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Attention: J. S. Wermiel, Chief
Reactor Systems Branch
Office of Nuclear Reactor Regulation

Our ref: LTR-NRC-02-35

July 10, 2002

Subject: Proprietary Presentation Material for July 11th Meeting to Discuss Downcomer Boiling

Reference: 1. Letter from J. S. Galembush (Westinghouse) to S. Bloom (NRC), "Proprietary Presentation Material from August 11, 2000 Meeting to Discuss Downcomer Boiling", LTR-NRC-00-5979, September 7, 2000.

Dear Mr. Wermiel:

Enclosed are copies of the proprietary and non-proprietary versions of the presentations for the subject meeting entitled "Treatment of Downcomer Boiling in the 1981 Westinghouse Large Break LOCA Evaluation Model with BASH (BASH-EM)" and "Application of Sudo Void Fraction Correlation: Validation at Full Scale and Justification of Assumptions".

This submittal contains Westinghouse proprietary information consisting of trade secrets, commercial information, or financial information which we consider privileged or confidential pursuant to 10 CFR 9.17(a)(4). Therefore, it is requested that the Westinghouse proprietary information attached hereto be handled on a confidential basis and be withheld from public disclosure. Accordingly, correspondence with respect to this letter should reference the Application for Withholding and accompanying Affidavit (AW-00-1422) that were provided in Reference 1.

This material is for your internal use only and may be used solely for the purpose for which it is submitted. It should not be otherwise used, disclosed, duplicated, or disseminated, in whole or in part, to any other person or organization outside the Commission, the Office of Nuclear Reactor Regulation, the Office of Nuclear Regulatory Research, and the necessary subcontractors that have signed a proprietary non-disclosure agreement with Westinghouse without the expressed written approval of Westinghouse.

Very truly yours,

H. A. Sepp, Manager
Regulatory and Licensing Engineering

Attachments

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Very truly yours,

H. A. Sepp, Manager
Regulatory and Licensing Engineering

Attachments

# TREATMENT OF DOWNCOMER BOILING IN THE 1981 WESTINGHOUSE LARGE BREAK LOCA EVALUATION MODEL WITH BASH (BASH-EM)

PRESENTATION TO USNRC

JULY 11, 2002

RICHARD R. SCHOFF
WESTINGHOUSE ELECTRIC COMPANY, LLC
(412) 374-5685

## PURPOSE

TO PROVIDE ADDITIONAL INFORMATION REGARDING THE TREATMENT OF DOWNCOMER BOILING IN BASH-EM, IN RESPONSE TO THE USNRC LETTER OF MARCH 27, 2002[1]

## OVERVIEW

THE INFORMATION REQUESTED IN REF. 1 IS SUMMARIZED AS FOLLOWS:

| # | APP. K § | TOPIC |
|---|---|---|
| 1 | I.A.6 | REACTOR INTERNALS HEAT TRANSFER |
| 2 | I.D.3 | CALCULATION OF REFLOOD RATE |
| 3 | I.D.4 | INTERACTION OF STEAM WITH ECC WATER |
| 4 | I.D.5 | REFILL AND REFLOOD HEAT TRANSFER |
| 5 | II.2 | SOLUTION CONVERGENCE |
| 6 | II.3 | SENSITIVITY STUDIES |
| 7 | II.4 | COMPARISON TO APPLICABLE EXPERIMENTAL DATA |
| 8 | - | JUSTIFICATION FOR USE OF THE SUDO CORRELATION |
| 9 | - | JUSTIFICATION OF ASSUMPTIONS FOR OTHER BASH CALCULATED PARAMETERS AFTER DC BOILING |
| 10 | - | SUBMITTAL OF TECHNICAL JUSTIFICATION FOR USNRC REVIEW AND APPROVAL |
| 11 | - | PCT AND OXIDATION IMPACTS FOR ALL AFFECTED PLANTS THAT HAVE APPLIED THE LOCBART EXTENSION METHOD AS PART OF THEIR LICENSING BASIS |

- THIS PRESENTATION WILL ADDRESS ITEMS 1-6 AND 9
  - BASIC APPROACH: SUMMARIZE HOW CURRENTLY ADDRESSED IN BASH-EM (MOSTLY BY REFERENCE), AND DESCRIBE HOW TREATED AFTER DC BOILING
- NEXT, ITEMS 7 AND 8 WILL BE PRESENTED BY C. FREPOLI
- ITEMS 10 AND 11 AND CE PLANTS TO BE DISCUSSED FOLLOWING THESE PRESENTATIONS

## BASH-EM CODE STREAM

- MAIN CODES ARE SATAN-VI, BASH, AND LOCBART
  - SATAN-VI CALCULATES THE RCS BLOWDOWN THERMAL-HYDRAULIC TRANSIENT
  - BASH CALCULATES THE RCS REFILL AND REFLOOD THERMAL-HYDRAULIC TRANSIENTS
  - LOCBART CALCULATES THE HOT ASSEMBLY AND HOT ROD CLADDING HEATUP FOR ALL THREE PHASES OF THE LBLOCA TRANSIENT
- BASH CREATED BY MERGING THE BART-A1 CORE HEAT TRANSFER CODE WITH THE NOTRUMP SYSTEM THERMAL-HYDRAULIC CODE
- LOCBART CREATED BY MERGING THE BART-A1 CORE HEAT TRANSFER CODE WITH THE LOCTA-IV FUEL ROD CONDUCTION CODE

# 1. REACTOR INTERNALS HEAT TRANSFER

BASH STRUCTURAL METAL HEAT MODELS DESCRIBED IN WCAP-10266-P-A REVISION 2 [REF. 2]:

- SLAB MODEL USED FOR MOST STRUCTURES (§3.13)
- DETAILED MODEL USED FOR DOWNCOMER AND LOWER PLENUM STRUCTURES (§3.14)
  - ACCURATE CALCULATION REQUIRES RESOLUTION OF INTERNAL TEMPERATURE GRADIENTS
  - CONSIDERS PLATE, CYLINDRICAL, OR SPHERICAL GEOMETRY
  - ALLOWS FOR COMPOSITE MATERIAL (E.G., VESSEL)
  - IMPLICIT FINITE DIFFERENCE SOLUTION SCHEME
- HEAT LINKS CONNECT METAL AND FLUID NODES (§3.20)
  - SUBCOOLED, SATURATED, AND SUPERHEATED FLUID
  - REGIME-DEPENDENT HEAT FLUX CALCULATIONS, USING APPROPRIATE CORRELATIONS
  - USES MAXIMUM HEAT FLUX OF POSSIBLE REGIMES, WHICH PRODUCES CONDUCTION-LIMITED BEHAVIOR

FIGURE 1-1 SHOWS THE HEAT TRANSFER REGIME SELECTION LOGIC USED IN BASH FOR SUBCOOLED FLUID, WHICH IS APPLIED TO THE DOWNCOMER IN PWR CALCULATIONS

- 5 HEAT TRANSFER REGIMES CONSIDERED:
  - NATURAL CONVECTION (MACADAMS)
  - FORCED CONVECTION (DITTUS-BOELTER)
  - NUCLEATE BOILING (THOM)
  - TRANSITION BOILING (W TB CORRELATION)
  - FILM BOILING (SANDBERG)
- CHF BASED ON MACBETH CORRELATION

FIGURE 1-2 SHOWS THE TOTAL DOWNCOMER METAL HEAT RELEASE VS. TIME FOR A SAMPLE BASH PWR CALCULATION (4-LOOP ICE CONDENSER PLANT)

- SOME TRANSITION BOILING EARLY IN REFLOOD (~10 S); OTHERWISE NUCLEATE BOILING

# FIGURE 1-1

(a,c)

# FIGURE 1-2

(a,c)

# LOCBART EXTENSION METHOD USES HEAT FLOW RATE AT ONSET OF DC BOILING TO CALCULATE $V_{IN}$ REDUCTION

- SUBCOOLED NUCLEATE BOILING AT DC WALLS JUST PRIOR TO BULK FLUID REACHING SATURATION
- CONTINUOUS BEHAVIOR EXPECTED AT BOUNDARY OF SUBCOOLED AND SATURATED NUCLEATE BOILING REGIMES
- NO CREDIT FOR FURTHER REMOVAL OF WALL ENERGY, WHICH WOULD EVENTUALLY TERMINATE BOILING AND RESTORE DRIVING HEAD FOR CORE REFLOODING

# 2. CALCULATION OF REFLOOD RATE

## A. LOCKED ROTOR ASSUMPTION

- PUMP MODELED AS RESISTANCE IN COLD LEG, BASED ON LOCKED ROTOR CONDITION [REF. 2 §11.0]
- LOCKED ROTOR YIELDS MAXIMUM RESISTANCE THROUGH PUMP, WHICH REDUCES $V_{IN}$ AND INCREASES PCT [REF. 3]
- NO CHANGE TO LOCKED ROTOR ASSUMPTION AFTER ONSET OF DC BOILING

