



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

January 12, 1995

APPLICANT: Westinghouse Electric Corporation  
PROJECT: AP600  
SUBJECT: SUMMARY OF MEETING TO DISCUSS THE AP600 PASSIVE CONTAINMENT COOLING SYSTEM (PCS) ANALYSIS PROGRAM

A meeting concerning the AP600 PCS analysis program was held at the Westinghouse Energy Center in Monroeville, Pennsylvania on November 15 through 17, 1994. Representatives of Westinghouse Electric Corporation and the Office of Nuclear Regulation staff and their contractors were present (Enclosure 1). Enclosure 2 is a non-proprietary version of the handout materials presented by Westinghouse at the meeting that Westinghouse sent the Nuclear Regulatory Commission (NRC) on November 21, 1994 (NTD-NRC-94-4346). Enclosure 3 is the material presented by NRC and its contractors. Because this presentation material contained information considered proprietary by Westinghouse, only the non-proprietary information presented is enclosed. The following is a summary of the main results and conclusions from the meeting.

The first day of the meeting focused on the Large Scale Test (LST) scaling analysis. The NRC identified two major areas needing additional work. In the interior of the containment, the NRC requested additional work on the treatment of stratification and mixing. On the containment exterior, the NRC needs additional justification from Westinghouse on the use of forced convection heat transfer correlations in a situation that normally calls for a buoyancy driven correlation. Westinghouse also committed to do additional work in the area of steamline breaks because the scaling analysis were focused on loss-of-coolant accidents. There were several questions on the development and comparison of Froude numbers, which are used to characterize buoyant plumes in the containment. Westinghouse stated that they would look into these questions, including published work by Peterson. The NRC considers the scaling and understanding of Froude numbers essential to understanding of mixing in the containment. The NRC also identified a need for Westinghouse to look at uncertainties and to perform bounding analyses to understand margins.

The second day of the meeting concentrated on the analysis of LST test data and the results of WGOthic lumped parameter calculations of these tests. Westinghouse also presented draft outlines for future reports on test analysis and code validation. The NRC requested the addition of a new section to the verification and validation report to specifically discuss "lessons learned" from the WGOthic subdivided model.

Several presentations were made by NRC and its contractors. The NRC discussed preliminary results of sensitivity analyses of the AP600 using the CONTAIN code. These results show little pressure sensitivity to external water coverage but show a significant blowdown pressure sensitivity to mixing. Sandia National Laboratory discussed review of the WGOthic code, including

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January 12, 1995

concerns with the WGOthic subdivided volume approach. JTA (Sandia subcontractor) provided a status of analysis of the LST test data and validation of the CONTAIN code. ERI (Purdue University contractor) is analyzing the flow/heat transfer behavior of the annulus, including the possibility of flow reversals, using finite difference methods. Preliminary calculations of a model of the LST configuration under natural circulation conditions were presented. The focus of the presentation was that the model shows nonsymmetrical velocity distributions.

The NRC complimented Westinghouse for doing a lot of work. The participants discussed remaining hard spots. The following key areas of concern were identified:

1. Plumes and Froude numbers, How do Froude numbers of the experiment compare with the plant? Look at the physics of how a jet interacts with a volume from scaling point of view (first principle). This would extend the approach included in the scaling analysis to address these specific internal phenomena.
2. Westinghouse must be able to justify an evaluation model approach to account for mixing, stratification, and velocities. The NRC sees a success path going with lumped parameter with backup using finite difference model. Velocities extracted from lumped parameter model is new and a potential issue.
3. There is a need to better understand basis for use of forced convection in area of buoyant external riser flows.
4. Do LST tests simulate AP600 well enough so that specific statements concerning code validation can be made? To what extent can nonsimilar behavior be tolerated and yet still allow one to make quantitative statements regarding validation?

Need to normalize pi groups in a way that allows consistent comparison between inner and outer vessel processes to show that the LST covers the range of ratios of condensation and evaporation rates. Clarify whether similarity of pi groups for LST and AP600 is related to choice of normalization factors. Examine ways to use the scaling pi groups to address these questions.

What are the controlling phenomena for predicting pressure? (Scaling shows external heat transfer controlling, WGOthic shows not sensitive.)

What type of calculations make sense for certification? Role of best estimate versus bounding calculations.

5. How much is condensation affected by concentration? In order to understand importance of condensation vs. evaporation, need to look at them separately.

January 12, 1995

The following actions were agreed to from the meeting:

1. Westinghouse will use the tools developed in the scaling work to include consideration of stratification for steamline breaks.
2. Westinghouse will use the scaling analysis to look at uncertainty/bounding analyses.
3. Westinghouse will provide additional information on the comparison of LST and AP600 Froude numbers.
4. Westinghouse will provide additional information or point to previously submitted information which addresses the NRC concern on use of forced convection correlation in the annulus.
5. Westinghouse will look at the normalization of steam sources. Joining inside and outside containment on a similar basis to look at condensation and evaporation.
6. Westinghouse will provide information to clarify the normalization basis for the LST and AP600 pi groups used in the scaling analysis.
7. Westinghouse will provide information on a more detailed breakdown of the pi groups used in the scaling analysis.
8. Westinghouse/NRC to arrange a teleconference to discuss the test analysis and validation reports which Westinghouse will be submitting to support WGOthic verification and validation.
9. Westinghouse to provide water distribution data measured during the LST tests which was not included in final test data report.

**Original Signed By:**

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Docket No. 52-003

Enclosures:  
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Docket No. 52-003

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PCS ANALYSIS MEETING  
MEETING ATTENDEES  
NOVEMBER 15 THROUGH 17, 1994

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Enclosure 2 to NTD-NRC-94-4346



PRESENTATION  
TO  
UNITED STATES  
NUCLEAR REGULATORY COMMISSION

AP600 Passive Containment Cooling System (PCS)  
Analysis Program

Pittsburgh, PA

November 15, 1994

Enclosure 2

## Agenda

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### Day 1

Woodcock	1 hr.	PCS analysis program summary and status
Spencer	4 hrs.	Scaling report <ul style="list-style-type: none"><li>- methodology overview</li><li>- conclusions</li></ul>
Spencer	0.5 hr.	PCS open items relevant to scaling report <ul style="list-style-type: none"><li>- items 1, 3</li></ul>
Kennedy	0.5 hr.	Test analysis and code validation reports <ul style="list-style-type: none"><li>- schedule and outlines</li></ul>
NRC	0.5 hr.	Feedback from previous presentations

## Agenda (Cont.)

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### Day 2

Woodcock	0.5 hr.	Opening remarks
Kennedy	1.5 hrs.	Framework on usage of LST data <ul style="list-style-type: none"><li>- matrix of LSTs</li><li>- status of data reduction</li></ul>
Kennedy	2 hrs.	Test 212.1 <ul style="list-style-type: none"><li>- description of tests and data</li><li>- <u>WGOTHIC</u> lumped parameter results</li></ul>
Kennedy	1.5 hrs.	Test 222.1 <ul style="list-style-type: none"><li>- description of tests and data</li><li>- <u>WGOTHIC</u> lumped parameter results</li></ul>
Kennedy	1 hr.	Subdivided <u>WGOTHIC</u> results
Kennedy	0.5 hr.	Blind test description
NRC	0.5 hr.	Feedback from previous presentations



## Agenda (Cont.)

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### Day 3

Woodcock	0.5 hr.	Opening remarks
NRC	1 hr.	AP600 calculation results
NRC	1 hr.	LST calculation results
Woodcock	2 hrs.	PCS open items review and status
All	1 hr.	Wrap-up and action items
Orr	1 hr.	Discussion of ADS phase A test results

## Purposes of Meeting

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- Establish common understanding of:
  - scaling
  - test data evaluation status
  - WGOTHIC calculations status
- Address open items

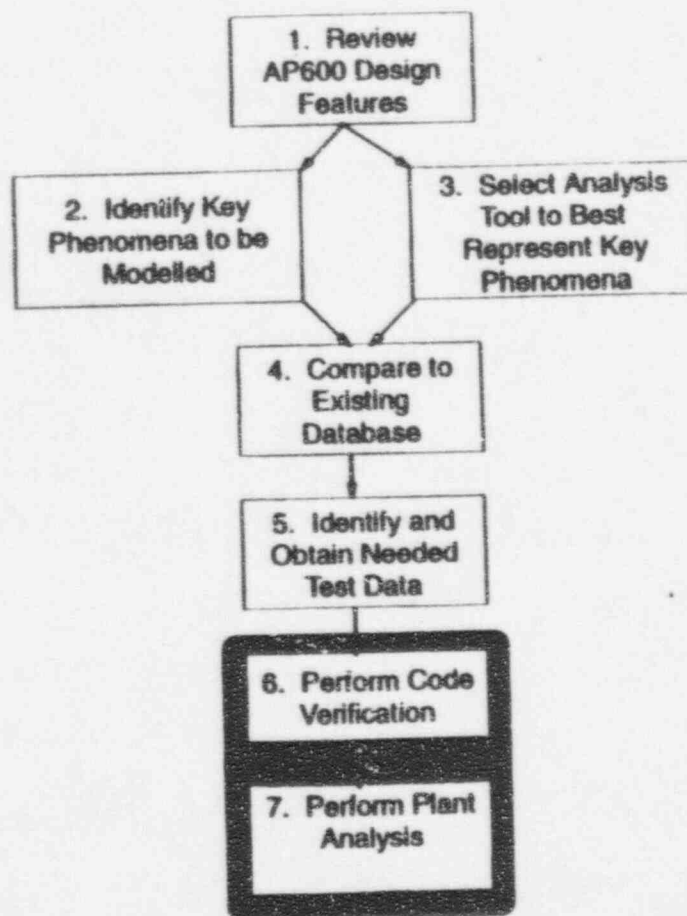


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**PCS ANALYSIS PROGRAM  
SUMMARY AND STATUS**

**Joel Woodcock  
Principal Engineer**

# AP600 PCS Test and Analysis Program





## Strategies Have Been Developed

- Overall PCS strategy
- Phenomena modeling (effort nearing completion)
- Scaling (effort complete)
- Test data evaluation process
- Code validation process
- Design certification documentation
  - NRC/Westinghouse interaction process
  - written reports

## Additional Detailed Strategies Are Being Developed

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- Topics:
  - mixing and stratification
  - evaluation of conservatisms and code uncertainty
  
- Considerations:
  - adequacy of the Evaluation Model can be established based on a common understanding of scaling, phenomena, and code calculations

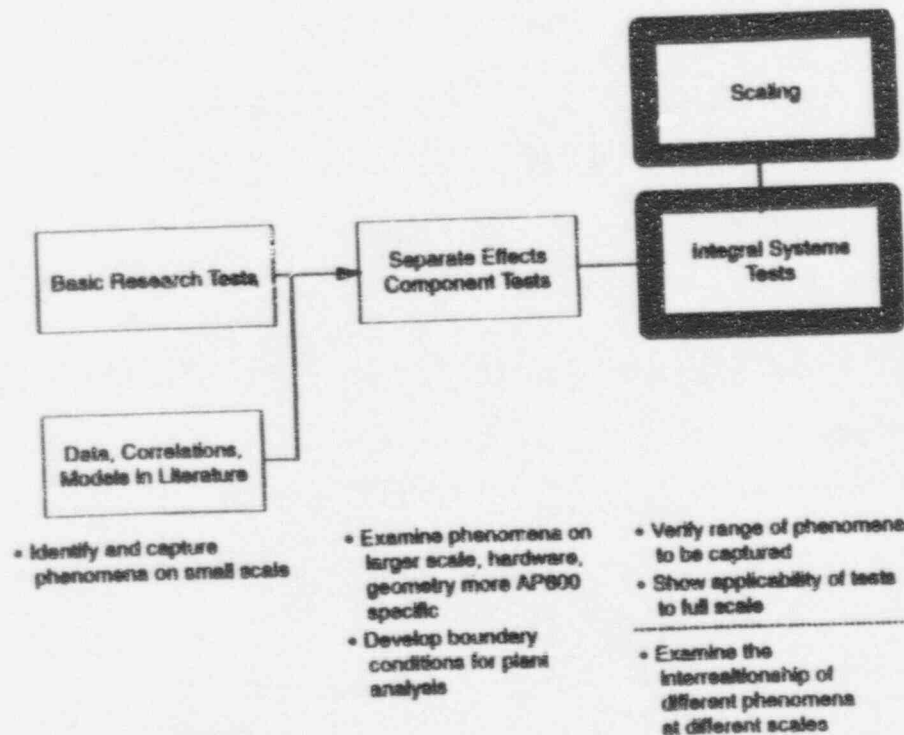
computer code

  - an appropriate approach is being developed

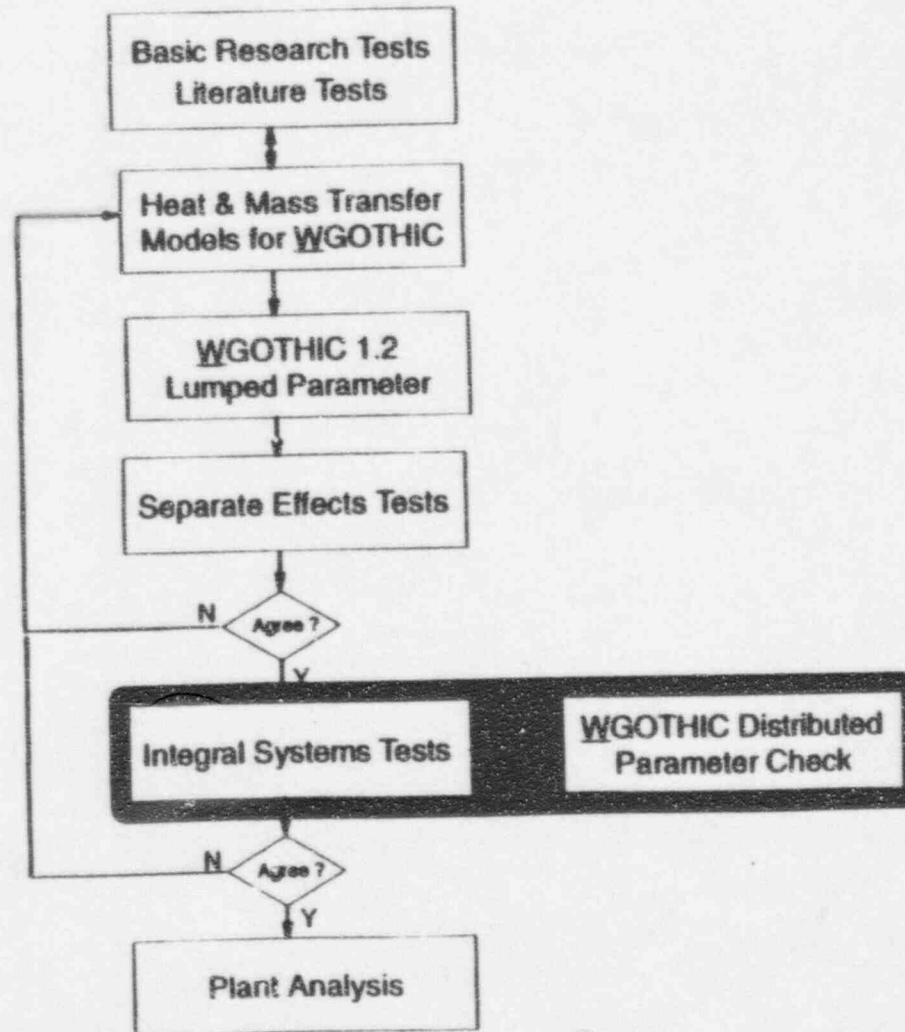


## 5. Identify and Obtain Needed Test Data

Basic research, separate effects, and integral tests are closely related



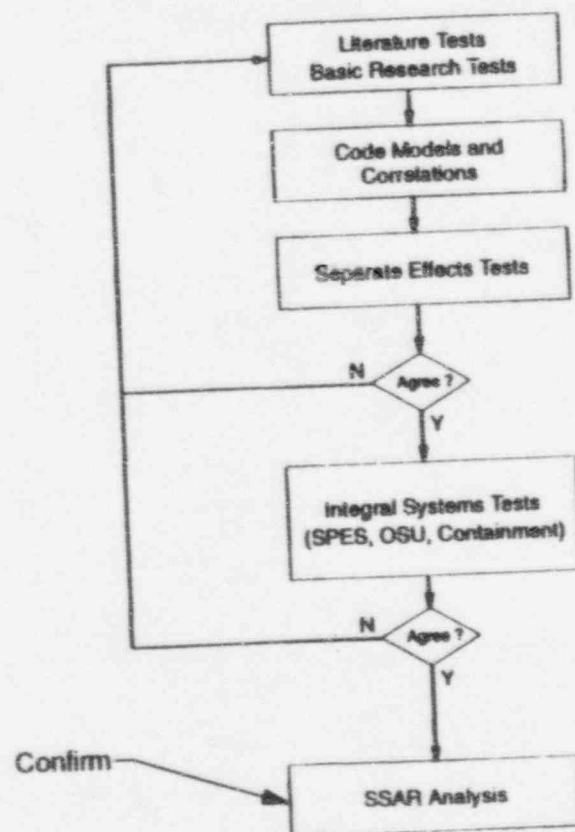
## 6. Perform Code Verification



## 6. Perform Code Verification

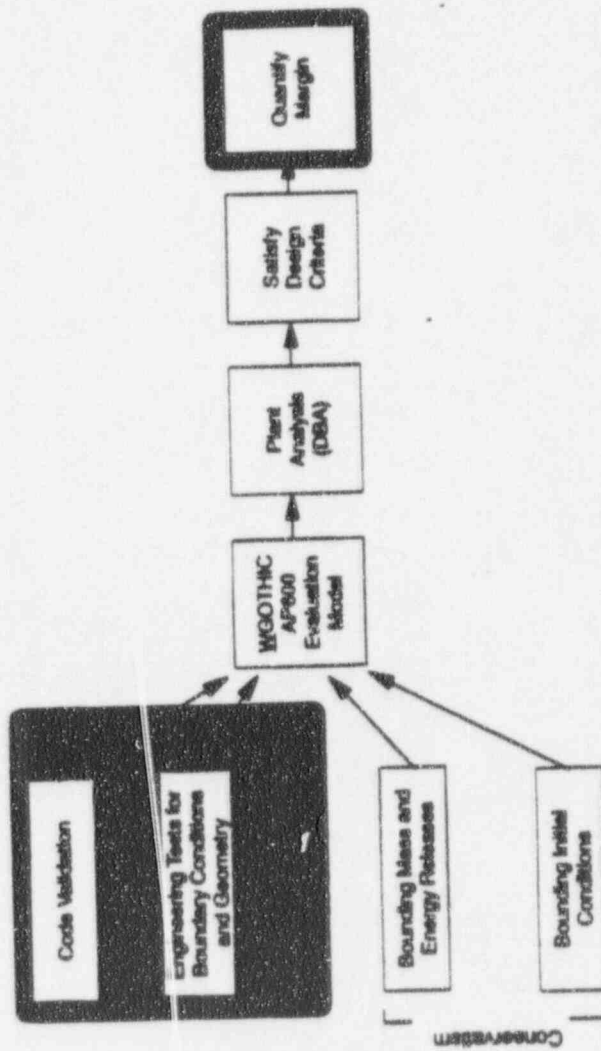


Code model validation leads to SSAR analysis





## 7. Perform Plant Analysis



# AP600 PCS Test and Analysis Program Schedule



## Schedule of PCS Reports

### Completed

- April 1994 • 1. Radiation heat transfer through fog in the PCS air gap (NTD-NRC-94-4100)
- April 1994 • 2. Liquid film heat transfer model validation (NTD-NRC-94-4100)
- June 1994 • 3. Quantification of effects of wind and thermal inversion on potential for recirculation of PCS effluent (NTD-NRC-94-4166)
- June 1994 • 4. AP600 PCS design basis analysis (DBA) model and margin assessment (NTD-NRC-94-4174)
- July 1994 • PCS scaling iteration 1 report
- July 1994 • 5. Containment surface wetting basis with respect to SSAR and film stability (NTD-NRC-94-4247)
- August 1994 • Expediting of EPRI GOTHIC reports
- August 1994 • WGOTHIC lumped parameter LST input definition and input deck (NTD-NRC-94-4271)
- August 1994 • 5. (supl) Supplemental information on water coverage and margin (NTD-NRC-94-4286)

## AP600 PCS Test and Analysis Program Schedule (Cont.)



### Schedule of PCS Reports (cont.)

#### Completed

- August 1994 • 6. Experimental basis for convective heat transfer correlations (NTD-NRC-94-4287)
- September 1994 • Final PCS scaling report (NTD-NRC-94-4318)
- October 1994 • 7. Experimental basis for the convective mass transfer correlations (NRC-NRC-94-4327)  
NTD

## AP600 PCS Test and Analysis Program Schedule (Cont.)



### Schedule of PCS Reports (cont.)

#### Future

- December 1994 • 8. Internal transient and stratification processes
- March 1995 • 9. Experimental basis for the AP600 containment vessel heat and mass transfer correlations
- April 1995 • Large-scale test data evaluation report
- April 1995 • WGOTHIC Final Verification and Validation Report
- April 1995 • WGOTHIC Blind Test Analysis Report
- May 1995 • Preliminary containment DBA SSAR markups
- October 1995 • Final containment DBA SSAR

## PCS Analysis Program Summary - Conclusion

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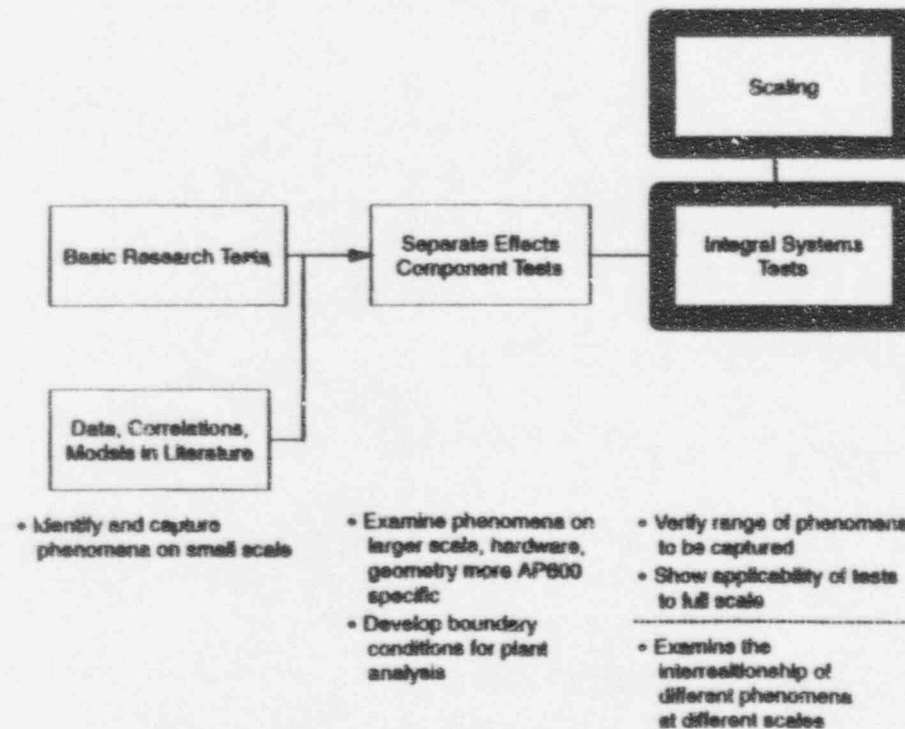


- PCS analysis program is well underway
- A strategy is complete or being developed for each issue identified to date

## 5. Identify and Obtain Needed Test Data



Basic research, separate effects, and integral tests are closely related





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# AP600 PCS Scaling Analysis

D. R. Spencer

Principal Engineer

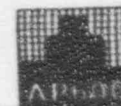


## Introduction

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This presentation summarizes the following highlights of the scaling analysis for the AP600 passive containment cooling system (PCS):

- Integrated structure for technical issue resolution (ISTIR) presented in NUREG/CR-5809
- Comments received from the NRC and ACRS review of a first iteration report
- Results and conclusions of the scaling analysis



## Scaling Analysis Approach

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- I. Safety Issue Accident Specification and Phenomena Evaluation
- II. Perform Scaling Analysis
- III. Develop Closure Relationships
- IV. Evaluate Scaling Group Values for AP600
- V. Scale the LST and Compare to AP600
- VI. Validate the Scaling Model
- VII. Nonprototypic Test Characteristics



## Summary

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The major results and conclusions of this scaling analysis are:

- All phenomena were identified and ranked in a phenomena identification and ranking table (PIRT)
- Control volume equations and closure relationships were developed for the significant phenomena and integrated into a scaling model that coupled the inside of containment to the external PCS
- The selected phenomenological models were dimensionless, scalable, and valid for application to both the LSTs and AP600

## Summary (Cont.)



- Comparison of the scaling model predictions to large-scale test (LST) results validated the completeness of the PIRT and the scaling model equations
- The LSTs with the steam source in the simulated steam generator compartment were representative of a double-end cold leg guillotine (DECLG)
- Nonprototypicalities were accommodated in the analytical scaling model:

[  $\epsilon$  ] a,c

## I. Safety Issue Accident Specification and Phenomena Evaluation



### I.1. Issue and Success Criteria

A group of design basis accidents known as high energy line breaks have the potential to challenge the design pressure of nuclear reactor containment. With no other active heat removal systems operational, the AP600 PCS will:

- Prevent the peak containment pressure from exceeding its design pressure
- Reduce the peak pressure at 24 hours to less than half the design pressure

# I. Safety Issue Accident Specification and Phenomena Evaluation

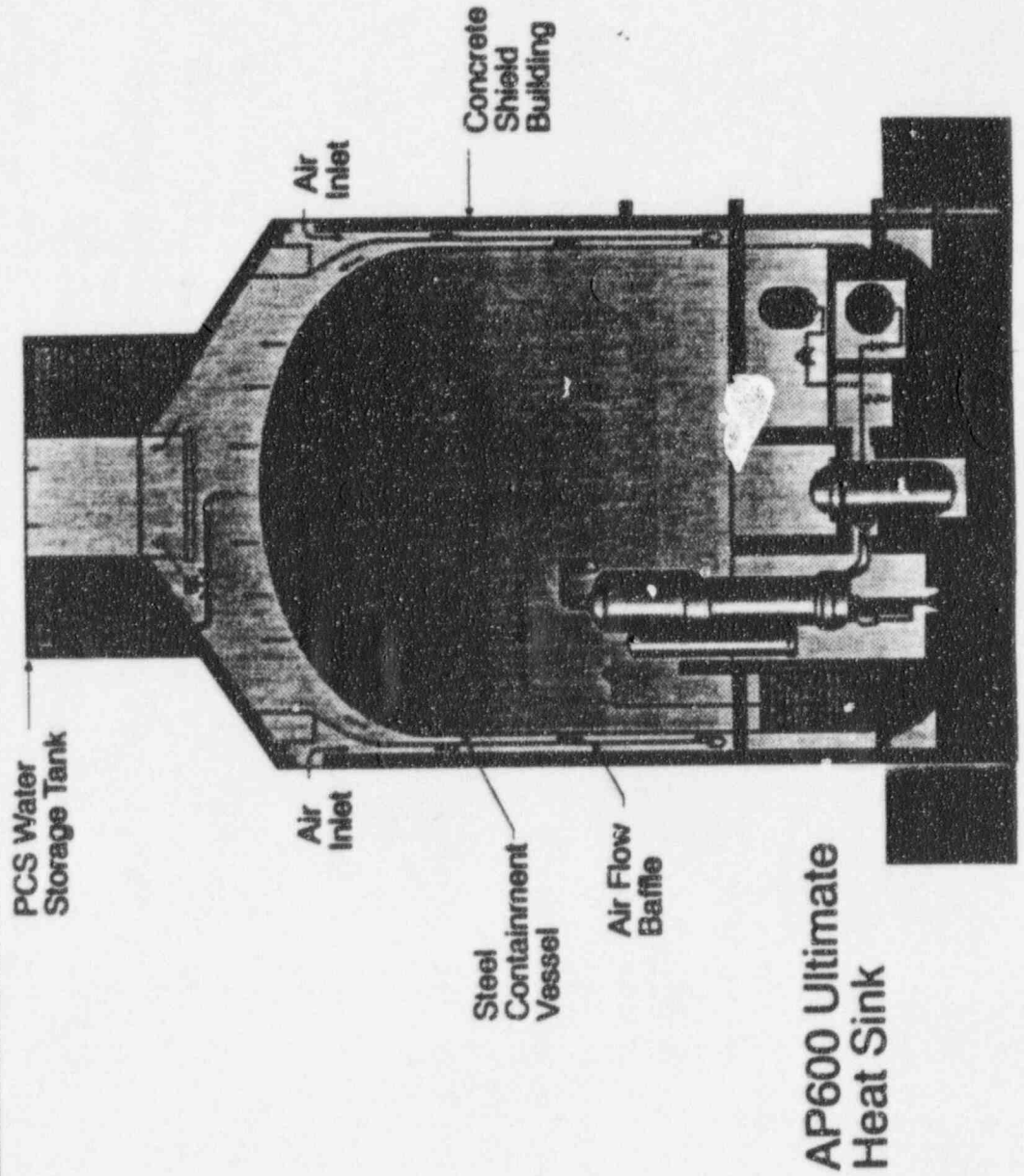


## I.2. Scenario/Plant/Accident Path

A DECLG rupture is postulated to occur in a steam generator compartment

- The plant is the 2-loop Westinghouse AP600 with a PCS
- No active containment cooling systems are operational
- The reactor cooling system (RCS) blows down, followed by the direct injection into the reactor of water stored in the accumulators, the core makeup tanks (CMTs) and the in-containment refueling water storage tank (IRWST)

# AP600 Passive Containment Cooling System





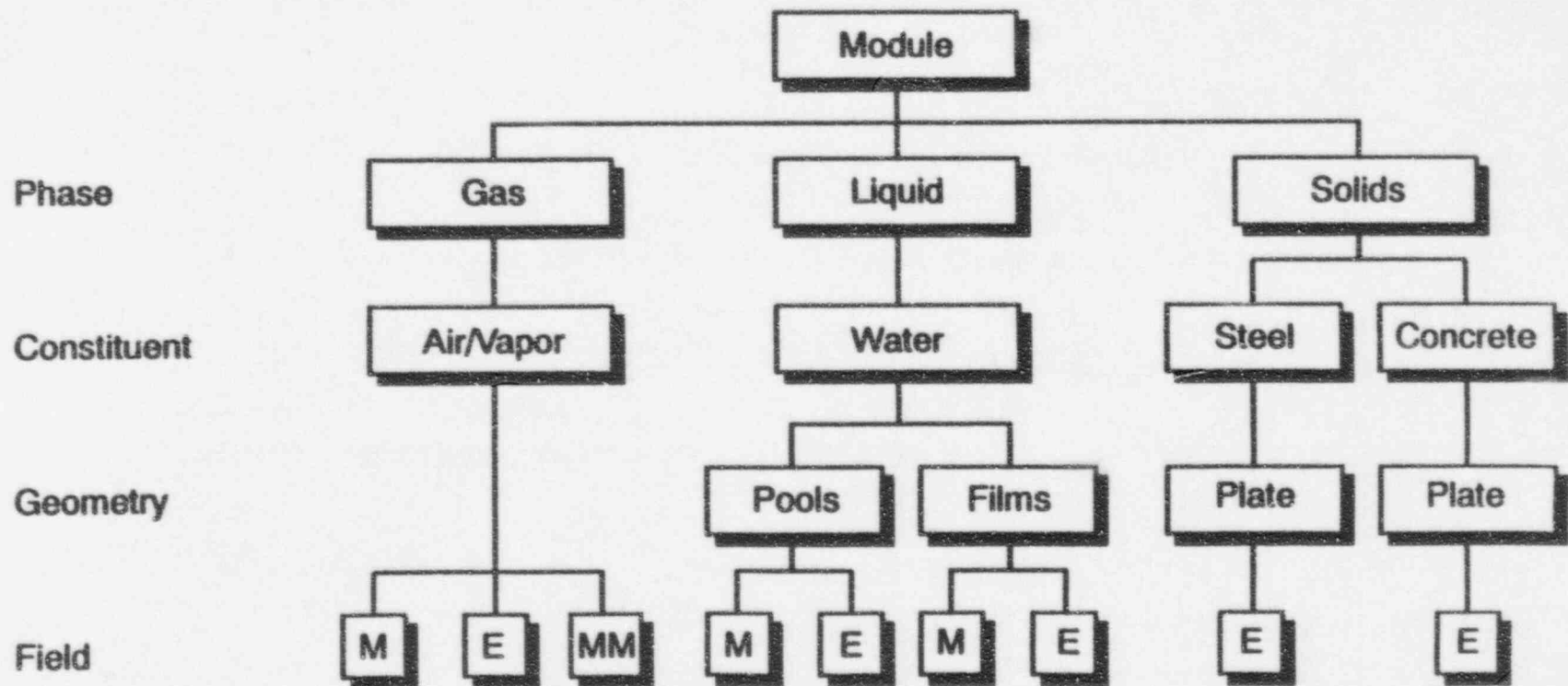
### I.3. Phenomena Identification and Ranking Table (PIRT)

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The PCS is partitioned spatially and temporally to facilitate identification of important phenomena

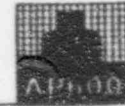
- Spatial partitions separate the inside and outside of containment
  - inside may be partitioned into regions and/or compartments
  - outside can be partitioned into the downcomer and riser
  - spatial partitions are characterized by phenomena specified for a "module"
- Temporal partitions include blowdown, pre-wetting, and post wetting
- The PIRT is presented for the post-wetting phase of the DECLG, the time period when the AP600 phenomenology is distinctly different than that of conventional plants

# Module Decomposition and Architecture



M = Mass  
 E = Energy  
 MM = Momentum

# PCS Post-Wetting Phenomena Identification and Ranking Table



a.c



## I. PIRT Conclusions

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The important volumetric phenomena:

- Inside containment: 2-component compressible gas
- In the riser: 2-component gas and buoyancy
- In the downcomer: buoyancy

The important surface phenomena are:

- Inside containment: the liquid film heat transfer and free convection mass transfer
- In the riser: the liquid film heat transfer and subcooling, the forced convection heat and mass transfer, and radiation



## I. PIRT Conclusions (Cont.)

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- In the downcomer: the free and forced convection heat transfer and radiation heat transfer

Important phenomena for solids are 1-D transient conduction heat transfer inside and 1-D steady-state conduction outside

Important inter-module phenomena are:

- Conduction inside to outside containment
- Convection, conduction, and form and friction losses outside containment



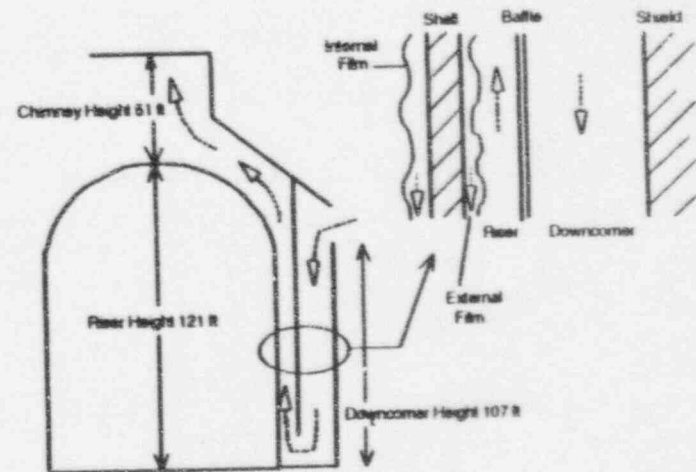
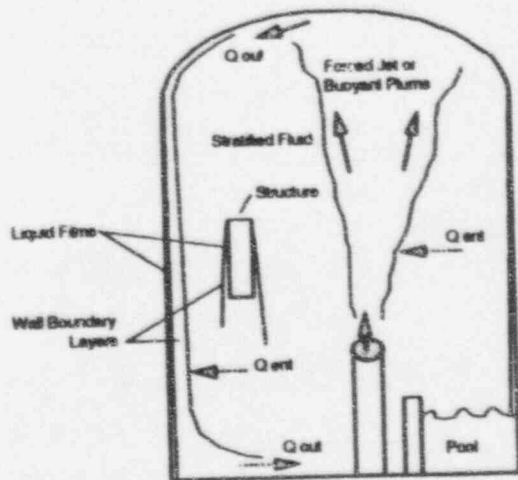
## II. Perform Scaling Analysis

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1. Transient control volume equations were developed for inside containment phenomena
2. Steady-state control volume equations were developed for the external PCS phenomena

## II. Schematic Model of AP600 Inside Containment

## Schematic of AP600 Showing Outside of PCS



## II.1. Internal Control Volume Equations

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The gas volume inside containment is:

- Driven by a single mass and energy source
- Buffered by extensive internal heat sinks
- Coupled to the external PCS through the shell by multiple heat removal paths

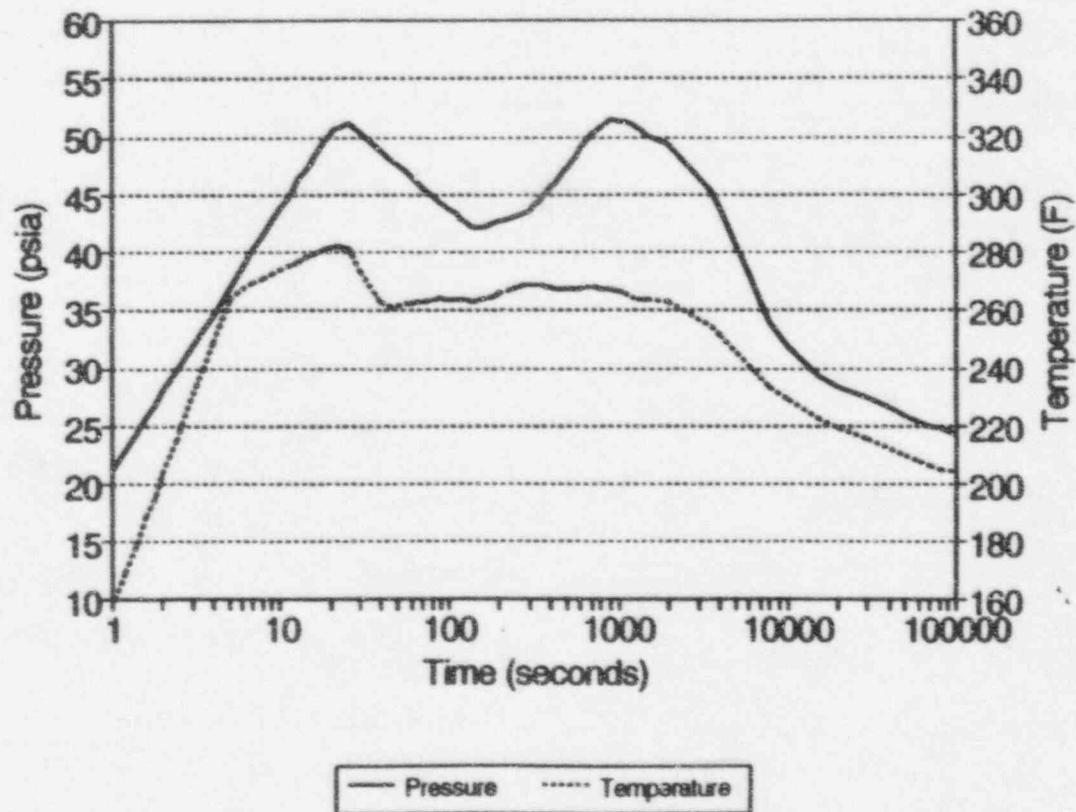
## II.1 The Mass and Energy Source

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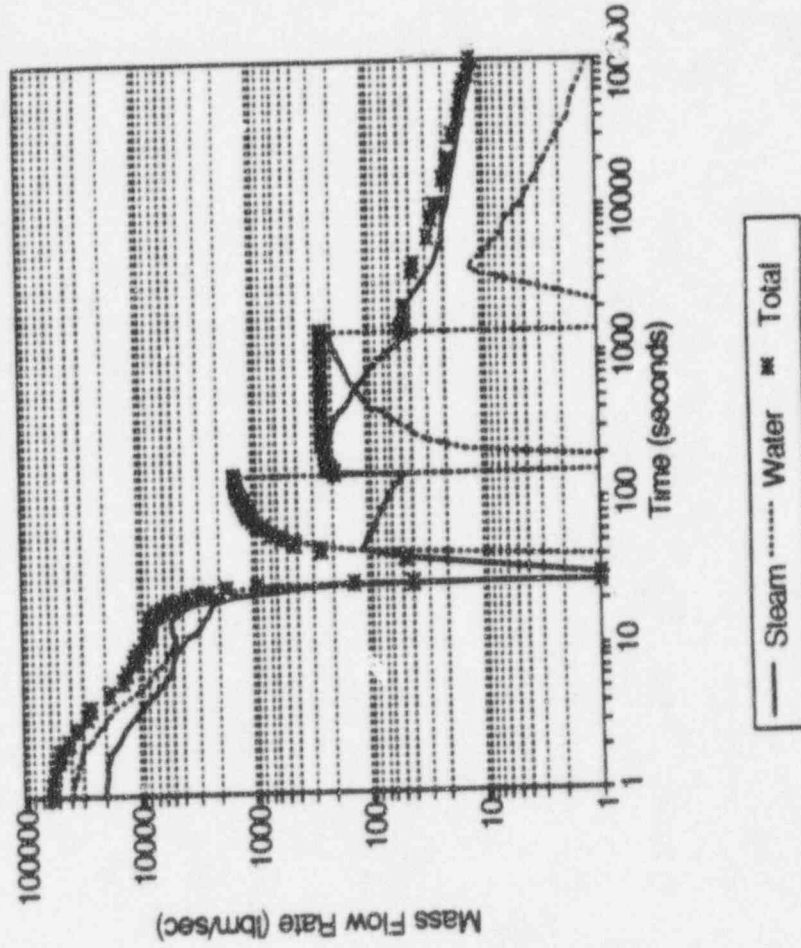
- The break introduces saturated steam and water at the saturation pressure of containment.
- The break water collects in the reactor cavity and steam generator compartment, which initially removes a significant fraction of the break energy with little pressurization of containment.
- Several thousand seconds into the transient, the stored energy in the pool becomes a modest additional source of saturated steam.
- The total mass and energy rates are given. The steam/water fractions that constitute the source into containment are determined from the transient pressure-temperature history.

