Westinghouse Electric Corporation
Energy Systems

Box 355
Pittsburgh Pennsylvania 15230-0355

AW-94-594

February 23, 1994

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

ATTENTION: MR. R. W. BORCHARDT

APPLICATION FOR WITHHOLDING PROPRIETARY INFORMATION FROM PUBLIC DISCLOSURE

SUBJECT: PRESENTATION MATERIALS FROM THE FEBRUARY 23-24, 1994 MEETING ON AP600 PCCS TESTS AND ANALYSIS

Dear Mr. Borchardt:

The application for withholding is submitted by Westinghouse Electric Corporation ("Westinghouse") pursuant to the provisions of paragraph (b)(1) of Section 2.790 of the Commission's regulations. It contains commercial strategic information proprietary to Westinghouse and customarily held in confidence.

The proprietary material for which withholding is being requested is identified in the proprietary version of the subject report. In conformance with 10CFR Section 2.790, Affidavit AW-94-594 accompanies this application for withholding setting forth the basis on which the identified proprietary information may be withheld from public disclosure.

Accordingly, it is respectfully requested that the subject information which is proprietary to Westinghouse be withheld from public disclosure in accordance with 10CFR Section 2.790 of the Commission's regulations.

Correspondence with respect to this application for withholding or the accompanying affidavit should reference AW-94-594 and should be addressed to the undersigned.

Very truly yours,

N. J. Liparulo, Manager
Nuclear Safety And Regulatory Activities

/nja

cc: Kevin Bohrer NRC 12H5

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PDR ADOCK 05200003
A PDR

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared Brian A. McIntyre, who, being by me duly sworn according to law, deposes and says that he is authorized to execute this Affidavit on behalf of Westinghouse Electric Corporation ("Westinghouse") and that the averments of fact set forth in this Affidavit are true and correct to the best of his knowledge, information, and belief:

Brian A. McIntyre

Brian A. McIntyre, Manager
Advanced Plant Safety & Licensing

Sworn to and subscribed
before me this 22 day
of February, 1994

Rose Marie Payne

Notary Public

Notarial Seal
Rose Marie Payne, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires Nov. 4, 1996
Member, Pennsylvania Association of Notaries

(1) I am Manager, Advanced Plant Safety and Licensing, in the Advanced Technology Business Area, of the Westinghouse Electric Corporation and as such, I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing and rulemaking proceedings, and am authorized to apply for its withholding on behalf of the Westinghouse Energy Systems Business Unit.

(2) I am making this Affidavit in conformance with the provisions of 10CFR Section 2.790 of the Commission's regulations and in conjunction with the Westinghouse application for withholding accompanying this Affidavit.

(3) I have personal knowledge of the criteria and procedures utilized by the Westinghouse Energy Systems Business Unit in designating information as a trade secret, privileged or as confidential commercial or financial information.

(4) Pursuant to the provisions of paragraph (b)(4) of Section 2.790 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse.

(ii) The information is of a type customarily held in confidence by Westinghouse and not customarily disclosed to the public. Westinghouse has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application of that system and the substance of that system constitutes Westinghouse policy and provides the rational basis required.

Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage, e.g., by optimization or improved marketability.

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

There are sound policy reasons behind the Westinghouse system which include the following:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

(b) It is information which is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

(c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

(d) Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Westinghouse of a competitive advantage.

(e) Unrestricted disclosure would jeopardize the position of prominence of Westinghouse in the world market, and thereby give a market advantage to the competition of those countries.

(f) The Westinghouse capacity to invest corporate assets in research and development depends upon the success in obtaining and maintaining a competitive advantage.

(iii) The information is being transmitted to the Commission in confidence and, under the provisions of 10CFR Section 2.790, it is to be received in confidence by the Commission.

(iv) The information sought to be protected is not available in public sources or available information has not been previously employed in the same original manner or method to the best of our knowledge and belief.

(v) Enclosed is Letter NTD-NRC-94-4067, February 23, 1994, being transmitted by Westinghouse Electric Corporation (W) letter and Application for Withholding Proprietary Information from Public Disclosure, N. J. Liparulo (W), to Mr. R. W. Borchardt, Office of NRR. The proprietary information as submitted for use by Westinghouse Electric Corporation is in response to questions concerning the AP600 plant and the associated design certification application and is expected to be applicable in other licensee submittals in response to certain NRC requirements for justification of licensing advanced nuclear power plant designs.

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

(a) Demonstrate the design and safety of the AP600 Passive Safety Systems.

(b) Establish applicable verification testing methods.

(c) Design Advanced Nuclear Power Plants that meet NRC requirements.

(d) Establish technical and licensing approaches for the AP600 that will ultimately result in a certified design.

(e) Assist customers in obtaining NRC approval for future plants.

Further this information has substantial commercial value as follows:

(a) Westinghouse plans to sell the use of similar information to its customers for purposes of meeting NRC requirements for advanced plant licenses.

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

Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar advanced nuclear power designs and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

The development of the technology described in part by the information is the result of applying the results of many years of experience in an intensive Westinghouse effort and the expenditure of a considerable sum of money.

In order for competitors of Westinghouse to duplicate this information, similar technical programs would have to be performed and a significant manpower effort, having the requisite talent and experience, would have to be expended for developing analytical methods and receiving NRC approval for those methods.

Further the deponent sayeth not.

WESTINGHOUSE ELECTRIC CORPORATION

PRESENTATION
TO
UNITED STATES
NUCLEAR REGULATORY COMMISSION

AP600 PCCS Tests and Analysis

(Part 1 - 2/23/94)

MONROEVILLE, PA
FEBRUARY 23-24, 1994

AGENDA

WESTINGHOUSE/NRC MEETING
AP600 PCCS TEST AND ANALYSIS

February 23, 1994

1:00	Welcome and Introduction	J. Gresham
1:15	WGOTHIC Validation Process Overview	J. Woodcock
2:00	NRC Perspective (PCCS Test and Analysis Issues)	C. Hoxie
2:45	PCCS Test Results Overview	F. Peters

AGENDA

WESTINGHOUSE/NRC MEETING
AP600 PCCS TEST AND ANALYSIS

February 24, 1994

8:00	Phenomenological Modeling Status	D. Spencer
	Lunch	
1:00	WGOTHIC Model Changes	M. Kennedy
1:30	WGOTHIC Validation Status	M. Kennedy
2:15	PCCS Test Analysis RAI Summary	M. Kennedy
3:00	NRC Consultation	
4:00	Meeting Wrap-up, Discussion of Action Items	All

INTRODUCTION

J. A. Gresham, Manager
Containment and Radiological Analysis

WGOTHIC VALIDATION PROCESS OVERVIEW

J. Woodcock
Containment and Radiological Analysis

WGOTHIC VALIDATION PROCESS OVERVIEW

SESSION AGENDA

- WGOTHIC Licensing Submittal Status
  - WCAP Revision 0 Bases
  - WCAP Revision 1 Enhancements
- Overview of Plans for Containment Code Validation and SSAR Confirmation Analysis
- Blind Test Analysis Plans
- WGOTHIC Licensing Review Status
- WGOTHIC Code Validation Status

WGOTHIC VALIDATION PROCESS OVERVIEW

WGOTHIC LICENSING SUBMITTAL STATUS

- WGOTHIC WCAP Revision 0 (& SSAR Revision 0) Bases:
- Separate effects and integral tests
  - University of Wisconsin condensation tests
  - Westinghouse Flat Plate tests for external heat transfer
  - Integral "Small Scale Tests"
  - Baseline Large Scale Tests without internals
- Used lumped parameter formulation of momentum equation
- Scaling and application to AP600 were provided
- Used as basis for SSAR Revision 0 analyses

WGOTHIC VALIDATION PROCESS OVERVIEW

WGOTHIC LICENSING SUBMITTAL STATUS (continued)

- WCAP-13246 is Being Revised
- SSAR Revision 0 models are sufficient to conservatively assess containment criteria for AP600
- RAI's requested additional information
  - Method of presentation of material
  - Discussion of other areas of potential concern
- Extend integral test database
  - Helium as additional noncondensible
  - Measure condensate collection at various locations
  - Add transient tests
- Reduce the small remaining uncertainty
  - Improved formulation of code conservation equations
  - Further increase the accuracy of heat/mass transfer correlations
  - Additional noding studies to improve noncondensible predictions

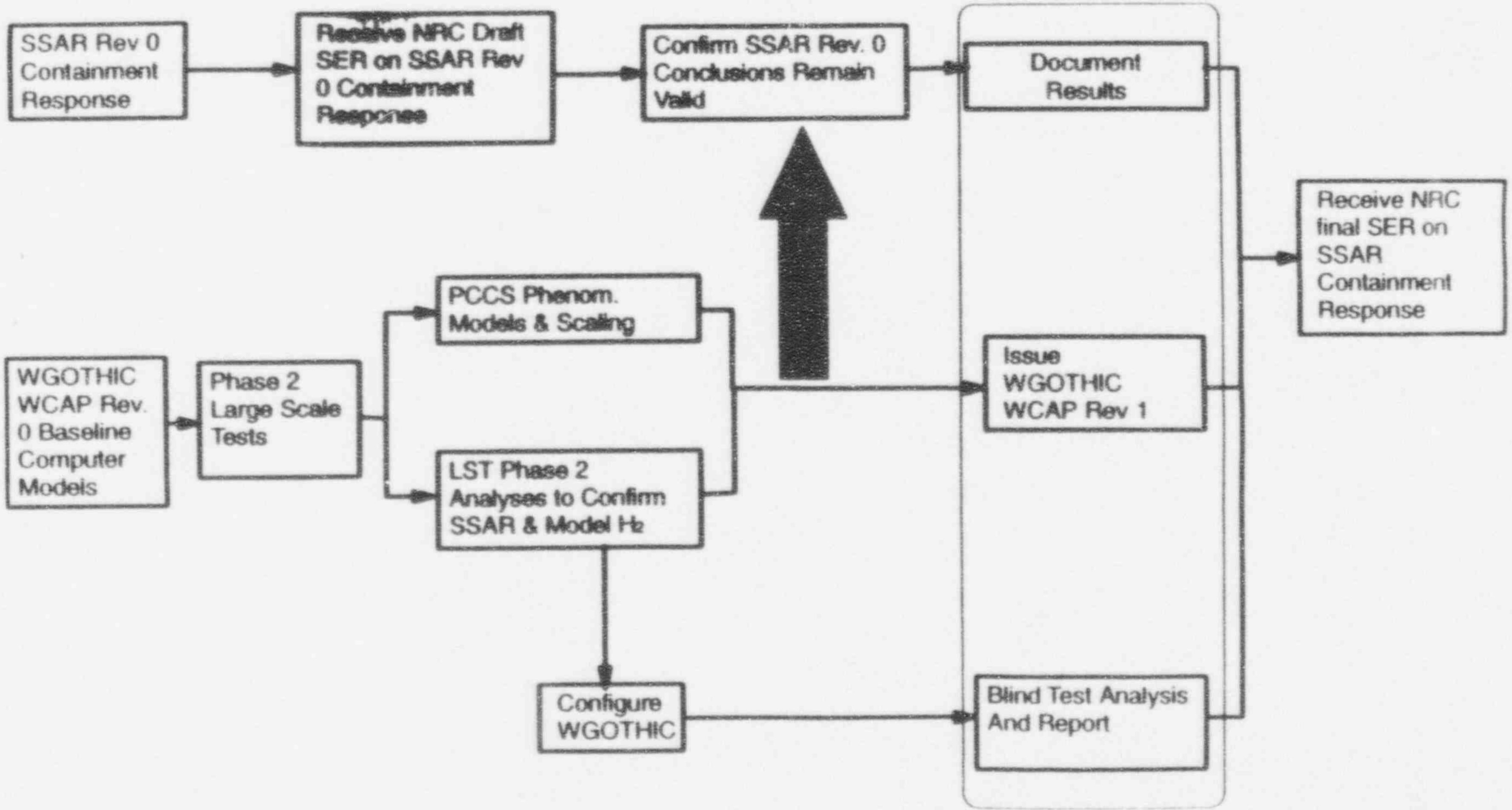
WGOTHIC VALIDATION PROCESS OVERVIEW

WGOTHIC LICENSING SUBMITTAL STATUS (continued)

- WGOTHIC WCAP Revision 1 Enhancements
- More accurate correlations including additional separate effects tests from the literature
- Distributed parameter ("subdivided") for internal volumes
- LST Confirmatory Tests
    - Helium addition and Transients with blowdowns
- Address feedback from NRC/ACRS meetings
- Will lead to confirmation of SSAR Revision 0 conclusions