## B. CARRYOVER FRACTION

- BART REPLACED SIMPLE "CARRYOUT CORRELATION" WITH MECHANISTIC ENTRAINMENT CALCULATIONS
- COMPLIANCE DEMONSTRATED IN REF. 2 BASED ON PREDICTIONS OF $V_{IN}$ AND $\int V_{IN}$
  - KEY PARAMETER FROM REFLOOD CALCULATION
  - DIRECT INFLUENCE ON PCT
- $V_{IN}$ REDUCED AFTER ONSET OF DC BOILING

## C. ACCUMULATOR NITROGEN DISCHARGE

- EFFECTS OF ACCUMULATOR NITROGEN DISCHARGE DISCUSSED IN APPENDIX F OF REF. 2
  - PRIOR EM STUDY SHOWED $V_{IN}$ INCREASE DUE TO PRESSURIZATION OF DOWNCOMER [REF. 4]
  - ALSO SUPPORTED BY EXPERIMENTAL RESULTS (E.G., LOFT)
- SEMISCALE TESTS INDICATED LONG-TERM INCREASE IN SYSTEM PRESSURE [REF. 5]
  - WOULD YIELD CORRESPONDING INCREASE IN $V_{IN}$
  - WOULD ALSO REDUCE ECC FLOW; SMALL EFFECT OVER PRESSURE RANGE OF INTEREST
- EFFECTS OF ACCUMULATOR NITROGEN DISCHARGE CONSERVATIVELY NEGLECTED IN BASH
- NO CHANGE TO TREATMENT AFTER DC BOILING

## 3. INTERACTION OF STEAM WITH ECC WATER

- BASH ASSUMES EQUILIBRIUM BEHAVIOR IN COLD LEGS [REF. 2 §11.0]
  - MAXIMIZES CONDENSATION OF STEAM FLOWING FROM INTACT COLD LEGS TO DOWNCOMER
  - MINIMIZES PRESSURIZATION OF DOWNCOMER DUE TO STEAM FLOWING THROUGH BROKEN NOZZLE
  - MINIMIZES SUBCOOLING OF FLUID ENTERING DOWNCOMER
  - REDUCES $V_{IN}$
- ADDITIONAL $\Delta P$ APPLIED IN COLD LEGS TO ACCOUNT FOR PRESSURE OSCILLATIONS DURING ACCUMULATOR INJECTION [REF. 2 §11.0; REF. 4 §2.2.1]
  - 1.8 PSI FOR 90° INJECTION ANGLE
  - 0.6 PSI FOR 45° INJECTION ANGLE
- EFFECTS OF DC BOILING/ENTRAINMENT CONSIDERED IN LOCBART EXTENSION METHOD
  - VERTICAL ENTRAINMENT EFFECTS REFLECTED THROUGH USE OF VOID FRACTION CORRELATION
  - LATERAL ENTRAINMENT EFFECTS CONSIDERED NEGLIGIBLE AT CONDITIONS OF INTEREST
  - DISCUSSED FURTHER WITH ITEMS 7 AND 8

## 4. REFILL AND REFLOOD HEAT TRANSFER

- COMPLIANCE ORIGINALLY DEMONSTRATED IN REF. 2 §11.0

- CONSERVATIVE BASH-EM MODELING LEADS TO A SUBSTANTIAL DELAY BETWEEN END-OF-BLOWDOWN AND BOTTOM-OF-CORE-RECOVERY
  - TYPICAL PWR REFILL PERIODS OF 10-15 SECONDS
  - ESTIMATED 180°F CONSERVATISM IN NUREG/IA-0127[6]
  - LOCBART ASSUMES ADIABATIC HEATUP (EXCEPT FOR ROD-TO-ROD RADIATION); LEADS TO SEVERE CLADDING TEMPERATURE EXCURSION

- DIRECT HEAT TRANSFER TO LIQUID IGNORED WHEN $V_{IN} \leq 1$ IN/S

- SIGNIFICANT HEAT TRANSFER PENALTY INCURRED IN LOCBART DUE TO BLOCKAGE TREATMENT
  - MODELED AS A REDUCTION IN MASS VELOCITY IN THE VICINITY OF THE BURST, WHICH DEGRADES HEAT TRANSFER AND INCREASES PCT
  - MAXIMUM FLOW REDUCTION CALCULATED BASED ON NUREG-0630[7] FORMULATION
  - EXPERIMENTS ALSO SHOW OFFSETTING BENEFITS DUE TO FLOW ACCELERATION, TURBULENCE INTENSIFICATION, AND DROPLET ATOMIZATION [REF. 8]; NOT EXPLICITLY MODELED IN LOCBART
  - FIGURE 4-1 ILLUSTRATES THE BLOCKAGE EFFECT FOR A SAMPLE CALCULATION; THIS REPRESENTS A SIGNIFICANT CONSERVATISM IN BASH-EM

# FIGURE 4-1

(a,c)

- LOCBART HEAT TRANSFER MODELS BENCHMARKED AGAINST FLECHT, FLECHT SEASET, G2 TESTS IN WCAP-10484-P-A ADDENDUM 1[9]
  - FOR SIMPLE EGG-CRATE GRIDS (FLECHT), LOCBART PREDICTS PCTs NEAR THE MEAN OF THE DATA, WITH A SLIGHTLY CONSERVATIVE CAPTURE FRACTION
  - FOR PRODUCTION-TYPE MIXING VANE GRIDS (G2), LOCBART PREDICTIONS BOUND NEARLY ALL OF THE DATA (FIGURES 4-2 TO 4-5)
  - HEAT TRANSFER BENEFIT OF MIXING VANES EVIDENT IN TESTS BUT NOT FULLY REALIZED BY THE MODEL
- NO CHANGE TO REFLOOD HEAT TRANSFER MODELING AFTER DC BOILING

