RESPONSES TO THE RAI QUESTIONS ON THE MAAP5 TOPICAL REPORT

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Enclosure 2

PRESENTATION OUTLINE

- MAAP5 Evaluation of Momentum Driven Velocities (Velocities Induced by a Blowdown or Spray Actuation)
- MAAP5 Enhanced Condensation Correlation
- Entrainment of Water Films in the Containment
- Nodalization
- Uncertainties Treated in Integral Analyses
- Integral Plant Analyses
- MAAP5 Methodology Review Schedule

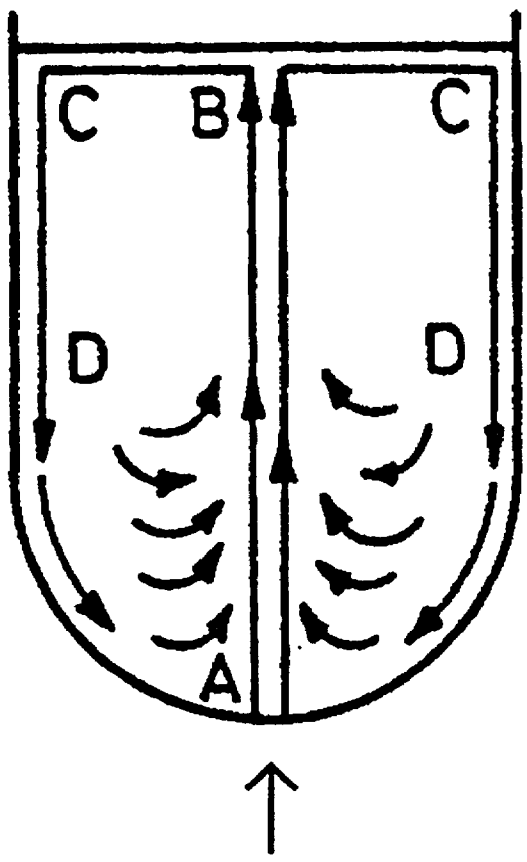
MOMENTUM DRIVEN VELOCITIES

- These are calculated on a nodal basis and treated as a property which is transferred to adjacent nodes by the continuity (mass centered) velocity (Streeter and Wylie).
- This velocity is used as the free stream velocity to characterize the rates of heat, mass and momentum transfer. In addition, this velocity determines whether water entrainment occurs in a node.
- The effective heat transfer coefficient is directly related to the effective frictional coefficient, i.e. a modified Reynolds analogy. Therefore, an increased frictional coefficient to reduce the momentum driven velocity also increases the heat transfer coefficient.
- The most effective way of evaluating this concept is through comparisons with measured values for the rates of transfer such as the measured heat transfer coefficients.

DEMONSTRATION OF MOMENTUM DRIVEN VELOCITIES

- Lane and Rice Experiments
- Enclosure Experiments of Kuhn, Kang and Peterson
- Spray Calculations of Marx
- CVTR Heat Transfer Measurements

LANE AND RICE EXPERIMENTS
(Recirculating Flows)



Incoming Jet

Vessel Diameter = 0.31 m

Assuming an aspect ratio of 1.5, length A-B is 0.45 m, and, the measured velocities at C and D are:

$V_C = 0.05$ m/sec

$V_D = 0.032$ m/sec

Continuity Velocity = 0.0012 m/sec

<u>Conclusion</u>: The continuity velocity is an order of magnitude less than the measured free stream velocities near the vessel wall.

ENCLOSURE EXPERIMENTS BY KUHN ET AL.
EXAMPLE OF THE CONTINUITY VELOCITY

$N_{Re,j} = 2.8 \times 10^5$ $\quad d_j = 15\ \text{mm}$ $\quad A_j = 1.77 \times 10^{-4}\ \text{m}^2$

$D_v = 2.29\ \text{m}$ $\quad H_v = 0.8\ \text{m}$

$$N_{Re,j} = \frac{\rho\, U_j\, d_j}{u} = \frac{U_j\, d_j}{\nu} \qquad U_j = \frac{N_{Re,j}\, \nu}{d_j}$$

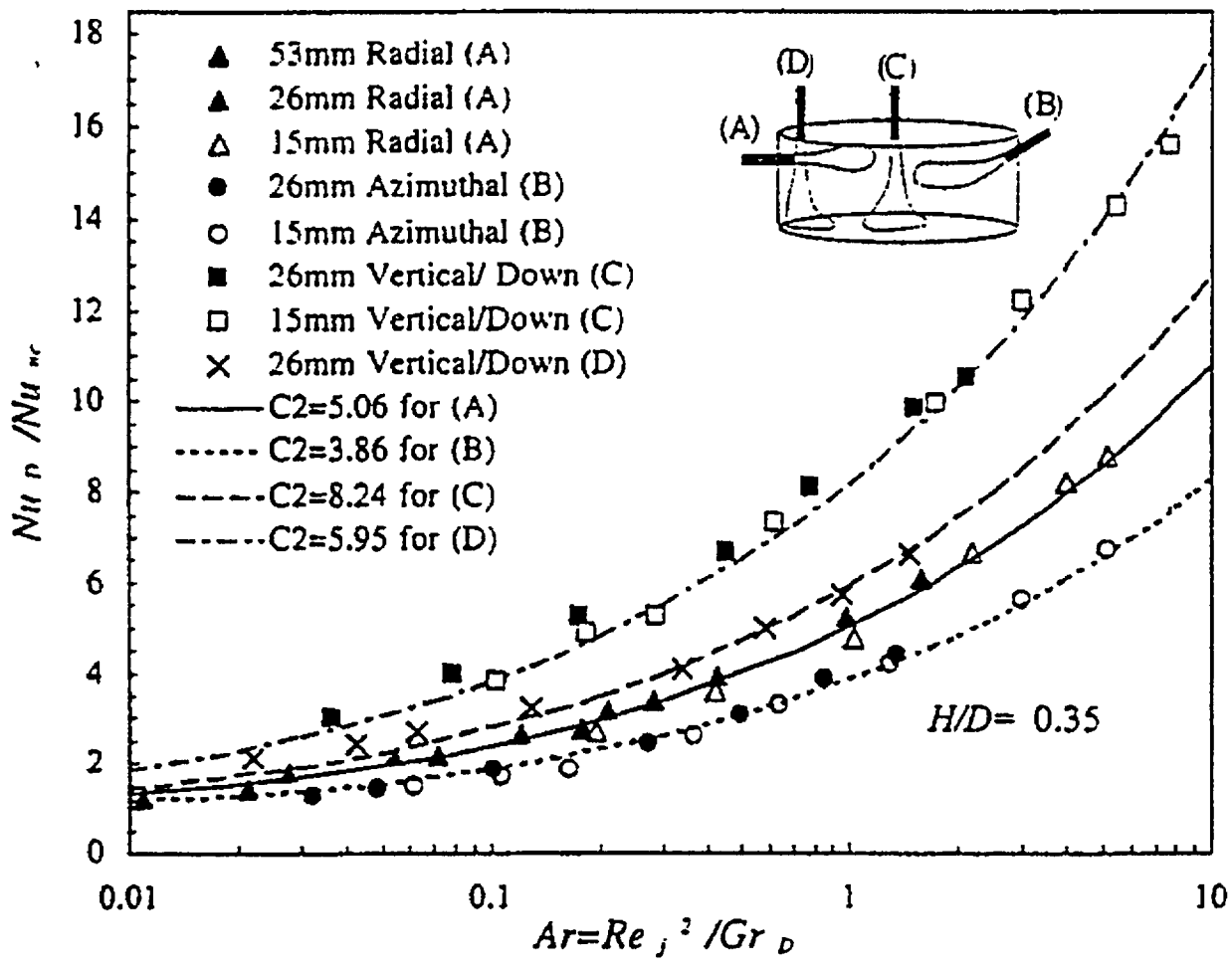
$\nu = 1.6 \times 10^{-5}\ \text{m}^2/\text{s}$ $\quad U_j = 299\ \text{m/sec}$

$$U_c = \frac{A_j}{A_v} U_j \qquad A_v = D_v\, H_v$$

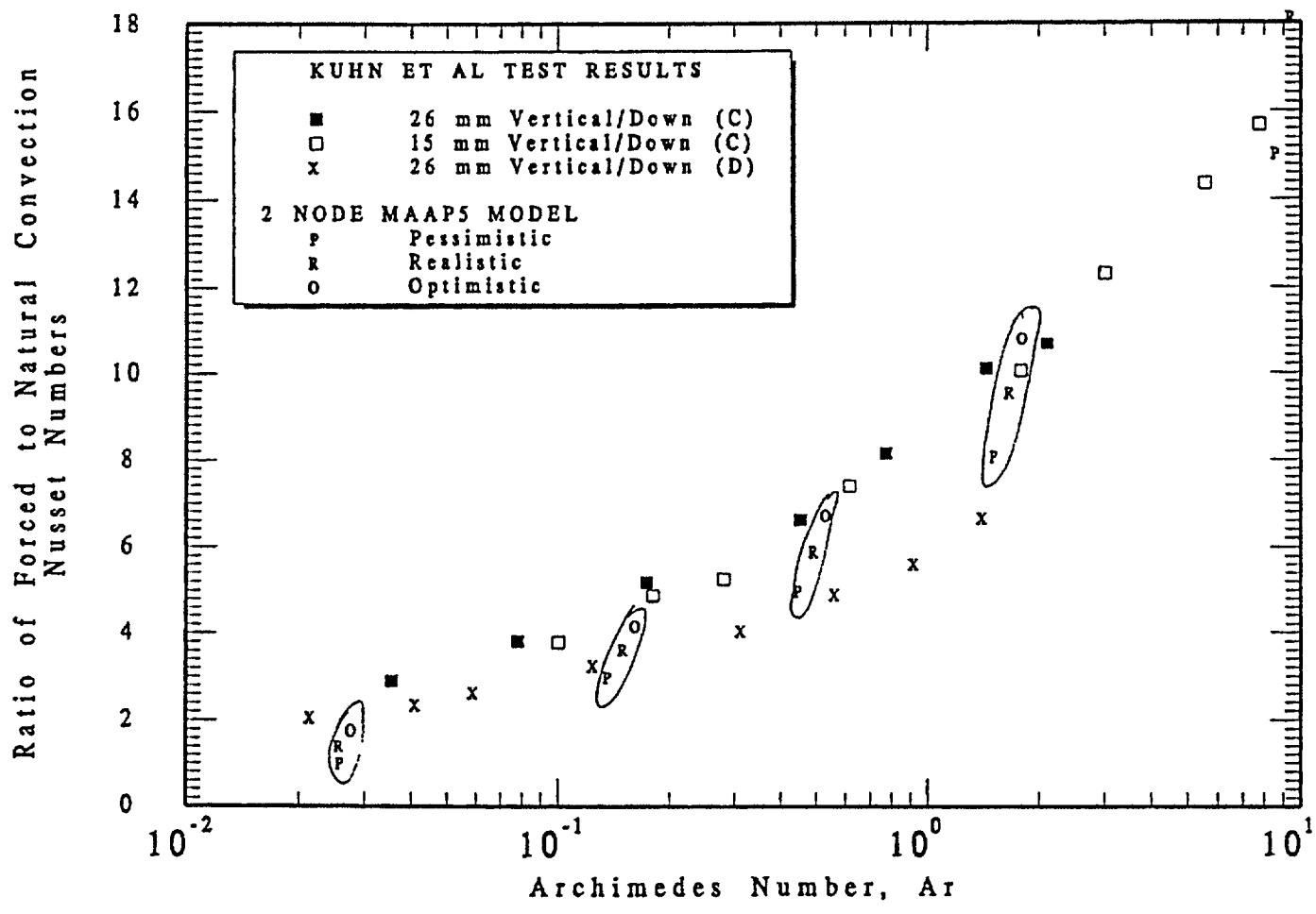
$$U_c = \frac{1.77 \times 10^{-4}}{(2.29)\, 0.8} (299) = 0.03\ \text{m/sec}$$

Measured velocities are two orders of magnitude greater.

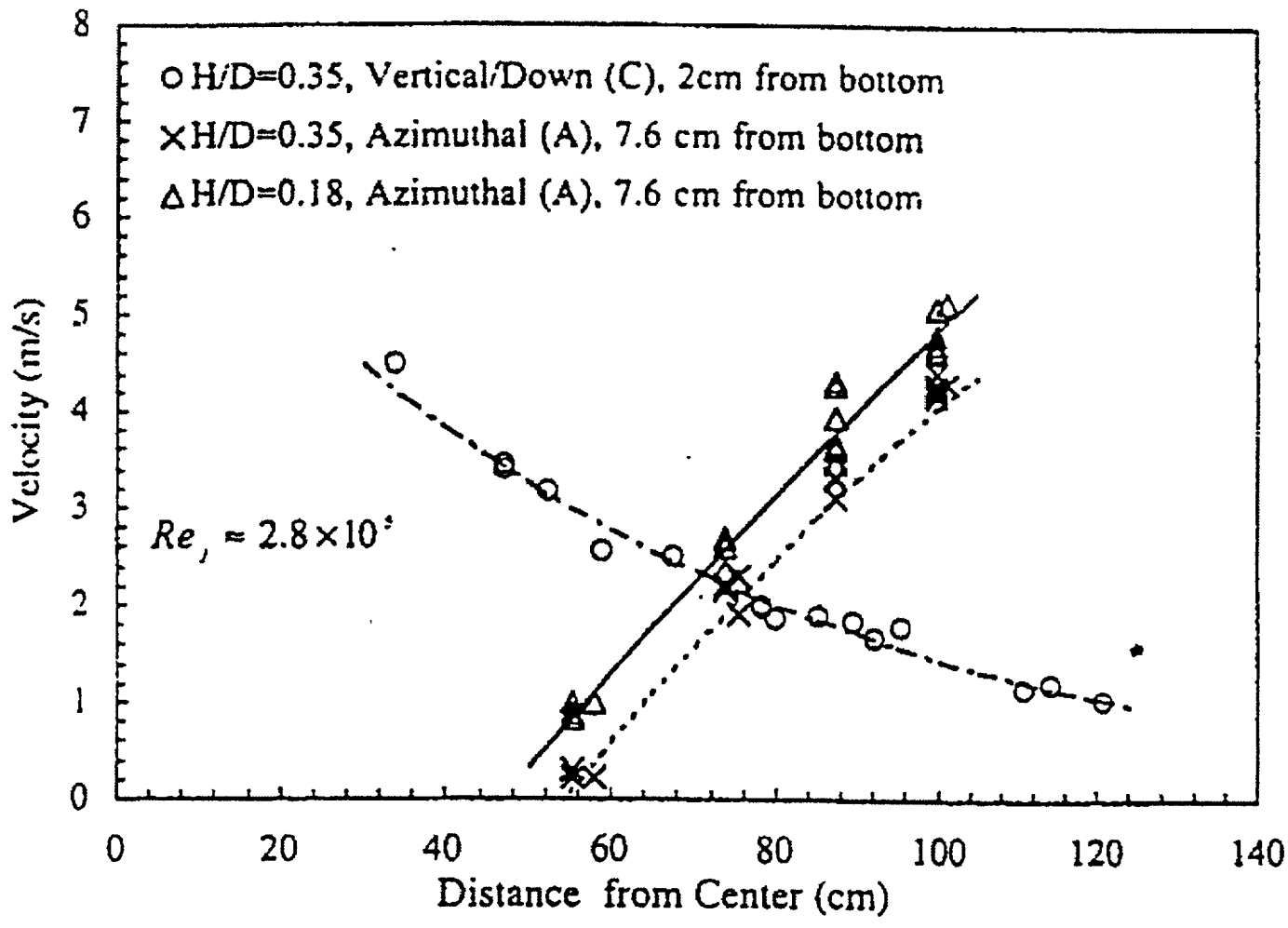
Result for Combined Natural and Forced-Convection Heat Transfer (Taken from Kuhn et al., 2002)



Comparison of the MAAP5 Calculated Free and Forced Convection Heat Transfer and the Experimental Data Reported by Kuhn et al. (Two Vertically Stacked Nodes)



Horizontal Velocities at Positions Near the Heated Bottom Surface (Taken from Kuhn et al., 2002)



ISOTHERMAL CONTAINMENT SPRAY FLOW CALCULATION BY MARX

(Marx, K. D., 1988, "Analysis and Computer Simulation of Confined Ring Vorticies Driven by Falling Sprays," Phys. Fluids, 31, pp. 263-277)

- Analytically investigated the influence of containment sprays on circulation in the containment gas space.
- Concluded substantial circulation would exist.
- The gas circulation velocity can be approximated by

$$U = \sqrt{2gh}$$

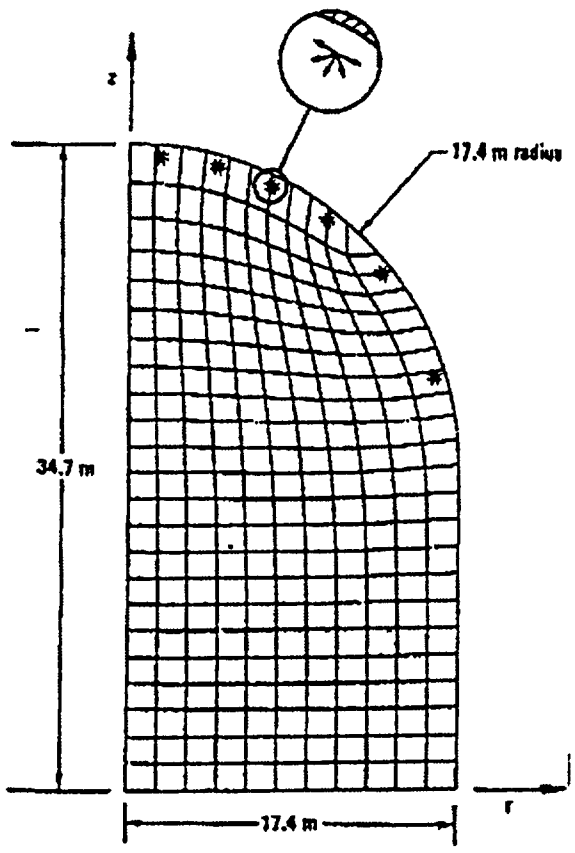
g = gravitational acceleration

h = average spray fall height

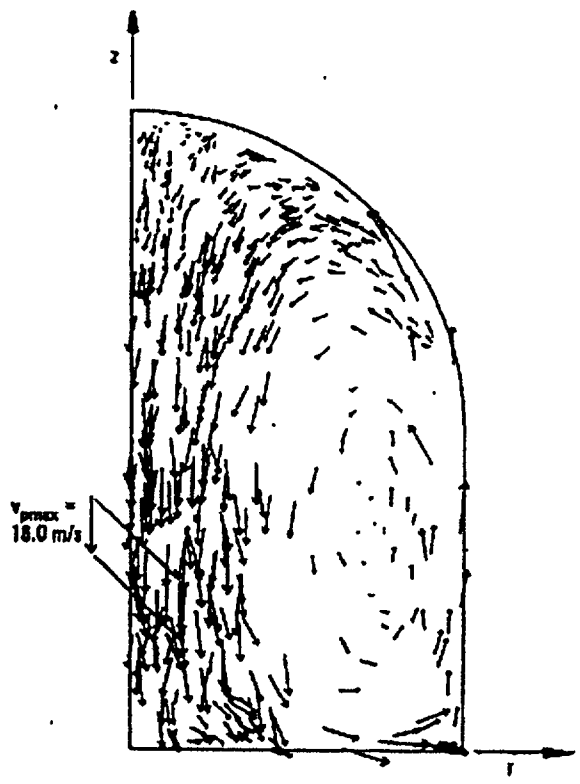
- Conclusion: The gas velocity induced by the spray flow has a strong influence on the rate processes at the containment wall.

Calculated Circulation Patterns
(Taken from Marx, 1988)

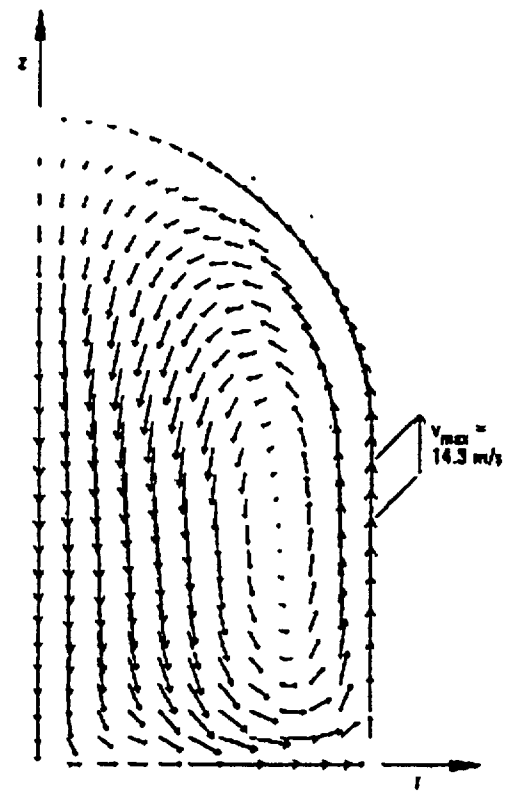
Finite Difference Grid Used by Marx



Calculated Spray Induced Circulation



Calculated Air Flow Circulation



CONTINUITY VELOCITY FOR THE CVTR EXPERIMENTS

$$W_s \approx 400{,}000 \text{ Lbm/hr} = 111 \text{ Lbm/sec} = 50.5 \text{ kg/sec}$$

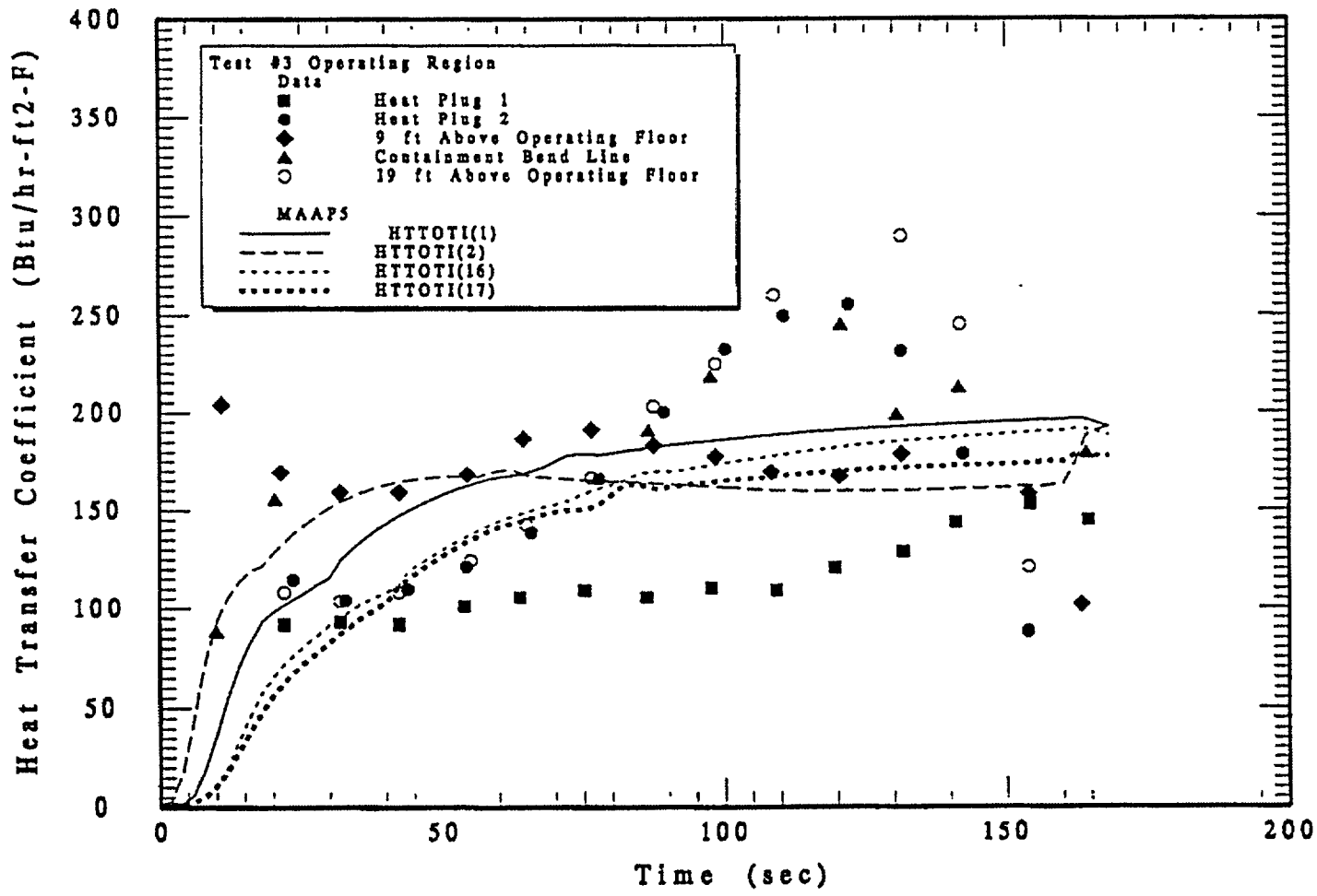
$$D_v = 58 \text{ ft} = 17.7 \text{ m}$$

$$A_v = 246 \text{ m}^2 \qquad \rho_s = 0.6 \text{ kg/m}^3$$

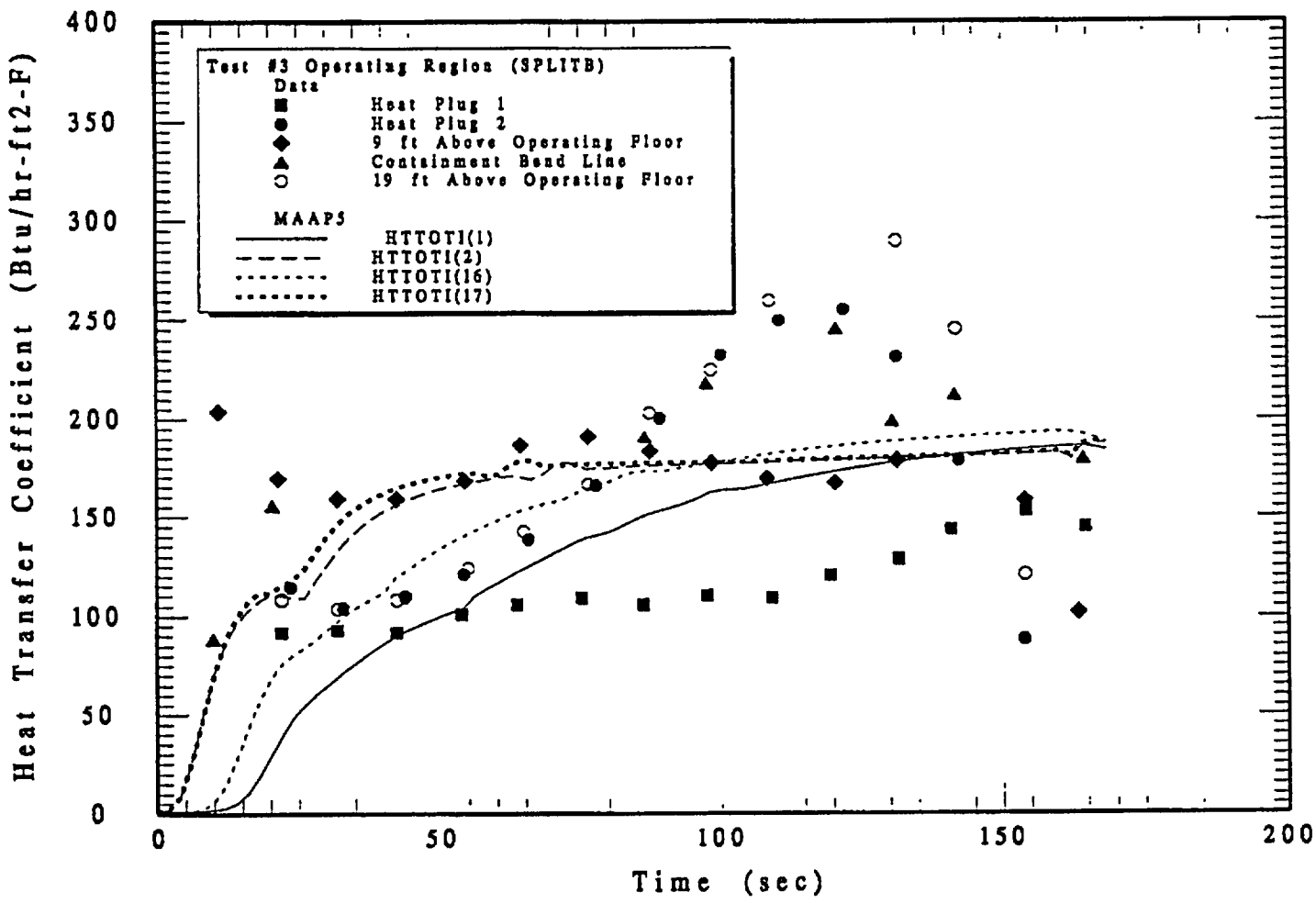
$$U_c = \frac{W}{\rho_s A_v} = \frac{50.5}{0.6\,(246)} = 0.34 \text{ m/sec} = 1.1 \text{ ft/sec}$$

Measured velocities ~ 15 ft/sec and 30 ft/sec are an order of magnitude greater than the continuity velocity.