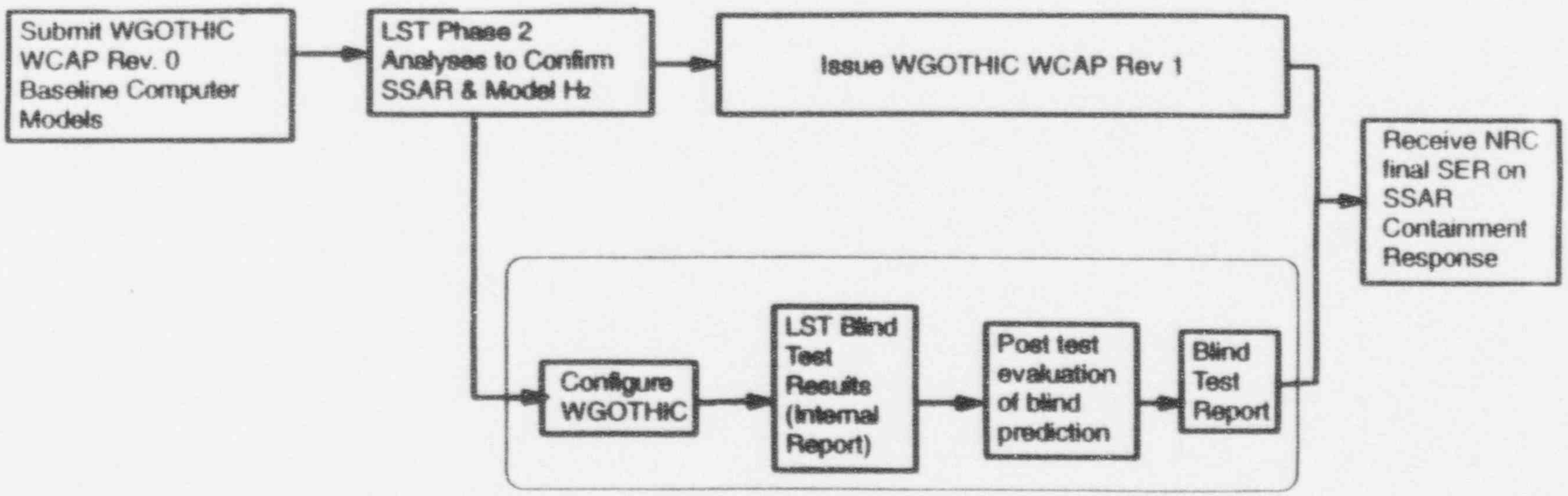
WGOTHIC VALIDATION PROCESS OVERVIEW

Overview of Containment Code Validation and SSAR Confirmation Analyses



WGOTHIC VALIDATION PROCESS OVERVIEW

Blind Test Analysis Plans



WGOTHIC VALIDATION PROCESS OVERVIEW

WGOTHIC LICENSING REVIEW STATUS

- RAIs on WGOTHIC WCAP Revision 0

  Received: 15

- RAIs on SSAR Revision 0 Containment Analysis

  Received: 1

WGOTHIC VALIDATION PROCESS OVERVIEW

WGOTHIC CODE VALIDATION STATUS

- All PCCS tests completed, LST quick look reports being issued
- WCAP Revision 1 Code and Validation Enhancements underway
  - Improve accuracy
  - Further reduce uncertainty
  - Understand sensitivities to key calculational parameters
  - Provide additional documentation supporting scalability of models and methods for use of code
- Confirmation of AP600 SSAR conclusions for containment will be based on final LST and calculation results
- Early identification of issues/concerns is necessary for us to factor them into our plans with minimal impact

PCCS TEST RESULTS OVERVIEW

F. E. Peters
Test Engineering

PCCS TEST RESULTS OVERVIEW

AP600 TEST PROGRAM OVERVIEW			
TEST DESCRIPTION	CATEGORY	TESTING STATUS	TEST PURPOSE
PASSIVE CONTAINMENT COOLING SYSTEM TESTS IN SUPPORT OF AP600 DESIGN			
Air Flow Path Delta P Test	Basic Research	Completed	Obtain pressure drop data through the downcomer and annulus
Water Film Formation Test	Basic Research	Completed	Confirm wettability of coated steel surface
Heated Plate Test	Basic Research	Completed	Confirm PCCS heat transfer capability
Bench Wind Tunnel Experiment	Basic Research	Completed	Assess effects of wind on shield building design (inlet/outlet location)
Condensation Tests - Bare surface upward	Basic Research	Completed	Comparison with past separate effects tests
Condensation Tests - Bare surface downward	Basic Research	Completed	Obtain heat transfer coefficients with downward facing surfaces
Condensation Tests - Painted surface down	Basic Research	Completed	Obtain the effect of AP600 paint on heat transfer performance
Condensation Tests - Light noncondensibles	Basic Research	Completed	Obtain the effect of light noncondensibles on HT performance
Condensation Tests - Stagnation Flow Conditions	Basic Research	Completed	Obtain the HT performance under stagnant flow conditions
Condensation Tests - Stagnation/light noncondensibles	Basic Research	Completed	Obtain the heat transfer performance under stagnant flow conditions in the presence of light noncondensibles
Condensation Tests - 2D condensation	Basic Research	In Progress	Measure condensation HT coefficient using 2D test model

PCCS TEST RESULTS OVERVIEW

AP600 TEST PROGRAM OVERVIEW			
TEST DESCRIPTION	CATEGORY	TESTING STATUS	TEST PURPOSE
PASSIVE CONTAINMENT COOLING SYSTEM TESTS IN SUPPORT OF AP600 DESIGN CERTIFICATION			
Integral (small scale) Tests - Phase 1 (Feasibility)	Safety Related	Completed	Determine feasibility of water enhanced cont. cooling system
Integral (small scale) Tests - Phase 2A (Extension Tests)	Safety Related	Completed	Demonstrate operation of PCCS over increased range of operating conditions. Confirm PCCS internal and external HT capabilities
Integral (small scale) Tests - Phase 2B (Continuation Tests)	Safety Related	Completed	Demonstrate operation of Passive Containment Cooling System with prototypic steam injection
1/8th Scale Heat Transfer Test - Phase 1 (Baseline)	Safety Related	Completed	Obtain HT data for WGOTHIC validation with minimal intervals
1/8th Scale Heat Transfer Test - Phase 2 (Confirmatory)	Safety Related	Completed	Obtain HT data for WGOTHIC computer code validation
Water Distribution System Test - Phase 1 (20 ft Diameter)	Safety Related	Completed	Investigate performance of passive containment cooling system center water delivery/distribution device
Water Distribution System Test - Phase 2 (1/8th Sector)	Safety Related	Completed	Measure containment water coverage using distribution system
Water Distribution System Test - Phase 3 (1/8th sector with selected distribution system)	Safety Related	Completed	Measure containment water coverage using selected design distribution system
Wind Tunnel Test - Phase 1	Safety Related	Completed	Investigate wind sensitivity of shield building design
Wind Tunnel Test - Phase 2	Safety Related	Completed	Assess wind loads on containment baffle
Wind Tunnel Test - Phase 4A	Safety Related	Completed	Verify Phase 1 & 2 test results at higher Reynolds numbers
Wind Tunnel Test Phase 4B	Safety Related	Completed	Investigate site topography effects on air flow through PCS annulus

PCCS TEST RESULTS OVERVIEW

OBJECTIVES

Examine, on a large scale, containment phenomena:

- Natural convection and steam condensation on the interior of the containment

- Exterior air and water heat removal

For use in validation of containment analysis computer codes

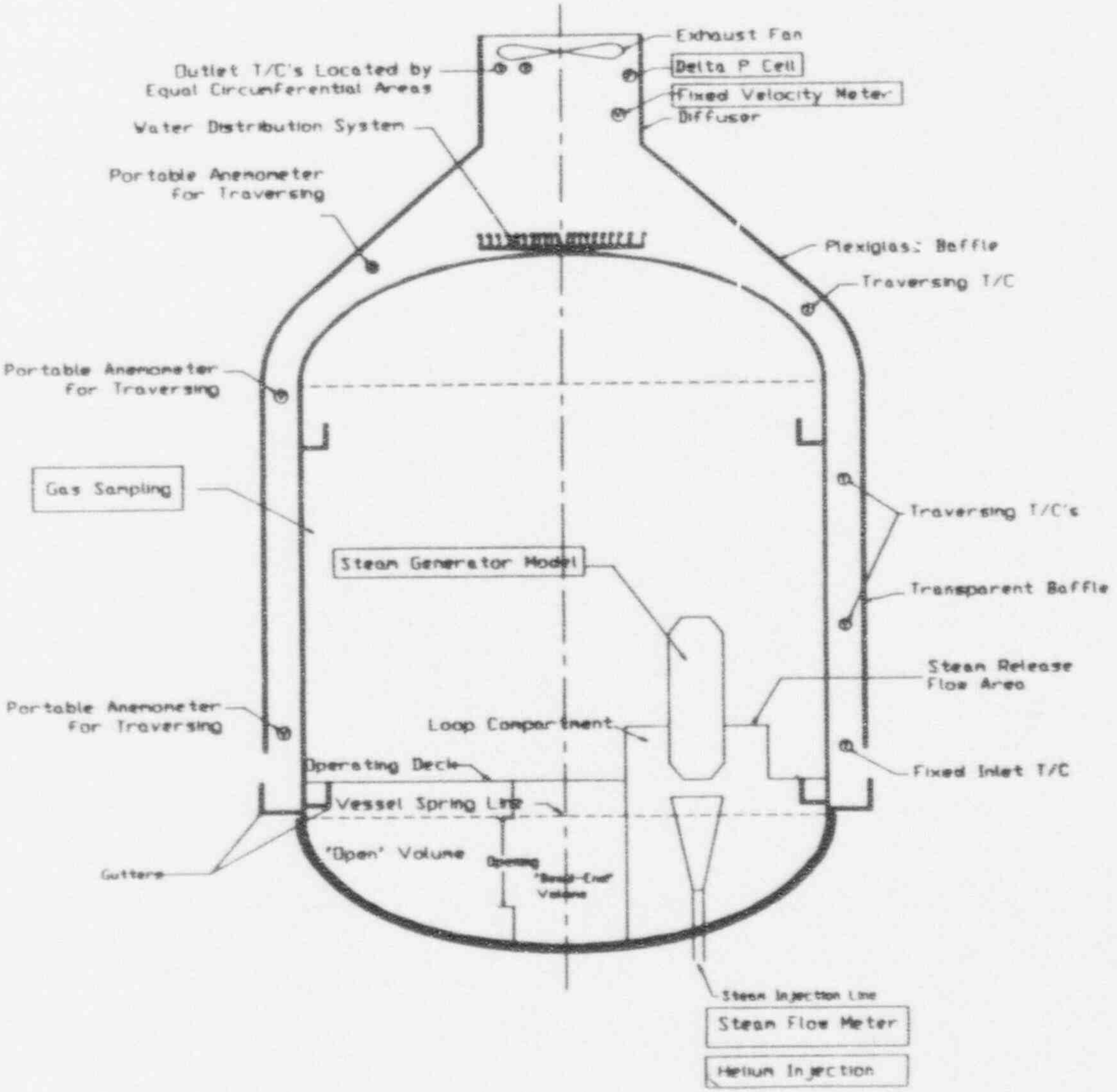
PCCS TEST RESULTS OVERVIEW

TEST FACILITY

- 1/8th scale AP600 instrumented test vessel
- 10,000 lb/hr, 100 psig steam supply system
- Natural convection air cooling
- Forced air exterior cooling to 20 ft/sec
- 30 gpm exterior water film supply
- 400 channel data acquisition system, (26 channel per sec max)