# FIGURE 4-2

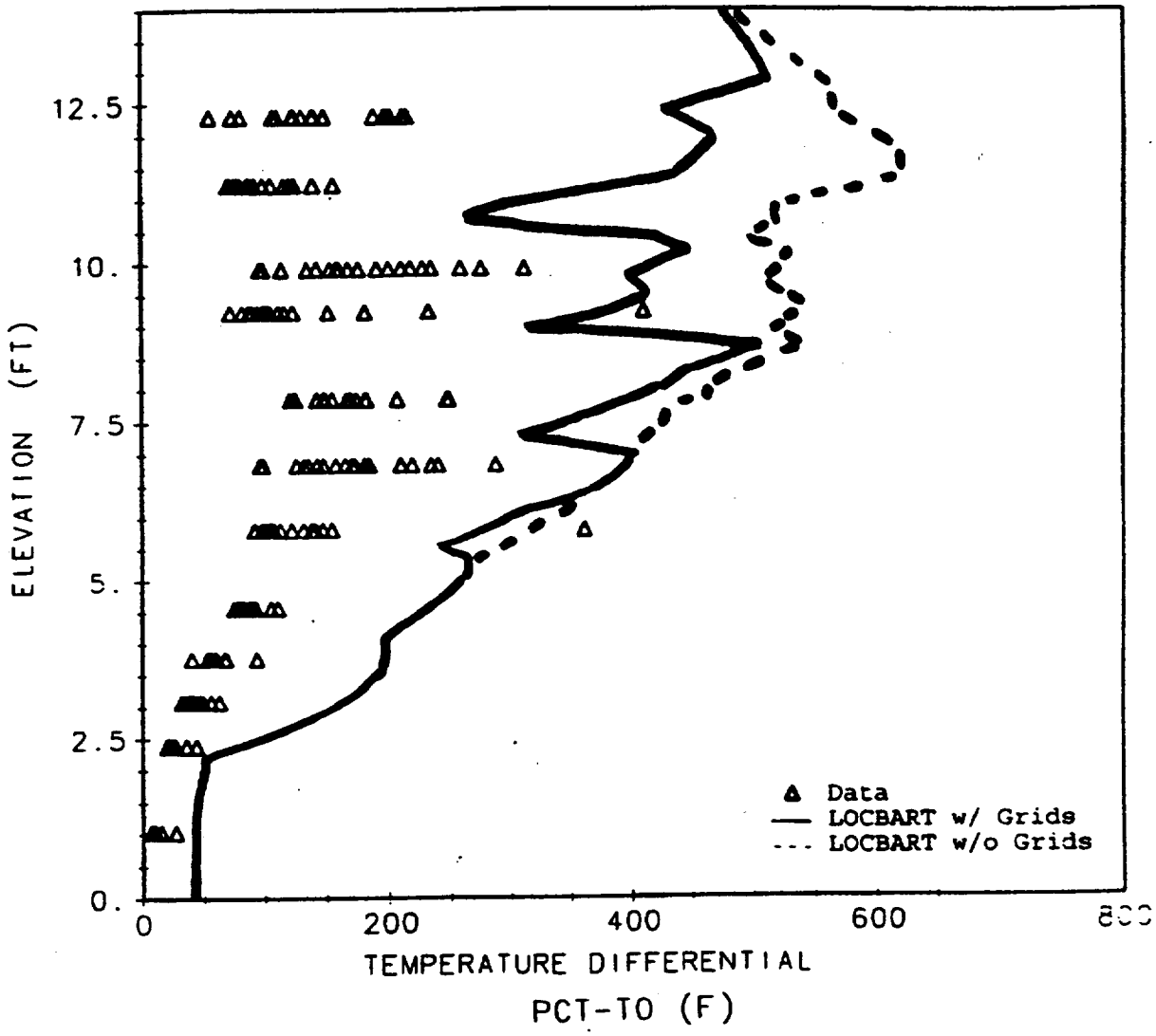



**Figure 102. Maximum Clad Temperature Rise (PCT-TO) Versus Elevation for G2 562.**

# FIGURE 4-3

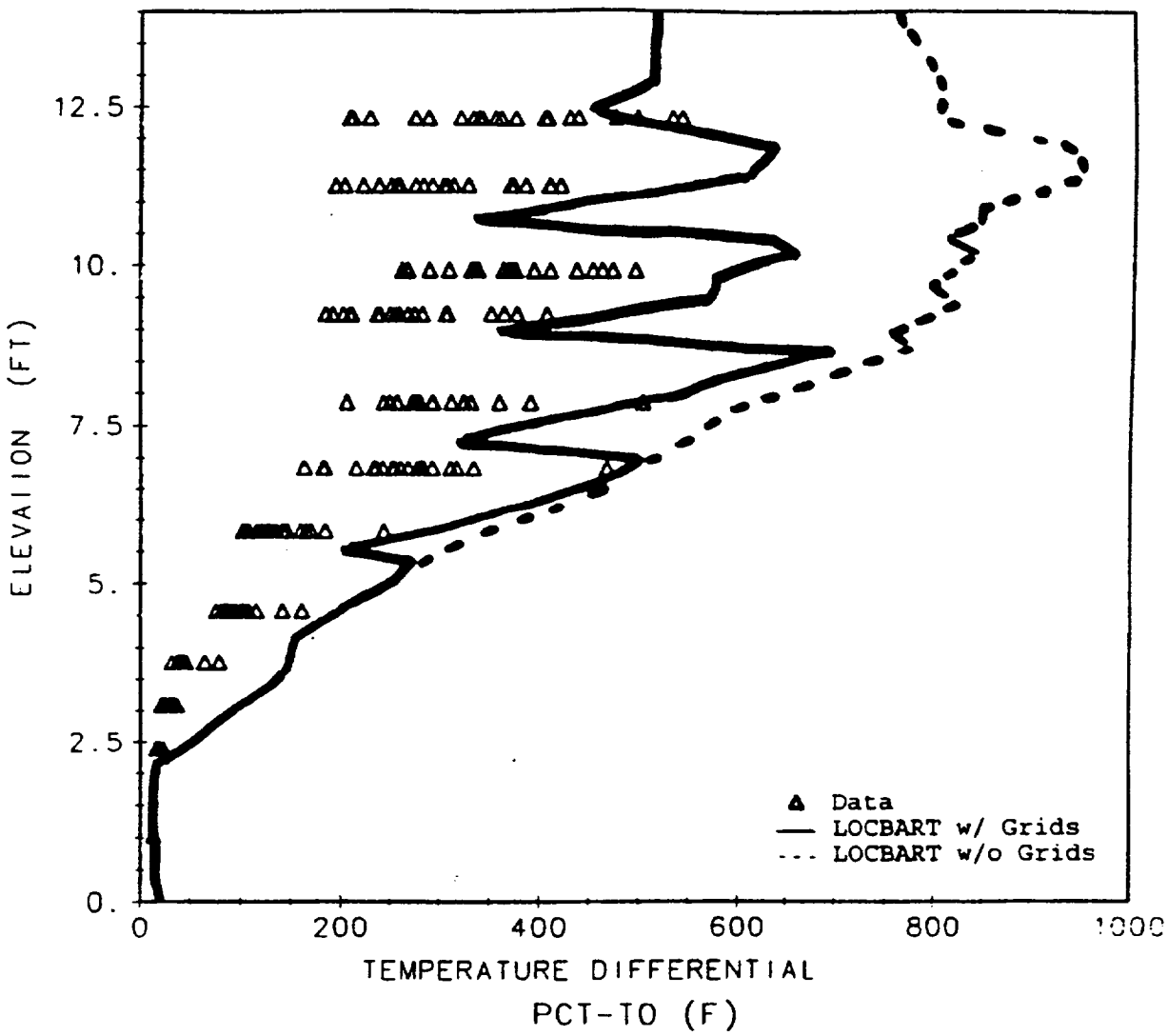



**Figure 111. Maximum Clad Temperature Rise (PCT-TO) Versus Elevation for G2 564.**

# FIGURE 4-4

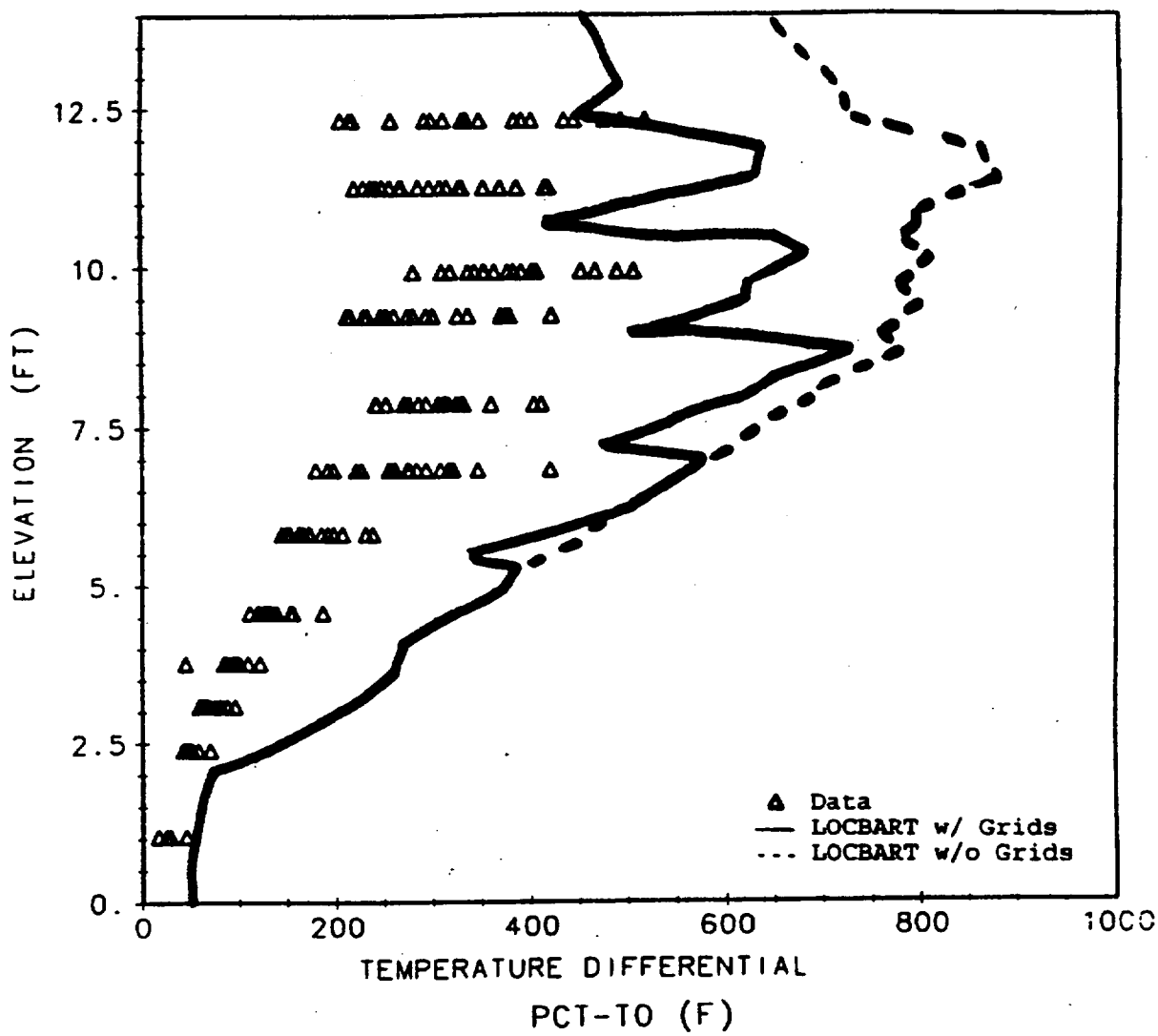



**Figure 120. Maximum Clad Temperature Rise (PCT-TO) Versus Elevation for G2 568.**

FIGURE 4-5

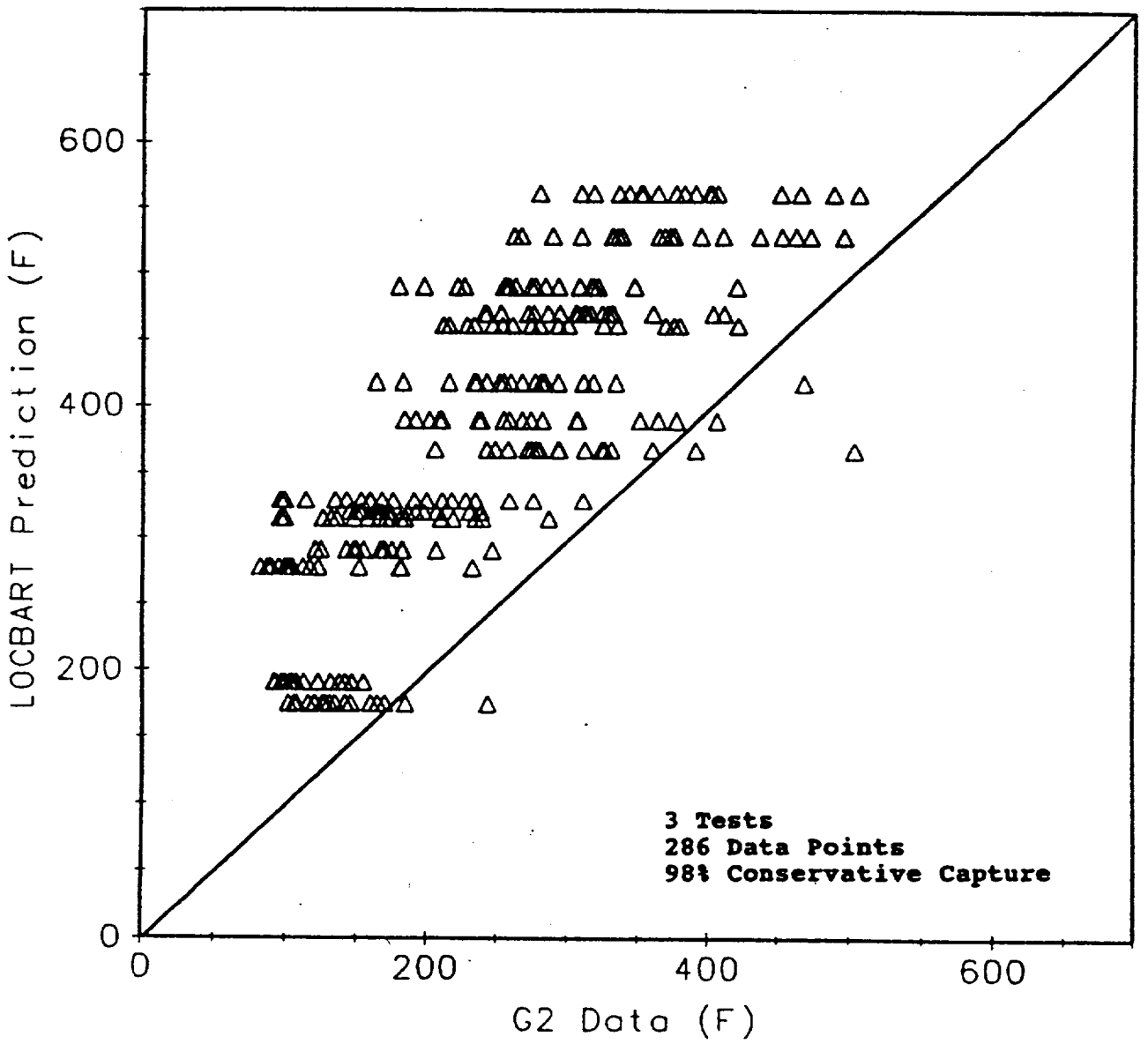



**Figure 129. G2 Experiments Data Versus LOCBART Model Clad Temperature Rise Adjusted for [ ].a,c**

# 5. SOLUTION CONVERGENCE

- [

]$^{(a,c)}$

# FIGURE 5-1

(a,c)

- BASH SOLUTION CONVERGENCE DEMONSTRATED IN REF. 2 §11.0