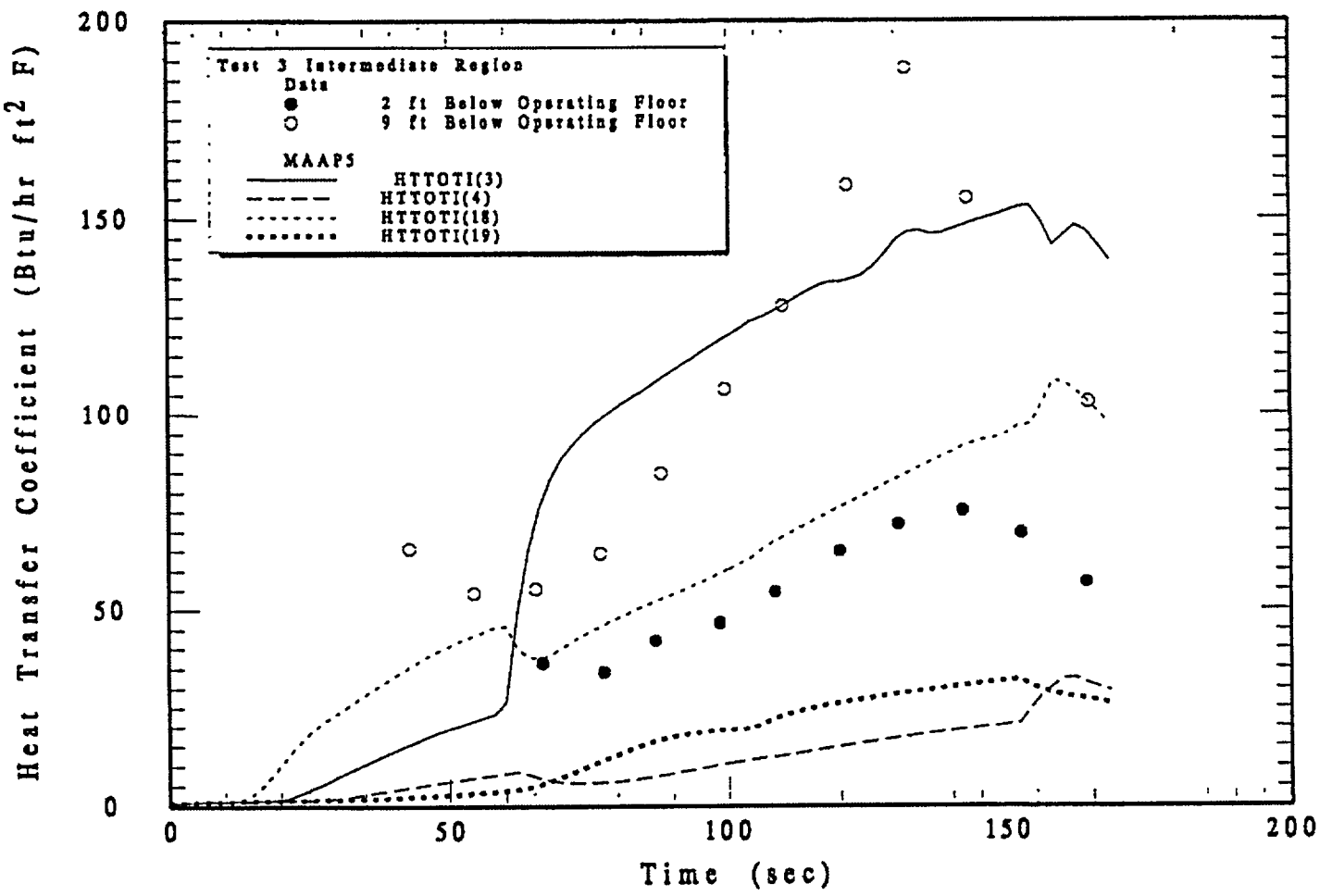
Comparison of the MAAP5 and Measured Heat Transfer Coefficients Above the Operating Deck When the Steam is Discharged Only into Node 2 (12 Node Model)



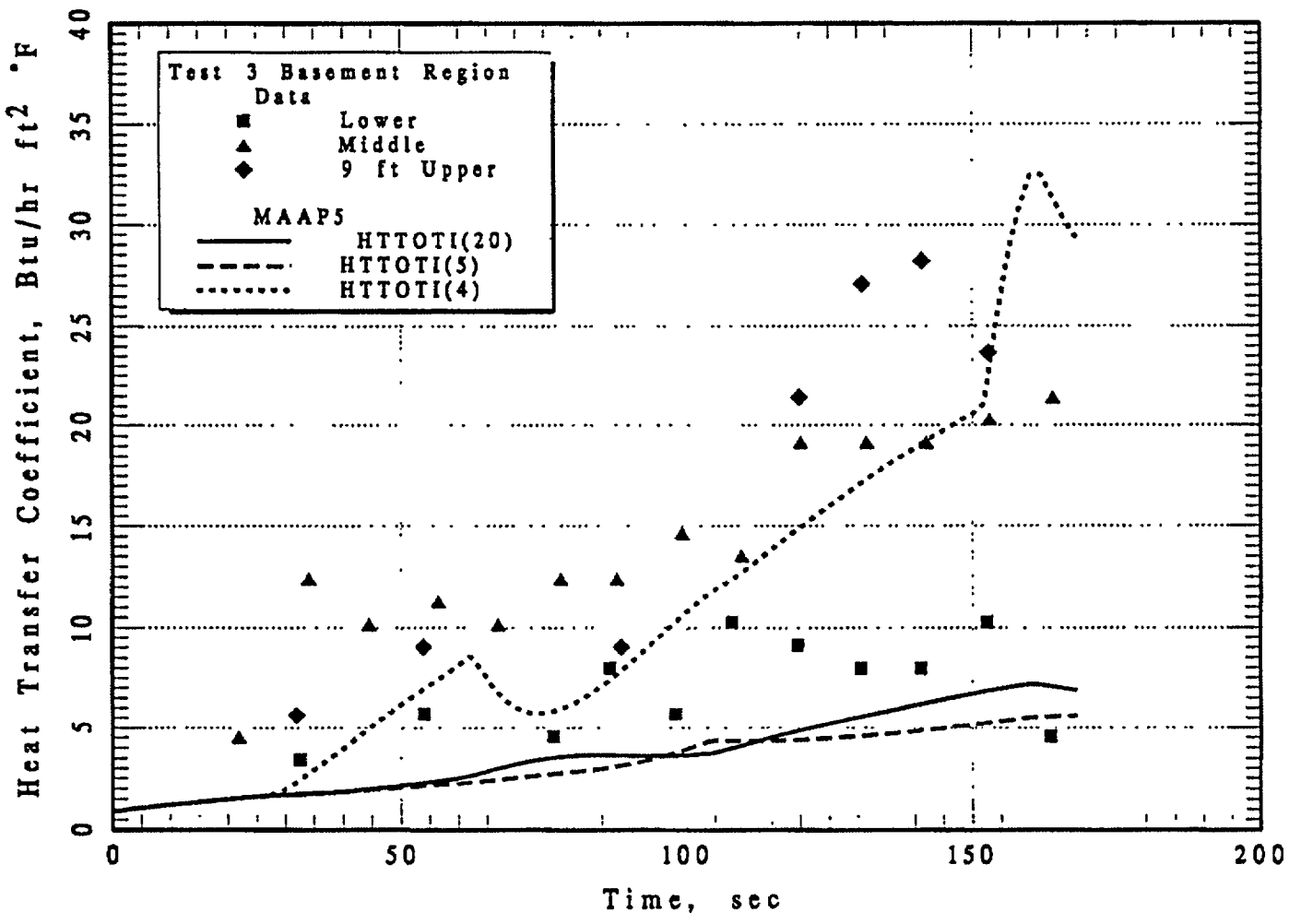
Comparison of the MAAP5 and Measured Heat Transfer Coefficients Above the Operating Deck When the Steam is Discharged Simultaneously into Nodes 2 and 6 (12 Node Model)



Comparison of the MAAP5 and Measured Heat Transfer Coefficients for CVTR Test 3 in the Region Immediately Below the Operating Floor (12 Node Model)



Comparison of the MAAP5 and Calculated Heat Transfer Coefficients for CVTR Test 3 in the Basement Region (12 Node Model)



CONCLUSION

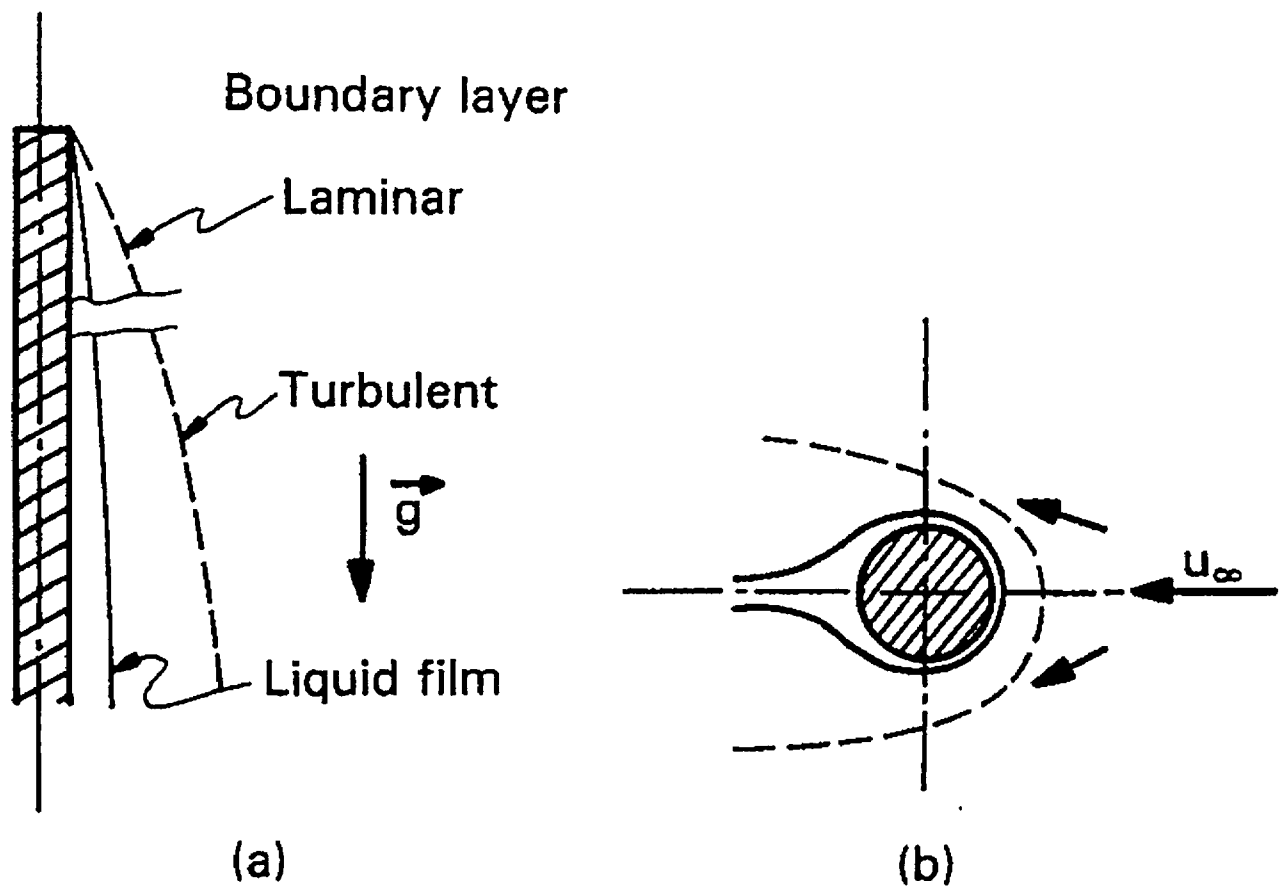
The MAAP5 models provide a good representation for the rates of energy transfer to the containment walls at all elevations in the CVTR experiments, i.e.

- above the operating floor,
- in the intermediate region,
- in the basement region.

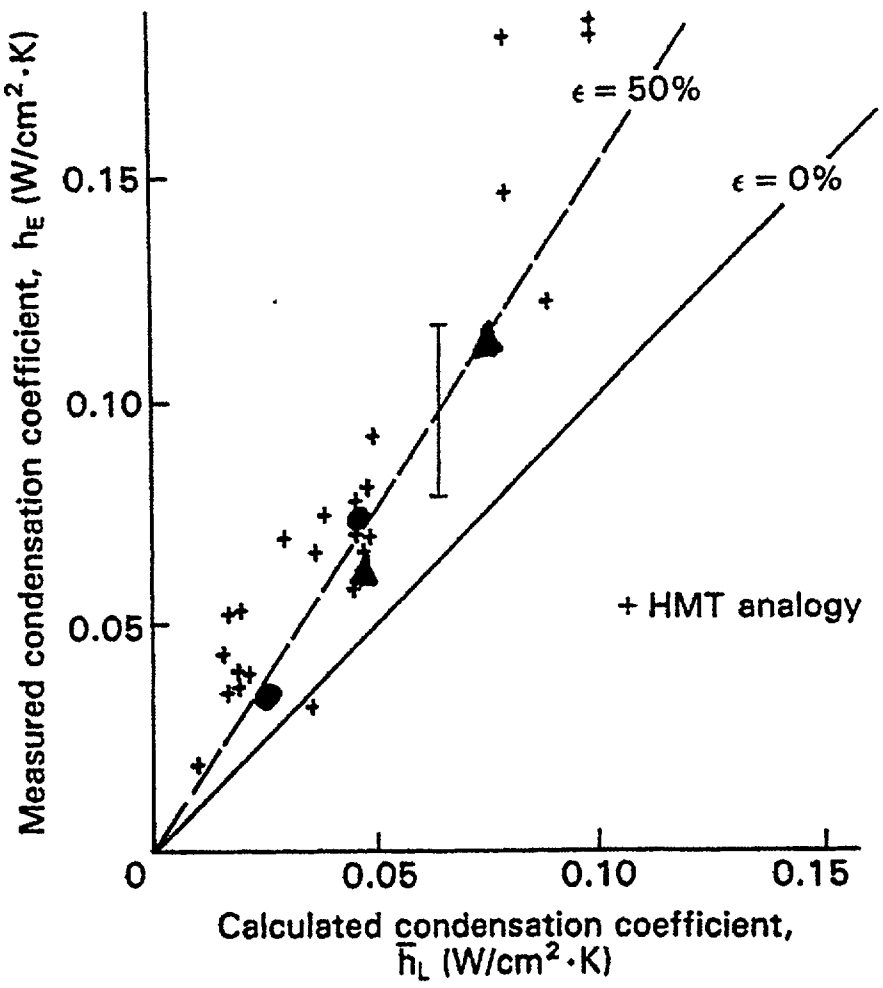
MAAP5 ENHANCED CONDENSATION MODEL

- Basis is the MAAP4 model which is formulated as a heat-mass transfer analogy (HMT).
- MAAP5 modifies the MAAP4 model with a correction factor that was developed to account for deviations from the HMT approach.
- Corrections to the HMT approach have been used by others, e.g.
  - suction in the boundary layer due to condensation
    - Huhtiniemi and Corradini,
    - Kuhn, Schrock and Peterson,
  - or a multiplication of a HMT approach
    - Vernier and Solignac.

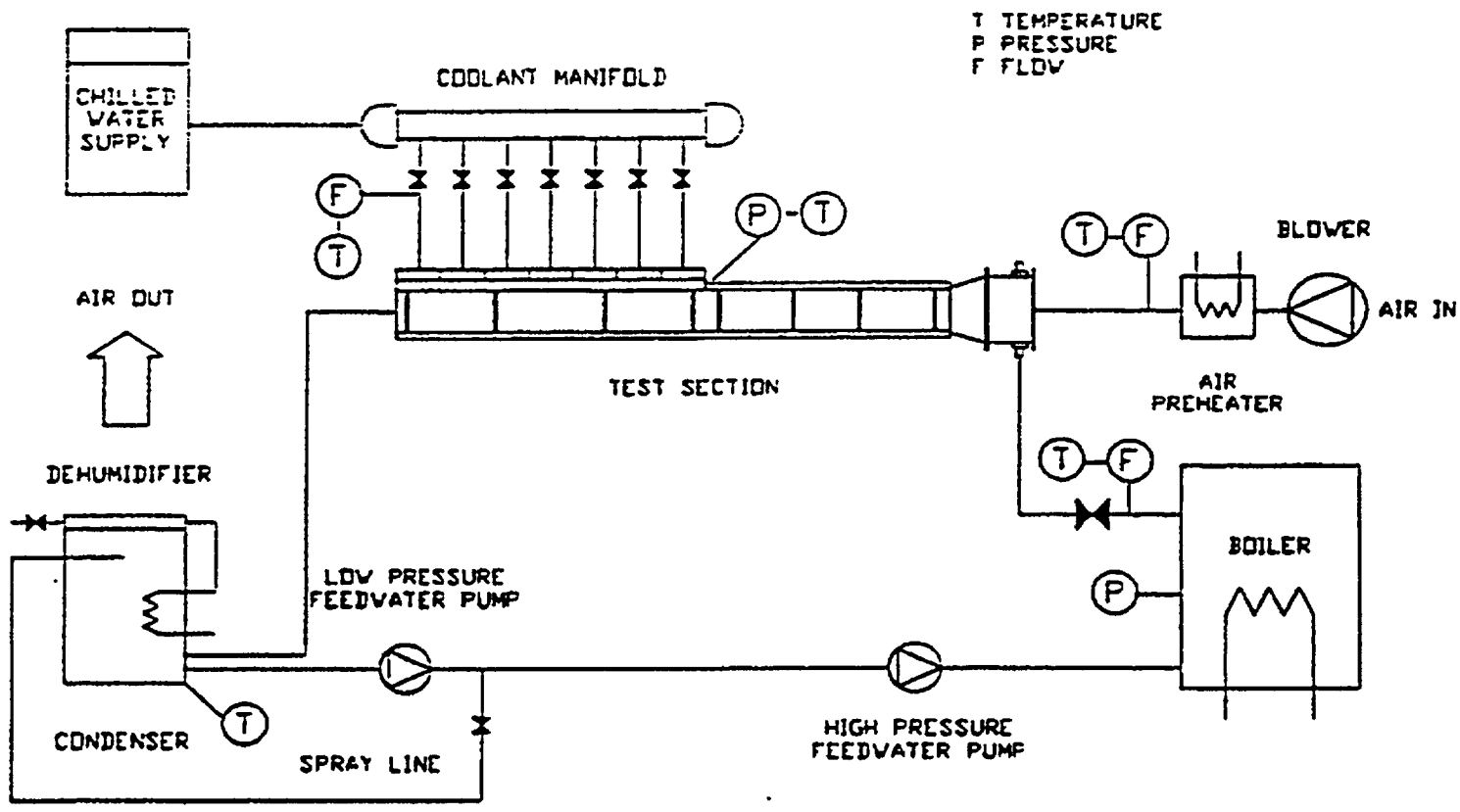
ECOTRA Experiments
Simple Situations Relevant to ECOTRA II:
(a) Natural Convection and (b) Forced Convection
(Taken from Vernier and Solignac, 1987)



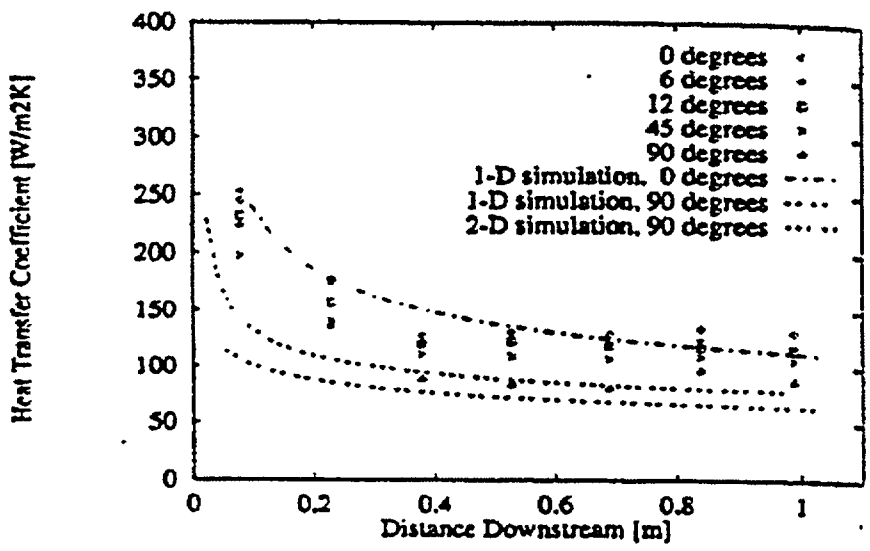
Comparison of the MAAP5 Condensation Model with the Forced Convection Data from the ECOTRA Experiment (● is for a pressure of 1.5 atm and π is for 3.0 atm) (Taken from Vernier and Solignac, 1987).



