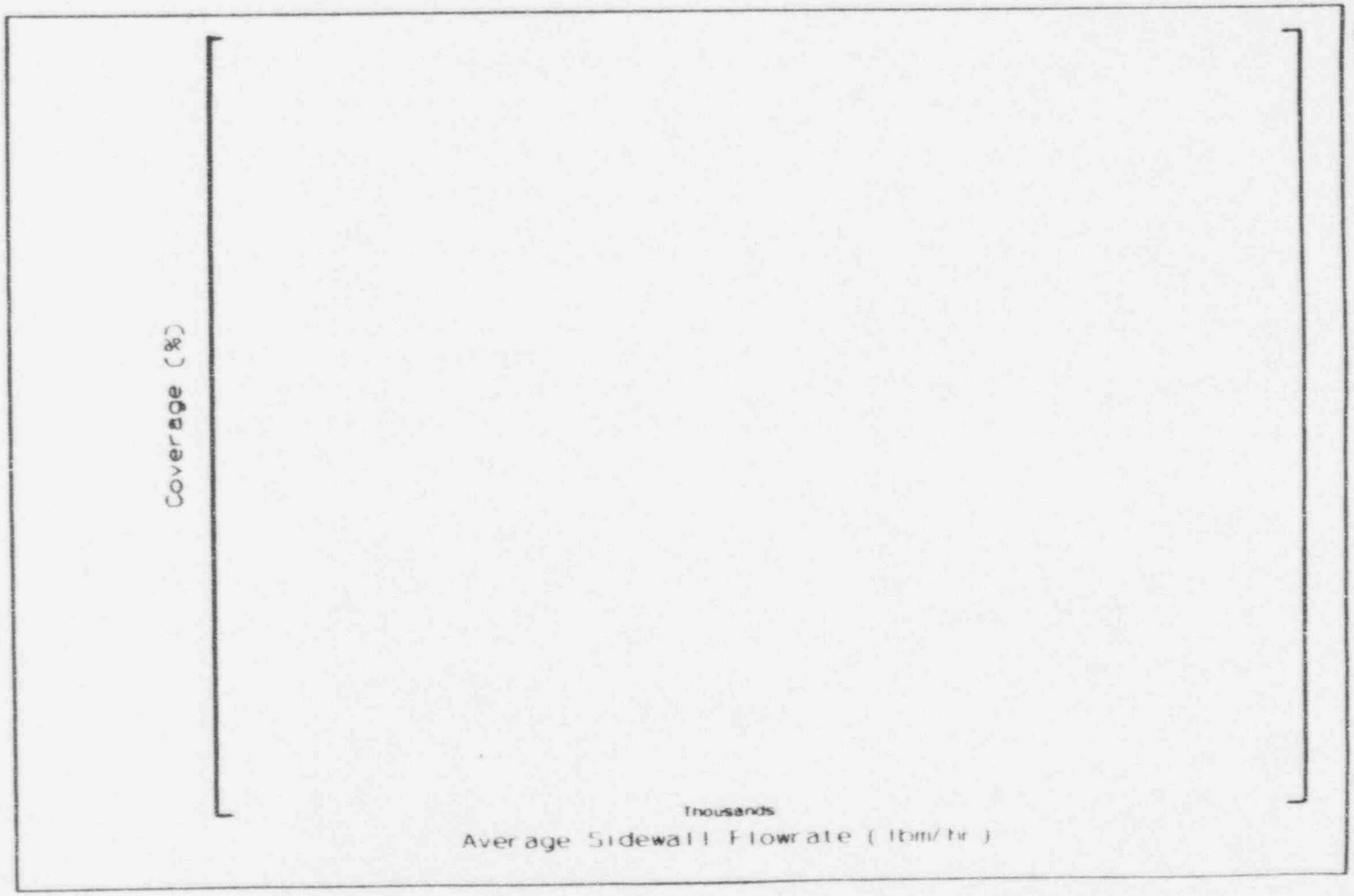
Full Scale Water Distribution Tests



Full Scale Water Distribution Tests



Coverage Data From Phase 3 Water Distribution Tests



(a,c)

STC Wet Flat Plate Tests (WCAP-12665 rev. 1)

Purpose of Tests

1. To obtain data on evaporative heat and mass transfer.
2. To observe film hydrodynamics including possible formation of dry patches due to surface tension instabilities.

Apparatus

The test section is a heated, 6-ft long, 2-ft wide steel plate. The plate was coated with the selected inorganic zinc coating. An air duct was formed with a clear Plexiglas cover to allow film flow visualization.

Results

A wavy laminar water film was formed easily, even in the vertical orientation and showed no instability or tendency to form rivulets.

The film was not susceptible to instabilities that lead to dry patch formation at any heat flux density or plate surface temperature encountered.

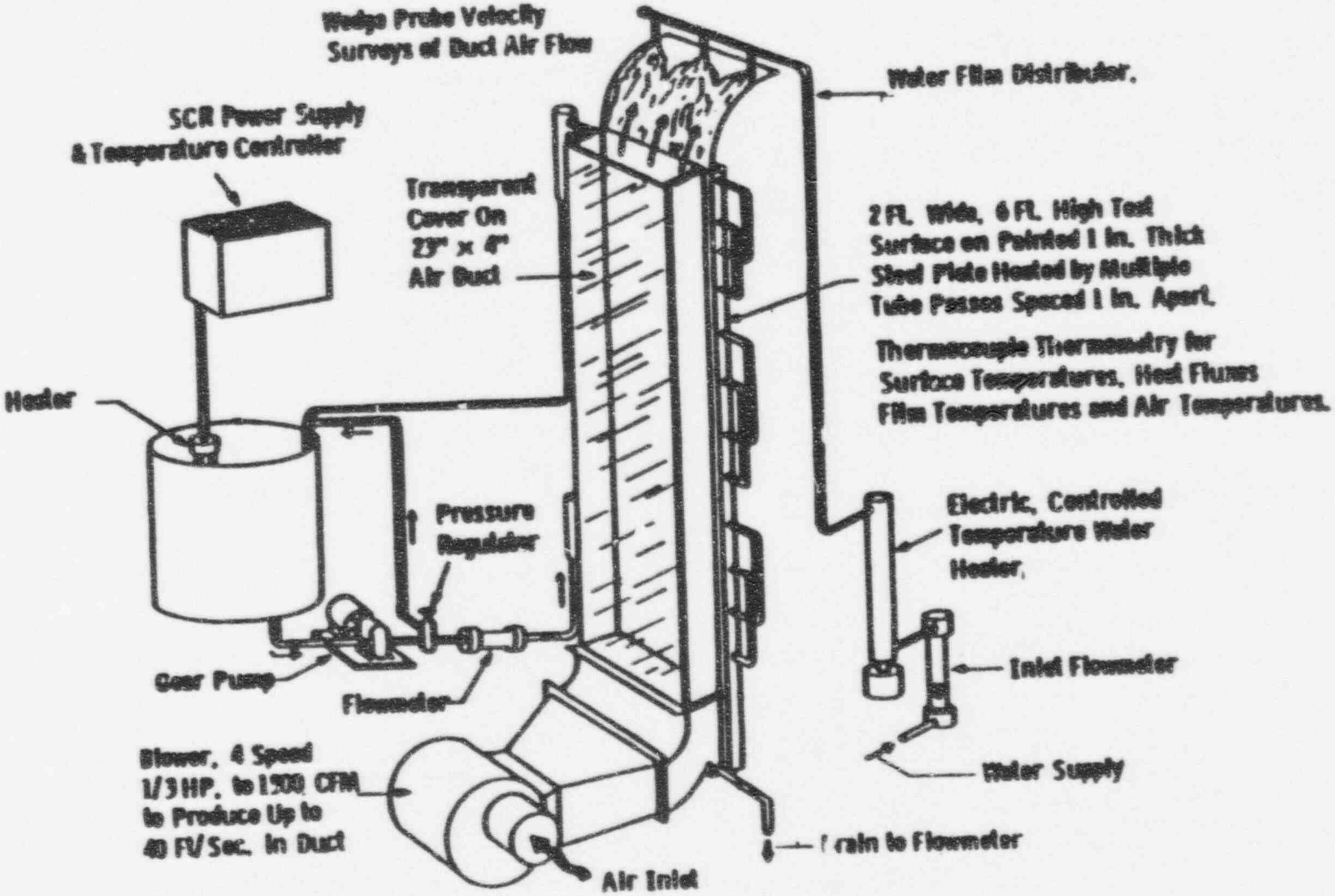
The film was not adversely affected by the countercurrent cooling air flow.

Range of STC Flat Plate Test Parameters

AP600

	Minimum	**Maximum**	
Air Flow	5.9	38.7	ft/s
Film Flow	0	318	lbm/hr-ft
Avg. Heat Flux	680	3700	BTU/hr-ft^2

STC Heated Flat Plate Test Apparatus



Small-Scale Integral Tests (WCAP-14134)

Purpose of Tests

1. To obtain heat and mass transfer data in an integral setting over an increased range of operating conditions, including postulated severe accident conditions.
2. To evaluate the impact of low environmental temperatures on the containment and air baffle structures.

Apparatus

The test facility consisted of a 24-ft tall, 3-ft diameter pressure vessel surrounded by a transparent baffle enclosing an air annulus.

Results

A uniform water film was easily formed using simple weirs.

