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Attention: Mr. G. Shukla, Project Manager

Your ref:
Our ref: LTR-NRC-02-60

December 4, 2002

Subject: Response to RAI on the "Topical Report on Modular Accident Analysis Program Version 5 (MAAP5) Pressurized Water Reactor (PWR) Large Dry Containment Model," WCAP-15844

Dear Mr. Shukla:

The purpose of this letter is to provide responses to the NRC Request for Additional Information (RAI) regarding the Westinghouse "Topical Report on Modular Accident Analysis Program Version 5 (MAAP5) Pressurized Water Reactor (PWR) Large Dry Containment Model," WCAP-15844, which have been generated based on your review to date. The subject RAI and responses have been attached for your review prior to our meeting on December 11, 2002. These responses were developed following a clarification telecon with personnel from your organization.

If you have any questions, please do not hesitate to contact John DeBlasio on (412) 374-5741.

Very truly yours,

J. S. Galembush, Acting Manager
Regulatory and Licensing Engineering

Attachment

cc: D. Collins
R. Clark

TD10

2.0 MAAP5 Topical Report

2.1 General Items:

Item 2.1.1. Have the new MAAP5 general containment models and validation of those models been independently reviewed? What is the technical review process for new modeling in the MAAP code?

Response to Item 2.1.1.

Yes, the new MAAP5 general containment models and their validation have been independently reviewed. The code was developed per QA procedures that satisfy the requirements of 10CFR50, Appendix B. The technical review process for the new modeling in the MAAP5 code included an independent Design Review Committee at FAI composed of senior staff members that are independent of the code development team. A testing plan was prepared and executed and the validation results were independently reviewed. Each MAAP5 model package that documents the code modification, testing, and its validation were independently reviewed by a qualified analyst.

The MAAP5 Design Review Committee for the MAAP5 PWR containment model included Dr. Hans K. Fauske (Committee Chair), an internationally known expert in the fields of two-phase flow and heat transfer as they relate to reactor safety and Dr. Michael Epstein also an internationally known expert in the area of heat and mass transfer and a former editor of the ASME Journal of Heat Transfer. The members of the MAAP5 Design Review Committee made important review contributions related to how the models are formulated, tested and implemented in containment design basis analyses. In addition, the MAAP4 generalized containment model, which is the basis for the MAAP5 model, was reviewed by the EPRI sponsored MAAP4 Design Review Committee comprised of the following individuals:

- Dr. Paul Nakiyama – Chairman,
- Professor Neil Todreas,
- Professor Richard Lahey,
- Dr. Sol Levy,
- Professor John Trapp,
- Professor Donald Olander, and
- Dr. Richard Hobbins.

The MAAP4 Design Review Committee also made important contributions to the model formulation, testing and implementation with respect to all types of containment designs. The Committee's findings and recommendations are documented in the Jason Associates Corporation report "Final Report: MAAP4 Design Review," transmitted to EPRI in June of 1995.

Item 2.1.2. Have descriptions of the new MAAP5 general containment models and validation been published in any Journals or Conference papers? Has there been a peer review of these models?

Response to Item 2.1.2.

No, the new MAAP5 general containment models and their validation have not been published in any journals or conference papers to date. Yes, a peer review of these models has been performed given the FAI Design Review Committee activity and the external reviews provided by the Beaver Valley project team. The Beaver Valley project team includes representatives from FENOC, Stone & Webster, and Westinghouse/Energy Center in addition to FAI personnel. The FENOC organization performed an independent review of the Beaver Valley MAAP5 model and the calculational results obtained by applying MAAP5, and a comparison run was performed by Stone & Webster using the LOCTIC code.

Item 2.1.3. How will documentation of the new MAAP5 GCM be presented in the MAAP manuals? Will the topical report be absorbed into the manual set?

Response to Item 2.1.3.

The new MAAP5 GCM will be documented in the MAAP manuals as new and updated subroutine descriptions plus an expanded benchmarking description in the appropriate user manual volume. The Topical Report will not be literally absorbed into the manual set, i.e., as a stand-alone section or Appendix. However, its content will be added to the MAAP5 user's manual as appropriate. The subroutine descriptions, as already supplied to the NRC and technical descriptions provided in the MAAP5 Topical Report will be incorporated into the modified MAAP manuals.

Item 2.1.4. What uncertainties (modeling or input parameters) associated with a) mixed and forced convection condensation, 2) momentum-driven velocity, and 3) water entrainment have been identified through separate effects tests?

Response to Item 2 1.4.

The uncertainties associated with natural convection condensation (characterized by the FCOND parameter) were identified through the Dehbi separate effects experiments. These resulted in the establishment of realistic, pessimistic and optimistic uncertainty boundaries. The existence of momentum-driven velocities are demonstrated through the Lane and Rice experiments (Lane, A. G. C. and Rice, P., 1982, "The Flow Characteristics of a Submerged Bounded Jet in a Closed System," Transactions IChemE, Vol. 60, pp. 245-248). However, because of the free surface, these experiments are not satisfactory for developing uncertainty boundaries. Therefore, the uncertainties related to the effective friction factor (frictional dissipation as characterized by the FFMULT parameter) for momentum-driven flows are characterized through standard representations and the uncertainty boundaries were developed with large scale tests. The water entrainment mechanism uses the correlations recommended by Ishii and Grolmes which had been developed through separate effects tests related specifically to entrainment phenomena.

Item 2.1.5. Does the term □momentum-driven velocity,□ as calculated in the MAAP code, have a definition that would allow measurement and/or validation of the momentum velocity model equations? In other words, is the momentum-driven velocity a physical quantity or an abstraction?

Response to Item 2 1.5.

The momentum-driven velocity in the MAAP5 containment model calculates lumped parameter velocities within the containment atmosphere including the conservation of momentum resulting from the break discharge flow. More importantly, these velocities are used to characterize the nodal rates of heat, mass and momentum transfer. Consequently, in terms of directly measurable quantities, the momentum-driven velocities are best measured/evaluated by how well they characterize the rates of energy transfer, etc. are represented. (For these comparisons see the response to Question 2.2-10.)

The MAAP5 containment model represents the convection heat transfer coefficient from the gas using the modified Reynolds analogy (Colburn equation) , i.e. the heat transfer coefficient is proportional to the effective friction factor. Increasing the effective friction factor to reduce the calculated velocities has the compensating influence of increasing the heat transfer coefficient. Consequently, substantially changing the friction factor to decrease the calculated momentum-driven velocities results in a small change in the calculated peak containment pressure. For example see the CVTR5 results listed in Table 1 for different values of the friction factor multiplier (FFMULT)

Table 1
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	20.0
	15.0	19.0
16	1.0	22.6
	1.5	21.9
	6.0	19.9
	15.0	19.0

2.2 Clarification Items:

Item 2.2.1. How does an empirical calibration of the natural convection condensation model (improved MAAP5 condensation) apply to other modes of condensation, such as mixed or forced convection condensation?

Response to Item 2.2.1.

The empirical calibration factor developed for the natural convection condensation model is a multiplication factor that enhances the MAAP4 calculated value. This factor is a function of the steam mole fraction. Without steam, this multiplication factor is unity and it increases with the steam mole fraction. This multiplication factor is also used in the forced convection heat transfer coefficients associated with condensation.

The benchmarks for the MAAP5 containment model are continually being extended For example, Huhtiniemi and Corradini (1993) reported on condensation in the presence of noncondensable gases under forced convection conditions. These are discussed in the response to the next question.

Item 2.2.2. Why were no forced convection condensation separate effects tests used in the validation of the improved MAAP condensation modeling?

Response to Item 2.2.2.

The enhancement to the MAAP5 forced convection model using the momentum-driven calculated velocity was a natural extension of the MAAP4 forced convection model. In this regard, FAI considered that the benchmarks with the large number of intermediate and large scale experiments were the appropriate benchmarks for forced convection. However, FAI is always interested in expanding the benchmarks related to these models. In our discussions with the NRC staff and ACRS we have asked if there are other benchmarks that should be examined. The only suggestion received was from Dr. Tom Kress (ACRS) who recommended including the Marviken blowdown. The MAAP5 Topical Report was expanded to include a comparison with the Marviken blowdown experiment identified as International Standard Problem #17.

In response to this question the benchmarks for the condensation model as presented in the Topical Report have been extended to include forced convection condensation data points reported by Huhtiniemi and Corradini. (Huhtiniemi, I. K and Corradini, M. L., 1993, "Condensation in the Presence of Noncondensable Gases," Nuclear Engineering and Design, 141, pp. 429-446). In these experiments, velocities of 1, 2 and 3 m/sec were investigated for the concurrent condensation of a steam-air-water mixture. The condensate had a substantial influence on the local effective heat transfer as the film develops and thickens. Hence, the most appropriate measurement location to be compared with the MAAP5 mixed/forced convection condensation (which is related to the mass transfer impedance in the gas) is the heat transfer coefficient measured at the beginning of the condensing length. A comparison of these measurements with the MAAP5 model is given in the following table. As illustrated, the MAAP5 pessimistic correlation, which is used for DBA peak pressure and temperature evaluations, has values less than the experimental data.