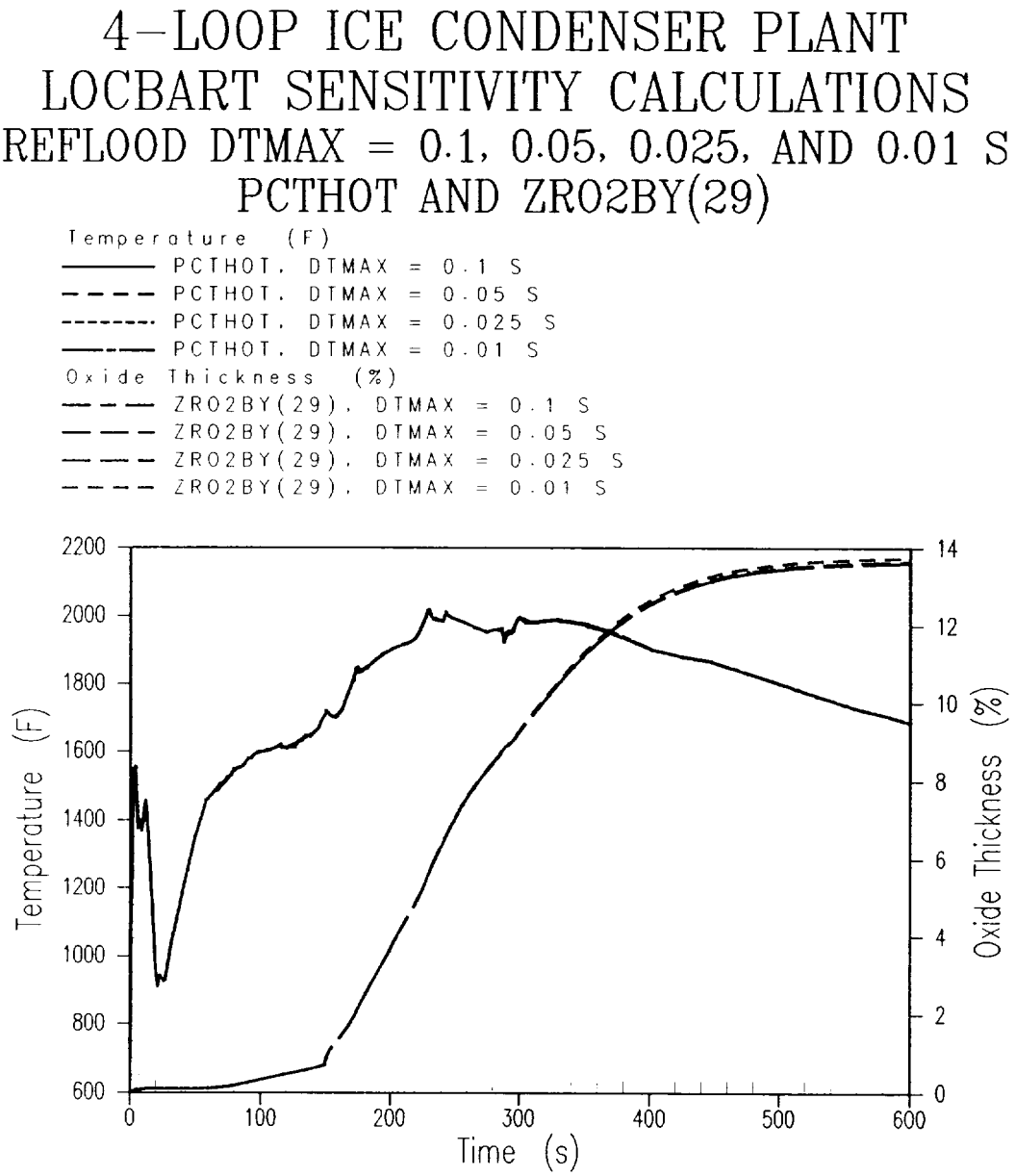
- LOCBART SOLUTION CONVERGENCE BASED ON AXIAL NODE SPACING AND TIME STEP SELECTION

  - AXIAL NODE SPACING DETERMINED BY MAXIMUM ALLOWABLE VALUE FROM WCAP-9561-P-A[10] (6″), RESOLUTION OF BLOCKAGE PROFILE (3″), AND MINIMUM VALUE ALLOWED BY APP. K §I.A.5 (3″); NO CHANGE TO NODE SPACING AFTER DC BOILING

  - TIME STEP SIZE DURING REFLOOD CALCULATED INTERNALLY USING APPROPRIATE SELECTION CRITERIA; SAMPLE CALCULATIONS SHOW MINIMAL EFFECT OF REDUCTION IN MAXIMUM ALLOWABLE VALUE (FIGURE 5-2)

- SAMPLE LOCBART CALCULATIONS SHOW EXPECTED RESPONSE TO VARIATIONS IN CORE INLET FLOODING RATE AFTER DC BOILING (FIGURES 5-3 TO 5-5)