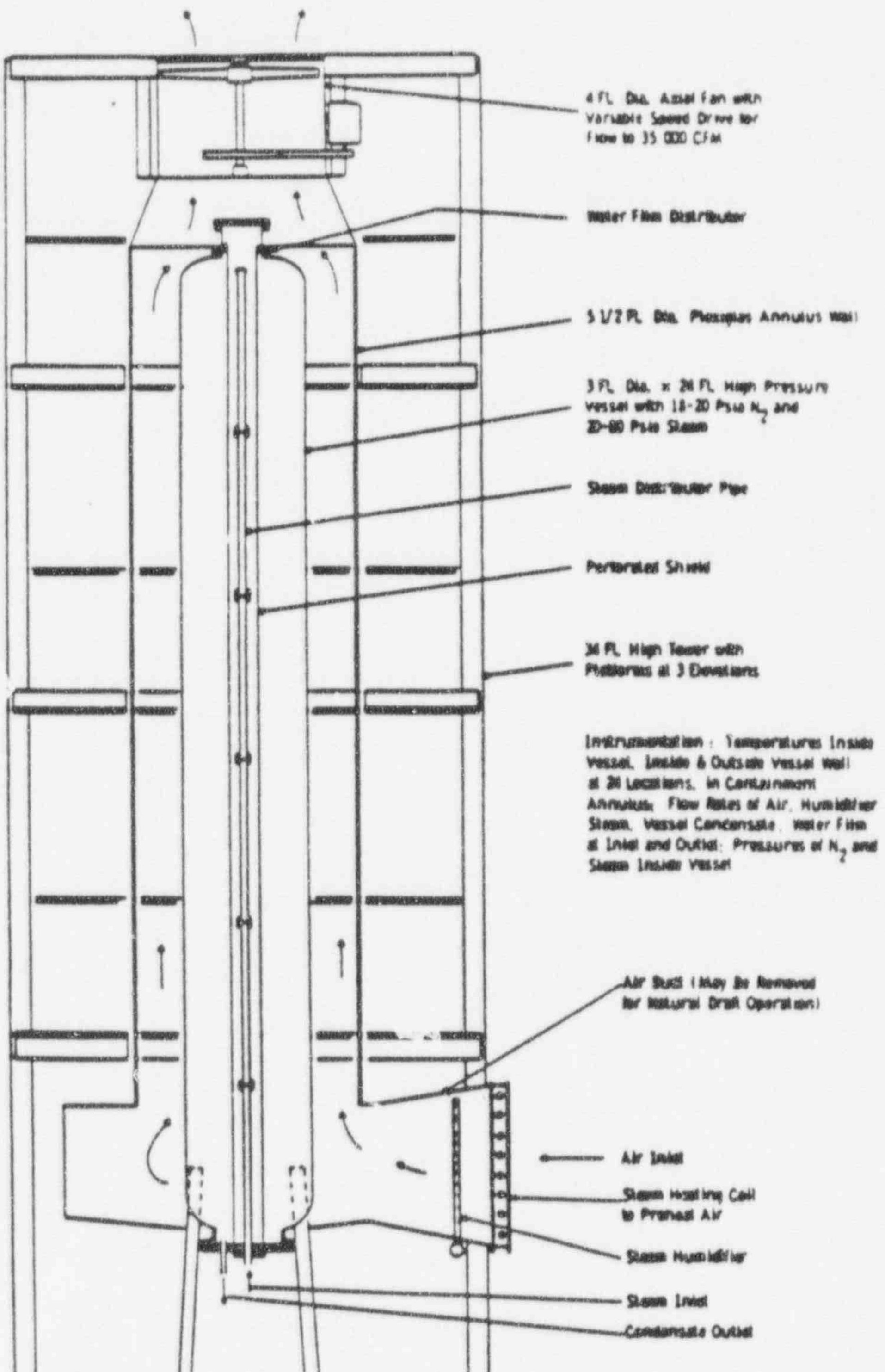
The water film was stable, even at evaporating heat fluxes 3 times higher than is likely to be encountered in the AP600.

The film had no tendency to become less uniform or form rivulets on the cylindrical wall.

Range of Small-Scale Test Parameters

	Minimum	**Maximum**
Air Flow	8	20 ft/s
Film Flow	0	2.6 gpm
Steam Flow	100	1637 lbm/hr
Avg. Heat Flux	95	7600 BTU/hr-ft^2

Section View of AP600 Integral Small-Scale Test



Instrumentation: Temperatures Inside Vessel, Inside & Outside Vessel Wall at 24 Locations, in Containment Annulus; Flow Rates of Air, Humidifier Steam, Vessel Condensate, Water Film at Inlet and Outlet; Pressures of N_2 and Steam Inside Vessel

Large-Scale Integral Tests (WCAP-14135, PCS-T2R-050)

Purpose of Tests

To obtain heat and mass transfer data in an integral setting, including the effects of natural convection and steam condensation on the interior of a 1/8 scale vessel.

Apparatus

The test facility consisted of a 1/8 scale pressure vessel surrounded by a transparent baffle enclosing a 3-in wide air annulus.

Results

As the heat flux was increased (or film flow rate was decreased), dry stripes were produced near the water stream impact site on the dome.

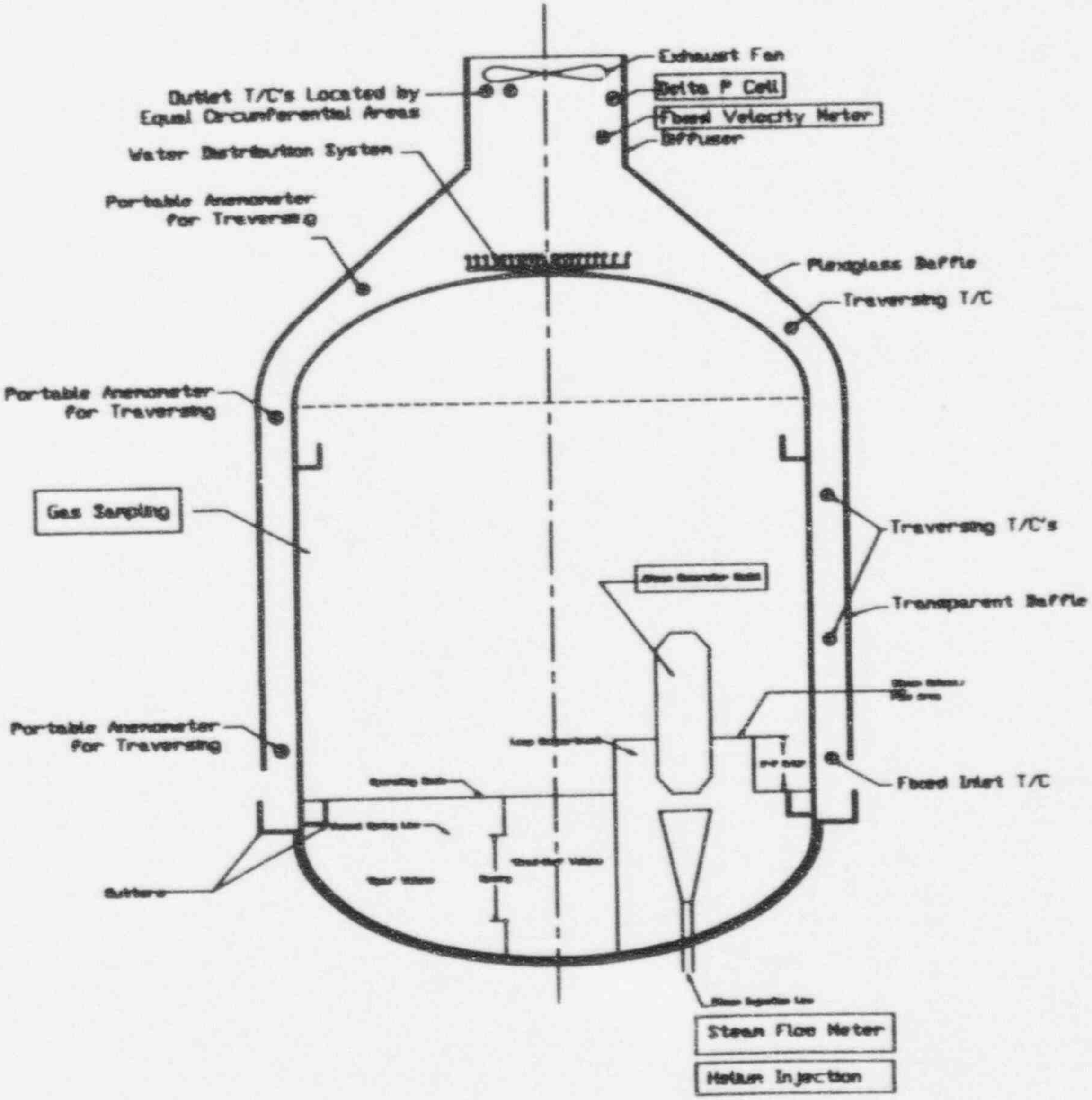
The width of the dry stripes increased with increasing heat flux or decreasing water flowrate.

A hot, dry vessel was easily wetted without forming rivulets or causing the film to leave the surface.

Range of Large-Scale Test Parameters

	Minimum	Maximum	
Air Flow	FREE	16	ft/s
Film Flow	0	317	lbm/hr-ft
Steam Flow	450	5900	lbm/hr
Avg. Heat Flux	600	7700	BTU/hr-ft^2

AP600 Large-Scale PCS Test



Video Tape Presentation

Key Observations from Videotapes:

- Water Distribution Test
    - The weir system creates stripes of film on the vessel that cover about 90% of the surface below the weirs
- Large-Scale Test (wetting of a hot, dry vessel)
    - The coated surface wets and re-wets readily
- STC Flat Plate (dryout and re-wetting of surface)
    - Water film remains thin to complete evaporation, consistent with a receding contact angle near zero

Analytical Water Coverage Model

- Need to analytically predict how a film stripe behaves as it evaporates.

- Available models were examined and a modified form of the Zuber-Staub Model was developed and validated with test data.