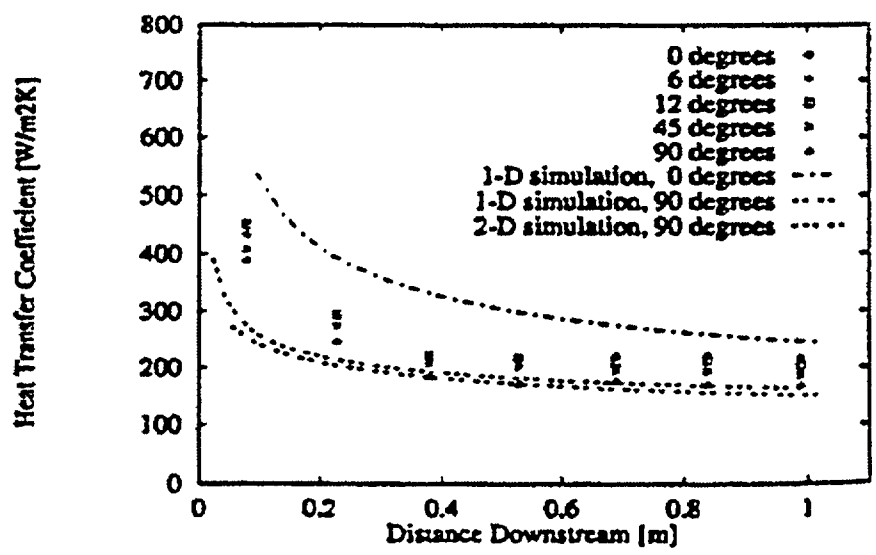
Schematic of Facility Used by Huhtiniemi and Corradini
(Taken from Huhtiniemi and Corradini, 1993)



Local Heat Transfer Coefficient (CEB), 70C, Low Velocity
(Taken from Huhtiniemi and Corradini, 1993)



Local Heat Transfer Coefficient (CEB), 70C, High Velocity
(Taken from Huhtiniemi and Corradini, 1993)



Comparison of the MAAP5 Model With the Forced Convection Data of Huhtiniemi and Corradini

Steam-Air Mixture Temp. (°C)	Mixture Velocity (m/s)	MAAP5 Condensation Correlation ($W/m^2/°C$)			Experimental Data ($W/m^2/°C$)
		Optimistic	Realistic	Pessimistic	
70	1	346	261	174	200-250
70	3	604	524	361	390-460
95	1	843	727	605	980-1100

EVIDENCE OF WATER ENTRAINMENT

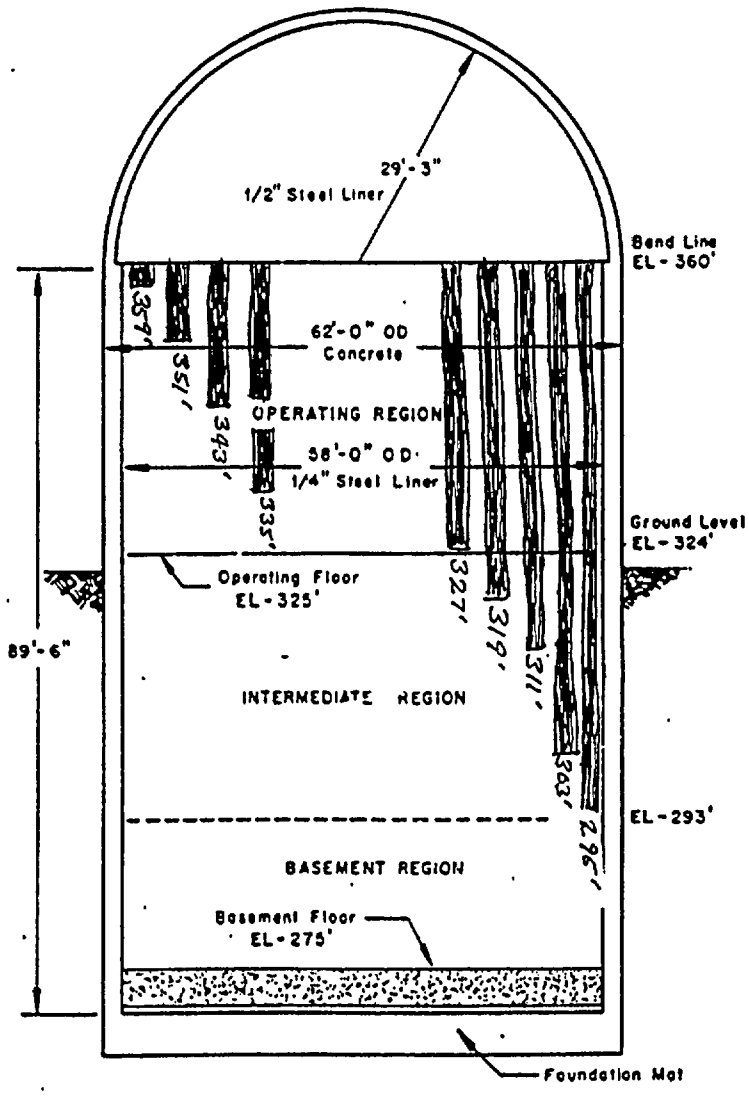
- All CVTR tests show evidence of entrainment above the operating floor.
- The measured velocities above the operating floor are comparable to entrainment velocities, e.g. Kutateladze

$$U_{ent} = \frac{3\sqrt[4]{g\sigma\left(\rho_w - \rho_g\right)}}{\sqrt{\rho_g}}$$

  g – gravitational acceleration
  σ - steam/gas surface tension
  ρ_w – water density
  ρ_g – gas mixture density
  U_{end} ~ 14.7 m/sec (48 ft/sec)

  Actual velocity is dependent on the physical configuration and the water film thickness.
- All CVTR tests show evidence of no entrainment below the operating floor.
- The measured velocities below the operating floor are less than entrainment velocities.

Schematic of the Wall Condensate Collection Segments



CVTR Condensate Catch Can Results
(Taken From Schmitt et al., 1970)

Condensate Catch Cans	Elevation* (ft)	Liner Area (ft^2)	Test 3 (No Spray) (m*l*)	Test 4 (290 gpm Spray) (m*l*)	Test 5 (500 gpm Spray) (m*l*)
1	359	1	7,330	6,000	8,640
2	351	9	640	670	720
3 (Rate Gauge 3)	343	17	6,850	3,960	4,760
4	335	25	5,990	5,800	5,360
5	327	33	5,050	4,000	2,130
Operating Floor 325 ft.					
6 (Rate Gauge 2)	319	41	15,520	18,000[a]	14,100
7	311	49	3,550	2,530	1,830
8 (Rate Gauge 5)	303	57	3,420	3,100	2,330
9	295	65	4,350	[b]	2,730

* Elevation of the operating floor is 325 ft.
[a] Full catch can.
[b] Catch can detached from mounting.

EVIDENCE OF ENTRAINMENT IN CVTR

- Wall segments were isolated to enable the condensate from that segment to be collected and measured.
- The expected trend of increasing condensate for an order of magnitude change in the vertical condensing surface area was not observed above the operating floor (325 ft). Conclusion: Film drainage is not the dominant mechanism for water entering the collection canister.
- There is a small trend in the condensate catch can data indicating more mass accumulated near the springline than near the operating floor. Conclusion: This is where the local velocities would be expected to be greater and the airborne water mass is deposited in the catch can devices by entrainment and circulation.
- Below the operating floor the collected condensate masses increase with increasing condensing area as expected. The measured and calculated velocities below the operating floor are below those required for entrainment. Conclusion: The velocities above the operating floor are sufficient for entrainment.

ENTRAINMENT BELOW THE OPERATING FLOOR IN CVTR

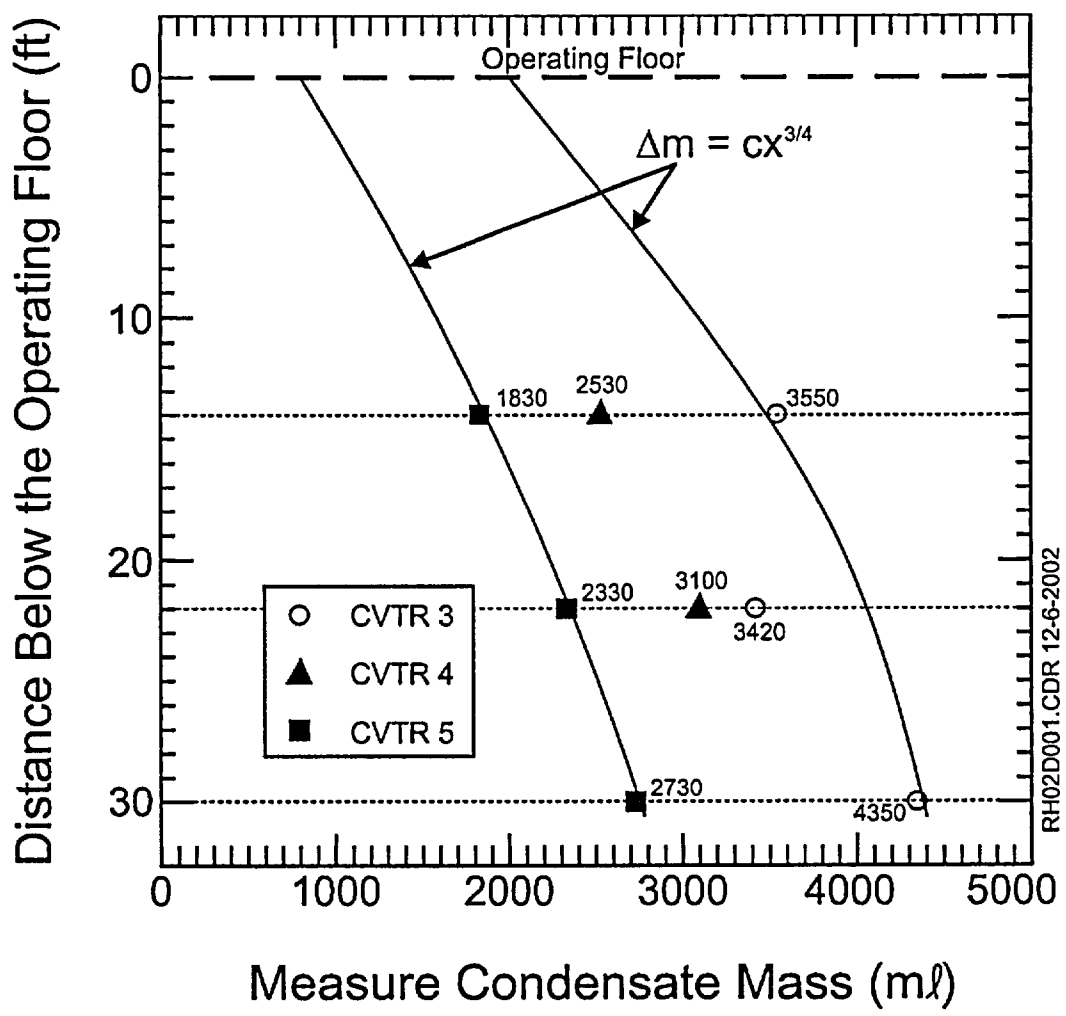
- For laminar condensation and a constant temperature difference the condensate film increases as the condensing length to the 1/4 power (Kreith and Bohn, Principles of Heat Transfer).
- The condensate mass flow varies as the film thickness cubed

$$\dot{m} \propto \delta^3$$

- Therefore the collected condensate mass varies with the condensing length as

$$\Delta m \propto x^{3/4}$$

Condensate Collection Profile for the CVTR Experiments



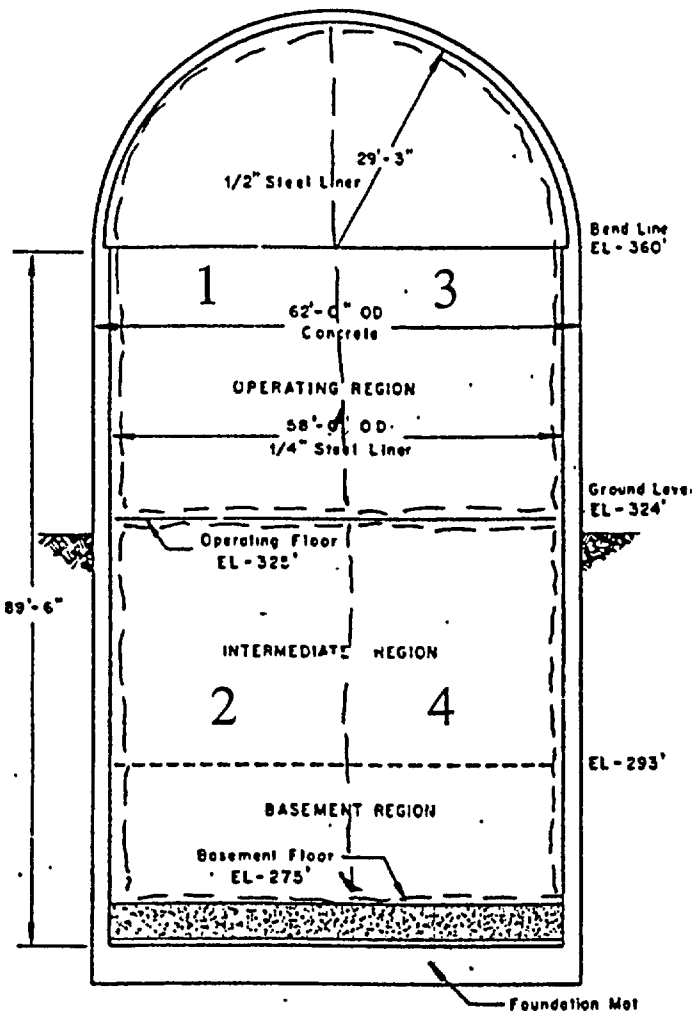
NODALIZATION

The CVTR Experiments provides a good test case for nodalization studies. This provides test results for

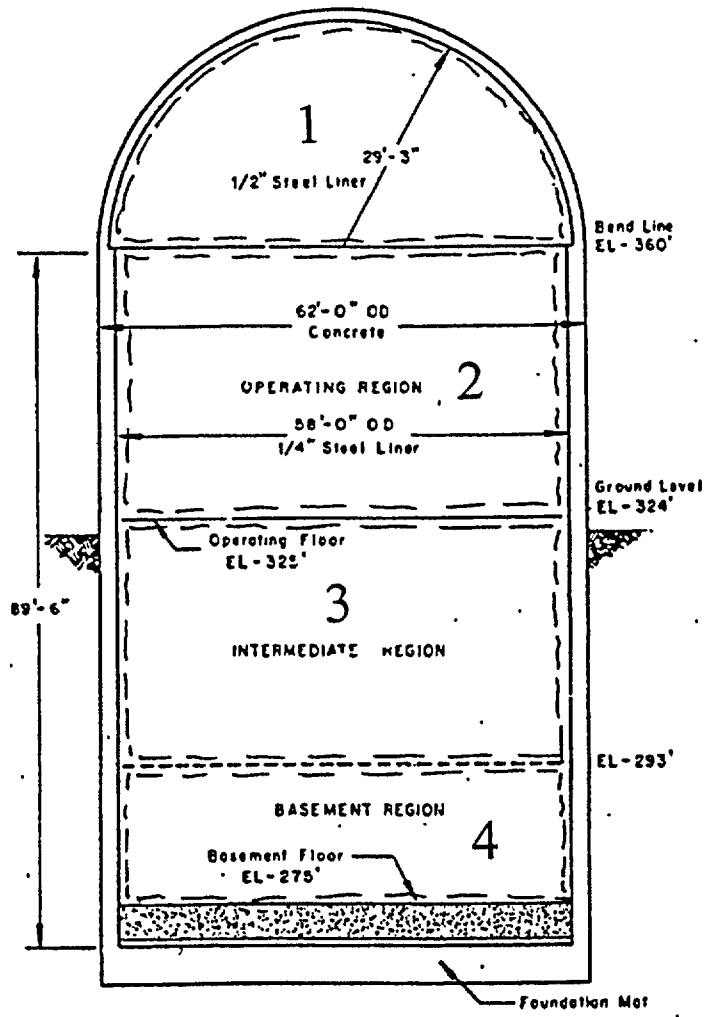
- containment pressurization,
- stratification,
- wall heat transfer measurements a a function of elevation in the containment,
- velocities during the blowdown,
- water entrainment.

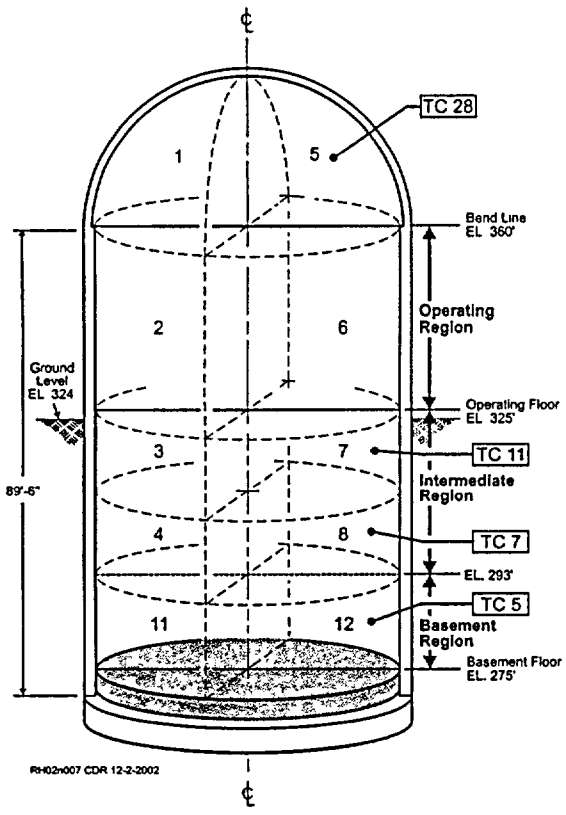
Nodalization studies have been performed with 1, 6, 12, 13, 14, 16 and 18 nodes.

CVTR 6 Node:
"Window Pane"



CVTR 6 Node:
4 Vertically Stacked Nodes




TC 28
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Operating
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EL 324
Operating Floor
EL 325'
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TC 11
Intermediate
Region
89'-6"
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TC 7
EL. 293'
TC 5
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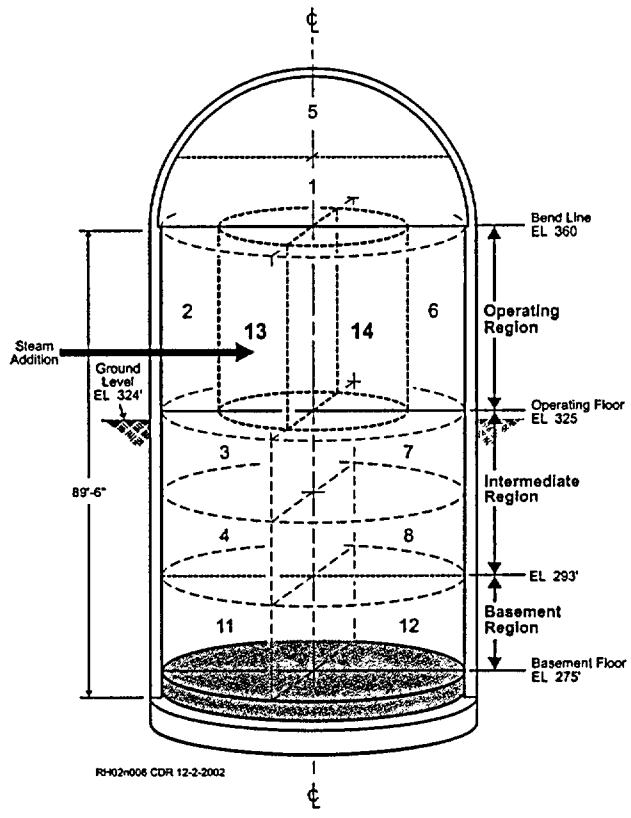
12
Basement
Region
Basement Floor
EL. 275'
RH02n007 CDR 12-2-2002

12V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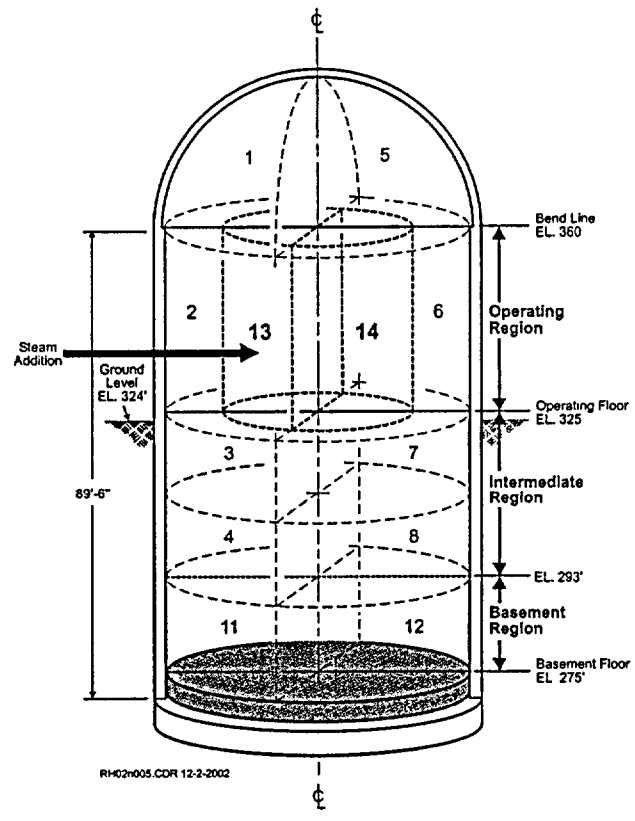
14H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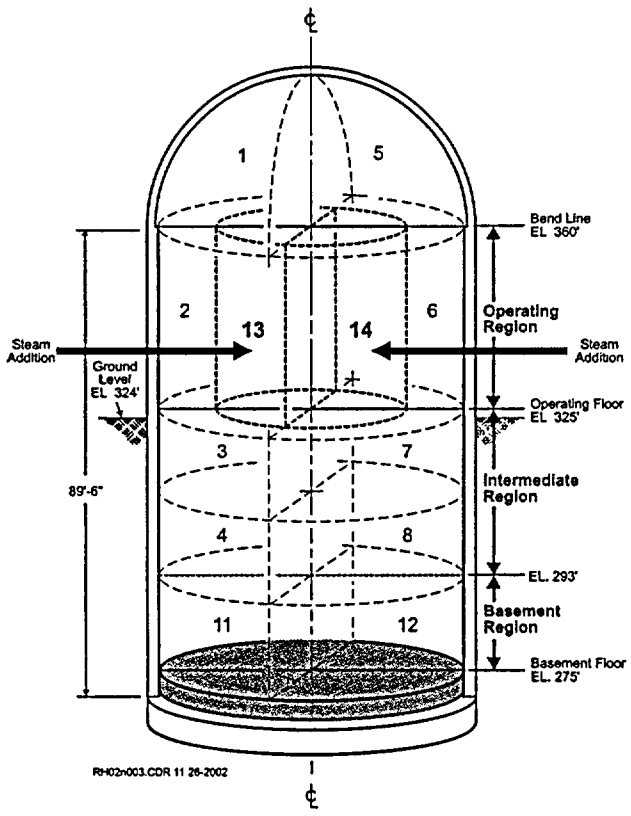
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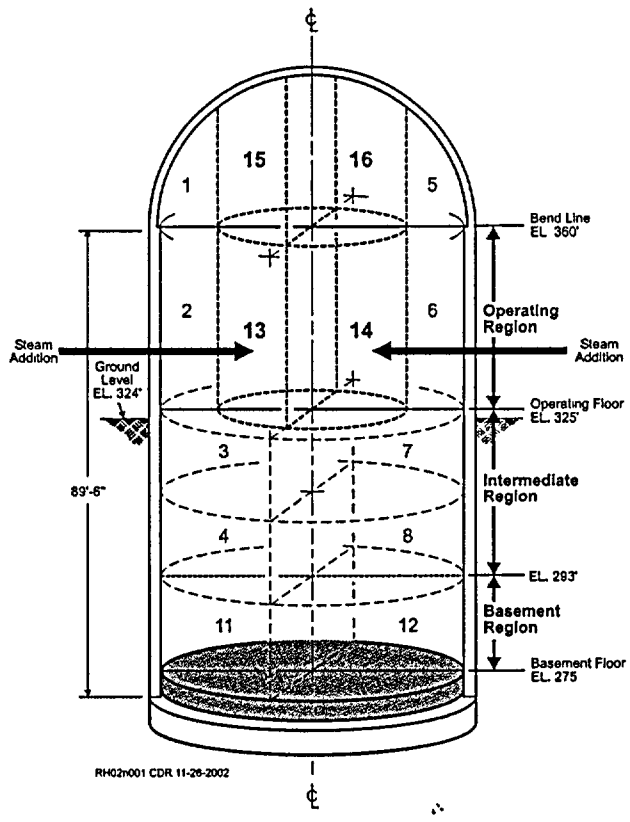
14V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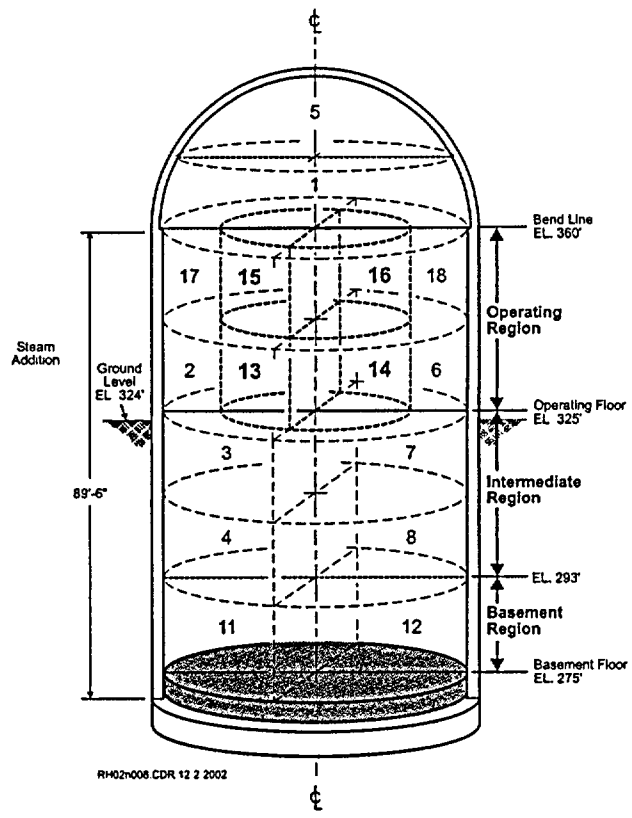
16V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18H

Nodalization Studies
Test Case: CVTR 3
Measured Peak Pressure = 17.6 psig

Nodalization	Steam Added to Node(s)	Calculated Peak Pressure (psig)	
		Top Nodes Are Vertical	Top Nodes Are Horizontal
1	1	19.28	
6	1 1 & 3	23.72 22.72	25.77 (1) 22.46 (2)
12	2 2 & 6	22.46 20.30	22.72 22.27
14	13 13 & 14	23.75 22.42	23.64 22.66
16	13 13 & 14	22.74 22.27	
18 (most representative of CVTR injection)	13 13 & 14	22.62 22.18	22.77 22.44
18	15 15 & 16	23.85 23.77	23.85 23.82

Influence of Increasing the Effective Friction Factor for CVTR5 (Measured Peak Pressure ~ 17.75 psig)

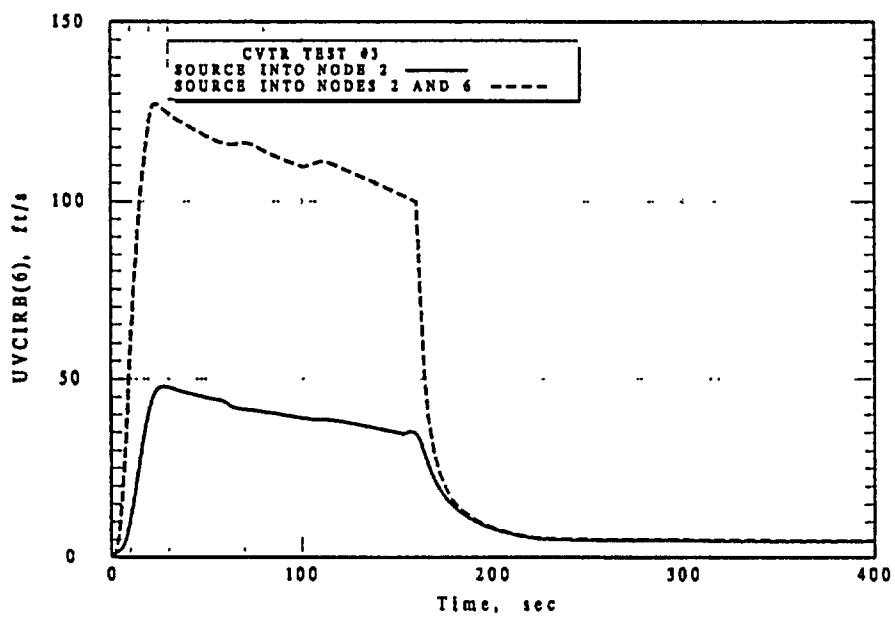
Containment Model	FFMULT (Dimensionless)	Peak Pressure (psig)
12	1.0	21.9
	1.5	21.2
	6.0	19.1
	15.0	18.3
14H	1.0	23.1
	1.5	22.3
	6.0	10.0
	15.0	19.0
16	1.0	22.6
	1.5	21.9
	6.0	19.9
	15.0	19.0

Conclusion: Increasing the effective friction factor increases the heat transfer coefficient and reduces the calculated peak pressure.