## II.1 Pressure and Temperature Histories during a DECLG Break





## II.1 Steam and Water Mass Flow Rates from a DECLG Break



## II.1 Internal Heat Sinks



The internal heat sinks include steel structures, concrete structures, the IRWST, and the containment atmosphere. The internal heat sinks slow the initial containment pressurization rate, and later slow the depressurization rate.

- The steel was separated into 5 groups based upon thickness:
  - the steel with thicknesses less than 0.255 ft. has Biot numbers less than 1, so it can be accurately modeled as lumped masses
  - the shell steel was treated as distinct because it has a cooling water source on the outside after 11 minutes
  - the steel liner on the concrete was modeled with the concrete



## II.1 Internal Heat Sinks (Cont.)

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- All concrete is 2 ft. or thicker (2-ft. thick concrete has a time constant of approximately 124 hours)
  - the concrete was modeled with a finite element conduction model with heat capacity
  - 94% of the concrete is located below deck

## II.1 Internal Heat Sinks (Cont.)

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## II.1 Containment Gas Volume



The containment gas volume mass and energy conservation equations can be combined and put in the following form with the time rate of change of pressure as the dependent variable:

$$\left[ \text{Equation 1} \right] \quad \text{a,c} \quad \text{(1)}$$

Equation 1 was made dimensionless and each term of the resulting dimensionless equation was then divided by the steam source term,  $\dot{m}c_p T$  to produce the time constants and pi groups

## II.1 Internal Scale Groups



a,c



## II.2. External Control Volume Equations

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Heat is removed from containment and rejected to the environment by:

- Evaporation of the external liquid film
- Subcooled heat capacity of the external film
- Convective heat transfer from the wet and dry portions of containment
- Radiation heat transfer from the wet and dry external surfaces

## II.2. External Control Volume Equations (Cont.)

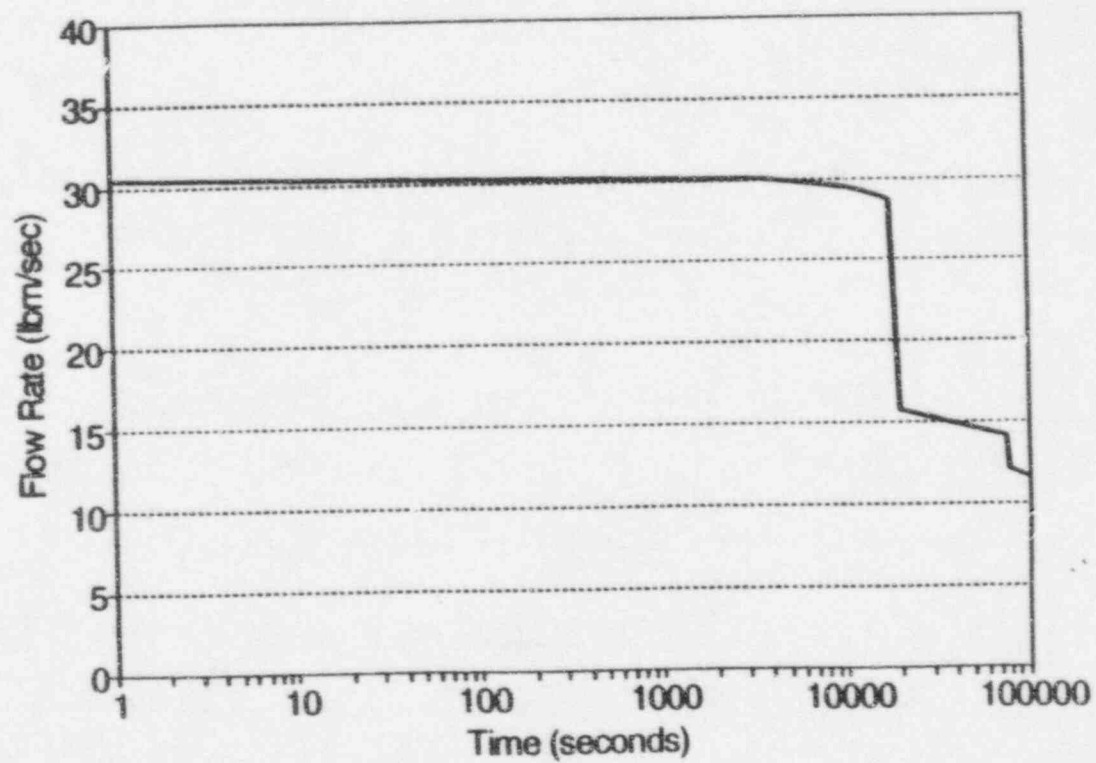
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These heat transfer mechanisms must be included in control volume equations for:

- External liquid film
- Baffle
- Shield
- Riser and downcomer (the air flow path)

## II.2 External Cooling Water Flow Rate



## II.2 External Liquid Film



The external liquid film covers the subcooled region and the wet (evaporating) region

- The temperature of the subcooled region is low enough that radiation, convective heat transfer, and convective mass transfer can be neglected
- The area of the subcooled film is that area required to heat the subcooled film from its inlet temperature to the temperature of the evaporating film
- The subcooled region film outflow is the inflow to the wet region film

## II.2 External Liquid Film (Cont.)



The 4 pi groups for the external film are:



a,c

## II.2 Baffle Control Volume

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- The baffle can be treated as an isothermal structure with no resistance to heat flow
- The baffle receives radiation from the dry portions of the containment shell and from the external film
- The baffle radiates to the shield building and interacts through convective heat transfer with the downcomer and riser

## II.2 Baffle Control Volume (Cont.)



The four baffle pi groups are:

a,c



## II.2 Shield Building Control Volume

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- The time constant of the 3-ft. thick shield is over 200 hours
- It was assumed that the convection from the shield to the downcomer air is equal to the radiation from the baffle
- The shield energy equation gives one additional pi group:

[ ] a,c



## II.2 Air Flow Path Control Volumes

- The riser and downcomer make up the PCS air flow path
- The riser and downcomer energy equations produce no unique pi groups and have already been derived for the external film, dry shell, baffle, and shield
- The integral form of the momentum equation was derived by taking the dot product of a differential form of the momentum equation and integrating around a closed path:

a,c

## II.2 Air Flow Path Control Volumes (Cont.)



- The left side of Equation 19 is the total system form, acceleration, and friction loss with a value of approximately  $[3.5 \rho_n v_n^2 / 2]^{a,c}$  so:

$$\left[ \right] \quad a,c$$

- Normalizing the terms on the right side of the equal sign by the left side gives the following three pi groups:

$$\left[ \right] \quad a,c$$



### III. Closure Relationships

---

Calculation of the heat and mass transfer to the individual liquid films is possible with the following assumptions:

- The inside of the AP600 containment is well mixed and can be represented by a single volume
- Air and steam are ideal gasses
- The break supplies steam and water at a saturation pressure equal to the pressure of containment
- The steam is saturated at the liquid film surface temperature

The heat and mass transfer relationships are the correlations developed for use on AP600 in the WGOTHIC code, except that only free convection is used inside containment

## IV. Evaluate Scaling Group Values for AP600

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1. Internal PCS Energy Scaling
2. Internal PCS Momentum Scaling
3. External PCS Energy Scaling
4. External PCS Momentum Scaling

## IV.1 Internal PCS Energy Scaling



The time constants and pi groups for the AP600 containment were calculated using the transient scaling model out to 10,000 seconds. The pi groups were manipulated as follows:

- All internal heat sinks (steel and concrete) were combined and are represented by one pi group
- The shell heat removal was divided into subcooled, evaporating, and dry fractions with a pi group for each
- Convection heat transfer for all internal structures was combined into one pi group

## IV.1 Internal PCS Energy Scaling



a,c



## IV.1 Conclusions

---

- Convection, radiation, and subcooled heat capacity are small in comparison to mass transfer
- Internal heat sinks have a major effect until several thousand seconds
- Late in the transient, the pool evaporation becomes an additional source of steam that should not be neglected

## IV.2 Internal PCS Momentum Scaling (Froude Numbers)



The Froude number for the steam source in containment can be examined to provide insight into internal mixing processes

- The Froude number is defined:  $\rho_{jet} v^2 / (\rho_{amb} - \rho_{jet}) gH$
- The Froude numbers calculated for AP600 are:

Blowdown Peak	Post-Blowdown Peak	Value at 2000 seconds	Value at 10,000 seconds
1200	0.28	0.003	0.0009

### Conclusion:

- The jet kinetic energy is not significant during the post-wetting phase

## IV.3 External PCS Energy Scaling



a,c

### IV.3 Conclusions

---



- Evaporation is the major heat removal mechanism
- Heat transfer to the subcooled external liquid film and convective heat transfer are both second order
- Radiation heat transfer from containment is approximately 50% that of convection or subcooling
- The sensible heat input to the air flow path is approximately 10% of the total energy input to the riser
- The 3 to 4 times greater sensible energy input to the riser than to the downcomer will promote a stable flow of air through the external PCS

## IV.4 External PCS Momentum Scaling



a,c



## IV.4 Conclusions

---

- The downcomer momentum is a small negative part of the total buoyancy-induced driving pressure
- Buoyancy is 35% due to molecular weight and 65% due to temperature rise
- The downcomer has a minor effect on the air flow in the downcomer-riser-chimney flow path

## V. Scale the LST and Compare to AP600

---



### V.1 AP600/LST Energy Scaling

- The important scaling group in AP600 is represented by evaporation
- The second-order scaling group for subcooled heat transfer is also included because it is more than second-order in the LST

# V.1 The Ratios of pi Groups $\Pi^R = \Pi_{AP600} / \Pi_{LST, meas}$



a,c

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## V.1 Conclusions

---

- Evaporative heat transfer in the LST is the major heat removal mechanism and is 30% of that in AP600
- Heat transfer to the subcooled film accounts for less than 20% of the total heat removal from the LST, but is 4 times greater than the subcooled heat removal in AP600
- The safety-related assumption in AP600 that the water source is at 120°F causes the subcooled mismatch to be approximately twice what it would be at more nominal temperature
- The calculation of heat transfer to the subcooled liquid accounts for the difference between the LST and AP600

## V.2 AP600/LST Internal Momentum Scaling (Froude Numbers)



The LSTs were conducted with 3 different steam source configurations:

- A 3-in. diameter pipe
- An 18-in. diameter diffuser
- An 18-in. diffuser located in a simulated steam generator compartment

## V.2 AP600/LST Internal Momentum Scaling (Froude Numbers)



A review of all LSTs showed that Froude numbers greater than 200 produced a test with small differences between the above-deck and below-deck air concentrations (well-mixed)

Such high Froude numbers are similar to the AP600 blowdown values ( $Fr = 1200$ ) and support the expectation of a well-mixed containment during blowdown

The LST conducted with the simulated steam generator produced steady-state Froude numbers that ranged from 0.0002 to 0.02

This range of steady-state Froude numbers spans the post-wetting Froude number range for AP600  $Fr < 0.016$

## VI. Validate the Scaling Model

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A transient scaling model and a steady-state scaling model were developed

### VI.1. Transient Model

The transient scaling model was run for the first 10,000 sec. of the transient

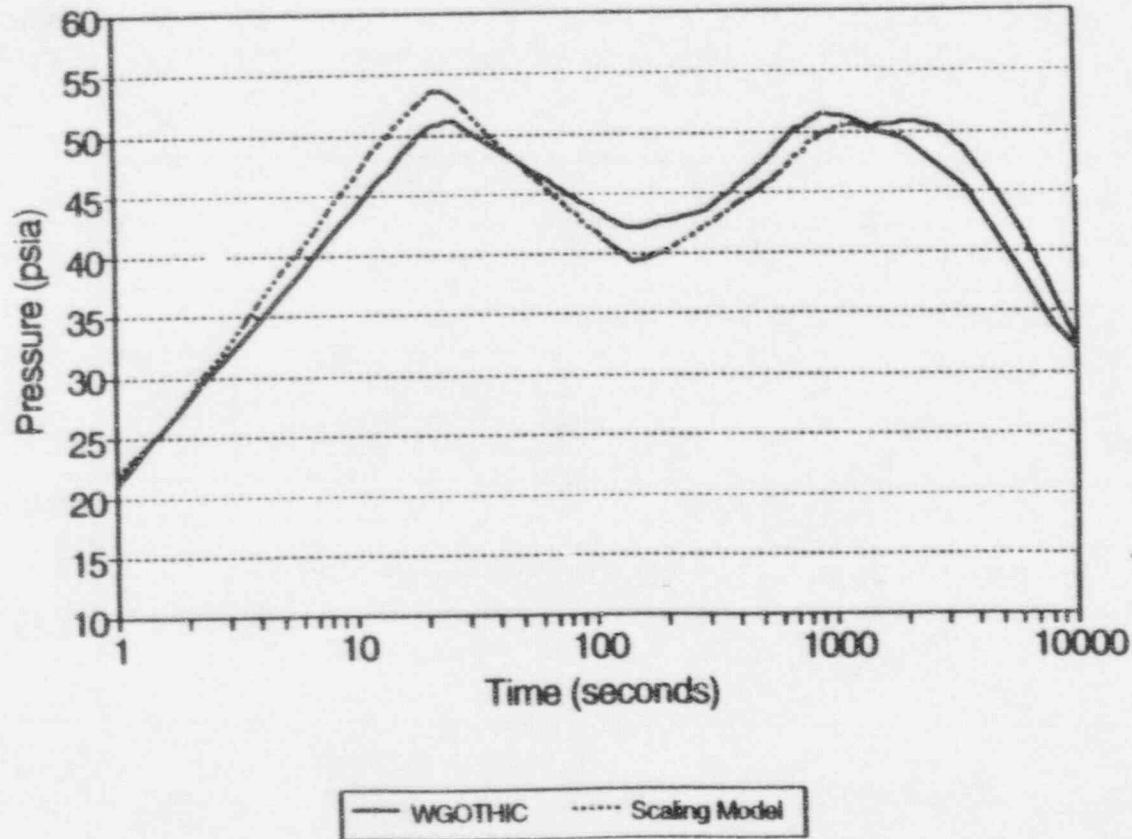
- The containment pressure is weakly coupled to the air annulus until the external film is applied at 11 minutes
- After 11 minutes the external flow rate was 30 lbm/sec and all of the water was assumed to be evaporated through 10,000 seconds

#### Conclusion:

- A comparison of the transient scaling model pressure to the WGOTHIC pressure for the DECLG shows very good agreement

VI.1

# Scaling Model Pressure History Comparison to WGOTHIC Prediction



## VI.2 Steady-State Scaling Model



Steady-State Scaling Model Predictions of LST				
AP600 Time (sec)	2000	4000	8000	4000
P,T (psia, °F)	48.5, 262	43, 250	33.5, 230	43, 250
LST	218.1B	217.1A	222.1	222.3B*
	Heat Rejection: Predicted/Measured			
Well-mixed Model	0.70	0.81	0.97	0.75
With Measured Air	0.96	0.98	0.97	0.78

\* High Froude number test with 3 in. source elevated. Air/steam was well-mixed above and below deck.



## VI.2 Conclusions

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- The well-mixed scaling model predicts heat rejection that is low to nominal, regardless of Froude number
- The scaling model accurately predicts measurements when measured concentrations are used and Froude numbers are low:
  - the model for the dominant transport mechanism (mass transfer) is valid, but requires concentrations and velocities (or low velocities) for accuracy
  - velocity and concentration are the only significant open issues in the modeling
- The scaling model underpredicts tests with high Froude numbers, with or without measured concentrations
- The conclusions drawn from using the scaling model, i.e., the relative magnitude of the pi groups, do not depend upon the extent to which either the LST or AP600 is well mixed

## VII. Nonprototypic Test Characteristics



There are only 2 significant nonprototypic characteristics in the LST, both of which are understood and are accommodated analytically

[ ] a,c

## VII.1 Entrainment into Break Compartment



a,c





## VII.2 External Subcooling



17



## Summary

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The major results and conclusions of this scaling analysis are:

- All phenomena were identified and ranked in a phenomena identification and ranking table (PIRT)
- Control volume equations and closure relationships were developed for the significant phenomena and integrated into a scaling model that coupled the inside of containment to the external PCS
- Comparison of the scaling model predictions to LST results validated the completeness of the PIRT and the scaling model equations

## Summary (Cont.)



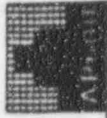
- The selected phenomenological models were dimensionless, scalable, and valid for application to both the LSTs and AP600
- The LSTs with the steam source in the simulated steam generator compartment were representative of a DECLG break
- Nonprototypicalities are accommodated in the analytical scaling model:

a,c

# Draft PCS Open Items List



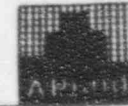
Seq. No.	Alt. No.	Subject: Description: Status:	Closeout Resolution
1.	952.100	<p>Subject: PCCS Scaling Analysis</p> <p>Description: Westinghouse to submit complete PCS scaling analysis</p> <p>Status:</p> <ul style="list-style-type: none"> <li>a. (W) 9/1/94 - First iteration of PCS scaling analysis submitted 7/28/94</li> <li>b. (W) 9/1/94 Final PCS scaling analysis to be submitted 9/30/94</li> <li>c. (W) 9/1/94 Status of PCS scaling analysis (first iteration) presented at 7/26/94 meeting</li> <li>d. (NRC) 7/26/94 PIRT chart presented at 7/26/94 meeting good start. Needs more work:                             <ul style="list-style-type: none"> <li>- Rationale behind H, M, or L choices</li> <li>- Close the loop... tie the PIRT to the scaling analysis</li> <li>- PIRT should be more than Dan Spencer product only</li> </ul> </li> <li>e. (NRC) 7/26/94 PIRT will have to be expanded to account for exterior of containment</li> <li>f. (NRC) 7/26/94 Westinghouse should collapse the scaling equations into a single <math>dp/dt</math> equation. Would reduce the number of parameters. More understandable for review. We do not see the value jet/plume, liquid film, containment atmosphere approach.</li> <li>g. (NRC) 7/26/94 Westinghouse should collapse the scaling equations into a single <math>dp/dt</math> equation. Would reduce the number of parameters. More understandable for review. We do not see the value jet/plume, liquid film, containment atmosphere approach.</li> <li>h. (NRC) 7/26/94 Insights from PIRT and Scaling could guide the <u>W</u>GOTHIC review</li> <li>i. (NRC) 7/26/94 Magnitude of pi groups ---- Westinghouse presented some .... Ratio of pi groups (LST to AP600) ... not yet.</li> <li>j. (NRC) 7/26/94 Scaling distortions in going from LST to AP600? List each, and describe impact of distortion.</li> <li>k. (NRC) 7/26/94 A LST vs. AP600 distortion...for small facility the subcooling is important...for AP600 is not important since only a small area on the dome is subcooled.</li> <li>l. (NRC) 7/27/94 Rational for flow paths (or lack thereof) in the LST vs AP600. What is the impact. Review RAI for area and volume rationale for LST vs AP600. NRC does not believe that RAI discusses flow paths.</li> <li>m. (NRC) 7/27/94 Search out a test that is closer to the plant.</li> <li>n. (NRC) 7/28/94 Westinghouse will present iteration 2 of the SASM scaling report for AP600 in the Sept-Oct time frame at an ACRS meeting. Paul Boehnert requested that the report be available for review at least 2 weeks before the meeting. NRC requested a NRC-Westinghouse meeting shortly before the ACRS meeting.</li> </ul>	<p>Sec. 2.5.1</p> <p>Done</p> <p>Done</p> <p>Table 2-1</p> <p>Eq. 3</p> <p>Deleted</p> <p>Tables 7-1 &amp; 7-2</p> <p>Table 8-1</p> <p>Sec. 9.0</p> <p>Sec. 8.0</p> <p>Sec. 7.2 &amp; 7.3</p> <p>Table 8-1</p> <p>Done</p>



## Draft PCS Open Items List (Cont.)

Seq. No.	Air No.	Subject: Description: Status:	Closeout Resolution
3.	952.102	Subject: PCS Air Flow in Annulus Description: Westinghouse to submit an analysis of air flow in the annulus (both wet and dry cases)	Sec. 7.2 & 7.3

F



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TEST ANALYSIS AND CODE  
VALIDATION REPORTS  
SCHEDULE AND OUTLINES

M. Kennedy, Engineer

## Test Analysis and Code Validation Reports Summary and Schedule



<u>Report</u>	<u>Issue Date</u>
Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations Report*	March 1995
Large-Scale Test Data Evaluation Report*	April 1995
<u>WGOTHIC</u> Blind Test Analysis Report	April 1995
<u>WGOTHIC</u> Final Verification and Validation Report	April 1995
* Not previously discussed	

# Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations Report

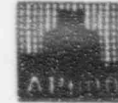
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- Heat and Mass Transfer Correlations
  - Annulus region
  - Inside containment
  
- Experimental Basis for the Heat and Mass Transfer Correlations
  - Separate effects tests
  - Large-scale tests (LSTs)
  
- Assessment of Results

# Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations Report Draft Outline

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## Executive Summary

## Introduction

## Heat and Mass Transfer Correlations

- Annulus region
- Inside containment

## Experimental Basis for the Heat and Mass Transfer Correlations

- Hugot tests
- Eckert and Diaguila tests
- Siegel and Norris tests
- Westinghouse STC dry flat plate tests
- Westinghouse STC flat plate evaporation tests
- University of Wisconsin condensation tests
- Gilliland and Sherwood evaporation tests
- LSTs

## Assessment of Results

## Conclusions

## References

## Large-Scale Test Data Evaluation Report

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- Compare and Contrast Results of the LSTs
- Quantify Effect of Various Parametric Changes Made in Tests
- Identify Parallels to the Scaling Analysis

## WGOTHIC Blind Test Analysis Report

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- LST and Facility Description
- WGOTHIC Heat and Mass Transfer Correlations
- LST Lumped Parameter Input Model Description
- Blind Test Prediction
- Evaluation of Blind Test Predictions
- Computer Code Model Assessment

# WGOTHIC Blind Test Analysis Report Draft Outline



## Executive Summary

### Introduction

- Objective and scope of report

### LST and Facility Description

- Discuss experimental facility including geometric layout, instrumentation, and other information, as required for understanding the code analyses, reference the test reports for test facility details
- Brief description of the tests

### WGOTHIC Heat and Mass Transfer Correlations

- Baseline computer code models, Reference WCAP-13246, Rev.0
- Test analysis/computer model validation
  - Discuss changes made to the baseline computer code models
  - Discuss validation of improved models (Reference analysis reports and final V&V report)

### LST Lumped Parameter Input Model Description

- Description of nodalization and nodalization diagram(s)
- Boundary and initial conditions used

### Blind Test Prediction

### Blind Test Evaluation

- Compare measured results to the code predictions
  - Assess whether timing of predicted results agrees with measured
  - Identify and explain discrepancies between the measured and predicted results (code deficiencies and/or measurement inaccuracy)

### Computer Code Model Assessment

- Summary of blind test analysis
- Adequacy of WGOTHIC for PCS analysis

## Conclusions

## References

# WGOTHIC Final Verification and Validation Report

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## PCS Test Program Summary

- Separate Effects Tests
- LST

## WGOTHIC Formulation

- Lumped Parameter
- Heat and Mass Transfer Correlation

## LST Lumped Parameter Input Model Description

## WGOTHIC Final Verification and Validation Report (Cont.)

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### Experimental Basis for WGOTHIC Heat and Mass Transfer Correlations

- Separate Effects Tests
- LST

### WGOTHIC Lumped Parameter Validation

- Separate Effects Tests
- LST

### Code Uncertainty Evaluation

# WGOTHIC Final Verification and Validation Report Draft Outline

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## Executive Summary

### Introduction

- Discussion of background information and supporting documentation
- Objective and scope of report
- Role of PCS in safety analysis
- Use of WGOTHIC in safety analysis

### PCS Test Program Summary

- Separate Effects Tests
  - Discuss experimental facility as required for understanding the code analyses
  - Brief description of the tests
  - How the data was used to validate WGOTHIC
- LST
  - Discuss experimental facility as required for understanding the code analyses
  - Brief description of the tests
  - What tests were compared with WGOTHIC and why

### WGOTHIC Formulation

- WGOTHIC lumped parameter formulation
- WGOTHIC PCS heat and mass transfer correlations

### LST Lumped Parameter Input Model Description

- Nodalization diagrams
- Nodalization rationale



## WGOTHIC Final Verification and Validation Report Draft Outline (Cont.)

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- Boundary and initial conditions
- Relate LST noding to plant
- Sensitivity studies

### Experimental Basis for WGOTHIC Heat and Mass Transfer Correlations

- Separate effects tests
- LST

### WGOTHIC Lumped Parameter Validation

- Separate effects tests
  - Measured and predicted comparisons
- LST
  - Compare measured and predicted results
  - Assess whether timing of predicted results agrees with measured
  - Identify and explain discrepancies between the measured and predicted results (code deficiencies and/or measurement inaccuracy)

### Code Uncertainty Evaluation

#### Conclusions

- Summary of the verification and validation analysis
- Adequacy of WGOTHIC for PCS analysis
- Assessment of results on the plant calculations

#### References

#### Appendix

- Subdivided LST model and results



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PRESENTATION  
TO  
UNITED STATES  
NUCLEAR REGULATORY COMMISSION

AP600 Passive Containment Cooling System (PCS)  
Analysis Program

Pittsburgh, PA

November 16, 1994



# Agenda

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## Day 1

- |          |         |   |
|----------|---------|---|
| Woodcock | 1 hr.   | PCS analysis program summary and status   |
| Spencer  | 4 hrs.  | Scaling report <ul style="list-style-type: none"><li>- methodology overview</li><li>- conclusions</li></ul>       |
| Spencer  | 0.5 hr. | PCS open items relevant to scaling report <ul style="list-style-type: none"><li>- items 1, 3</li></ul>            |
| Kennedy  | 0.5 hr. | Test analysis and code validation reports <ul style="list-style-type: none"><li>- schedule and outlines</li></ul> |
| NRC      | 0.5 hr. | Feedback from previous presentations  |

## Agenda (Cont.)



Day 2

Woodcock	0.5 hr.	Opening remarks
Kennedy	1.5 hrs.	Framework on usage of LST data <ul style="list-style-type: none"><li>- matrix of LSTs</li><li>- status of data reduction</li></ul>
Kennedy	2 hrs.	Test 212.1 <ul style="list-style-type: none"><li>- description of tests and data</li><li>- <u>WGOTHIC</u> lumped parameter results</li></ul>
Kennedy	1.5 hrs.	Test 222.1 <ul style="list-style-type: none"><li>- description of tests and data</li><li>- <u>WGOTHIC</u> lumped parameter results</li></ul>
Kennedy	1 hr.	Subdivided <u>WGOTHIC</u> results
Kennedy	0.5 hr.	Blind test description
NRC	0.5 hr.	Feedback from previous presentations

## Agenda (Cont.)

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### Day 3

Woodcock	0.5 hr.	Opening remarks
NRC	1 hr.	AP600 calculation results
NRC	1 hr.	LST calculation results
Woodcock	2 hrs.	PCS open items review and status
All	1 hr.	Wrap-up and action items
Orr	1 hr.	Discussion of ADS phase A test results



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FRAMEWORK ON USAGE  
OF LARGE-SCALE TEST DATA

M. Kennedy, Engineer

## Framework on Usage of LST Data

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The data from each test will be evaluated in at least one of four ways:

- Phenomenological and Scaling Reports (Phenom)
- Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations Report (H&MT)
- Large-Scale Test Data Evaluation Report (Data)
- WGOTHIC Lumped Parameter Code Comparisons (WGOTHIC)

## Phenomenological and Scaling Reports

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- Water Distribution Reports
  - Twelve tests from the Baseline with internals and Baseline without internals (201.1, 202.1, 203.1, 201.2, 202.2, 203.2, 204.1, 205.1, 206.1, 207.3, 207.4, 211.1)
  - Tests were used to validate the PCS film flow coverage model
  
- Scaling Reports
  - Four tests from the Phase 2 and Phase 3 tests (218.1B, 217.1A, 222.1, 222.3B)
  - Tests were used in steady-state scaling model

## Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations

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- Phase 2, Phase 3, and dry confirmatory tests
- Local data from LST tests will be used to validate heat and mass transfer correlations in an integral setting

## Large-Scale Test Data Evaluation Report

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- Baseline test without internals, Baseline tests with internals, Phase 2, and Phase 3 tests
- Phenomena will be described and shown using the test data based on information or objectives the test data can support

## WGOTHIC Lumped Parameter Code Comparisons



- Four Baseline (without internals) tests and selected tests from Phase 2 and Phase 3
- Tests are used to validate the code

## Phase 2 and 3 LST WGOTHIC Matrix



Phase 2 and 3 tests to be run with WGOTHIC have 14 different steady-state conditions:

212.1 A, B, C  
214.1 A, B  
216.1 A, B  
219.1 A, B, C  
222.1  
222.4 A, B  
220.1

These tests were chosen based on the variables that produced the largest effects, as shown in the scaling analysis and the test data.

Other effects will be addressed in the Test Data Evaluation Report and the Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations Report.

Phase 2 and 3 WGOTHIC Matrix



Significant Variables	Test Numbers
<b>External Heat and Mass Transfer</b>	
External Natural/Forced Convection	214.1A : 214.1B
Water Coverage Fraction	212.1 : 216.1
Type of Water Coverage (Quadrant vs. Stripes)	216.1: 212.1, 214.1
Wet/Dry	216.1A : 216.1B
Dry/Wet, Water on Hot Vessel	219.1A: 219.1B
<b>Internal Heat and Mass Transfer</b>	
Momentum	222.1 : 222.4
Noncondensables	212.1, 222.1, 222.4, 214.1, 216.1, 219.1, 220.1

# Summary of LST Data Evaluation



Run & Test Number	Description			H&MT	Phenom	Data	WGOTHIC
Baseline w/o Internals	Steady-State Tests						
	P <sub>v</sub> (psia)	PCS Coverage %	Velocity Air (ft/s)				
R9L-201.1	23.4	100	9.6		X	X	X
R10L-202.1	43.3	91	9.7		X	X	
R8L-203.1	54.2	84	9.6		X	X	X
R11L-207.1	43.9	69, quadrant	9.7			X	X
R12L-207.2	44.8	71	9.4			X	X
Baseline w/ Internals							
R17AL-201.2	24.3	100	12.3		X	X	
R34L-202.2	45.1	83	11.7		X	X	
R27L-203.2	54.5	78	11.3		X	X	
R24L-204.1	44.0	86	15.2		X	X	
R23L-205.1	43.0	84	7.2 (free)		X	X	
R26L-206.1	44.8	80	5.5		X	X	
R21L-207.3	45.6	68, quadrant	11.5		X	X	
R20L-208.1	43.8	46, quadrant	11.9			X	
R22L-207.4	45.1	77	11.5		X	X	
R28AL-210.1	54.3	80	11.5			X	
R28L-211.1	54.3	80	(free)		X	X	

# Summary of LST Data Evaluation (Cont.)



Run & Test Number	Description			H&MT	Phenom	Data	WGOTHIC
Phase 2	$P_v$ (psia)	PCS Coverage %	Velocity Air (ft/s)				
RC039-202.3	45	89	13.9	X		X	
RC041-203.3	52	86	13.4	X		X	
	ms (lb/s)	PCS (%)	Characteristics				
RC048-212.1	0.36/0.56/0.84	100/100/95	3 steady-state $P_v$	X		X	X
RC050-213.1	0.34/0.54/0.84	100/87/52	3 steady-state $P_v$	X		X	
RC044-214.1	1.1	78/82	Free/forced air	X		X	X
RC045-215.1	1.1	79/83	Free/forced air blocked	X		X	
RC046-216.1	0.6	79/25	PCS quadrant	X		X	X
RC052-217.1	1.2	80/76	He, no long term HS	X	X	X	
RC053-218.1	1.1	87/83	He, long term HS	X	X	X	
RC057-219.1	0.1	0/0/100	He, dry/wet PCS	X		X	X
RC062-220.1	6/0.7	100/85	Blowdown, blind test				X
RC056-221.1	2.1/0.1	96/99/0	Blowdown, He, wet/dry PCS	X	X	X	

# Summary of LST Data Evaluation (Cont.)



Run & Test Number	Description			H&MT	Phenom	Data	WGOTHIC
<b>Phase 3</b>	<b>ms (lb/s)</b>	<b>PCS (%)</b>	<b>Characteristics</b>				
RC061-222.1	5.5/3/0.6	100/92	Blowdown	X		X	X
RC065-222.2	6/2.5/0.7/1.6	91/73	Blowdown, diffuser 6 ft. above deck	X		X	
RC064-222.3	6/2.5/0.7/1.3	100/87	Blowdown, 3" pipe 6 ft. above deck- side	X	X	X	
RC066-222.4	5.3/2.7/0.9/ 1.3	100/74	Blowdown, 3" pipe 6 ft. above deck-up	X		X	X
RC069-223.1	0.25/1.6	74	Initial Evacuation	X		X	
RC067-224.1	0.3	100	Initial Pressurization	X		X	
RC068-224.2	0.6	100	Initial Pressurization	X		X	
<b>Dry Confirmatory Tests</b>	<b>P<sub>v</sub> (psia)</b>	<b>Velocity Air (ft/s)</b>	<b>Characteristics</b>				
RC014C-101.2	24.3	3.4 (free)	Steady-state	X			
RC014B-104.2	44.8	4.6 (free)	Steady-state	X			
RC014A-107.3	94.8	5.4 (free)	Steady-state	X			
RC013-109.4	94.5	10.6	Steady-state	X			

104

# Summary of LST Data Evaluation (Cont.)



Run & Test Number	Description			H&MT	Phenom	Data	WGOTHIC
Dry Confirmatory Tests (Cont.)	ms (lb/s)	Velocity Air (ft/s)	Characteristics				
RC023-115.1	0.7	11.1	Transient	X			
RC024-116.1	0.08	4.5 (free)	Transient	X			
RC017-117.1	0.07	11.3/4 (free)	Transient	X			
RC029-118.1	0.11	5.8	Helium	X			
RC027-119.1	0.11	12.4	Helium	X			
RC026-120.1	0.07	11.8	Helium	X			

Note:

ms = steam mass flow rate (lb/s)      HS = heat sink  
 PCS = PCS water coverage (%)      He = helium  
 P<sub>v</sub> = Vessel pressure



## Status of LST Data Reduction

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- LST Data Reduction via Phenomenological and Scaling Reports (Phenom)
  - Complete
  
- Experimental Basis for the AP600 Containment Vessel Heat and Mass Transfer Correlations (H&MT)
  - Data from 10 dry large-scale tests have been reduced
  - Data from 2 wet large-scale tests have been reduced
  - Evaluation is underway
  
- Large-Scale Test Data Evaluation Report (Data)
  - Started
  
- WGOTHIC Lumped Parameter Code Comparisons (WGOTHIC)
  - Four baseline tests have been completed
  - Phase 2 and 3 tests are in progress (212.1 A, B, C and 222.1)



## Framework on Usage of LST Data Conclusions

---

- The Test Data from the Following Data Series will be Evaluated:
  - Baseline tests with internals
  - Baseline tests without internals
  - Phase 2 tests
  - Phase 3 tests
  - Dry confirmatory tests
  
- Westinghouse Maximizes the Use of the LST Data Via H&MT, Phenom, Data, and WGOTHIC
  
- Tests from the Phase 2 and 3 Series:
  - Have been selected for comparison to the WGOTHIC code
  - Cover the range of important parameters as identified in the scaling analysis and shown in the test results



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LST DATA AND  
WGOTHIC LUMPED PARAMETER  
STATUS

M. Kennedy, Engineer

## LST Data and WGOTHIC Lumped Parameter Status

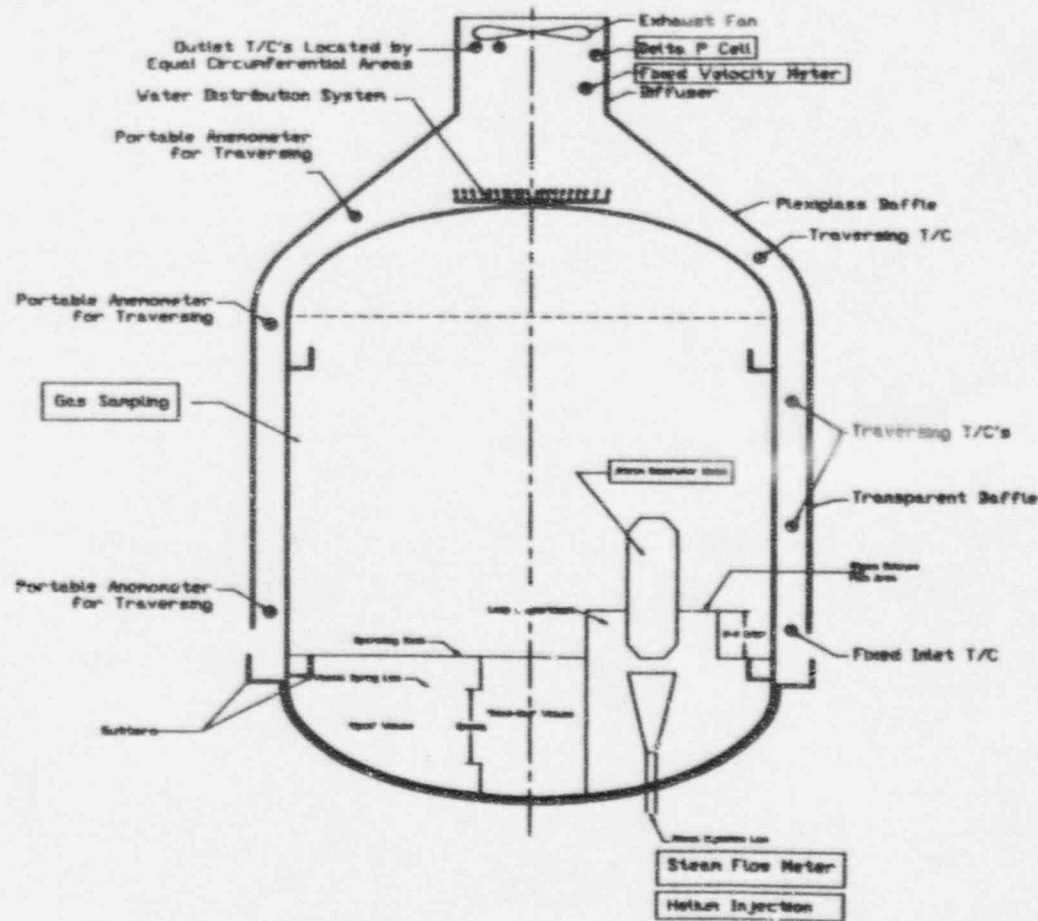
---



### Agenda

- Test Facility Description
- Lumped Parameter Noding
- Test 212.1
  - Data evaluation
  - Lumped parameter WGOTHIC code comparisons
- Test 222.1
  - Data evaluation
  - Lumped parameter WGOTHIC code comparisons