PCCS TEST RESULTS OVERVIEW

Test Facility Configuration



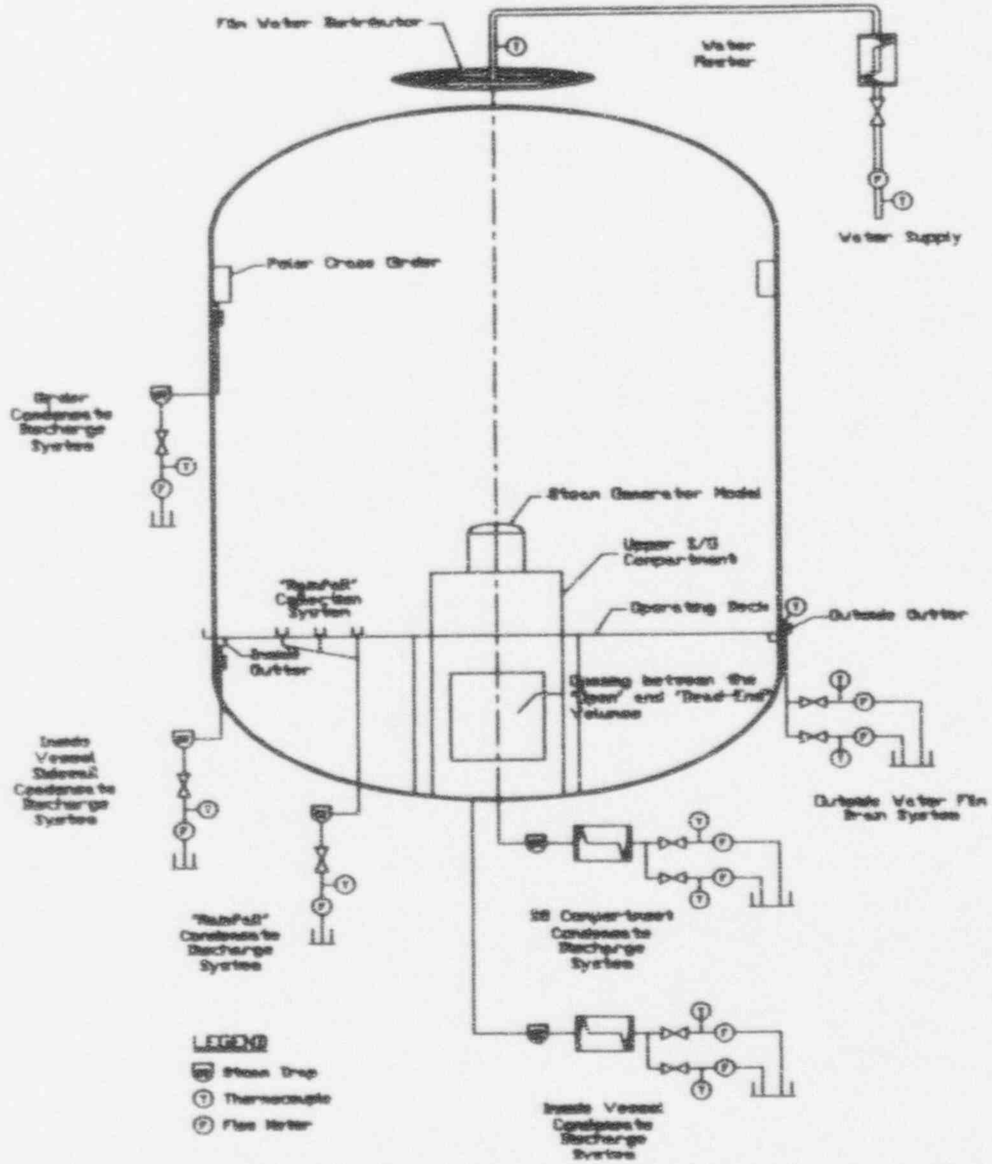
PCCS TEST RESULTS OVERVIEW

Instrument Rake Locations

(a,c)

PCCS TEST RESULTS OVERVIEW

Condensate Collection Systems



PCCS TEST RESULTS OVERVIEW

BASELINE TESTS - COMPLETED

- Steady state heat transfer tests
- Report issued (WCAP-13566)

PHASE 2 TESTS - EXTEND DATA BASE - COMPLETED

- Steady state and transient simulations
- Effect of light noncondensibles
- Internal heat sinks
- Quick look reports issued (PCS-T2R-014,-015,-017,-018,-022,-023)
- Blind blowdown test (Test description report PCS-T2R-020)

PCCS TEST RESULTS OVERVIEW

PRE-TESTS

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

PHASE 3 TESTS - FOLLOW-ON - COMPLETED

- Stepped blowdown steam discharge
- Alternate steam discharge
- Vacuum
- Pressurized vessel

PCCS TEST RESULTS OVERVIEW

(a,c)

PCCS TEST RESULTS OVERVIEW

(a,c)

PCCS TEST RESULTS OVERVIEW

(a,c)

OVERVIEW OF TEST RESULTS

- Comparison of heat loss calculations
- Nominal heat transfer performance
- Helium behavior
- Annulus air flow
- Other observations

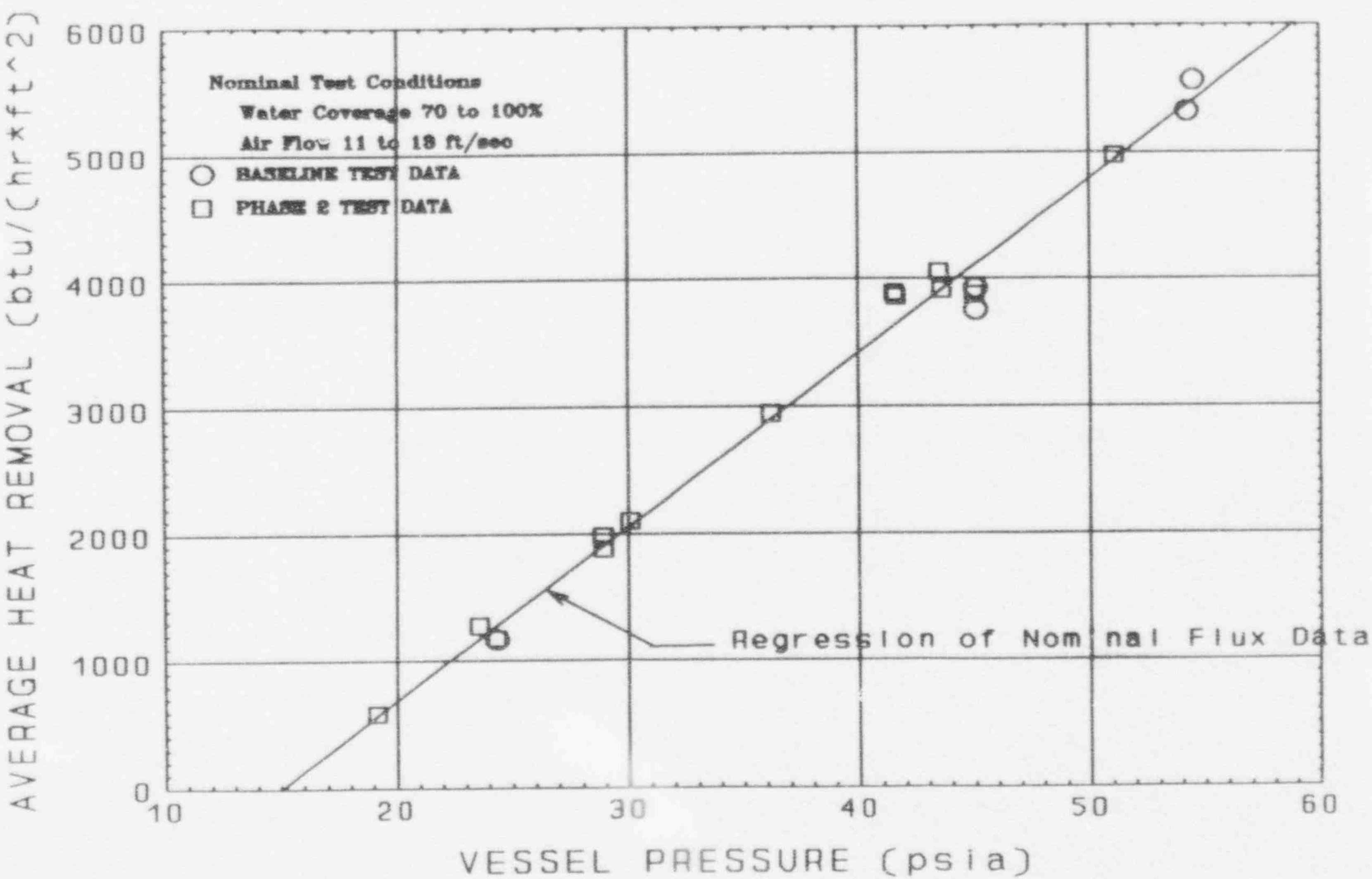
PCCS TEST RESULTS OVERVIEW

Large Scale Test Heat Removal Rates

(a, b)

PCCS TEST RESULTS OVERVIEW

Average Heat Removal Rate vs. Vessel Pressure



PCCS TEST RESULTS OVERVIEW

OBSERVATIONS:

- Heat removal rates show consistent results with multiple calculation methods

- Tests produce repeatable results

- Heat removal rates are linear with pressure

PCCS TEST RESULTS OVERVIEW

Noncondensible Behavior - Dry Tests vs. Wet Tests

(a,b)

PCCS TEST RESULTS OVERVIEW

Effects of Long Term Heat Sinks

(a,b)

PCCS TEST RESULTS OVERVIEW

Effects of Cooling Water on Noncondensible Gas Distribution

(a,b)

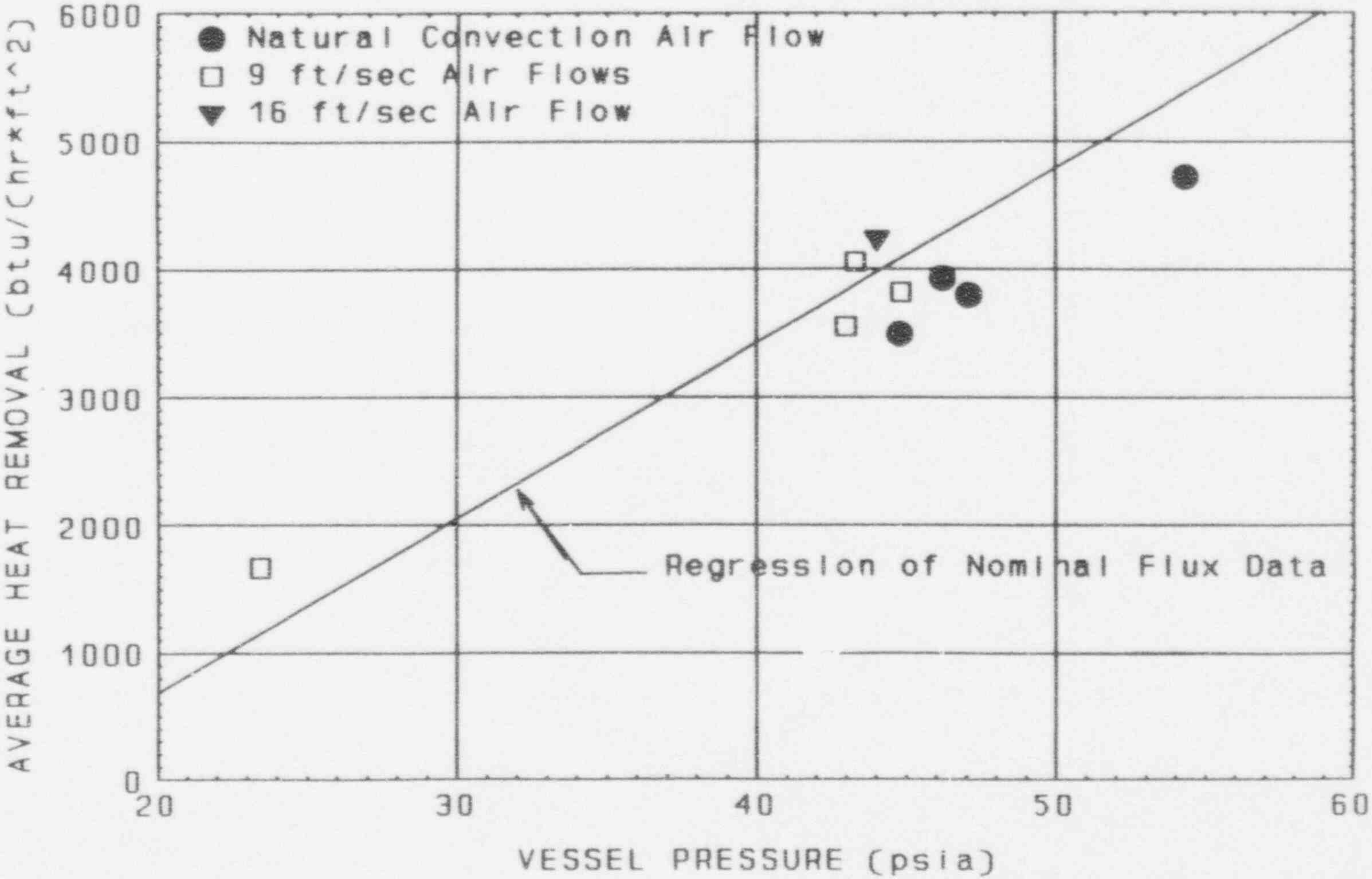
PCCS TEST RESULTS OVERVIEW

OBSERVATIONS:

- Helium becomes well mixed in all cases
- Helium mixing is slower with no water cooling
- Helium distribution becomes uniform throughout the vessel faster with water cooling
- Little effect on helium distribution was noted from the addition of long term heat sinks
- Sampling system shows consistent behavior and provides a suitable technique for determination of noncondensible measurements
- Strong noncondensible stratification observed particularly below operating deck

PCCS TEST RESULTS OVERVIEW

Effect of External Air Flow on Average Heat Removal Rate



PCCS TEST RESULTS OVERVIEW

OBSERVATIONS:

- Air velocity has a small but noticeable effect on heat removal rates

- Smoke tests with vessel at ~100°F show strong upward flow

- Very little effect of 50% air flow blockage

PCCS TEST RESULTS OVERVIEW

OTHER OBSERVATIONS:

- Approximately 95% of the condensate is collected from the vessel dome and sidewall
- 5% is collected from the open, closed, steam generator and rainfall areas
- Condensate approximately equally divided between dome and side wall
- No observable rainfall (below detection limits)
- Internal velocities observed are low (0 to 5 ft/sec)

PCCS TEST RESULTS OVERVIEW

CONCLUSIONS:

- Consistent test data
- Air stratifies within containment
- Helium mixes well inside the test vessel
- 95% of the condensate is removed above the operating deck
- No rainfall observed

WESTINGHOUSE ELECTRIC CORPORATION

PRESENTATION
TO
UNITED STATES
NUCLEAR REGULATORY COMMISSION

AP600 PCCS Tests and Analysis

(Part 2 - 2/24/94)

MONROEVILLE, PA
FEBRUARY 23-24, 1994

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PHENOMENOLOGICAL MODELING STATUS

Part 1: Containment Analysis Approach

Part 2: Response to Questions from March 1993 NRC PCCS Meeting at STC

D. R. Spencer
Containment and Radiological Analysis

Part 1: Containment Analysis Approach

I. Specify the phenomena to be modeled.

II. Select analytically valid models.

III. Verify scalability of models:

1. Determine range of relevant AP600 dimensionless groups.
2. Collect separate effects data sets and perform comparisons.