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

Item 2.2.3. What is the source of the apparent modeling error in the MAAP4 condensation model as indicated in the Dehbi tests? Discuss usage of a sensible heat transfer Grashof number (using temperature differences) vs. a composition Grashof number using density differences. Why is a sensible heat transfer Grashof number used for steam condensation in the presence of noncondensible gases?

Response to Item 2.2.3.

The difference between the MAAP4 and MAAP5 condensation model as indicated in the comparison with the Dehbi test results is a modeling shortcoming in the MAAP4 representation. Specifically, the MAAP4 model uses a single-phase representation for the convective transport of steam and air to the condensing surface. Inherent in this single-phase representation is the condition that the velocity at the wall is equal to zero. In reality, the "wall" for the gas space condensing on a vertical surface is a moving condensate film surface. Therefore, the transport from the free stream to the film surface is greater than that which is represented by a single-phase model which inherently assumes that the velocity of the "wall" is zero.

The basis for the MAAP5 condensation model was the existing MAAP4 formulation. As such, the principle focus was to enhance the correlation to be consistent with the measured heat transfer rates. Since both the basic model and the enhanced model are correlations, the formulation for the Grashof number was not altered.

Item 2.2.4. What is the justification for using the Dittus-Boelter equation (duct internal flow) for turbulent convection within confined enclosures?

Response to Item 2.2.4.

MAAP5 does not use the Dittus-Boelter equation for turbulent convection. Rather, it uses the modified Reynolds analogy (Colburn equation) in the form of:

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

where

- N_{Nu} is the Nusselt number,
- f is the effective friction factor,
- N_{Re} is the fluid Reynolds number, and
- N_{Pr} is the fluid Prandtl number.

For the fluids of interest, the Prandtl number is close to unity. This formulation directly relates the effective heat transfer coefficient and the effective turbulent dissipation at a surface such that the dependency between these two processes is captured by the model

The Dittus-Boelter equation is only used in the Topical Report to illustrate the development of the correction factor for the MAAP4 condensation model. In particular, this involves correction factors related to the motion of the film at the interface and the water properties.

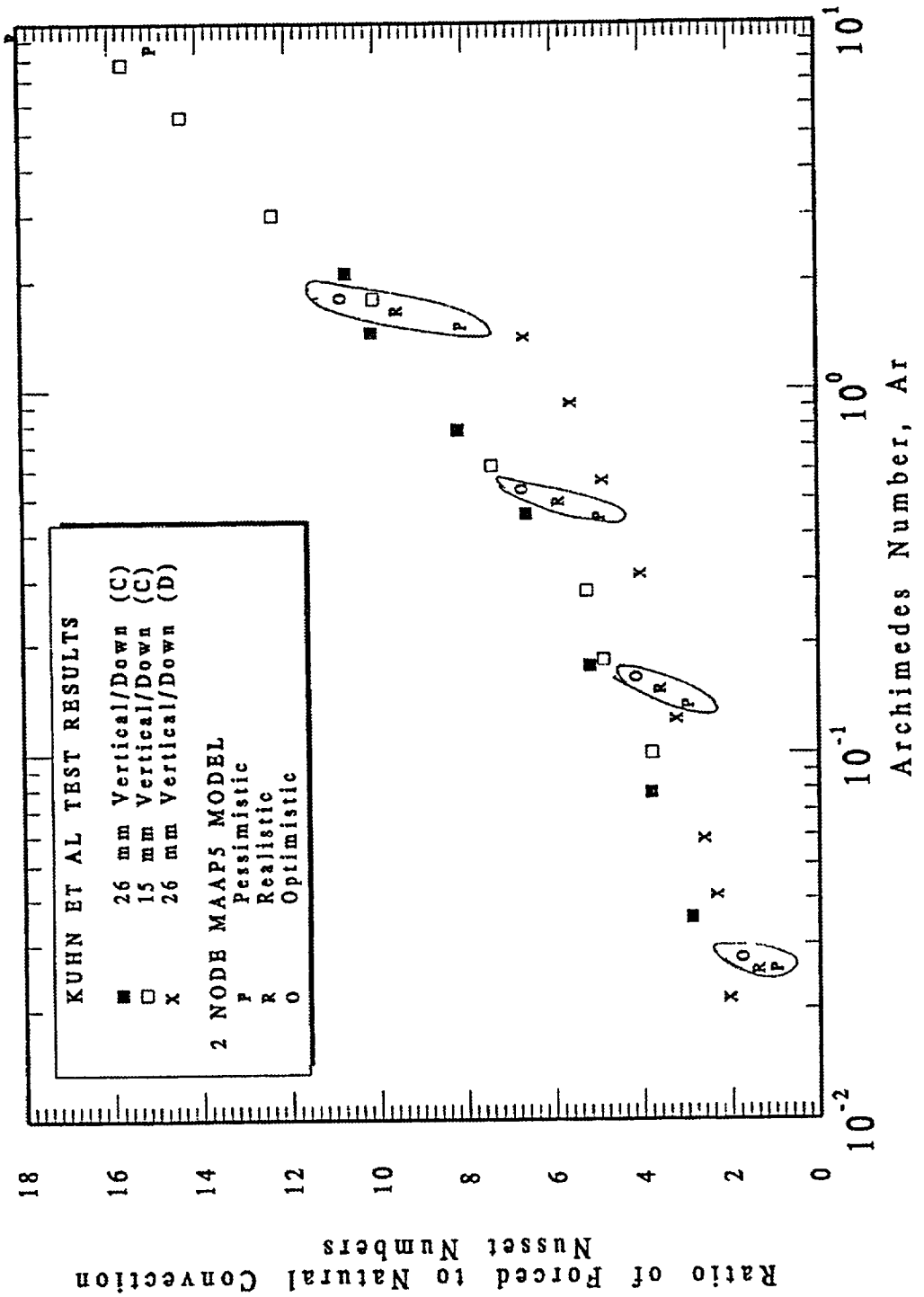
Item 2.2.5. What is the justification for using the Dittus-Boelter or any other one-dimensional heat transfer correlation with the □momentum-driven velocity□ derived as having a property value with no directional dependence? Same question for entrainment correlations?

Response to Item 2 2.5.

The use of standard heat transfer correlations for forced flow within a containment is common practice in the modeling of containment response, although in other applications, a continuity (mass flow rate based) velocity is generally used instead of a velocity that is consistent with conservation of momentum within a node. For example, applying the one-dimensional continuity velocity consistent with the flow rate in the CVTR calculations results in a value of the order of 1 ft/sec. This is neither consistent with the velocities measured by the anemometers nor the measured heat transfer coefficients on the containment wall. Therefore, the application of standard heat transfer coefficient correlations to containments should be consistent with the velocities that develop the wall shear stress as well as the rate of energy transfer. In the MAAP5 approach, this velocity is one that is consistent with the total fluid momentum within a given node. The most effective way of evaluating this approach is through the measured rates of energy transfer in the numerous small scale or intermediate scale containment experiments. Similar considerations hold for applying water entrainment correlations.

As additional justification for considering the "momentum-driven velocity" as a characterization of the free stream velocity to be used in correlations describing the rates of heat, mass and momentum transfer, a benchmark has been performed with enclosure experiments reported by Kuhn et al. (Kuhn, S. Z., Kang, H. K. and Peterson, P. F., 2002, "Study of Mixing and Augmentation of Natural Convection Heat Transfer by A Forced Jet in a Large Enclosure," Trans. of the ASME, Journal of Heat Transfer, Vol. 124, pp. 660-666). In these experiments, a gas jet was injected into an enclosure and an equal mass flow rate was exhausted through another port. The influence of the induced flow by the jet was characterized in terms of a ratio of the enhanced convective Nusselt number divided by the natural convection Nusselt number as a function of the Archimedes number (defined as the jet Reynolds number squared divided by the Grashof number based upon the enclosure diameter). Of particular interest in the MAAP benchmark, are the tests in which the air jet was injected vertically downward into the center of the enclosure or next to the enclosure wall. The jet flow induced a significant momentum-driven velocity as reflected by the augmented heat transfer from the heated bottom surface. (The continuity velocity in these experiments is of the order 1.0 mm/sec which is far less than the velocities required to explain the enhanced heat transfer.) Figure 1 compares the optimistic, realistic and pessimistic values for the enhanced heat transfer calculated by the MAAP5 model. It is to be remembered that the pessimistic value (that designated by the P in the attached figure) is the value that is used in evaluating the containment peak pressure and temperature response. As illustrated, there is agreement between the enhanced forced convection heat transfer coefficients in these enclosure tests and those calculated by the MAAP model.