Modifed Zuber-Staub Model

- Predicts the occurance of a stable dry stripe within a flowing film by performing a force balance at the tip of a dry stripe.

$$\frac{\rho}{15}\left[g\sin\beta\,\frac{\rho}{\mu}\right]^{2}\delta^{4} + \rho g\cos\beta\,\frac{\delta}{2} = \frac{\sigma(1-\cos\theta)}{\delta} + \frac{d\sigma}{dT}\frac{\dot{q}''}{k}\cos\theta + \rho_v\left(\frac{\dot{q}''}{\rho_v h_{fg}}\right)^{2}\frac{\Delta\rho}{\rho_l}\cos^{2}\theta$$

- Stagnation Force + Body Force = Surface Tension+Thermocapillary Force+Vapor Thrust
- The vapor thrust component is small except at very high heat fluxes (>10^6 BTU/hr-ft^2) and can be neglected for AP600.
- Solve for δ and determine Γ_{min} as follows

$$\Gamma_{\min} = \frac{g\sin\beta}{3\mu}\delta^{3}$$

Model Development

- To Determine the Local Minimum Stable Film Thickness, Must Know
  - Fluid properties: ρ, μ, σ
  - Surface orientation, β
  - Film thickness, δ (or Γ)
  - Heat flux
  - Contact wetting angle for the surface, θ

- Define the Ratio between Flow Rates at the Minimum Film Thickness, Γ_{min}, and the Local Film Thickness, Γ

$$R = \frac{\Gamma}{\Gamma_{min}}$$

- The Zuber-Staub Model for a Smooth Surface Determined that for $R>1.0$, the Film Would Remain Stable

Model Development

Determination of the Contact Wetting Angle

- Wetting angle measured using an optical comparator
  - Heated and unheated surface
  - Weathered and unweathered surface
- All measurements indicate that a contact wetting angle for weathered surfaces ranging from $\theta = [\qquad\qquad]^{a,c}$ should be used in the film stability analysis.
- The evaluation model bounds the effects of wetting angle

Model Development

Contact Wetting Angle

TEST RESULTS

Description of Test		Contact Angle Weathered Sample	Contact Angle Unweathered Sample
2. Room Temperature, T=80°F			
3. Heated, T=110°F			
4. Heated, T=180°F	t=0 sec.		
	t=15 sec.		
	t=30 sec.		
	t=60 sec.		

(a,c)

Model Development

- To Use this Model for AP600 Wetted Coverage it was Necessary to:
  - Determine the value of R at which the flow becomes unstable for a rough surface with welds and other imperfections, R_{ref}.
  - Once the film becomes unstable it continues at incipient stability

For incipient stability:

$$\Gamma = R_{ref}\,\Gamma_{min}$$

- Thus, for an Unstable Evaporating Film, the Coverage Fraction Decreases Continually
- Sixteen Large-Scale Heat Transfer Tests are Predicted Using Various Values of R_{ref}
- $R_{ref} = 1.75$ Conservatively Predicts the LST Coverage Results

Model Validation

a,c

Application to AP600

Test Data Show:

1. The shell will be covered with a large number of film stripes instead of a continuous sheet of film.
2. About 10 minutes is required to establish steady state coverage at the 220 gpm PCS film flow rate.
3. Water coverage will decrease as the PCS film flow rate decreases with time.
4. Film continues to thin until completely evaporated.

Analytical Model Predicts:

The film stripes will thin and split, causing the coverage to decrease from top to bottom of the vessel as the water evaporates.

WGOTHIC AP600 Clime Model

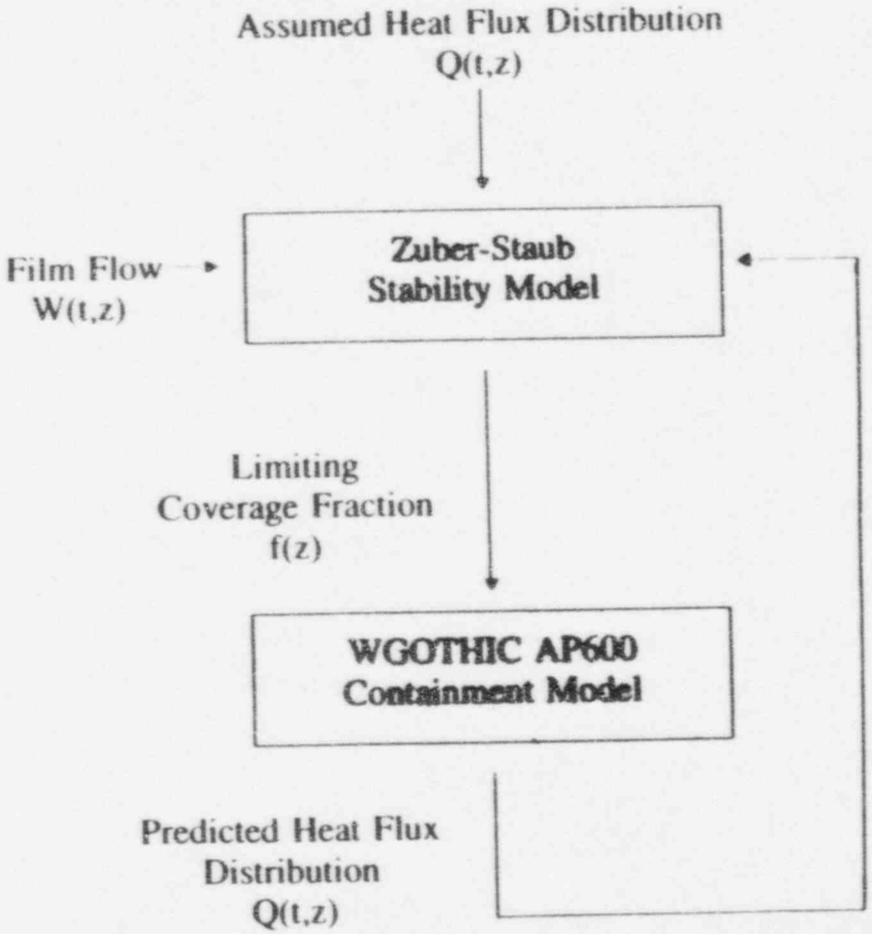
- The shell is divided into 7 elevation planes (3 on the dome and 4 on the vertical sidewall).

- The modified Zuber-Staub model is used to determine a bounding value for film flow and coverage (area and wetted perimeter) for each elevation plane for all times.

- The surface of each shell elevation is divided into wet and dry sections based on the film coverage.

- Although water is available for cooling the dome within a minute, a conservative 11 minute delay is assumed before any water begins to flow onto the shell surface.

Assumed Heat Flux Distribution



Process for Determining Water Coverage Fraction for AP600

Film Coverage Chronology (220 gpm)

- Chronology for AP600

Time (s)	**Event**
0.0	Large, double ended cold leg LOCA occurs
10.0	PCS AOV strokes open
30.0	PCS piping is filled
33.0	Water begins to flow onto dome
183.0	First weir is filled and begins to spill
333.0	Second weir is filled and begins to spill
600.0	Steady state coverage on dome

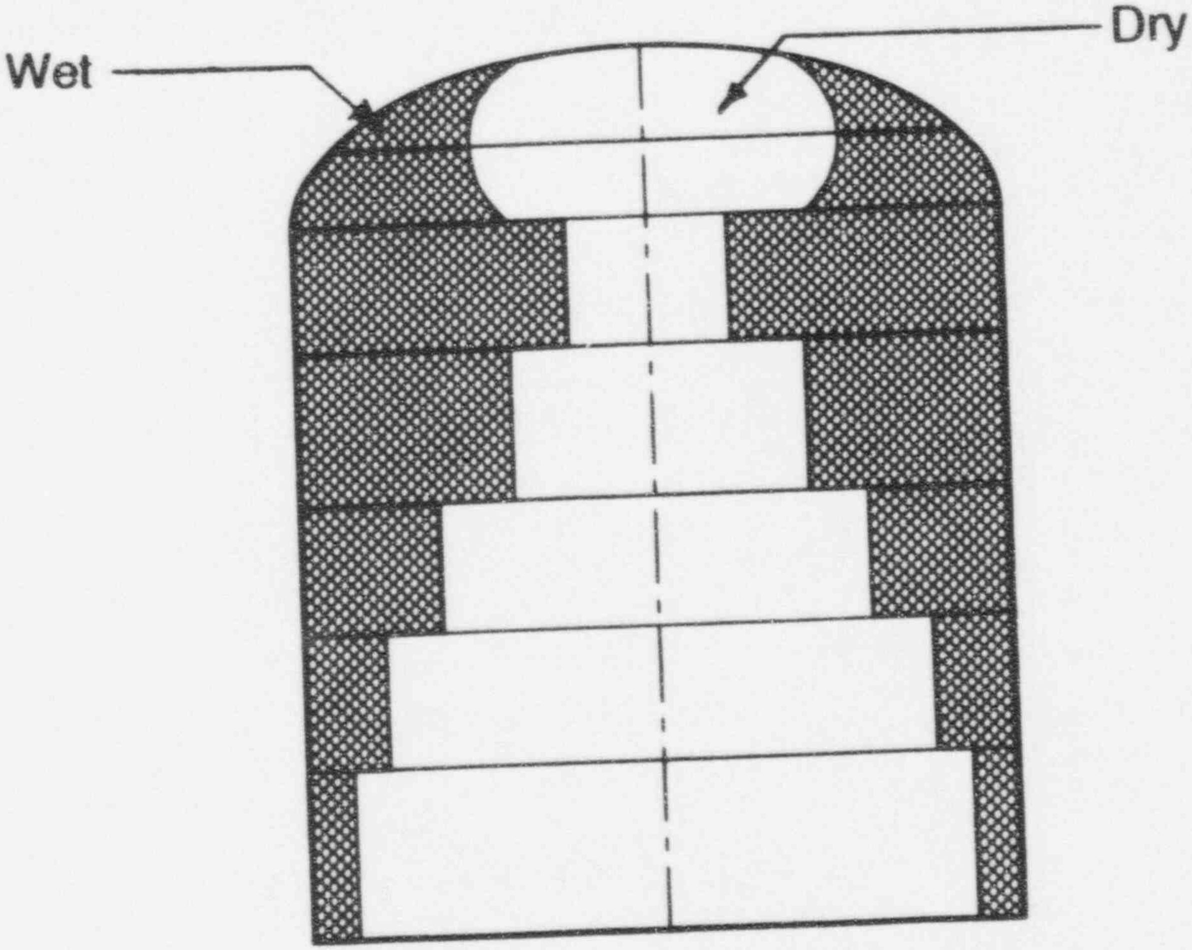
- Evaluation model conservatively assumes no water on the shell until after steady state water coverage is established