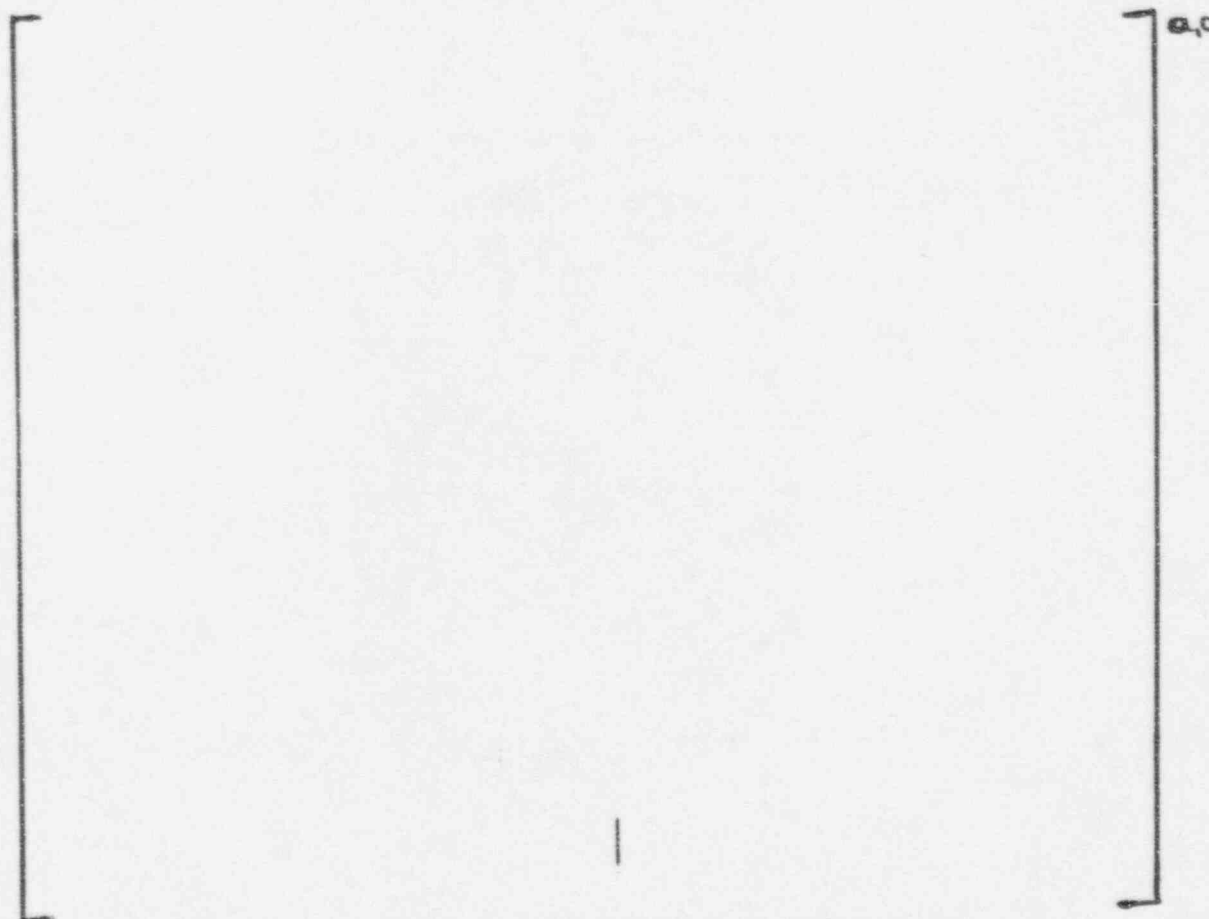
# Test Facility Description



Section View of AP600 Large-Scale PCS Test Phase Two Configuration

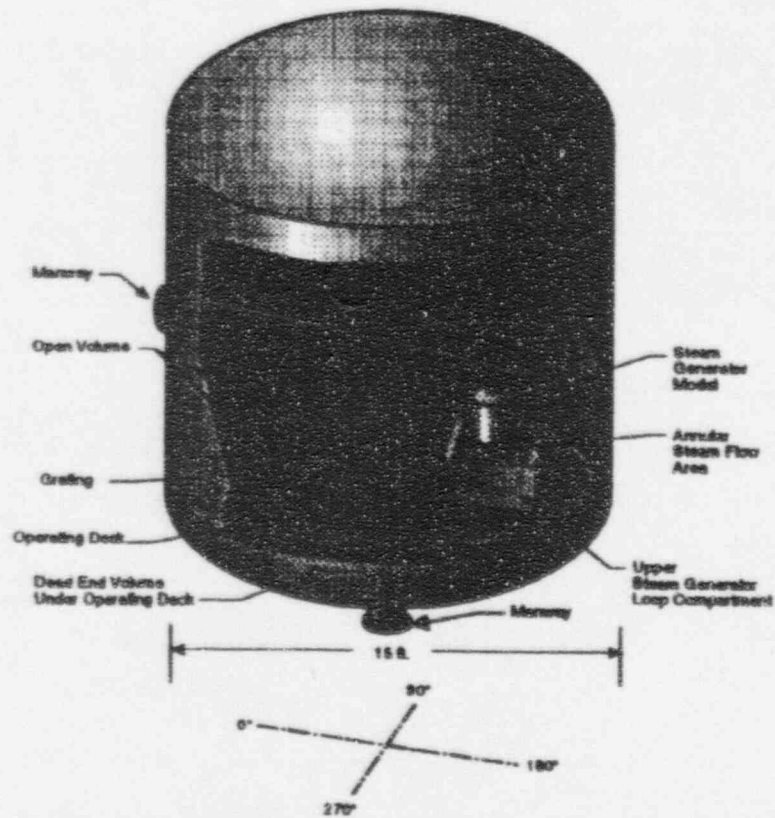
1-98

# Test Facility Description



Large-Scale PCS Instrumentation Elevations

# Test Facility Description



Large-Scale PCS Test Facility

112

## Lumped Parameter Noding



- Location of internal equipment is used in determining noding
- Between the operating deck and the upper internal gutter there are 4 elevations, each having 13 nodes
- The three elevations above the upper internal gutter each have eight nodes; more detailed noding was used in the four elevations below the internal gutter to model the plume area
- The radial divisions are also determined based on internal geometry
- Compartments below the operating deck are modeled as individual volumes

# Lumped Parameter Noding



**Elevation Noding Diagram of LST Lumped Parameter Model**

114

# Lumped Parameter Noding



Plan View of LST Vessel Lumped Parameter Noding from Operating Deck to Upper Internal Gutter

# Lumped Parameter Noding



Plan View of LST Vessel Lumped Parameter Noding from Upper Internal Gutter to Top of Vessel

## Test 212.1

---



### Data Evaluation Summary

- Test Characteristics
- Observations

## Test 212.1

---



### Test Characteristics

- Three steam flow rate levels, reaching a steady-state pressure with each flow rate
- Forced convection in air annulus



## Test 212.1

### Observations

- Boundary Conditions
- Exterior Water Coverage
- Noncondensable Axial Distribution in Vessel
- Vessel Wall Axial Temperatures
- Temperature Difference through Vessel Wall
- Vessel Internal Rake Temperatures
- Internal Velocity Meters

Test 212.1



Vessel Pressure and Steam Flow History Test 212.1, Run RC048



Test 212.1

Tab

Steam Inlet Temperature, Test 212.1



121



Test 212.1

a.b

**Vessel and Steam Line Pressure Test 212.1**

[

122

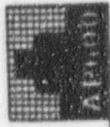
Test 212.1



[

PCS Water Temperature, Test 212.1

] a.b



Test 212.1

o.b

PCS Water Flow, Test 212.1

124

Page 31

Test 212.1



a.b

**Ambient Temperature, Test 212.1**

125



**External Air Exit Velocity, Test 212.1**

a.b

126



## Test 212.1

---

### Exterior Water Coverage

- First Steady State                      100% Wet
- Second Steady State                    100% Wet
- Third Steady State                      95% Wet



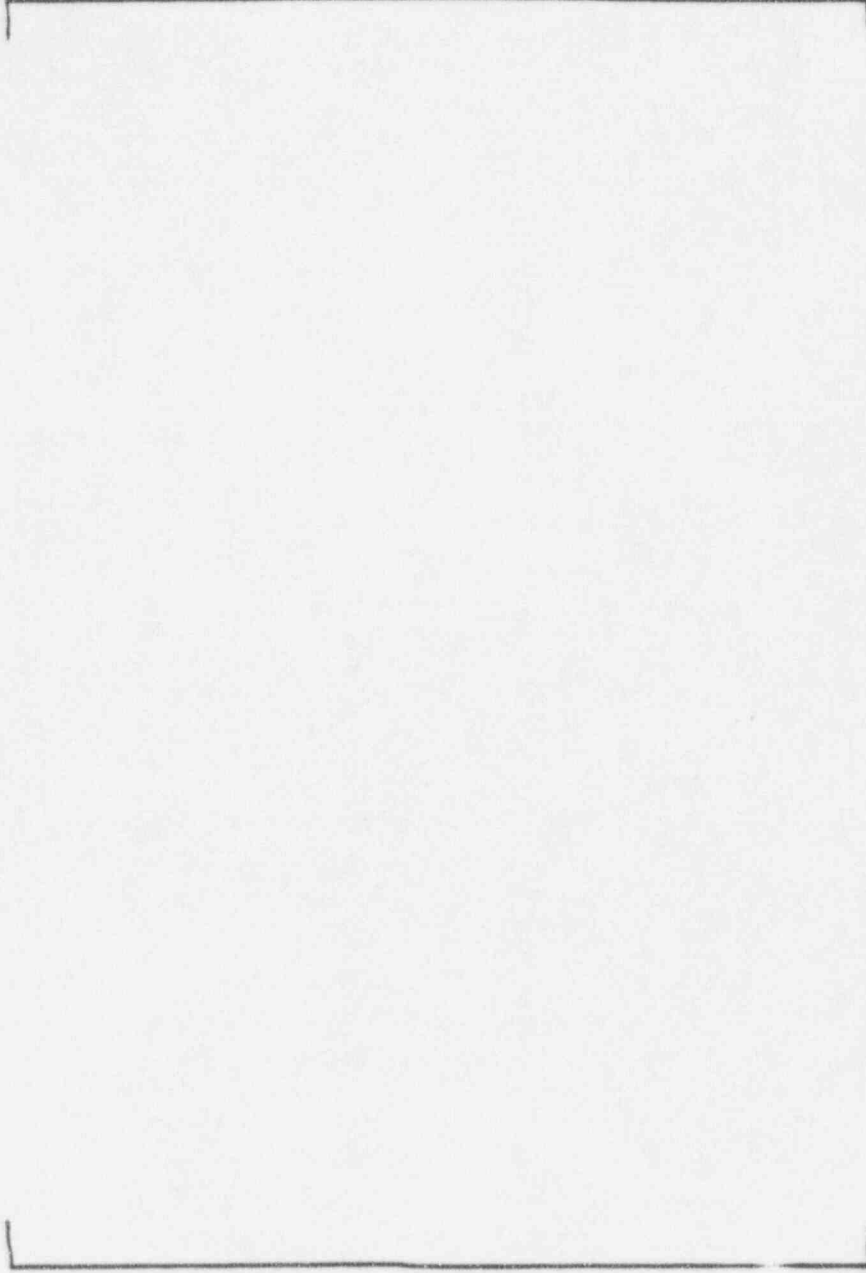
## Noncondensable Axial Distribution in Vessel

- Measurements were taken at the dome and below the operating deck at elevation F



Test 212.1

a,b



Noncondensable Gas Sampling Results Test 212.1, Run RC048

129

## Test 212.1

---



### Axial Vessel Wall Temperatures

- Vessel Fluid Temperatures (1" away from vessel wall)
- Vessel Internal Wall Temperatures

# Test 212.1



## *Inside Vessel Fluid Temperatures* *Test 212.1, Run RC048*

a,b





*Inside Vessel Wall Temperatures*  
*Test 212.1, Run RC048*

a,b

132

## Test 212.1

---



### Temperature Difference through the Vessel Wall

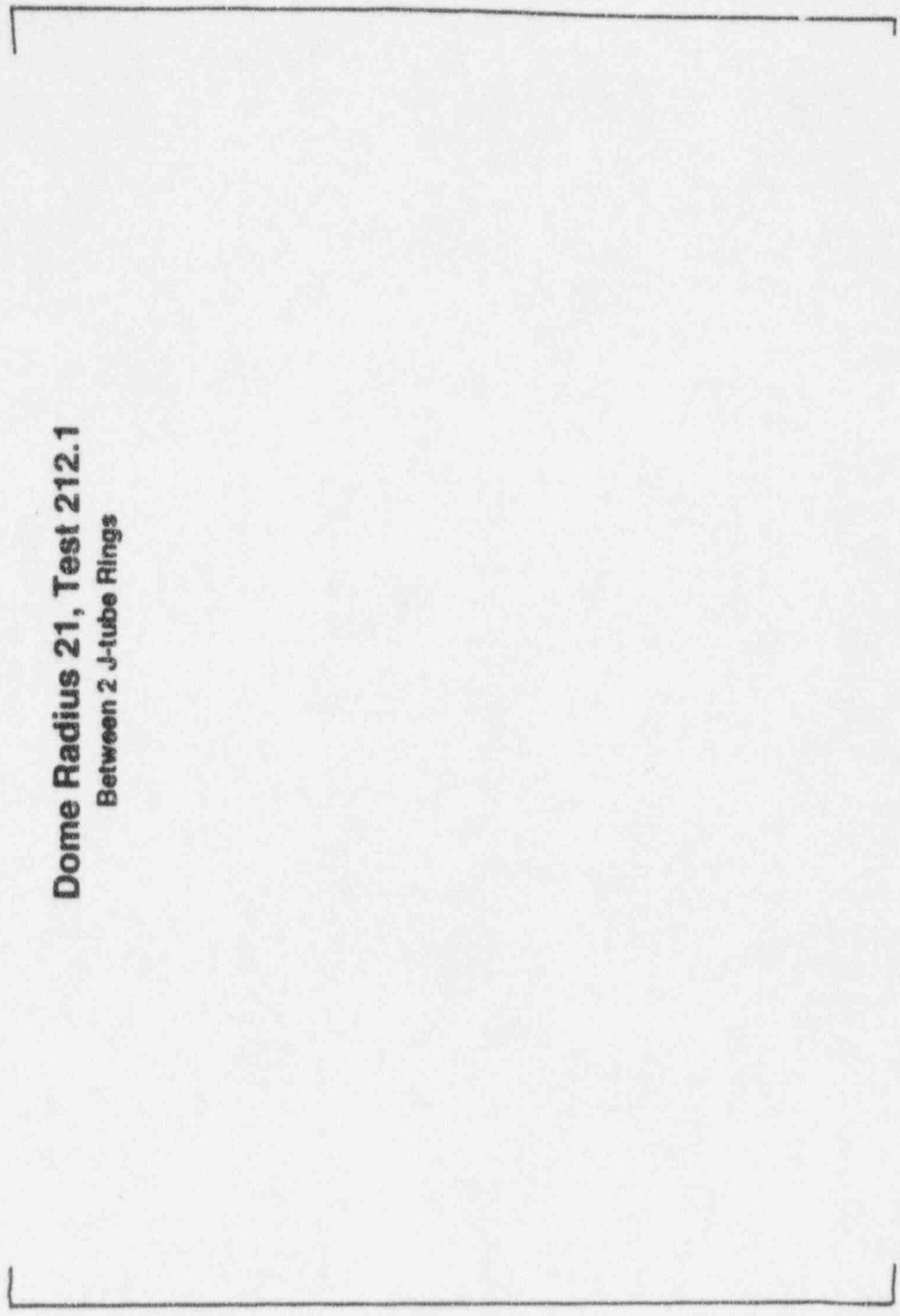
- Shown at the LST characteristic elevations
- Shown for a point in time from each steady state

Test 212.1



**Dome Radius 21, Test 212.1**  
Between 2 J-tube Rings

a,b



134

Test 212.1



a.b

**Dome Radius 42, TEST 212.1**

135

Test 212.1



**Dome Radius 63, TEST 212.1**

136

Test 212.1



a/b

Dome Radius 84, TEST 212.1

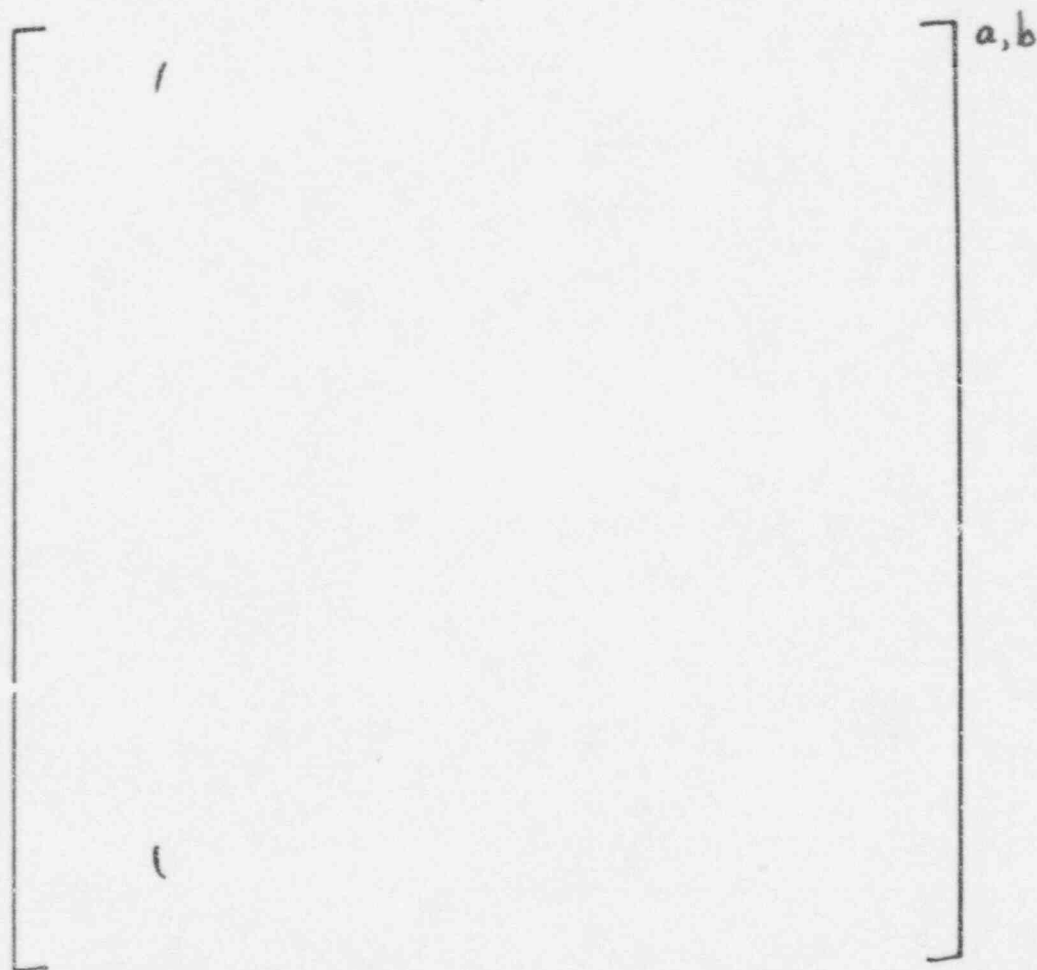
137

Test 212.1



$a_j b$

**Elevation A, TEST 212.1**



Test 212.1



**Elevation B, TEST 212.1**

140

Test 212.1



Elevation C, TEST 212.1

a,b

Test 212.1



a, b

Elevation D, TEST 212.1

[

142

Test 212.1



a,b

Elevation E, TEST 212.1

143

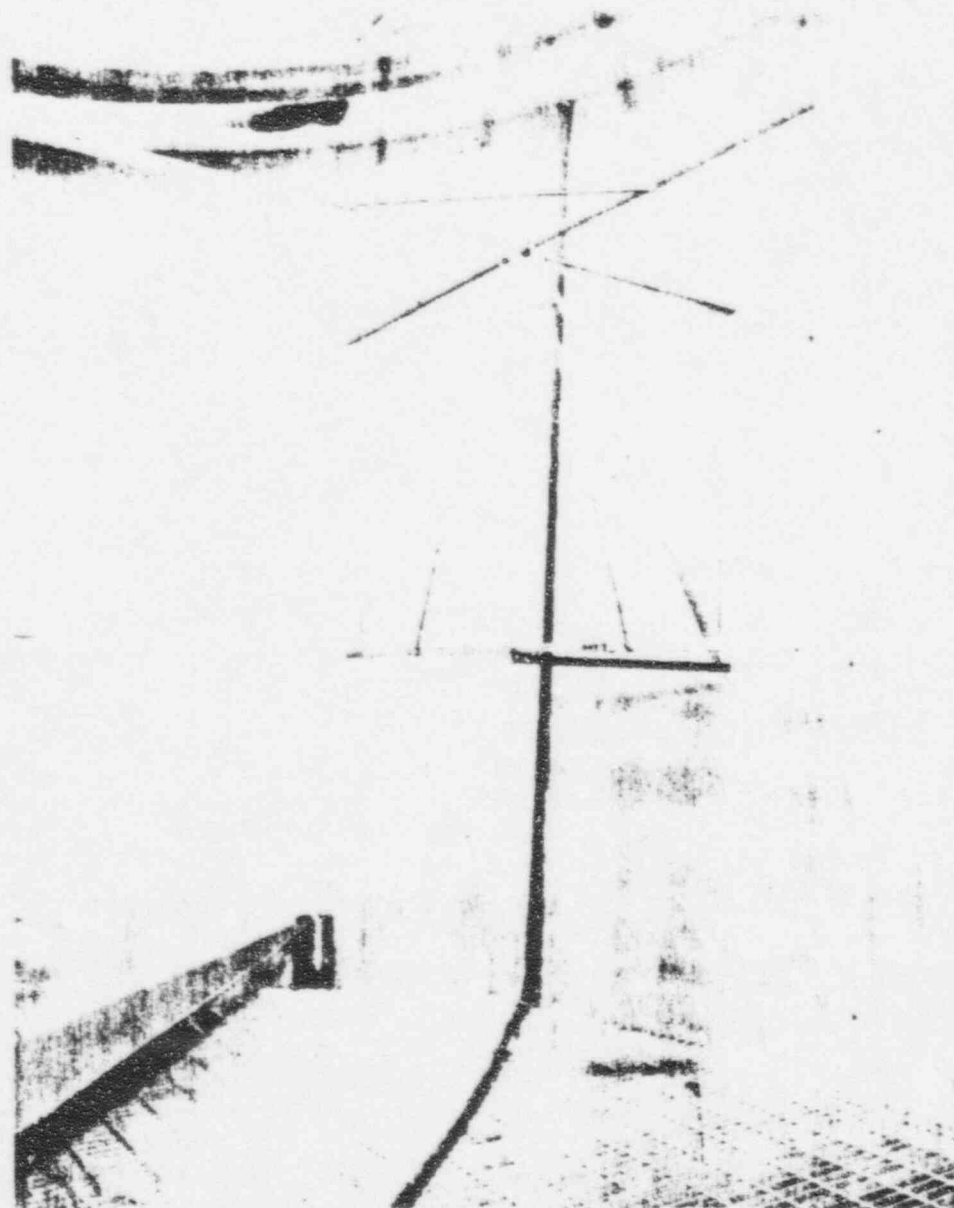
## Test 212.1

---

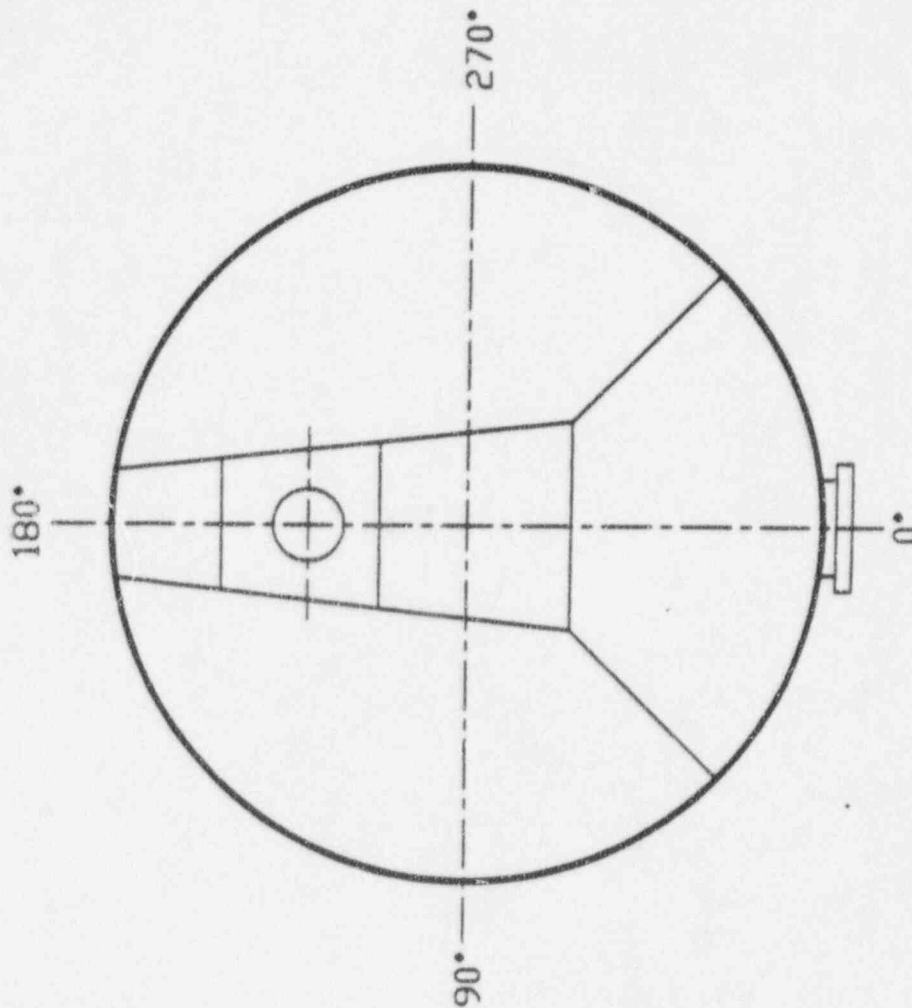


### Internal Vessel Rake Temperatures

- Shown at the LST characteristic elevations
- Shown for a point in time from each steady state



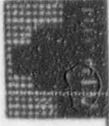
Test 212.1



Cross Section Orientating Convention

144

Test 212.1



a, b



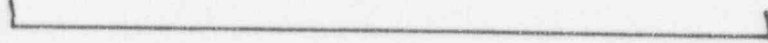
147

Test 212.1

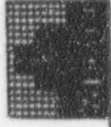


WU

a, b



Test 212.1



1 #1.

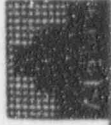
TEST 212.1, Time 14.2894 hrs

0°

100°

a, b

Test 212.1



1 1 1 1

a, b



156

Test 212.1



a, b

151



Observations

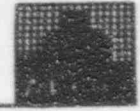
- Internal velocity meters along the wall indicated the following:

[ ]<sup>a, b</sup>

- Exterior water coverage for the first and second steady-state periods was 100% wet. For the third steady-state period, the water coverage was 95%.

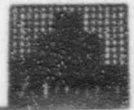
## Test 212.1

---



### Observations (cont.)

- Vessel is air rich below steam injection.
- Temperature difference across the vessel wall is fairly uniform as a function of azimuthal position at each steady state, except where the vessel exterior is dry.
- Vessel rake temperatures show that the internal temperature increases over the steam injection point.



## Lumped Parameter WGOTHIC Code Comparisons

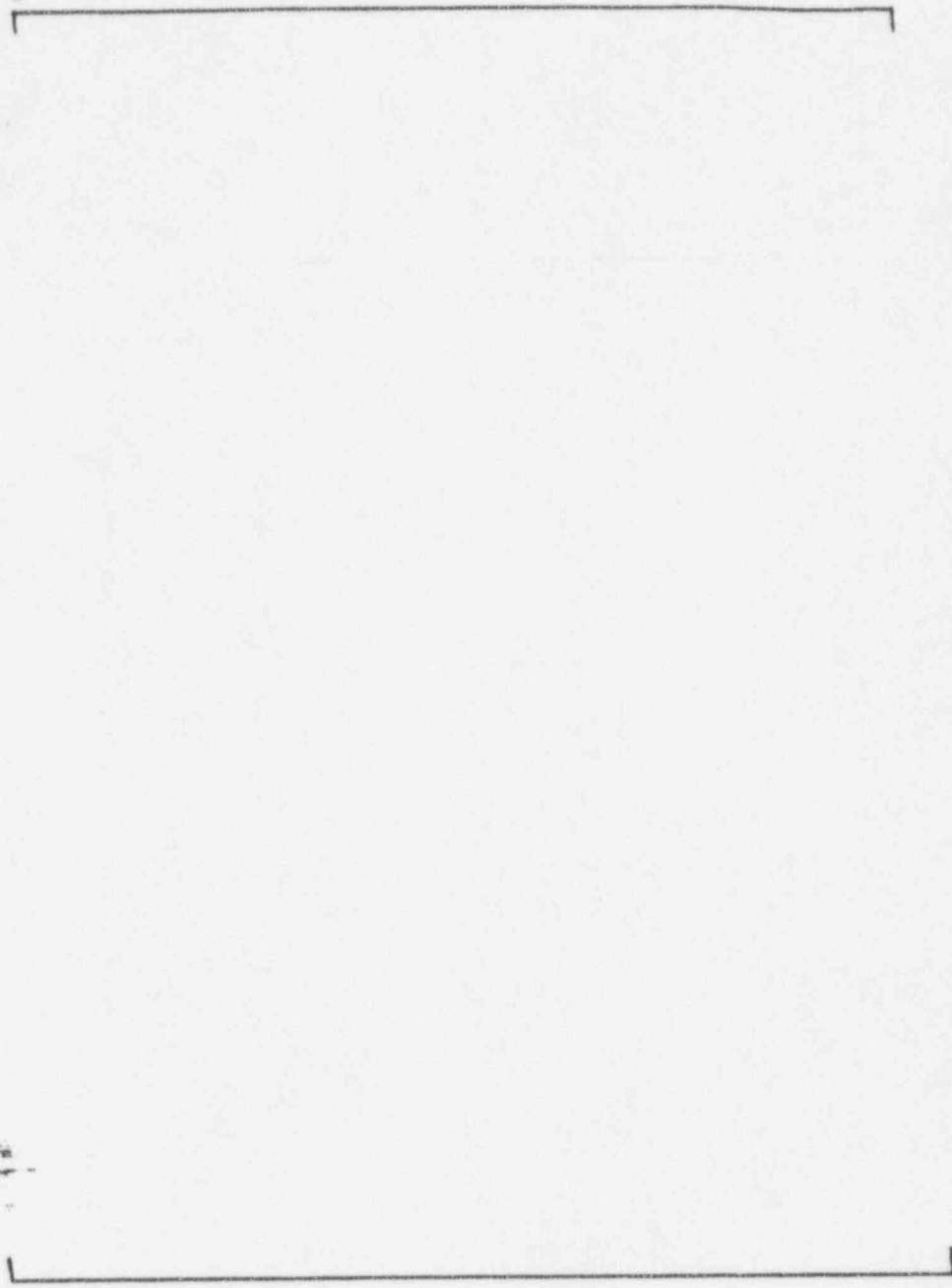
- Base Case
- Sensitivity Studies
- Conclusions



Test 212.1

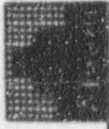
$a, b$

$a, b$

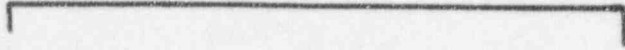


155

# Test 212.1

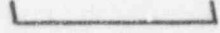
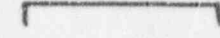


$a, b$

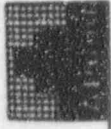


Average Condensate Flow Rate (lb/h) at Each Steady State Period

$a, b$

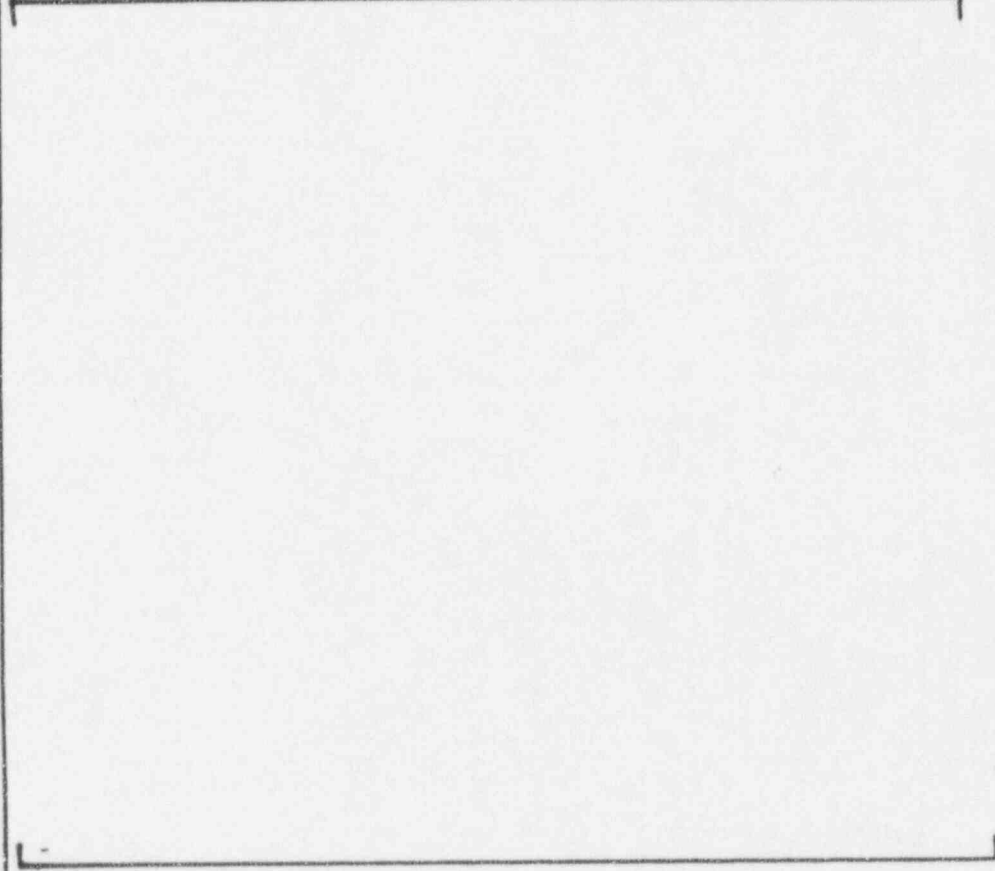


156



Test 212.1

a, b



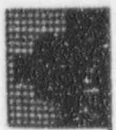
157



Test 212.1

$a, b$

$a, b$

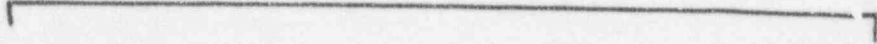


Test 212.1

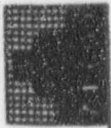
$a, b$



$a, b$



159



Test 212.1

1.1

[

a, b

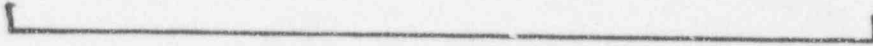
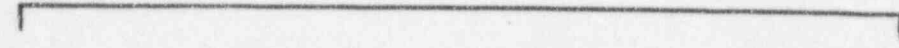
]

160

Test 212.1



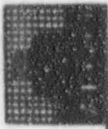
$a, b$



..

161

Test 212.1



a,b

[

162



Test 212.1

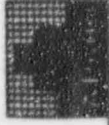
14-48

a.p



163

Test 212.1



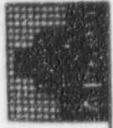
4,

[

a,b ]

164

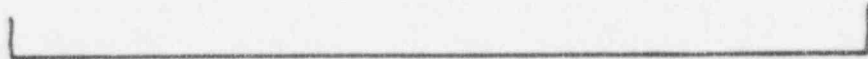
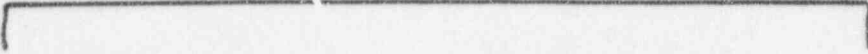
Page 71



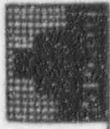
Test 212.1

141

a,b

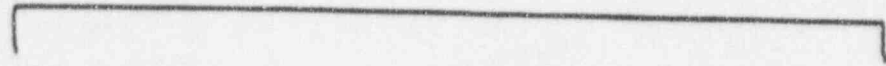


165



Test 212.1

ab



166

## Test 212.1

---



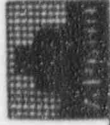
- Vessel pressure overpredicted by 5% at steady state.
- Condensation and evaporation are underpredicted by less than 4% at steady state.
- The velocity predictions along the wall are too high. The predicted velocities are 5-8 ft./s. The measurements show the velocities are [1-3]ft./s along the vessel wall.
- The model is calculating over-mixing of the noncondensables in the vessel.
- The predicted vessel fluid temperatures are too cool above the steam source and too hot below the steam source.