Figure 1: Comparison of the MAAP5 calculated free and forced convection heat transfer and the experimental data reported by Kuhn et al.



Item 2.2.6. What is the technical basis for a momentum balance constructed using scalar forces and non-directional momentum influx terms? Isn□t the classical momentum balance equation a vector equation? Where in the technical literature does one find a similar equation or momentum defined as a fluid property that can be transported as such? Can one transport momentum with an inter-compartment velocity that is significantly different in value than the momentum-driven velocity?

Response to Item 2.2.6.

Certainly momentum is a vector quantity. The approach using momentum balances within control volumes can be found both in Streeter and Wylie (1975), Fluid Mechanics, 6th Edition, pp. 109-113, and Bird, Stewart and Lightfoot (1960), Transport Phenomena, pgs. 35 and 76. In the first reference, the concept is presented that a control volume balance can be applied to mass, energy or momentum as properties of the flow which are transported with the "velocity of the center of mass of the system," i.e. the one-dimensional or continuity velocity. (The continuity velocity is derived from the mass flow rate, the cross-sectional flow area and the fluid density.)

On page 76, Bird, Stewart and Lightfoot describe the unsteady momentum balance as

$$\begin{Bmatrix} \text{rate of} \\ \text{momentum} \\ \text{accumulation} \end{Bmatrix} = \begin{Bmatrix} \text{rate of} \\ \text{momentum} \\ \text{in} \end{Bmatrix} - \begin{Bmatrix} \text{rate of} \\ \text{momentum} \\ \text{out} \end{Bmatrix} + \begin{Bmatrix} \text{sum of forces} \\ \text{acting on} \\ \text{system} \end{Bmatrix}$$

This is the same characterization given in equation (3-16) in the MAAP5 Topical Report. Applying this concept to control volumes such as dividing the vessel in the Lane and Rice experiments (discussed in Section 3 of the MAAP5 Topical Report) into two axial nodes clearly demonstrates that a momentum balance requires a velocity different than the one-dimensional continuity velocity. This is the momentum driven velocity and can be manifested as increased turbulence, circulation and/or recirculation between nodes.

Using a control volume concept is an approximation, but one that is common practice in many applications for reactor safety analysis. However, it is important for such concepts to represent the conservation of momentum as it influences the hydrodynamic response during an RCS or steam generator blowdown. For example, considering the four "layers" nodalization scheme used for one of the CVTR analyses in the MAAP5 Topical Report (see Appendix E), the continuity velocity related to the incoming steam flow is of the order of 1 ft/sec. Measurements during the experiment recorded velocities of 15 to 30 ft/sec This difference is due to the momentum of the steam discharge into the test facility. Such velocities also have an important influence on the rates of frictional dissipation and heat transfer. In the MAAP5 approach, we have developed a control volume approach to evaluate the approximate velocities (momentum-driven velocities) within each control volume associated with the blowdown. These velocities, which are consistent with the momentum added to the system and decay due to frictional dissipation, are used to evaluate heat transfer rates, frictional dissipation and entrainment and the associated momentum is transported (convected) to other nodes by the continuity velocity. Finally, the validity of this approach is demonstrated by the detailed experiment benchmarks provided in the MAAP5 Topical Report.

Item 2.2.7. Are the FFMULT and FCOND pessimistic, realistic, and optimistic values used for the CVTR calculations those values defined on page 8-6 and 7 of the Topical?

Response to Item 2.2.7.

Yes, the FFMULT and FCOND pessimistic, realistic, and optimistic values on pages 8-6 and 8-7 of the MAAP5 Topical Report were used for the CVTR calculations.

Item 2.2.8. To what degree does water entrainment enter into the CVTR calculation? Provide a water entrainment time history profile in compartments for test 3.

Response to Item 2 2.8.

The impact on the containment pressure and gas temperatures of water entrainment are shown in the attached plots for the CVTR test #3. The peak pressure (Figure 1) increases about 0.7 psi when water entrainment is not credited. The peak gas temperature in the node 1 (Figure 2) increases about 25°F without the water entrainment. Figure 3 illustrates that entrainment is occurring only in node #2 which is receiving all of the break discharge in this calculation.

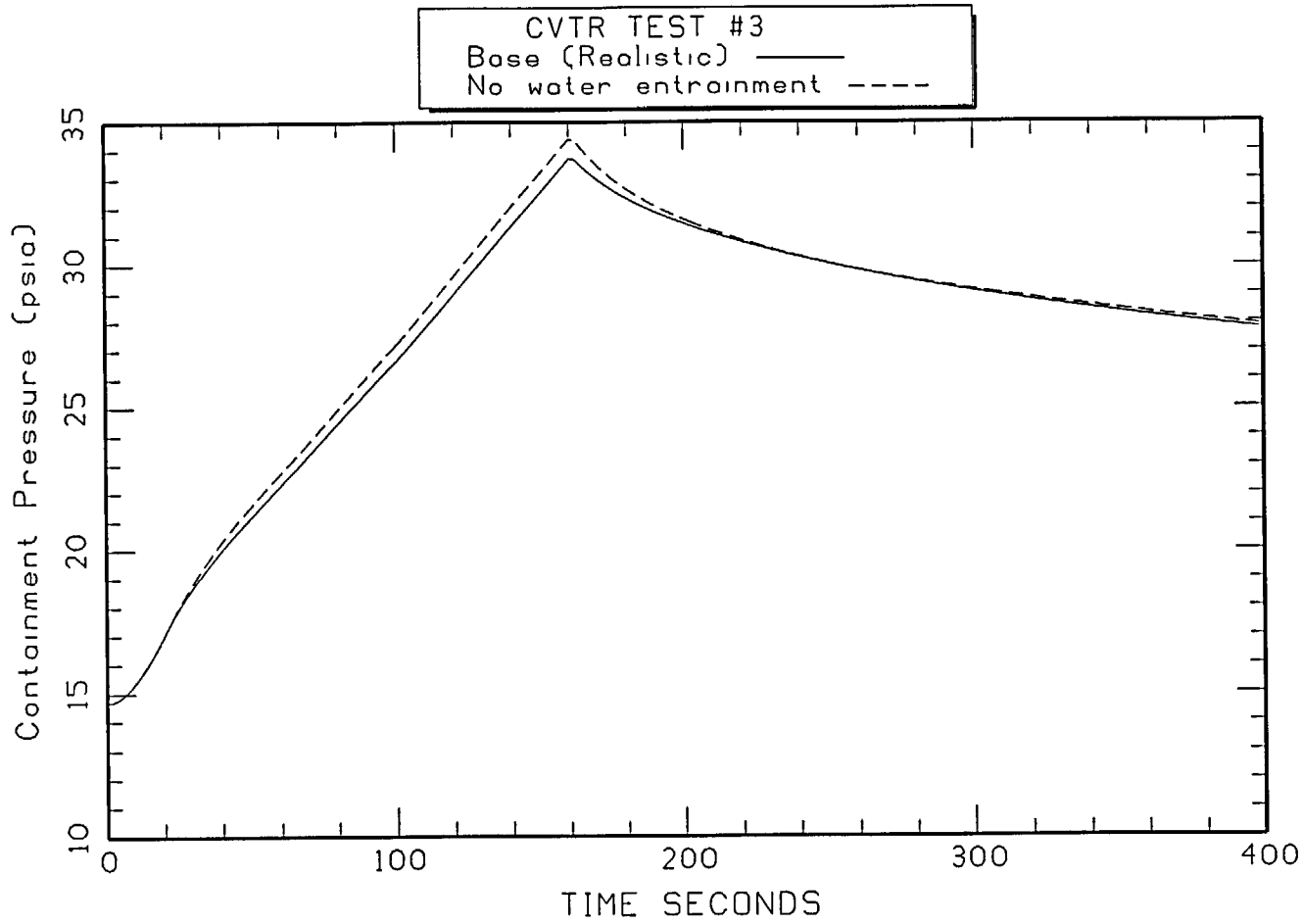

CVTR TEST #3
Base (Realistic)
No water entrainment
Containment Pressure (psia)
35
30
25
20
15
10
0
100
200
300
400
TIME SECONDS