Time (s)	**Event**
0.0	Large, double ended cold leg LOCA occurs
660.0	PCS water applied over the shell in evaluation model

Description of Climes

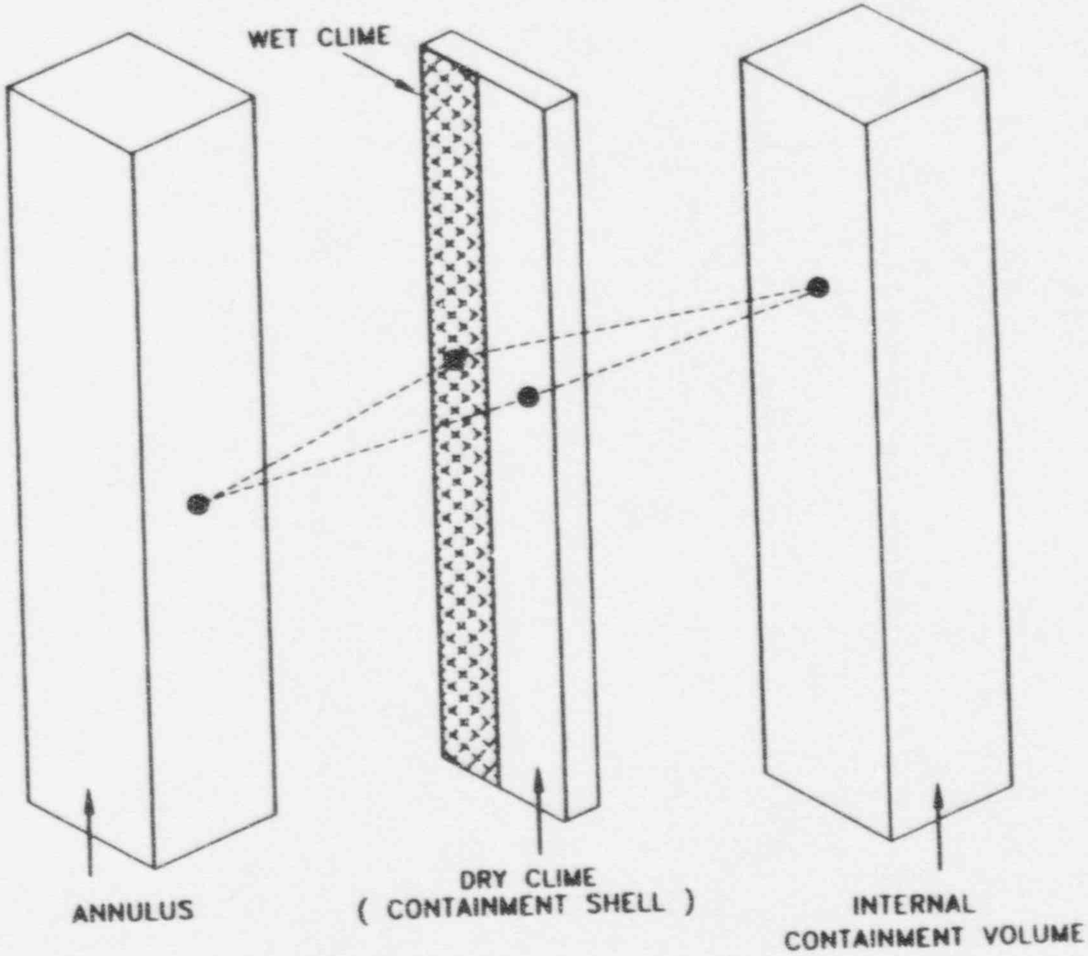
- A special conductor (Clime) is used in WGOTHIC to calculate the mass and energy transfer for each section of the shell. (condensation, conduction, evaporation convection and radiation)
- Stacks of climes are created to track the films.
- After condensation or evaporation, the remainder of the film is transported down through the stack of climes.

WGOTHIC Clime Model



Representation of the WGOTHIC Clime Water Coverage Input for Half of the Containment Shell

WGOTHIC Clime Model



WGOTHIC AP600 Water Coverage Sensitivities Completed

Water Coverage Sensitivity

Base case coverage established using modified Zuber-Staub model with a maximum 40% coverage limit assumed for the top 2 climes on the dome.

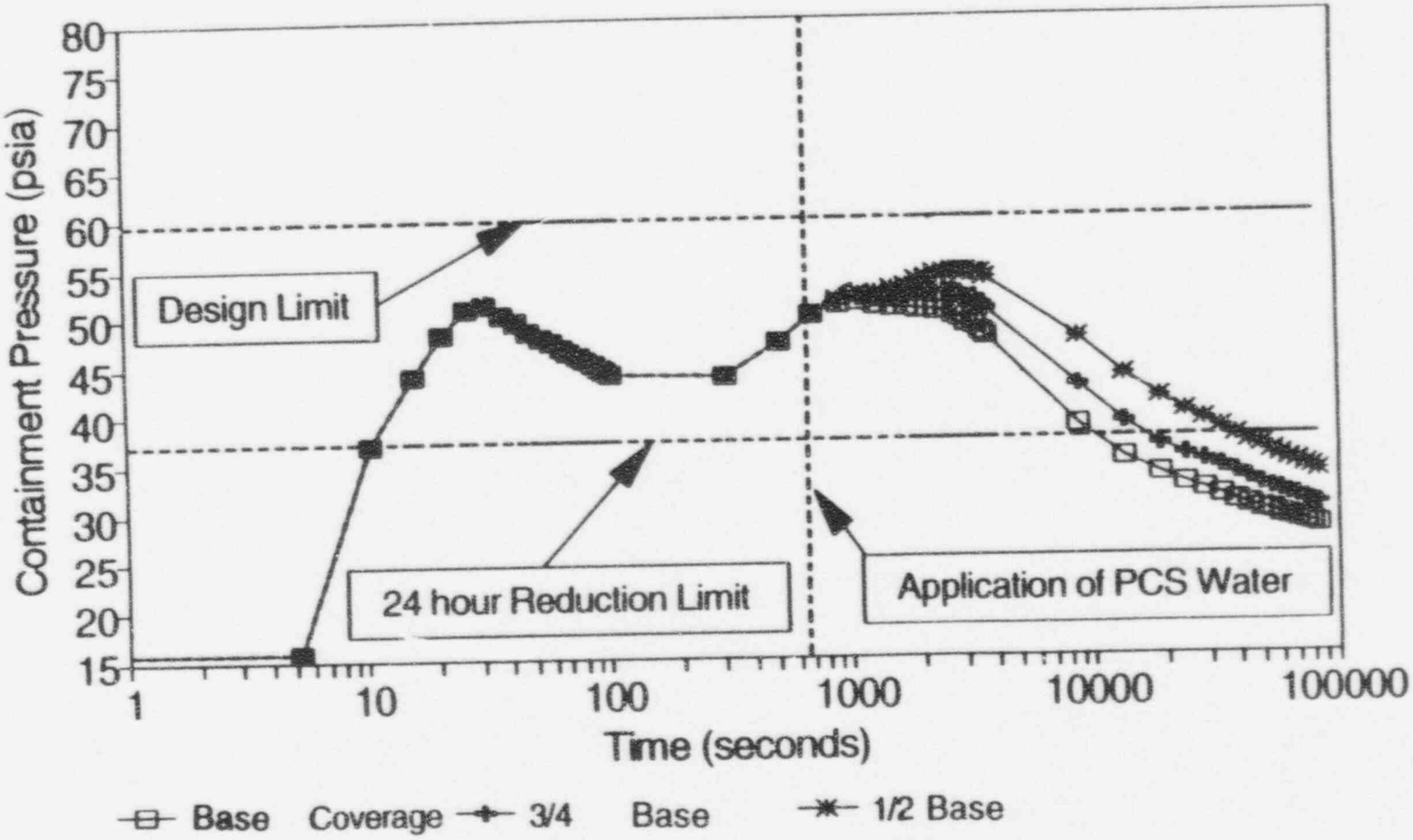
	Dome Coverage			Sidewall Coverage			
Avg	Top	Mid	Bot	Top	Mid1	Mid2	Bot
48%	40%	40%	66%	55%	43%	34%	30%
36%	40%	40%	48%	36%	31%	28%	26%
24%	40%	40%	37%	19%	18%	17%	16%

Water Coverage
(Fraction of Total Surface Area)

	<u>48%</u>	<u>36%</u>	<u>24%</u>
Peak Pressure	51.2	52.1	54.2 psia
24 hr Pressure	27.9	30.0	33.5 psia

WGOTHIC Water Coverage Model

WGOTHIC Water Coverage Sensitivity Based on Film Stability Model



Conclusions

- The modified Zuber-Staub model for predicting water coverage has been validated and bounds essentially all test data
- The WGOTHIC AP600 containment pressure response model is relatively insensitive to the input water coverage fraction and the bounding DBA coverage is not near any cliffs
- A bounding water coverage is established for input to the WGOTHIC AP600 containment model