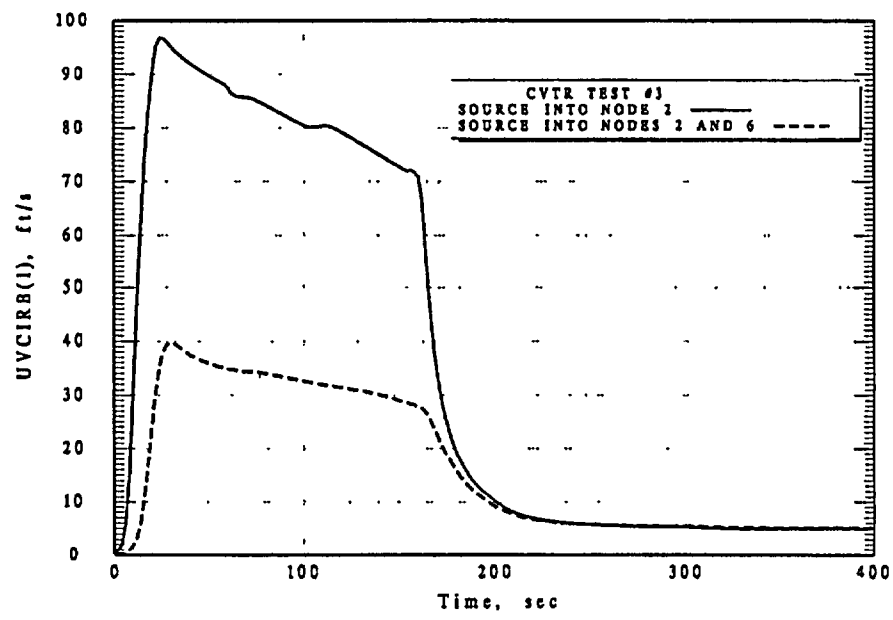
CONCLUSION FROM THE NODALIZATION STUDIES

The MAAP5 model is not strongly influenced by the nodalization with respect to peak pressure. However, the stratification and related heat transfer in various containment regions requires nodalization in the vertical direction.

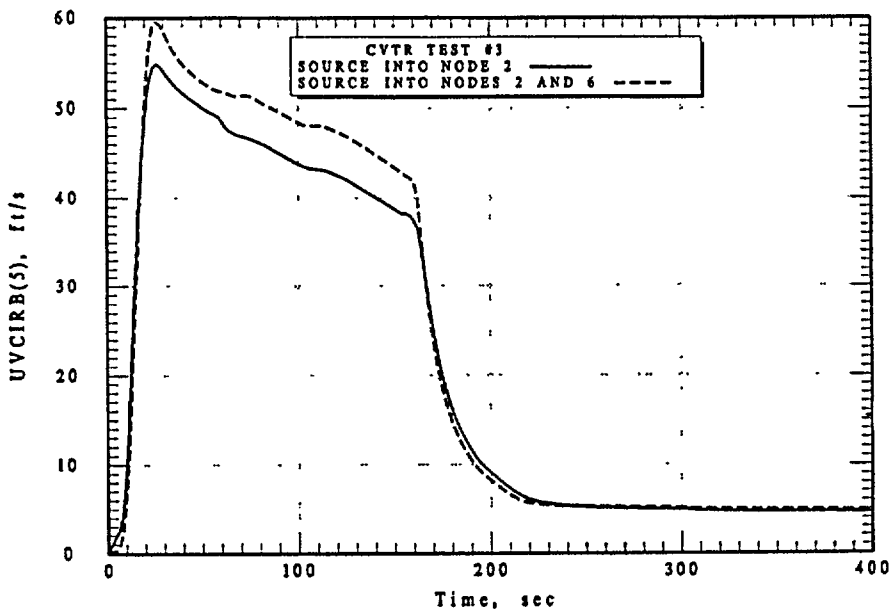
Calculated Velocities in Node 6 for Steam Discharge Into Node 2 and Also for Equal Discharges Into Nodes 2 and 6



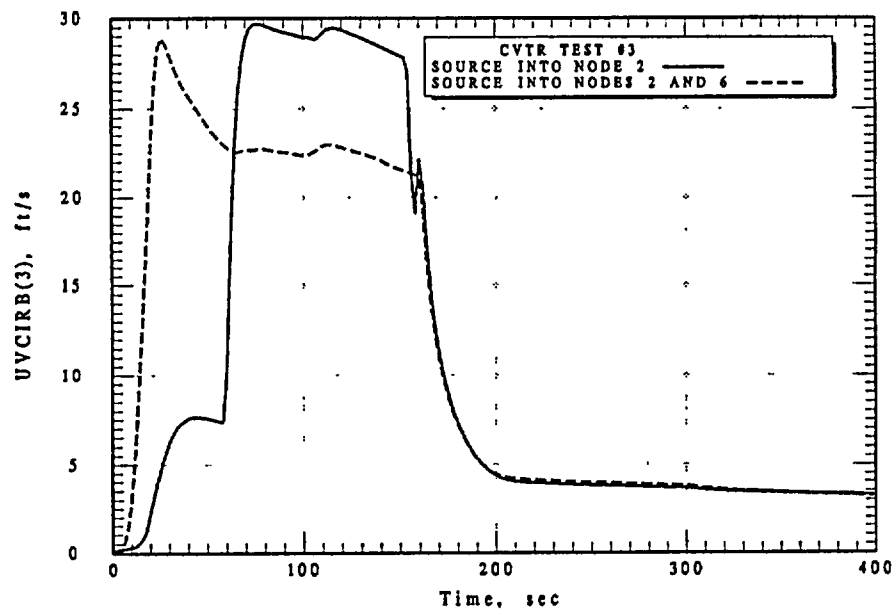
Calculated Velocities in Node 1 for Steam Discharge Into Node 2 and Also for Equal Discharges Into Nodes 2 and 6



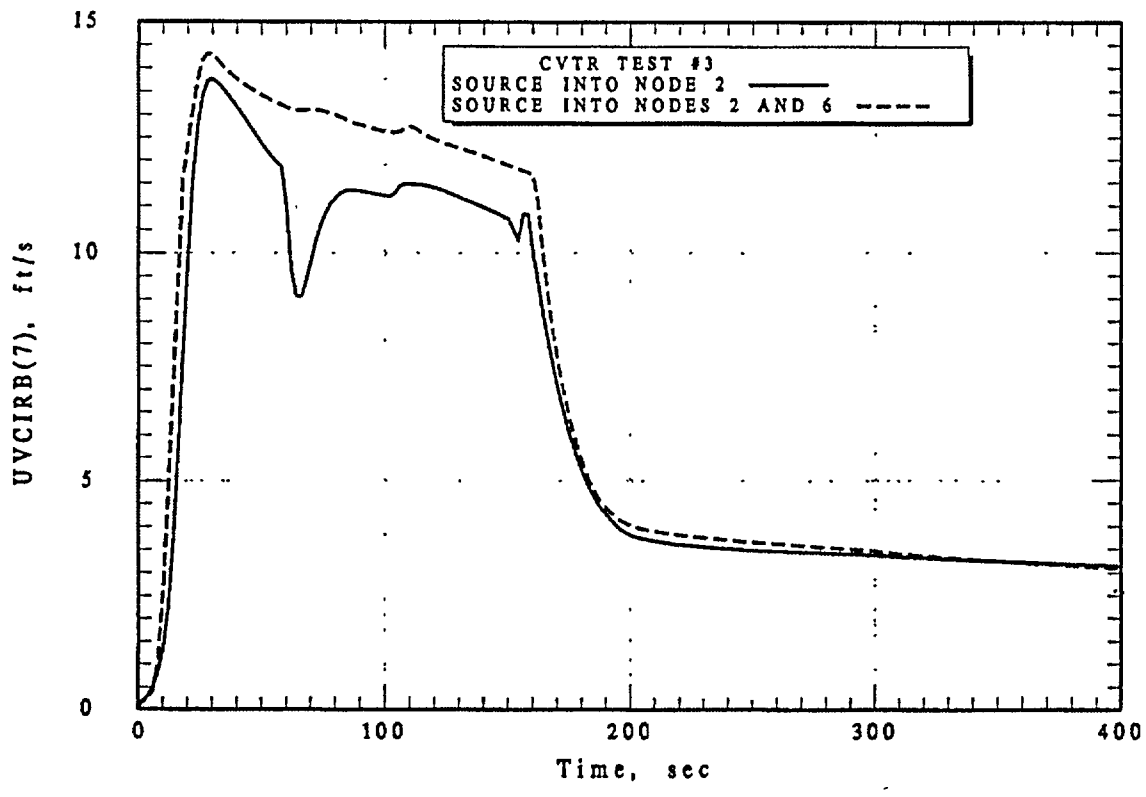
Calculated Velocities in Node 5 for Steam Discharge Into Node 2 and Also for Equal Discharges Into Nodes 2 and 6



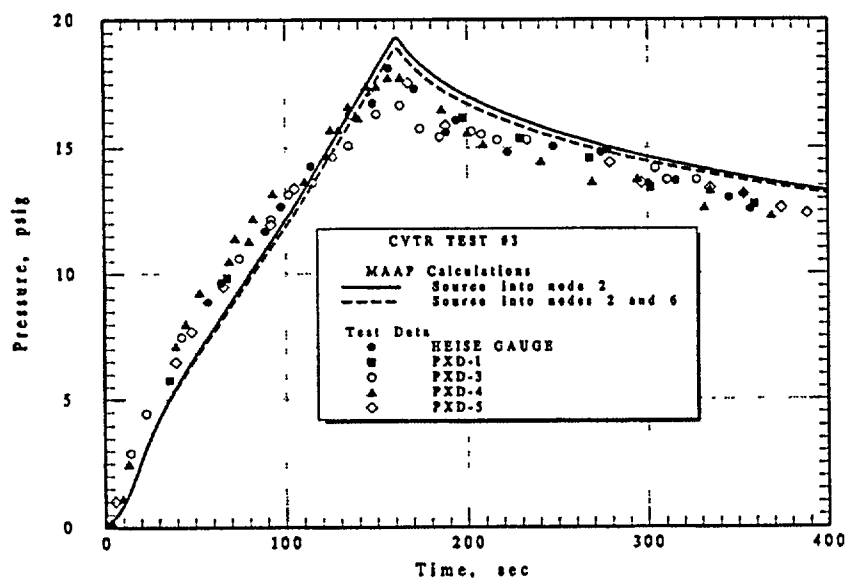
Calculated Velocities in Node 3 for Steam Discharge Into Node 2 and Also for Equal Discharges Into Nodes 2 and 6



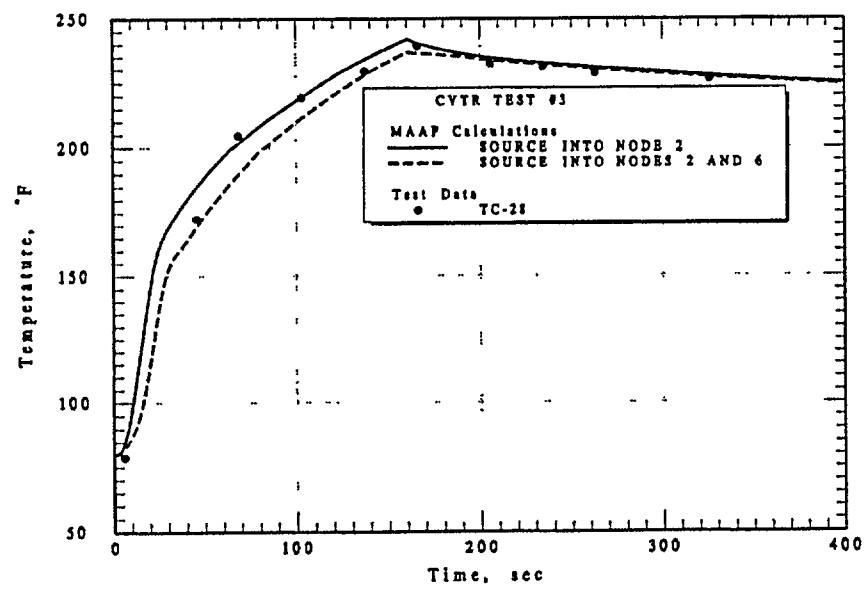
Calculated Velocities in Node 7 for Steam Discharge Into Node 2 and Also for Equal Discharges Into Nodes 2 and 6



Comparison of CVTR Response for the M&E Released Into a Single Node or Into Adjacent Nodes Along with the Experimentally Measured Pressures



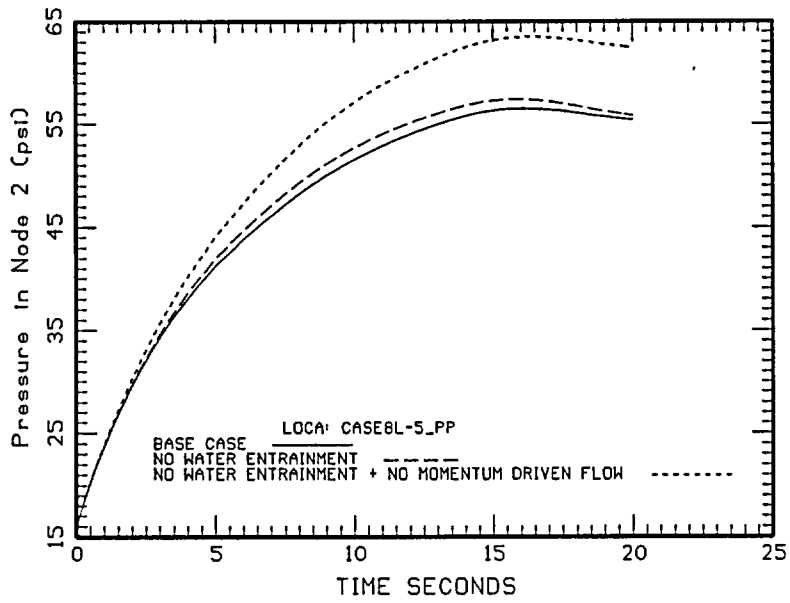
Comparison of CVTR Response for the M&E Released Into a Single Node or Into Adjacent Nodes Along with the Experimentally Measured Temperatures in the Upper Dome

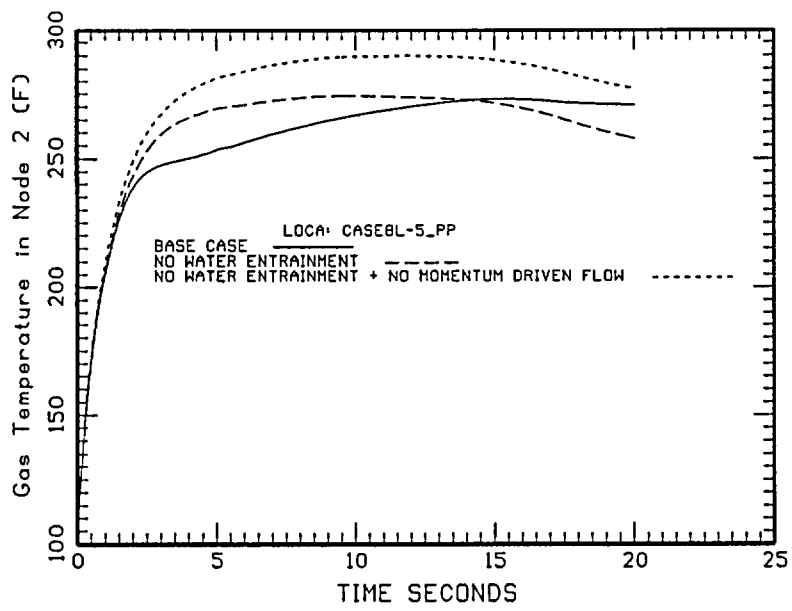


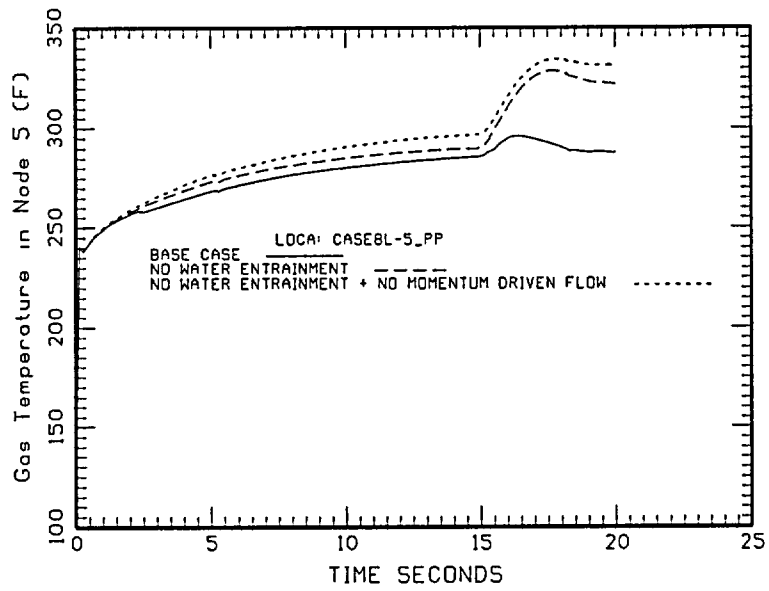
MAAP5 UNCERTAINTY PARAMETERS

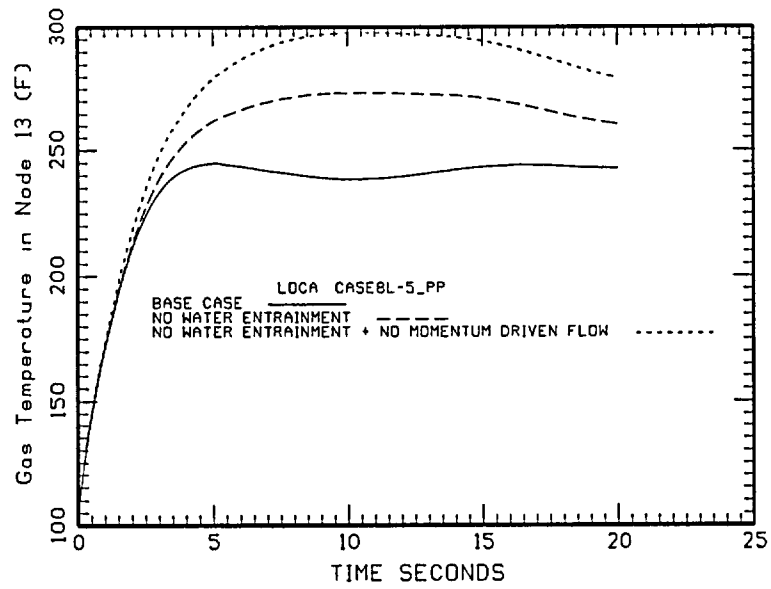
- The major enhancements in the MAAP5 PWR large dry containment model are:
  - Nodal velocities consistent with the momentum added during blowdown and/or containment spray actuation.
  - An enhanced steam condensation correlation.
  - Entrainment of water films when the momentum driven velocity exceeds the entrainment criteria.
- The principle uncertainty parameters are
  - the effective friction factor,
  - the enhanced steam condensation correlation.
- The pessimistic boundaries are used to evaluate the design basis response.
- The pessimistic uncertainty parameters used in the small scale, intermediate scale and large scale benchmarks are the same parameters used to analyze the Beaver Valley containments.