Figure 1

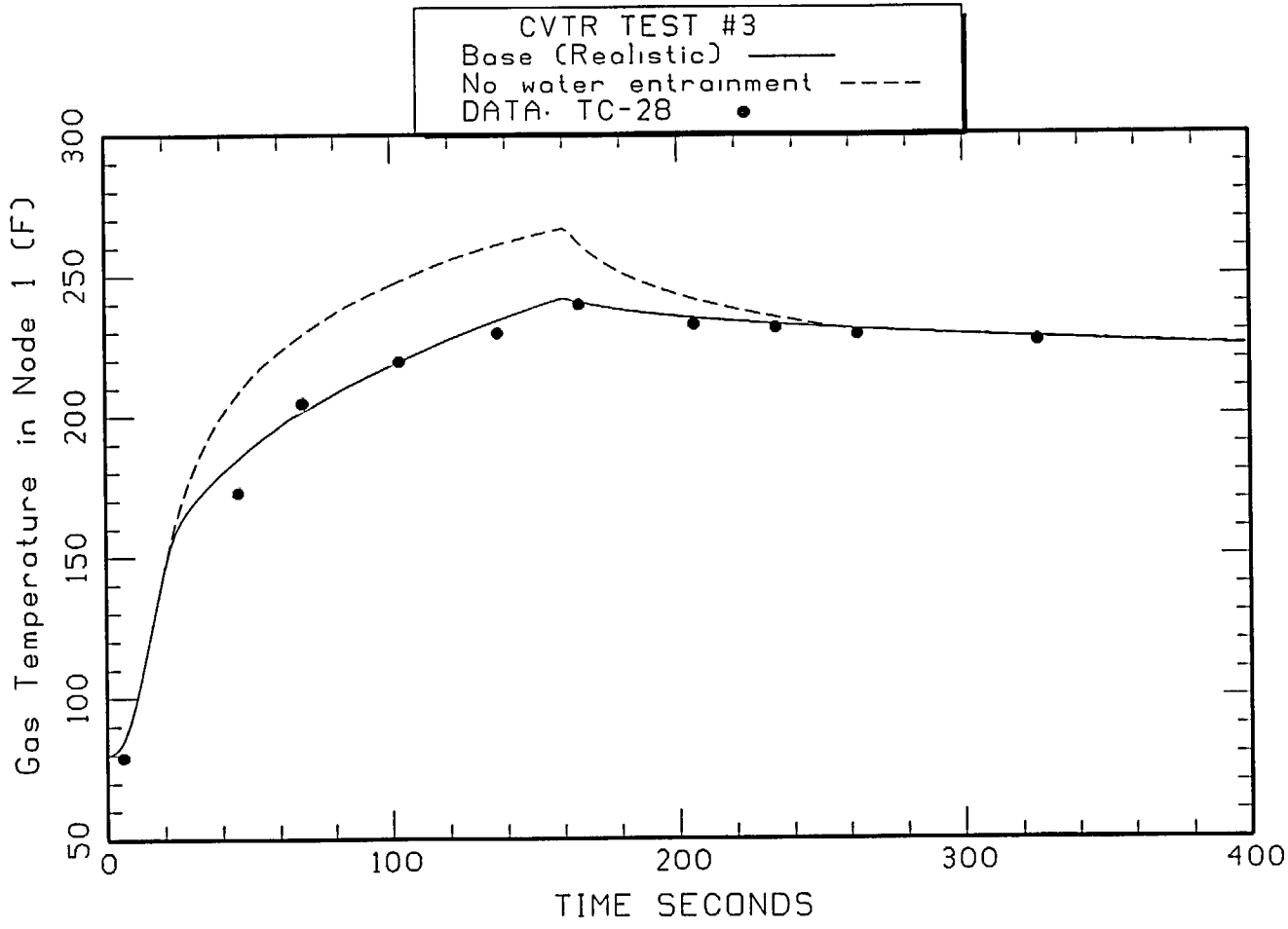

CVTR TEST #3
Base (Realistic)
No water entrainment
DATA· TC-28
Gas Temperature in Node 1 (F)
300
250
200
150
100
50
0
100
200
300
400
TIME SECONDS

Figure 2

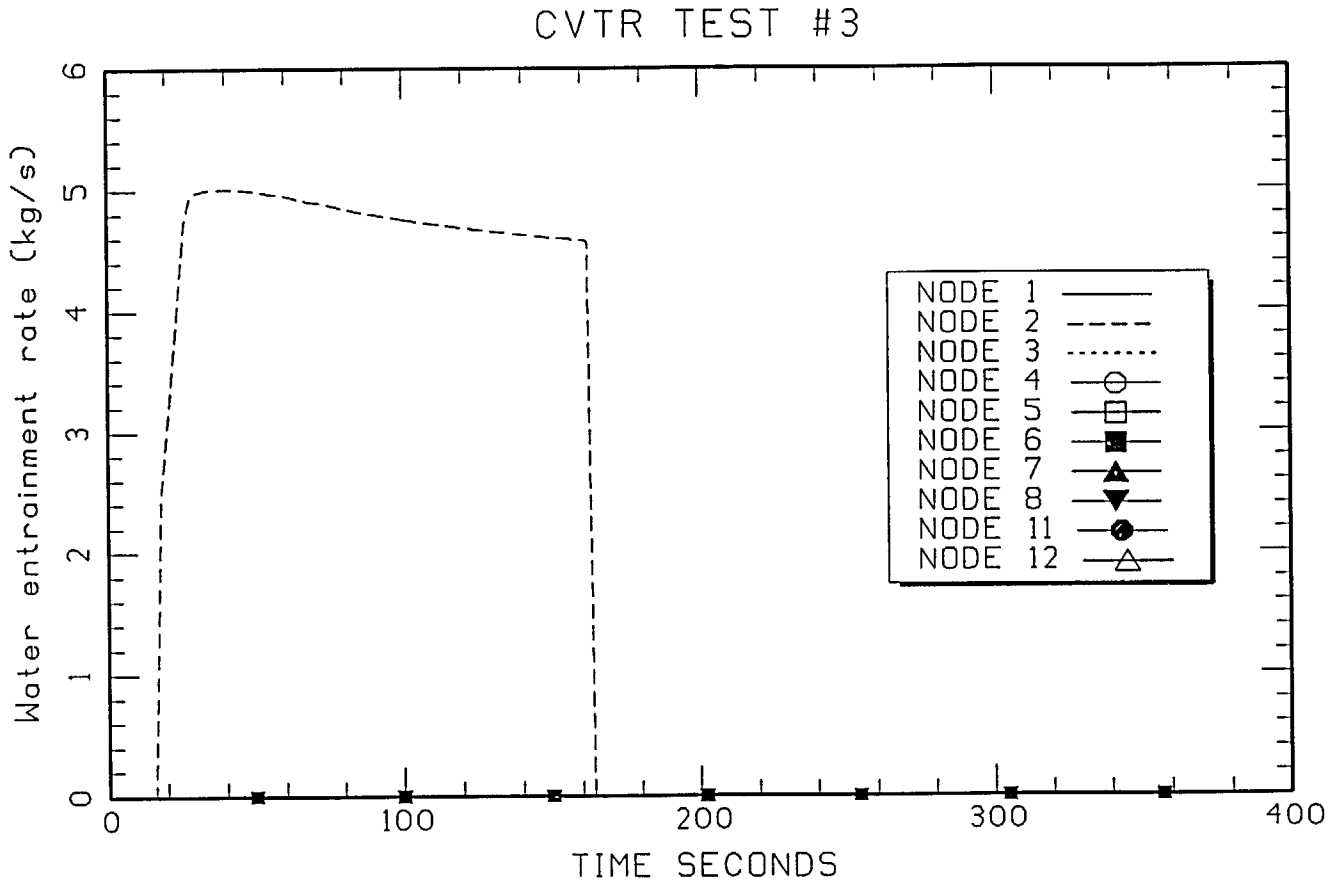

CVTR TEST #3
Water entrainment rate (kg/s)
0
1
2
3
4
5
6
0
100
200
300
400
TIME SECONDS
NODE 1
NODE 2
NODE 3
NODE 4
NODE 5
NODE 6
NODE 7
NODE 8
NODE 11
NODE 12

Figure 3

Item 2.2.9. It appears that FAI is using the CVTR test#3 measured velocity as a partial validation of the □momentum-driven velocity□ model. However, measurements (both direct and indirect), as well as published CFD calculations for test #3, all indicate that the peak wall velocity is 5-6 times lower than calculated using MAAP. Further, the annular gap velocity calculated by MAAP is approximately twice the value reported in the CVTR final report. Please comment. What additional, direct validation of calculated momentum-driven velocity has been obtained (other than CVTR) through the 5SSTAR process?

Response to Item 2.2 9.

As described in the CVTR experimental report, steam was introduced above the operating deck through a 10 inch diffuser pipe (numerous small holes) to discharge the steam in several directions. In the MAAP5 Topical Report CVTR has been analyzed assuming that the steam was discharged into a single node above the operating deck (node 2 of the 12 node MAAP5 containment model). Additionally, for the RAI responses the containment response has been analyzed assuming that the steam was discharged equally into nodes 2 and 6 (both nodes are immediately above the operating deck).