H. WGOTHIC COMPUTER CODE

December 7, 1995

J. Woodcock, Principal Engineer
Containment and Radiological Analysis

Contact: John Butler
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WGOTHIC Code

Outline

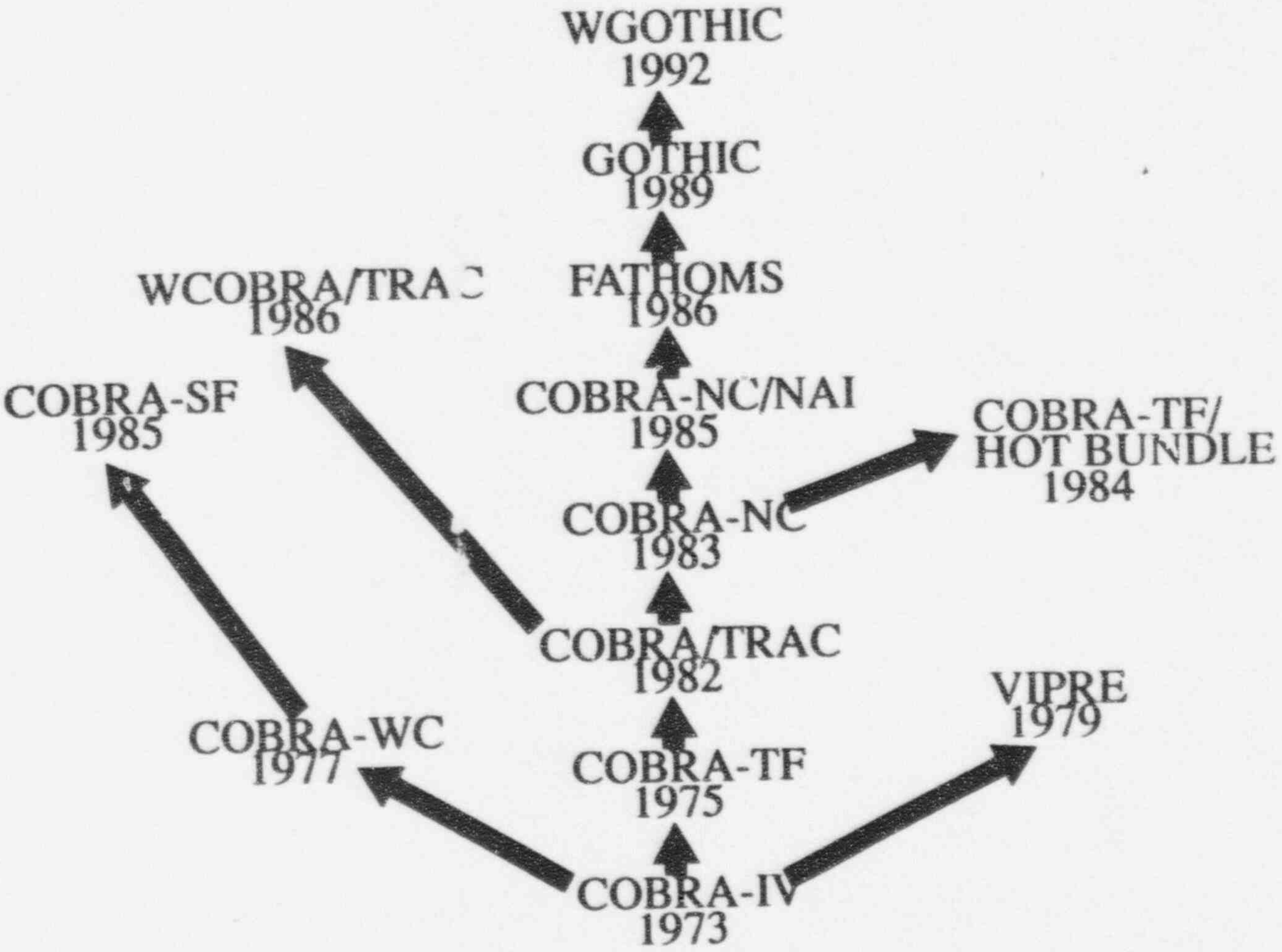
- WGOTHIC code history
- WGOTHIC code features
- WGOTHIC <--- heat and mass transfer subroutines
- EPRI-sponsored peer review of GOTHIC
- WGOTHIC verification and validation methods
- Use of separate effects tests in WGOTHIC validation
- Use of LST in WGOTHIC validation
- Models used in PCS DBA
- Identification of key elements and assumptions for lumped and distributed parameter

WGOTHIC Code History

- Generation Of Thermal-Hydraulic Information for Containments (GOTHIC)
- Developed from COBRA Codes Developed in 1960's by Battelle Pacific Northwest Laboratories
- Designed as a General Purpose Thermal-Hydraulics Code for Licensing, Safety, and Operating Analysis of Nuclear Power Plant Containments and Other Confinement Buildings

WGOTHIC Code History

AP600



WGOTHIC
1992

GOTHIC
1989

WCOBRA/TRAC
1986

FATHOMS
1986

COBRA-SF
1985

COBRA-NC/NAI
1985

COBRA-TF/
HOT BUNDLE
1984

COBRA-NC
1983

COBRA/TRAC
1982

VIPRE
1979

COBRA-WC
1977

COBRA-TF
1975

COBRA-IV
1973

WGOTHIC Code Features

- The base GOTHIC code
  - solves mass, energy, momentum equations for fields representing steam/gas mixture, liquid pools, and liquid drops
  - can be used in two modes, lumped parameter (node-network) or distributed parameter (finite element using large volumes)
  - includes engineered safety equipment models such as pumps, fans, vacuum breakers, heat exchangers.

- Westinghouse-GOTHIC was created by adding subroutines for special conductors, called "Climes," to the GOTHIC code
  - heat and mass transfer correlations for the PCS
  - wall-to-wall radiant heat transfer between clime conductors
  - liquid film tracking

- The Climes subroutines interface with GOTHIC via heat and mass source terms in the GOTHIC governing equations

WGOTHIC Code Feature Summary

Governing Equations

- Mass conservation
- Energy conservation
- Momentum conservation
- State equations

Engineered Safety Equipment

- Pumps
- Fans
- Valves
- Doors
- Heat exchangers
- Vacuum breakers
- Spray nozzles
- Coolers
- Heaters
- Volumetric fans
- Trips

Conductors

- External
- Internal
- Wall
- Tube
- Rod
- Climes

Modeling Features

- Lumped parameter
- Distributed parameter
- Boundary conditions
- Junctions

Time Step Control

- Large changes in phase volume
- Courant limit
- Large changes in total pressure
- Gravitational limit

Input/Output

- Preprocessor
- Postprocessor
- Graphical output
- ASCII output
- Debug output

WGOTHIC Lumped vs. Subdivided

- Lumped Parameter

- Velocity estimated from junction flows for heat transfer purposes

- Film tracking only on PCS surface
  Film is instantly transported to pool from internal heat sink walls

- Pool/Drop geometry
  Liquid fields for pools and drops only

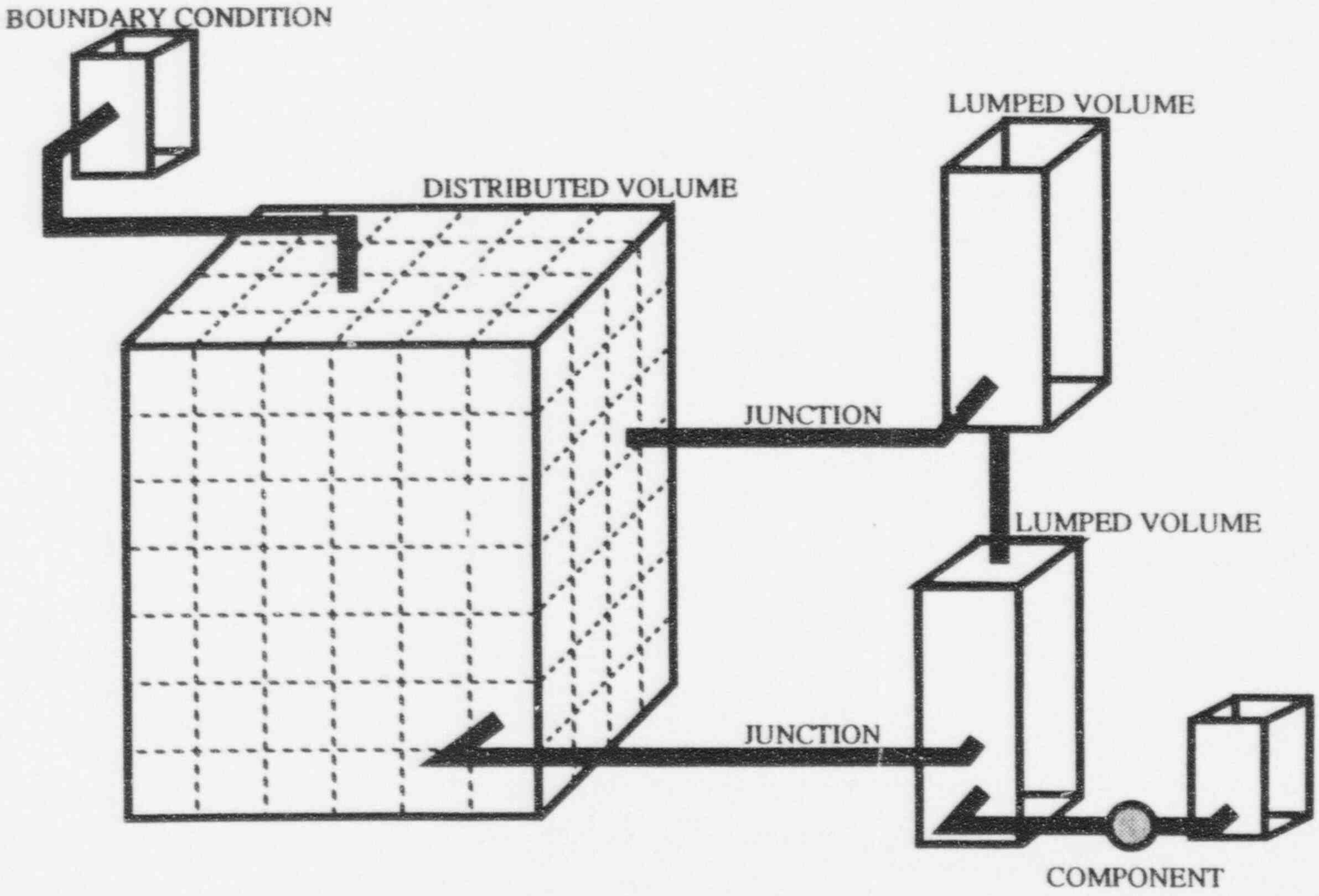
- Distributed parameter

- Local velocities calculated

- Film tracking on PCS and internal heat sinks

- Flow regimes
  single-phase liquid
  dispersed bubbly flow
  slug flow
  churn-turbulent flow
  film/film mist flow
  single-phase vapor