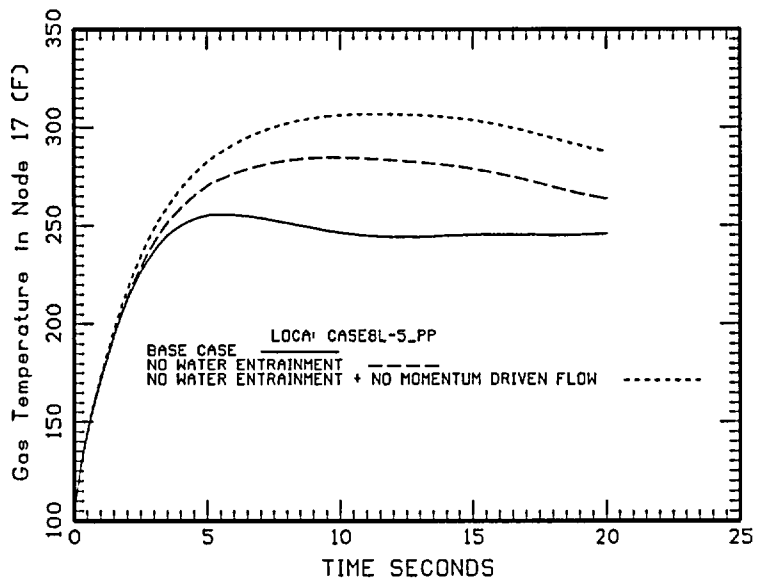
INTEGRAL PLANT ANALYSES ADDRESSED IN RAI RESPONSES

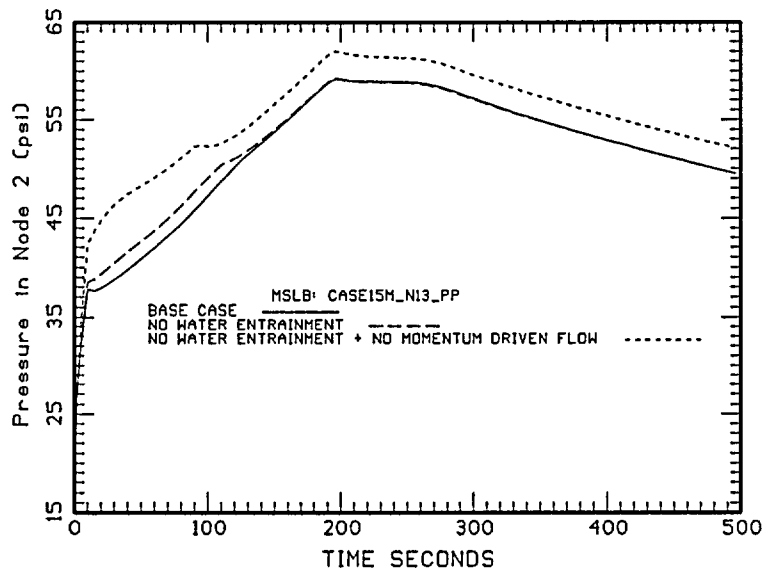

Pressure in Node 2 (psi)
65
55
45
35
25
15
0
5
10
15
20
25
TIME SECONDS
LOCA: CASE8L-5_PP
BASE CASE
NO WATER ENTRAINMENT
NO WATER ENTRAINMENT + NO MOMENTUM DRIVEN FLOW

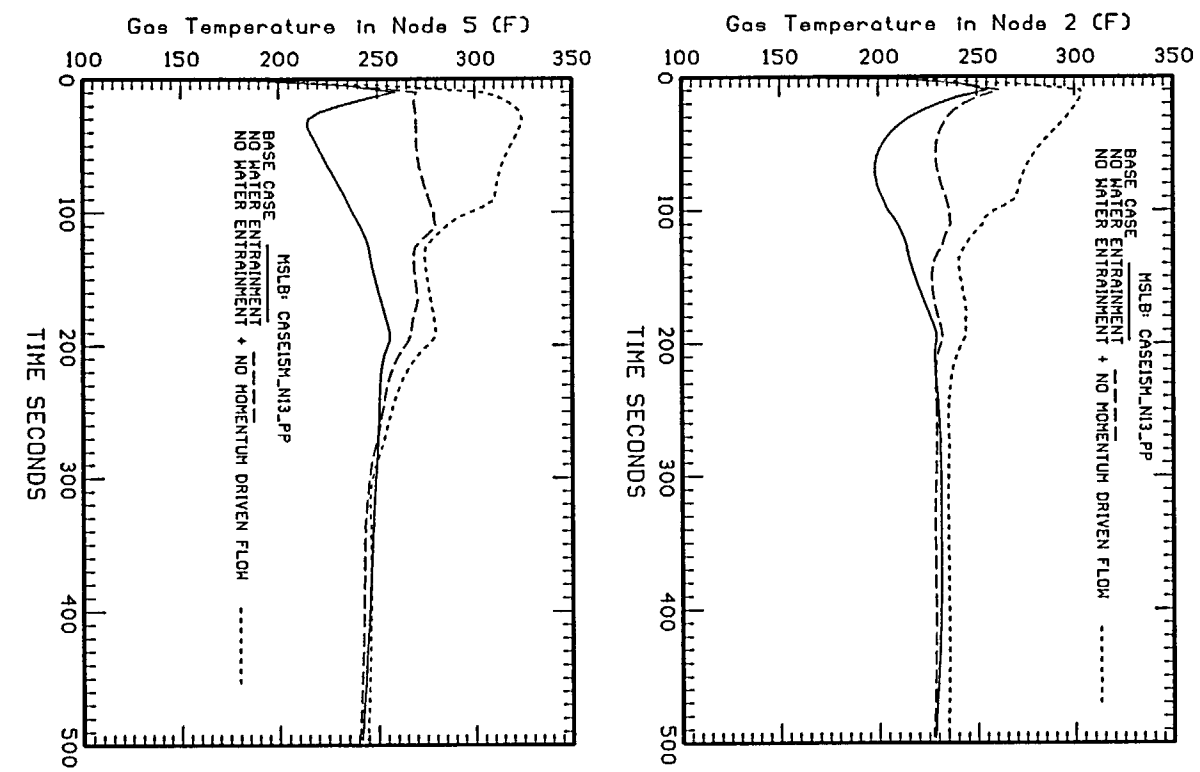

Gas Temperature in Node 2 (F)
300
250
200
150
100
0
5
10
15
20
25
TIME SECONDS
LOCA: CASE8L-5_PP
BASE CASE
NO WATER ENTRAINMENT
NO WATER ENTRAINMENT + NO MOMENTUM DRIVEN FLOW

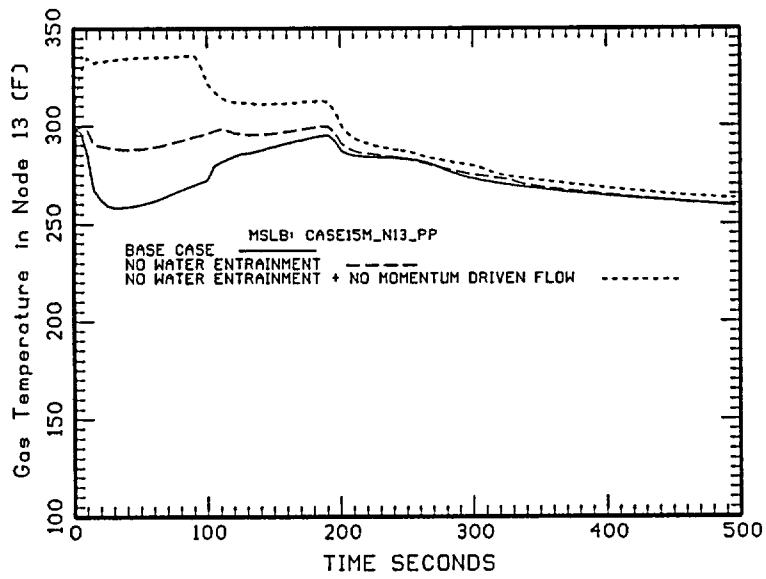

Gas Temperature in Node 5 (F)
100
150
200
250
300
350
0
5
10
15
20
25
TIME SECONDS
LOCA: CASE8L-5_PP
BASE CASE
NO WATER ENTRAINMENT
NO WATER ENTRAINMENT + NO MOMENTUM DRIVEN FLOW

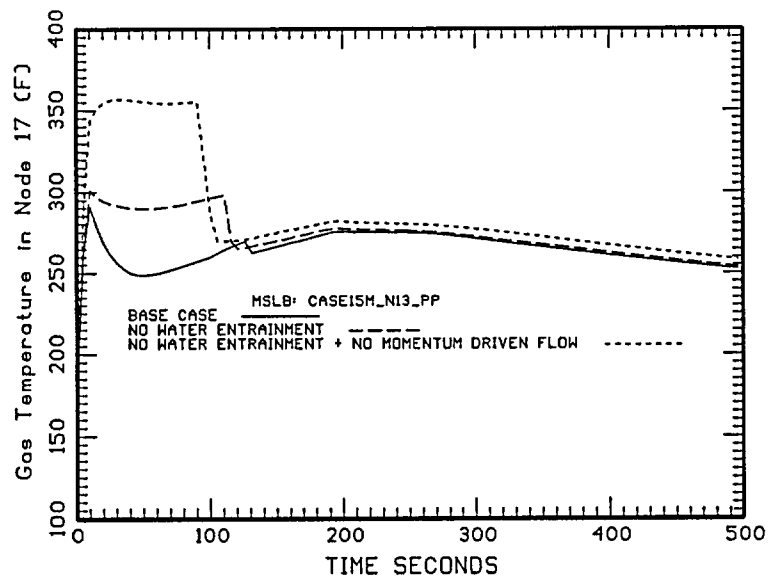

Gas Temperature in Node 13 (F)
100
150
200
250
300
0
5
10
15
20
25
TIME SECONDS
LOCA CASE8L-5_PP
BASE CASE
NO WATER ENTRAINMENT
NO WATER ENTRAINMENT + NO MOMENTUM DRIVEN FLOW

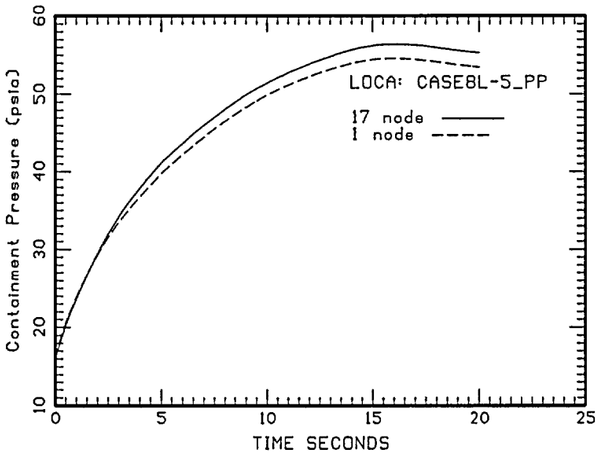

Gas Temperature in Node 17 (F)
350
300
250
200
150
100
0
5
10
15
20
25
TIME SECONDS
LOCA: CASE8L-5_PP
BASE CASE
NO WATER ENTRAINMENT
NO WATER ENTRAINMENT + NO MOMENTUM DRIVEN FLOW

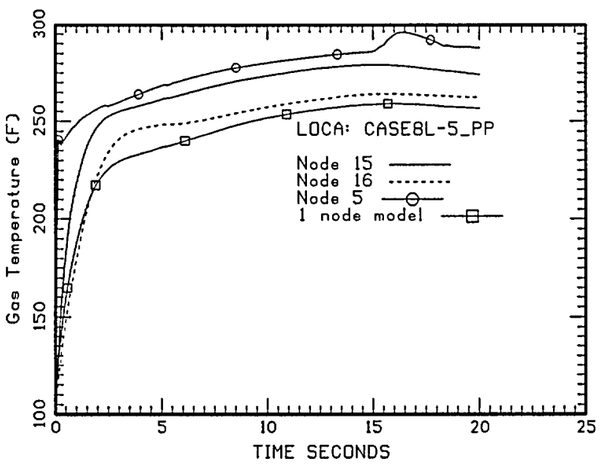

Pressure in Node 2 (psi)
65
55
45
35
25
15
0
100
200
300
400
500
TIME SECONDS
MSLB: CASE15M_N13_PP
BASE CASE
NO WATER ENTRAINMENT
NO WATER ENTRAINMENT + NO MOMENTUM DRIVEN FLOW

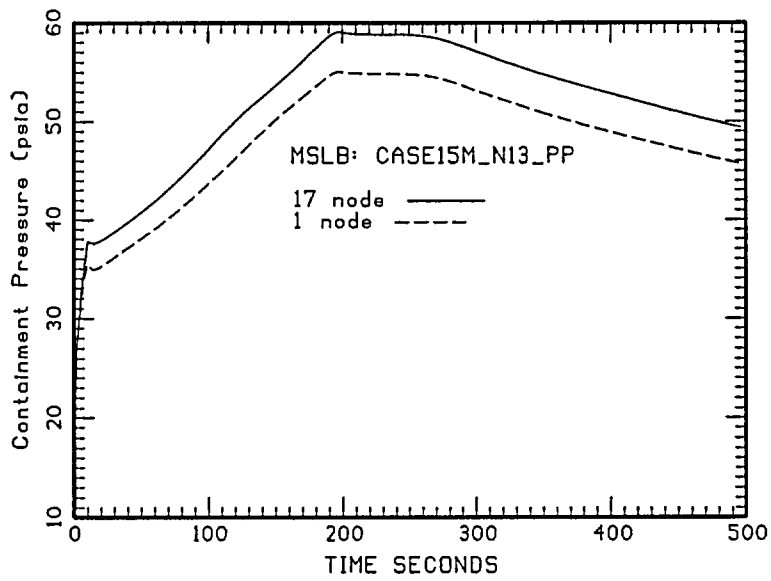

Gas Temperature in Node 5 (F)
100
150
200
250
300
350
0
100
200
300
400
500
TIME SECONDS
MSLB: CASE15H_N13_PP
BASE CASE
NO WATER ENTRAINMENT
NO WATER ENTRAINMENT + NO MOMENTUM DRIVEN FLOW
Gas Temperature in Node 2 (F)
100
150
200
250
300
350
0
100
200
300
400
500
TIME SECONDS
MSLB: CASE15H_N13_PP
BASE CASE
NO WATER ENTRAINMENT
NO WATER ENTRAINMENT + NO MOMENTUM DRIVEN FLOW

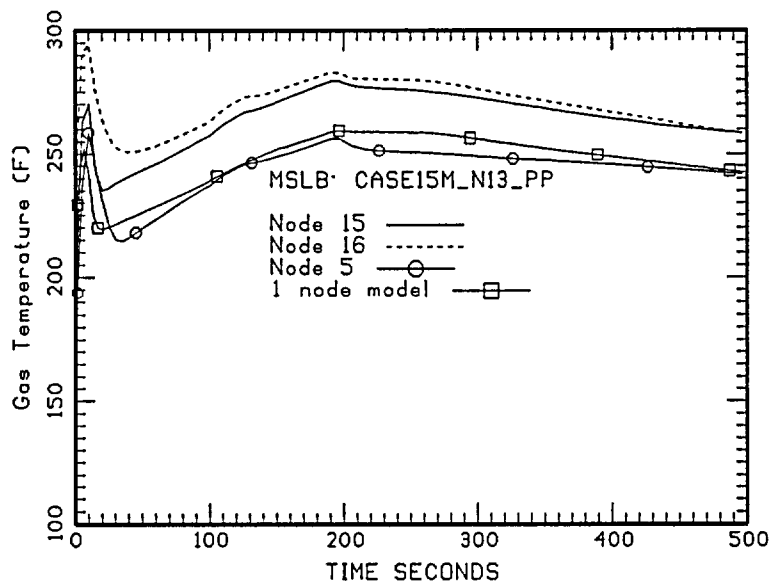

Gas Temperature in Node 13 (F)
100
150
200
250
300
350
0
100
200
300
400
500
TIME SECONDS
MSLB: CASE15M_N13_PP
BASE CASE
NO WATER ENTRAINMENT
NO WATER ENTRAINMENT + NO MOMENTUM DRIVEN FLOW


Gas Temperature in Node 17 (F)
100
150
200
250
300
350
400
0
100
200
300
400
500
TIME SECONDS
MSLB: CASE15M_N13_PP
BASE CASE
NO WATER ENTRAINMENT
NO WATER ENTRAINMENT + NO MOMENTUM DRIVEN FLOW

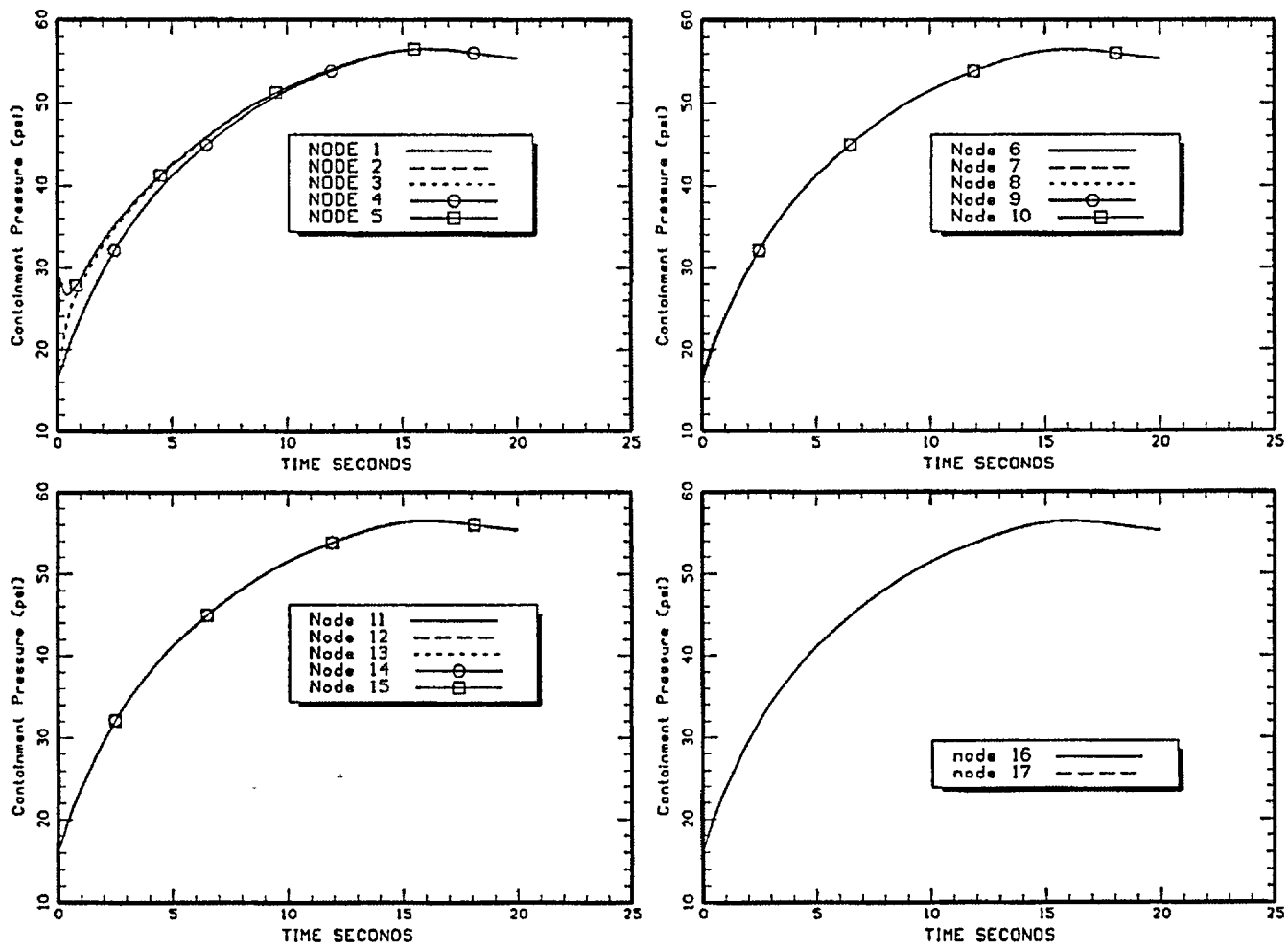

LOCA: CASE8L-5_PP
17 node
1 node
Containment Pressure (psia)
TIME SECONDS
10
20
30
40
50
60
0
5
10
15
20
25


LOCA: CASE8L-5_PP
Node 15
Node 16
Node 5
1 node model
Gas Temperature (F)
TIME SECONDS
100
150
200
250
300
0
5
10
15
20
25

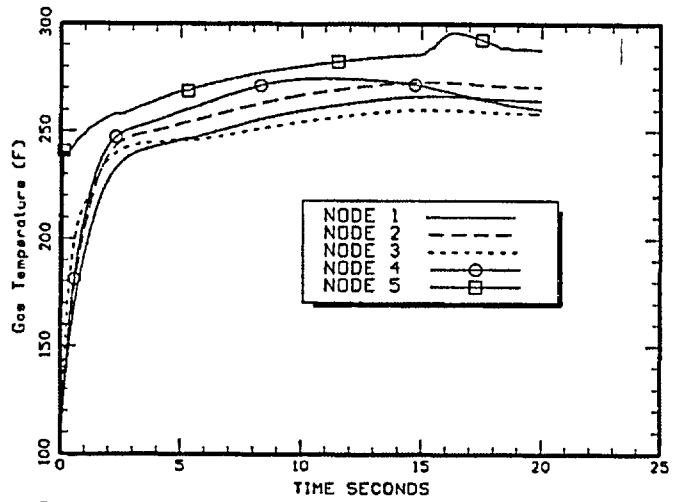

MSLB: CASE15M_N13_PP
17 node
1 node
Containment Pressure (psia)
TIME SECONDS
10
20
30
40
50
60
0
100
200
300
400
500

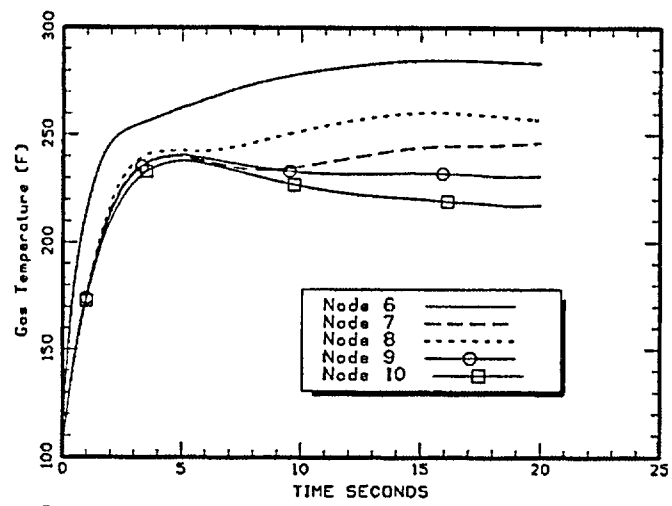

MSLB: CASE15M_N13_PP
Node 15
Node 16
Node 5
1 node model
Gas Temperature (F)
TIME SECONDS
100
150
200
250
300
0
100
200
300
400
500

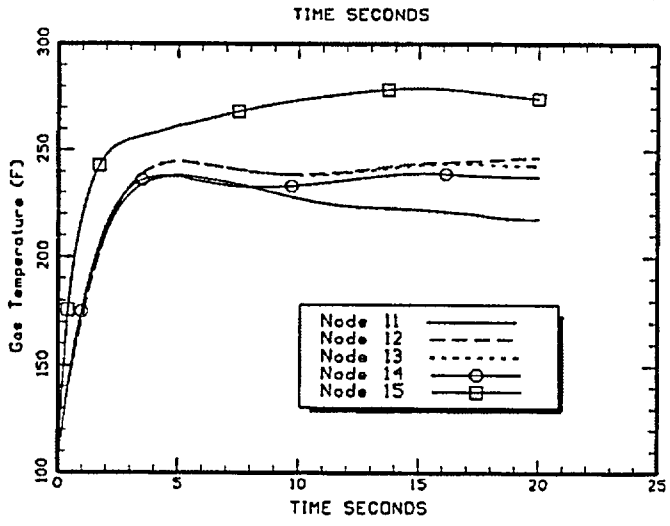
LOCA CASE8L-5_PP

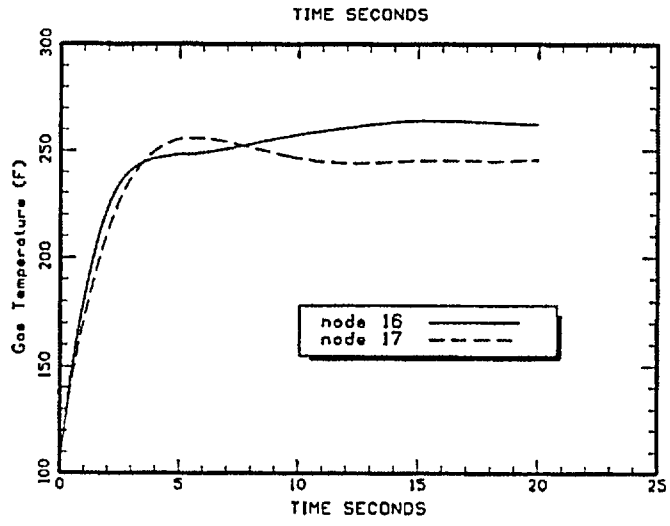


LOCA CASE8L-5_PP









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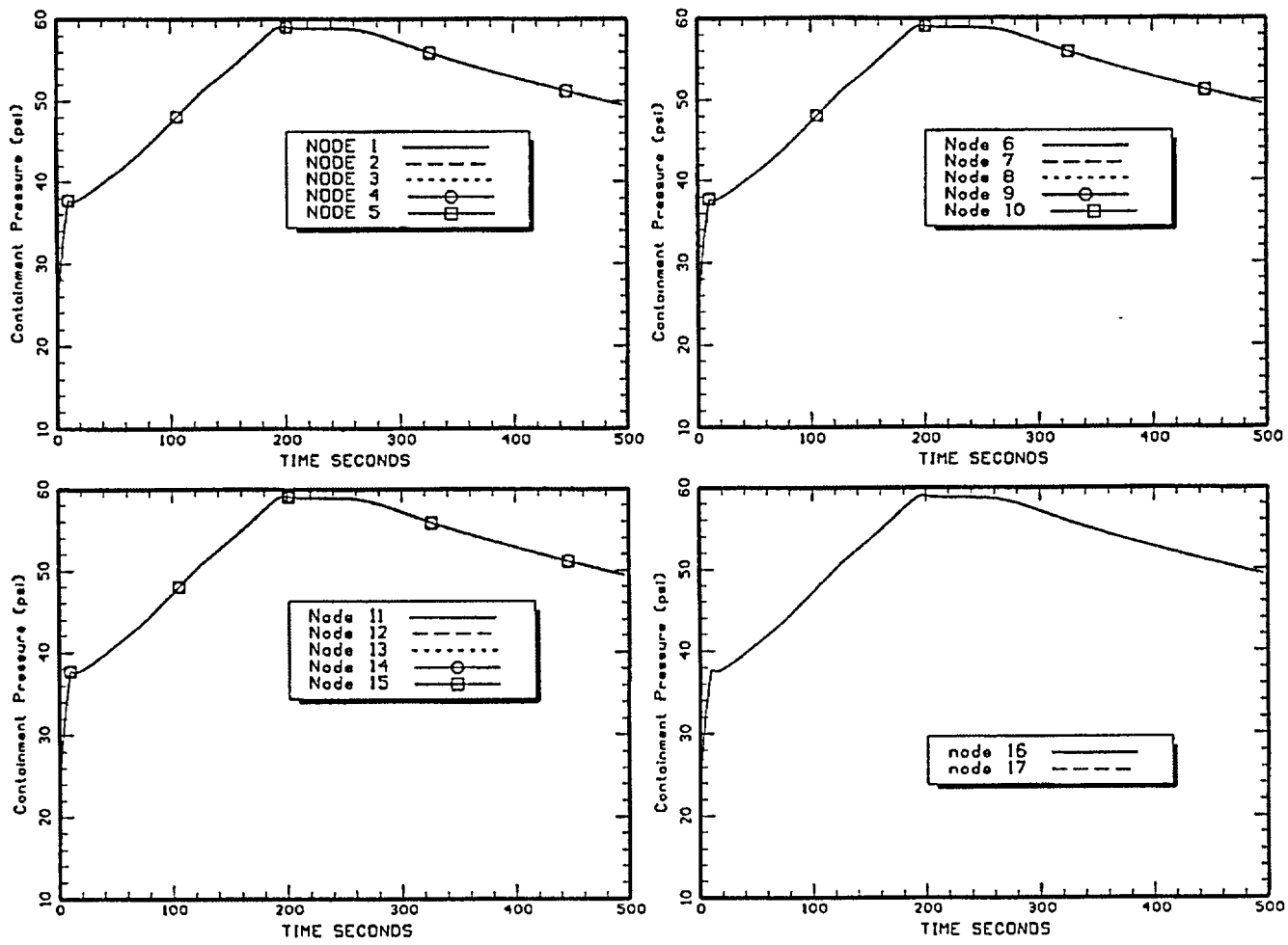