IV. Perform verification of models with WGOTHIC.

V. Determine the effect of hydrogen and transients on the models.

VI. Validate AP600 modeling assumption on external wetted coverage (Part 2).

I. PHENOMENA TO BE MODELED

1. Liquid film: heat transfer, enthalpy transport and stability.
2. Convective heat transfer: with, without mass transfer
3. Mass transfer: condensation, evaporation
4. Jets and Plumes: velocity fields, transport/entrainment
5. Entrance effects for heat and mass transfer in channels
6. Internal mixing/stratification of steam-air-hydrogen

II. SELECT MODELS

1.0 Convective Heat Transfer

1.1 EXTERNAL

The McAdams[1] turbulent free convection heat transfer correlation:

$$Nu_{x,free} = 0.13(Gr_x Pr)^{1/3} \quad (1)$$

and the Colburn[2] turbulent forced convection heat transfer correlation:

$$Nu_{d,forc} = 0.023 Re_d^{4/5} Pr^{1/3} \quad (2)$$

are used for the external convective heat transfer to or from the surfaces.

1.2 INTERNAL

The McAdams turbulent free convection heat transfer correlation:

$$Nu_{x,free} = 0.13(Gr_x Pr)^{1/3} \quad (3)$$

and the smooth flat plate[3] turbulent forced convection heat transfer correlation:

$$Nu_{x,forc} = 0.0296 Re_x^{4/5} Pr^{1/3} \quad (4)$$

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

1.3 COMBINED FREE AND FORCED

The correlations for combined free and forced convection heat transfer from Churchill[4] are, for opposed free and forced convection:

$$Nu = (Nu_{free}^3 + Nu_{forc}^3)^{1/3} \quad (5)$$

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

$$abs(Nu_{free}^3 - N_{forc}^3)^{1/3} \quad ; \quad 0.75Nu_{free} \quad ; \quad 0.75Nu_{forc} \quad (6)$$

The lower limit in the latter equation, which prevents the value of Nu_c from going to zero when Nu_{free} and Nu_{forc} are equal, comes from Eckert and Diaguila[5].

2.0 Mass Transfer

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

$$Sh = Nu\left(\frac{Sc}{Pr}\right)^{1/n} \tag{7}$$

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

$$Sh = \frac{h_m L}{D_v} \tag{8}$$

is multiplied by a correction factor, θ, to account for the effect of mass transfer. (The mass transfer correction is discussed in Part 2).

3.0 Liquid Film Heat Transfer

The Chun and Seban[6] correlation for wavy laminar films was selected for use in the WGOTHIC code. The dimensionless correlation for the film Nusselt number is:

$$Nu = 0.822\, Re^{-.22} \tag{9}$$

where

$$Nu = \frac{h}{k}\left(\frac{\nu^2}{g\sin(\theta)}\right) \quad and \quad Re = \frac{4\Gamma}{\mu} \tag{10}$$

4.0 Liquid Film Enthalpy Transport

The liquid film enthalpy transport model solves the transient energy equation at a point at the center of the liquid film for each clime:

$$\rho c_p\left(\frac{\partial T}{\partial t} + w\frac{\partial T}{\partial z}\right) = k\frac{\partial^2 T}{\partial x^2} \tag{11}$$

where x is normal to the surface and z is parallel to the surface. The energy equation is coupled to the wall and the liquid film surface by the equations:

$$k_{wall}\frac{\partial T_{wall}}{\partial x}\bigg]_{wall} = k_{film}\frac{\partial T_{film}}{\partial x}\bigg]_{wall} \quad and \quad k_{film}\frac{\partial T_{film}}{\partial x}\bigg]_{surf} = \dot{q}''_{rad} + \dot{q}''_{conv} + \dot{q}''_{mass} \tag{12}$$

5.0 Entrance Effect

The average value of h(x) between x_1 and x_2 is:

$$\frac{\bar{h}_{x_1,x_2}}{h_\infty} = 1 + F_1\frac{d\,(x_2^3 - x_1^3)}{L^3(x_2 - x_1)} \tag{13}$$

The multipliers F_1 are the coefficients recommended by Boelter, Young and Iverson[7] to account for the entrance effect:

$$\frac{h_m}{h_\infty} = 1 + F_1\frac{d}{L} \tag{14}$$

II. SELECT MODELS (continued)

References:

1. W. H. McAdams, *Heat Transmission*, Third Edition, McGraw-Hill, 1954.

2. A. P. Colburn, "A Method of Correlating Forced Convection Heat Transfer Data and a Comparison With Fluid Friction", *Transactions of the AIChE*, Vol. 29 (1933), p. 174.

3. H. Schlichting, *Boundary Layer Theory*, Sixth Edition, McGraw-Hill.

4. S. W. Churchill, "Combined free and Forced Convection Around Immersed Bodies", Section 2.5.9, and "Combined Free and Forced Convection in Channels", Section 2.5.10 in E. U . Schlunder, Ed.-in-Chief, *Heat Exchanger Design Handbook*, Hemisphere Publishing Corp. 1983.

5. E. R. G. Eckert and A. J. Diaguila, "Convective Heat Transfer for Mixed, Free, and Forced Flow Through Tubes", *Transactions of the ASME*, May, 1954, pp 497-504.

6. R. K. R. Chun and R. A. Seban, "Heat Transfer to Evaporating Liquid Films",*Journal of Heat Transfer*, November, 1971, pp 391-396.

7. L. M. K. Boelter, G. Young and H. W. Iverson, *NACA TN* 1451, 1948.

III. VERIFY SCALABILITY OF MODELS

1. **Determine Range of Relevant AP600 Dimensionless Groups**

(a,b)

III. VERIFY SCALABILITY OF MODELS (continued)

2. Collect Separate Effects Data Sets and Perform Comparisons: Range of Parameters

Table 1

Scaling Parameters for Liquid Films in AP600

	Condensing			Evaporating		
	Reynolds Number Over Dome	Reynolds Number Vertical Side	Prandtl Number	Reynolds Number Over Dome	Reynolds Number Vertical Side	Prandtl Number
AP600	[					] (a,b)
Large Scale Test	0-179	0-213	1.1-4.1	332-3235*	169-781	1.6-4.2
Wisconsin Tests	40-519	48-519	1.9-2.0	na	na	na
Chun and Seban	na	na	na	na	320-21,000	1.77-5.7

*Location at which the normal to the dome surface makes an angle of 57 degrees with the horizontal, corresponding to 7.0% of the total dome surface area or 2.6% of the total heat transfer surface area.

III. VERIFY SCALABILITY OF MODELS

2. Collect Separate Effects Data Sets and Perform Comparisons: Data Comparisons

(a,c)

0

IV. PERFORM VERIFICATION OF MODELS WITH WGOTHIC

Separate Effects Tests:

1. Wisconsin Condensation Tests
2. STC Flat Plate Evaporation Tests
3. Dry Free Convection Using Selected Literature Sources (e.g. Hugot, Siegel and Norris, ANL, Miyamoto, etc.)
4. STC Dry Forced Convection
5. Jet Comparisons

Integral Test Comparisons:

1. STC Small Scale (Integral) Tests
2. STC Large Scale Tests
3. NUPEC Tests M-4-3 and M-7-1 (ISP-35)

V. DETERMINE EFFECT OF H^2 AND TRANSIENTS ON MODELS

HYDROGEN

1. Determine range of dimensionless parameters characterizing hydrogen in AP600.
2. Evaluate MIT, Wisconsin, and literature sources for hydrogen effect on models.
3. Verify model capability by WGOTHIC comparisons to LST.

TRANSIENTS

1. Determine range of dimensionless parameters characterizing transients in AP600.
2. Evaluate literature sources for transient effect on models.
3. Verify model capability by WGOTHIC comparisons to LST.

PART 1 CONCLUSIONS

1. **Westinghouse is working a methodical, disciplined approach to model validation for the W̲GOTHIC code.**

   - **Individual models are selected, scaled and validated outside the code, and**

   - **Individual models are implemented in the code, and comprehensive, integral validation performed with the code.**

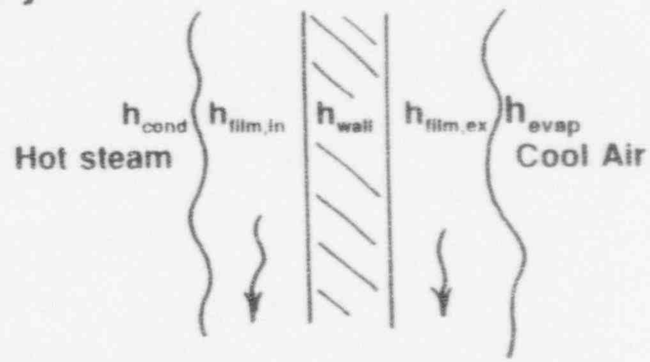
2. **The approach embodies input received from the NRC, NRC Consultants and ACRS Consultants in previous meetings**

PART 2 - QUESTIONS FROM MARCH 1993 NRC PCCS MEETING AT STC

- **Most of the model development and validation activity completed since the March 1993 meeting, and currently underway can be summarized within the context of questions raised during the March 1993 meeting. These questions are:**

1. Containment Heat Transfer Sensitivity to Liquid Film Uncertainty
2. Grashof Number Range and Length Parameter
3. McAdams Correlation for Horizontal Dome Surface
4. Liquid Film Flow Rate Dependence in STC Flat Plate Evaporation Tests
5. Validate the Heat/Mass Transfer Analogy for the Dome
6. Effect of Fog on the Radiation Heat Transfer in the PCCS Air Gap
7. Evaporation vs Condensation: Mass Transfer Corrections
8. Jet Modeling and Break Location
9. Liquid film Stability
10. Local Comparisons

Containment heat transfer sensitivity to liquid film uncertainty



In AP600 at peak steady-state heat flux,

$h_{film,in}$ > 900 B/hr-ft^2-F internal
$h_{film,ex}$ > 500 B/hr-ft^2-F external
h_{wall} = 192
h_{cond} = 30 to 100
h_{evap} = 30 to 100

The total thermal resistance is thus:

$$h_{e,ref} = \left(\frac{1}{100} + \frac{1}{900} + \frac{1}{192} + \frac{1}{100} + \frac{1}{100} + \frac{1}{500}\right)^{-1} = 35.31$$

Using an uncertainty of 40% on the film heat transfer coefficient both inside and outside:

$$h_{e,unc} = \left(\frac{1}{100} + \frac{1.4}{900} + \frac{1}{192} + \frac{1.4}{500} + \frac{1}{100}\right)^{-1} = 33.82$$

The effect on containment heat transfer is proportional to the ratio of the heat transfer coefficients with and without uncertainties. The ratio is 0.958. The containment heat transfer will be reduced by 4.2% if the full liquid film uncertainty is applied.

CONCLUSION: The containment heat transfer is not sensitive to the uncertainty on the liquid film heat transfer coefficient.

GRASHOF NUMBER RANGE AND LENGTH PARAMETER

The Grashof number in AP600 at the time of peak internal pressure is approximately 2×10^{15}. This is based on the Grashof number definition:

$$Gr = \frac{g \rho_{film} (\rho_{wall} - \rho_{bulk}) L^3}{\mu_{film}^2} \qquad (1)$$

and temperature measurements from LST 203.2.

Experimental measurements of Grashof numbers as high as 4×10^{14} (Katoake, et. al.[1]) show that the Nusselt number can be related to $Gr^{1/3}$. Because the same length parameter appears in the Nusselt number to the first power, and in the Grashof number to the third power, the length cancels and the heat transfer coefficient is not a function of the length parameter at high Grashof numbers. Consequently, it is not significant what length parameter is used in the Grashof number for free convection in turbulent flow in either the air annulus or inside containment.

The independence of the heat transfer coefficient from a length parameter, for turbulent heat transfer on vertical surfaces longer than 2 to 3 feet, was persuasively argued by Jacob[2]. A Grashof number exponent of 1/3 is commonly used by many authors to represent the relationship to the Nusselt number at high Grashof numbers.