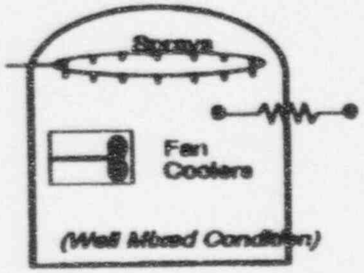
WGOTHIC Lumped vs. Subdivided



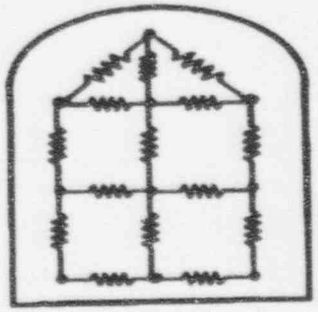
WGOTHIC

WGOTHIC is an Advancement over Traditional Containment Codes

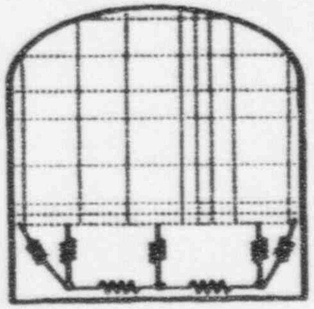
Traditional Plant Containment Analysis
(Single Node Lumped Parameter)



*WGOTHIC Lumped Parameter **
(Node-Network)

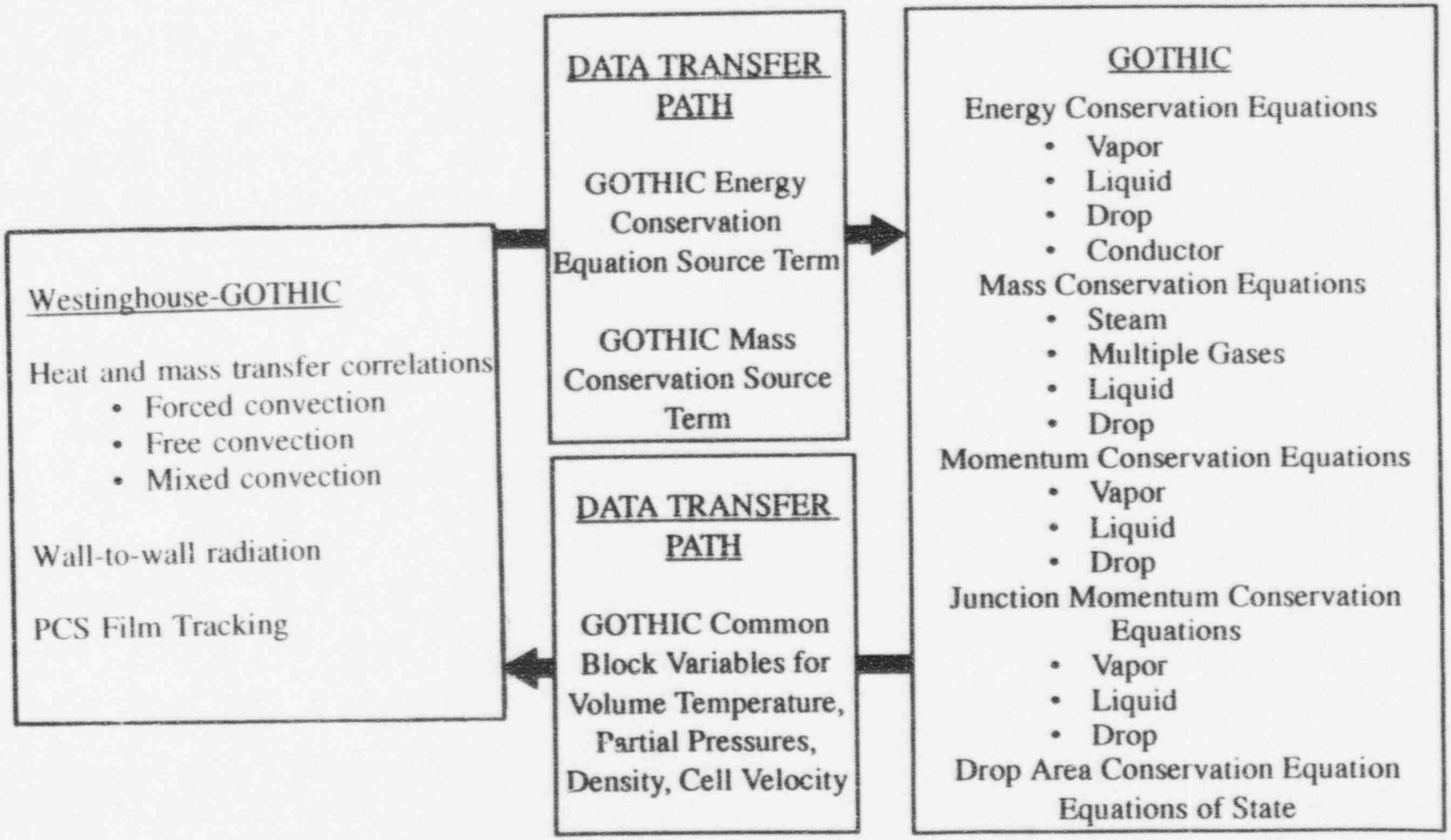


*WGOTHIC Distributed Parameter **
(Finite Difference, Large Mesh)



** Not actual noding. For illustration only.*

WGOTHIC Climes Subroutine Interface



Westinghouse-GOTHIC

Heat and mass transfer correlations
- Forced convection
- Free convection
- Mixed convection

Wall-to-wall radiation

PCS Film Tracking

DATA TRANSFER PATH

GOTHIC Energy Conservation Equation Source Term

GOTHIC Mass Conservation Source Term

DATA TRANSFER PATH

GOTHIC Common Block Variables for Volume Temperature, Partial Pressures, Density, Cell Velocity

GOTHIC

Energy Conservation Equations
- Vapor
- Liquid
- Drop
- Conductor

Mass Conservation Equations
- Steam
- Multiple Gases
- Liquid
- Drop

Momentum Conservation Equations
- Vapor
- Liquid
- Drop

Junction Momentum Conservation Equations
- Vapor
- Liquid
- Drop

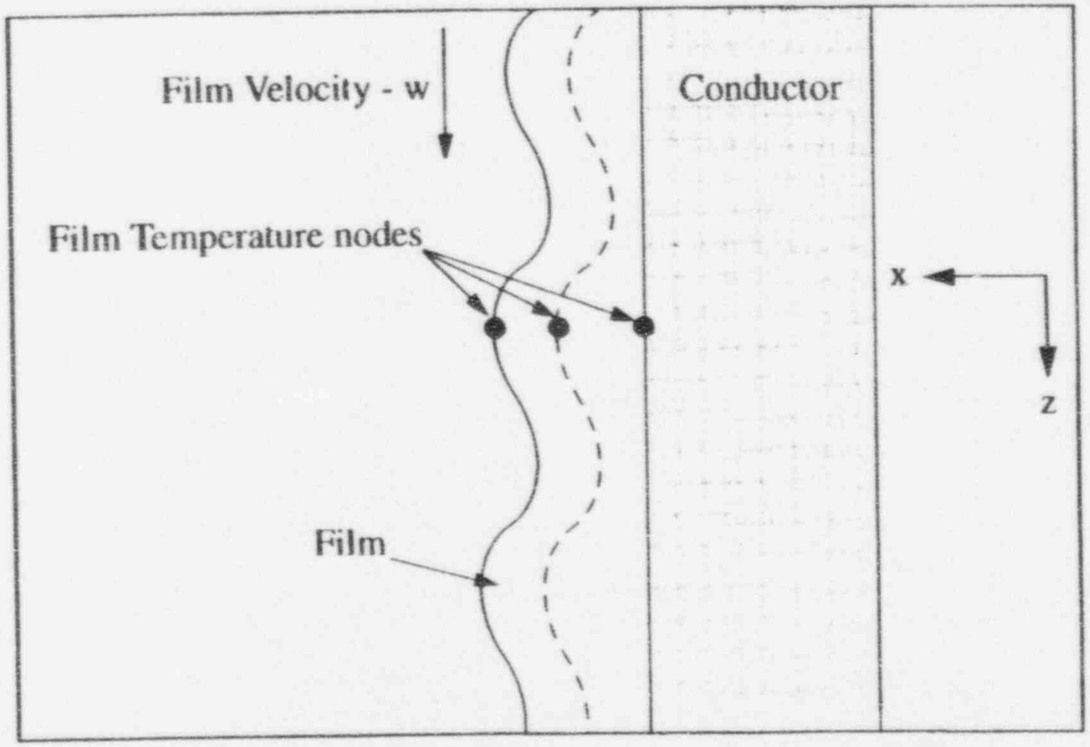
Drop Area Conservation Equation

Equations of State

Westinghouse Film Energy Transport

LIQUID FILM ENERGY TRANSPORT EQUATION

$$\rho c_p\left(\frac{\partial T}{\partial t}film + w\frac{\partial T}{\partial z}film\right) = k\frac{d^2 T}{dx^2}film$$



Correlations Selected for AP600 Climes

Convective Heat Transfer

EXTERNAL

The McAdams turbulent free convection heat transfer correlation: $Nu_{d,free} = 0.13(Gr_d Pr)^{1/3}$

and the Colburn turbulent forced convection heat transfer correlation: $Nu_{d,forc} = 0.023Re_d^{4/5}Pr^{1/3}$
are used for the external convective heat transfer to or from the surfaces.