## Test 212.1

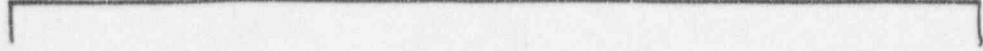
- Sensitivity Studies on Base Case:
  - Increase external heat and mass transfer
  - Increase internal heat and mass transfer
  - Turn off forced-convection component inside vessel so free-convection component is used for heat and mass transfer

148

Test 212.1

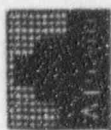


a,b



169

Test 212.1

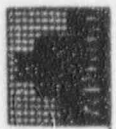


a,b



176

Test 212.1



a,b

[

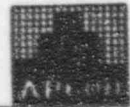
17/

## Test 212.1

---



- Sensitivity Study Results on Base Case:
  - Increasing the external heat and mass transfer by 30% decreased the predicted pressure by 1-2%
  - Increasing the internal heat and mass transfer by 30% decreased the predicted pressure by ~10%
  - Using only the free-convection component for heat and mass transfer inside the vessel increased the predicted pressure by ~13%
  - Internal mass transfer is limiting for this test



## Test 222.1

---

### Data Evaluation Summary

- Test Characteristics
- Observations
- Steam Flow Measurements

173

## Test 222.1


---



### Test Characteristics

- Maximum flow of 5.5 lb/s for ~ 20 seconds, reduce flow to 3 lb/s for ~ 45 seconds, reduce flow a third time and come to steady state
- Forced convection in the air annulus

174



## Test 222.1

### Observations

- **Boundary Conditions**
- **Exterior Water Coverage**
- **Noncondensable Axial Distribution in Vessel**
- **Vessel Wall Axial Temperatures**
- **Temperature Difference Through Vessel Wall**
- **Vessel Internal Rake Temperatures**
- **Internal Velocity Meters**

Test 222.1



ab

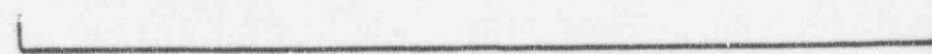
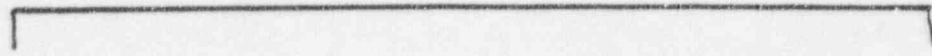
[

176

Test 222.1



ab



177

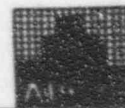
Test 222.1



a,b

Steam Line Temperature, Test 222.1

178

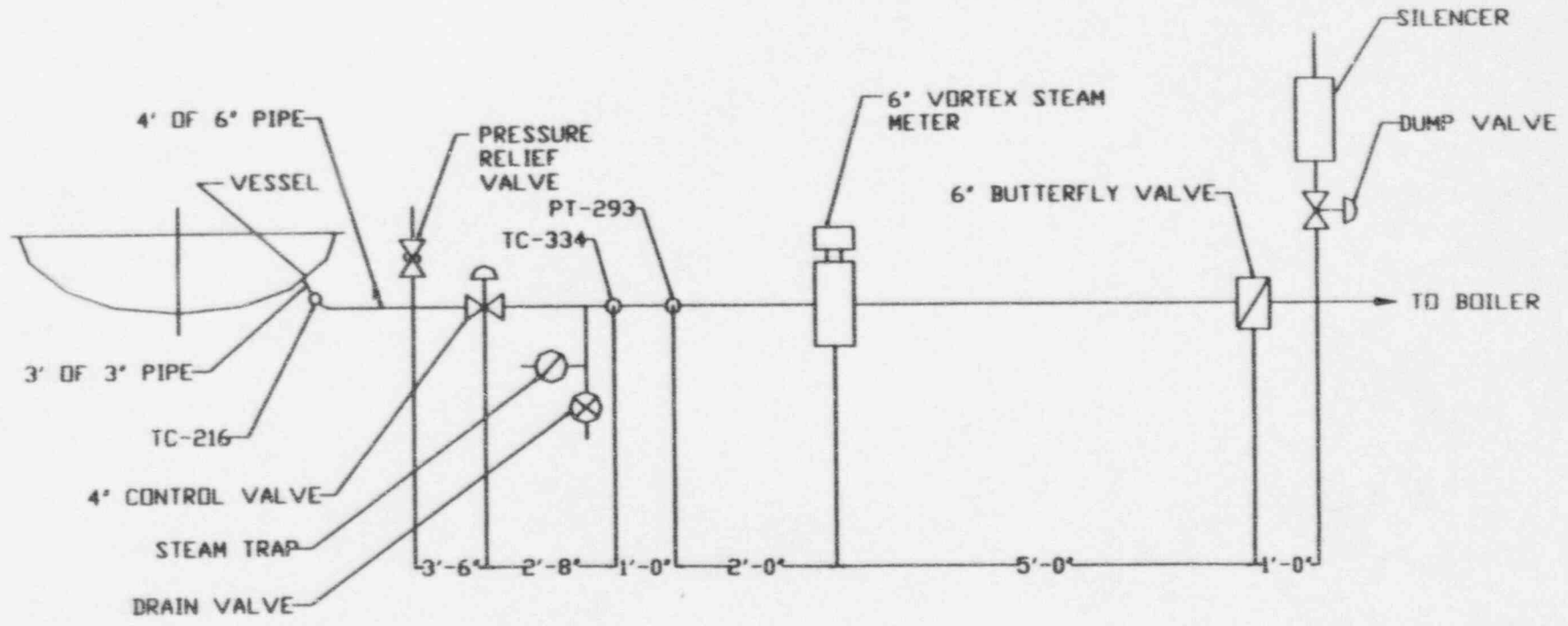
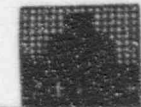


**Steam Inlet Temperature, Test 222.1**

a,b

177

# Test 222.1



**High Capacity Steam Line Schematic**

180

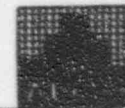


Test 222.1

a,b

**Vessel and Steam Line Pressure Test, 222.1**

181



**PCS Water Temperature, Test 222.1**

a,b

182

Test 222.1



PCS Water Flow, Test 222.1

a,b

183

Test 222.1

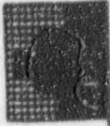


a,b

**Ambient Temperature, Test 222.1**

184

Test 222.1



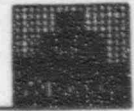
a,b

**External Air Exit Velocity, Test 222.1**

185

## Test 222.1

---

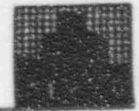


### Exterior Water Coverage

- Initially 100% wet
- At steady state 92% wet

## Test 222.1

---



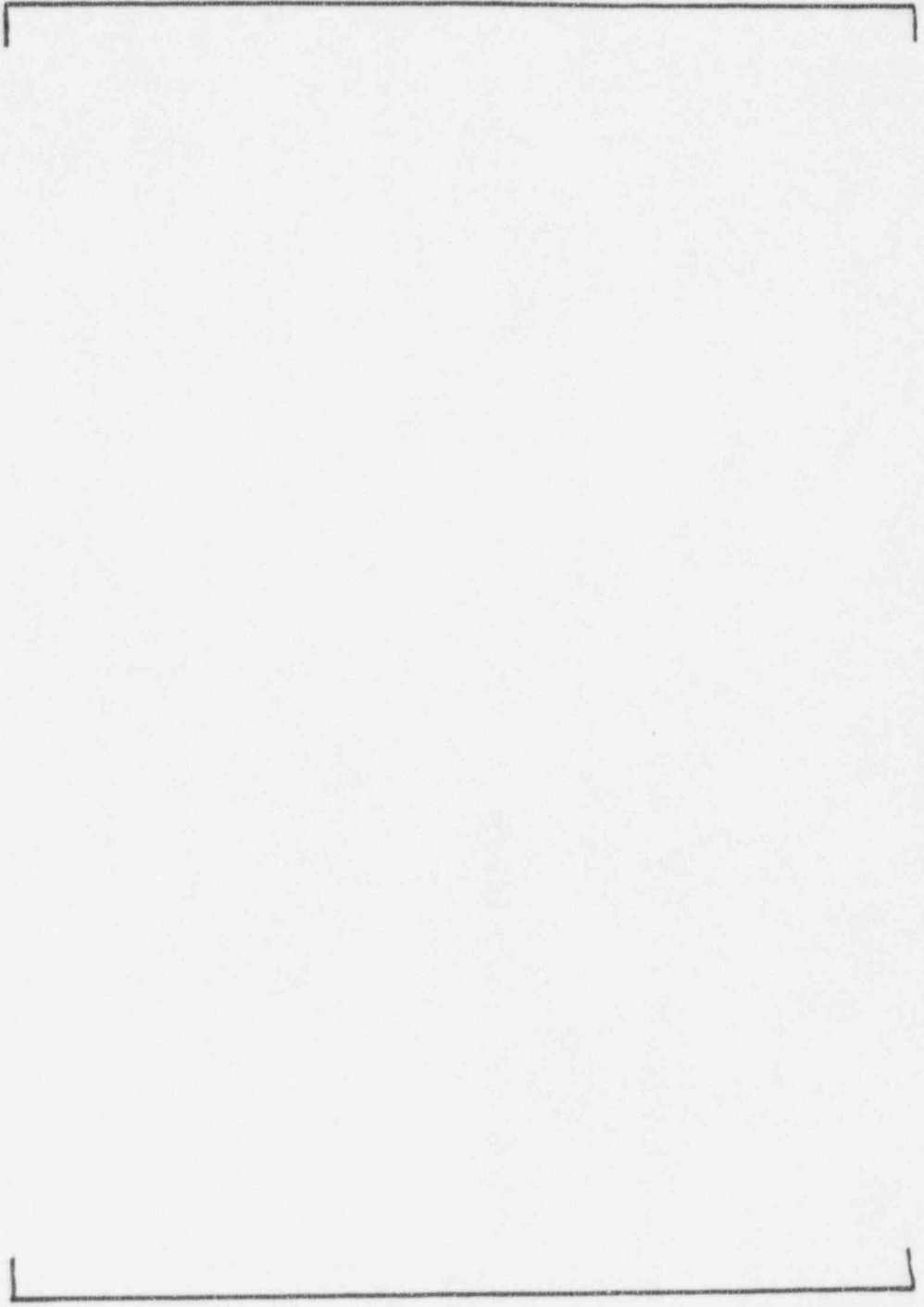
### Noncondensable Axial Distribution in Vessel

- Measurements were taken at the Dome, and elevations A, E, and F

Test 222.1



a,b



Noncondensable Concentrations Test 222.1, Run RC061

188

## Test 222.1

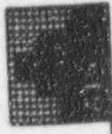
---



### Axial Vessel Wall Temperatures

- Vessel Fluid Temperatures (1" away from vessel wall)
- Vessel Internal Wall Temperatures

Test 222.1



a,b

*Inside Vessel Fluid Temperatures*  
Test 222.1, Run RC061

190

Page 97

Test 222.1



a,b

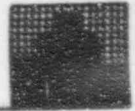
*Inside Vessel Wall Temperatures*  
Test 222.1, Run RC061

191

Page 98

## Test 222.1

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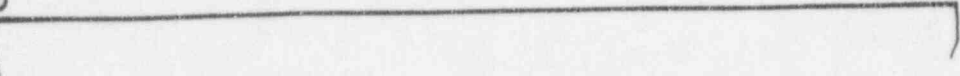
### Temperature Difference Through Vessel Wall

- Shown at the LST characteristic elevations
- Shown for a point in time for the steady state

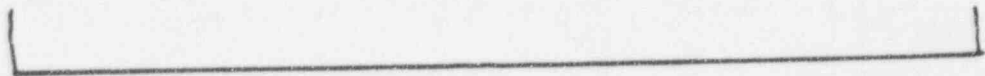
Test 222.1



a,b

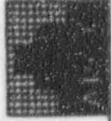


**Dome Radius 21, TEST 222.1**  
**Between 2 J-tube Rings**



173

Test 222.1



**Dome Radius 42, TEST 222.1**

ab

194

Test 222.1

Dome Radius 63, TEST 222.1

ab

195  
12

Test 222.1



Dome Radius 84, TEST 222.1

a.b

196

Test 222.1



a,b



PCS Water Coverage, Test 222.1

197

Test 222.1



ab

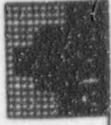
198

5

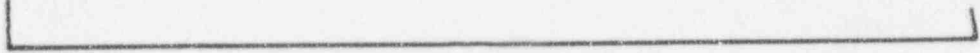
**Elevation A, TEST 222.1**

[

Test 222.1



a,b



**Elevation B, TEST 222.1**

199

06

Test 222.1



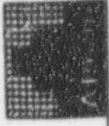
**Elevation C, TEST 222.1**

a/b

200

17

Test 222.1



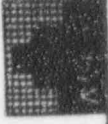
**Elevation D, TEST 222.1**

a,b

201

08

Test 222.1



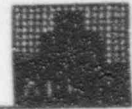
04b

**Elevation E, TEST 222.1**

202

## Test 222.1

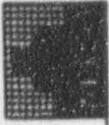
---



### Internal Vessel Rake Temperatures

- Shown at the LST characteristic elevations
- Shown for a point in time from the steady-state

Test 222.1



a,b

TEST 222.1, Time 13.1097 hrs

204

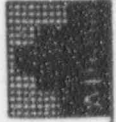


## Velocity Meters

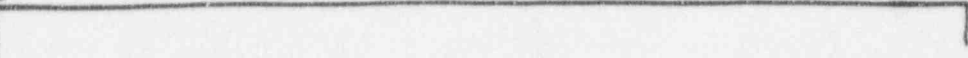
- Dome - 42" - 345° - 1.5", D-180° - 2", and E-30° - 2" anemometers read average velocities of 0.5 - 0.6 ft./s
- A-90° - 1.5" anemometer read an average velocity of 1 ft./s
- Dome - 42" - 165° - 1.5" anemometer has either failed or the velocity is below the sensor threshold

205

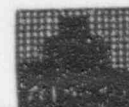
Test 222.1



a,b



206



## Test 222.1

---

### Observations

- Internal velocity meters along the wall indicated the following:
  - at locations DO-345°, D-180°, and E-30°, average velocity is 0.5-0.6 ft./s
  - at location A-90°, average velocity is 1 <sup>f+</sup>ft/s
- Vessel is air rich below steam injection
- Temperature difference across the vessel wall is fairly uniform as a function of azimuthal position, except where the vessel exterior is dry
- Vessel rake temperatures show that the internal temperature increases over the steam injection point

207



## Steam Flow Measurements

- Vortex meter consistently performs at 8-12% lower than indicated by the condensate over the steady-state period. Therefore, the vortex meter is used for the time dependent flow rate and the condensate measurement is used for the steady state.
- The vortex meter's operating range is from 5.9 to 0.45 lb/s, however at the end of the blowdown, the flow meter measures the flow rate to be as low as 0.03 lb/s. For over two minutes at the end of the blowdown, the meter is below its operating range.
- The steam line pressure is not measured at the vessel inlet, however it is measured upstream. The pressure drop through the line can be calculated so that the inlet steam pressure may be input into the code.

Test 222.1

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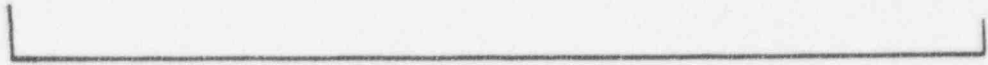
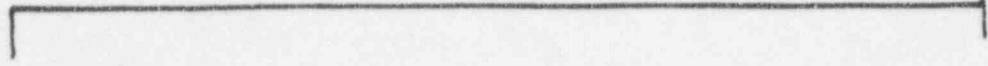


## Lumped Parameter WGOTHIC Code Comparisons

Test 222.1



a,b

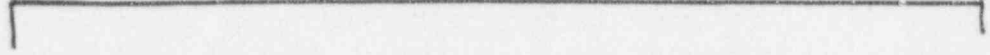


210

Test 222.1



a.b

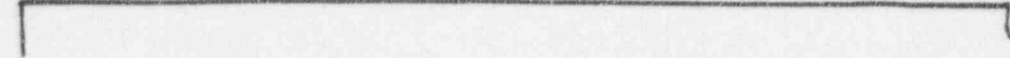


211

Test 222.1

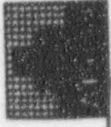


a,b

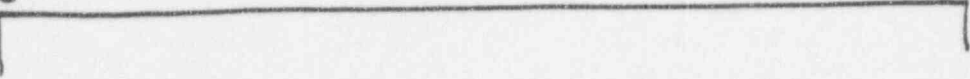


2/2

Test 222.1

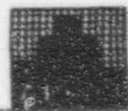


a,b



213

Test 222.1

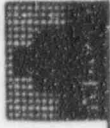


Average Condensate Flow Rate (lb/s) Steady-State Period

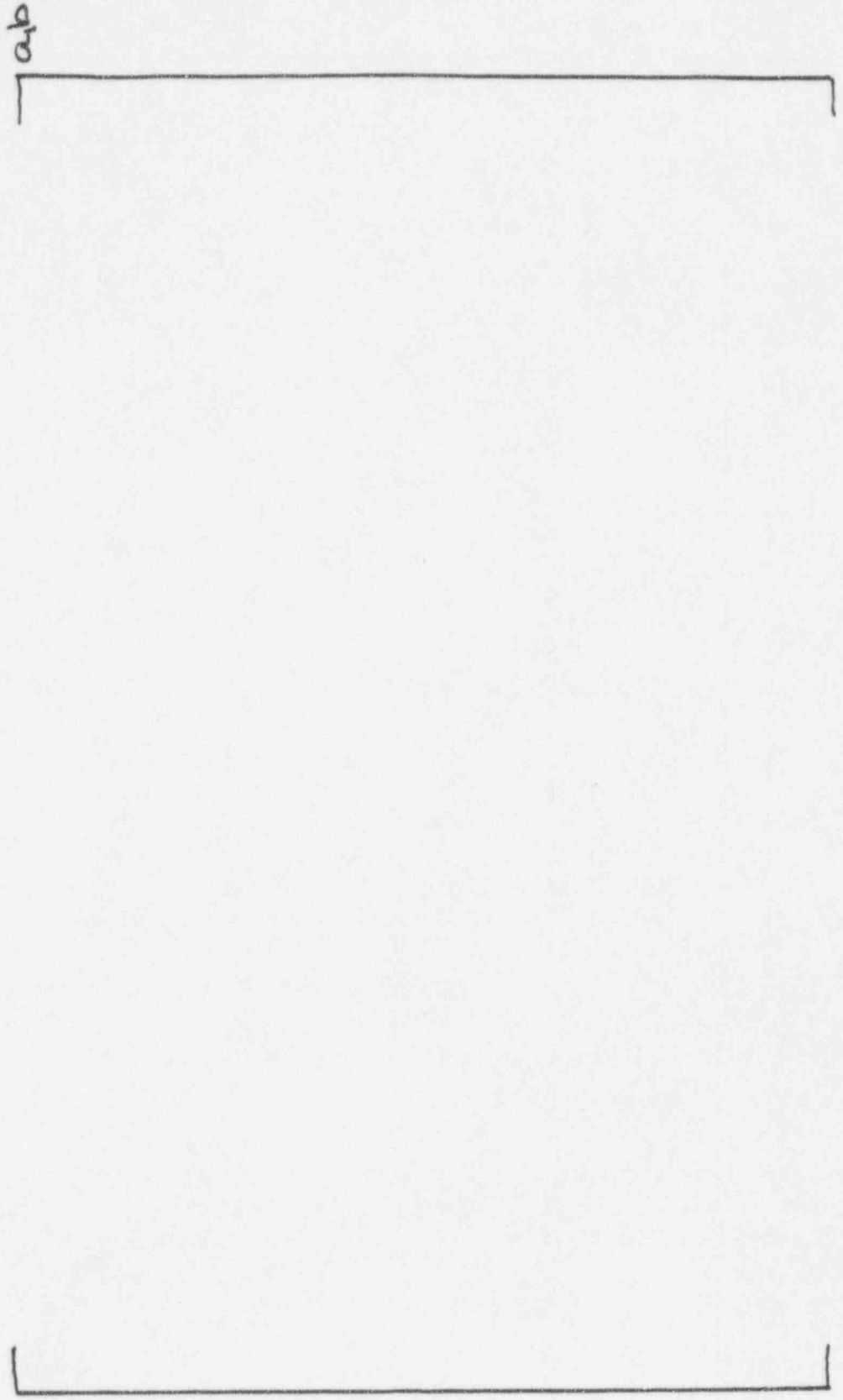
[

] ab

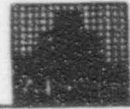
214



Test 222.1



Test 222.1



Average Evaporation Rate (lb/s) Steady-State Period

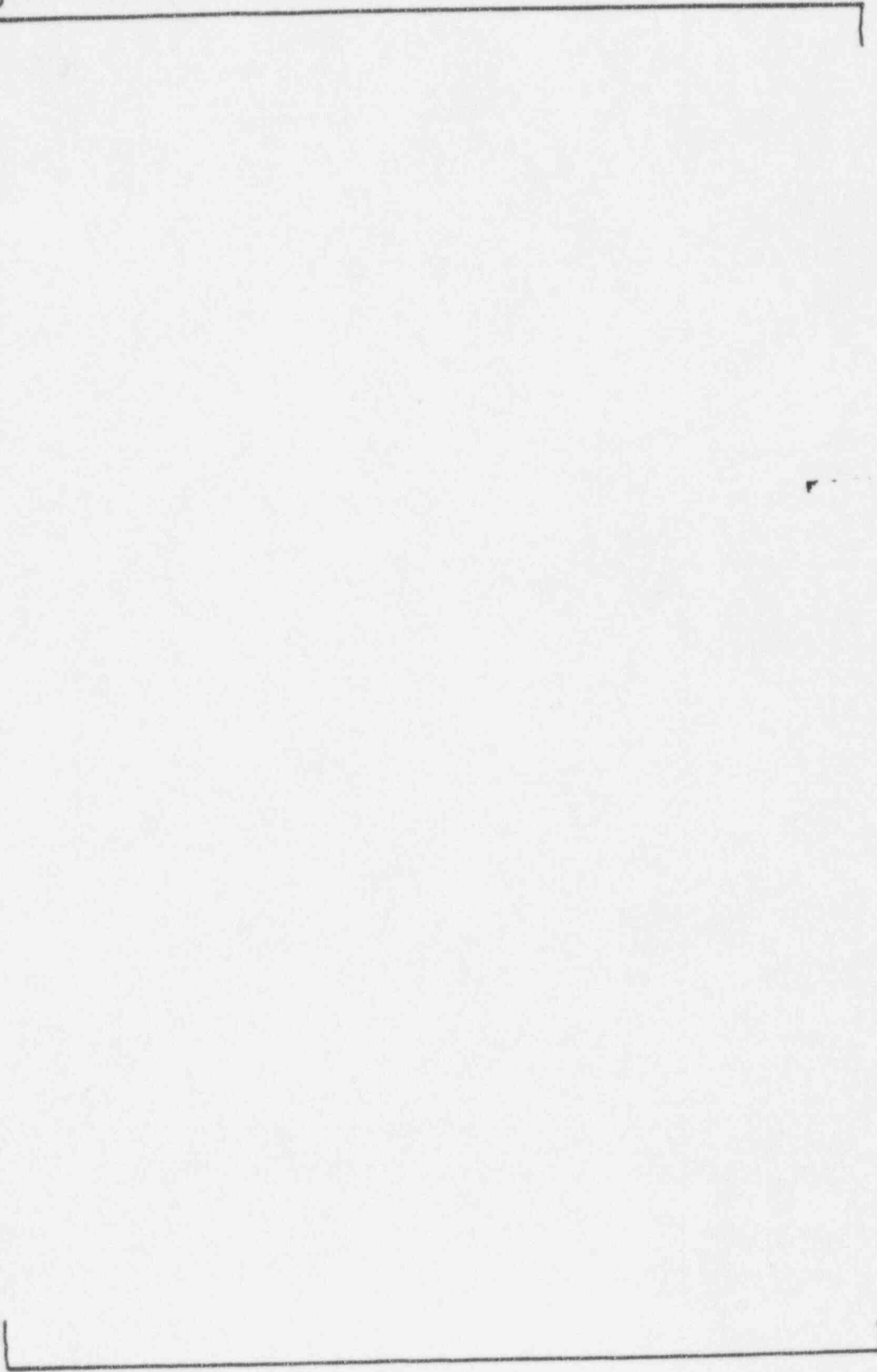
[

] ab

Test 222.1



a,b



217

Page 124

Test 222.1

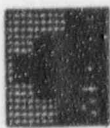


218

218

Page 125

Test 222.1



a.p

219

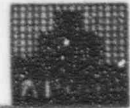
Test 222.1



a,b

220

Page 127

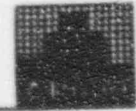


## Conclusions for Lumped Parameter

- Vessel pressure overpredicted by 6% at steady state and for peak pressure.
- Vessel pressure underpredicted by 18% at dip after blowdown. However, the inlet steam vortex meter is reading significantly below (in some instants by a factor of 10) its operating range. The steam flow rate is believed to be higher than indicated by vortex meter.
- Condensation and evaporation are underpredicted by less than 6%.
- The velocity predictions along the wall are too high. The average predicted velocity is 10 ft./s. The measurements show the velocities are ~ 1 ft./s along the vessel wall.
- The model is calculating over-mixing of the noncondensables in the vessel.

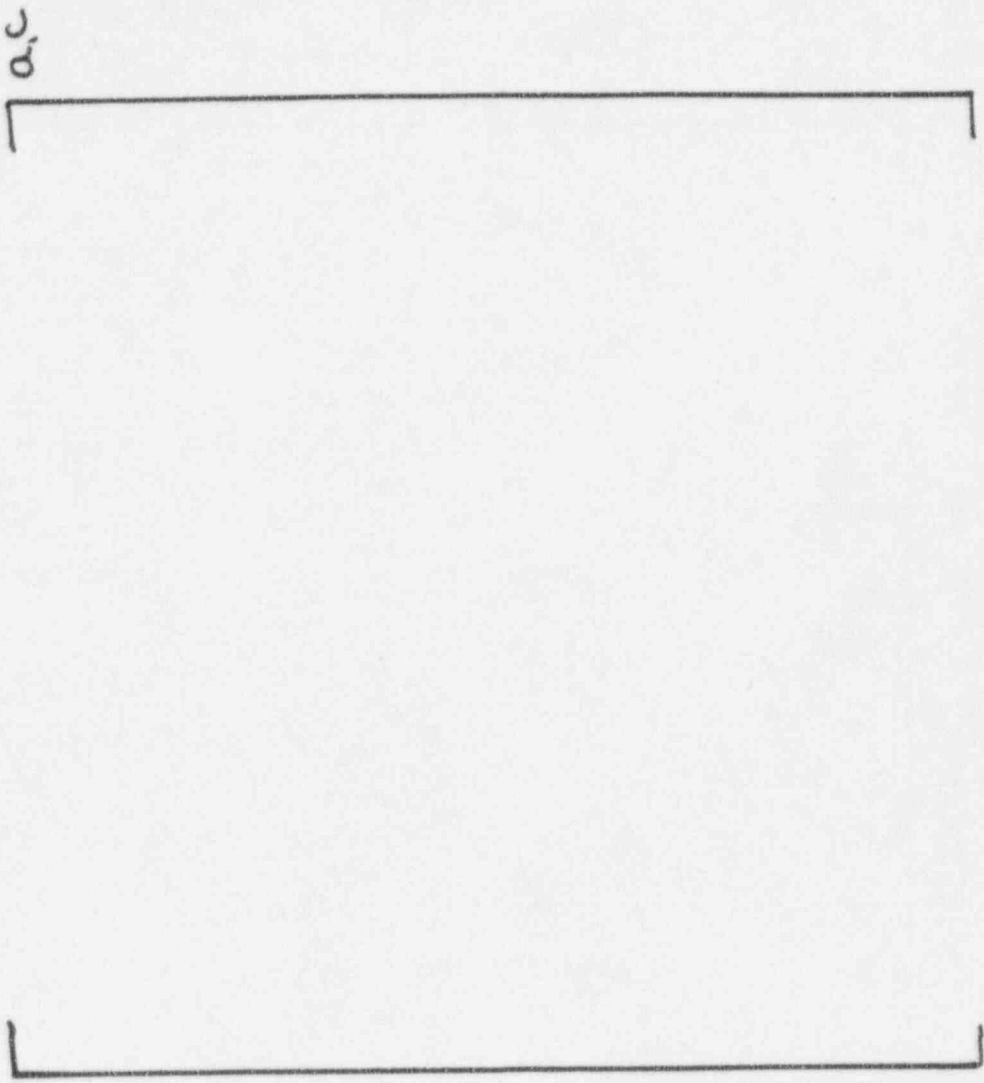
## Subdivided WGOTHIC Model

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- Noding of LST Model
  
- Test 212.1A
  - Base Case
  
  - Sensitivity to explore mixing effects

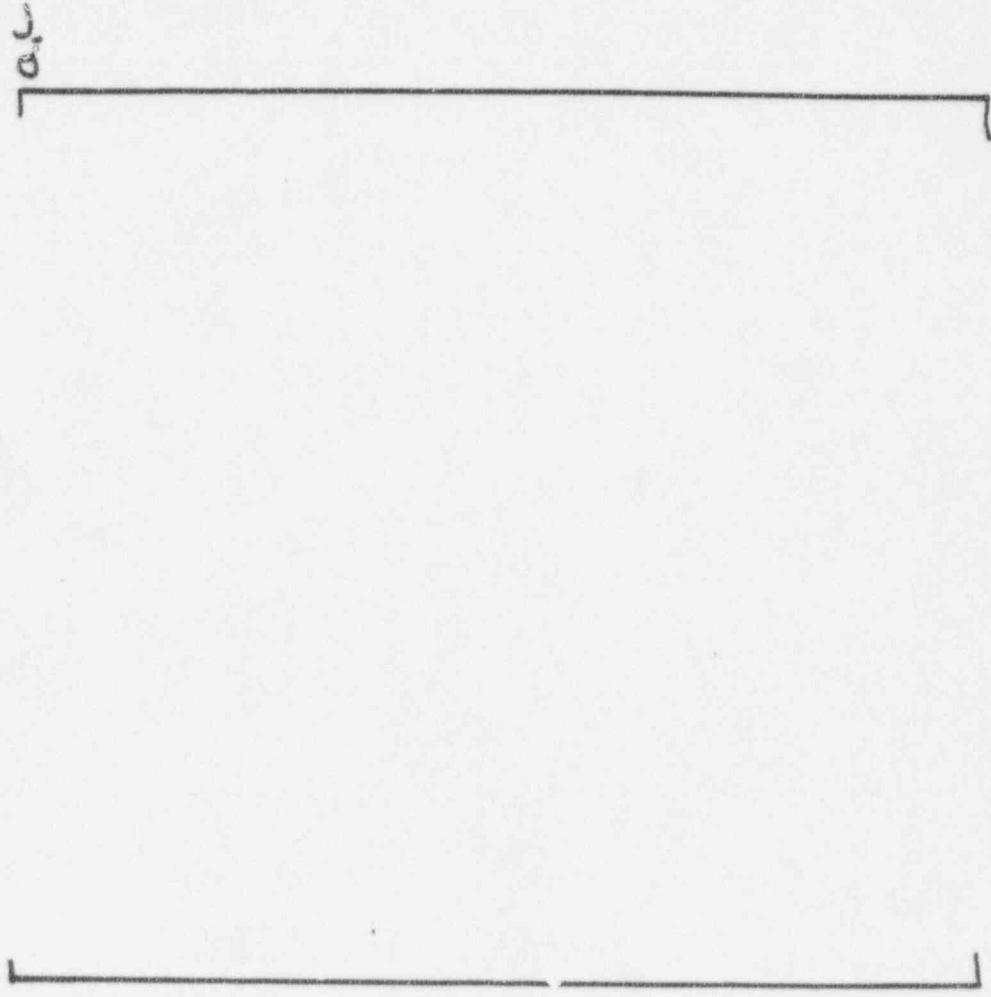
# Subdivided WGOTHIC Model



Noding Diagram of Subdivided LST

223

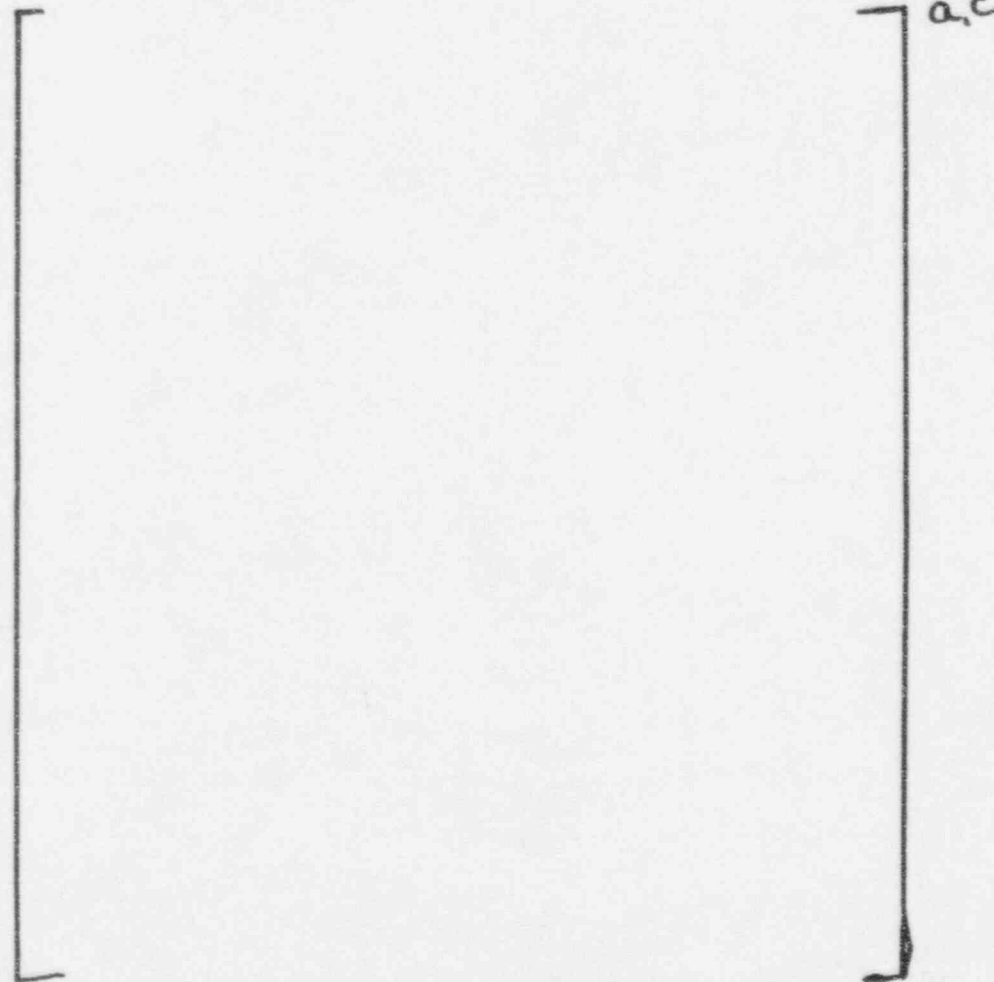
# Subdivided WGOTHIC Model



Subdivided Noding Above Operating Deck

224

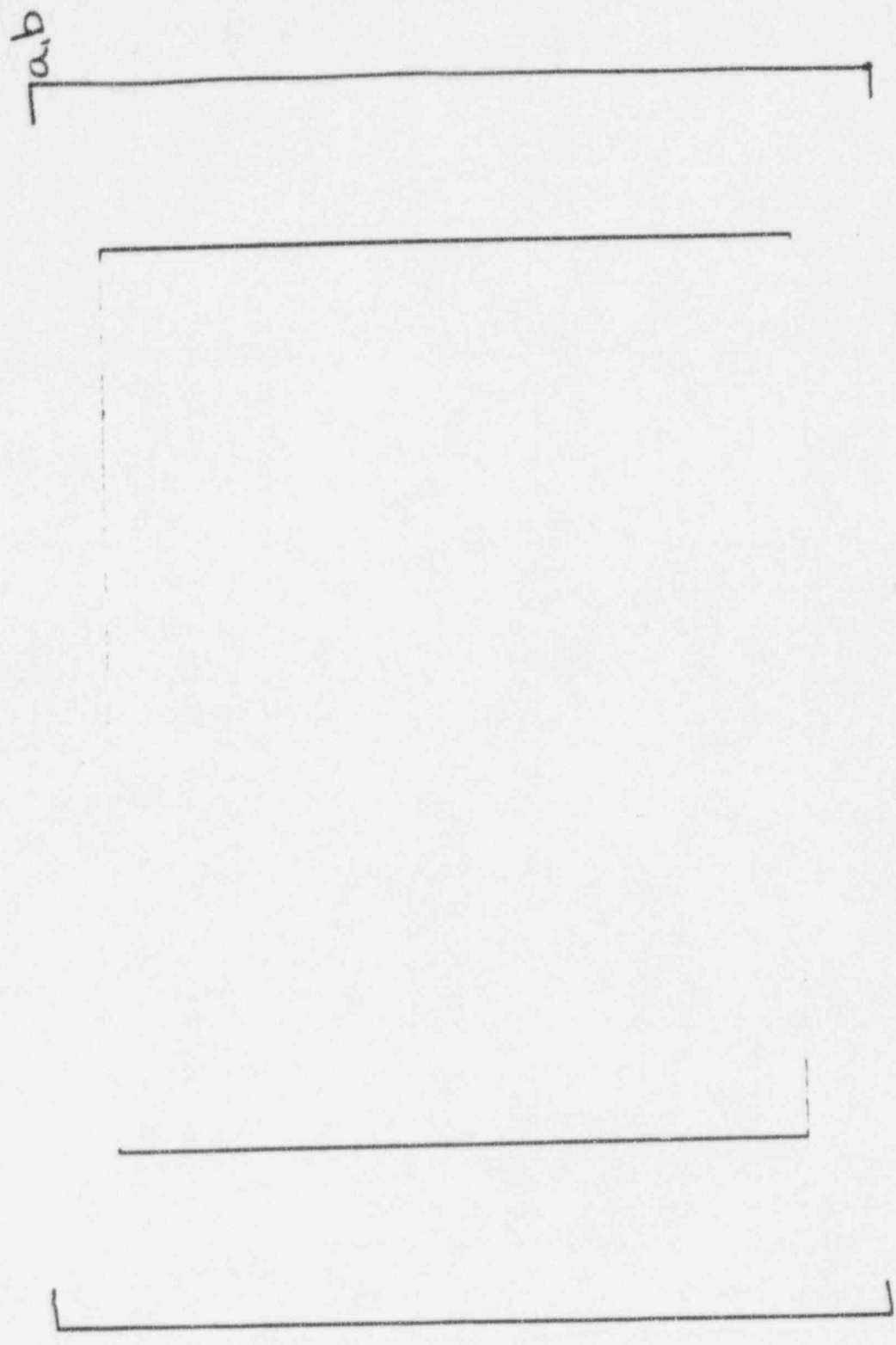
# Subdivided WGOTHIC Model



Subdivided Noding Below Operating Deck

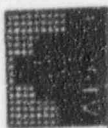
225

Subdivided WGOTHIC Model

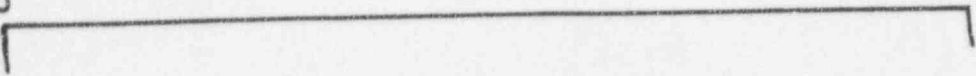


226

Subdivided WGOTHIC Model



ab



227

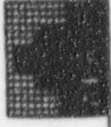
Subdivided WGOTHIC Model

*External Excess Water vs. Time  
Measured and Predicted*

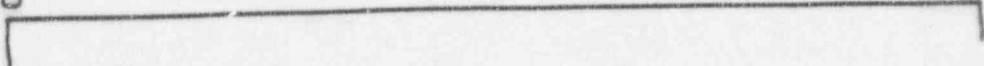
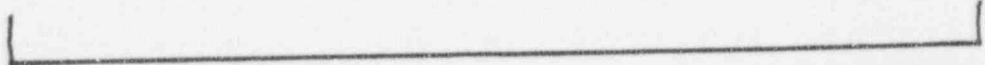
a,b

228

# Subdivided WGOTHIC Model



a,b

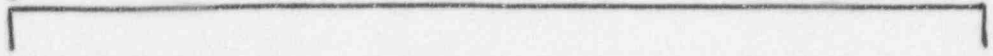


229

Subdivided WGOTHIC Model



a,b



230

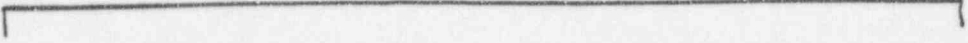


Test 212.1



PCS Water Temperature, Test 212.1

a.b



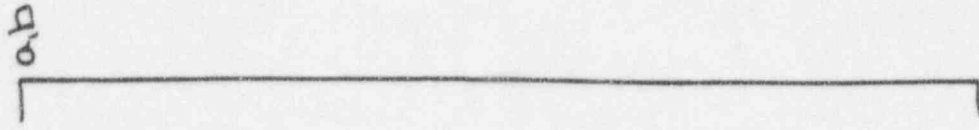
123



Test 212.1



PCS Water Flow, Test 212.1



a/b

124



Test 212.1

a,b

Ambient Temperature, Test 212.1



**External Air Exit Velocity, Test 212.1**

a,b



## Test 212.1

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### Exterior Water Coverage

- First Steady State                      100% Wet
- Second Steady State                    100% Wet
- Third Steady State                      95% Wet

## Test 212.1

---



### Noncondensable Axial Distribution in Vessel

- Measurements were taken at the dome and below the operating deck at elevation F

Test 212.1



**Noncondensable Gas Sampling Results Test 212.1, Run RC048**



### Axial Vessel Wall Temperatures

- Vessel Fluid Temperatures (1" away from vessel wall)
- Vessel Internal Wall Temperatures

Test 212.1



a,b

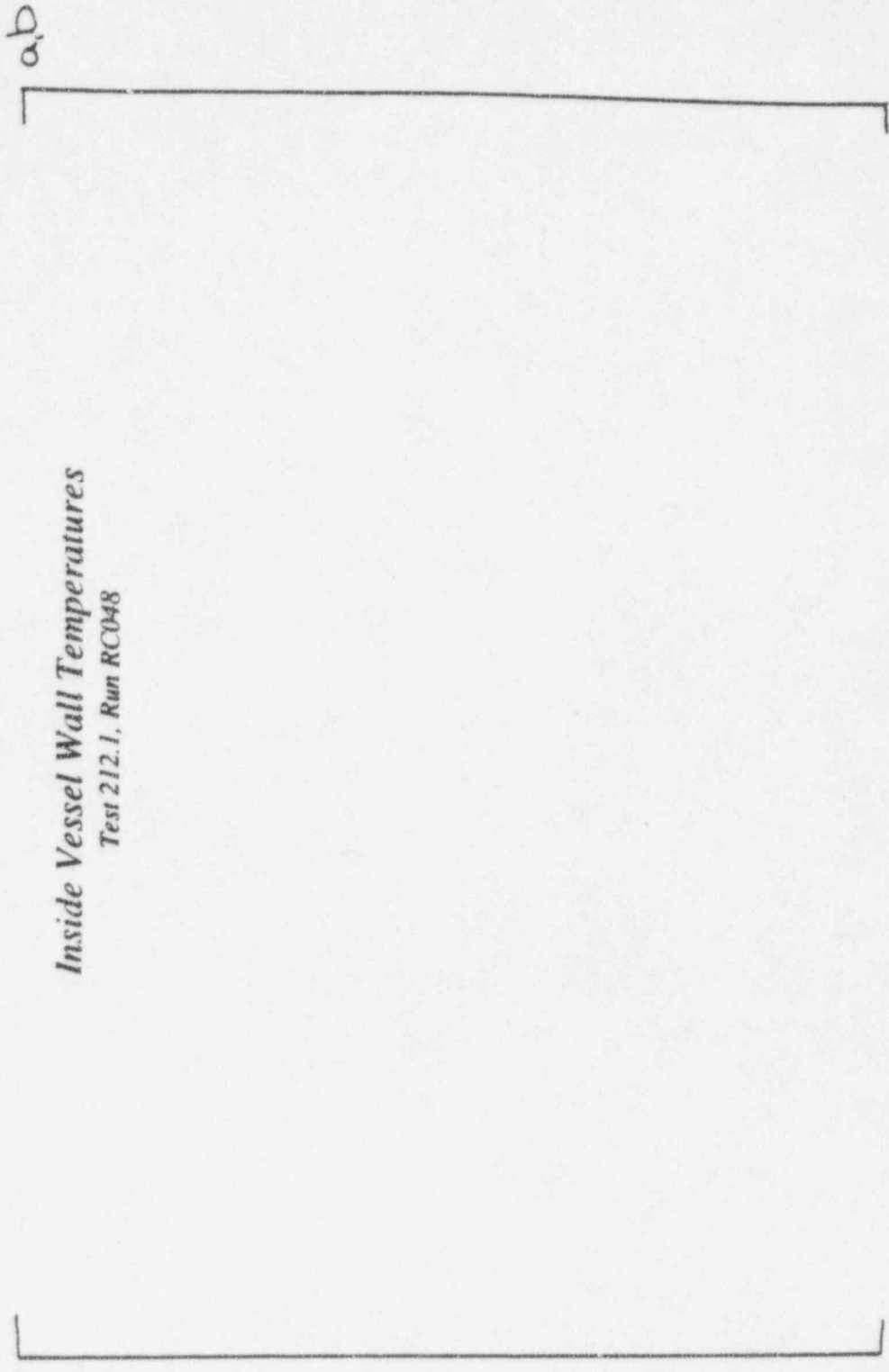
*Inside Vessel Fluid Temperatures*

Test 212.1, Run RC048

131

Page 38

Test 212.1



*Inside Vessel Wall Temperatures*  
*Test 212.1, Run RC048*

132



## Temperature Difference through the Vessel Wall

- Shown at the LST characteristic elevations
- Shown for a point in time from each steady state