CONCLUSION: Whether the analyst uses length or hydraulic diameter in the Grashof number will not affect the value of the heat transfer coefficient.

---

1. Y. Kataoka, T. Fujii, and M. Murase, "Heat Removal Capability and System Pressure of the Water-Wall Type Passive Containment Cooling System", ASME/JSME Nuclear Engineering Conference - Volume 1, ASME 1993.

2. M. Jacob, *Heat Transfer*, Volume I, John Wiley & Sons, 1949, pp 526-534.

McADAMS CORRELATION FOR HORIZONTAL DOME SURFACE

The McAdams correlation for vertical surfaces with turbulent heat transfer:

$$Nu_L = 0.13(Gr_L Pr)^{1/3} \tag{1}$$

underpredicts the Vliet[1] test data for $Gr < 2x10^{12}$. The Vliet data, shown in Figure 1, cover plate inclinations from 30 to 85 degrees from horizontal. The above correlation also underpredicts the McAdams correlation for horizontal plates:

$$Nu_L = 0.14(Gr_L Pr)^{1/3} \tag{2}$$

Vliet correlated his data with the full gravitational acceleration, not the component parallel to the plate.

Kreith recommended Equation 1 for calculating free convection heat transfer to the inside of atmospheric balloons (50 < D < 400 ft). Although no local distribution information is available, data for laminar free convection over the outside of spheres shows little local Nusselt number variation between zero (the stagnation point) and 90 degrees.

CONCLUSION: The McAdams correlation for free convection on vertical plates is valid for use on the inner surface of the AP600 containment, for surfaces of any slope. The gravitational acceleration should be used in the Grashof number without correction for the angle.

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1. G. C. Vliet, "Natural Convection Local Heat Transfer on Constant-Heat Flux Inclined Surfaces", *Journal of Heat Transfer*, November, 1969, pp 511-516.

Vliet Test Data

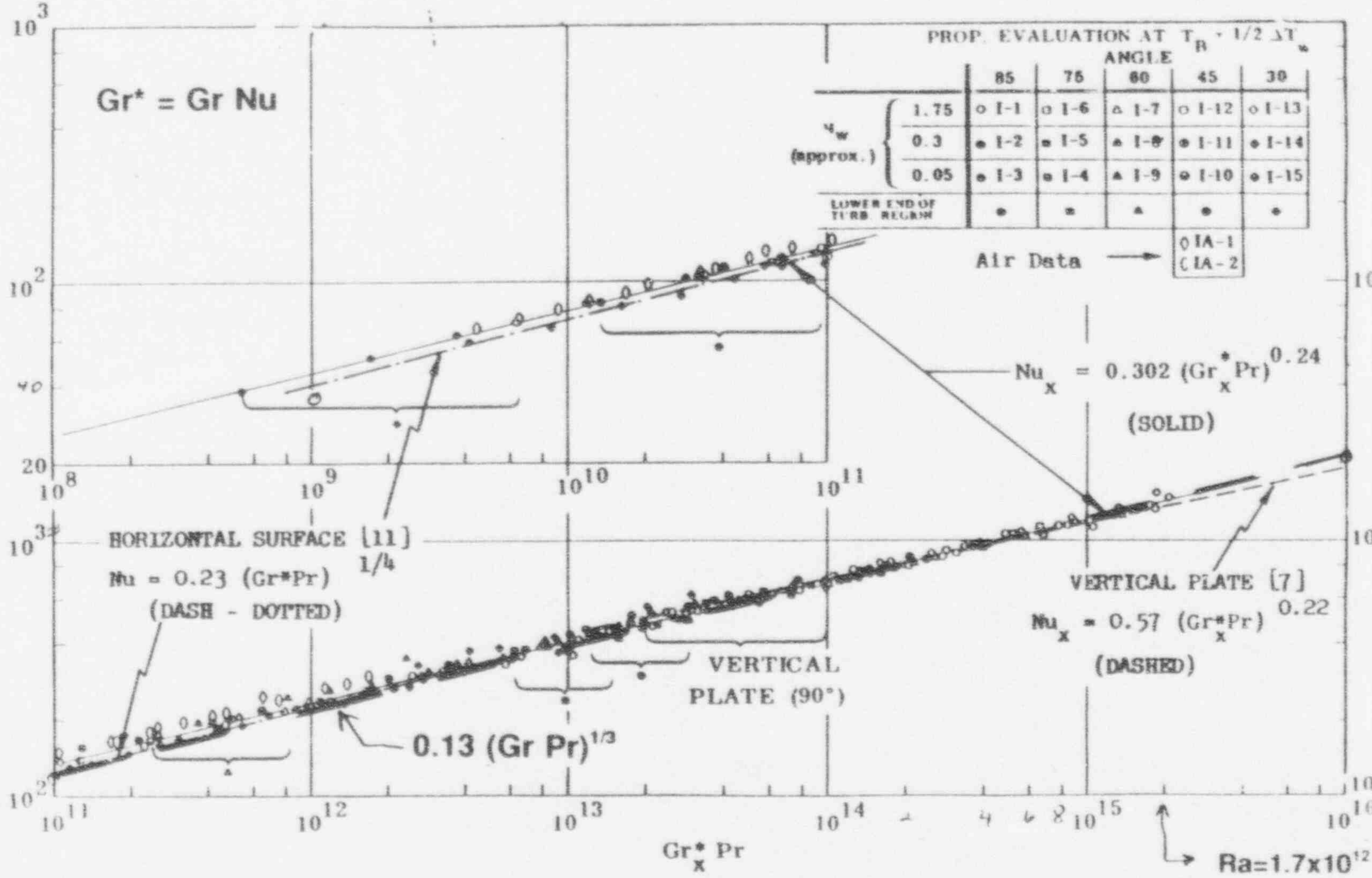


Figure 1. Turbulent natural convection correlation for inclined surfaces

LIQUID FILM FLOW RATE DEPENDENCE IN STC FLAT PLATE EVAPORATION TESTS

The author's presentation of the STC flat plate mass transfer test results[1] did not show adequate agreement with the proposed correlation. The data appeared to deviate depending on the total film flow rate.

The correlation presented in the STC report did not include corrections for mass transfer and only accounted for the heat capacity of the liquid film in an approximate way. Figure 1 shows a comparison between the measurements and the proposed correlation, with corrections for mass transfer and entrance effects applied. The resulting deviation between the predictions and measurement is shown compared to the film flow rate in Figure 2, and a dimensionless ratio of the liquid film heat capacity to the total heat in Figure 3. The correlation with the energy fraction appears better, although neither shows a strong correlation.

STATUS: It was found that much of the unexplained variation in the STC report was due to the absence of mass transfer corrections. Multiple increment calculations produce better comparisons to integral measurements, as shown by our comparisons to the Wisconsin and Sherwood tests. Work is underway to model the STC flat plate tests using WGOTHIC with the liquid film subcooled enthalpy model and several calculational increments.

---

1. W. A. Stewart, A. T. Pieczynski, L. E. Conway, "Tests of Heat Transfer and Water Film Evaporation on a Heated Plate Simulating Cooling of the AP600 Reactor Containment", September 8, 1988, 88-8E9-ADLWR-R3, (Westinghouse Proprietary Class 2).

WGOTHIC Mass Transfer Correlation Comparison to STC Mass Transfer Data Showing Reynolds Number Dependence

[ ] (a,b)

Relationship Between Sherwood Numbers and Liquid Film Flow Rate for the STC Evaporation Tests

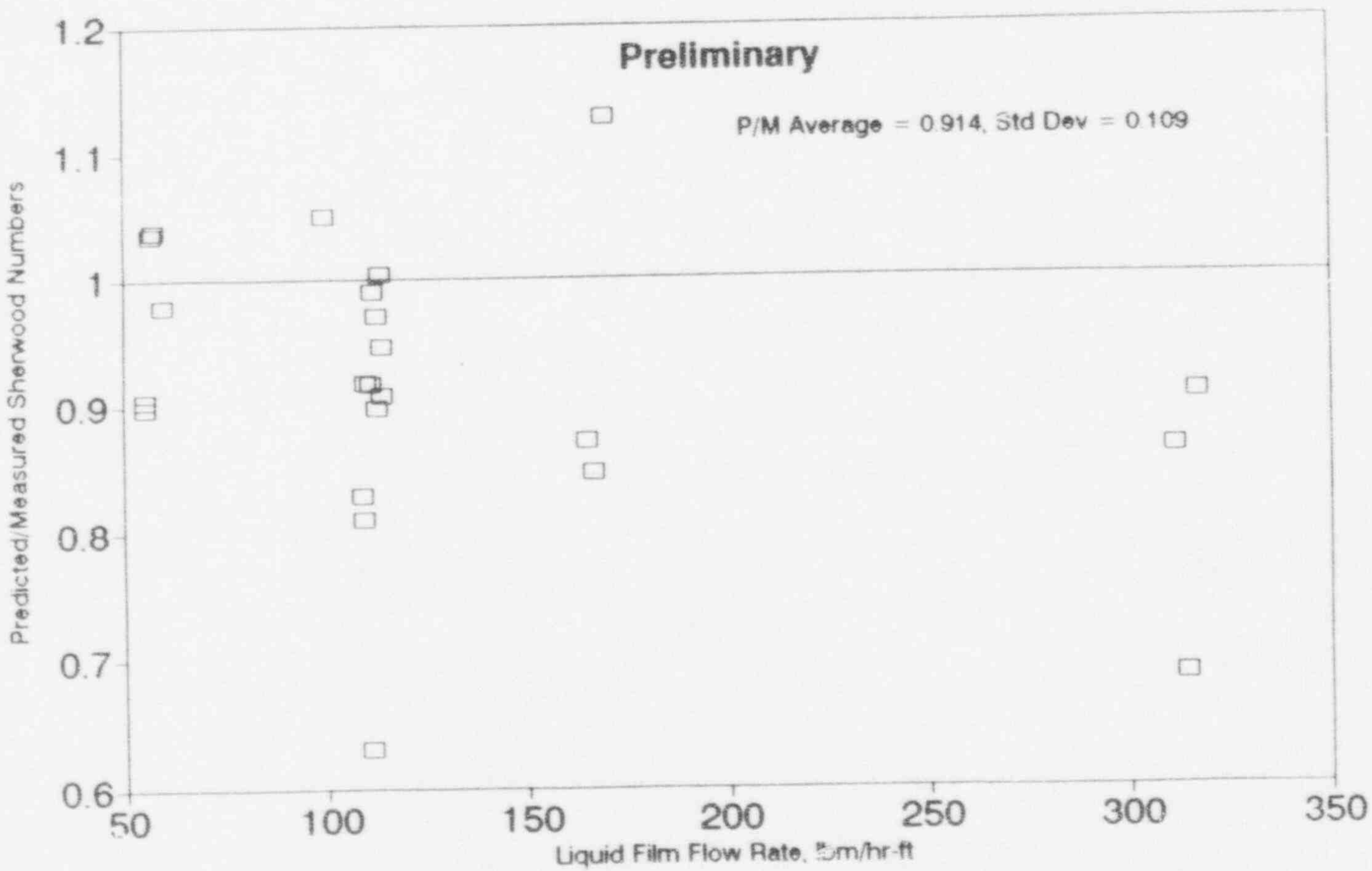


Figure 2. Relationship Between Sherwood Numbers and Liiquid Film Flow Rate for the STC Evaporation Tests.