The correlations for combined free and forced convection heat transfer from Churchill are, for turbulent opposed free and forced convection:

$$Nu = (Nu_{free}^3 + Nu_{forc}^3)^{1/3}$$

and for assisting free and forced convection, Nu is the larger of the following three expressions:

$$abs(Nu_{free}^3 - N_{forc}^3)^{1/3} \quad ; \quad Nu_{free} \quad ; \quad 0.75Nu_{forc}$$

The lower limit in the latter equation, which prevents the value of Nu from going to zero when Nu_{free} and Nu_{forc} are equal, comes from Eckert and Diaguila.

INTERNAL

The McAdams turbulent free convection heat transfer correlation: $Nu_{x,free} = 0.13(Gr_x Pr)^{1/3}$

is used for the internal convective heat transfer to or from the surfaces.

Correlations Selected for AP600 Climes

Convective Mass Transfer

The mass transfer correlation is derived from the heat transfer correlation using the heat and mass transfer analogy:

$$Sh = N\left(\frac{Sc}{Pr}\right)^{1/3}$$

The resulting mass transfer coefficient, k_g, from the Sherwood number definition:

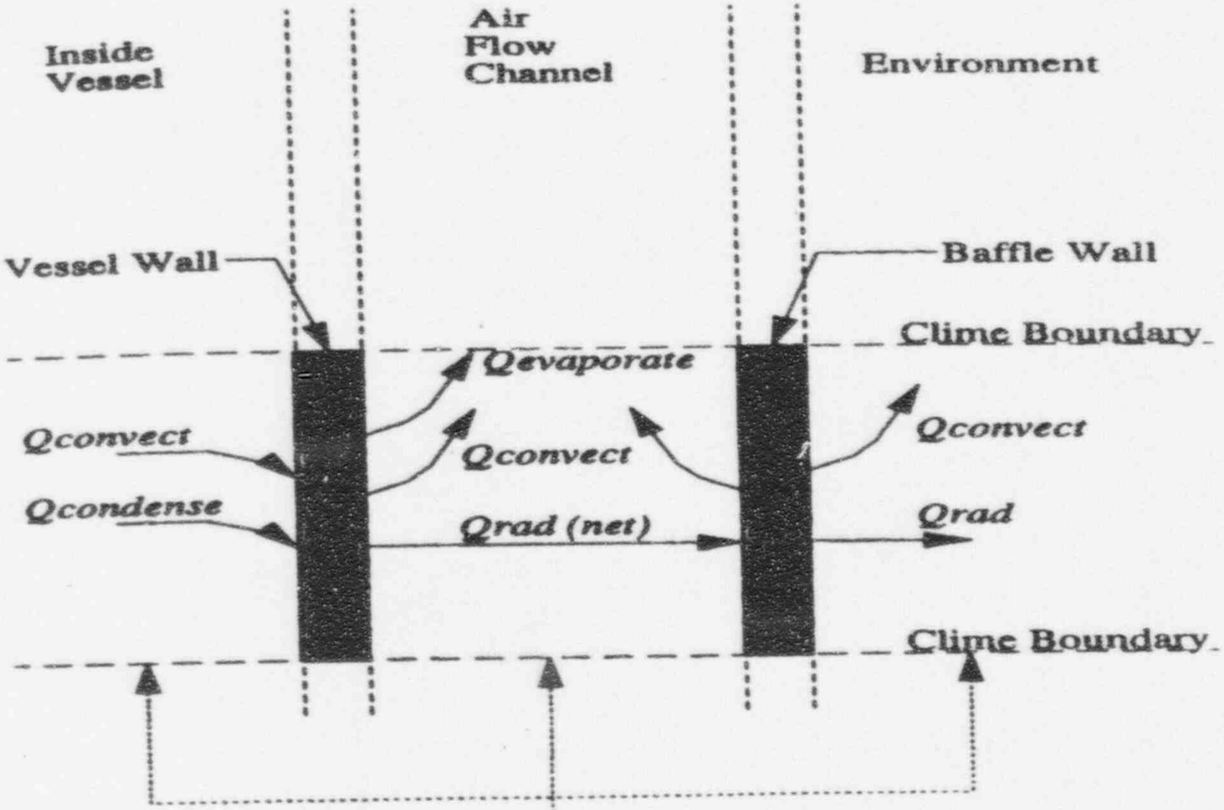
$$Sh = \frac{k_g \bar{R} T P_{Bm} L}{D_v P}$$

The mass flux of condensing or evaporating steam is calculated from the mass transfer coefficient:

$$\dot{m}'' = k_g M_{stm}(P_{stm,surf} - P_{stm,bulk})$$

WGOTHIC Wall Source Term Models

The Passive Cooling System Heat/Mass Transfer Package is Referred to as a "Clime."



Inside Vessel

Air Flow Channel

Environment

Vessel Wall

Baffle Wall

Clime Boundary

Qevaporate

Qconvect

Qcondense

Qconvect

Qrad (net)

Qconvect

Qrad

Clime Boundary

CLIME Heat and Mass Source Terms Interface with Westinghouse-GOTHIC Volumes, and the Volume Conditions Are Used in the CLIME Heat and Mass Transfer Correlations

EPRI-sponsored peer review of GOTHIC

- **A peer review of the GOTHIC code was held in 1991 to establish a reference point for putting the GOTHIC code package under a 10CFR50 Appendix B QA program**
  - Started with GOTHIC 3.4d
  - Reviewed documentation, coding, convergence, pre/post processor, code qualification package, and code adequacy for containment analysis.
  - Resulted in GOTHIC 4.0 and updated documentation

- **Results were that:**
  - Documentation is adequate to describe the theory and assumptions made, code logic, and user requirements, with some corrections noted
  - Source code is consistent with the documentation, with some corrections noted
  - Solution technique is stable
  - The code package offered the ability to provide more accurate and mechanistic results than other current containment codes
  - Application-specific qualification may be needed if the range of the GOTHIC qualification base is exceeded.

Applicability of peer review to WGOTHIC

The current configuration-controlled version of WGOTHIC is 1.2

WGOTHIC started from GOTHIC 3.4c

- The differences in GOTHIC 3.4c versus 3.4d are minor

The differences between WGOTHIC 1.2 and GOTHIC 4.0 have been shown to be minor in documentation provided to NRC

- Error corrections identified for intermediate GOTHIC versions have been incorporated into WGOTHIC up to the time WGOTHIC was configured
- Only a few minor differences exist between WGOTHIC 1.2 and GOTHIC 4.0
- Incorporation of those differences into a pre-configuration version of WGOTHIC show no significant difference in results other than during blowdown due to an improved droplet model
- We are incorporating differences into configuration version of WGOTHIC for DBA calculations

The peer review applies directly to WGOTHIC, excluding the AP600 heat and mass transfer subroutines which have been specifically verified and validated for use on AP600

[illegible]

WGOTHIC Verification and Validation Methods

Dedication

- Purchase of GOTHIC from Numerical Applications, Inc.
- Installation of GOTHIC on Platform
- Westinghouse Ran GOTHIC Code Qualification Test Matrix (20 tests)
- Configure GOTHIC

Design

- Develop Correlations from Separate Effects Tests
- Incorporate Modifications into WGOTHIC

Verification

- Run Subset of GOTHIC Code Qualification Test Matrix
- Verify Westinghouse Code Changes with Hand Calculations

Validation

- Rerun Subset of GOTHIC Code Qualification Test Matrix
- Reverify Westinghouse Code Changes with Hand Calculations
- Run Selected Large-Scale Tests
- Configure WGOTHIC

Application Development

- Run Additional Large-Scale Tests
- Develop Modelling Guides for Plant
- Develop Bounding Initial Conditions
- Issue Final Verification and Validation Report

WGOTHIC Module Coverage

ITEM	CSNI	STD PROB	BFMC	HEDL	LACE	MARV	CVTR	HDR	SST	LST
Fluid Momentum		X	X		X	X			X	X
Energy Transport	X	X	X		X	X			X	X
Noncondensable Gases	X	X	X	X	X	X	X	X		X
Equations of State	X	X	X		X	X				
Pressure Response	X	X	X	X	X	X	X	X	X	X
Temperature Response	X	X	X	X	X	X	X	X	X	X
Humidity Response	X		X	X	X	X	X	X	X	X
Hydrogen Transport		X	X							X
Energy Sources	X	X	X	X	X		X	X	X	X
Subcompartment Analysis			X			X				
High Energy Line Breaks			X							X
PWR Standard Containment					X					X
BWR Pressure Suppression		X				X				
Fluid/Structure Interaction			X							X
Conductors		X	X						X	X
Subdivided Volumes		X	X							X
Turbulence			X							
3-D Calculations			X	X			X			X
Climes									X	X

AP600 Specific Validation Leads to Evaluation Model

- **Use of separate effects tests in AP600 WGOTHIC validation**

Separate effects tests, discussed in more detail in the AP600 Test Program session, have been used to show that the correlations have been correctly programmed.