Test 212.1



a,b

**Dome Radius 21, Test 212.1**  
Between 2 J-tube Rings

[

134



Test 212.1

a,b

**Dome Radius 42, TEST 212.1**

135

Test 212.1



**Dome Radius 63, TEST 212.1**



136

Test 212.1



Dome Radius 84, TEST 212.1

ap

Test 212.1

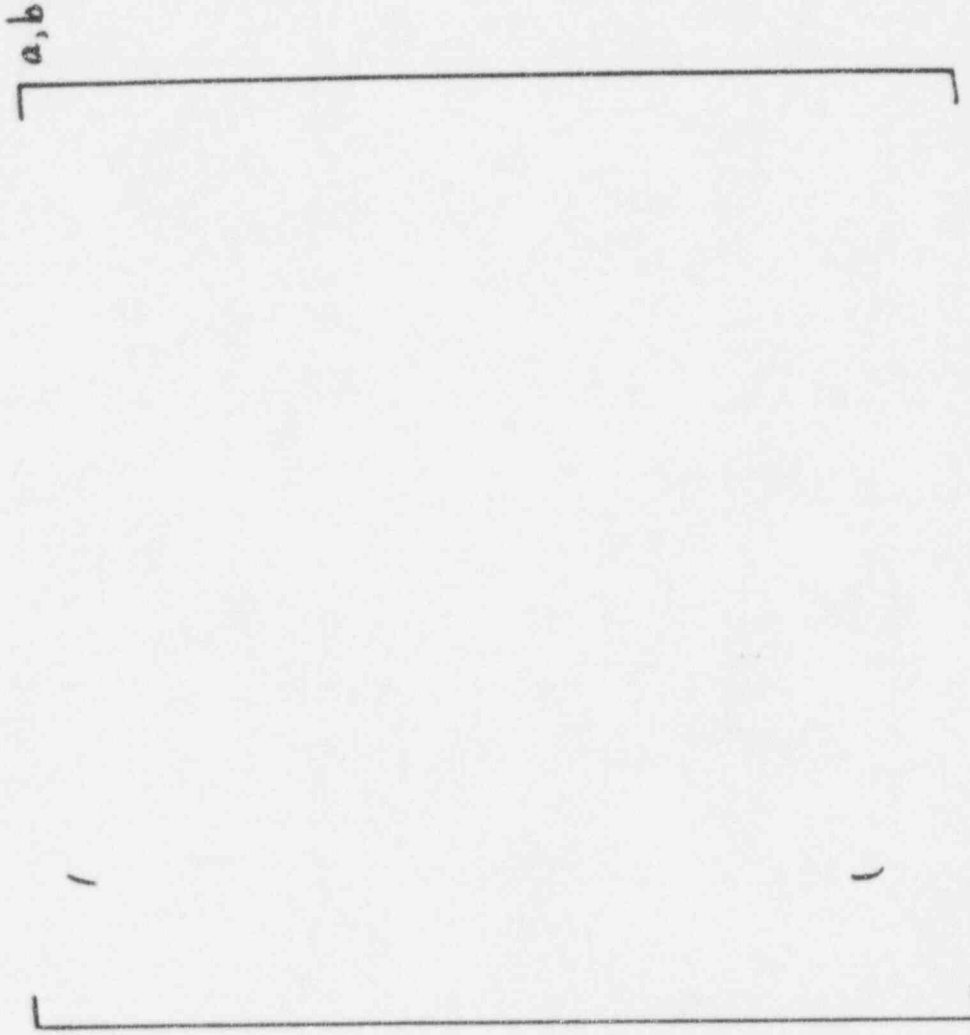


$\alpha, b$

Elevation A, TEST 212.1



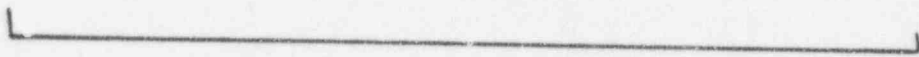
Test 212.1



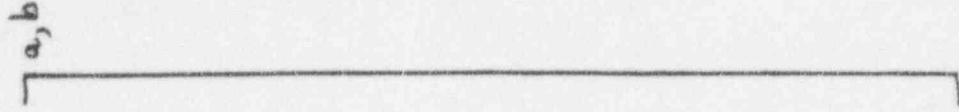
139

PCS Water Coverage, Test 212.1

Test 212.1



**Elevation B, TEST 212.1**



a,b

140

Test 212.1

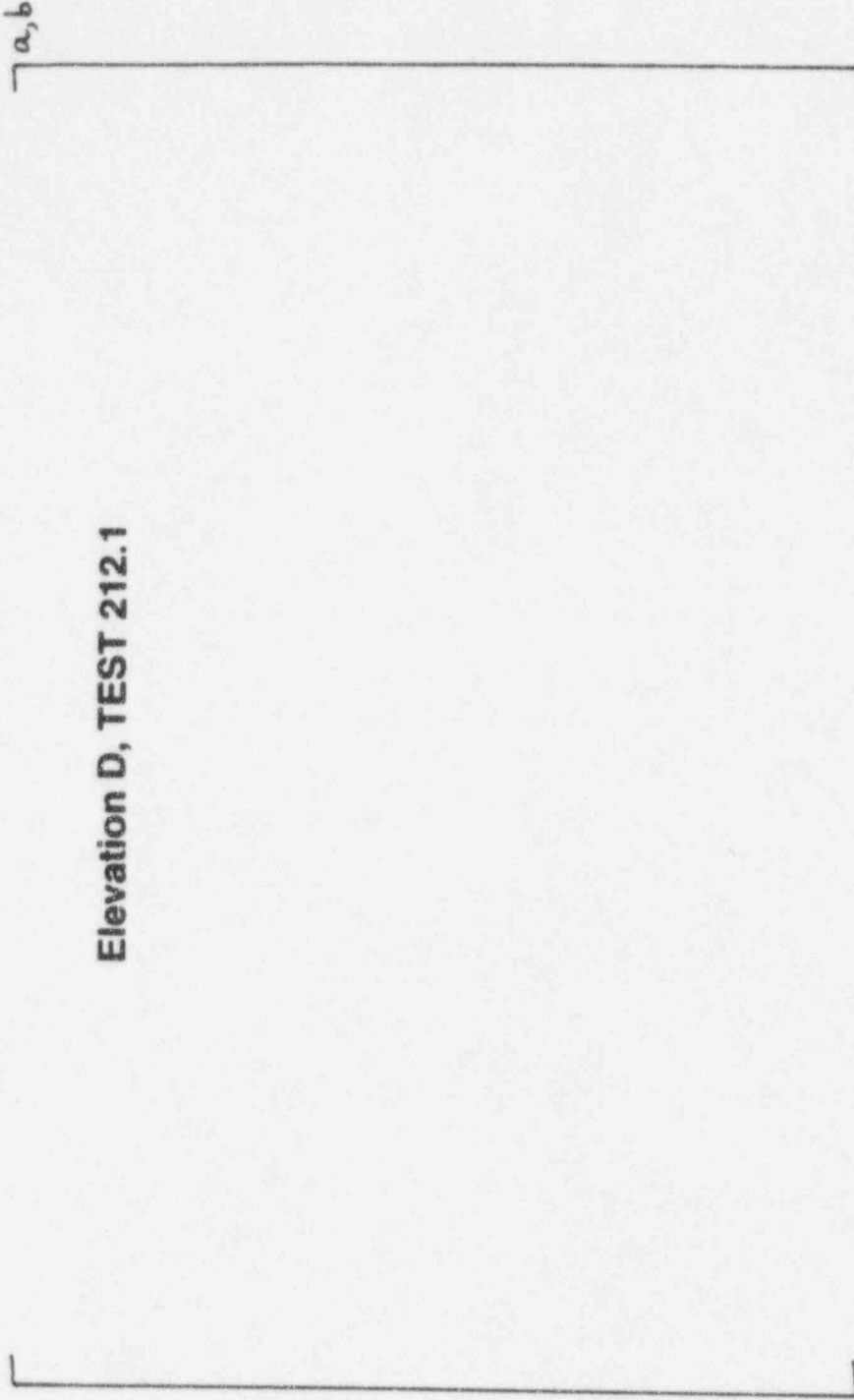


a, b

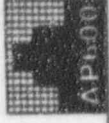
Elevation C, TEST 212.1

141

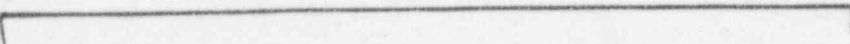
Test 212.1



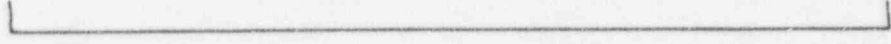
Test 212.1



a,b



**Elevation E, TEST 212.1**



143

## Test 212.1

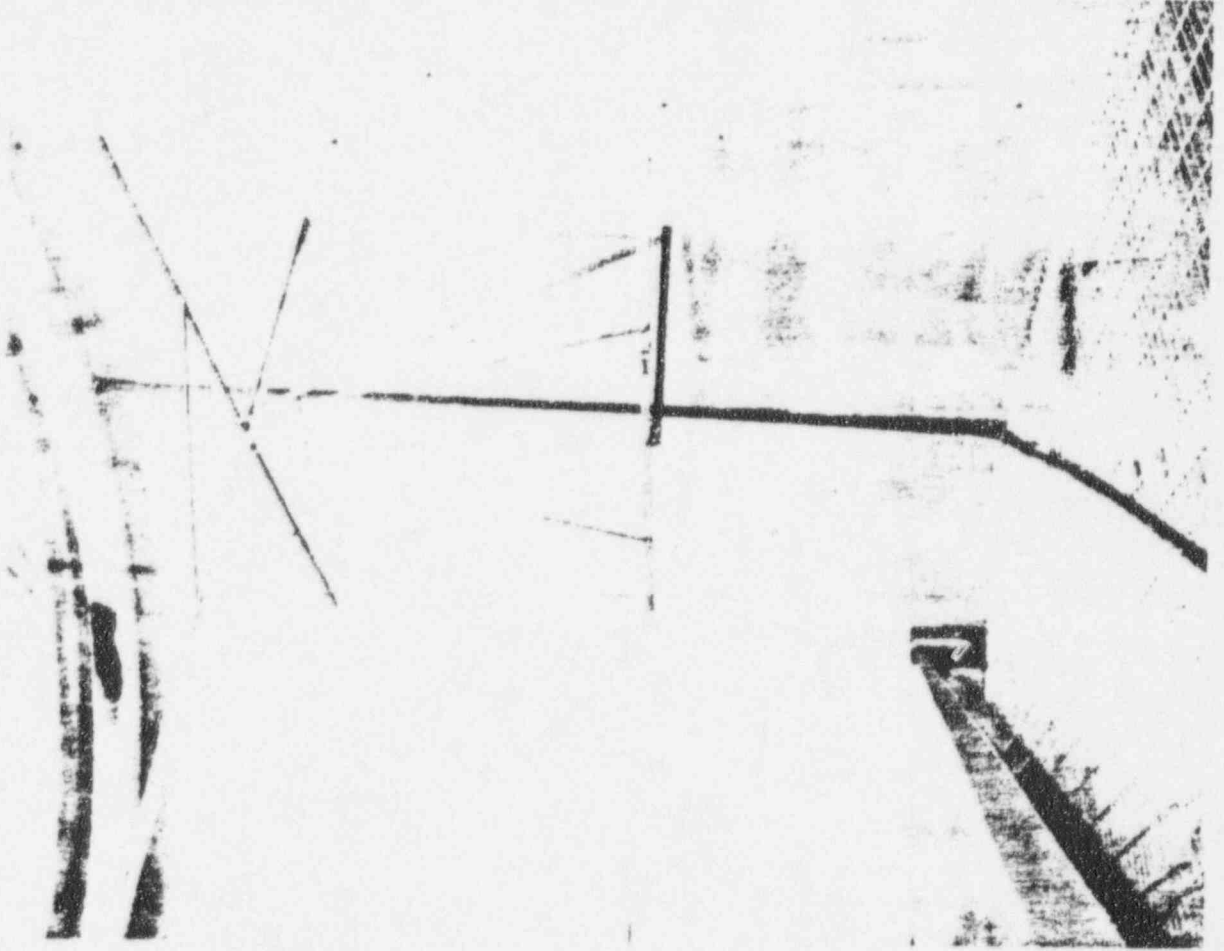
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### Internal Vessel Rake Temperatures

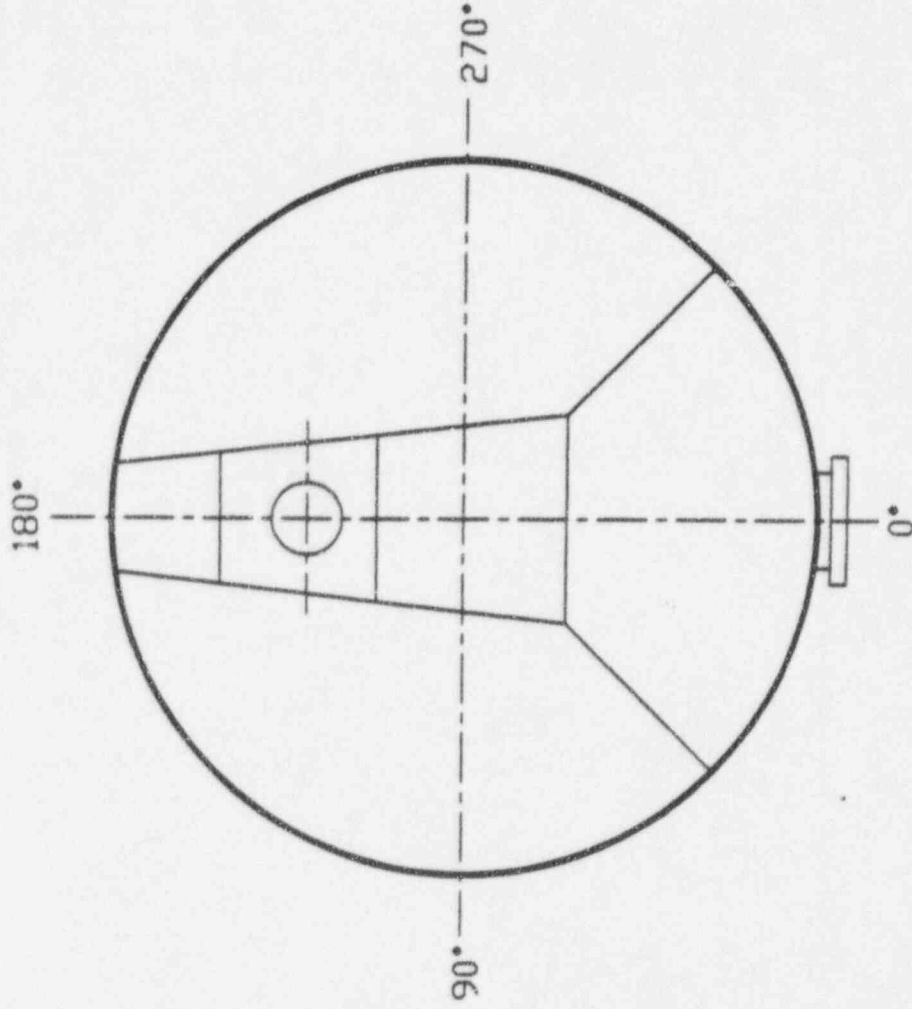
- Shown at the LST characteristic elevations
- Shown for a point in time from each steady state

Test 212.1



145

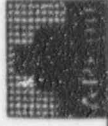
Test 212.1



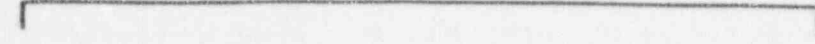
Cross Section Orientating Convention

146

Test 212.1



a, b



147



Test 212.1



1. 1#1.

[

TEST 212.1, Time 14.2894 hrs

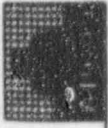
°

180°

a, b

]

Test 212.1



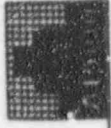
1 1 1 1

a, b

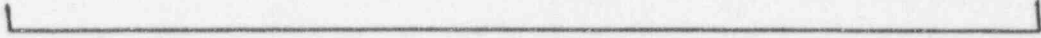
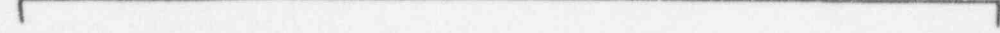


156

Test 212.1



$a, b$



151

## Test 212.1

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### Observations

- Internal velocity meters along the wall indicated the following:

[

] a,b

- Exterior water coverage for the first and second steady-state periods was 100% wet. For the third steady-state period, the water coverage was 95%.

## Test 212.1

---

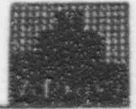


### Observations (cont.)

- Vessel is air rich below steam injection.
- Temperature difference across the vessel wall is fairly uniform as a function of azimuthal position at each steady state, except where the vessel exterior is dry.
- Vessel rake temperatures show that the internal temperature increases over the steam injection point.

## Test 212.1

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### Lumped Parameter WGOTHIC Code Comparisons

- Base Case
- Sensitivity Studies
- Conclusions

Test 212.1

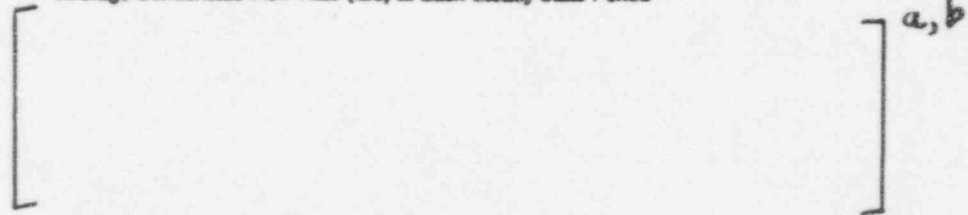


155

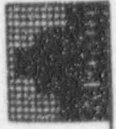
# Test 212.1



Average Condensate Flow Rate (lb/s) at Each Steady State Period

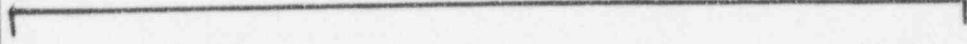


156

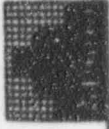


Test 212.1

a, b



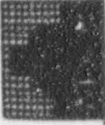
157



Test 212.1

$a, b$

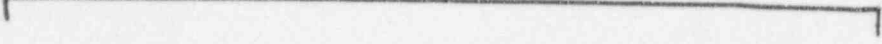
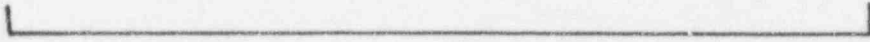
$a, b$



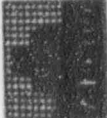
Test 212.1

$a, b$

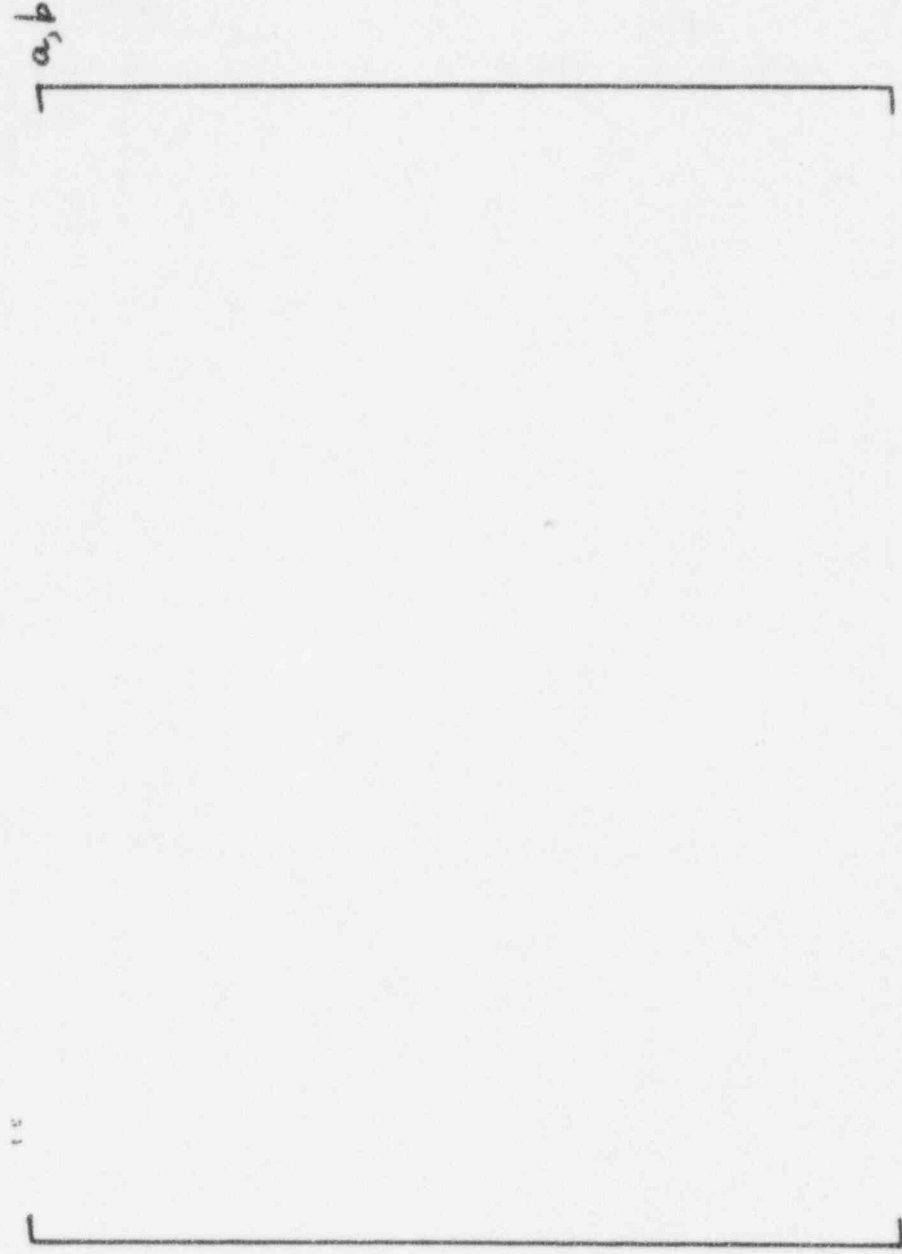
$a, b$



159

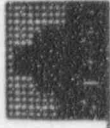


Test 212.1

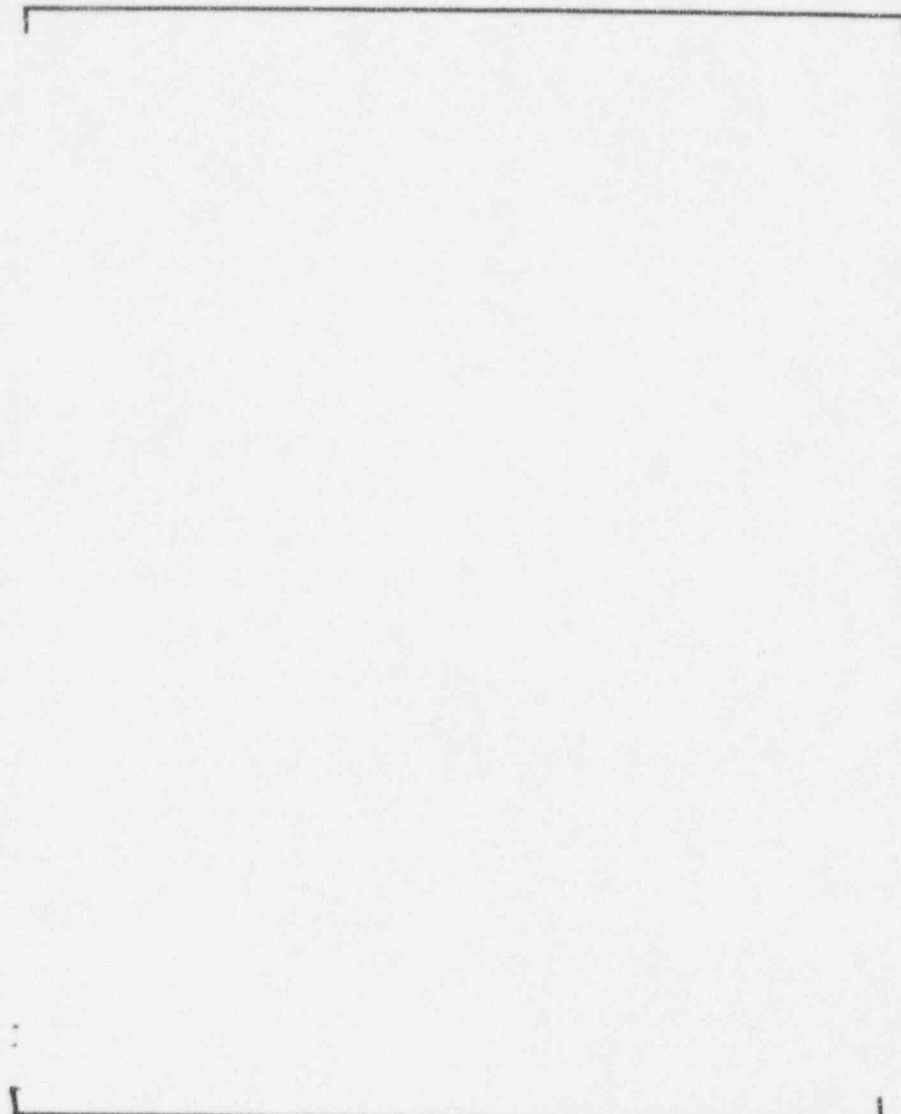


160

Test 212.1



a, b



161

Test 212.1



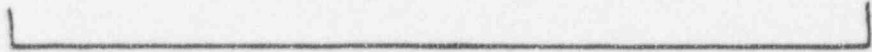
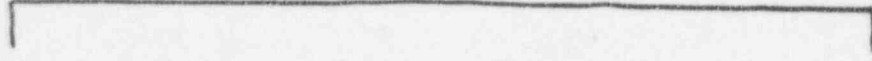
162

Test 212.1



14.4.08

a,b



163

Test 212.1



4,

[

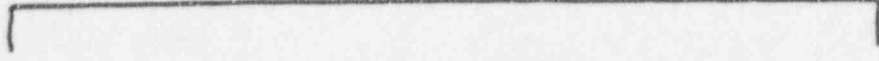
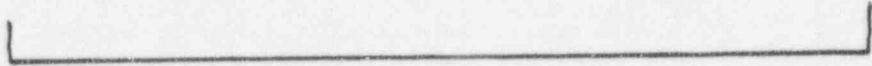
a,b  
]



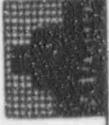
Test 212.1

1111

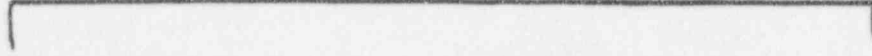
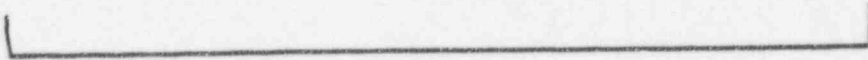
ap



Tes. 212.1



ab

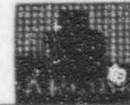


166

Page 73

## Test 212.1

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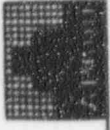


- Vessel pressure overpredicted by 6% at steady state.
- Condensation and evaporation are underpredicted by less than 4% at steady state.
- The velocity predictions along the wall are too high. The predicted velocities are 5-8 ft./s. The measurements show the velocities are [1-3]ft./s along the vessel wall.
- The model is calculating over-mixing of the noncondensables in the vessel.
- The predicted vessel fluid temperatures are too cool above the steam source and too hot below the steam source.

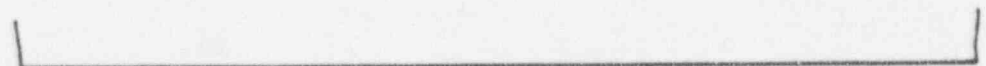
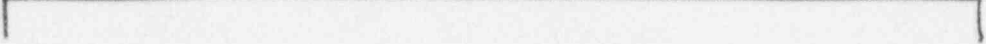
## Test 212.1

- Sensitivity Studies on Base Case:
  - Increase external heat and mass transfer
  - Increase internal heat and mass transfer
  - Turn off forced-convection component inside vessel so free-convection component is used for heat and mass transfer

Test 212.1

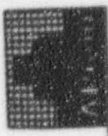


a,b



169

Test 212.1

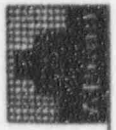


a,b

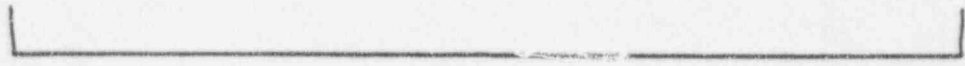
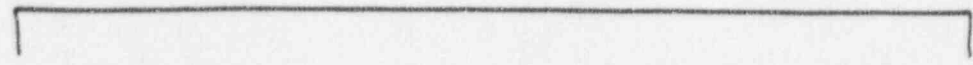


176

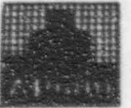
Test 212.1



a,b



171



- Sensitivity Study Results on Base Case:
  - Increasing the external heat and mass transfer by 30% decreased the predicted pressure by 1-2%
  - Increasing the internal heat and mass transfer by 30% decreased the predicted pressure by ~10%
  - Using only the free-convection component for heat and mass transfer inside the vessel increased the predicted pressure by ~13%
  - Internal mass transfer is limiting for this test



## Data Evaluation Summary

- Test Characteristics
- Observations
- Steam Flow Measurements



## Test 222.1

---

### Test Characteristics

- Maximum flow of 5.5 lb/s for ~ 20 seconds, reduce flow to 3 lb/s for ~ 45 seconds, reduce flow a third time and come to steady state
- Forced convection in the air annulus



**Test 222.1**

**Observations**

- **Boundary Conditions**
- **Exterior Water Coverage**
- **Noncondensable Axial Distribution in Vessel**
- **Vessel Wall Axial Temperatures**
- **Temperature Difference Through Vessel Wall**
- **Vessel Internal Rake Temperatures**
- **Internal Velocity Meters**

Test 222.1



[

] ab

176

Test 222.1



ab

[

177

Test 222.1



a.b

**Steam Line Temperature, Test 222.1**

178

Test 222.1



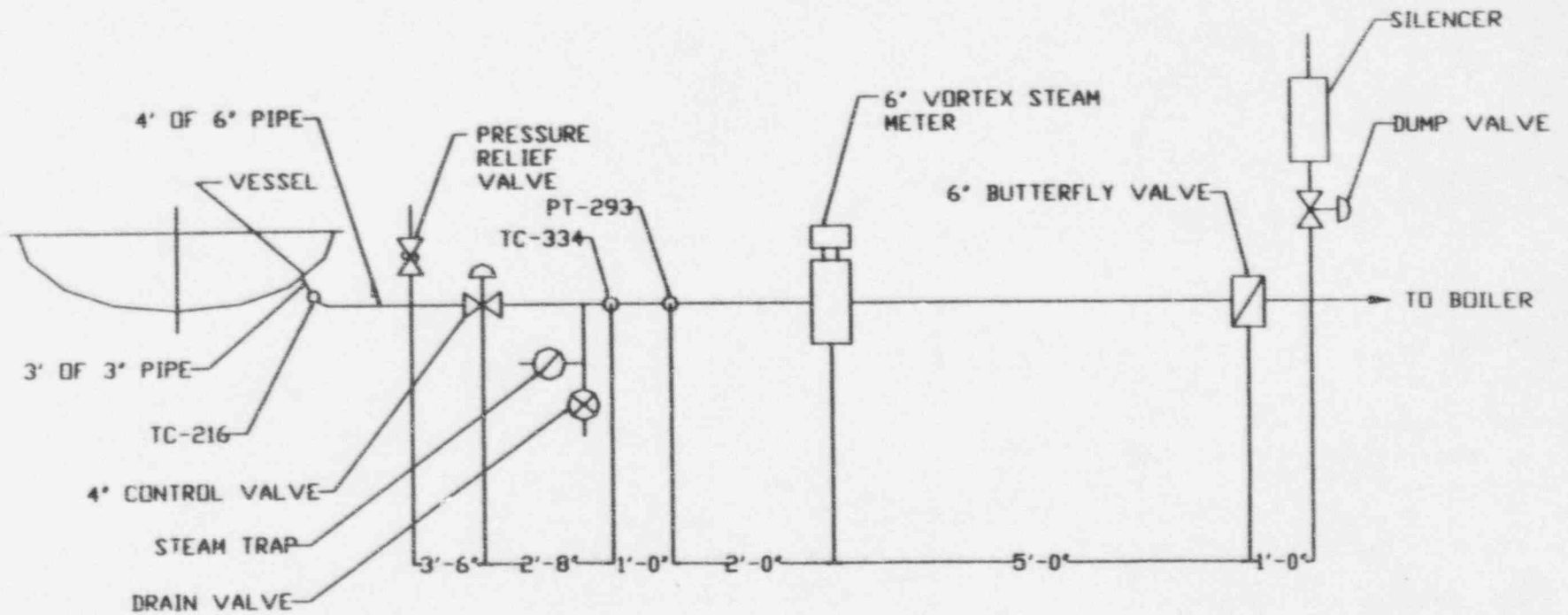
a,b



**Steam Inlet Temperature, Test 222.1**

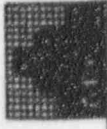
177

# Test 222.1



High Capacity Steam Line Schematic

180



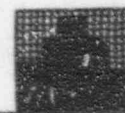
Test 222.1

a,b

**Vessel and Steam Line Pressure Test, 222.1**



181

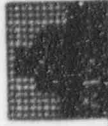


**PCS Water Temperature, Test 222.1**

a,b

182

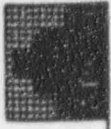
Test 222.1



a,b

**PCS Water Flow, Test 222.1**

183

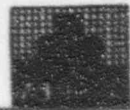


Test 222.1

a,b

**Ambient Temperature, Test 222.1**

184



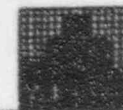
**External Air Exit Velocity, Test 222.1**

ab

185

## Test 222.1

---



### Exterior Water Coverage

- Initially 100% wet
- At steady state 92% wet

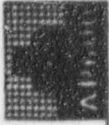
## Test 222.1

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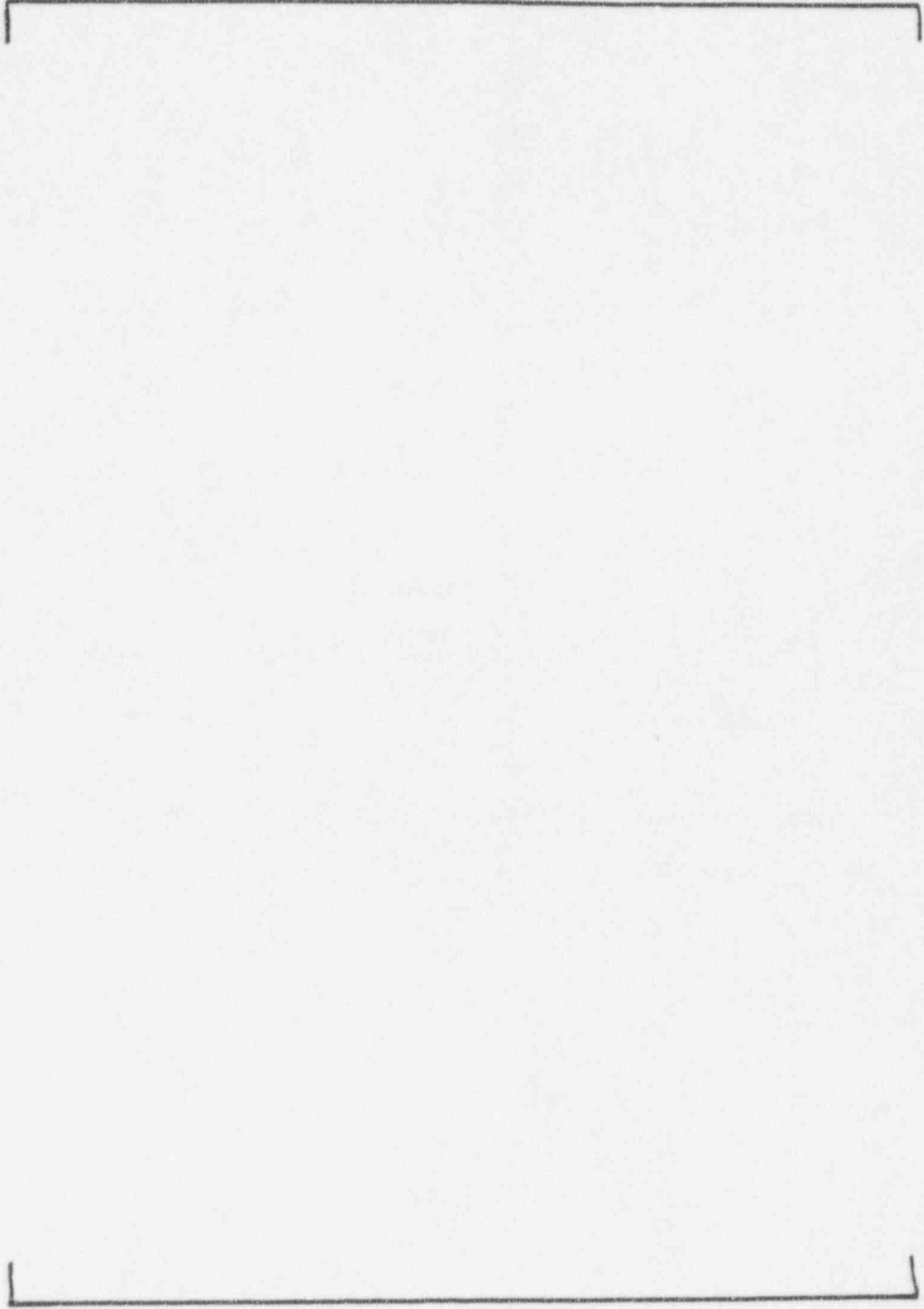
### Noncondensable Axial Distribution in Vessel

- Measurements were taken at the Dome, and elevations A, E, and F



Test 222.1

0.0



Noncondensable Concentrations Test 222.1, Run RC061

188

## Test 222.1

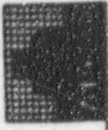
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### Axial Vessel Wall Temperatures

- Vessel Fluid Temperatures (1" away from vessel wall)
- Vessel Internal Wall Temperatures

Test 222.1



a,b

*Inside Vessel Fluid Temperatures*  
Test 222.1, Run RC061

190

Test 222.1



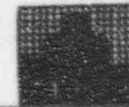
*Inside Vessel Wall Temperatures*  
*Test 222.1, Run RC061*

a,b

191

## Test 222.1

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### Temperature Difference Through Vessel Wall

- Shown at the LST characteristic elevations
- Shown for a point in time for the steady state

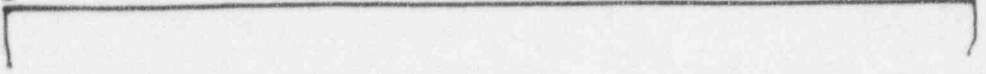
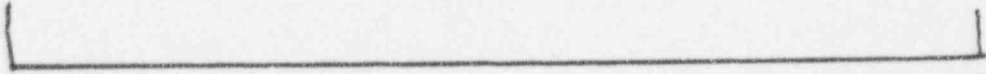
192

Test 222.1



a,b

**Dome Radius 21, TEST 222.1**  
**Between 2 J-tube Rings**

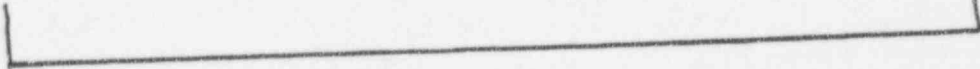


173

Test 222.1



a,b



**Dome Radius 42, TEST 222.1**



194



Test 222.1

a,b

Dome Radius 63, TEST 222.1

195  
12

[

Test 222.1



Dome Radius 84, TEST 222.1

a.b

196

Test 222.1



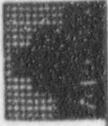
a,b



PCS Water Coverage, Test 222.1

197

Test 222.1



ab

Elevation A, TEST 222.1

198

5



Test 222.1



Elevation C, TEST 222.1

a,b

200  
17

Test 222.1



**Elevation D, TEST 222.1**

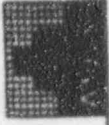
a,b

201

08

u.11538w-3

Test 222.1



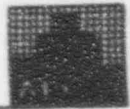
a,b

**Elevation E, TEST 222.1**

202

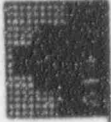
## Test 222.1

---



### Internal Vessel Rake Temperatures

- Shown at the LST characteristic elevations
- Shown for a point in time from the steady-state

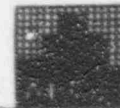


Test 222.1

a,b

TEST 222.1, Time 13.1097 hrs

204



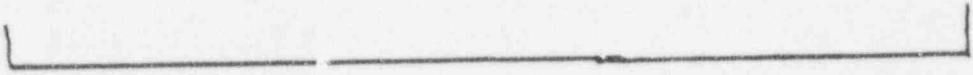
## Velocity Meters

- Dome - 42" - 345° - 1.5", D-180° - 2", and E-30° - 2" anemometers read average velocities of 0.5 - 0.6 ft./s
- A-90° - 1.5" anemometer read an average velocity of 1 ft./s
- Dome - 42" - 165° - 1.5" anemometer has either failed or the velocity is below the sensor threshold



Test 222.1

a,b



206

## Test 222.1

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### Observations

- Internal velocity meters along the wall indicated the following:
  - at locations D0-345°, D-180°, and E-30°, average velocity is 0.5-0.6 ft./s
  - at location A-90°, average velocity is 1 <sup>ft</sup>/~~lb~~/s
- Vessel is air rich below steam injection
- Temperature difference across the vessel wall is fairly uniform as a function of azimuthal position, except where the vessel exterior is dry
- Vessel rake temperatures show that the internal temperature increases over the steam injection point

207

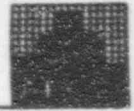


## Steam Flow Measurements

- Vortex meter consistently performs at 8-12% lower than indicated by the condensate over the steady-state period. Therefore, the vortex meter is used for the time dependent flow rate and the condensate measurement is used for the steady state.
- The vortex meter's operating range is from 5.9 to 0.45 lb/s, however at the end of the blowdown, the flow meter measures the flow rate to be as low as 0.03 lb/s. For over two minutes at the end of the blowdown, the meter is below its operating range.
- The steam line pressure is not measured at the vessel inlet, however it is measured upstream. The pressure drop through the line can be calculated so that the inlet steam pressure may be input into the code.