Relationship Between Sherwood Numbers and Liquid Film Energy Change for the STC Evaporation Tests

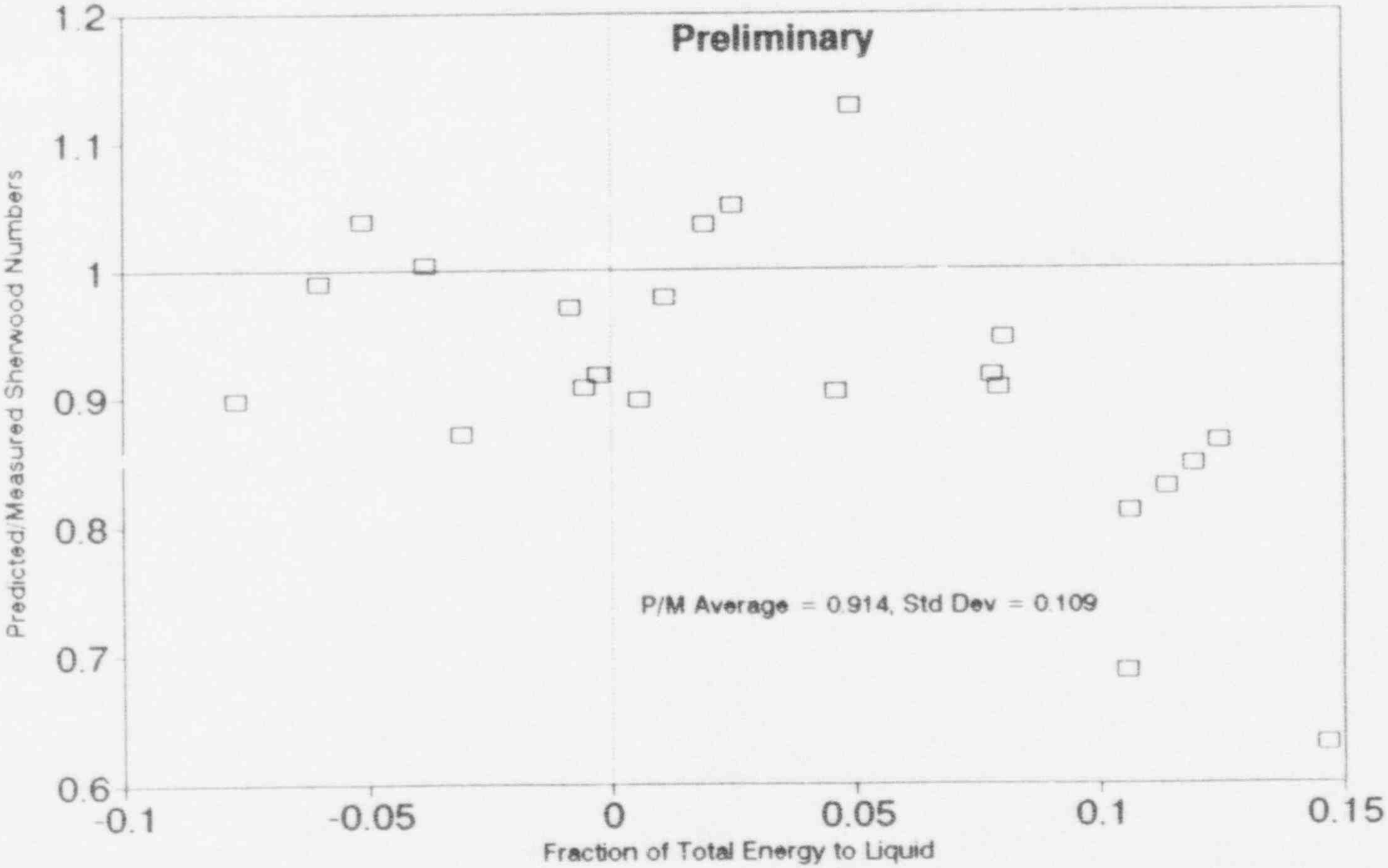


Figure 3. Relationship Between Sherwood Numbers and Liiquid Film Energy Change for the STC Evaporation Tests.

VALIDATE THE HEAT/MASS TRANSFER ANALOGY FOR THE DOME

The validity of the heat transfer correlation for inclined surfaces is supported by comparison to the Vliet[1] test data and presented in response to another question.

The Wisconsin condensation test results[2] for mixed free and forced convection on inclined surfaces are shown in Figure 1 as a function of the inclination angle. The results show that condensation is underpredicted by approximately the same amount for all angles from 0 to 90 degrees.

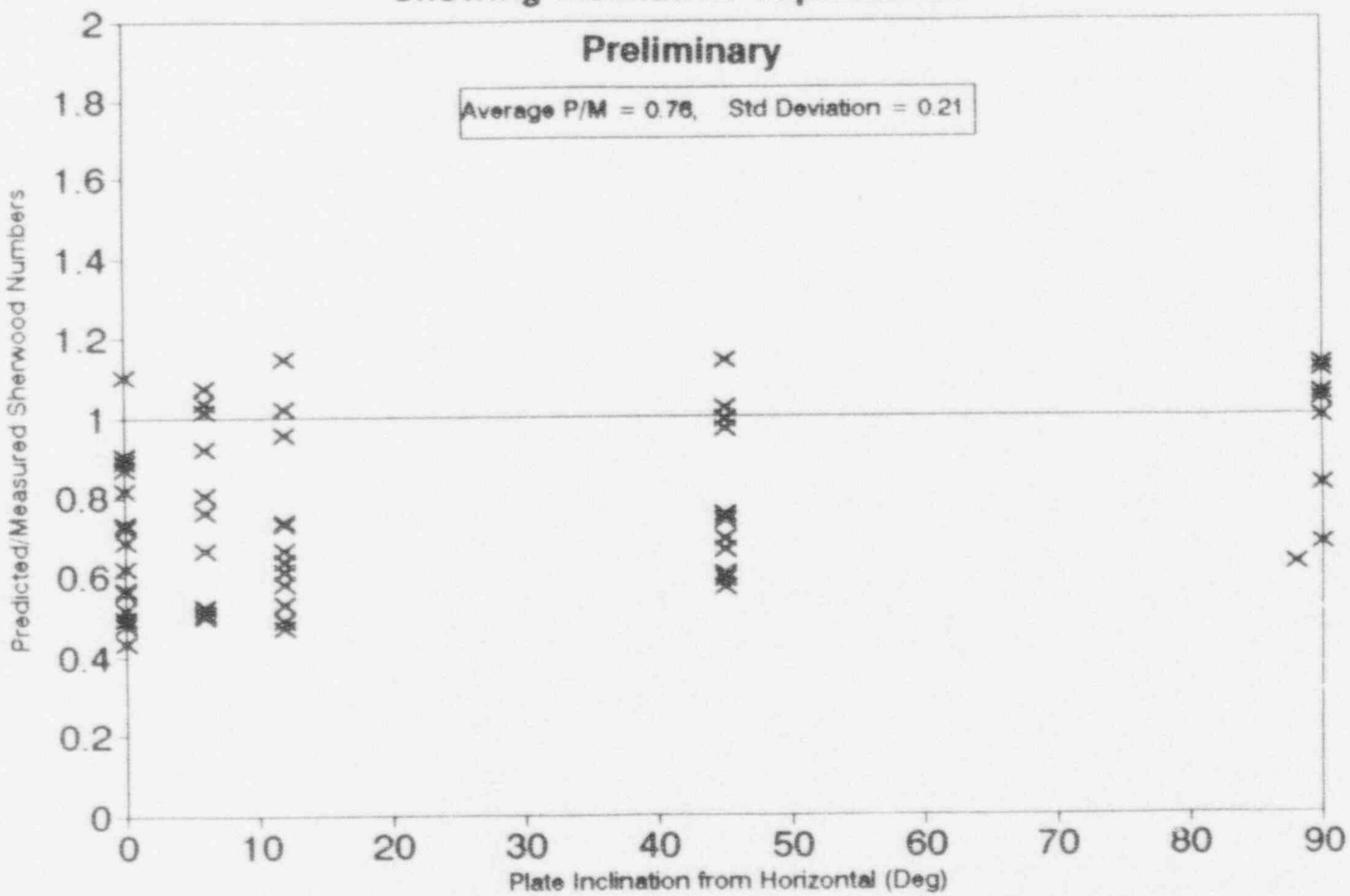
CONCLUSION: The heat/mass transfer analogy is valid for the dome.

---

1. G. C. Vliet, "Natural Convection Local Heat Transfer on Constant-Heat Flux Inclined Surfaces", *Journal of Heat Transfer*, November, 1969, pp 511-516.

2. I. Huhtiniemi, A. Pernsteiner, M. L. Corradini, "Condensation in the Presence of a Noncondensible Gas: Experimental Investigation", April 1991, Final Report.

WGOTHIC Mass Transfer Correlation Comparison to Wisconsin Test Data Showing Inclination Dependence



WGOTHIC Mass Transfer Correlation Comparison to Wisconsin Test Data Showing Inclination Dependence

EFFECT OF FOG ON THE RADIATION HEAT TRANSFER IN THE PCCS AIR GAP

An evaluation was performed to assess the effect of neglecting the presence of fog in the PCCS air gap on the containment heat transfer, the air temperature, and the baffle temperature. The interaction of radiant energy with fog is a complicated problem and its calculation is not compatible with the boundary layer models used in WGOTHIC. Under the worst inlet temperature assumption for the SSAR containment calculations, the 115 °F inlet temperature causes the local bulk humidity to remain below saturation throughout the air gap. Fog was observed in many of the Large Scale Tests which were conducted with inlet temperatures from 30 to 62 °F.

The evaluation showed that in the worst case, fog could cause the containment heat rejection to be 5% less than predicted, and the PCCS air temperature to be 2 °F greater than predicted by neglecting the presence of fog. Fog will reduce the energy deposited in the baffle, so neglecting fog results in overpredicting the baffle temperature.

CONCLUSION: Fog does not appear in the bulk PCCS air under the high inlet temperatures assumed for SSAR calculations. For the LST or more normal inlet conditions in AP600, fog may have a minor affect on the calculated containment heat transfer.

EVAPORATION VS CONDENSATION: MASS TRANSFER CORRECTIONS

The mass transfer correlation is valid for both evaporation and condensation as long as the appropriate mass transfer correction is applied. According to Bird, Stewart and Lightfoot[1], mass transfer necessitates corrections for momentum, heat and mass transfer at the surface. The appropriate correction factors for each of momentum, heat and mass transfer for the case with condensation or evaporation of a single vapor species in the presence of a noncondensible gas are:

$$f^{\bullet} = \theta f \qquad \theta = \frac{\phi}{e^{\phi} - 1} \qquad \phi = \frac{\dot{m}_v}{\rho v_{\infty} f/2} \tag{1}$$

$$h_c^{\bullet} = \theta h_c \qquad \theta = \frac{\phi}{e^{\phi} - 1} \qquad \phi = \frac{\dot{m}_v'' c_p}{h_c} \tag{2}$$

$$k_x^{\bullet} = \theta k_x \qquad \theta = \frac{\ln(R + 1)}{R} \qquad R = \frac{p_{v,surf} - p_{v,bulk}}{P - p_{v,surf}} \tag{3}$$

Note that equation 2 produces a heat transfer coefficient multiplier of $\theta = 0.28$ for evaporation and 2.4 for condensation at 10000 B/hr-ft^2-F and 10 ft/sec. For mass transfer the Equation 3 multiplier reduces to P/p_{Bm} on the conventional mass transfer coefficient, k_g, and gives typical multipliers of 1.8, 1.3 and 1.01 respectively for the Wisconsin, STC flat plate, and Sherwood tests.

Figure 1 presents the mass transfer comparisons with the multiplier equal to P/p_{Bm}.

STATUS: Work is underway to compare various mass transfer corrections for separate effects tests and to apply those to the heat and mass transfer correlations in WGOTHIC.

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1. R. B. Bird, W. E. Stewart, and E. N. Lightfoot, *Transport Phenomena*, John Wiley & Sons.

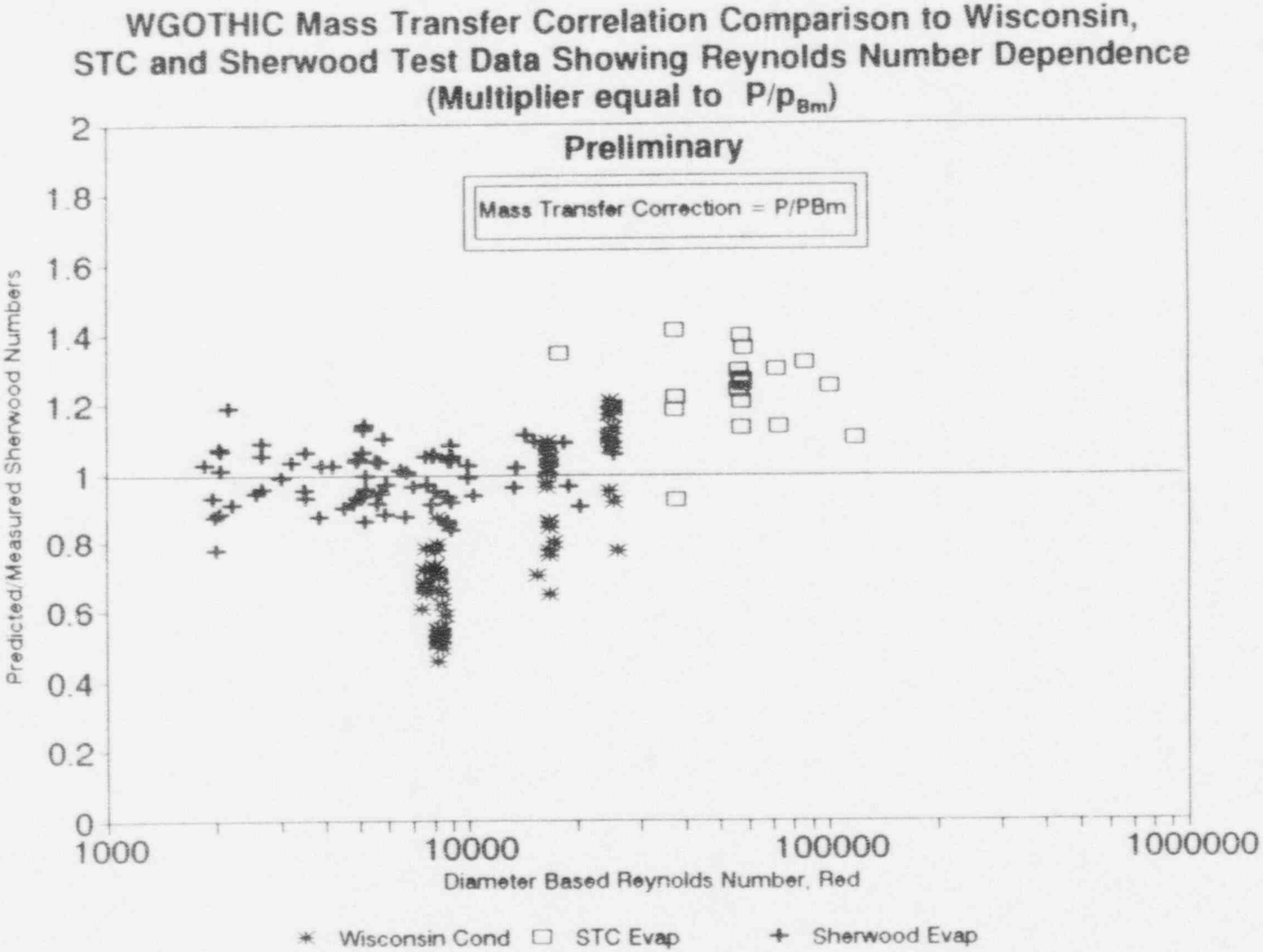

Figure 1. WGOTHIC Mass Transfer Correlation Comparison to Wisconsin, STCand Sherwood Test Data Showing Reynolds Number Dependence