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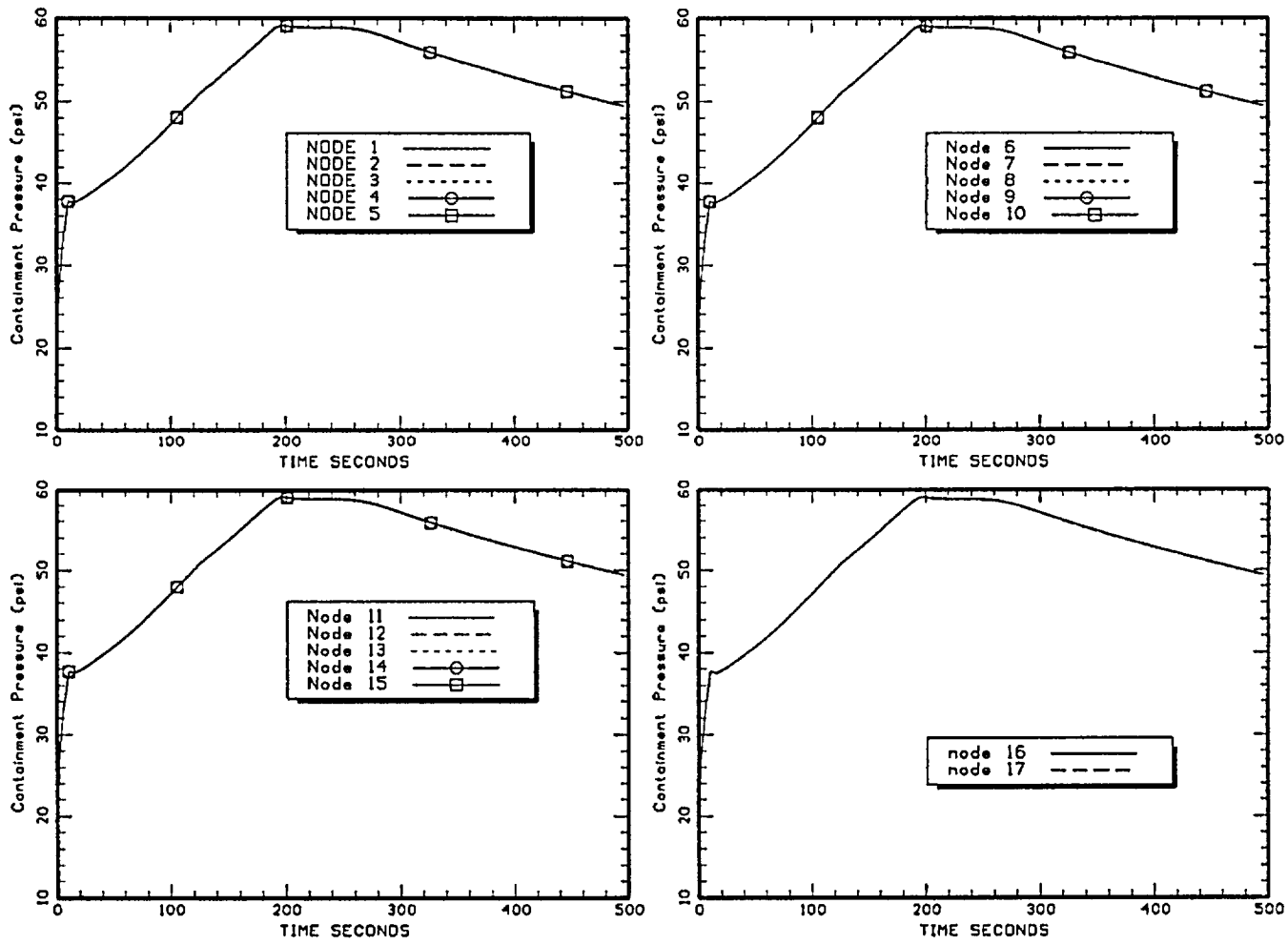
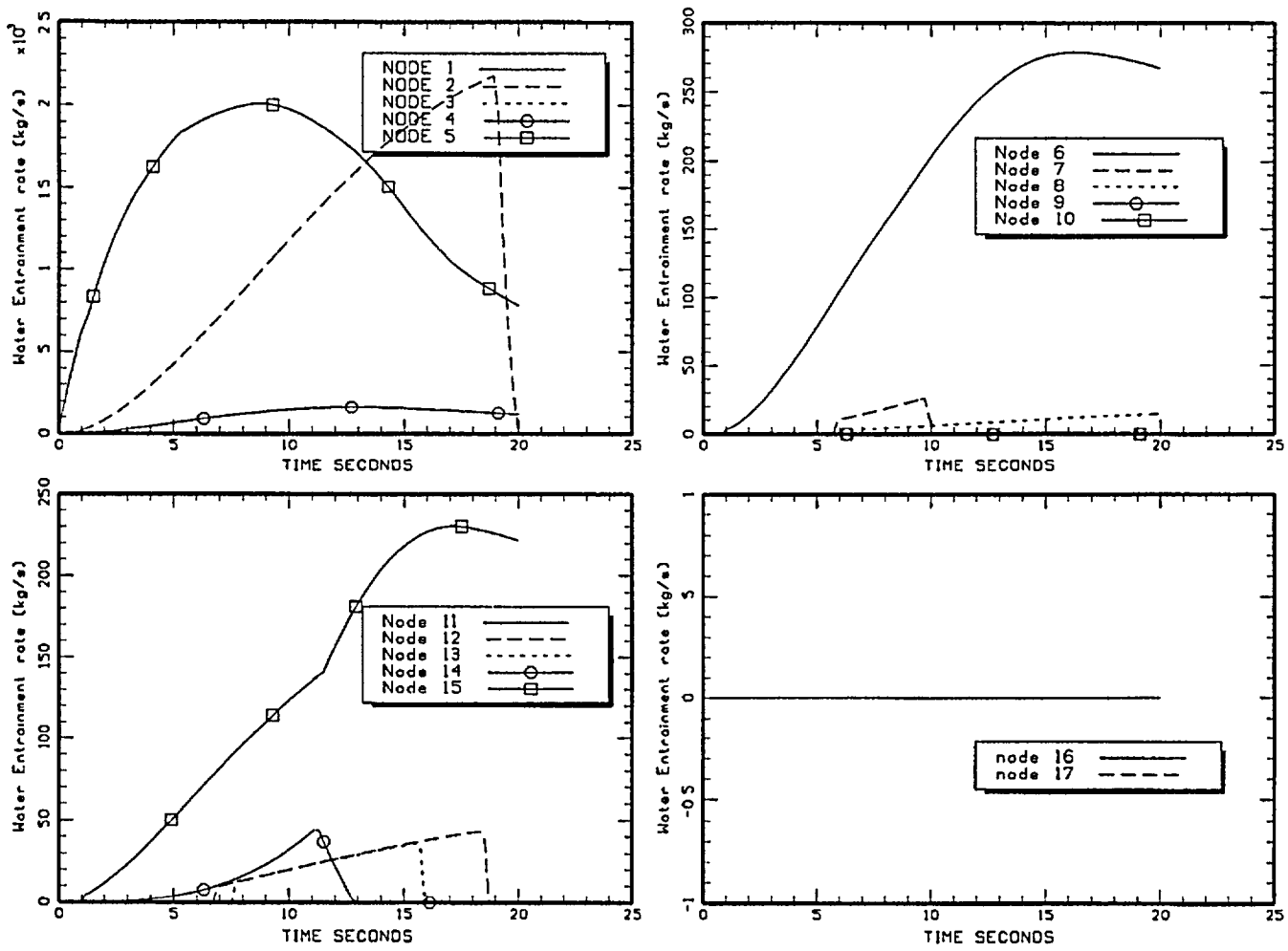
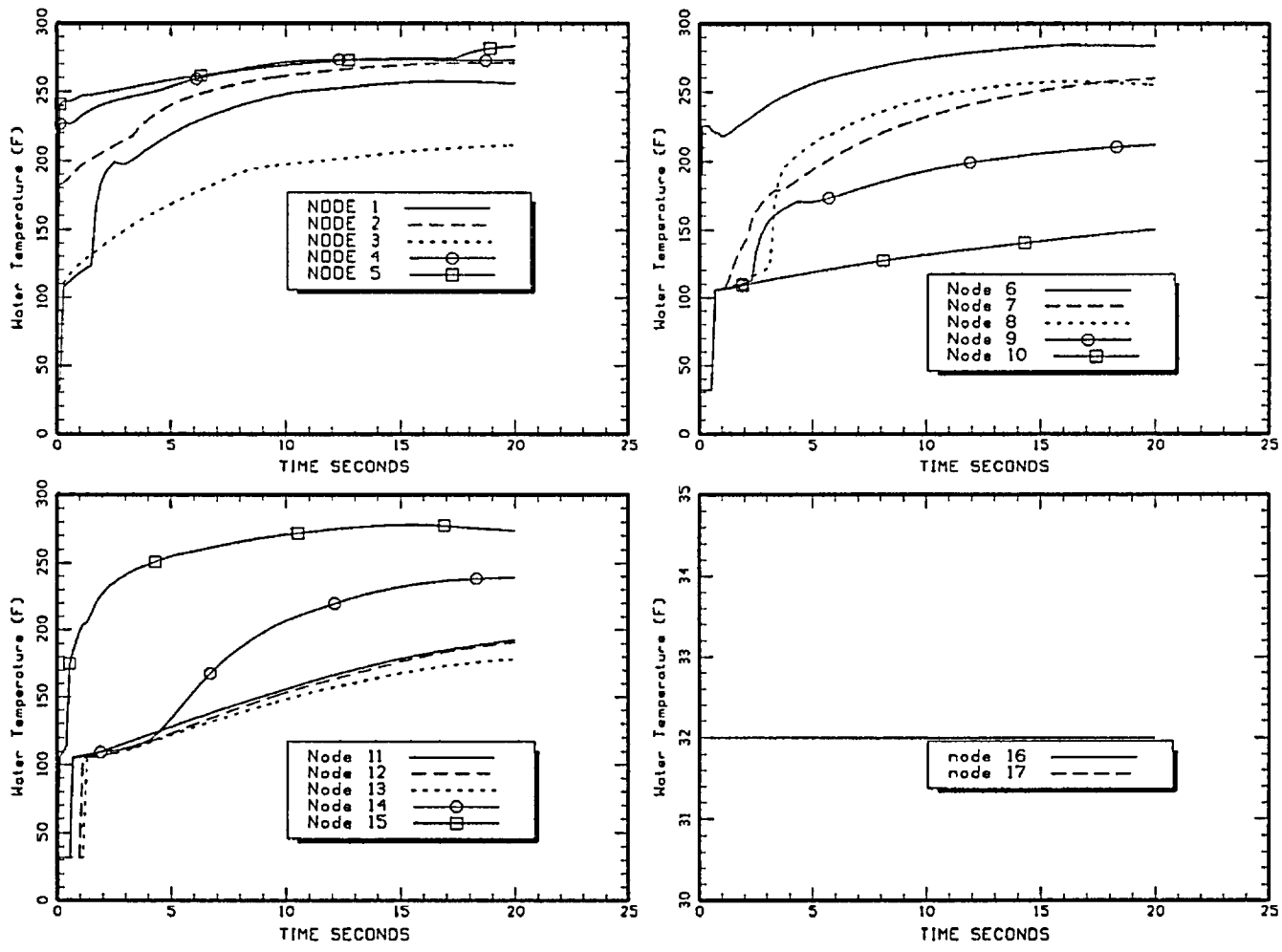


LOCA CASE8L-5_PP



LOCA CASE8L-5_PP



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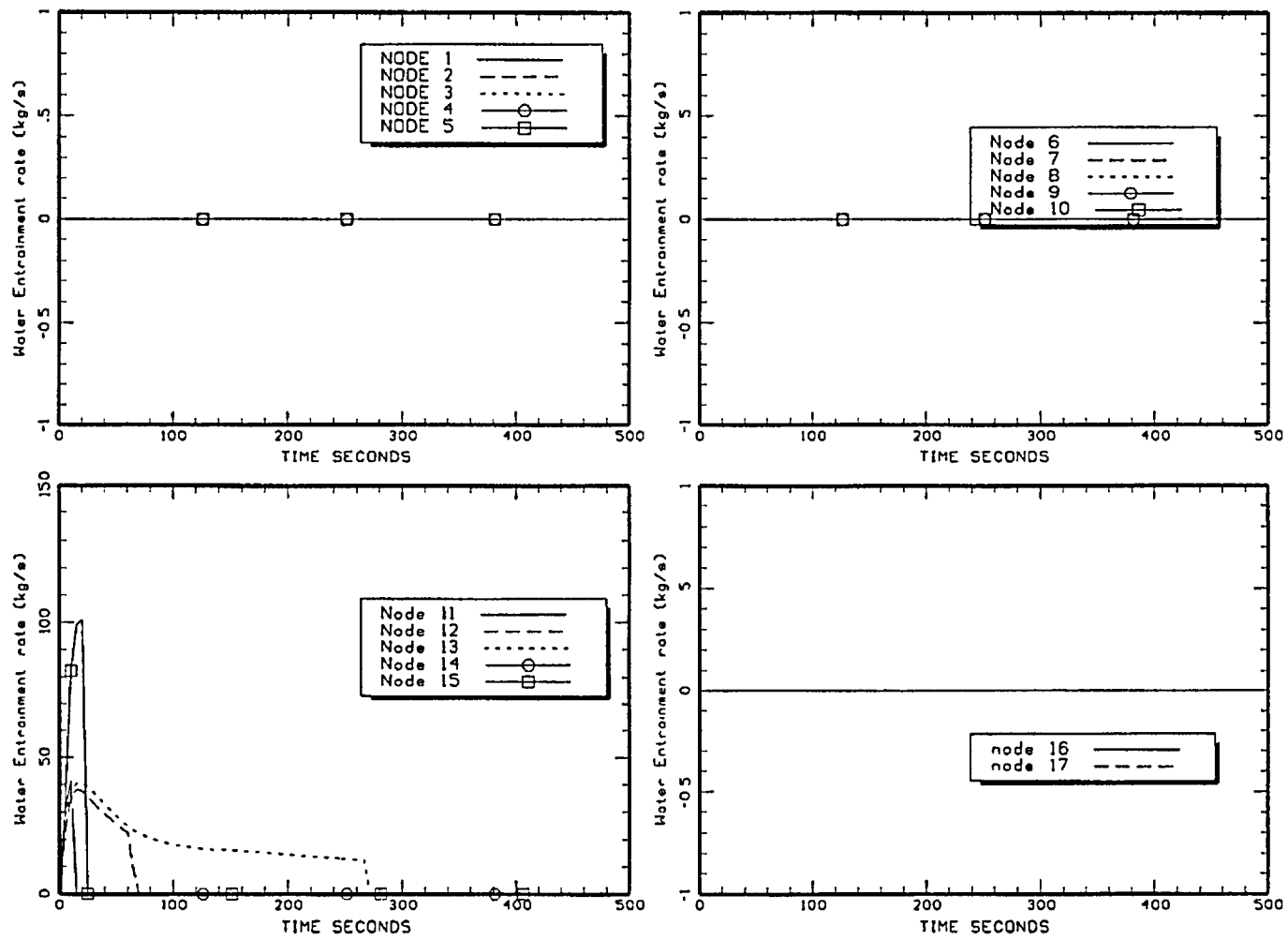

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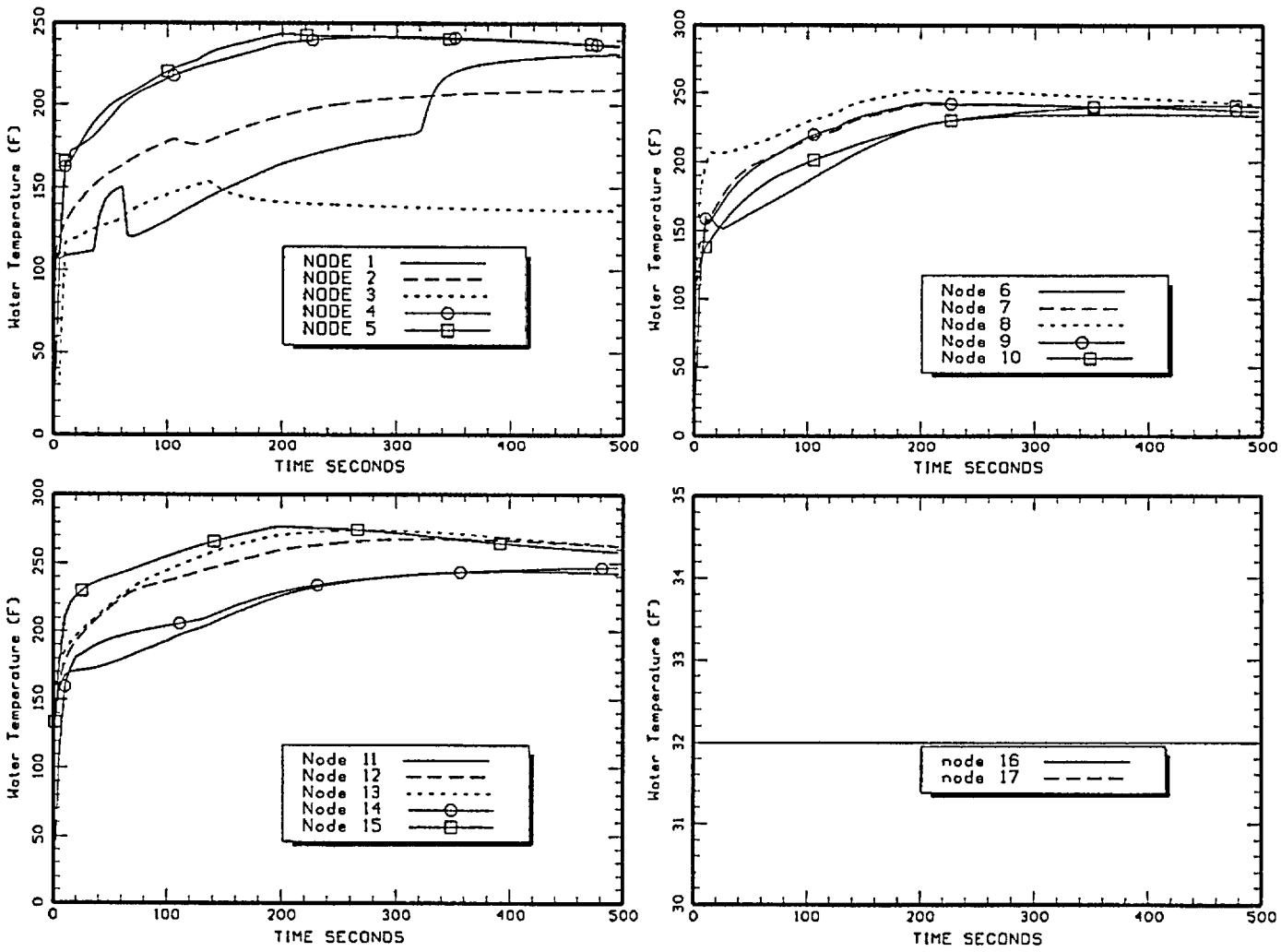
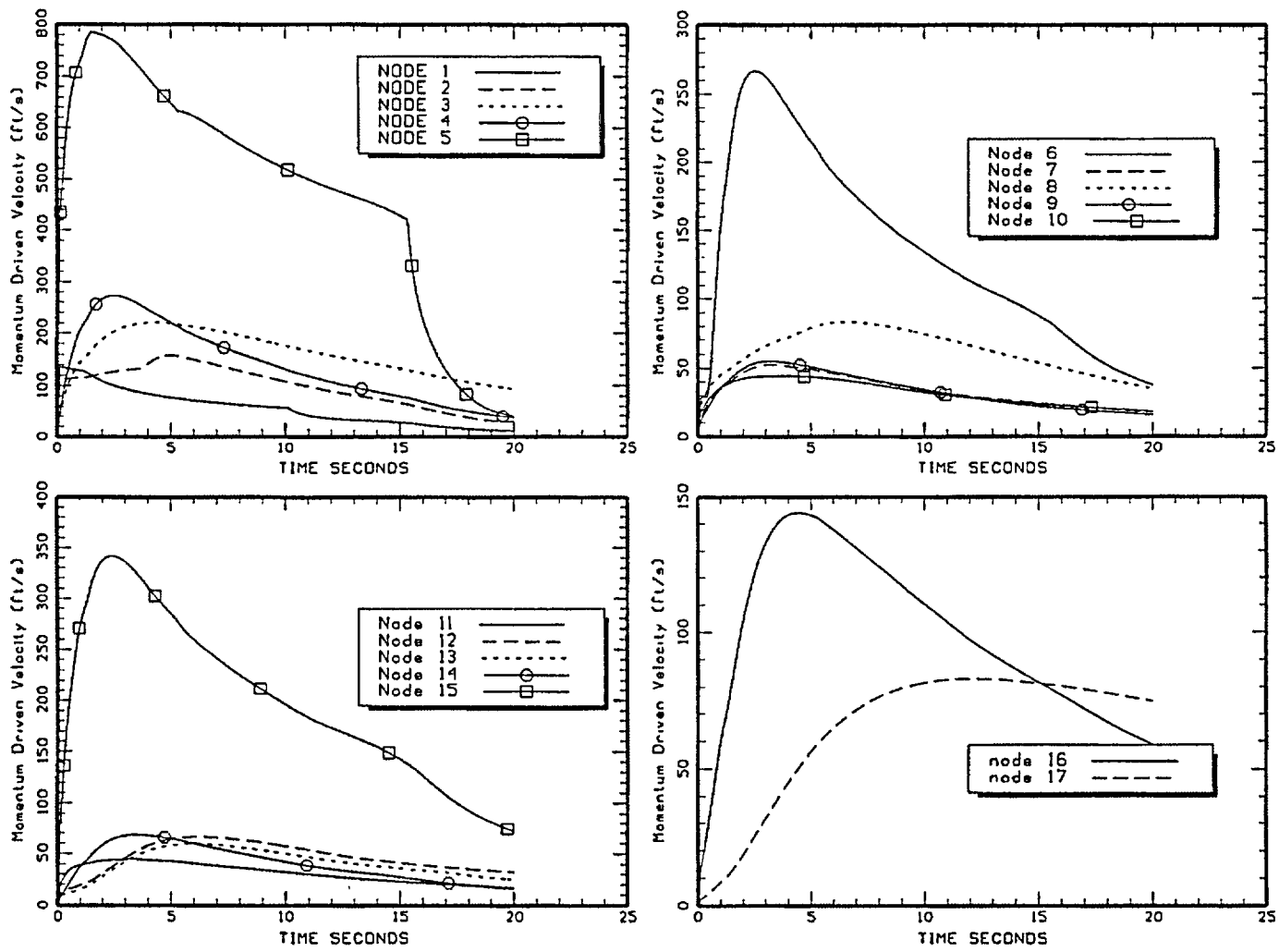
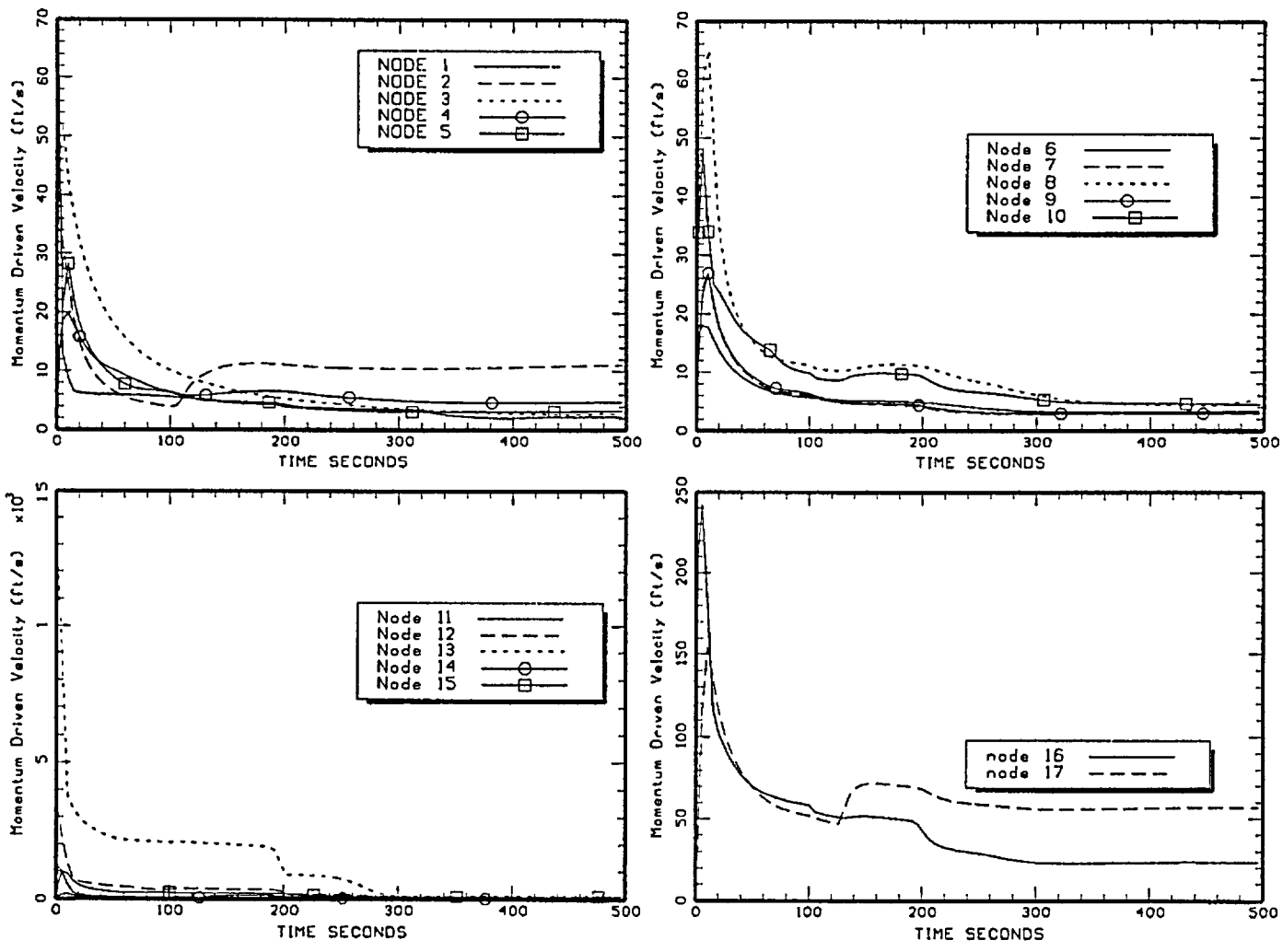