Test 222.1

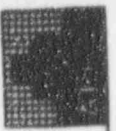
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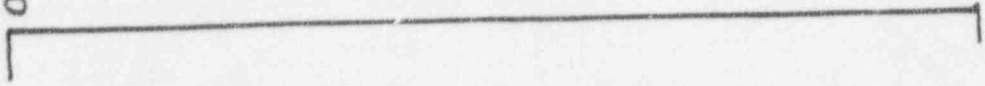
## Lumped Parameter WGOTHIC Code Comparisons

209

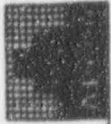
Test 222.1



a,b



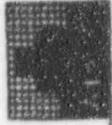
210



Test 222.1

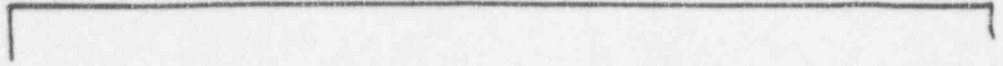


211



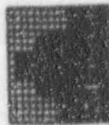
Test 222.1

a.b

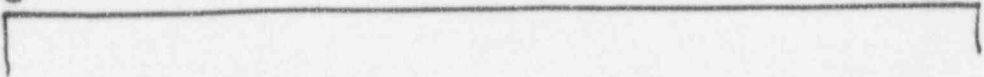


2/2

Test 222.1



a,b



213



Test 222.1



Average Condensate Flow Rate (lb/s) Steady-State Period

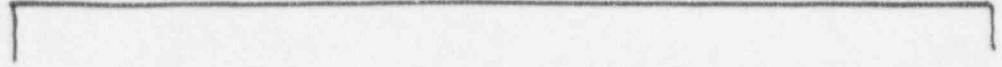
[

] ab

Test 222.1



ap



215

Test 222.1

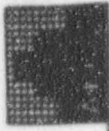


Average Evaporation Rate (lb/s) Steady-State Period

[

] ab

216



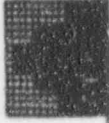
Test 222.1

a,b

217

Page 124

Test 222.1



pb

218

Page 125

12

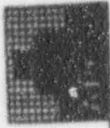
Test 222.1



a.p

219

Test 222.1



a,b

220

Page 127

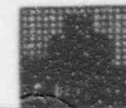


### Conclusions for Lumped Parameter

- Vessel pressure overpredicted by 6% at steady state and for peak pressure.
- Vessel pressure underpredicted by 18% at dip after blowdown. However, the inlet steam vortex meter is reading significantly below (in some instants by a factor of 10) its operating range. The steam flow rate is believed to be higher than indicated by vortex meter.
- Condensation and evaporation are underpredicted by less than 6%.
- The velocity predictions along the wall are too high. The average predicted velocity is 10 ft./s. The measurements show the velocities are ~ 1 ft./s along the vessel wall.
- The model is calculating over-mixing of the noncondensables in the vessel.

## Subdivided WGOTHIC Model

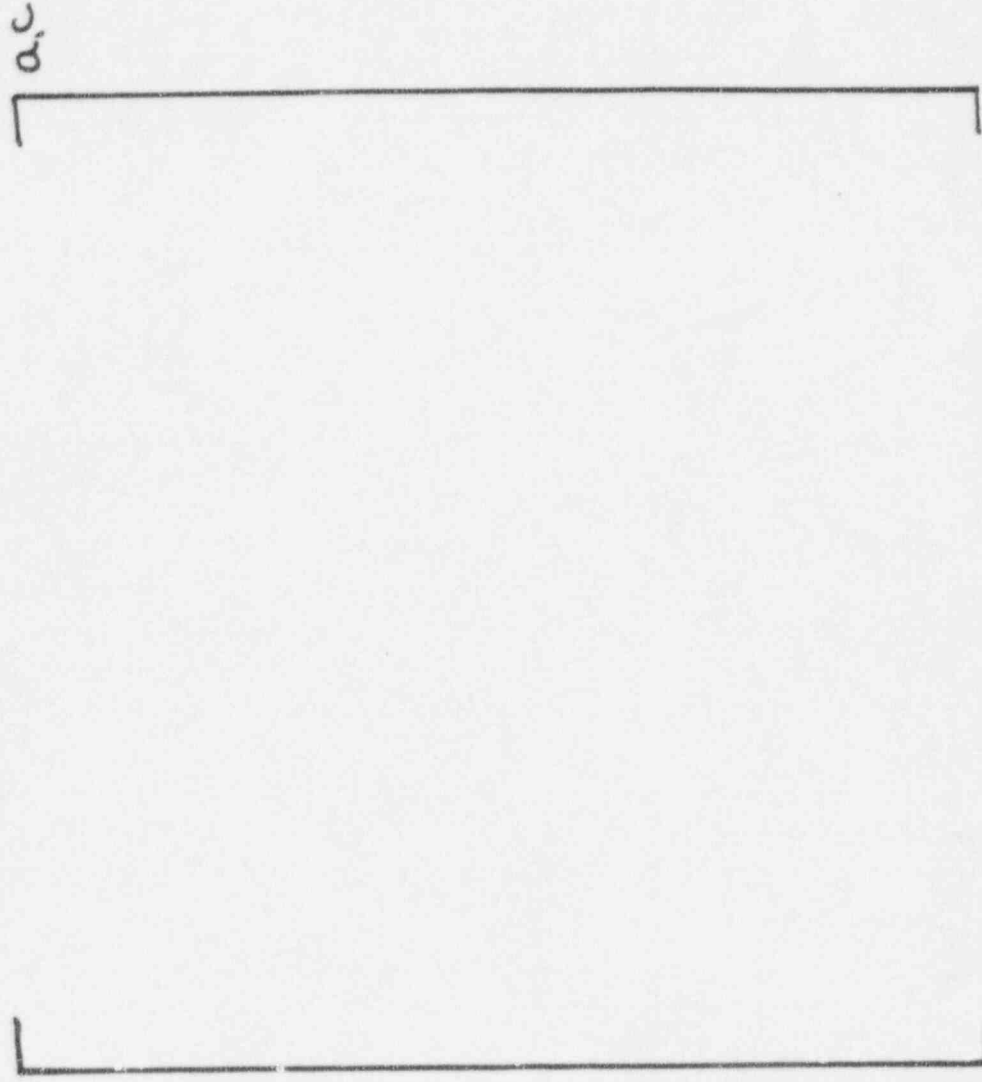
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- Noding of LST Model
  
- Test 212.1A
  - Base Case
  
  - Sensitivity to explore mixing effects

222

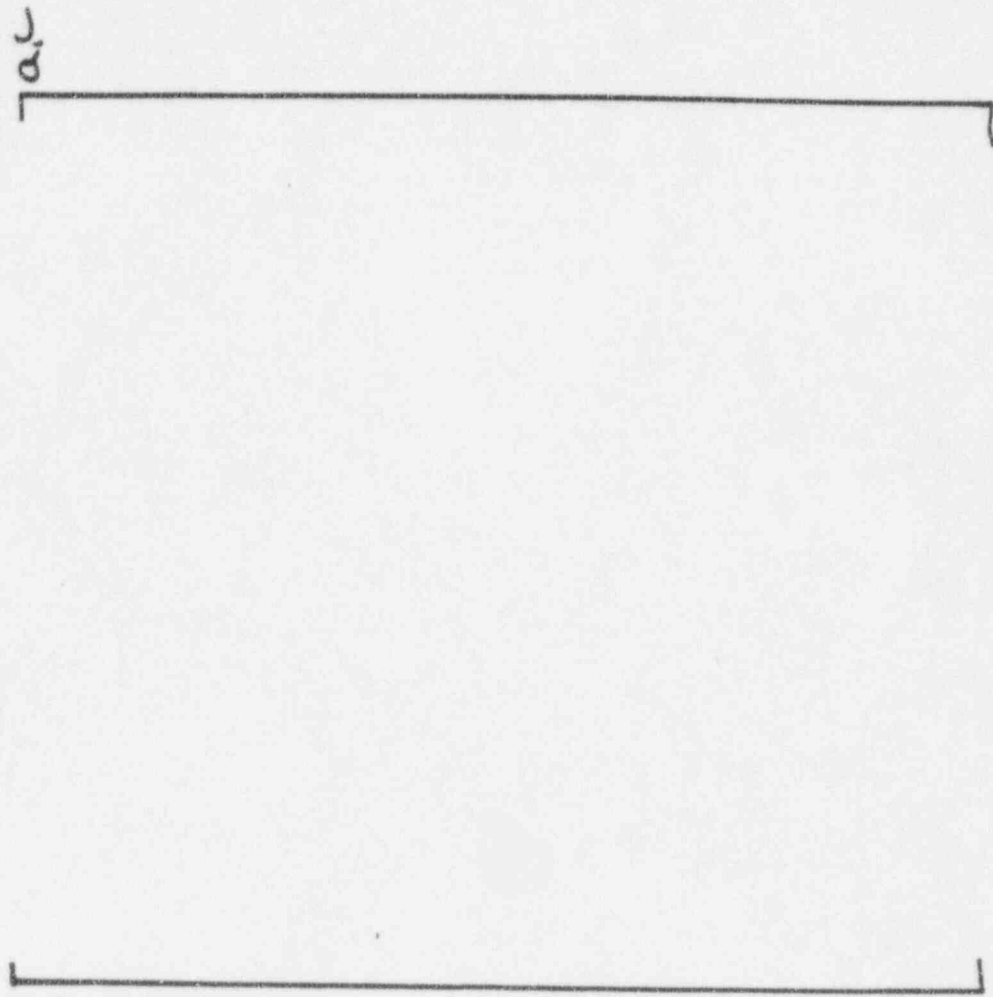
# Subdivided WGOTHIC Model



Noding Diagram of Subdivided LST

223

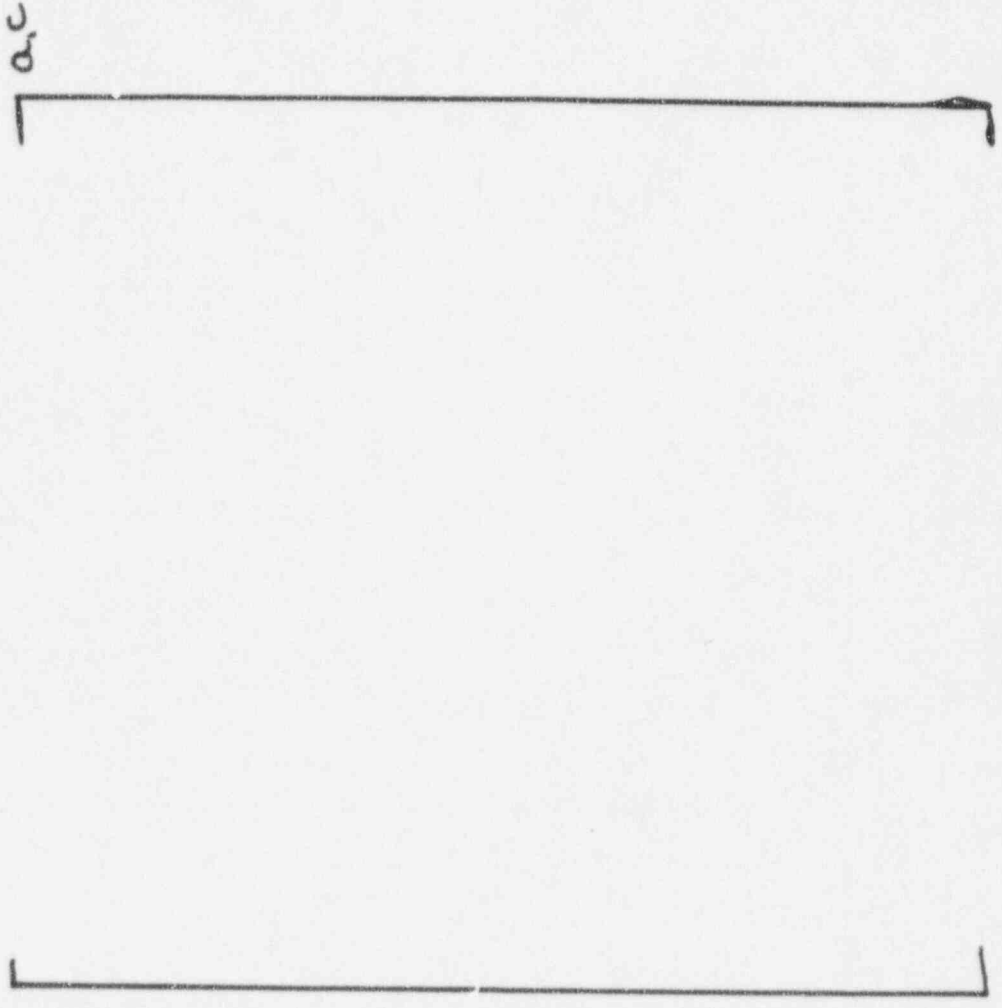
# Subdivided WGOTHIC Model



Subdivided Noding Above Operating Deck

224

# Subdivided WGOTHIC Model



Subdivided Noding Below Operating Deck

Subdivided WGOTHIC Model

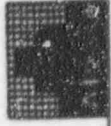


ab

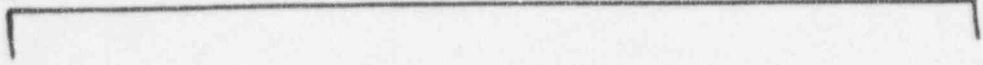


226

# Subdivided WGOTHIC Model

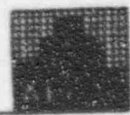


a,b



227

Subdivided WGOTHIC Model



*External Excess Water vs. Time  
Measured and Predicted*

a, b

822

# Subdivided WGOTHIC Model

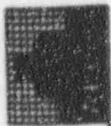


a,b

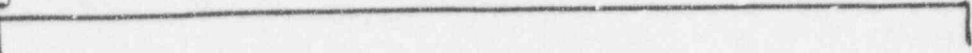


229

# Subdivided WGOTHIC Model

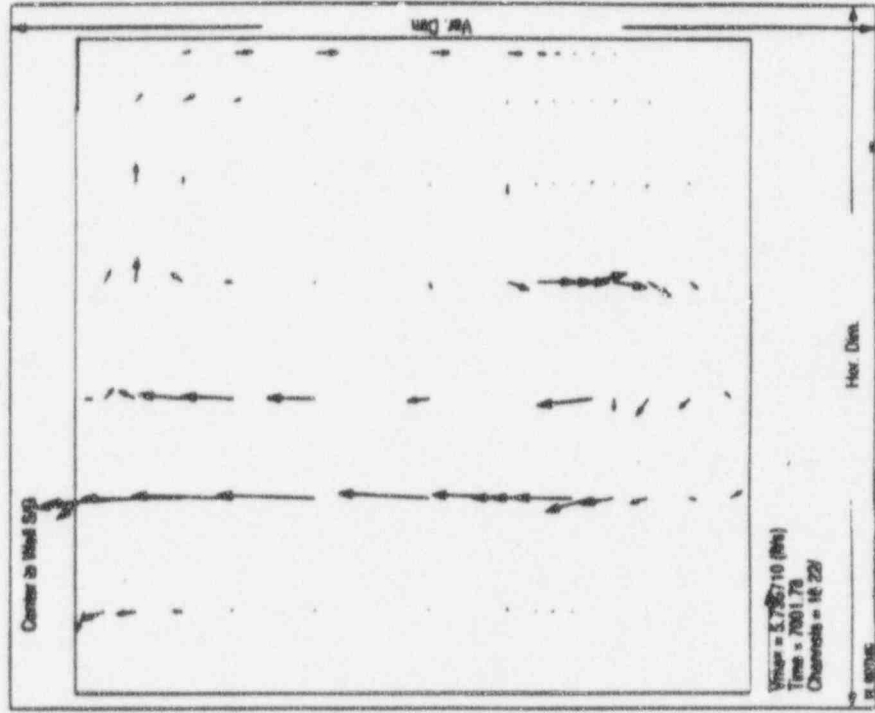


a,b



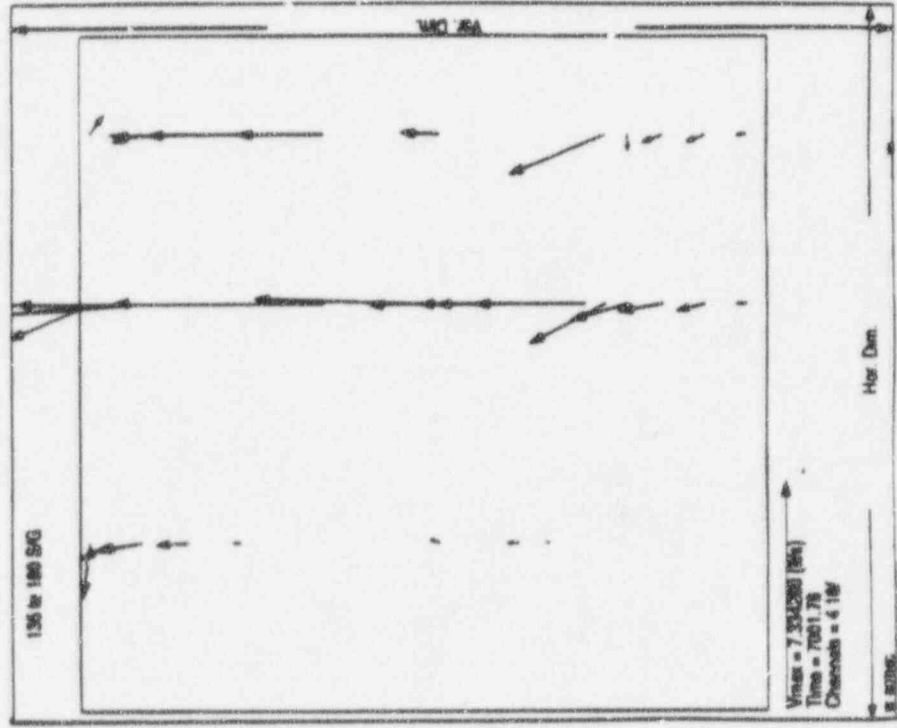
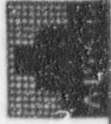
230

# Subdivided WGOTHIC Model



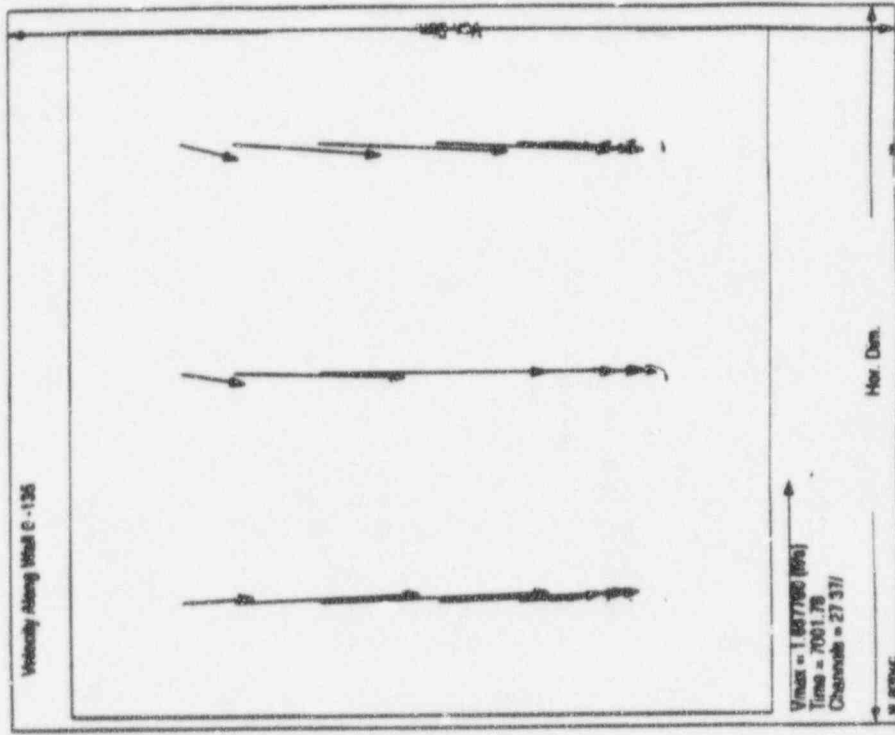
23/

# Subdivided WGOTHIC Model



232

# Subdivided WGOTHIC Model



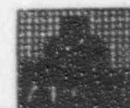


## Subdivided WGCT Model

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- Subdivided Model Results:
  - Subdivided model was consistent with the measured wall velocities of 1-3 ft./s.
  - Subdivided model illustrated the effect of large-scale circulation on long-term vessel pressure prediction.



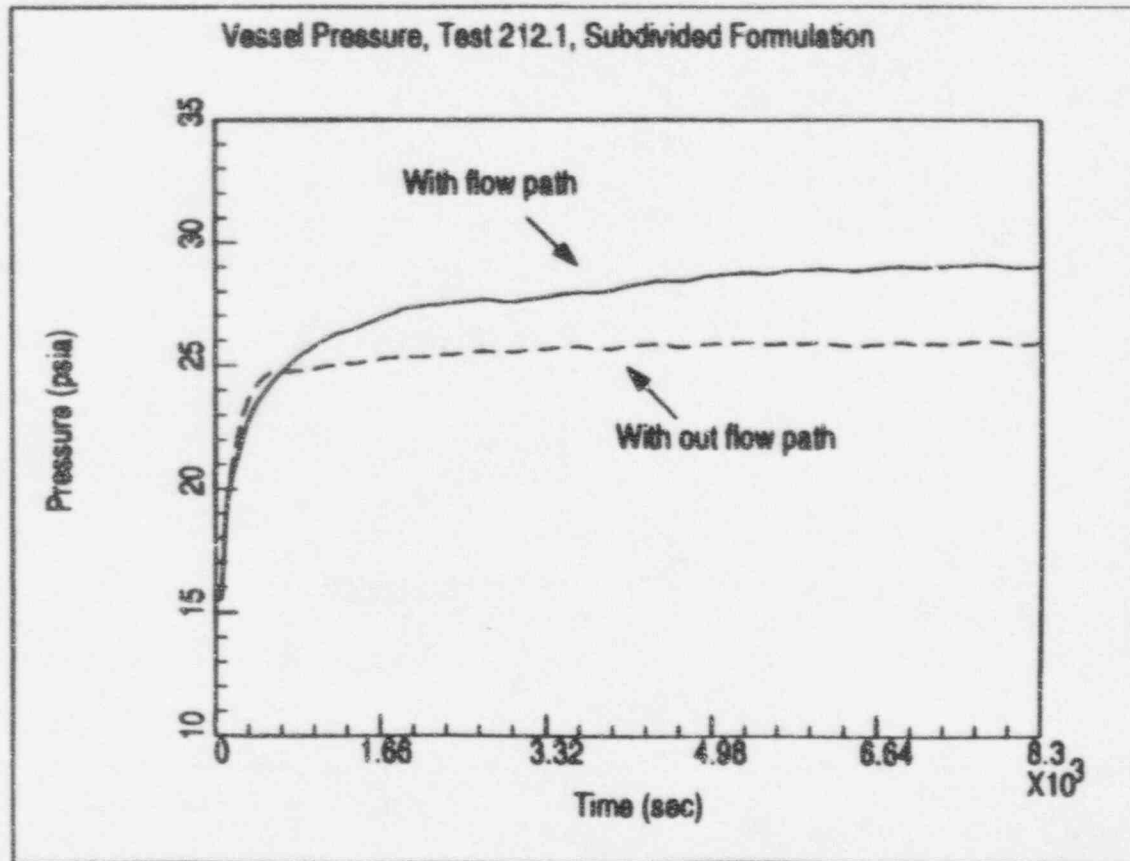
## Subdivided WGOTHIC Model

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- Exploring Mixing Effects with Subdivided Model
- To address non-prototypicality identified in scaling, a flowpath was added between the steam generator and dead-ended compartment in the LST