The MAAP5 calculated momentum driven velocities are illustrated for nodes 1, 2, 3 and 4 for the two different M&E assumptions. As illustrated in Figures 1 through 6, when the source is discharged only into node #2, that node and node #1 immediately have velocities significantly higher than those indicated by the ultrasonic anemometer in the annular gap (15 ft/sec) and near the bend line (30 ft/sec). When the mass and energy is assumed to be distributed between nodes 2 and 6, the velocity in the break nodes are approximately 3 times the reported velocity. However, those velocities in the nodes immediately above the break node(s), show velocities comparable to those in the CVTR experimental report. Also, it is to be noted that when the steam is injected only into node #2, the calculated velocity in node #6 is also comparable to that in the CVTR report. The results for nodes #3 and #7, which are immediately below the operating deck show calculated velocities comparable to those reported in the annular gap.

In summary, as anticipated, there are a spectrum of velocities calculated with those in the break node(s) being the maximum. However, velocities in the other nodes result in calculated values which are comparable to those given in the CVTR data report.

As discussed in the response to question 2.2.5, an additional benchmark for the momentum-driven velocity has been developed with the experiments of Kuhn et al These results demonstrate calculated heat transfer rates in agreement with the measured values.

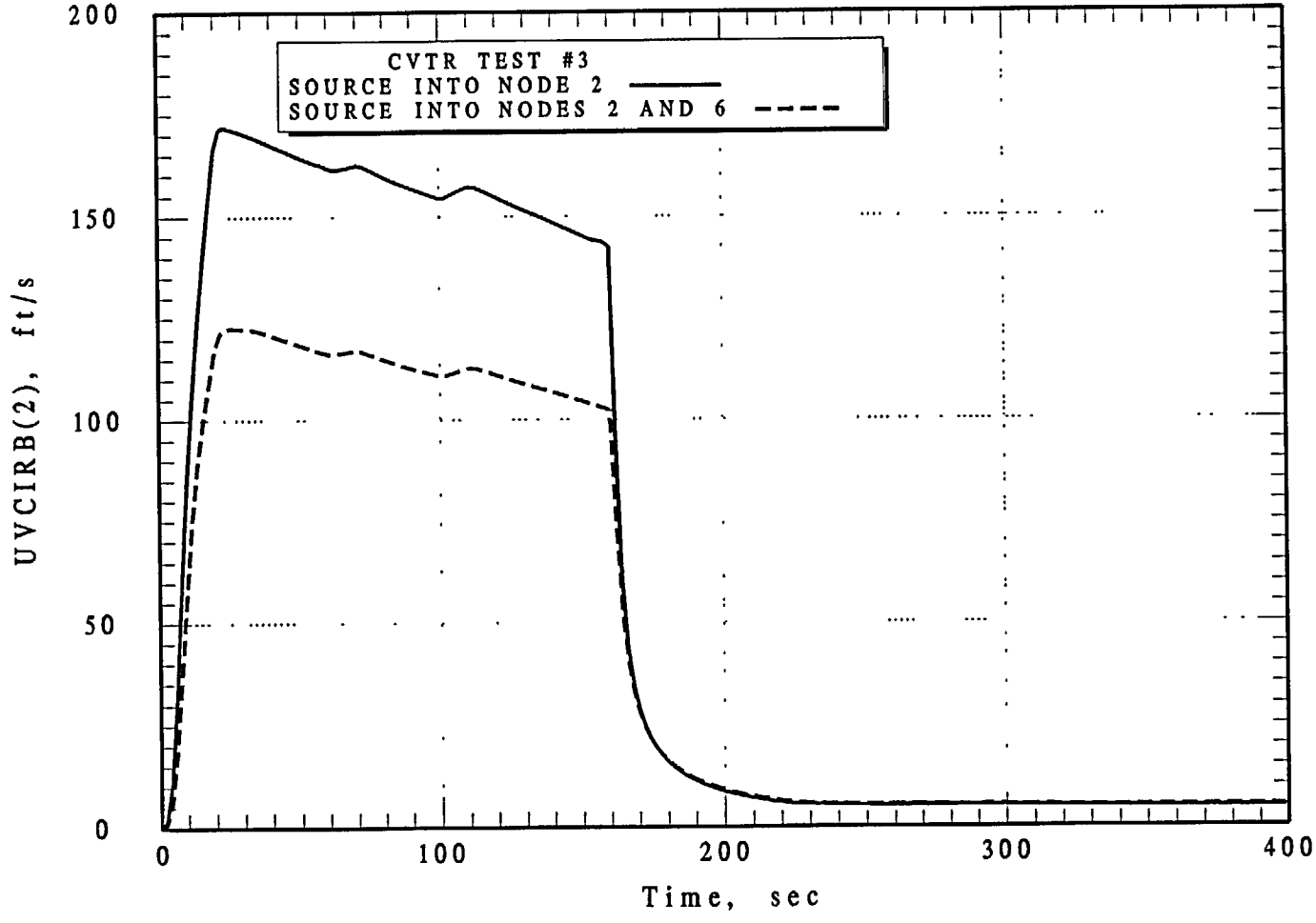


Figure 1: Calculated velocities in node 2 for steam discharge into node 2 and also for equal discharges into nodes 2 and 6.

Figure 2: Calculated velocities in node 6 for steam discharge into node 2 and also for equal discharges into nodes 2 and 6.

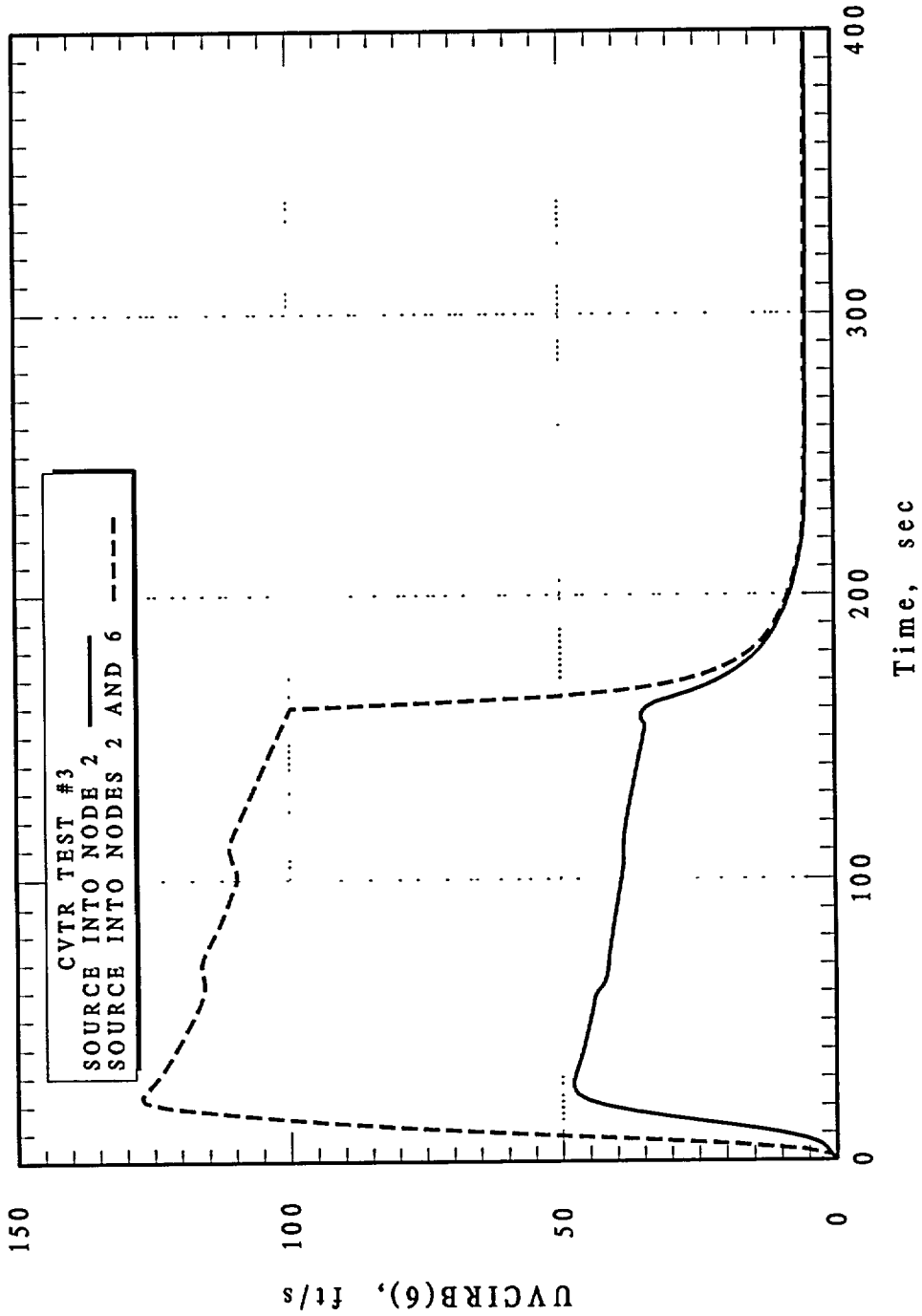


Figure 3: Calculated velocities in node 1 for steam discharge into node 2 and also for equal discharges into nodes 2 and 6.