LOCA CASE8L-5_PP



MSLB: CASE15M_N13_PP



MAAP5 Topical Report Review Schedule

Meeting/Information Exchange	Date
Meeting with the NRC staff to present the MAAP5 methodology.	6/20/01
Meeting with NRC staff to discuss MAAP5 applications to Beaver Valley and Point Beach.	11/27/01
Meeting with ACRS TH Subcommittee to discuss MAAP5 methodology.	11/28/01
MAAP5 PWR Large Dry Containment Topical Report submitted.	3/02
MAAP5 Topical Report overview.	4/24/02
RAIs received on the MAAP5 methodology.	11/02
Responses to RAIs on the MAAP5 methodology submitted.	12/02
Meeting with the NRC staff to discuss the RAI responses for MAAP5.	12/11/02
Future meeting(s) with the ACRS - TH Subcommittee - Full Committee	 1/03 (?) ?
Future meetings with the NRC staff.	?
Anticipated MAAP5 methodology approval to support Beaver Valley implementation schedule.	6/1/03

REVIEW OF CONTAINMENT RAI RESPONSES FROM FENOC/W/FAI

Jack Tills, JTA.
NRC/RES Contractor

December 11, 2002

NRC Headquarters
Rockville, Maryland

Enclosure 3

Outline of Review for RAIs Reponses

- FENCO usage of MAAP5 Containment Analysis Results
- W/FAI Responses to RAIs on MAAP5 Heat and Mass Transfer Modeling
- W/FAI Responses to RAIs on MAAP5 “Momentum-driven” velocity
- General Comments on the Status of the BVPS Containment Analysis and W/FAI MAAP5 Topical Report Review

FENOC Usage of MAAP5

- Departure from LOCTIC Containment Analysis
  - Single to Multi-cell Analysis
  - LOCTIC condensation models unavailable to multi-cell treatment
    - Natural convection condensation (Uchida correlation) for MSLB and long-term analysis
    - Forced convection condensation (Tagami correlation) for LOCA
- MAAP5 Forced Convective Condensation Model Required to Meet Containment Design Specification for Peak Pressure and Temperature (e.g., 45 psig design limit)
  - Improved condensation model (Empirical correlation applied to MAAP4)
  - Momentum-driven velocity used in standard forced convective correlation
- MAAP5 Water Entrainment Model of Secondary Importance (e.g., LOCA)

BV Containment Conversion Submittal [Baseline Analysis Requested in RAIs]

Peak Containment LOCA Pressure Comparison		
Code/Option	Break	Peak Pressure, psig
BVPS-1		
LOCTIC/PF+Tagami x 2	8L	43.3
MAAP5	8L*	42.5
BVPS-2		
LOCTIC/PF+Tagami x 2	3L	44.7
MAAP5	3L*	43.4

* Break into node #7.

Peak MSLB Containment Pressure Comparison		
Code/Option	Break	Peak Pressure, psig
BVPS-1		
LOCTIC/Uchida x 2	15M	44.5
MAAP5	15M*	44.9
BVPS-2		
LOCTIC/Uchida x 2	17M	44.6
MAAP5	16M*	44.9

* Break into node #13.

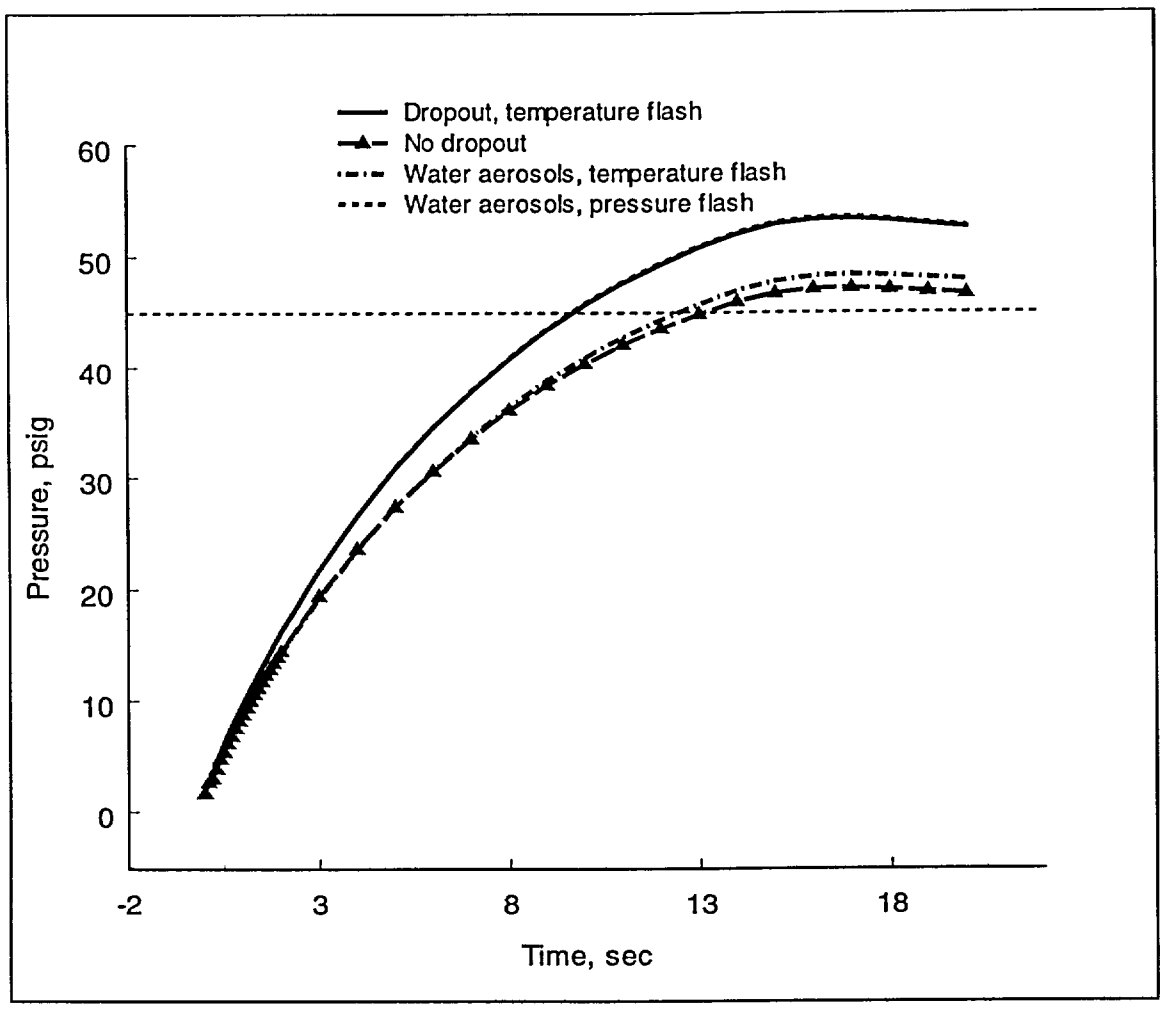
BVPS Unit 2
LOCA Analysis

BVPS Calculation	Code	Mode	Peak Pressure psig
Updated FSAR (Rev 13)	LOCTIC (Single-cell)	Temperature Flash (TF) Tagami	44.7
Response to Item 1.1.5		Temperature Flash (TF) Tagami Atmospheric, Up-rated source	49.1
Conversion FSAR		Pressure Flash (PF) 2 X Tagami Atmospheric, Up-rated source	44.7
Conversion FSAR	MAAP5 (Multi-cell)	Pressure Flash (PF) with 5% to water aerosols Atmospheric, Up-rated source	43.4

BVPS Unit 1
LOCA Analysis

BVPS Calculation	Code	Mode	Peak Pressure psig
Updated FSAR (Rev 13)	LOCTIC (Single-cell)	Temperature Flash (TF) Tagami	40.0
Response to Item 1.1.5		Temperature Flash (TF) Tagami Atmospheric, Up-rated source	47.6
Conversion FSAR		Pressure Flash (PF) 2 X Tagami Atmospheric, Up-rated source	43.3
Conversion FSAR	MAAP5 (Multi-cell)	Pressure Flash (PF) with 5% to water aerosols Atmospheric, Up-rated source	42.5
Response to Item 1.1.4		Exclude Water Entrainment	43.2
Response to Item 1.1.4		Exclude Water Entrainment Exclude Forced Convection	48.7
Preliminary Review	CONTAIN (Multi-cell)	Pressure Flash (PF) with 0% to water aerosols Natural convection Atmospheric, Up-rated source	53.4

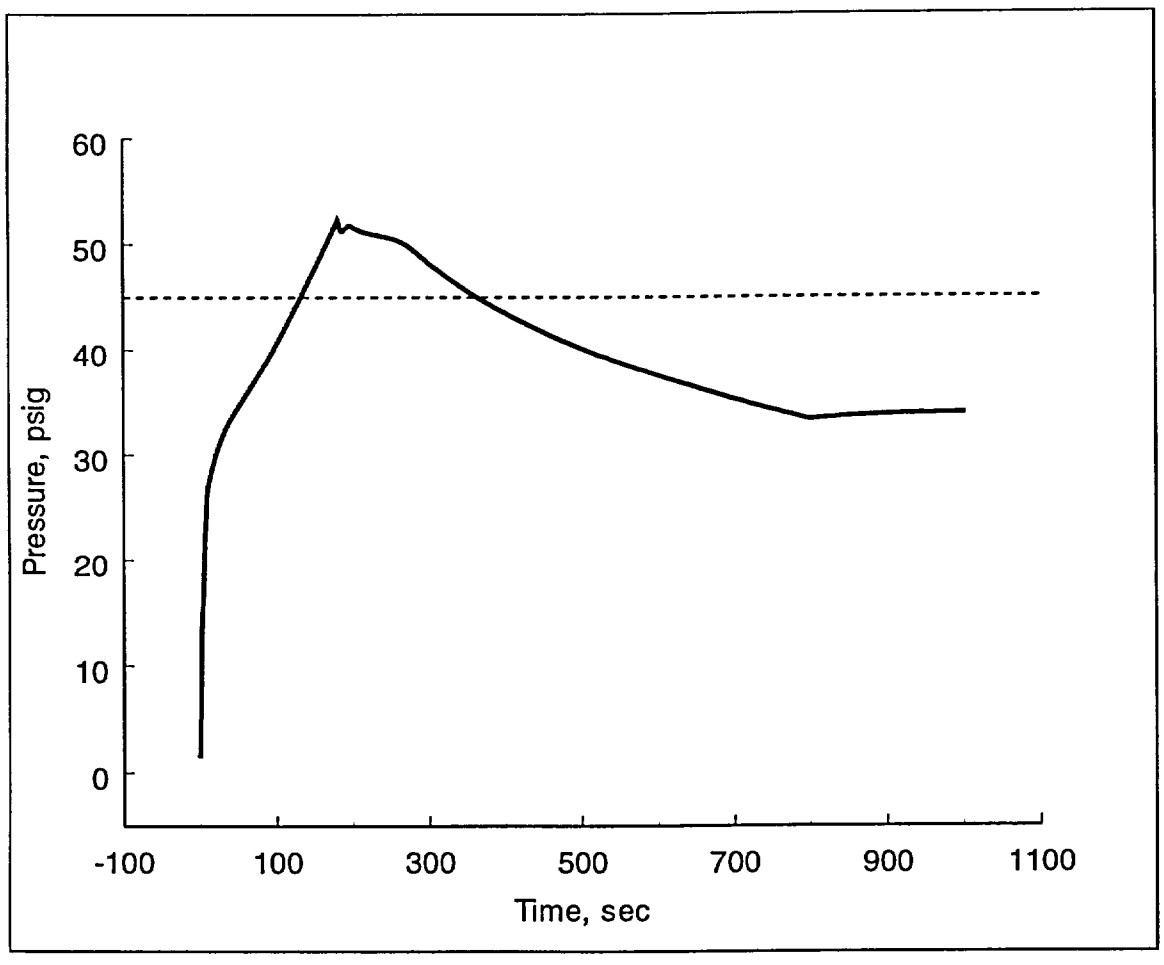
Preliminary CONTAIN Review Calculations
LOCA Analysis (BVPS Unit 1)



BVPS-1
MSLB Analysis

BVPS Calculation	Code	Mode	Peak Pressure psig
Updated FSAR	LOCTIC (Single-cell)	Uchida	
Response to Item 1.1.5		Uchida Atmospheric, Up-rated source	47.2
Conversion FSAR		2 X Uchida Atmospheric, Up-rated source	44.5
Conversion FSAR	MAAP5 (Multi-cell)	Atmospheric, Up-rated source	43.4
Response to Item 1.1.4		Exclude Water Entrainment	~ 43
		Exclude Water Entrainment Exclude Force Condensation	47.7
Preliminary Review	CONTAIN (Multi-cell)	Natural Convection Condensation	52.3

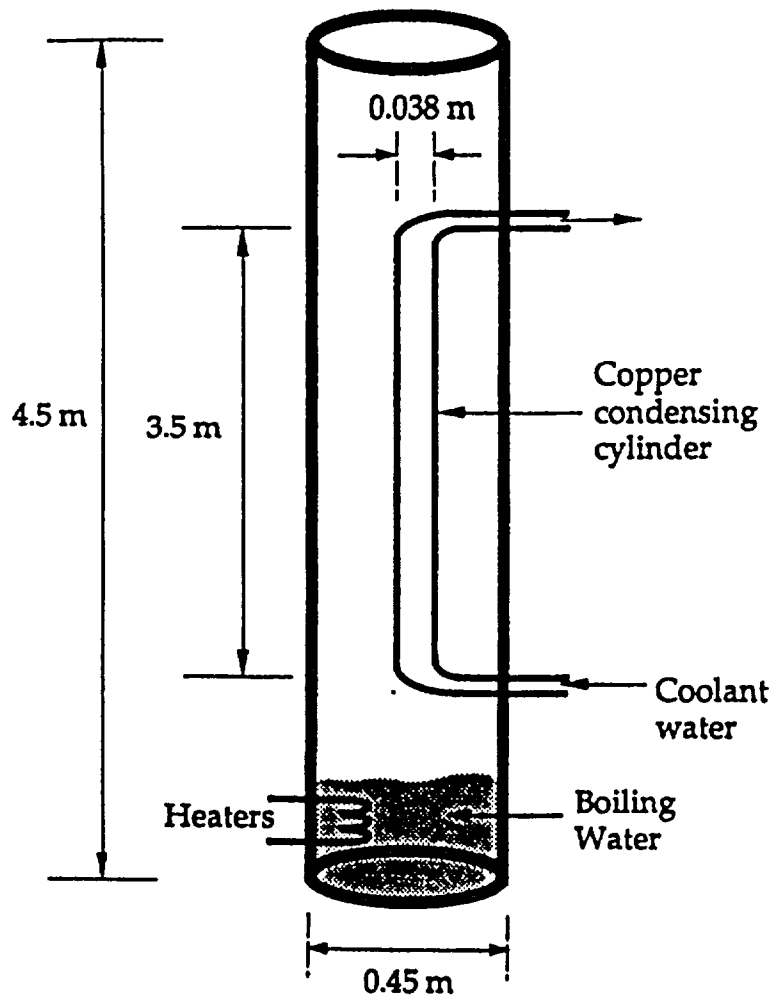
Preliminary CONTAIN Review Calculation (Multi-cell) BVPS Unit 1 MSLB (Case 15M-N13-1.4)



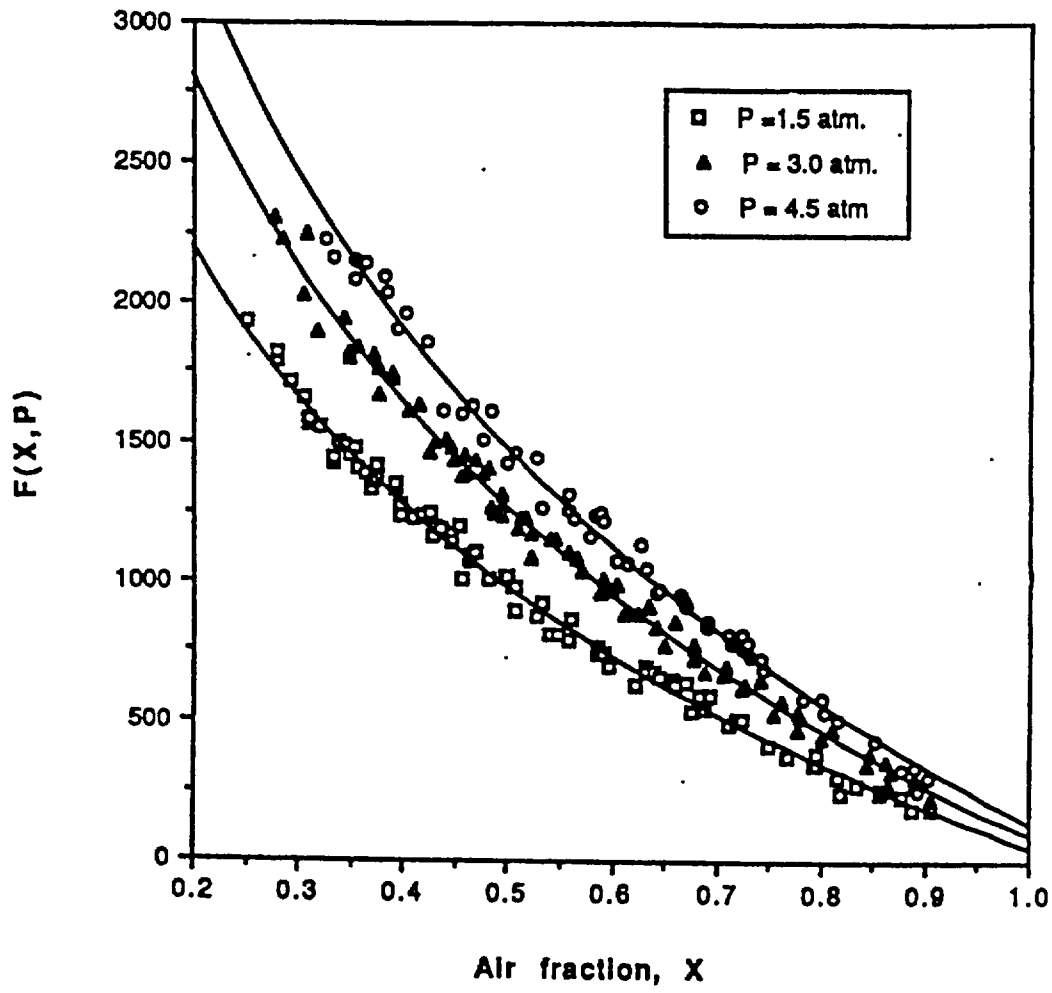
MAAP5 Condensation Model Review

- MAAP4 Model Shortcoming
  - Sensible vs. Compositional Grashof number
  - Moving condensate interface
- Improvement based on Dehbi Natural Convection Exper.
  - Dehbi data points vs. Dehbi correlation
  - Experimental uncertainty
  - CONTAIN condensation model comparison
- Empirical Correction Applied to Forced Convection Condensation
  - Natural convection correction applied to force convection
- Forced Condensation Experiment (Wisc. Flat plate test)
  - MAAP5 overprediction anticipated
  - Comparison with CONTAIN