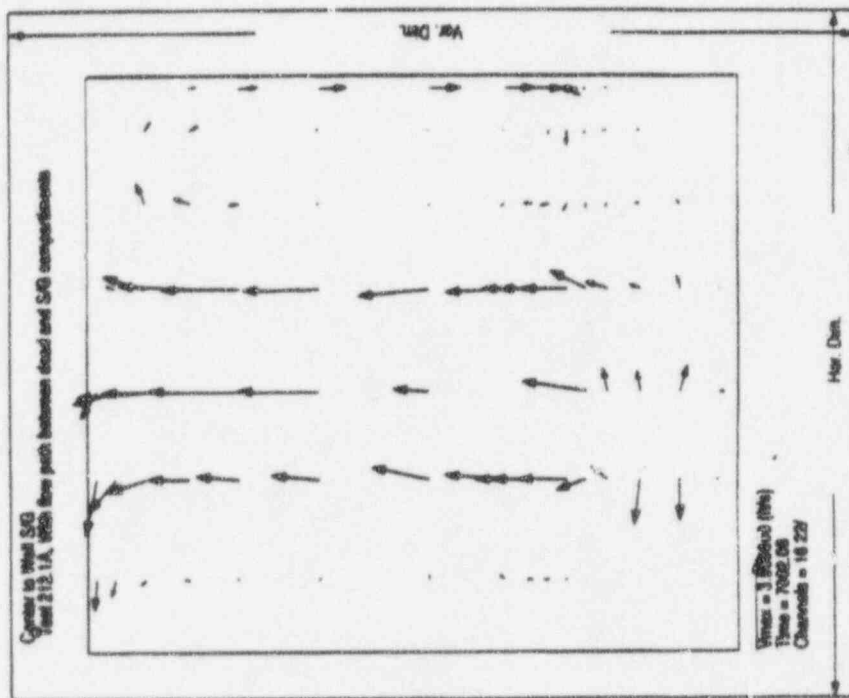
236

# Subdivided WGOTHIC Model



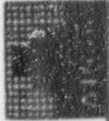
237

# Subdivided W\_GOTHIC Model

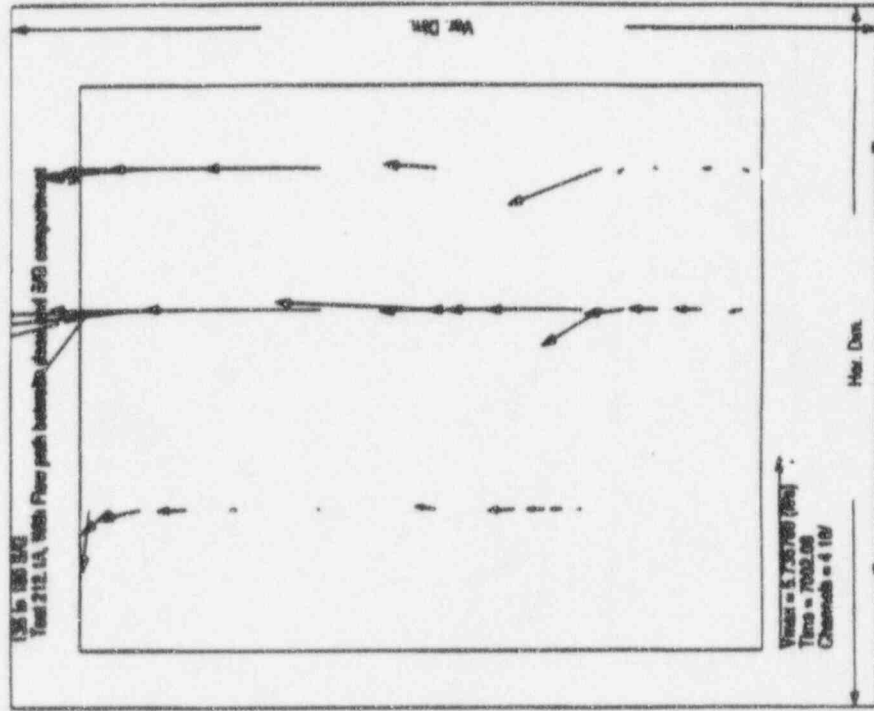


7

238

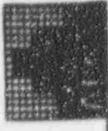


# Subdivided WGOTHIC Model

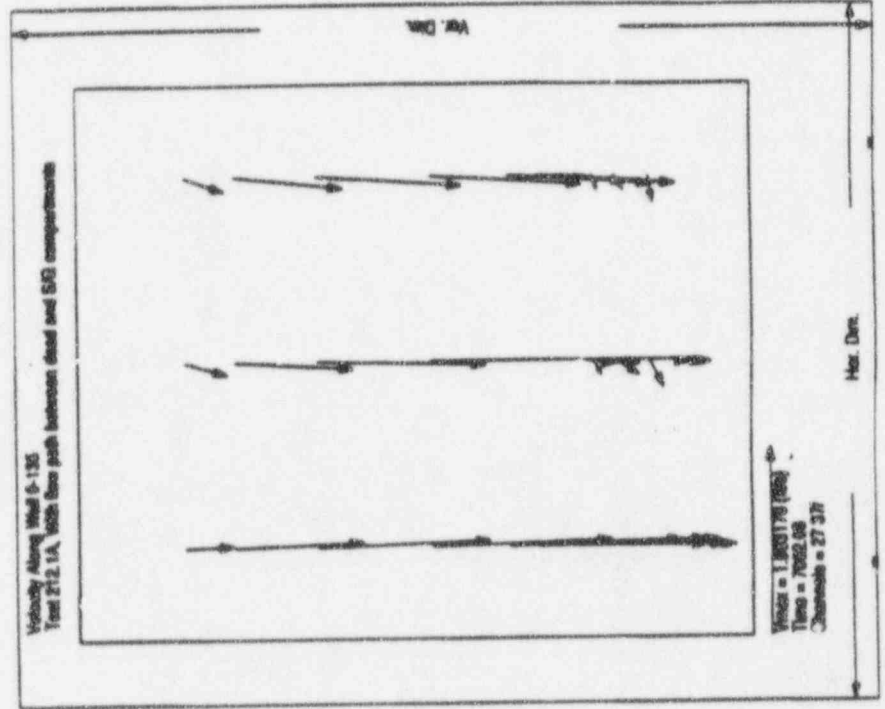


239



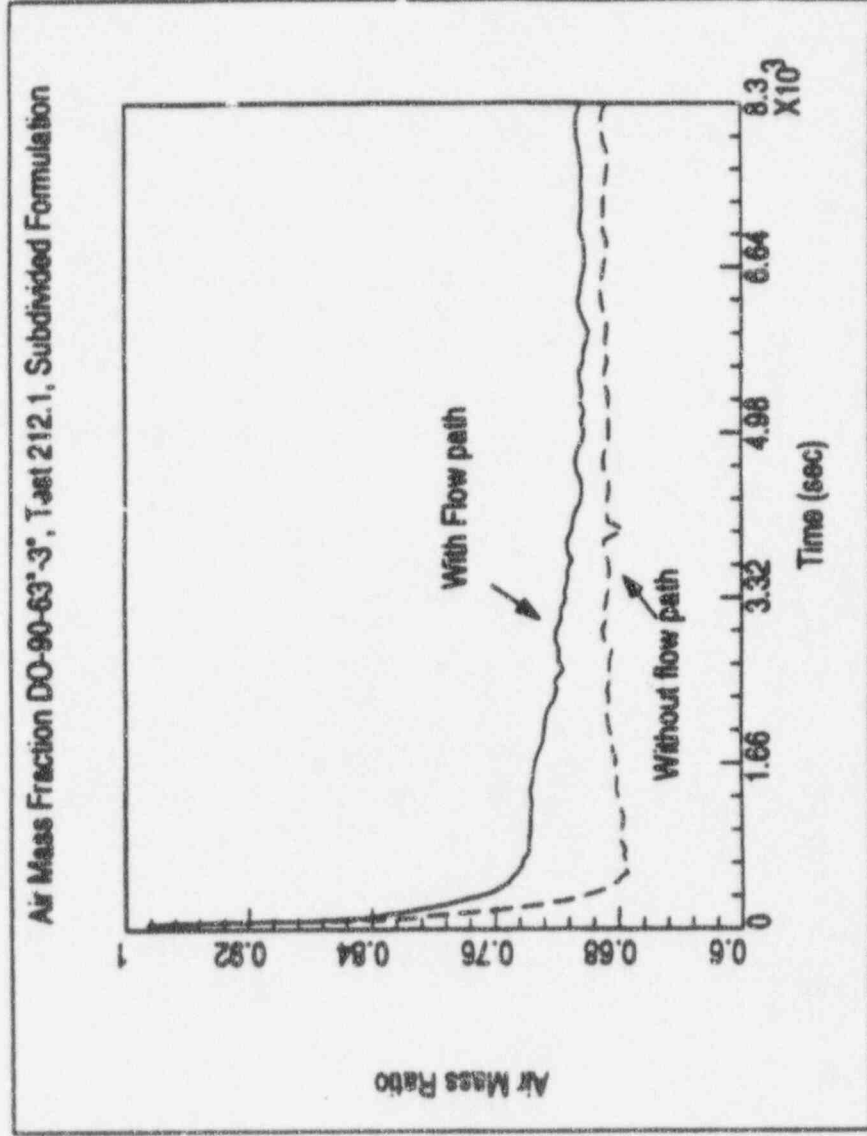


# Subdivided WGOTHIC Model



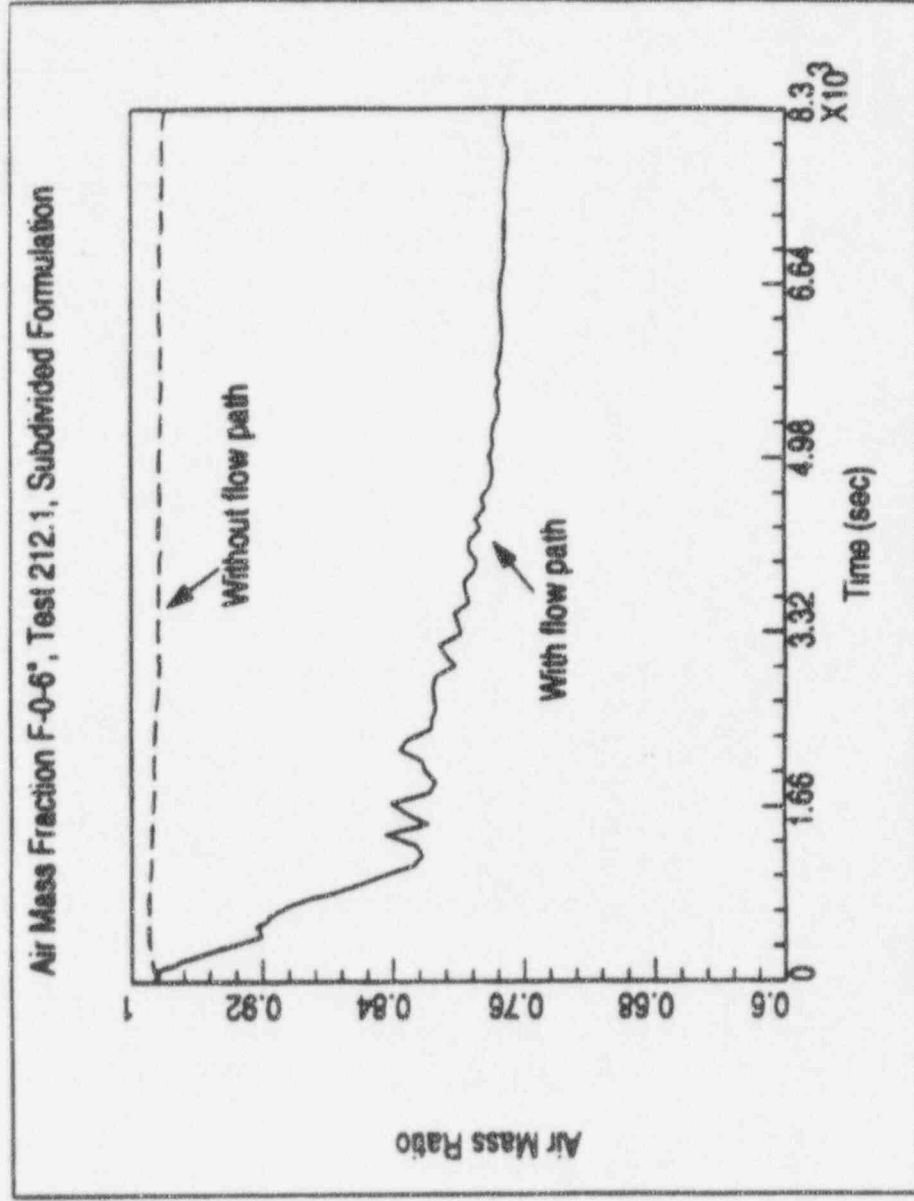
241

# Subdivided WGOTHIC Model

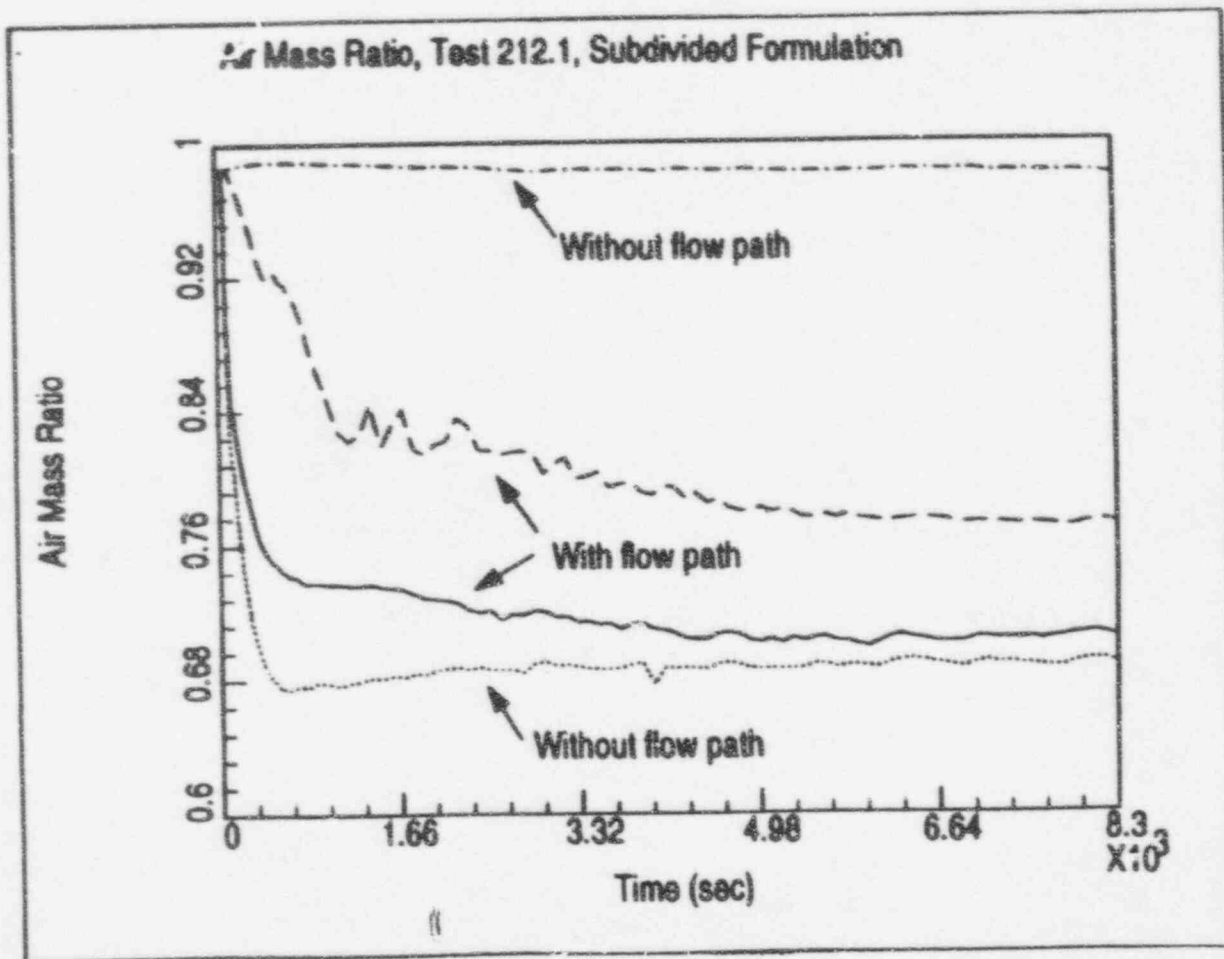


242

# Subdivided WGOthic Model



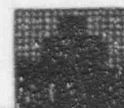
# Subdivided WGOTHIC Model



244

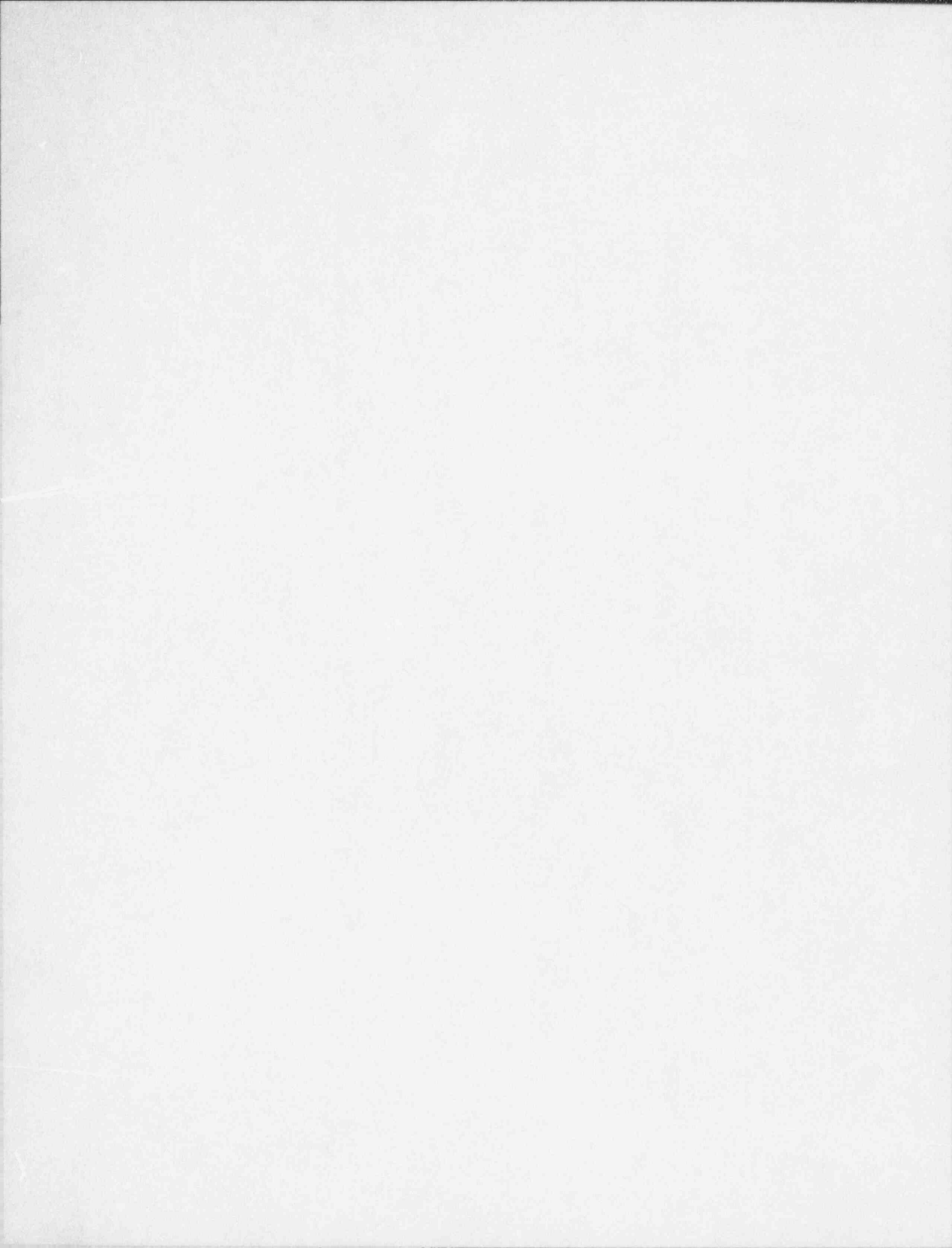
## Subdivided WGOTHIC Model

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Opening a path between the steam generator compartment and the dead-ended compartment:

- Modeled a configuration more like the plant
- Mixed noncondensables from below the deck
- Increased the subdivided base case predicted pressure by 13%



## Blind Test 220.1

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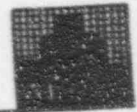


### Agenda

- Objective & Process
- Test Configuration

## Blind Test 220.1

---



### Objective

- The blind test:
  - provides confidence to the LST model
  - shows that the modeling approach does not require test specific tuning
- The input deck has been submitted. Changes to the deck will be identified.
- Input deck is robust enough to model the Phase 2/3 tests (boundary and initial conditions will be changed for each test).



## Blind Test 220.1

---

### Process

- Model 2 large-scale tests to check out model
  - Test 212.1 (3 steady-state vessel pressures)
  - Test 222.1 (blowdown)
  
- Blind test prediction
  
- Continue with the remaining specified LST to cover range of important parameters

## Blind Test 220.1

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### Test Configuration

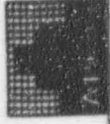
- Rented boiler configuration
- Steam Flow
  - 1) The steam line pressure is not measured at the vessel inlet, however it is measured upstream. The pressure drop through the line can be calculated so that the inlet steam pressure may be input into the code.
  - 2) Maximum steam flow of 5.9 lb/s for ~20 s, reduce flow to ~0.5 lb/s, and come to steady state.
  - 3) Shortly after the end of the blowdown the vortex meter measures the flow rate to be as low as 0.09 lb/s. This is below the meter's operating range of 5.9 lb/s to 0.45 lb/s.



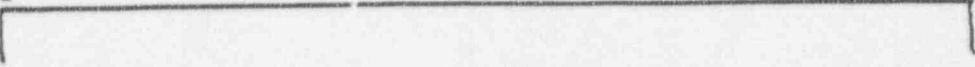
Description (Cont.)

- 4) It was recommended (p. 4-142, WCAP-14135) that 15% be added to the vortex steam flow meter at steady-state because the vortex meter was consistently reading lower than the condensate flow measurements.
- Forced convection in the air annulus.
  - Initial vessel pressure was not provided. A separate request is being made from test engineering.

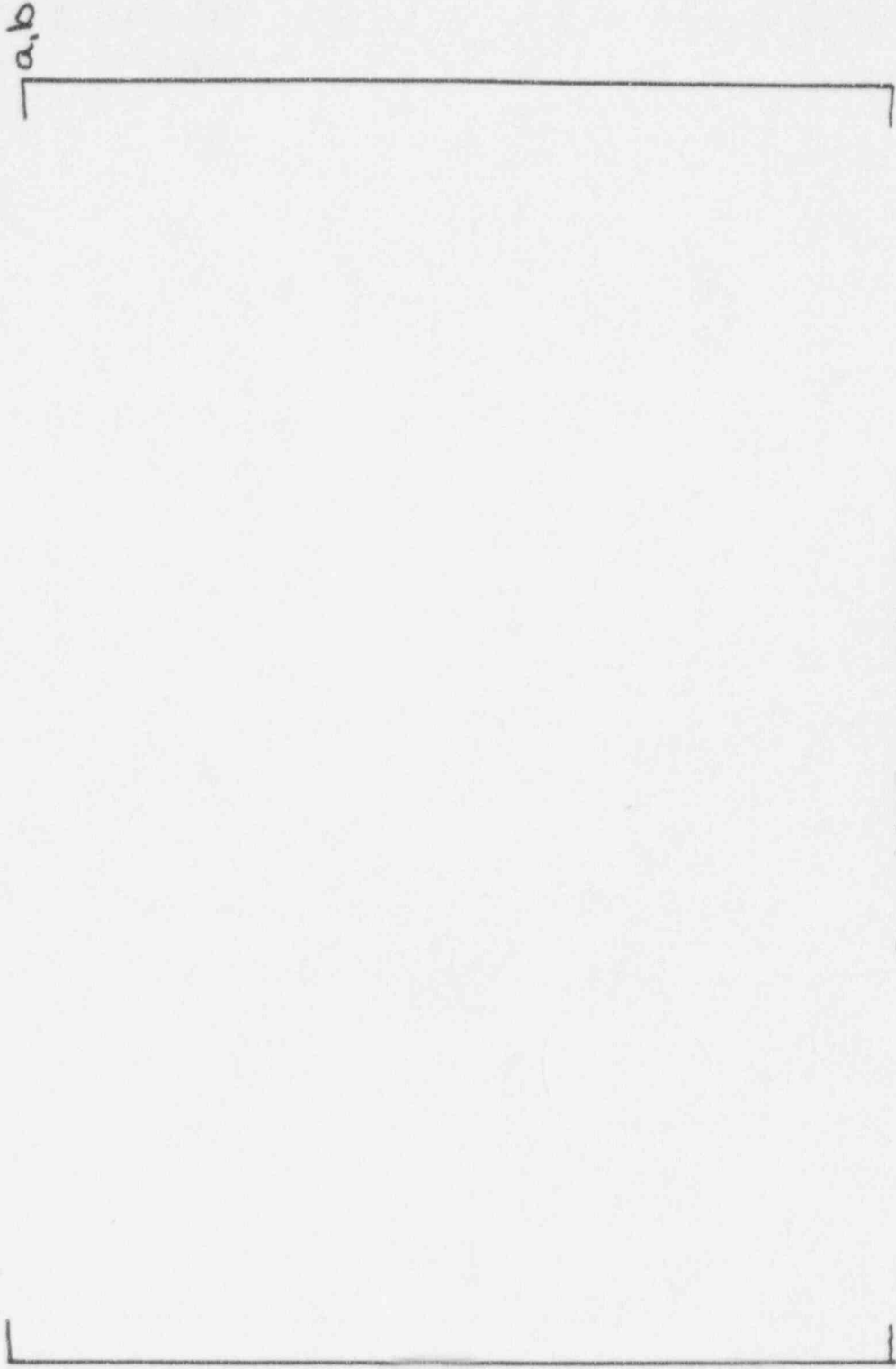
Blind Test 220.1



ab



# Blind Test 220.1



Steam Inlet Test 220.1, Run RC062

253



Blind Test 220.1

a,b



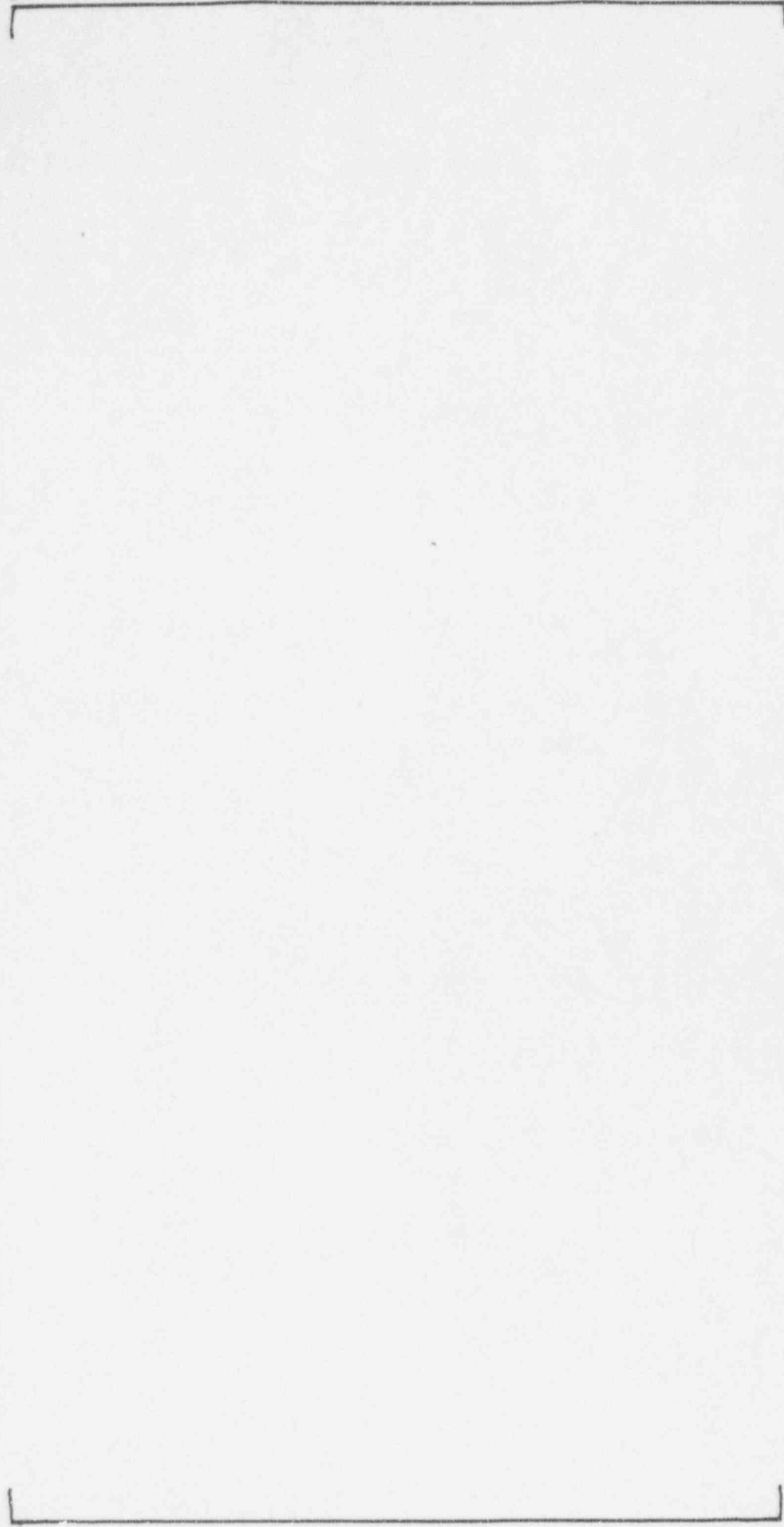
Steam Inlet Temperatures Test 220.1, Run RC 62

254

Blind Test 220.1



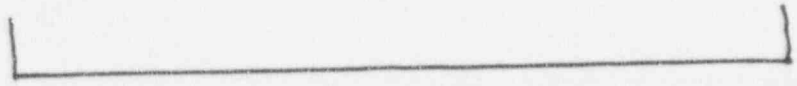
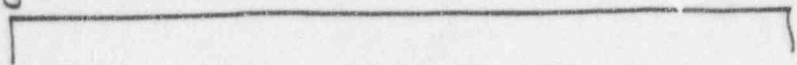
a,b



Blind Test 220.1



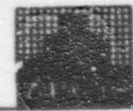
a.b



256

1 230 102

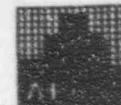
# Draft PCS Open Items List



Seq. No.	Alt. No.	Subject: Description: Status:	Closeout Resolution
* 9.		<p><b>Subject:</b> Maximize the value of the entire LST test database.</p> <p><b>Description:</b> Westinghouse to demonstrate maximum appropriate use of LST database.</p> <p>a. (NRC) 7/27/94 Milk the data. Have Tills type analysis performed on break orientation Phase 3 runs.</p> <p>b. (NRC) 7/27/94 For each test that was run, what was the purpose... and what did they learn?</p> <p>c. (NRC) 7/27/94 Milk data. Look at mixing. How important. If mixing is always good under all conditions, and if mixing good in plant... in much better situation.</p> <p>d. (NRC) 7/28/94 NRC is concerned because Westinghouse is not planning computer runs of 9 of 12 phase 2 tests, and 6 of 7 phase 3 tests. NRC needs Westinghouse rationale for doing so little computational analysis of the tests. Westinghouse did promise to look at the data from all tests, and to try to milk the data. Westinghouse only plans to run for phase 2/3 LST: 2 tests in <u>WGOTHIC</u> finite difference mode, 3 tests (one of which is the blind test) in lumped parameter mode. For the Phase 1 (or baseline LST tests)... Westinghouse ran 5 or 6 out of the 17 tests using <u>WGOTHIC</u> 1.0. Some of those tests were re-run using <u>WGOTHIC</u> 1.2 for the June 30, 1994 report.</p> <p>e. (NRC) 7/28/94 NRC concern is that the previous testing letter credited the closure of questions on non-condensibles affecting heat transfer, and questions on break release location and orientation based upon an understanding that Westinghouse would analyze the phase 3 LST tests that dealt with these items. This item may need to be revisited now that Westinghouse has stated that they will only analyze one of the seven phase 3 tests. NRC needs Westinghouse rationale for this approach.</p> <p>f. (NRC) 7/26/94 We will see no <u>WGOTHIC</u> calcs for phase 3 other than 1 (1 out of 7)</p>	<p>Strategy for usage of test data to validate methodology presented on 11/16/94</p>

257

# Draft PCS Open Items List



Seq. No.	Alt. No.	Subject: Description: Status:	Closeout Resolution
• 2.	952.101	Subject: PCS Interior Velocities Description: Westinghouse to submit calculations of PCS interior velocities using the <u>W</u> GOthic code Status: a. (NRC) 7/27/94 Two effects: Mixed Convection / velocities... vs. stratification and over-mixing. Two effects, how does one sort them out.	NRC Presentation 1/16/94

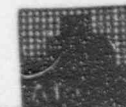
# Draft PCS Open Items List



Seq. No.	Alt. No.	Subject: Description: Status:	Closeout Resolution
* 6.		<p>Subject: WGOthic calculation comparisons to tests</p> <p>Description: Westinghouse to provide additional information on <u>WGOthic</u> calculation comparisons to tests</p> <p>Status:</p> <ul style="list-style-type: none"> <li>a. (NRC) 7/27/94 Vessel inside surface temperatures ... underpredicted on sidewalls, and overpredicted on the dome. Why?</li> <li>b. (NRC) 7/27/94 Evaporation on shell... 821 (measured) vs. 990 (calculated). Overpredicting evaporation. Nonconservative calc. Very poor experimental data in this regard due to time lags and fluctuations in city water supply.</li> <li>c. (NRC) 7/27/94 20% error in evaporation rate... vs. temperatures. NRC recommends engineering evaluation of impact independent of code analysis.</li> <li>d. (NRC) 7/27/94 Tuning of hydraulic parameter, and tuning of heat flux in the dome to match or compensate for no subcooling model [in original SSAR Rev. 0 models].</li> <li>c. (NRC) 7/27/94 Figure 22 (7/27/94 presentation) Westinghouse blames Uchida as overconservative on heat sinks... therefore their predicted pressures are slightly high. Yet Westinghouse offers no "proof" that Uchida is the cause (such as a computer run in which a best estimate heat transfer correlation is used instead of Uchida).</li> <li>d. (NRC) 7/27/94 Air partial pressure measured vs. predicted... good agreement. Stratification is well predicted it appears. However, NRC would like to have seen a plot of containment atmosphere temperatures along the axis of the containment from the operating deck level to the dome. Also, some representation of the velocity fields calculated by <u>WGOthic</u>.</li> <li>e. (NRC) 7/27/94 Worry that compensating errors may be hidden in global measures such as pressure. The limited wall temperature distributions presented are not overly encouraging since calculations and experiment do not match.</li> <li>f. (NRC) 7/27/94 Stratification changes where the heat transfer takes place.... Redistribution of noncondensibles changes where the heat transfer takes place. Possible competing effects.</li> <li>g. (NRC) 7/28/94 NRC would like to see more 3-D plots; velocity; stratification.</li> </ul>	Information and strategy discussed w/NRC 11/16/94

259

# Draft PCS Open Items List



Seq. No.	Alt. No.	Subject: Description: Status:	Closeout Resolution
* 8.		<p>Subject: Application of <u>W</u>GOTHIC to AP600 for SSAR evaluations</p> <p>Description: Westinghouse to provide bridge from LST to AP600 to justify applications of <u>W</u>GOTHIC.</p> <p>Status:</p> <ul style="list-style-type: none"> <li>a. (NRC) 7/27/94 Suppose excellent finite difference calcs. Westinghouse will calculate same test lumped. Will be differences... Where is the bridge to the AP600. Westinghouse does not plan to run finite difference AP600.</li> <li>b. (NRC) 7/27/94 Poor temperature predictions in wall (presented on 7/27/94). Equipment qualification implies temperatures are important.</li> <li>c. (NRC) 7/28/94 Finite difference... No follow-through to the AP600. The NRC will never see a <u>W</u>GOTHIC finite difference calculation for the AP600. Incomplete package.</li> <li>d. (NRC) 7/28/94 NRC is unsure as to Westinghouse approach after they run finite difference LST and Lumped LST. Where is the bridge to the AP600? Contrast this to Jack Tills' presentation... Tills: Systematic look at the data for a test; physical picture of what happened in the test.</li> </ul>	Information and strategy presented to NRC on 9/27/94 and 11/16/94

260



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PRESENTATION  
TO  
UNITED STATES  
NUCLEAR REGULATORY COMMISSION

AP600 Passive Containment Cooling System (PCS)  
Analysis Program

Pittsburgh, PA

November 17, 1994



## Agenda

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### Day 1

Woodcock	1 hr.	PCS analysis program summary and status
Spencer	4 hrs.	Scaling report <ul style="list-style-type: none"><li>- methodology overview</li><li>- conclusions</li></ul>
Spencer	0.5 hr.	PCS open items relevant to scaling report <ul style="list-style-type: none"><li>- items 1, 3</li></ul>
Kennedy	0.5 hr.	Test analysis and code validation reports <ul style="list-style-type: none"><li>- schedule and outlines</li></ul>
NRC	0.5 hr.	Feedback from previous presentations



## Agenda (Cont.)

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### Day 2

Woodcock	0.5 hr.	Opening remarks
Kennedy	1.5 hrs.	Framework on usage of LST data <ul style="list-style-type: none"><li>- matrix of LSTs</li><li>- status of data reduction</li></ul>
Kennedy	2 hrs.	Test 212.1 <ul style="list-style-type: none"><li>- description of tests and data</li><li>- <u>WGOTHIC</u> lumped parameter results</li></ul>
Kennedy	1.5 hrs.	Test 222.1 <ul style="list-style-type: none"><li>- description of tests and data</li><li>- <u>WGOTHIC</u> lumped parameter results</li></ul>
Kennedy	1 hr.	Subdivided <u>WGOTHIC</u> results
Kennedy	0.5 hr.	Blind test description
NRC	0.5 hr.	Feedback from previous presentations



## Agenda (Cont.)

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### Day 3

Woodcock	0.5 hr.	Opening remarks
NRC	1 hr.	AP600 calculation results
NRC	1 hr.	LST calculation results
Woodcock	2 hrs.	PCS open items review and status
All	1 hr.	Wrap-up and action items
Orr	1 hr.	Discussion of ADS phase A test results



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PCS OPEN ITEMS  
REVIEW AND STATUS

Joel Woodcock  
Principal Engineer

265



## Westinghouse Has Responded to PCS Open Items

- Discussions and submittals have been directed at clarifying and addressing the identified open issues
  - eight phenomenological reports and one supplement have been completed addressing basic PCS phenomena and SSAR model margins
  - preliminary and final PCS scaling reports have been completed
  - WGOTHIC lumped parameter input decks have been provided
  - eleven full days of meetings have been held with the NRC in 1994
- Open items identified to date have been addressed by providing:
  - specific information in reports and meetings
  - plans and schedules for work in progress that provide a path to resolution

266

## PCS Open Item Summary

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1. PCS scaling analysis
2. PCS interior velocities
3. PCS air flow in annulus
4. Validity of cold water distribution tests to predict hot coverage
5. How do water distribution model findings support the DBA analysis
6. WGOTHIC calculations of LST phase 3 tests
7. Bases for heat and mass transfer correlations
8. Application of WGOTHIC to AP600
9. Maximize the value of the entire LST test database
10. Path to resolution for PCS issues
11. WGOTHIC blind test predictions

## Conclusions

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- PCS issues identified to date have been closed or have a defined path to resolution
- Keys to closure of future issues that may arise (DSER, meetings) are:
  - issues that are specific, precise, and well-defined
  - open, focused communication



### Chronology of Events Leading to PCS External Wetting

Activity	$\Delta$ Time (sec)	Time (sec)
Break		0.0
Valve opens (solenoid-actuated, air-operated)	20.0	20.0
Fill pipe to bucket	30.0	50.0
Fill bucket	3.0	53.0
Fill weirs and establish steady coverage	600.0	653.0
Water assumed available for heat removal in evaluation model	-	655.0

Pressure response is not significantly affected by small variations in initiation time due to low post-blowdown pressurization rate

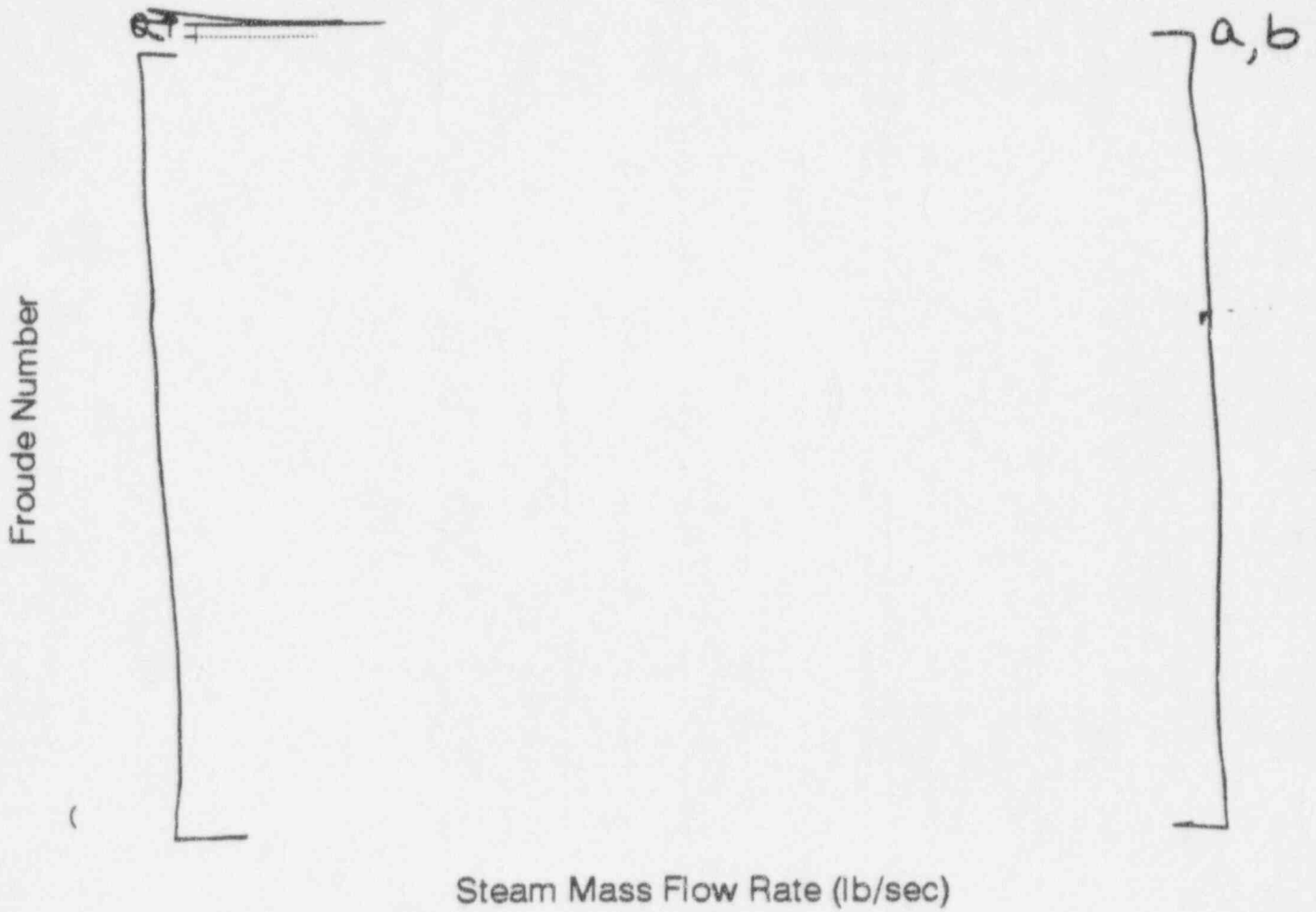
Sensitivities to initiation have been presented

WESTINGHOUSE PROPRIETARY  
CLASS II

PRELIMINARY

270

### Froude Numbers From LST Phase 2



122

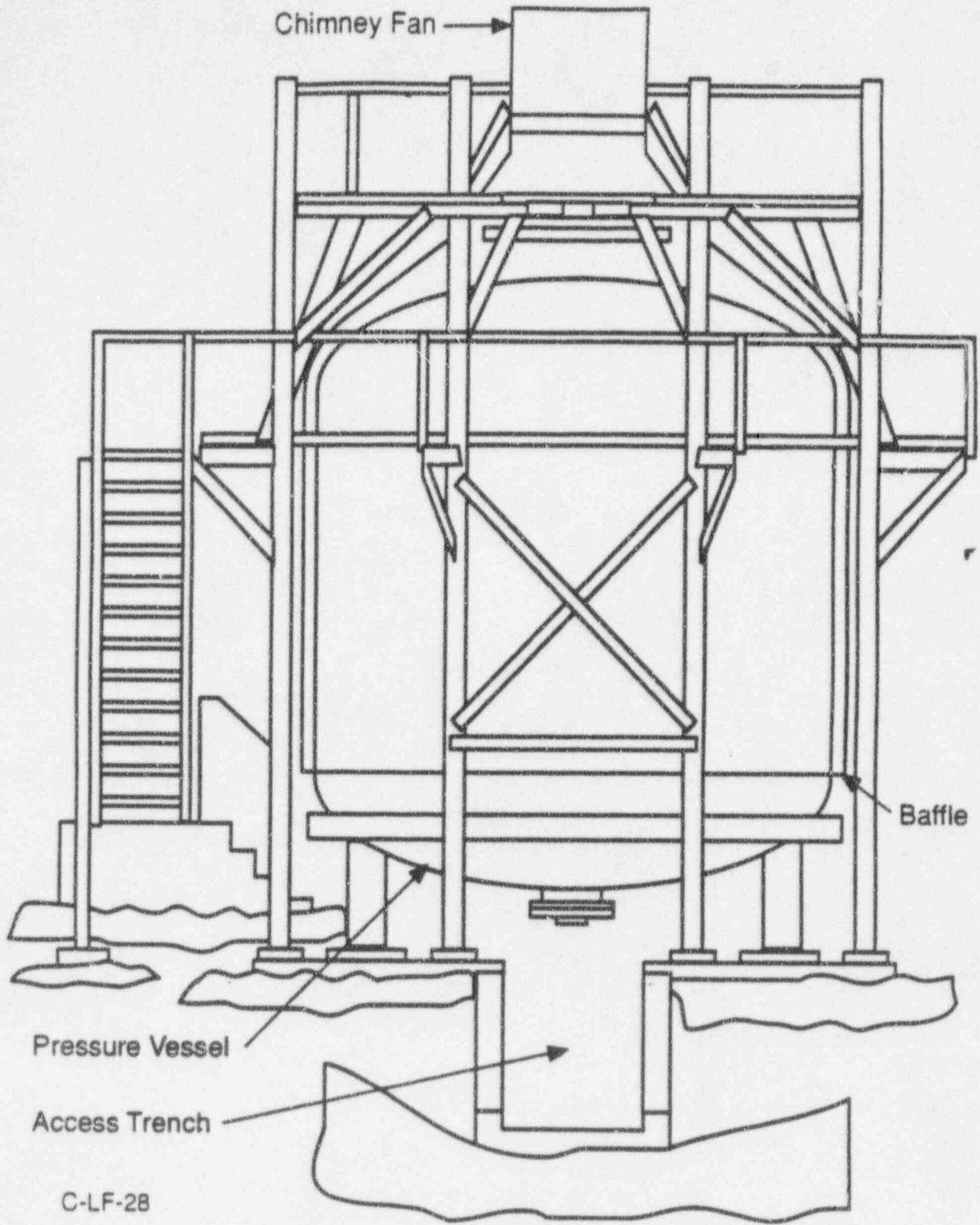


Figure 3-9 Large-Scale PCS Test Facility

272

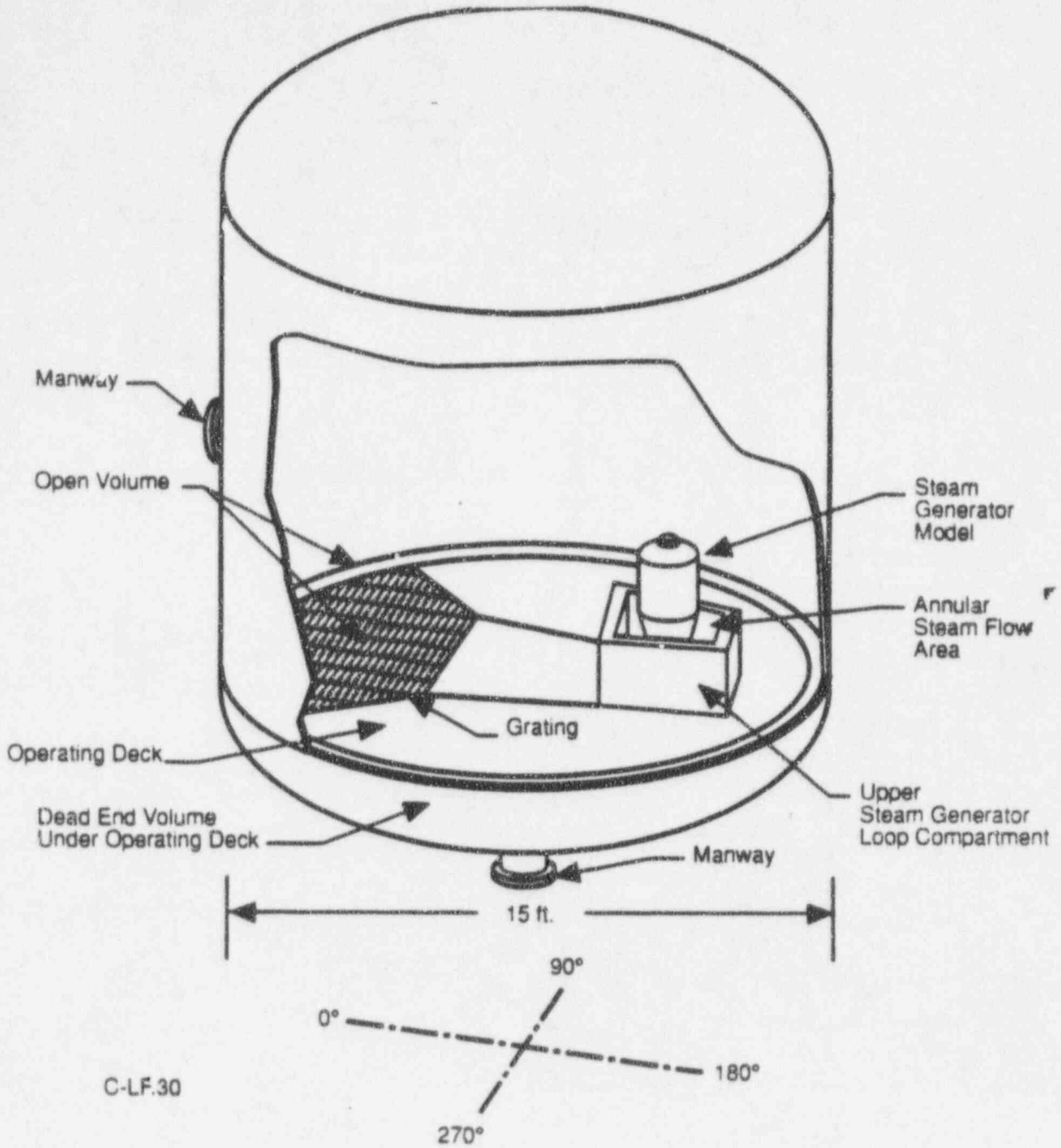
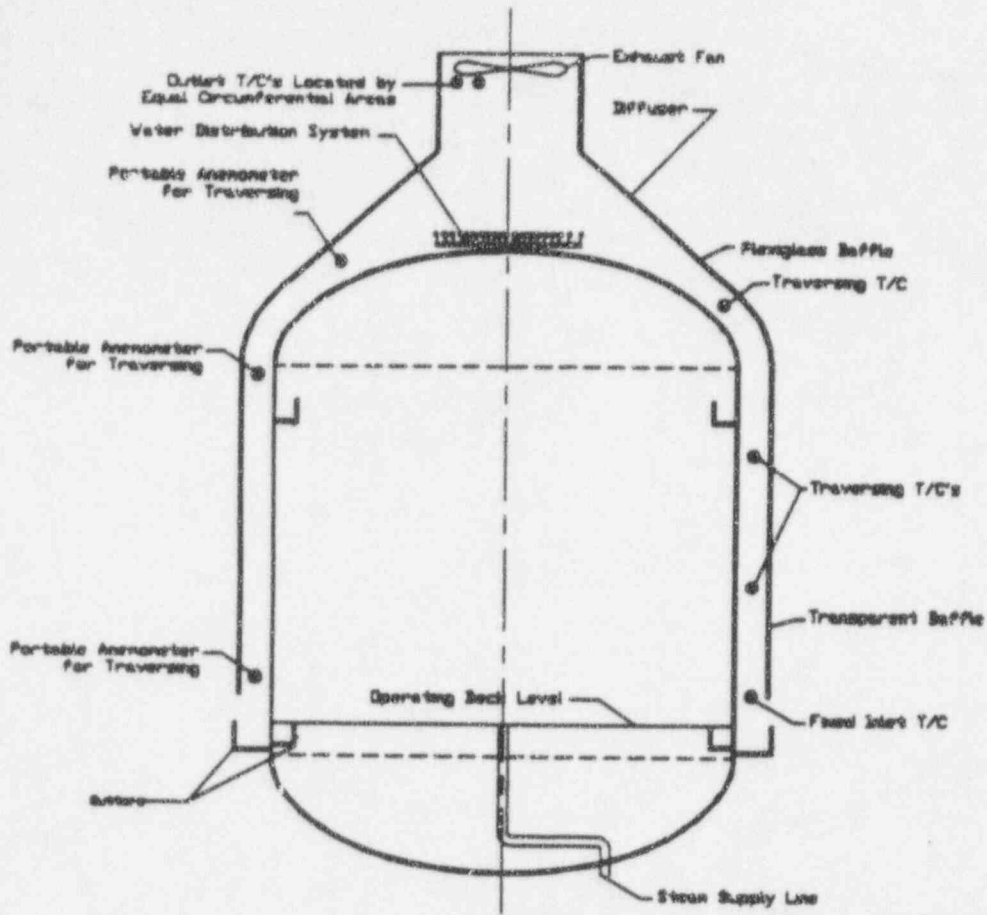
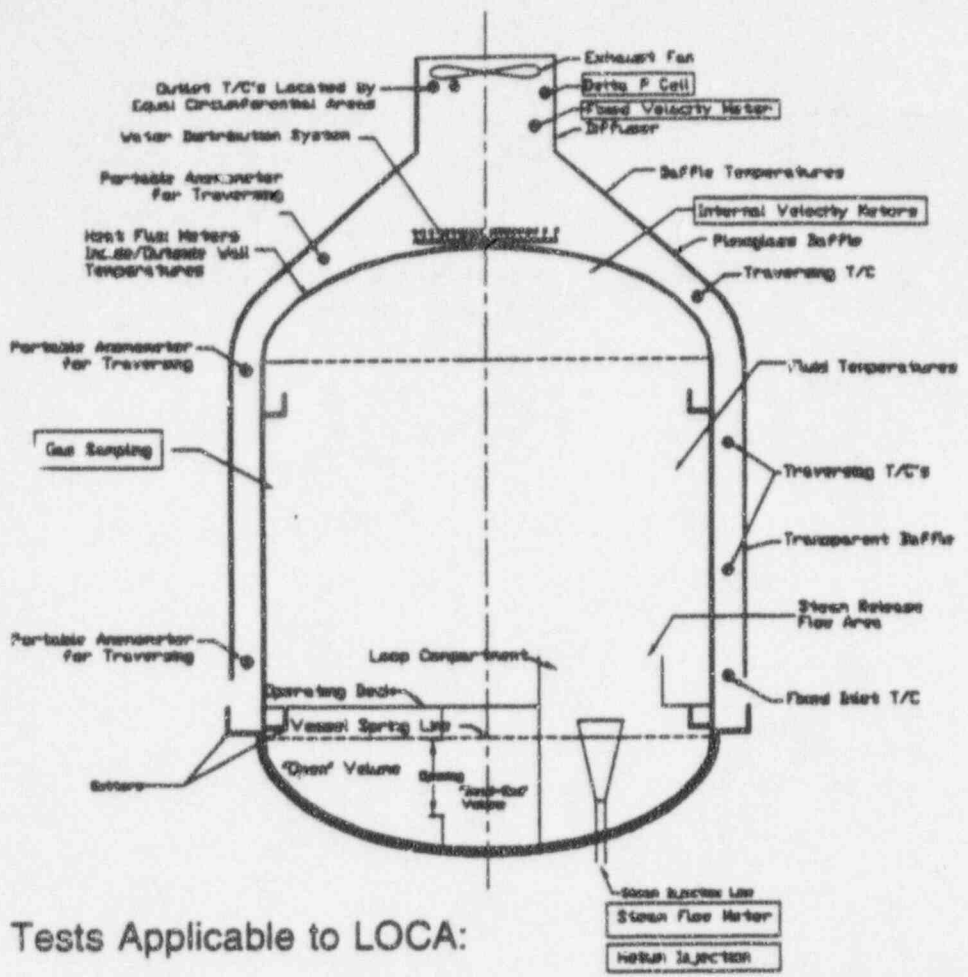