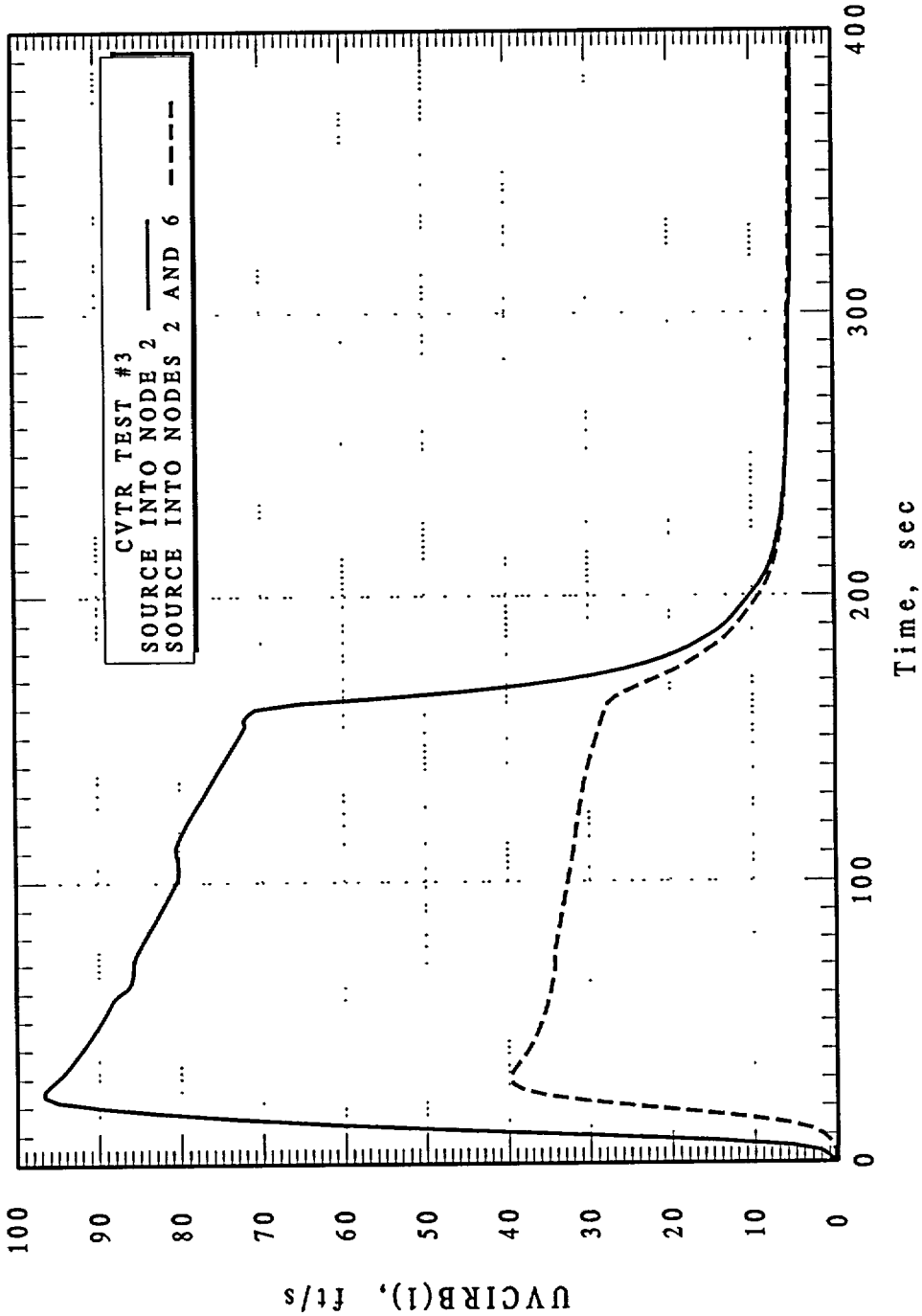


Figure 4: Calculated velocities in node 5 for steam discharge into node 2 and also for equal discharges into nodes 2 and 6.

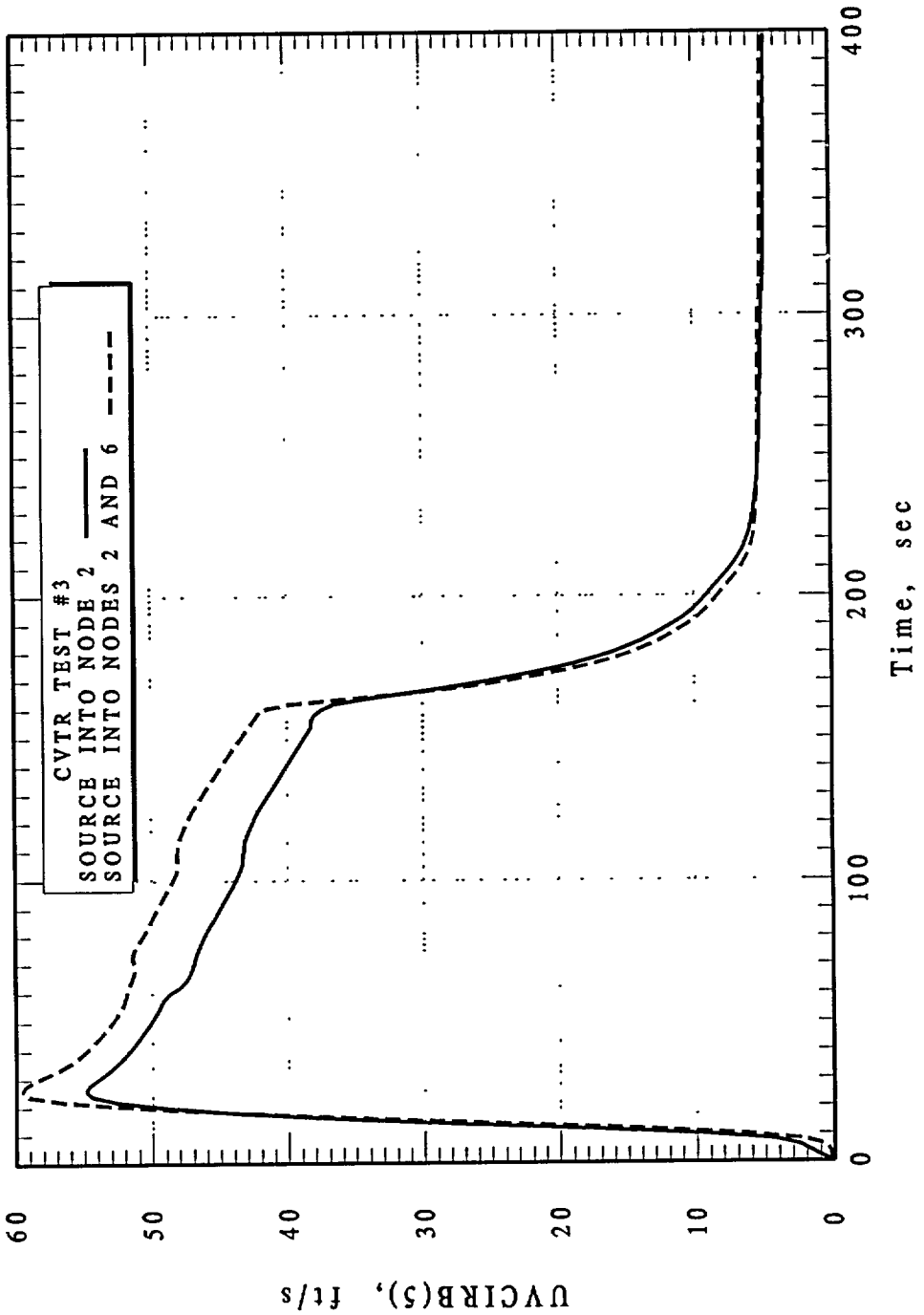


Figure 5: Calculated velocities in node 3 for steam discharge into node 2 and also for equal discharges into nodes 2 and 6.