Dehbi Natural Convection Condensation Exper. Facility

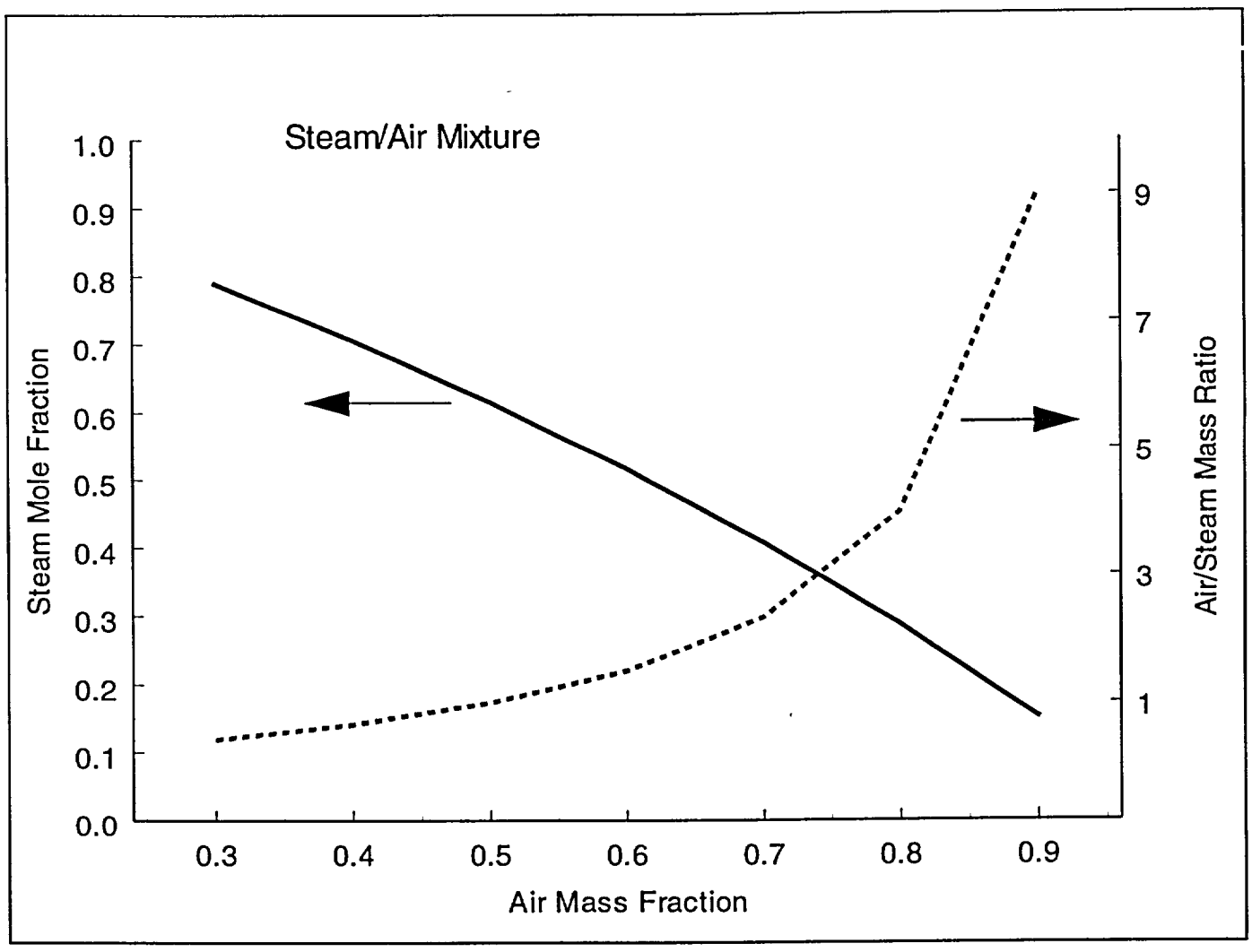


Dehbi Correlates Experiment Data for Average HTC

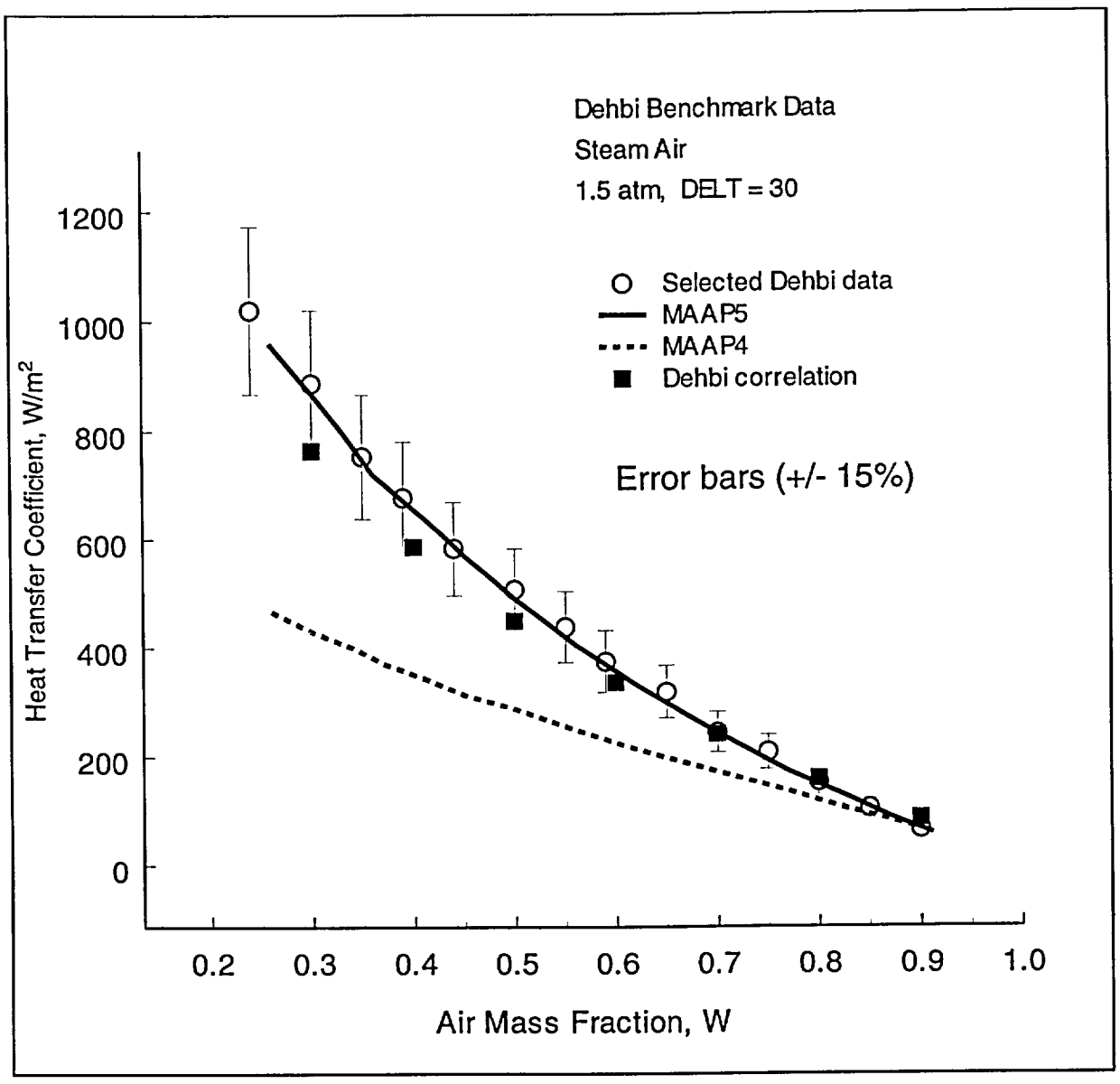


Reported Uncertainty:
+/- 15%

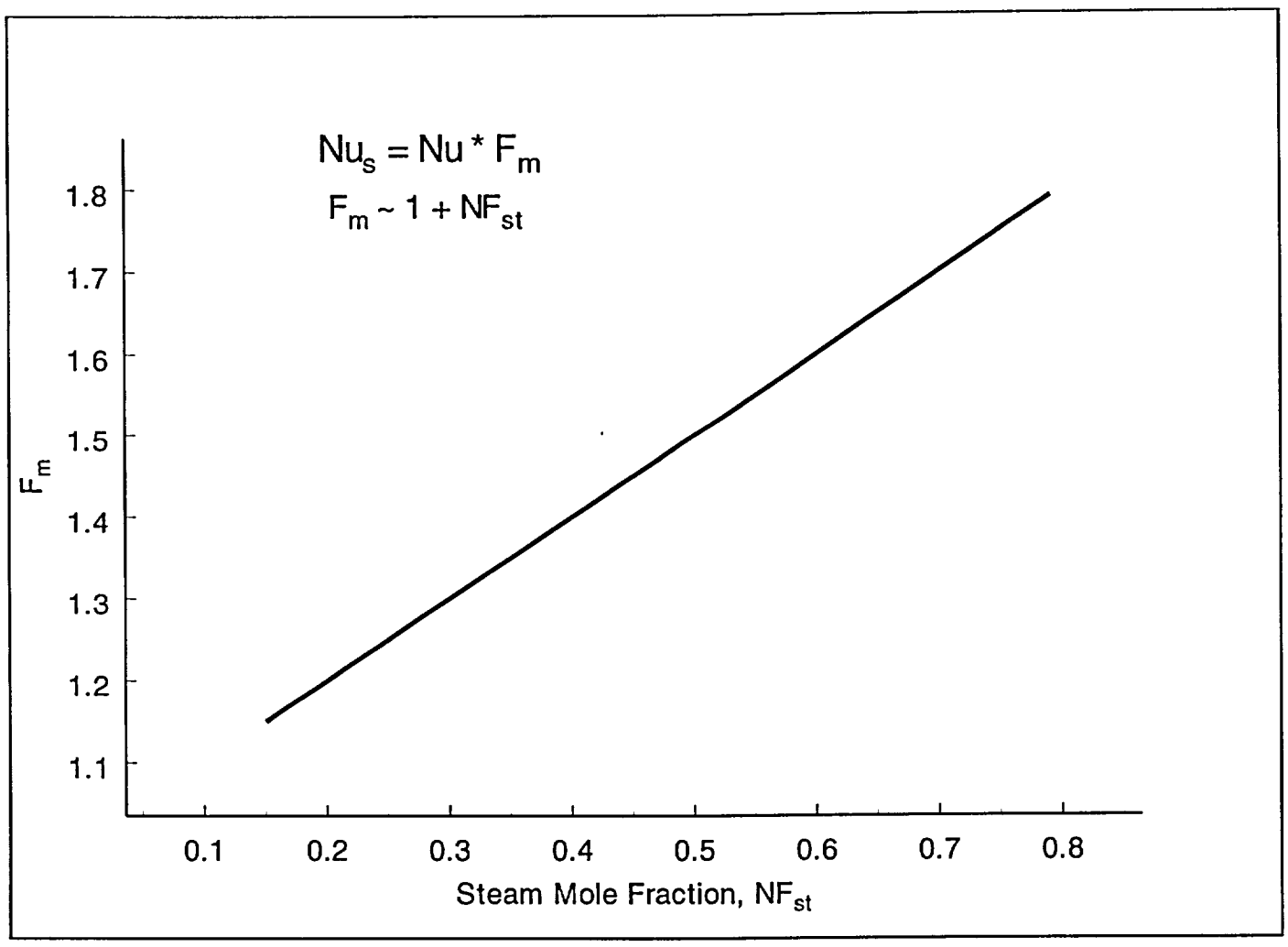
Steam Mole Fraction/Air Mass Fraction/Air Steam Mass Ratio



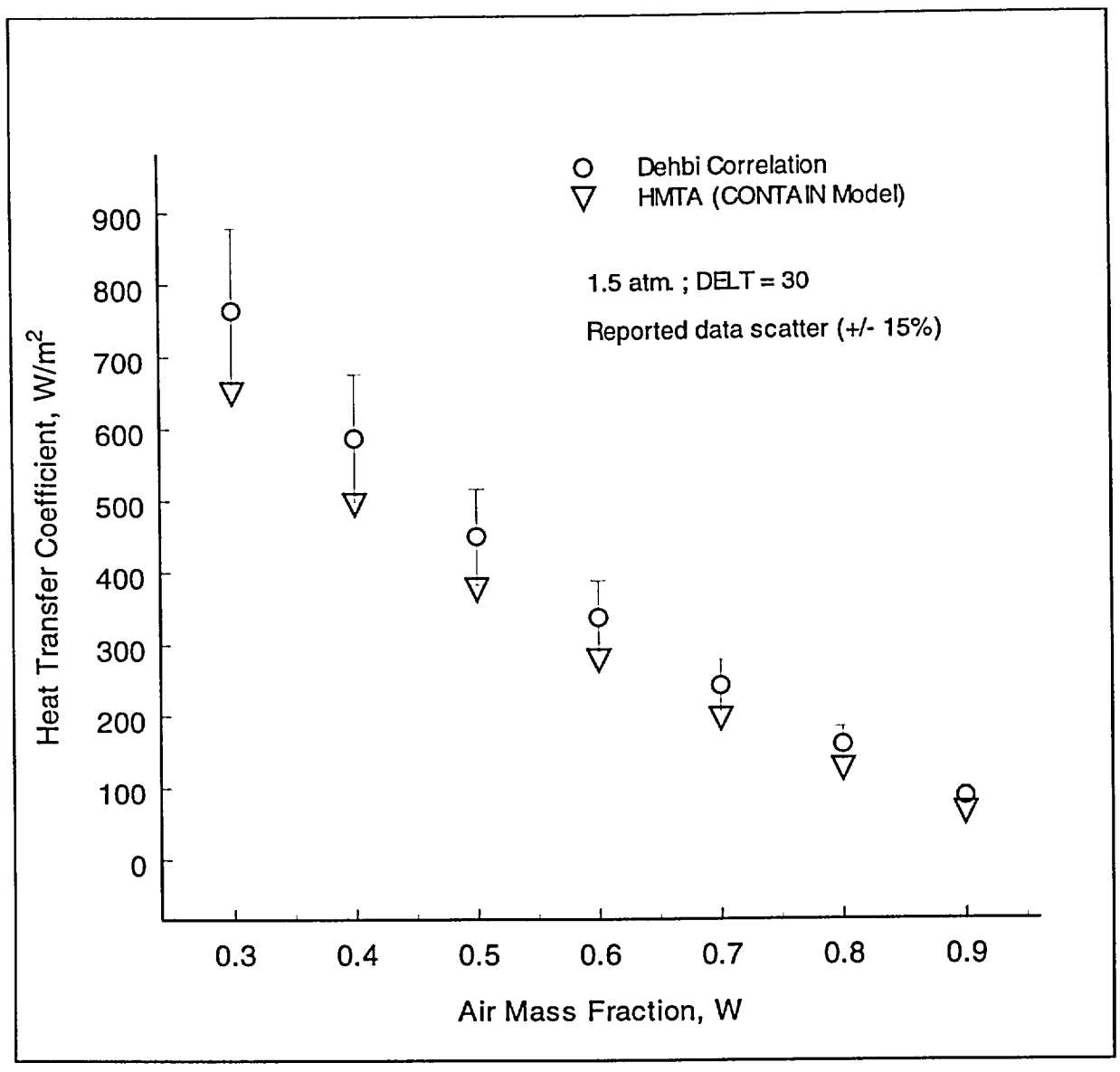
Experimental Basis for MAAP5 Correction Correlation



MAAP5 Condensation Model Improvement



Dehbi Experiment Comparison with CONTAIN HMTA Model



Various Forms of the Grashof Number

$$Gr = \frac{g\left|\rho_g - \rho_{if}\right| L^3}{\rho_{BL} \nu_{BL}^{\ 2}}$$

Multi-component gas
(Condensation, HMTA)

CONTAIN
MELCOR
GOTHIC, etc

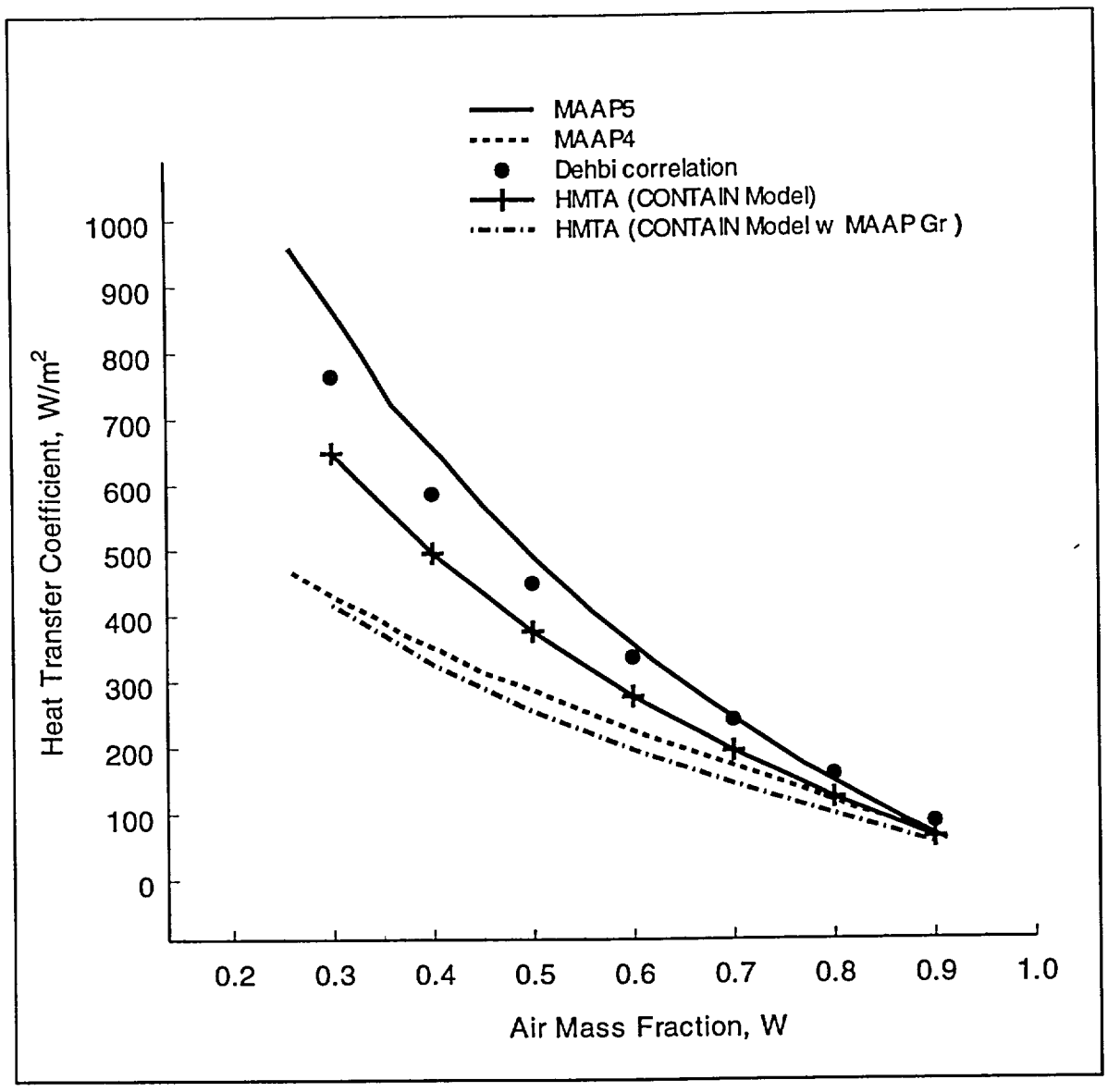
$$\frac{\rho_g - \rho_{wall}}{\rho_{wall}} \approx \beta (T_g - T_{wall})$$

Single component gas
(Sensible HT)

$$Gr = \frac{g\left|T_g - T_{wall}\right| \beta L^3}{\upsilon_g^{\ 2}}$$

MAAP4
MAAP5

Effect of Grashof Number Formulation



Suggested Cause for MAAP4 Shortcoming

- MAAP4 does not account for condensate motion
  - No analytical evidence of the degree of error
  - CONTAIN HMTA model with film tracking indicates average film velocity of ~ 0.25 m/s for HTC = 650 W/m2-K – well below the limit of relative velocity effects

- Grashof Number Formulation
  - Clear statement of applicability (Other codes, literature, etc.)
  - Analytical results strongly suggest that the Gr formulation is the cause of the MAAP4 shortcoming for the Dehbi test

Example of the Non-Conservative Aspects of the MAAP5 Condensation Model

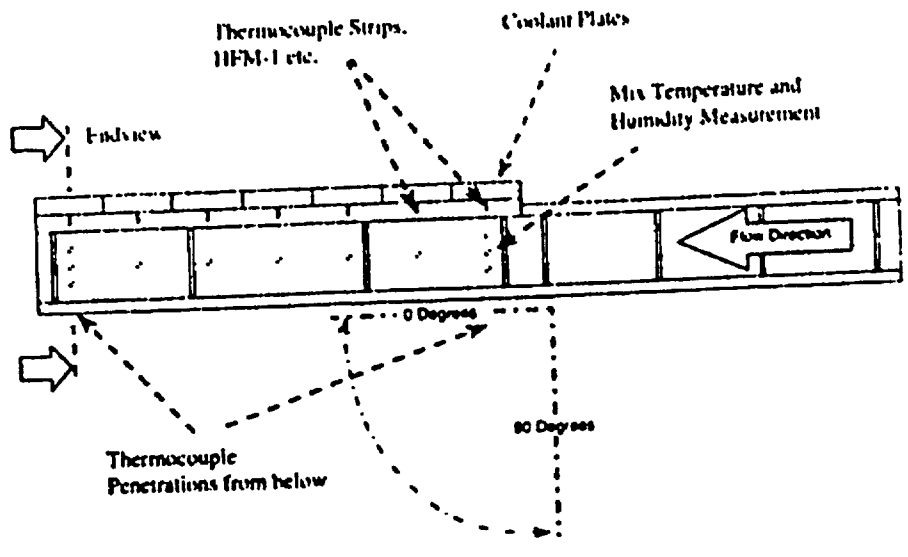


Figure 3.14 Condensing apparatus for the Wisconsin flat plate condensation tests.

MAAP5 Calculation of Wisc. Flat Plate Tests

Steam-Air Mixture Temp. (°C)	Mixture Velocity (m/s)	MAAP5 Condensation Correlation ($W/m^2/°C$)			Experimental Data ($W/m^2/°C$)
		Optimistic	Realistic	Pessimistic	
70	1	346	261	174	200-250
70	3	604	524	361	390-460
95	1	843	727	605	980-1100

- Overprediction of tests
  - -- 23% high for realistic values (70 deg C, 3 m/s)
  - -- Steam mole fraction ~ 0.3 (low conc.)
  - -- F_m ~ 1.3
  - -- At high steam mole fraction expect larger overprediction
- CONTAIN HMTA comparisons for Wisc. Tests
  - -- Calculations within +/- 10% expr. Uncertainty band
  - -- 1 m/s calculated with natural convective condensation
  - -- 3 m/s calculated with forced convective condensation

CONTAIN Calculations of Forced Convective Condensation

Table 3.8 Comparison of CONTAIN and Experimental average heat transfer coefficients for the Wisconsin flat plate condensation experiments.

Case #	T_{mix}, C	T_w, C	m_{air}/m_{steam}	V, m/s	h_{calc}(ref)	h_{exp}	$h_{exp(max, min)}$
1	70	30	3.5	1	**103.8**	111.1	122.2 99.99
2	70	30	3.5	3	**210.7**	213.9	235.3 192.5
3	80	30	1.78	1	**165.4**	163.9	180.3 147.5
4	80	30	1.78	3	**296.9**	305.6	336.2 275.0
5	90	30	0.68	1	**292.1**	255.5	281.1 229.95
6	95	45	0.29	1	**501.5**	546.	600.6 491.4

Summary of MAAP5 Condensation Model Review

- Optimistic and Pessimistic bounds are arbitrary
- Empirical correction for natural convective condensation corrects for a single component Gr <u>not</u> motion of interface
  - Natural convective model tends to be somewhat non-conservative (FCOND = 1)
- Empirical correction should not be applied to forced convective condensation model
- Forced convective model in MAAP5 is <u>non-conservative</u>

Confusion over Forced Convective Correlation Item 2.2.4

We note that the Colburn equation that is used in MAAP5 for forced convection is an equation developed such that the friction factor $f_{eff} = 0.046 / N_{Re}^{02}$ (see description to INDFLO, Momentum Drive Induced Flows). If this friction factor is applied to the equation

$$N_{Nu} = (f_{eff} / 2) N_{Re} N_{Pr}^{1/3},$$

then it would appear at least that the resulting equation form would be

$$N_{Nu} = 0.023 N_{Re}^{08} N_{Pr}^{1/3}$$

which is defined on page 4-6 of the Topical as the Dittus-Boelter equation.

The confusion continues – the above effective friction coefficient is referenced to Krieth, (1960) where as far as I can ascertain the Reynolds analogy is demonstrated for turbulent flow over a flat plate where

$$N_{Nu} = 0.036 N_{Re}^{08} N_{Pr}^{1/3},$$

and for duct flow,

$$N_{Nu} = 0.023 N_{Re}^{08} N_{Pr}^{1/3}.$$

Presumably, the flat plate correlations is being used, but the documentation is absolutely unclear on this.

Momentum-drive Velocity Modeling

- Momentum balance equation is a vector equation not a scalar equation (see page 76, Bird, Stewart, and Lightfoot)
- Velocity in a 3-D volume can not be calculated without use of the continuity and energy equation
- Momentum-driven velocity (as a scalar or property) is a non-physical quantity (velocity must have magnitude and direction)
  - Absolutely no evidence that the momentum-driven velocity is a circulation velocity
  - Absolutely no evidence that one-dimension, standard heat transfer, friction or drag correlations can be used with momentum-driven velocity
- Wall energy transfers in integral tests may be inadequate measures for confirming wall velocities (high velocity show no sensitivity)
- CVTR test is not a confirmation of the momentum-driven velocity model (significant overprediction of measured velocities regardless of source nodalization)
- No other usage found in open literature

Bird, Stewart and Lightfoot

§3.2 THE EQUATION OF MOTION

For a volume element $\Delta x\ \Delta y\ \Delta z$, such as that used in the previous section, we write a momentum balance in this form:

$$\begin{Bmatrix}\text{rate of}\\ \text{momentum}\\ \text{accumulation}\end{Bmatrix} = \begin{Bmatrix}\text{rate of}\\ \text{momentum}\\ \text{in}\end{Bmatrix} - \begin{Bmatrix}\text{rate of}\\ \text{momentum}\\ \text{out}\end{Bmatrix} + \begin{Bmatrix}\text{sum of forces}\\ \text{acting on}\\ \text{system}\end{Bmatrix} \quad (3.2\text{–}1)$$

Note that Eq. 3.2–1 is just an extension of Eq. 2.1–1 to unsteady-state systems. We may proceed then in much the same way as in Chapter 2.

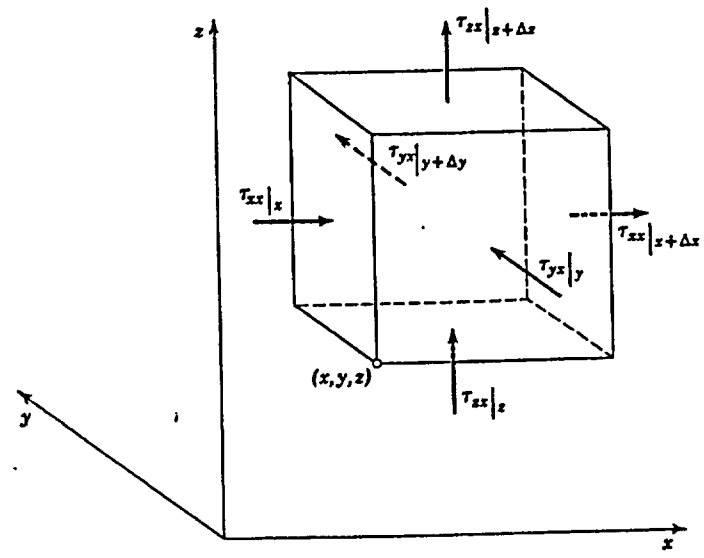


Fig. 3.2–1. Volume element $\Delta x\ \Delta y\ \Delta z$ with arrows indicating the direction in which the x-component of momentum is transported through the surfaces.

Warns that this is a vector equ.

However, in addition to considering unsteady-state behavior, we will allow the fluid to move through all six faces of our volume element in any arbitrary direction, as in §3.1. It should be emphasized that Eq. 3.2–1 is a *vector* equation with components in each of the three coordinate directions x, y, and z. For simplicity, we begin by considering the x-component of each term in Eq. 3.2–1; the y- and z-components may be handled analogously.

First let us consider the rates of flow of the x-component of momentum

Fluid Mechanics
Frank M. White

$$\frac{d}{dt}(m\mathbf{V})_{\text{syst}} = \sum \mathbf{F} = \frac{d}{dt}\left(\iiint_{\text{CV}} \mathbf{V}\rho \, d\mathcal{V}\right) + \iint_{\text{CS}} \mathbf{V}\rho(\mathbf{V}_r \cdot \mathbf{n}) \, dA \qquad (3.35)$$

The following points concerning this relation should be strongly emphasized:

1. The term **V** is the fluid velocity relative to an *inertial* (nonaccelerating) coordinate system; otherwise Newton's law must be modified to include noninertial relative-acceleration terms (see the end of this section).
2. The term $\sum \mathbf{F}$ is the *vector* sum of all forces acting on the control-volume material considered as a free body; i.e., it includes surface forces on all fluids and solids cut by the control surface plus all body forces (gravity and electromagnetic) acting on the masses within the control volume.
3. The entire equation is a vector relation; both the integrals are vectors due to the term **V** in the integrands. The equation thus has three components. If we want only, say, the x component, the equation reduces to

$$\sum F_x = \frac{d}{dt}\left(\iiint_{\text{CV}} u\rho \, d\mathcal{V}\right) + \iint_{\text{CS}} u\rho(\mathbf{V}_r \cdot \mathbf{n}) \, dA \qquad (3.36)$$

and similarly, $\sum F_y$ and $\sum F_z$ would involve v and w, respectively. Failure to account for the vector nature of the linear-momentum relation (3.35) is probably the greatest source of student error in control-volume analyses.

Warning

Reaction to Response to RAIs and Status of Review Process

- Comments are not favorable to licensee's submittal
- Continuing with addition confirmatory calculations for BVPS-1 and 2
  - Preliminary results indicate peak pressure (LOCA & MSLB) is significantly beyond design limits
- Full text of comment on response being prepared (item by item)--TBD
  - Additional RAIs may be requested