# FIGURE 5-2


4-LOOP ICE CONDENSER PLANT
LOCBART SENSITIVITY CALCULATIONS
REFLOOD DTMAX = 0.1, 0.05, 0.025, AND 0.01 S
PCTHOT AND ZRO2BY(29)
Temperature (F)
PCTHOT, DTMAX = 0.1 S
PCTHOT, DTMAX = 0.05 S
PCTHOT, DTMAX = 0.025 S
PCTHOT, DTMAX = 0.01 S
Oxide Thickness (%)
ZRO2BY(29), DTMAX = 0.1 S
ZRO2BY(29), DTMAX = 0.05 S
ZRO2BY(29), DTMAX = 0.025 S
ZRO2BY(29), DTMAX = 0.01 S
Temperature (F)
2200
2000
1800
1600
1400
1200
1000
800
600
Oxide Thickness (%)
14
12
10
8
6
4
2
0
0
100
200
300
400
500
600
Time (s)

# FIGURE 5-3

(a,c)

# FIGURE 5-4

(a,c)

# FIGURE 5-5

(a,c)

# 6. SENSITIVITY STUDIES

- ORIGINAL BASH-EM SENSITIVITY STUDIES DESCRIBED IN REF. 2 §11.0

- SENSITIVITY CALCULATIONS COMPLETED FOR ASSEMBLY BLOCKAGE, REFLOOD $\Delta t_{MAX}$, AND $V_{IN}$ AFTER DC BOILING, AS DESCRIBED PREVIOUSLY

- ADDITIONAL SENSITIVITY CALCULATIONS COMPLETED FOR MAXIMUM ECC FLOWS, DC METAL HEAT RELEASE, AND BASH-EM VS. BELOCA, AS DESCRIBED BELOW

## A. MAXIMUM ECC FLOWS

- BASH SER [REF. 2] REQUIRES ANALYSIS OF MAXIMUM ECC FLOW CASE (MAX SI)

- RECENT BASH-EM CALCULATIONS PREDICT LIMITING RESULTS ASSUMING LOSS OF AN ECC TRAIN (MIN SI)

- MAX SI SENSITIVITY CALCULATION COMPLETED FOR 4-LOOP ICE CONDENSER PLANT

  - DOWNCOMER BOILING DELAYED SUBSTANTIALLY (FIGURE 6-1)

  - [

    ]$^{(a,c)}$ (FIGURE 6-2)

  - CLADDING TEMPERATURE AND OXIDATION REDUCED SUBSTANTIALLY AFTER MIN SI CASE REACHES DC BOILING, SINCE [

    ]$^{(a,c)}$ (FIGURE 6-3)

# FIGURE 6-1

(a,c)

# FIGURE 6-2

(a,c)

# FIGURE 6-3

(a,c)

## B. DC METAL HEAT RELEASE

- SENSITIVITY CALCULATION COMPLETED WITH BASH DC HEAT LINKS TURNED OFF JUST PRIOR TO BOILING
  - DC LIQUID TEMPERATURE REMAINS BELOW SATURATION (FIGURE 6-4)
  - CONTINUOUS BEHAVIOR OBSERVED WHEN HEAT LINKS ARE TURNED OFF, WITH NO APPARENT DIFFICULTY THEREAFTER (FIGURE 6-5)
  - [

    ]$^{(a,c)}$ (FIGURE 6-6)
  - CLADDING TEMPERATURE AND OXIDATION REDUCED SUBSTANTIALLY AFTER BASE CASE REACHES DC BOILING (FIGURE 6-7)

# FIGURE 6-4

(a,c)

# FIGURE 6-5

(a,c)

# FIGURE 6-6

(a,c)

# FIGURE 6-7

(a,c)

## C. COMPARISON OF BASH-EM AND BELOCA RESULTS

- BASH-EM CALCULATIONS WERE COMPLETED FOR 2 PLANTS THAT ARE NOW LICENSED W/BELOCA:
  - 3-LOOP, DRY CONTAINMENT (PLANT "A")
  - 4-LOOP, ICE CONDENSER (PLANT "B")
- USED STANDARD BASH-EM METHODOLOGY TO THE EXTENT POSSIBLE, WITH INPUTS SELECTED BASED ON BELOCA VALUES WHERE APPROPRIATE
- ALLOWS REASONABLY DIRECT COMPARISON OF BASH-EM PCT AND BELOCA $50^{TH}$ AND $95^{TH}$ PERCENTILE PCTs
- [

]$^{(a,c)}$

# FIGURE 6-8

(a,c)

# FIGURE 6-9

(a,c)

# 9. JUSTIFICATION OF ASSUMPTIONS FOR OTHER BASH CALCULATED PARAMETERS AFTER DC BOILING

## A. INPUTS TO $(V_{IN})_4$ CALCULATION

- [

  ]$^{(a,c)}$

- DC METAL HEAT RELEASE DISCUSSED PREVIOUSLY (REPRESENTATIVE-TO-CONSERVATIVE TREATMENT)

## B. LOCBART INPUTS

- $V_{IN}$ DISCUSSED PREVIOUSLY

- [

]$^{(a,c)}$

# FIGURE 9-1

(a,c)

# FIGURE 9-2

(a,c)

## CONCLUSIONS

- PRIOR TO DC BOILING, BASH-EM COMPLIES WITH THE FOLLOWING APPENDIX K REQUIREMENTS CITED IN THE USNRC LETTER OF MARCH 27, 2002 [REF. 1]:
  - §I.A.6 REACTOR INTERNALS HEAT TRANSFER
  - §I.D.3 CALCULATION OF REFLOOD RATE
  - §I.D.4 INTERACTION OF STEAM WITH ECC WATER
  - §I.D.5 REFILL AND REFLOOD HEAT TRANSFER
  - §II.2 SOLUTION CONVERGENCE
  - §II.3 SENSITIVITY STUDIES

- NO CHANGES ARE INTRODUCED AFTER DC BOILING THAT ADVERSELY AFFECT APPENDIX K COMPLIANCE

- MODEL REVIEW AND SENSITIVITY CALCULATIONS IDENTIFIED VARIOUS CONSERVATIVE ASPECTS OF METHODOLOGY, SOME OF WHICH ARE SIGNIFICANT

- [

  ]$^{(a,c)}$

## REFERENCES


1. LETTER FROM S. DEMBEK (USNRC) TO H. SEPP (W), "POTENTIAL NON-CONSERVATIVE MODELING OF DOWNCOMER BOILING IN THE APPROVED WESTINGHOUSE 1981 EVALUATION MODEL USING BASH", MARCH 27, 2002.

2. WCAP-10266-P-A REVISION 2, "THE 1981 VERSION OF THE WESTINGHOUSE ECCS EVALUATION MODEL USING THE BASH CODE", MARCH 1987.

3. WCAP-8170, "CALCULATIONAL MODEL FOR CORE REFLOODING AFTER A LOSS OF COOLANT ACCIDENT (WREFLOOD CODE)", JUNE 1974.

4. WCAP-8471-P-A, "THE WESTINGHOUSE ECCS EVALUATION MODEL: SUPPLEMENTARY INFORMATION", APRIL 1975.

5. NUREG/CR-4945, EGG-2509, "SUMMARY OF THE SEMISCALE PROGRAM (1965-1986)", JULY 1987.

6. NUREG/IA-0127, GRS-101, MPR-1346, "REACTOR SAFETY ISSUES RESOLVED BY THE 2D/3D PROGRAM", JULY 1993.

7. NUREG-0630, "CLADDING SWELLING AND RUPTURE MODELS FOR LOCA ANALYSIS", APRIL 1980.

8. F. J. ERBACHER, "CLADDING TUBE DEFORMATION AND CORE EMERGENCY COOLING IN A LOSS OF COOLANT ACCIDENT OF A PRESSURIZED WATER REACTOR", NUCLEAR ENGINEERING AND DESIGN 103, PP. 55-64, 1987.

9. WCAP-10484-P-A ADDENDUM 1, "SPACER GRID HEAT TRANSFER EFFECTS DURING REFLOOD", SEPTEMBER 1993.

10. WCAP-9561-P-A, "BART-A1: A COMPUTER CODE FOR THE BEST ESTIMATE ANALYSIS OF REFLOOD TRANSIENTS", MARCH 1984.

# Application of Sudo Void Fraction Correlation

## Validation at Full Scale and Justification of Assumptions

July 11, 2002

Cesare Frepoli

# Conditions of Interest

- D ~ 8 in.
- P = 14.7 - 30 psia
- $j_l$ ~ 0 in/sec
- Heated Wall [ ] (a,c)

# Correlation Database (Original)

## Steam-Water Data (Adiabatic)

- D = 2.5 - 19 in.
- P = 90 - 1600 psia
- $j_l$ = 0 - 12 in/sec

## Air-Water Data

- D = 2.1 - 6 in.
- P = 14.7 psia
- $j_l$ = 0 in/sec

# Correlation Form

$$\alpha = \frac{Y}{AX^m}$$

where:

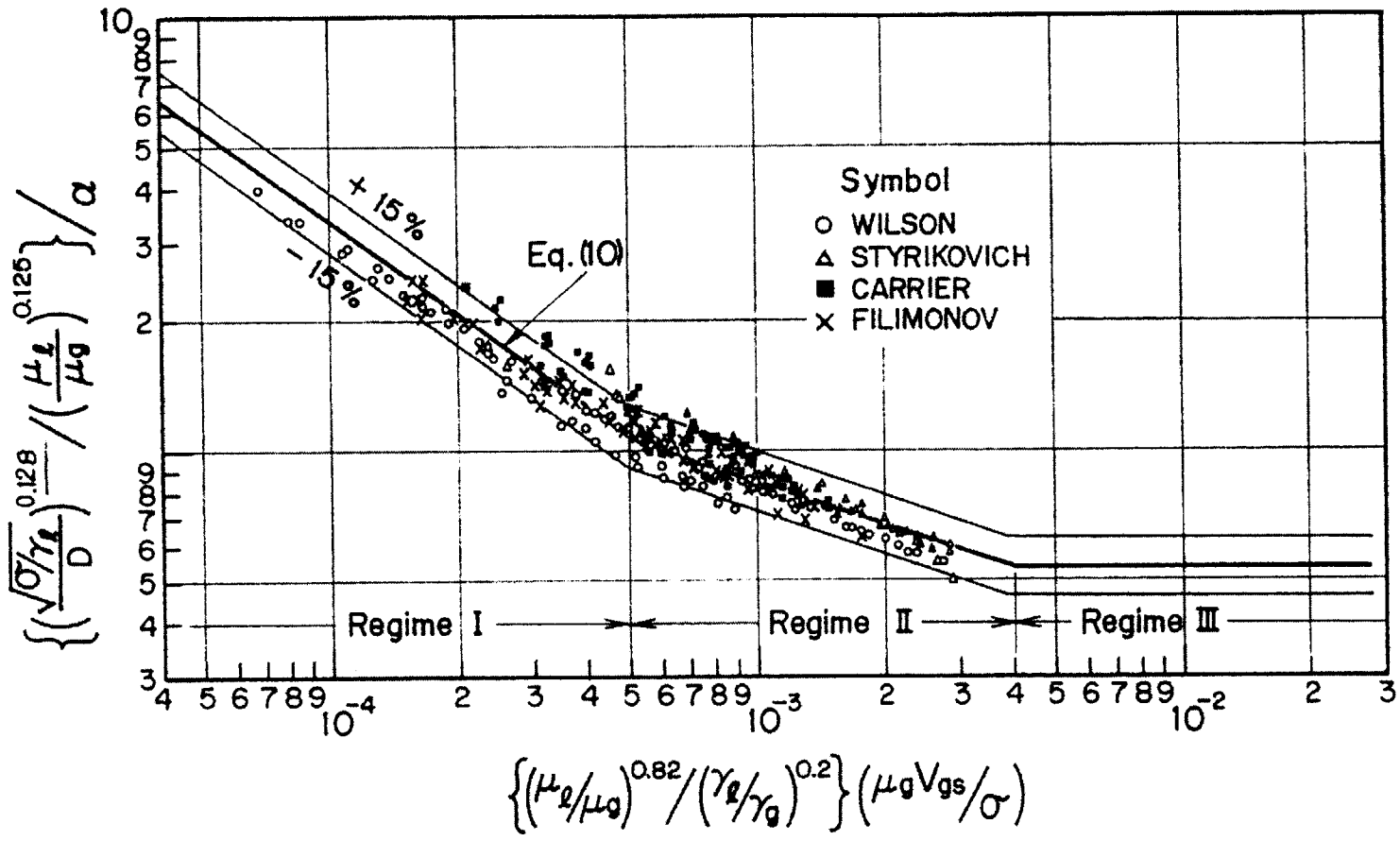
$Y \sim D^{-0.128}$

$X \sim j_g$

3 flow regimes considered (bubbly, slug, annular)

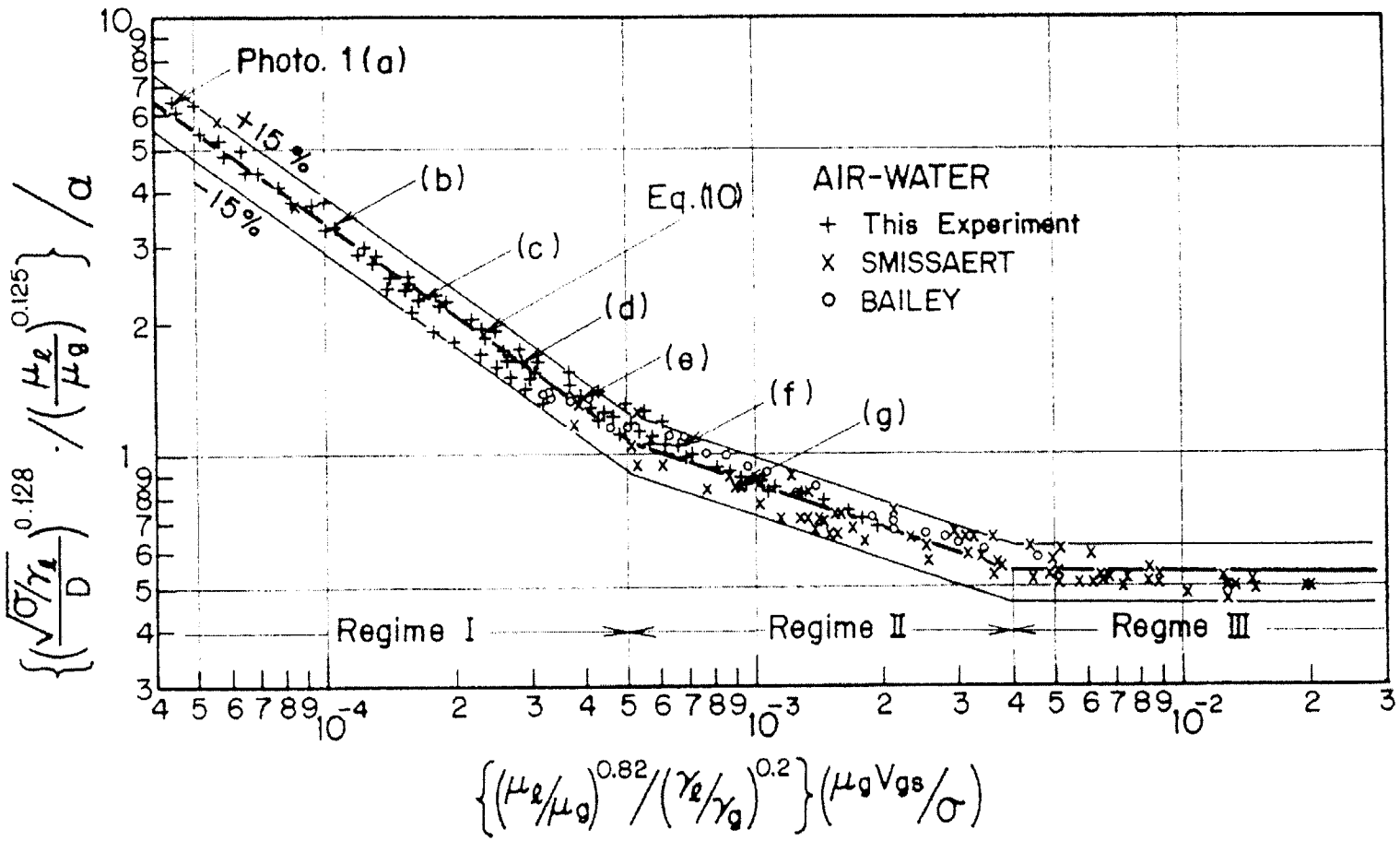
Error band of $\pm$ 15%

# Comparisons with Data (Sudo, 1980)




(a) Steam-water system

# Comparisons with Data (Sudo, 1980)




The alphabets (a)~(g) correspond to Photo. 1(a)~(g).

(b) Air-water system

# Validation Using JAERI Downcomer Boiling Separate Effects Test

**Facility Description:**

- Full Scale Rectangular Downcomer Flow Channel:
  - –(39" wide, 7.9" gap, 256" high).
  - –Heaters on both sides to simulate metal heat release
  - –Heated walls: 2" thick carbon steel plates with 0.24" stainless cladding
- Initial wall temperature uniform over the heated length (197")
- Two injection lines:
  - – Initial injection line directly connected at the lower plenum (0-30 sec).
  - – LPCI line connected at the top of the heated length.
- Water overflow line and extraction line.