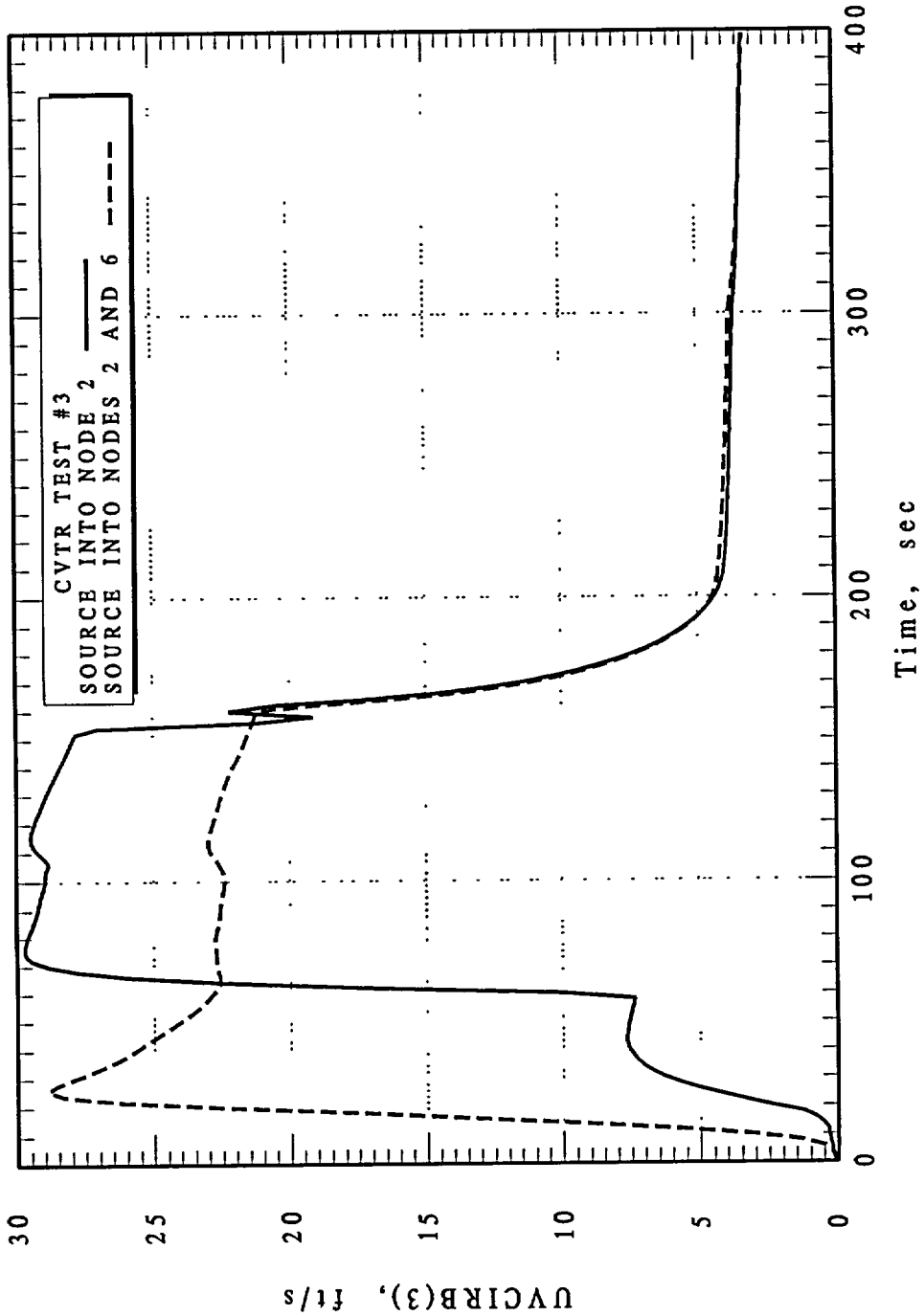
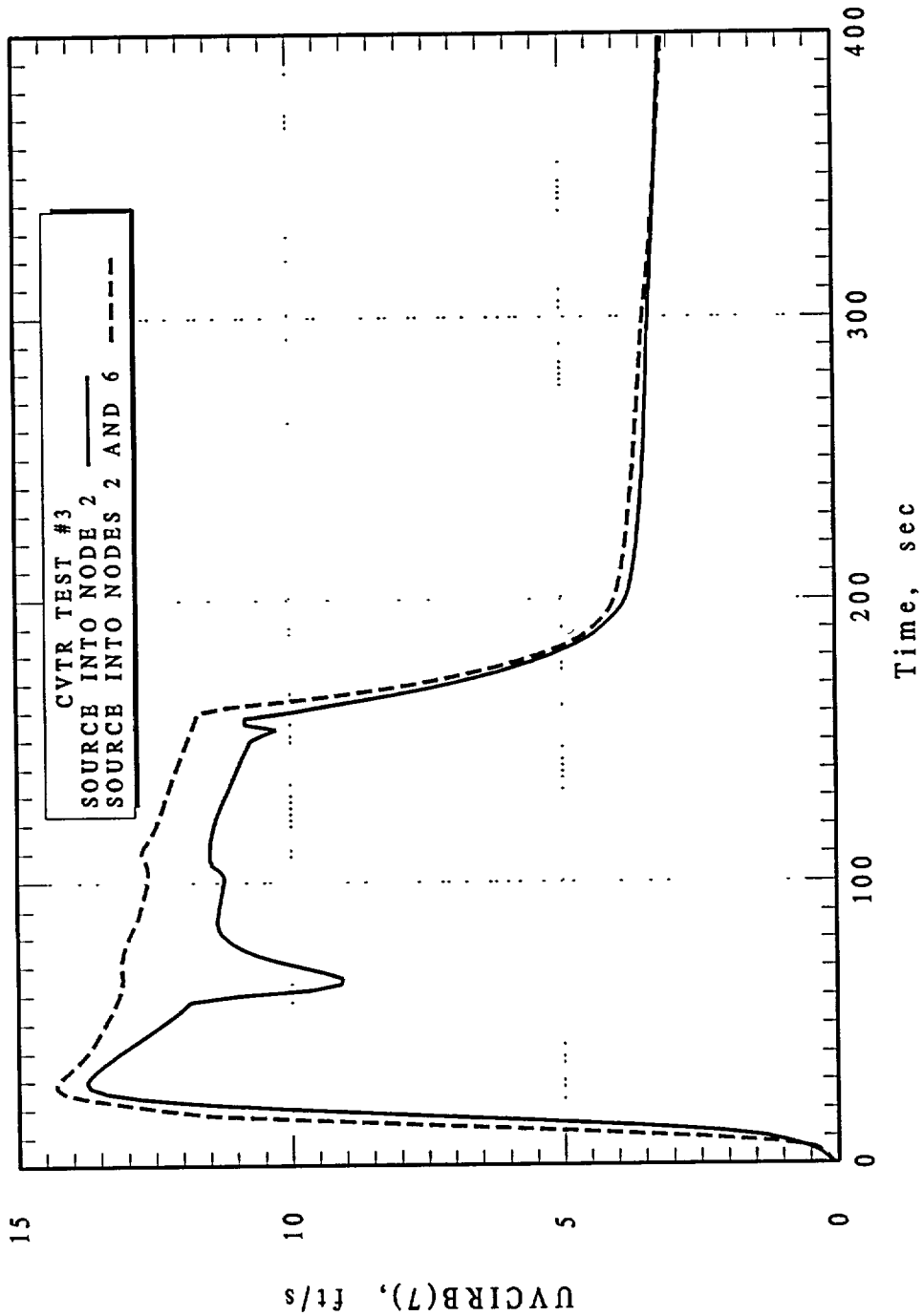


Figure 6: Calculated velocities in node 7 for steam discharge into node 2 and also for equal discharges into nodes 2 and 6.



Item 2.2.10. Provide a comparison of CVTR heat plug #2 heat transfer coefficients calculated for the MAAP uncertainty parameters.

Response to Item 2.2.10.

The information provided in the CVTR experimental report includes calculations of the overall heat transfer coefficients at two heat plugs. Thermocouple measurements in the instrumented plugs enabled the authors to deduce the effective time dependent surface heat transfer coefficients. Comparisons are provided below for the MAAP5 calculated surface heat transfer coefficients in the nodes above, and below, the operating deck.

As described in the experimental report, steam was introduced above the operating deck through a 10 inch diffuser pipe (numerous small holes) to discharge the steam in several directions. CVTR has been analyzed assuming that the steam was discharged into a single node above the operating deck (node 2 of the 12 node MAAP5 containment model). Additionally, the response has been analyzed assuming that the steam was discharged equally into nodes 2 and 6 (both nodes are immediately above the operating deck). Figure 1 shows the containment pressure responses using these two assumptions with the associated temperature responses being shown in Figure 2. Only small differences are calculated in the global response of the containment peak pressure and temperature.

The Heat Transfer Coefficients (HTCs) deduced through the heat plug measurements, as well as those HTCs deduced from the measured temperatures on the inside and outside of the containment liner, are compared (Figure 3) with the MAAP5 calculated values when the mass and energy release is discharged only into node #2. Figure 4 compares the same quantities when the mass and energy release is simultaneously discharged into nodes 2 and 6. In these figures heat transfer coefficient HTTOT(1) is for the containment wall heat sink in node 1, HTTOTI(2) is the calculated heat transfer coefficient to the wall in node 2, HTTOTI(16) is the heat transfer coefficient to the containment wall in node 5 and HTTOTI(17) is the heat transfer coefficient to the containment wall in node 6. The calculated and measured heat transfer coefficients are in agreement.