JET MODELING AND BREAK LOCATION

Work is underway to implement criteria and guidance provided by NAI in their GOTHIC documentation on nodalization and mixing lengths necessary for jet modeling. LST confirmatory and follow-on tests produced data for blow-down transients and steady-state operation with jets simulating breaks:

- in the steam generator compartment with the diffuser,
- at the top of the steam generator with and without the diffuser, pointed up, and
- at the top of the steam generator without the diffuser, pointed horizontally.

STATUS: Work is underway on jet scaling, modeling and comparisons with WGOTHIC.

LIQUID FILM STABILITY

Wetting instability puts a lower limit on the thickness of a liquid film. A film which is too thin may separate into two thicker rivulets, or may contract until it's thickness is equal to the lower stability limit. Many authors have addressed liquid film stability and have proposed models to consider the effect of surface tension, heat flux, wetting angle, thermocapilarity, vapor thrust and inertia.

The model must produce agreement with the available body of test results with specific models for heated vs isothermal tests to allow extrapolation from the isothermal Wetting Distribution Tests to the heated AP600. In addition, the model must explain the following observations from the Westinghouse tests:

1. The addition of surfactant to the water in the Water Distribution Tests had little effect on the wetted coverage.

2. The Flat Plate Tests achieved complete wetted coverage at a flow rate of 60 lbm/hr-ft with 15 lbm/hr-ft evaporation.

3. The Large Scale Test achieved complete wetted coverage with 9000 lbm/hr water flow at cold isothermal conditions and a steam flow of 1600 lbm/sec. Complete coverage could not be achieved at 9000 lbm/hr water flow and 1800 lbm/hr steam flow (test 10/18/93).

LIQUID FILM STABILITY (continued)

Investigations to date suggest that:

Vigorous mixing in the storage tank and the turbulent pumped application to the dome, may have prevented the surfactant from diffusing to the water surface where it must collect to be effective.

The porosity of the inorganic zinc coating causes capillary transport of water from the flowing film, through the thickness of the coating to produce a visibly wet surface a couple of inches wide for room temp evaporation and a couple of tenths of an inch for high LST heat fluxes.

The uniformity of the initial flow distribution is important to maximizing coverage.

STATUS: Work is underway to develop analytical models to relate the isothermal, full scale wetting test results to the hot AP600.

LOCAL COMPARISONS

Work is underway to present the WGOTHIC models in the form of dimensionless comparisons of locally measured parameters.

HEAT TRANSFER: Figures 1 and 2 show the Eckert and Diaguila[1] dry convective heat transfer test measurements plotted as functions of the Reynolds number and Grashof numbers, respectively.

LIQUID FILM: Figure 3 shows the local liquid film Nusselt numbers derived from the Wisconsin[2] pure steam condensation tests compared to the Chun and Seban[3] wavy laminar film correlation.

MASS TRANSFER: In many cases investigators do not make local measurements. The tests reported by Gilliland and Sherwood[4] are a good example. Figure 4 shows the original comparison from which G&S concluded that the Sherwood number correlation is:

$$Sh = 0.023\,Re^{0.83}Sc^{.44} \qquad (1)$$

The data were approximately 25% greater than the expected correlating function:

$$Sh = 0.023\,Re^{0.8}Sc^{0.4} \qquad (2)$$

even with the P/p_{Bm} mass transfer correction.

LOCAL COMPARISONS (continued)

I repeated the G&S calculations using the WGOTHIC models for a 1 increment calculation and reproduced the G&S numbers almost exactly. (The value of steam-air diffusion coefficient used by G&S was approximately 10% lower than currently accepted values.) [
the mass transfer and found my predicted mass transfer to be .986 times the measured values with a standard
] The discrepancy in the G&S calculation was due to the use of an average evaporation flux in the Sherwood number calculation whereas the mass flux distribution was actually a log-mean function which reduced to approximately 10% of the inlet value at the outlet. Figure 5 compares the 1 step predicted/measured mass transfer with the 10 step calculations.

Although we can accurately calculate the measured results, a meaningful "overall" Sherwood number cannot be defined. The conclusion is that integral tests with significant internal variation cannot be represented by a single Sherwood number. Since local measurements were not made, only integral comparisons are possible.

One increment calculations for the Wisconsin tests produced an average of .814 with a 0.212 standard deviation; preliminary results from multiple step calculations give an average of .918 with a standard deviation of 0.253.

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1. E. R. G. Eckert and A. J. Diaguila, "Convective Heat Transfer for Mixed, Free, and Forced Flow Through Tubes", *Transactions of the ASME*, May, 1954, pp 497-504.
2. I. Huhtiniemi, A. Pernsteiner, M. L. Corradini, "Condensation in the Presence of a Noncondensible Gas: Experimental Investigation", April 1991, Final Report.
3. R. K. R. Chun and R. A. Seban, "Heat Transfer to Evaporating Liquid Films", *Journal of Heat Transfer*, November, 1971, pp 391-396.
4. E. R. Gilliland and T. K. Sherwood, "Diffusion of Vapors into Air Streams", *Industrial and Engineering Chemistry*, Vol. 26, No. 5, pp. 516-523.

Assisting Mixed Convection Heat Transfer Dependence on Reynolds Number

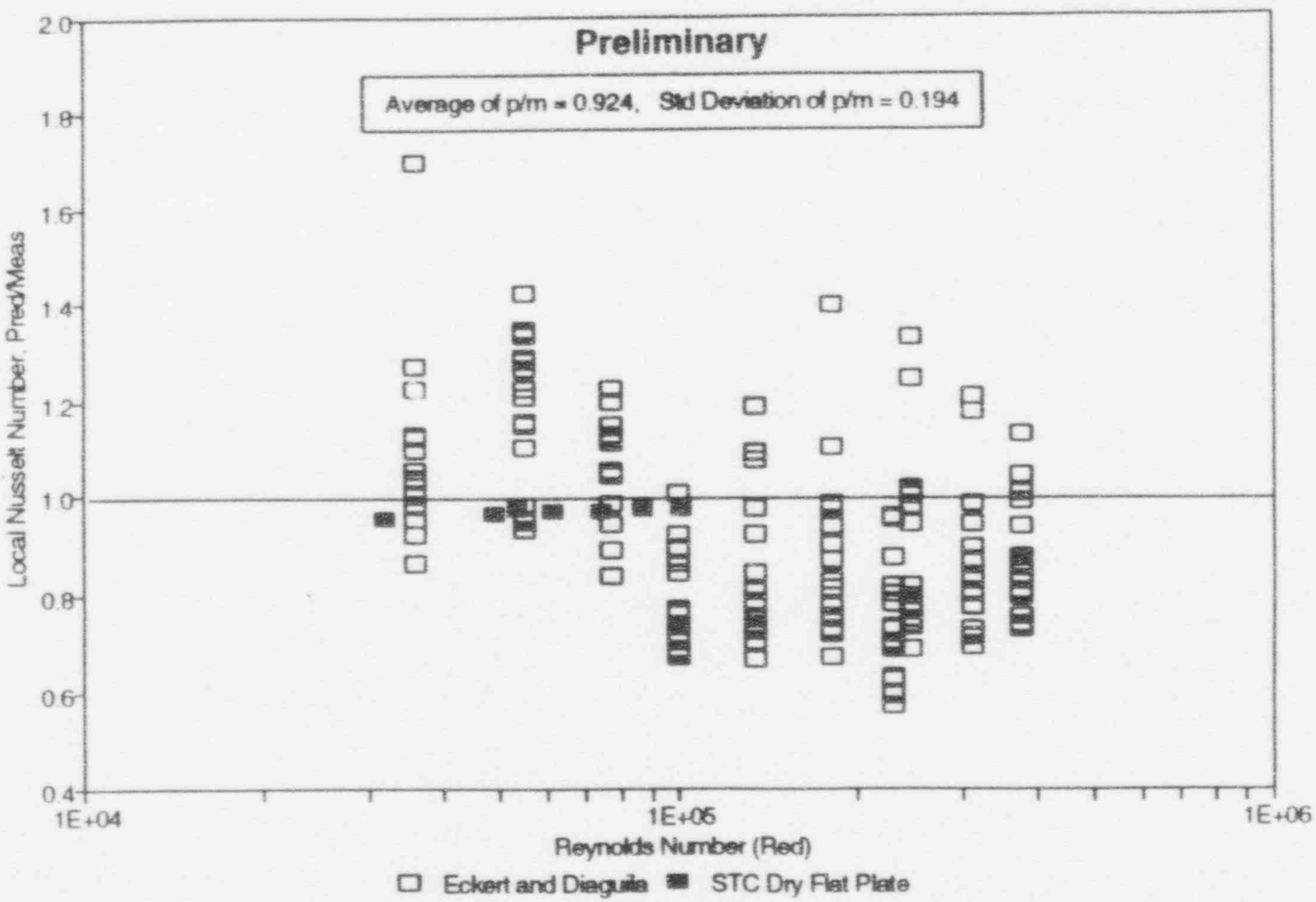

Figure 1. Assisting Mixed Convection Heat Transfer Dependence on Reynolds Number

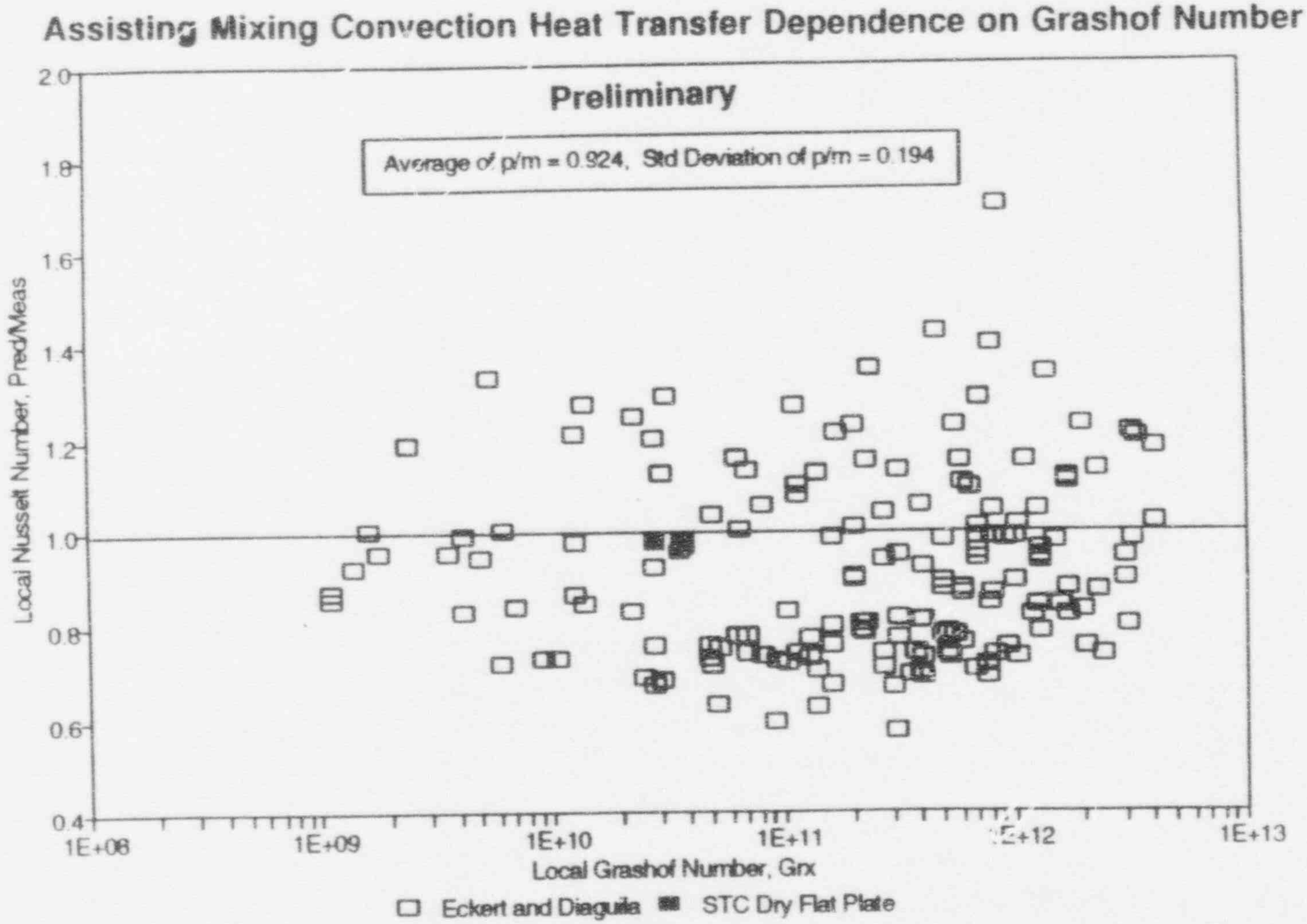

Figure 2. Assisting Mixed Convection Heat Transfer Dependence on Grashof Number

Chun and Seban Liquid Film Nusselt Number Correlation Comparison to the Wisconsin Condensation Test Local Data