# Validation Using JAERI Downcomer Boiling Separate Effects Test

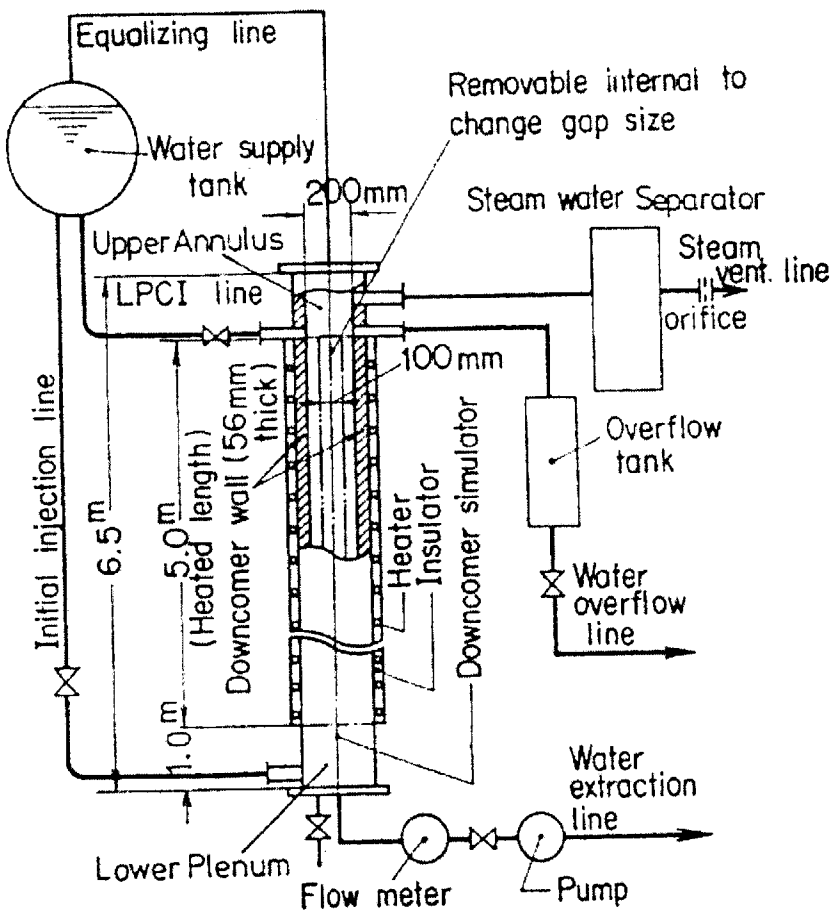



**Fig. 1** Schematic of test apparatus

# Validation Using JAERI Downcomer Boiling Separate Effects Test

**Instrumentation:**

- Thermocouples at different elevations and at different distance from the wall surface are used to calculate local heat flux via solution of inverse heat conduction.
- Indication from pressure tap DP1 is used to determined the collapsed liquid level across the heated length of the test facility.

# DP Cell Placement

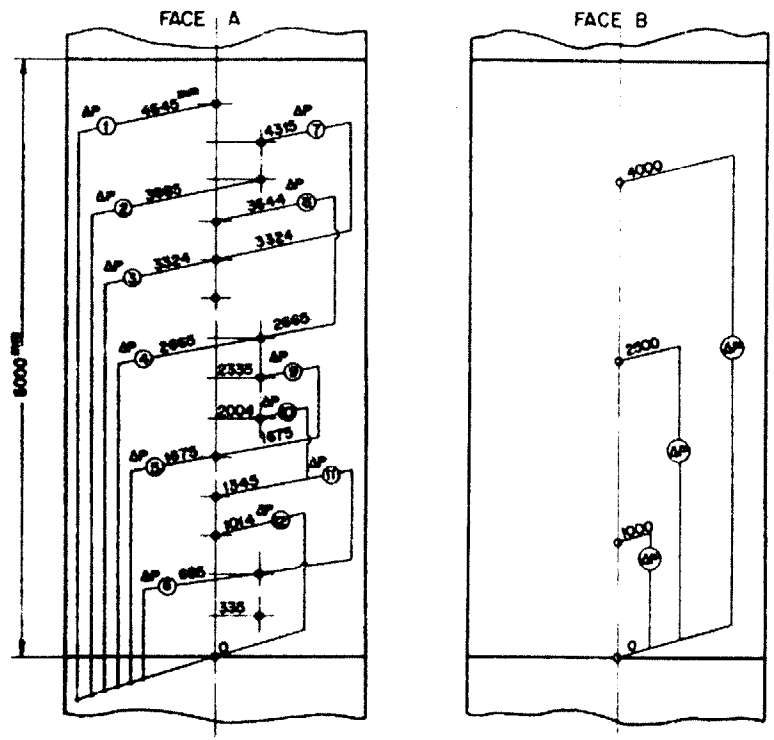



Fig. 8(a) Pressure tap locations for measuring the effective water head and pressure difference along the elevation (A-Face).

Fig. 8(b) Pressure tap locations for measuring the effective water head and pressure difference along the elevation (B-Face).

# Validation Using JAERI Downcomer Boiling Separate Effects Test

**Test Procedure:**

- Heaters are turned-off once the wall has reached the desired (uniform) temperature over the heated length.
- Saturated water is injected at high rate (8 in/s) directly at the lower plenum to quickly establish a mixture level across the full height of the downcomer (simulate accumulator).
- Once the mixture level reaches the overflow line, bottom injection is stopped and saturated water at low rate (1.4 in/s) is injected above the top of the heated length (simulate pumped SI).

# Validation Using JAERI Downcomer Boiling Separate Effects Test (cont'd)

## Application of Sudo Correlation per Standard W Methodology

(a,c

- 

# Standard W Application of Sudo Correlation vs. JAERI SET Data

$(a,c)$

# Validation Using JAERI Downcomer Boiling Separate Effects Test (cont'd) - Results

- Transient effects are not captured by the W method
- Observations:
  - Maximum CLL at ~25 sec after beginning of reflood
  - Minimum CLL ~80 sec after beginning of reflood
  - Quasi-equilibrium reached at about 140 sec after beginning of reflood
- Predictions:

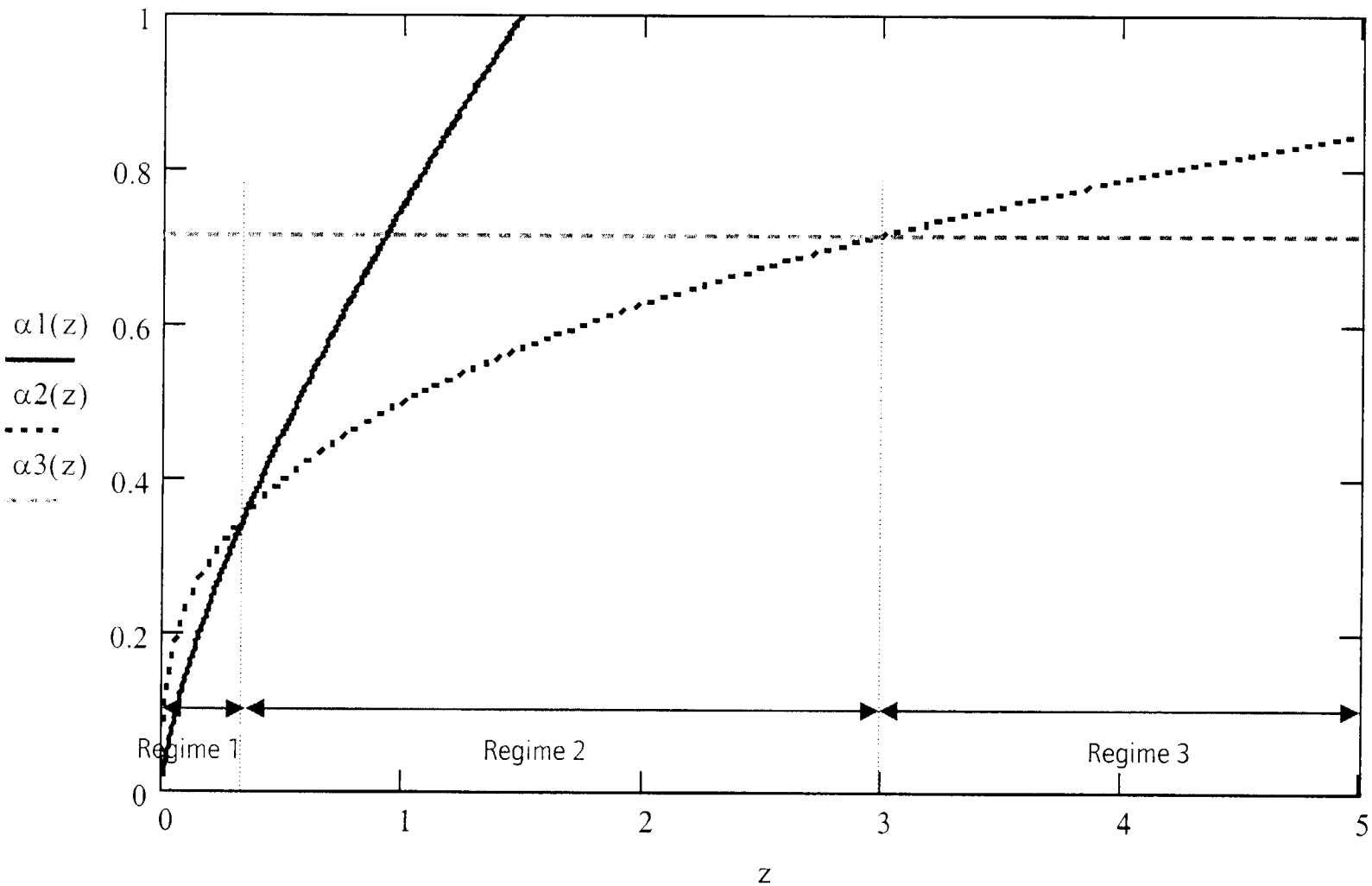
$(a,c)$

# Range of Conditions in JAERI Test vs. Typical PWR Application

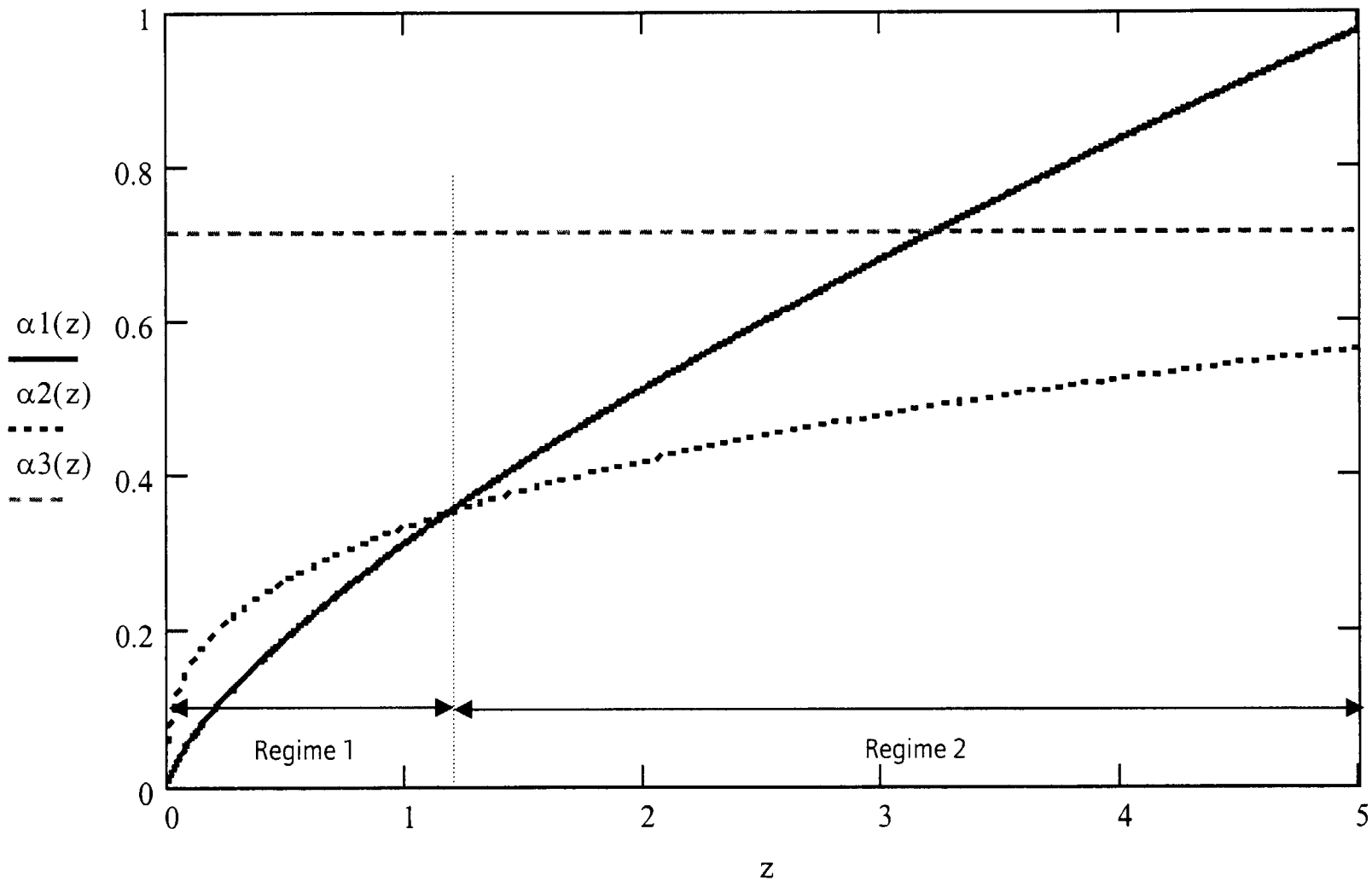
| | JAERI (t=15s) | JAERI (t=200s) | PWR 4-loop/ice |
|---|---|---|---|

$(a,c)$

# Void Fraction Prediction for JAERI Test (Beginning of Reflood)



# Void Fraction Prediction for JAERI Test (200 sec)



# Void Fraction Prediction for Typical PWR Application (4-Loop Ice Condenser)

$(a,c)$

# Range of Conditions in JAERI Test vs. Typical PWR Application (cont'd)

(a,c)

# Standard W Application of Sudo Correlation vs. JAERI SET Data

$(a,c)$

# Transient Effects Observed in JAERI Tests

- Void accumulation period (during the first 60 sec. after boiling initiation)
- Pressure transient affects the saturation temperature.
- For saturated water, the net vapor generation/condensation which results from a pressure transient is given by:

$$\Gamma = \frac{(1-\alpha)\rho_f C_{pf}\left(\frac{dT_s}{dP}\right)_s \left(\frac{dP}{dt}\right) V_{DC}}{h_{fg}}$$

$(a,c)$

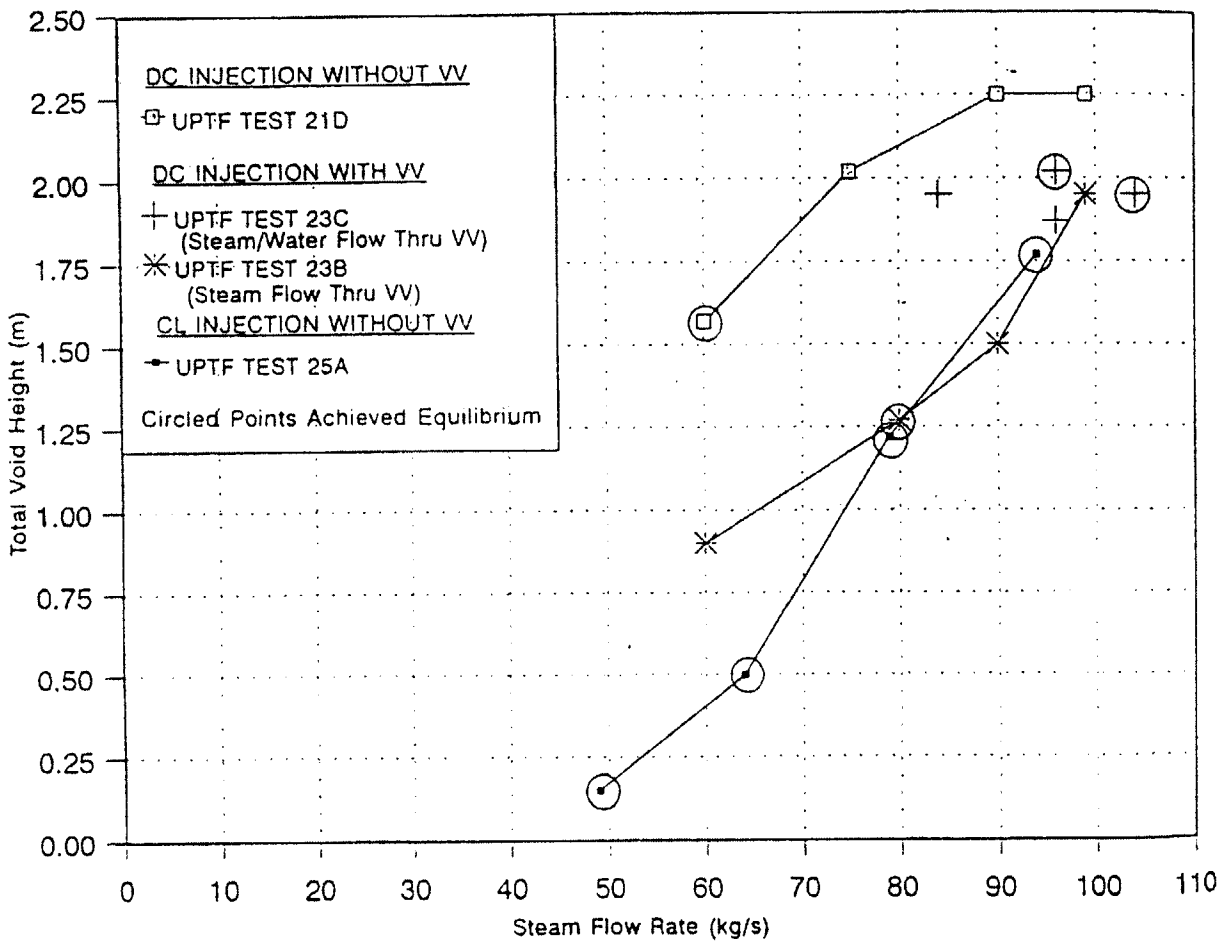
[ ]

# Other Considerations - Entrainment

- Vertical Entrainment (from steam generated inside the DC)
  - –Captured through use of Sudo correlation
- Lateral Entrainment (sweep out from Intact Loop Steam Flow)
  - –Not captured by Sudo correlation

$(a,c)$

# Other Considerations - Entrainment



# Conclusions

$(a,c)$