- **Use of LST in WGOTHIC validation**

Priority tests were identified to establish the most important tests for validation based on a range of the parameters that have the largest effect on vessel pressure.

Models of the LST have been used to develop bounding evaluation model

- 550 node model shows very good agreement with test data, showing that there are no compensating errors in that calculation and important phenomena have been modelled.
- Reduced to 375 nodes based on noding studies showing that perturbations of noding had relatively small effects to serve as basis of distributed parameter evaluation model.
- 79 node lumped parameter shown to overpredict the degree of mixing.

WGOTHIC Models Excluded From PCS DBA

The following models available via base GOTHIC coding are excluded from the AP600 PCS DBA analysis

- Gido-Koestel Condensation
- Tube and rod conductors
- Components
    - Pumps and fans
    - Valves
    - Heat exchangers
    - Vacuum breakers
    - Spray nozzles
    - Coolers
    - Volumetric fans
- Coupled boundary conditions
- Ice condenser models

Identification of Key Elements and Assumptions

- Geometry, boundary, and initial conditions are conservatively bounded

- Climes heat and mass transfer routines use conservatively bounded heat and mass transfer correlations

- Full symmetry noding for AP600 evaluation models, including dome modelling, is established based on

    375 node ½ symmetry distributed parameter LST model

    79 node ½ symmetry lumped parameter LST model

WGOTHIC Conclusions

- WGOTHIC Contains the Basic Equations and Features Needed to Model the LST and AP600
- Westinghouse Links to GOTHIC Code:
  - Limited to mass and energy equations source term and common data
  - Do not alter GOTHIC solution scheme
  - Do not affect the GOTHIC code qualification basis
- Lumped/Distributed Modeling Schemes Used for the AP600 LST Have Been Employed in Code Qualification Analyses
- Models for Phenomena Rated Important in the PIRT Have Been Validated
- WGOTHIC is a Suitable Tool for Use in Analyzing the AP600

Scientech Briefing Meeting on AP600 PCS

I. AP600 PCS EVALUATION MODEL KEY ASSUMPTIONS AND RESULTS

December 7, 1995

J. Woodcock, Principal Engineer
Containment and Radiological Analysis

Contact: John Butler
Phone: 412-374-5268

Westinghouse Electric Corporation

AP600 PCS Evaluation Model Key Assumptions and Results

Outline

- Objective and key characteristics
- LOCA
- MSLB

Objective and Key Characteristics

- **Objective**

The bounding PCS DBA evaluation models include sufficient margin to reflect consideration of:

  - all appropriate energy sources
  - extent of experimental data available
  - bounding calculational model and input parameters

- **Key characteristics**

- Bounding mass and energy releases are determined based on Standard Review Plan guidance
- Initial and internal containment conditions are set to the Technical Specification limits
- Environmental boundary conditions bound values expected for the given site (See SSAR Chapter 2 for values used in AP600 generic analysis)
- Atmosphere is assumed to be quiescent since wind effects improve PCS performance
- Bounding phenomenological models are used

LOCA Evaluation Model Characteristics

- PCS water assumed to be available for cooling the shell at 660 seconds, neglecting any heat removed due to subcooled film or evaporation prior to that time

- Double Ended Cold Leg Guillotine (DECLG) break with a discharge coefficient of 1.0 is the limiting break

- Short term (~2000 seconds) peak pressure is analyzed with the distributed parameter AP600 evaluation model to allow biases that reduce internal heat sink efficiency

- Long term (24 hours) pressure reduction is analyzed with the lumped parameter AP600 evaluation model since it predicts the limiting condition of well-mixed containment by 24 hours.

- Results of the current evaluation model will be reflected in the final SSAR revision

MSLB Characteristics

- External heat transfer is negligible since the PCS water is not assumed to be available until 660 seconds and steamline breaks are over by about 450 seconds.

- Double ended MSLB with MSIV failure is the limiting steamline break

- MSLB is analyzed with the lumped parameter evaluation model, introducing significant conservatism since forced convection enhancements due to the highly energetic steam releases are neglected.

- Results of the current evaluation model will be reflected in the final SSAR revision

Conclusion

Bounding evaluation models have been established for the LOCA and Main Steamline Break

Scientech Briefing Meeting on AP600 PCS

J. Steps to Closure of Remaining Open Items

December 7, 1995

J. Woodcock, Principal Engineer
Containment and Radiological Analysis

Contact: John Butler
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J. Steps to Closure of Remaining Open Items

- Use of scaling
- Water coverage
- Uncertainties
- Mixing and stratification
- WGOTHIC code documentation
- Noding convergence

Use of scaling

AP600

- **Statement of issue**

  The role of scaling in development of the evaluation model should be documented, showing how scaling has been used to support development of bounding phenomenological models.

- **Closure path**

  Document role of scaling.

- **Status**

  Complete

  - Role of scaling documented in NTD-NRC-95-4561 (9/19/95)
  - Responses to priority RAIs have included clarification of role of scaling.

Water coverage

- **Statement of issue**

  Show how bounding water coverage values are established for use in the AP600 PCS evaluation model

  Evaluate results of LST 219 to assess ability of the containment surface to rewet after dryout

- **Closure path**

  Document how bounding values are derived for input to evaluation model as boundary condition

  Provide assessment of LST 219

- **Status**

  Complete

  - Documentation is in NTD-NRC-94-4247 (7/28/94) and NTD-NRC-94-4286 (8/31/94)
  - LST 219 temperature and flow oscillations are essentially in phase, showing no significant delay in rewetting after apparent dryout on the vessel surface at prototypical temperatures and flows

Uncertainties

AP600

- **Statement of issue**

  Provide documentation of how uncertainties are bounded in the evaluation model

- **Closure path**

  Provide roadmaps for how phenomena are bounded in the evaluation model

  Provide bases for heat and mass transfer correlation biases.

- **Status**

  Complete

  Documentation provided showing how uncertainties are bounded

  - Roadmaps in NTD-NRC-95-4545 (8/31/95)
  - Bases in NTD-NRC-95-4570 (9/28/95)

Mixing and stratification

- ## Statement of issue

  Show that the effects of mixing and stratification are bounded for the short term pressure peak.

- ## Closure path

  Provide sensitivities and calculations to explain how the effects of mixing and stratification are bounded in the evaluation model, including potential stratification biases from smaller breaks.

- ## Status

  Nearing completion

  - Hand calculations show heat sinks in the CMT/CVCS room saturate well before peak pressure. Quantification of effect of conservatively biased operating deck flow area has been documented (NTD-NRC-95-4596, 11/13/95). Results show conservative op-deck flow area bias has negligible effect on pressure response, since CMT/CVCS room heat sink saturation time remains less than time to reach peak containment pressure.

  - Documentation is complete for sensitivities showing the evaluation model bounds DECL, C_d= 0.6, Double-Ended Hot Leg and 7 inch diameter, elevated break

WGOTHIC Code Documentation

- **Statement of issue**

  NRC needs listing of GOTHIC models not being used by AP600 WGOTHIC

  Westinghouse to facilitate revision of GOTHIC equation documentation errors/problems

  Westinghouse to identify how WGOTHIC was modified to address items corrected in GOTHIC 4.0

- **Closure path**

  Updated documentation to be provided

- **Status**

  Complete

  - Models not being used by AP600 WGOTHIC are listed in NTD-NRC-95-4577 (10/12/95)
  - GOTHIC 4.0 documentation, correcting documentation errors noted in the peer review, has been provided in NTD-NRC-95-4563 (9/21/95)
  - Identification of the minor differences remaining between WGOTHIC 1.2 and GOTHIC 4.0 has been provided in NTD-NRC-95-4577 (10/12/95) and NTD-NRC-95-4595 (11/13/95), including calculations showing negligible impact on previously submitted analyses
  - The final SSAR revision results will incorporate updates to make WGOTHIC 1.2 consistent with GOTHIC 4.0

Noding convergence

- ## Statement of issue

  The AP600 distributed parameter model should be confirmed to be relatively insensitive to noding as shown for the LST distributed parameter models in WCAP-14382.

- ## Closure path

  Perform noding sensitivity calculations for the AP600 distributed parameter model.

- ## Status

  Noding studies complete. Documentation in progress.

  - Simplified distributed parameter models have been used to show that the WGOTHIC pressure response converges predictably and stably with noding refinement, with coarser nodes predicting increased mixing.
  - AP600 distributed parameter calculations performed using finer (550x2) and coarser (79x2) nodes than the distributed parameter evaluation model (350x2), show relative insensitivity to noding above the operating deck, including the effects of multiple below-deck compartments and internal heat sinks.

Scientech Briefing Meeting on AP600 PCS

K. Conclusions

December 7, 1995

J. Woodcock, Principal Engineer
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Contact: John Butler
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Scientech Briefing Meeting on AP600 PCS

Conclusions

- Phased submittals have provided technical documentation of key aspects of the PCS DBA bounding approach
- Similar phased approach recommended in support of the balance of the licensing review
- WGOTHIC Applications Report is defined as a compilation of the phased submittals

L. Summary and Action Items

December 7, 1995

J. Woodcock, Principal Engineer
Containment and Radiological Analysis

Contact: John Butler
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Scientech Briefing Meeting on AP600 PCS

Summary and Action Items

- Discussions of
    - NRC conclusions from the meeting and expectations for subsequent interactions
    - NRC direction for review focus topics
    - Westinghouse considerations to aid the review process
    - Process to mutually develop remaining schedule
- Action items documentation