Figure 3-10 Large-Scale PCS Test Facility



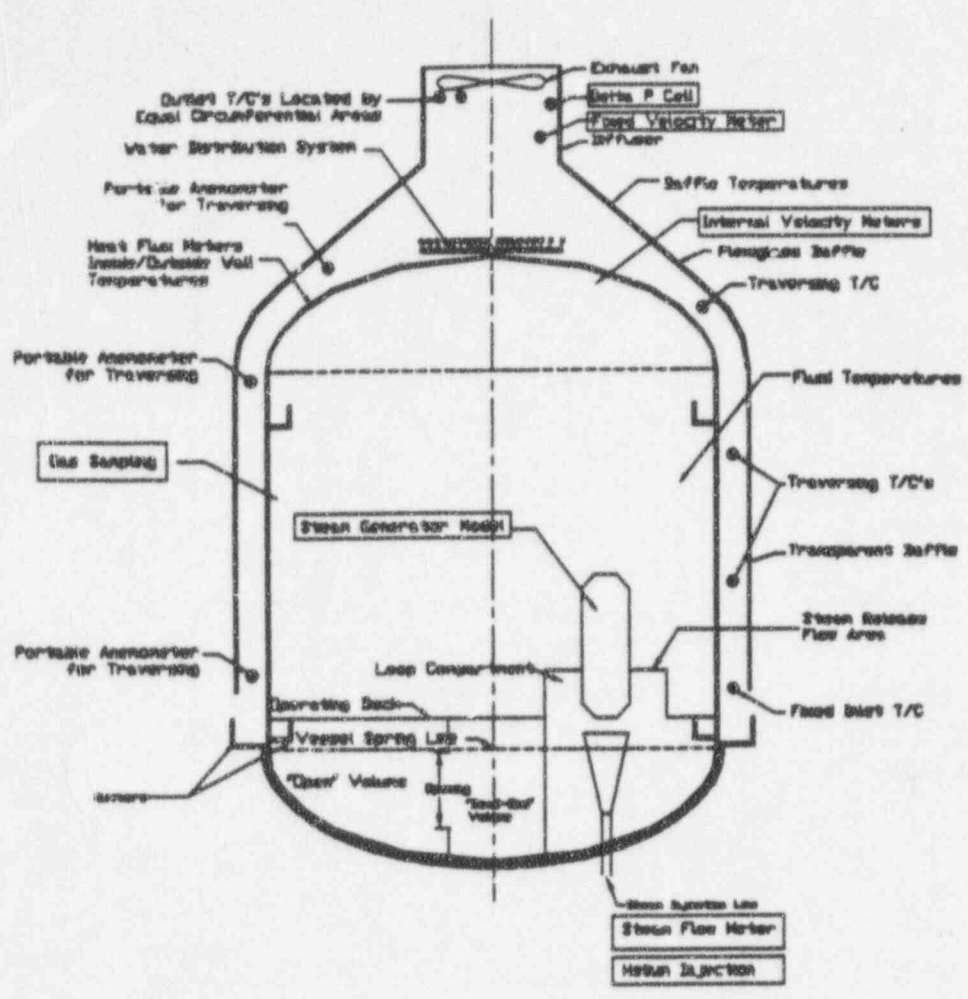
Tests Applicable to SLB:

- Phase 1 (Baseline, used in WCAP Rev. 0)



Tests Applicable to LOCA:

- Phase 2(a)

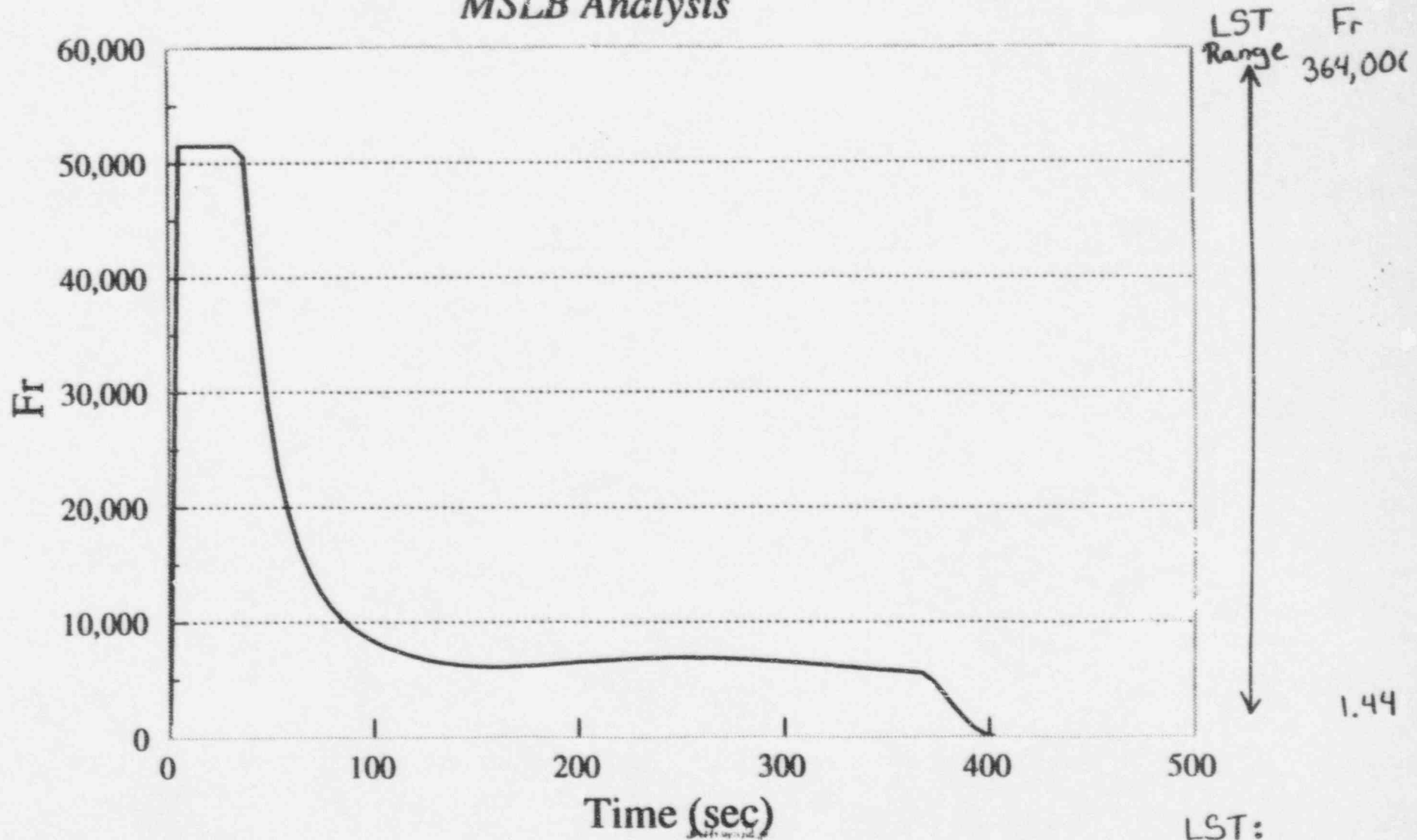


Tests Applicable to LOCA:

- Phase 2(b)
- Phase 3 Unelevated injection



*Froud Number versus Time*  
*MSLB Analysis*



LST:  
Phase 2  
Phase 3 - not  
277 elevati

NRC and NRC Contractor  
Presentation Material

Meeting on AP600  
Passive Containment Cooling System  
Analysis Program

Pages 4, 7-34, 44 not included. Contained information  
Westinghouse considers proprietary.

Enclosure 3

# LST Calculation Status and Results<sup>1</sup>

J. Tills<sup>2</sup>  
Modeling and Analysis Department  
Sandia National Laboratories  
Albuquerque, NM

WEC/NRC Meeting on AP600 PCS Analysis  
Monroeville, Pa  
November 15-17, 1994

*WEC PROPRIETARY INFORMATION ATTACHED*

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<sup>1</sup> This work was supported by the United States Nuclear Regulatory Commission and performed at Sandia National Laboratories.

<sup>2</sup> Jack Tills and Associates, Inc.

# **Presentation Outline**

**Introduction**

**LST Test Matrix for Containment Analysis**

**Analysis of Blowdown Test 222.1 (Phase 3)**

- Test Phenomena Identification
- Test Results
- CONTAIN version 112ad calculations

**Summary of Test 222.1 Analysis**

## **Progress Review for AP600 Related Work**

- ▶ **ALWR Heat and Mass Transfer Improvements (vers. 112ad)**
- ▶ **LST Calculations for Tests 202.3 and 212.1 redone using vers. 112ad**
- ▶ **Test 203.3 completed with wetting sensitivity**
- ▶ **Development of a Revised LST Matrix for Test Analysis**
- ▶ **Blowdown Test 222.1 Analysis completed**

## **Current AP600 Related Work in Progress**

- ▶ **Blowdown Test 221.1**
- ▶ **Updating CONTAIN AP600 Input Deck**
  - **HMT Improvement input**
  - **Pool tracking input**
- ▶ **Pool Tracking Model Checkout**
- ▶ **Hybrid Flow Solver Applied to LST Phase 3 Tests**

## LST Analysis Matrix

Key Phenomena	Model / Input	WEC LST Tests
Film evaporation/condensation	Heat and Mass Transfer (HMT)	202.3, 203.3, 212.1 223.1, 224.1, 224.2
Annulus radiation / partial wetting	Net enclosure - absorption model / film tracking	213.1(stage C), L104.1 (HWRF test)
Transient film cooling	film tracking / radiation	219.1
Natural convection cooling in PCCS	HMT / flow solver (buoyancy and friction terms)	214.1, L104.1
Transient mixing (blowdown)	flow solver / HMT (forced convection (nodalization))	221.1, 222.1
Stratification (stable)	Hybrid flow solver (nodalization)	222.1, 222.2, 202.3

## Summary of CONTAIN Calculation for Test 222.1

- ▶ **Good agreement for blowdown pressure**
  - slight over prediction of peak pressure
  - indication that early mixing is being predicted
  - lack of stratification (over mixing) below injection results in over prediction of grate temperature
  - over prediction of pressure relaxation caused by over mixing in vessel and early over estimation of heat transfer to internal structures (D and grate)
  - deadended room nodalization gives good prediction of below oper. floor stratification
  
- ▶ **Slight early over prediction of pressure believed to be caused by lack of asymmetric vessel wall heating due to steam plume (CONTAIN gives good prediction of wall temperatures away from rising plume)**
  
- ▶ **Late time pressure predicted with good accuracy if steam flow rate is smoothed.**
  
- ▶ **Quasi steady state pressure is very sensitive to steam injection rate ( pressure measurements are smooth; this implies that the vortex readings are probably inaccurate for use with late time transient pressure calc.)**
  
- ▶ **Exit annulus air temperature under predicted**

# **Critical Review of the Numerical Methods in the WGOTHIC Computer Code**

**William L. Oberkamp**  
**Aerosciences and Fluid Dynamics Department**  
**Mail Stop 0825**  
**Sandia National Laboratories**  
**Albuquerque, NM 87185-0825**  
**(Voice: 505-844-3799, FAX: 505-844-4523)**  
**(e-mail: wloberk@sandia.gov)**

**Review Meeting on AP600 PCCS Analysis**  
**Westinghouse Energy Center**  
**Monroeville, PA**  
**November 15 - 17, 1994**



**Sandia National Laboratories**

## **Outline of Presentation**

- Overview of WEC analysis approaches
- Concerns with subdivided volume methods in WGOTHIC
- Concerns with subdivided volume solutions from WGOTHIC
- Conclusions



Sandia  
National  
Laboratories

## Overview of WEC Analysis Approaches

- The lumped parameter approach is mathematically similar to a control volume approach.
- The subdivided volume approach numerically solves the partial differential equations for conservation of mass, momentum and energy.

Both approaches are actually very similar  
as implemented in WGOthic

- Boundary layers of vapor and liquid films on all solid surfaces are not computed in the subdivided volume approach, but are included through experimental correlations.

## Concerns With Finite Difference Methods

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- First-order upwind spatial differencing is used for the advection terms in the momentum and energy equations.
- This differencing scheme is known to produce significant artificial, i. e., numerical, viscosity unless very fine grids are used.
- The artificial viscosity is typically larger than the physical viscosity on coarse grids.
- First-order upwind differencing has proven to be so unreliable that the *ASME Journal of Fluids Engineering* will no longer publish any results computed with this scheme:

“...it has been demonstrated many times that, for first-order methods, the effect of numerical diffusion on the solution accuracy is devastating.”

## Concerns With Finite Difference Methods



- From the description of the numerical methods it is not clear that mass, momentum, and energy are conserved as a function of time.
- Specific areas of concern:
  - Method of exchange of mass, momentum, and energy between the vapor, liquid droplets, and continuous liquid phases.
  - Method of handling junctions, conductors, interface source terms, and wall source terms.

Has it been demonstrated that mass, momentum, and energy are conserved during the solution?

## Concerns with Finite Difference Solutions



- Only 550 grid points have been used for the 3-D solution.
- Accurate 3-D solutions published in the literature typically have 100 times that number of grid points.
- Reasonably good comparisons of predictions with experimental data does not prove the adequacy of numerical solution.
- Solution accuracy depends on two different factors: physical modeling accuracy and numerical solution accuracy.
- Grid convergence can only be determined by comparing solutions on different grid sizes.

**“The ASME *Journal of Fluids Engineering* will not accept for publication any paper reporting the numerical solution of a fluid engineering problem that fails to address the task of systematic truncation error testing and accuracy estimation.”**

# Example of Grid Convergence and Differencing Method



(From "Natural Convection of Air in a Square Cavity: A Bench Mark Numerical Solution", G. De Vahl Davis, International Journal for Numerical Methods in Fluids, vol. 3, pp. 249-264, 1983)

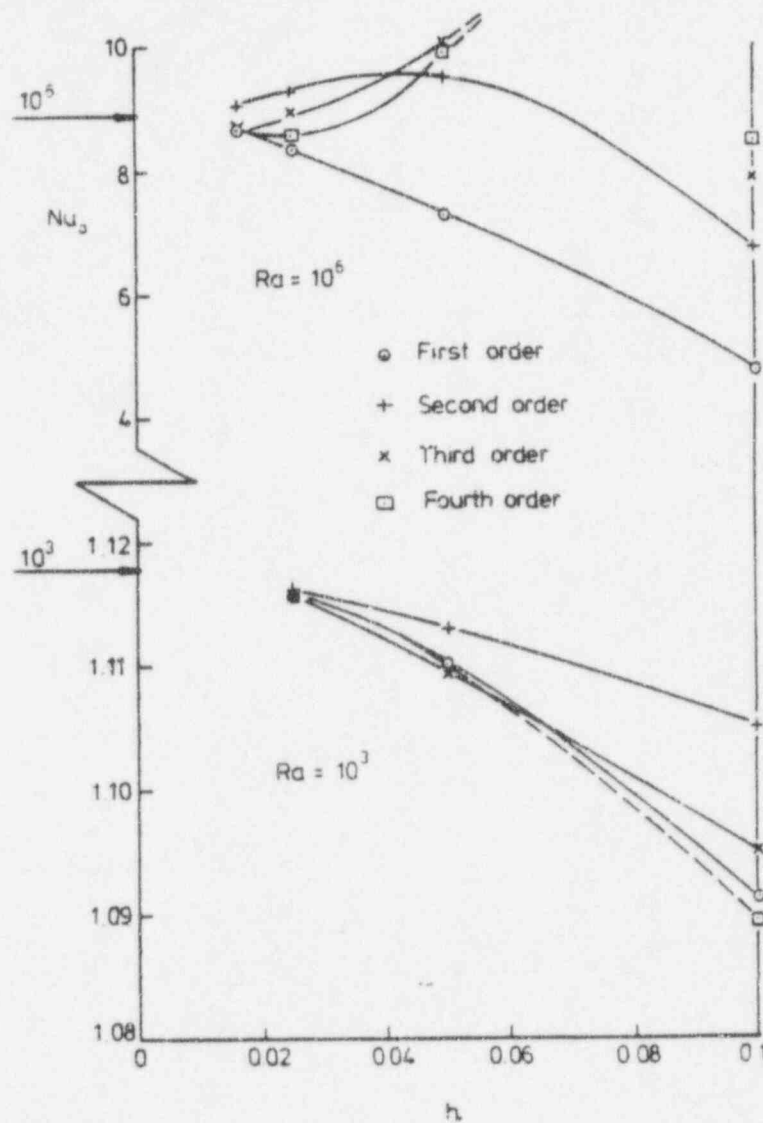


Figure 1.  $Nu_0$  as a function of mesh size and differentiation formula for  $Ra = 10^3$  and  $10^6$

## **Concerns with Finite Difference Solutions**

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- **First-order, backward time differencing is used to advance the solution in time.**
- **Specific areas for concern:**
  - **No quantitative measure for control of the integration time step. This can lead to inaccurate transient predictions.**
  - **Temporal lagging (“logarithmic damping”) of certain explicit terms in the equations causes the time integration method to be less than first-order accurate.**
  - **Poor agreement between pressure prediction and experimental measurement for the LST for times less than 2,000 sec. is troubling.**

## Conclusions

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- Two major concerns were uncovered in both numerical methods and numerical solutions of the subdivided volume approach.
- The present subdivided volume solutions are considered unreliable for predicting the adequacy of the PCCS in a major accident scenario.
- No conclusions are made concerning the adequacy of the PCCS design to cool and reduce the pressure inside the containment vessel.

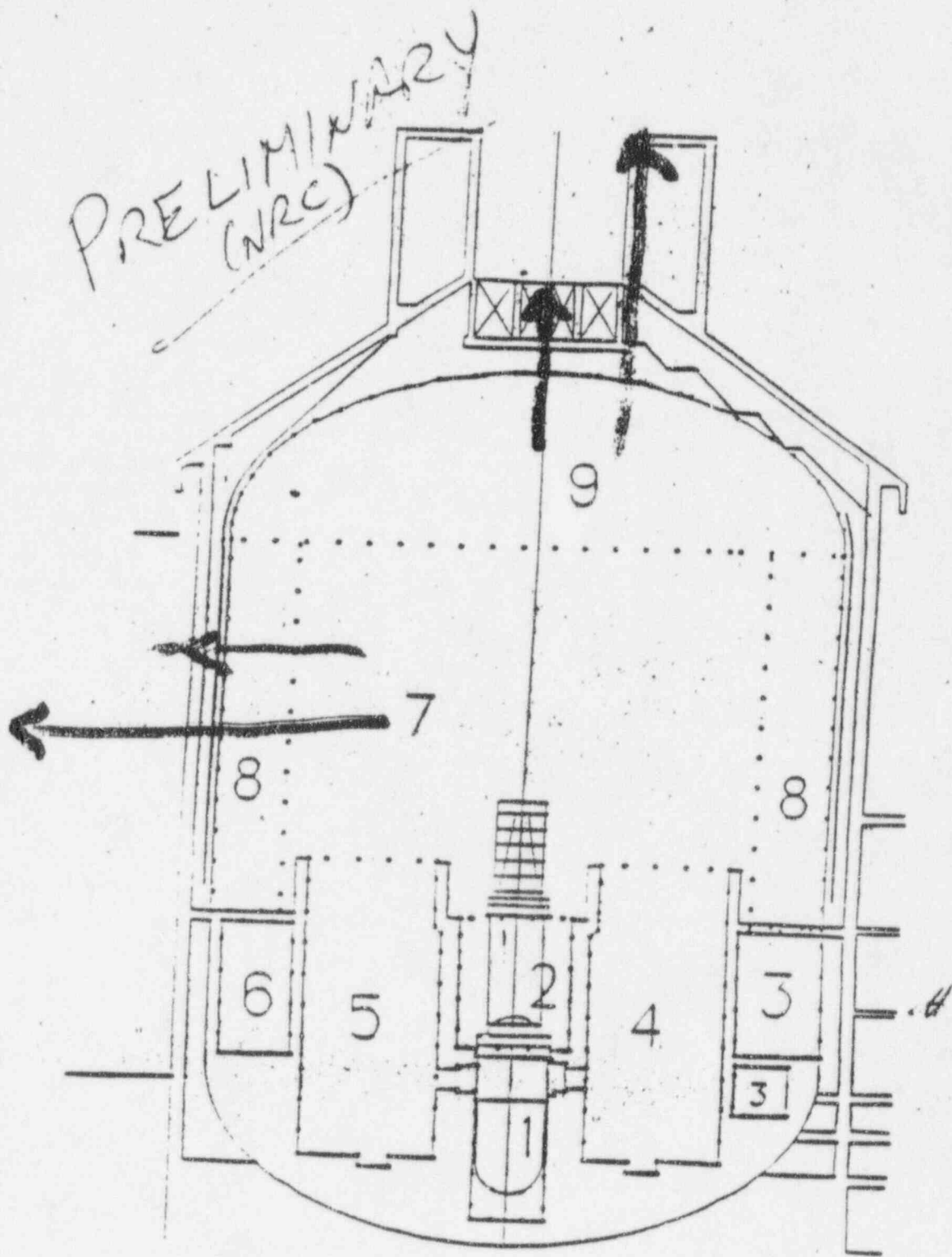
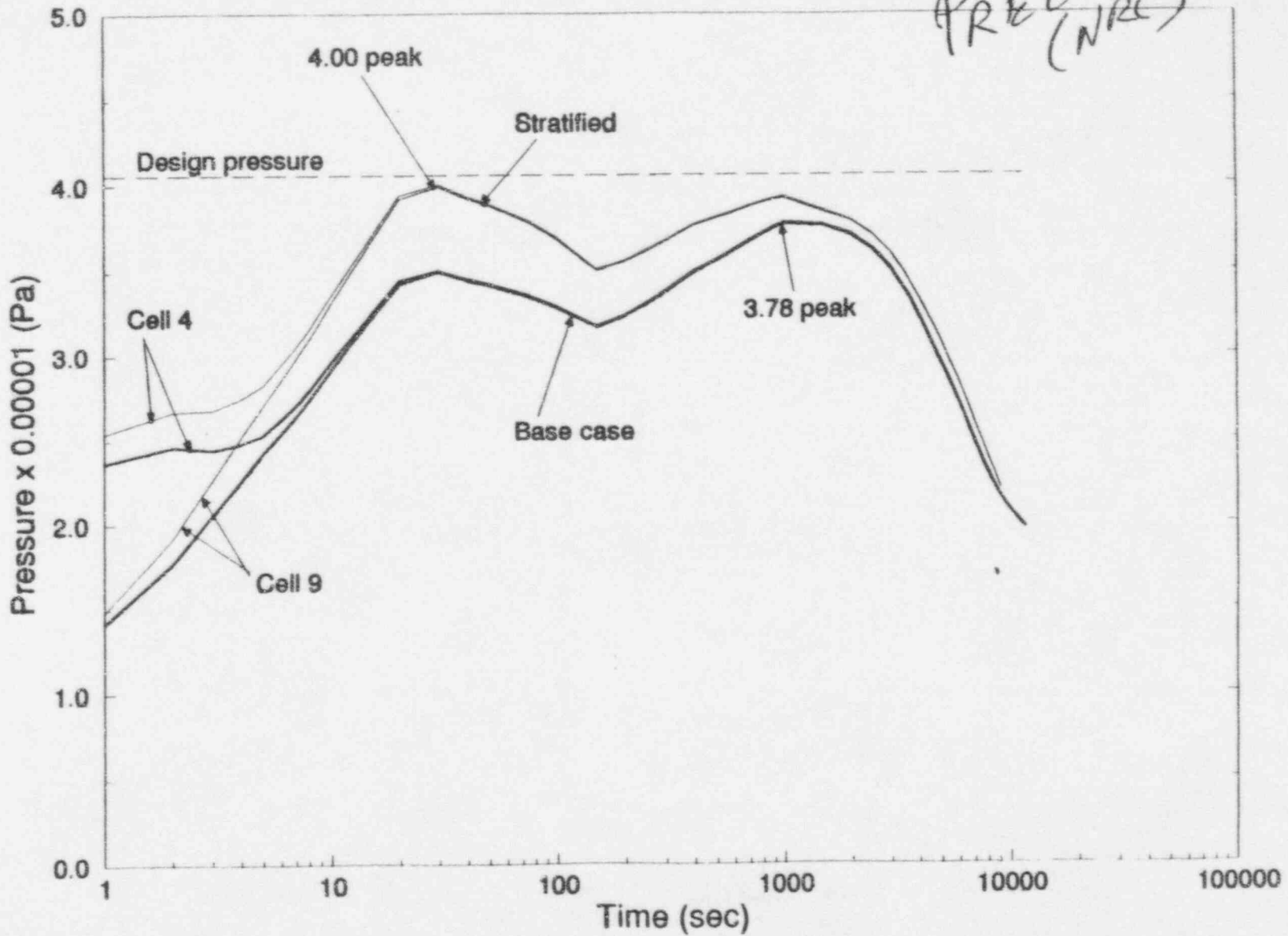


Figure 1 Section B-B of the AP600 plant (Rev 0) showing the locations of CONTAIN cells

# AP600 DECLGB

PRELIMINARY  
(NRC)

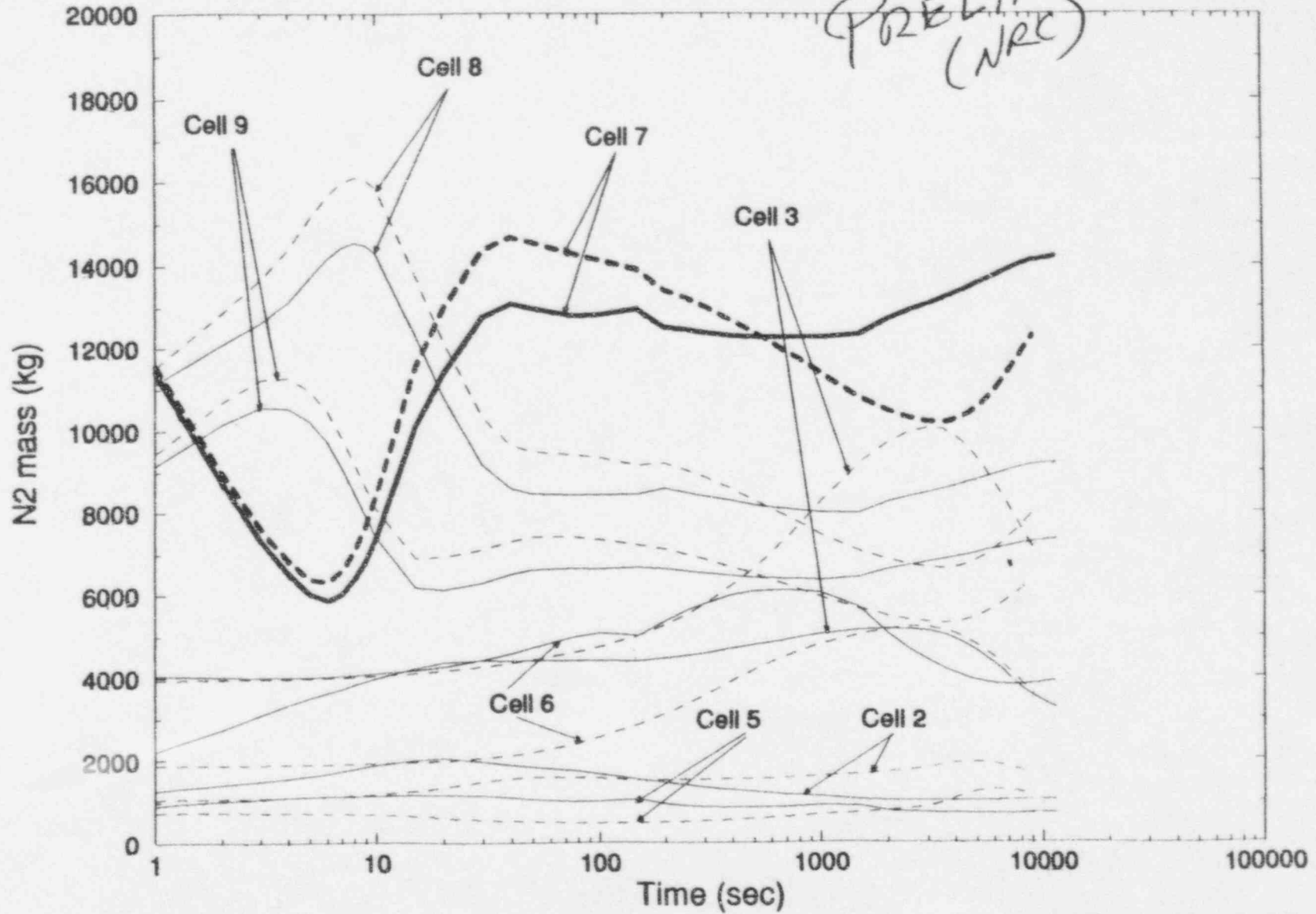


47

# AP600 DECLG

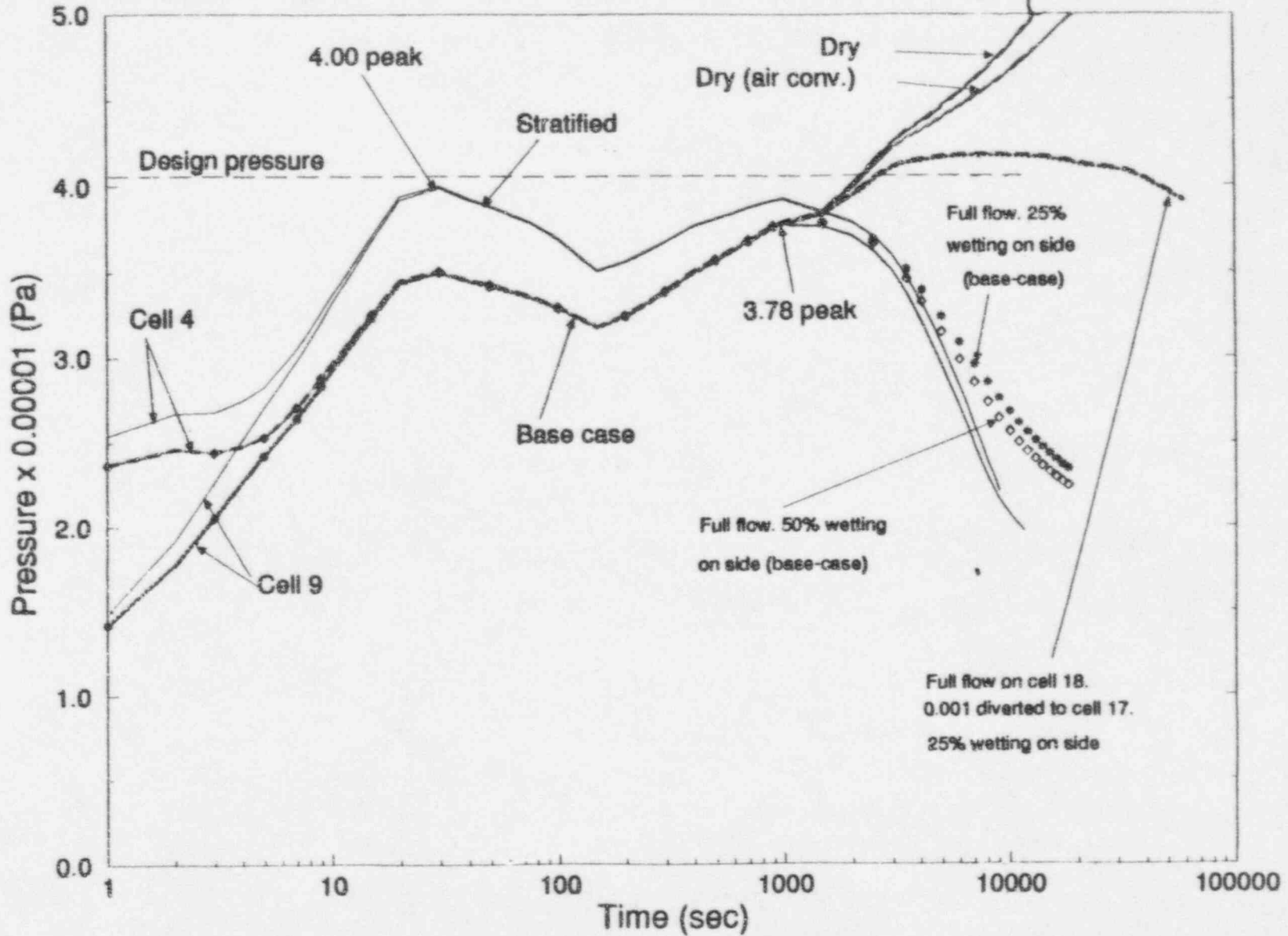
N2 mass

*PRELIMINARY  
(NRC)*



# AP600 DECLGB

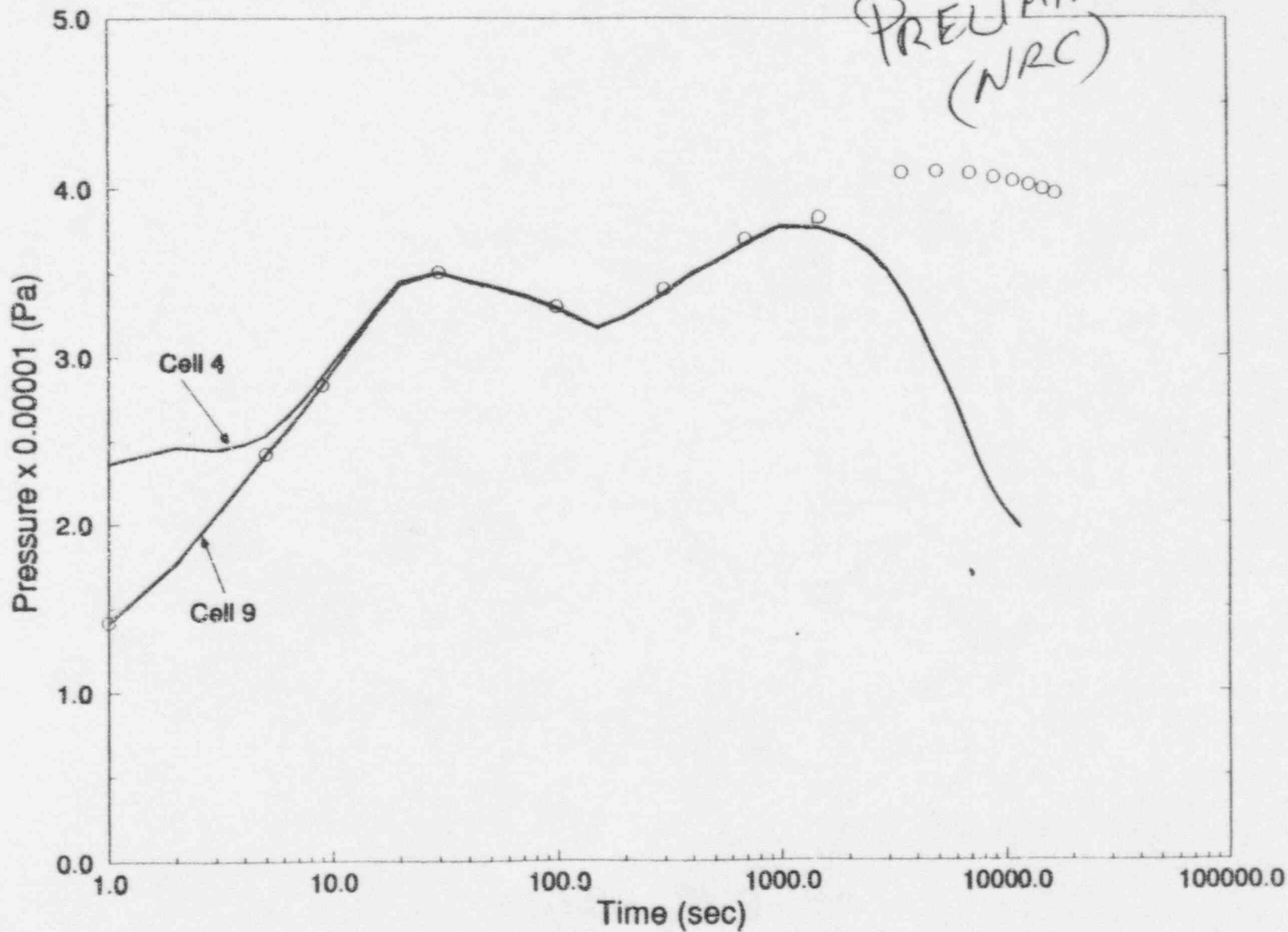
PRELIMINARY  
(NRC)



b7

# AP600 DECLGB

PRELIMINARY  
(NRC)



# AP600 DECLGB

PRELIMINARY  
(NRC)