(a,b)

Empirical Correlation of Turbulent Flow Data

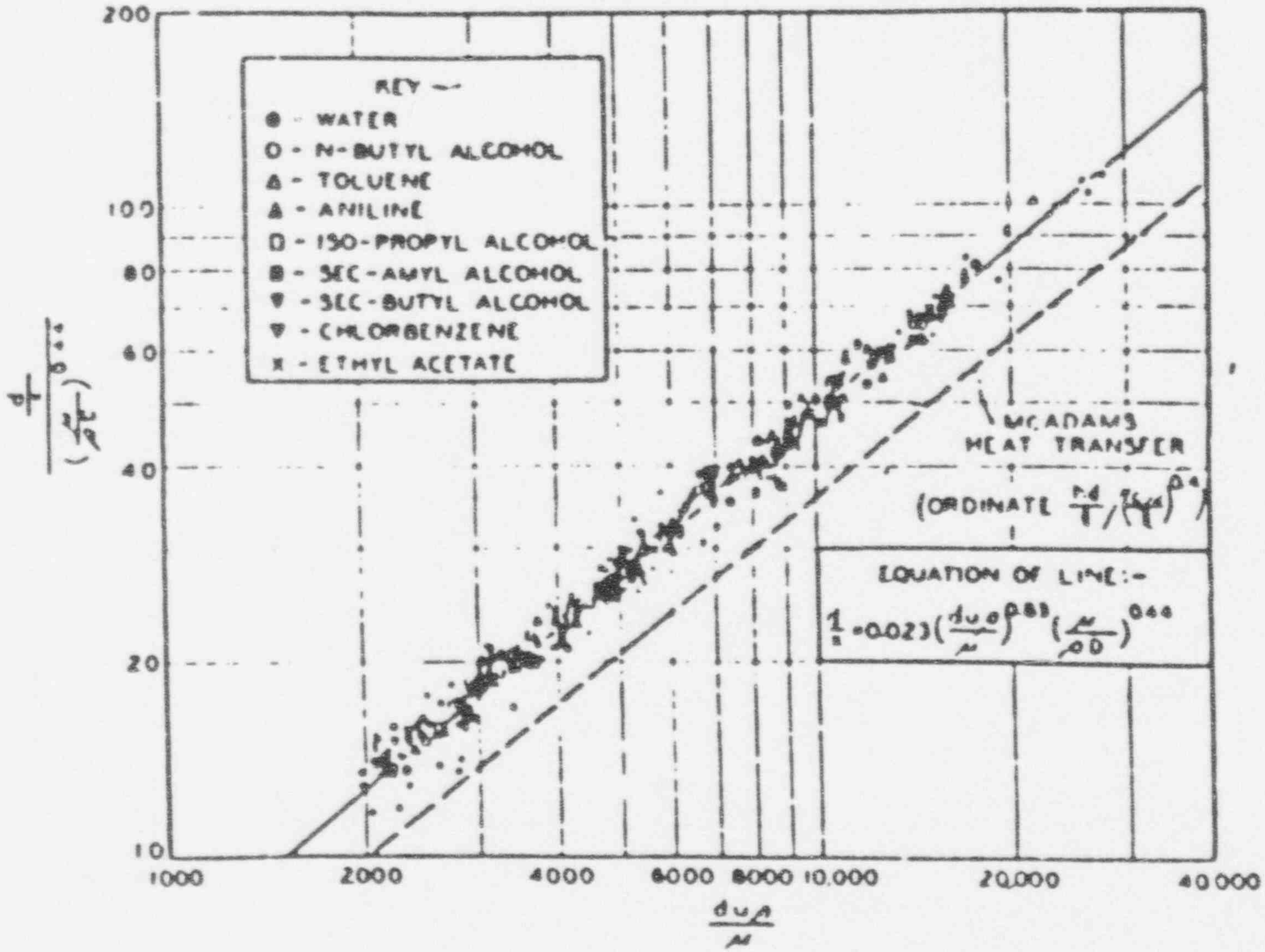

Figure 4 Empirical Correlation of Turbulent Flow Data

Predictions with 10 Increments and 1 Increment Compared to the Gilliland and Sherwood Evaporation Data

(a,c)

WGOTHIC MODEL CHANGES APPLIED AFTER WCAP REVISION 0

M. D. Kennedy
Containment and Radiological Analysis

WGOTHIC PROGRAMMING CHANGES

- Mixed Convection Model eliminates the need for the user to choose between free and forced convection

  Opposed free and forced convection:

$$h_c = (h_{free}^3 + h_{forc}^3)^{1/3}$$

  Assisting free and forced convection, h_c is largest of the following:

$$abs(h_{free}^3 - h_{forc}^3)^{1/3},\ \ 0.75h_{free},\ \ 0.75h_{forc}$$

- Mass Transfer Model

$$m_A = \frac{h_c P M_A}{\rho C_p R T p_{Blm}} \left[\frac{Pr}{Sc}\right]^{2/3} (p_{Ai} - p_{Ag})$$

- Film Stripping to model disruption of film on the inside of the vessel (caused by gutters) without disrupting film on the outside of vessel

WGOTHIC PROGRAMMING CHANGES

- Entrance Effect for Heat/Mass Transfer Coefficients
  - Model higher heat transfer coefficients which exist at the entrance of the air annulus
  - Entrance effects are a characteristic of the tests, and it is modelled to reduce uncertainty in test predictions
  - Entrance effects have negligible impact on heat transfer for AP600
- Restart Capability to facilitate long containment transient
- Subcooled Film Enthalpy Transport
  - Model heating of external water
  - Small effect on AP600 heat removal
  - Larger effect on the test heat removal, and it is modelled to reduce uncertainty in the test predictions
- User Friendly Options
  - Nondimensional numbers output
  - Preprocessor Enhancements

WGOTHIC PROGRAMMING CHANGES

TEST ANALYSIS INPUT AND MODELLING TECHNIQUE IMPROVEMENTS

- Utilize Programming Changes Identified Previously
- Use Flat Plate Heat Transfer Correlation Inside Vessel for Forced Convection
- Distributed Parameter / Subdivided Formulation to validate code's ability to predict hydrogen distribution
- Use Finer Noding in the vessel to better model gradients

WGOTHIC VALIDATION

M. D. Kennedy
Containment and Radiological Analysis

WGOTHIC MODEL VALIDATION

- Specify phenomena to be modeled
- Select analytically valid model
- Verify Scalability of models:
  - Determine range of relevant dimensionless groups
  - Collect separate effects data sets and perform comparisons
- Verify that models in WGOTHIC can represent the passive containment phenomena at different scales and be applied to the AP600
  - Collect separate effects data sets and perform comparisons with WGOTHIC models
  - Perform integral test comparisons with WGOTHIC
  - Determine the effect of hydrogen and transients on the models

WGOTHIC MODEL VALIDATION

SEPARATE EFFECTS TESTS

- Wisconsin Condensation Tests
- STC Flat Plate Dry and Evaporation Tests
- Dry Free Convection Heat Transfer Comparisons Using Selected Literature Sources (for example Hugot, Siegel and Norris, ANL, Miyamoto, etc.)
- Jet Comparisons

WGOTHIC MODEL VALIDATION

INTEGRAL TESTS ANALYSIS STATUS

- Completed and Reported in WCAP, Rev. 0:
  - Small Scale Tests
  - Large Scale Tests without internals
- On Going:
  - Large Scale Tests with internals, helium addition, and transients with blowdowns
  - Blind Test Analysis Process - transient with blowdown

WGOTHIC MODEL VALIDATION

GOTHIC QUALIFICATION REPORT TEST COMPARISONS

- BFMC tests D-1, D-15, D-16 - Blowdown pressure/temperature tests
- BFMC test - 6, 12, 20 - Hydrogen mixing tests
- BFMC C-13, 15 - Steamline break compartment response
- HEDL Tests HM-1 through 7 - LOCA with hydrogen release tests
- LACE tests - Aerosol behavior tests
- MARVIKEN Tests - Full scale steam/water blowdown into containment
- CVTR Tests - Full scale DBA tests
- HDR Tests - Steam/Water blowdown with hydrogen

WGOTHIC MODEL VALIDATION

CODE INPUT PARAMETERS

- Literature sources are used to determine input parameters such as loss coefficients, entrance effects, mixing length, material properties
- Noding guidelines determined from noding sensitivities performed on LST Model
- Base Case WGOTHIC model is developed
  - Basis for all input parameters clearly established
  - for different LST test runs, boundary conditions are changed
  - other parameters would only be changed consistent with noding requirements for jets

    → i.e. changes in steam supply orientation/location/velocity

    → such input changes will be clearly identified

WGOTHIC MODEL VALIDATION

LST NODING SENSITIVITIES

- Detailed noding in the vertical direction is essential just below the elevation at which the steam enters the containment in order to model the entrainment and predict noncondensible stratification
- Grid area in line with the jet should be no larger than the jet area so that artificial spreading is not induced
- Relatively small nodes along the wall are necessary to model concentration gradient caused by condensation
- Several elevations below the operating deck are needed to model the relatively rapid axial change in noncondensible gradient

WGOTHIC MODEL VALIDATION

BLIND TEST PROCESS

Stage 1 - Baseline Computer Code Models (WCAP, Rev.0)

Stage 2 - Test Analysis/Computer Model Validation (Ongoing)

Stage 3 - Blind Test Prediction

Stage 4 - Evaluation of Prediction

Stage 5 - Computer Model Update (Plan Assumes not Necessary)

Stage 6 - Blind Test Report

WGOTHIC MODEL VALIDATION

A COMPREHENSIVE VERIFICATION OF CODE MODELS

- Separate effects tests isolate particular phenomena to validate the individual code models

- Validate computer code with integral effects tests

  - Tests include integral effects of significant containment physics, such as internal flow field, steam delivery characteristics, compartments, long & short term heat sinks, exterior water film evaporation and air cooling heat removal

  - Demonstrate that models in code work well for integral tests

  - Show that code predicts internal flow field well (for example, internal temperature and noncondensible distributions, axial wall temperatures, local bulk velocities)

- Application to AP600

  - Can use computer code to scale up from integral test to AP600

PCCS TEST ANALYSIS RAI SUMMARY

M. D. Kennedy
Containment and Radiological Analysis

PCCS TEST ANALYSIS RAI SUMMARY

RAI #	SUBJECT
480.2	Mechanistic Heat/Mass Transfer Correlations
480.4	Dry Shell LST and SST Data
480.8	Natural Circulation of Air in the PCCS
480.9	HT to Internal Structures and Mixing in the Containment
480.10	Jet Discharge: Location/Orientation/Scaling
480.11	1/8 Scale Facility Instrumentation
480.12	1/8 Scale Facility Test Matrix
480.13	Westinghouse Scaling Approach[1]
480.14	Mechanistic Correlations in WGOTHIC[1]
480.15	WGOTHIC Validation Using Test Data[1]
480.16	WGOTHIC Numerics[1]
480.17	External Film Pattern/Water Distribution Tests[2]
480.18	Degree of "Rain" in the AP600 Containment
480.32	Hydrogen Control-Prediction of Hydrogen Distribution
951.2	WGOTHIC Condensation Model

[1] To be addressed in WCAP-13246, Rev. 1
[2] To be addressed further in an RAI revision