Heat transfer coefficients deduced for local temperature measurements are also reported for regions immediately below the operating floor and for the basement region. These are compared to the MAAP5 calculated values in Figures 5 and 6 for mass and energy release discharged into node #2. In these two figures, HTTOTI(3) is the wall heat transfer coefficient in node 3, HTTOTI(4) is the heat transfer coefficient in node 4 with HTTOTI(18) and HTTOTI(19) being the respective heat transfer coefficients in nodes 7 and 8 which are diametrically opposed to nodes 3 and 4. Correspondingly, the variable HTTOTI(5) is the heat transfer coefficient in node 11, which is at the bottom of the containment building and variable HTTOTI(20) is the heat transfer coefficient in node 12 which is diametrically opposed to node 11. Here also there is agreement between the measured and calculated values in both regions.

Figure 1: Comparison of CVTR response for the M&E released into a single node or into adjacent nodes along with the experimentally measured pressures.

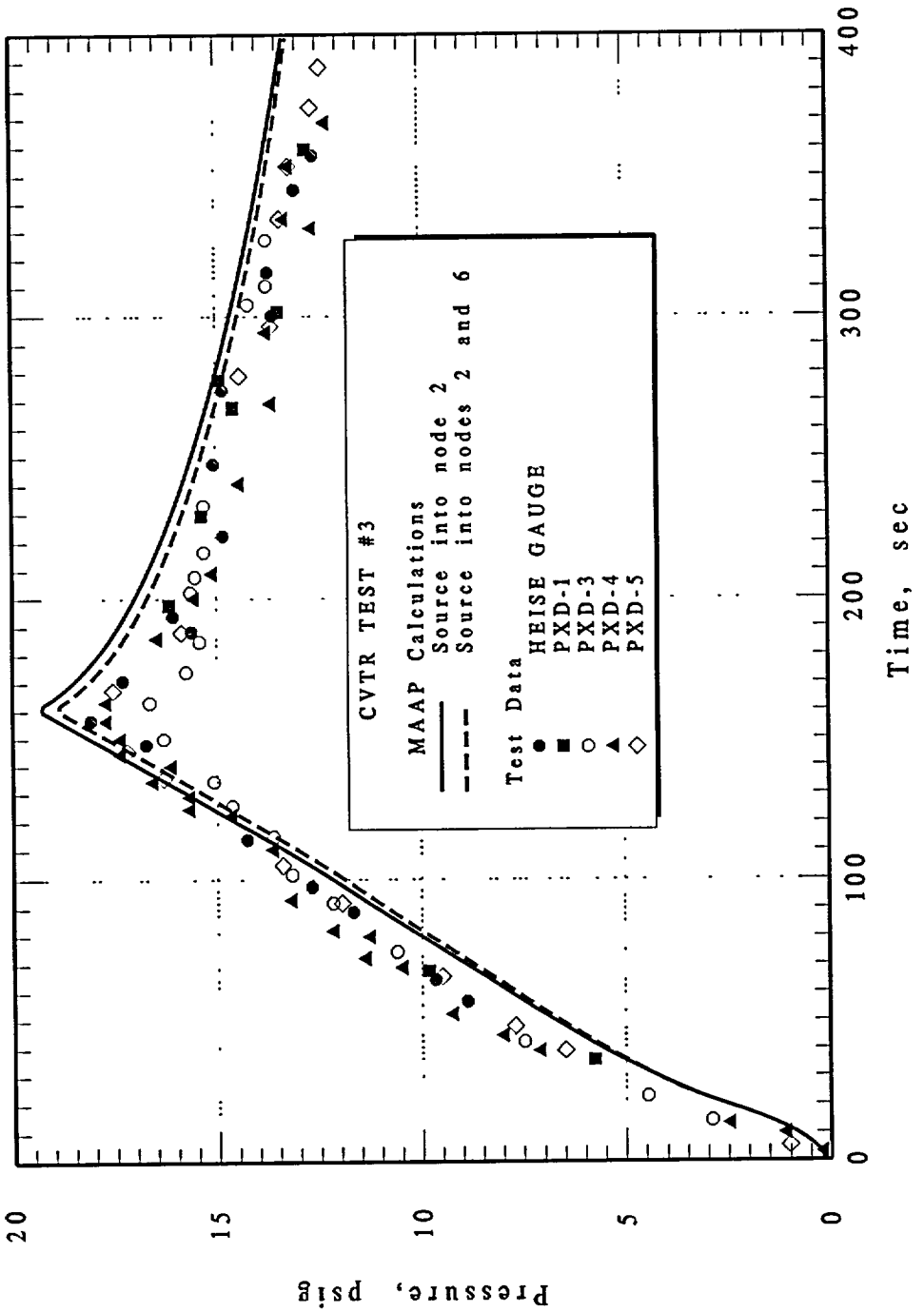


Figure 2: Comparison of CVTR response for the M&E released into a single node or into adjacent nodes along with the experimentally measured temperature in the upper dome.

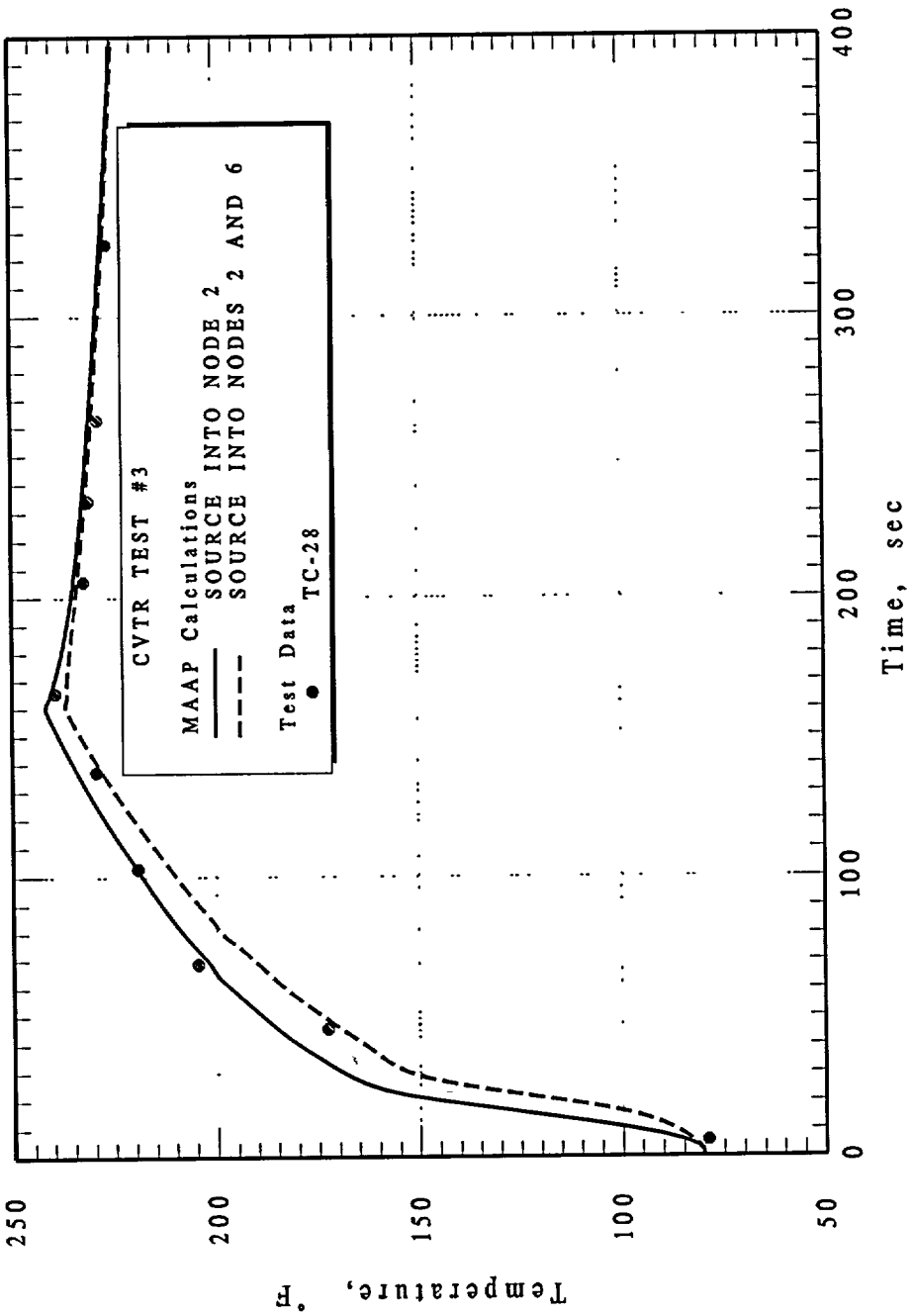


Figure 3: Comparison of the calculated and measured heat transfer coefficients above the operating deck when the steam is discharged into node 2.

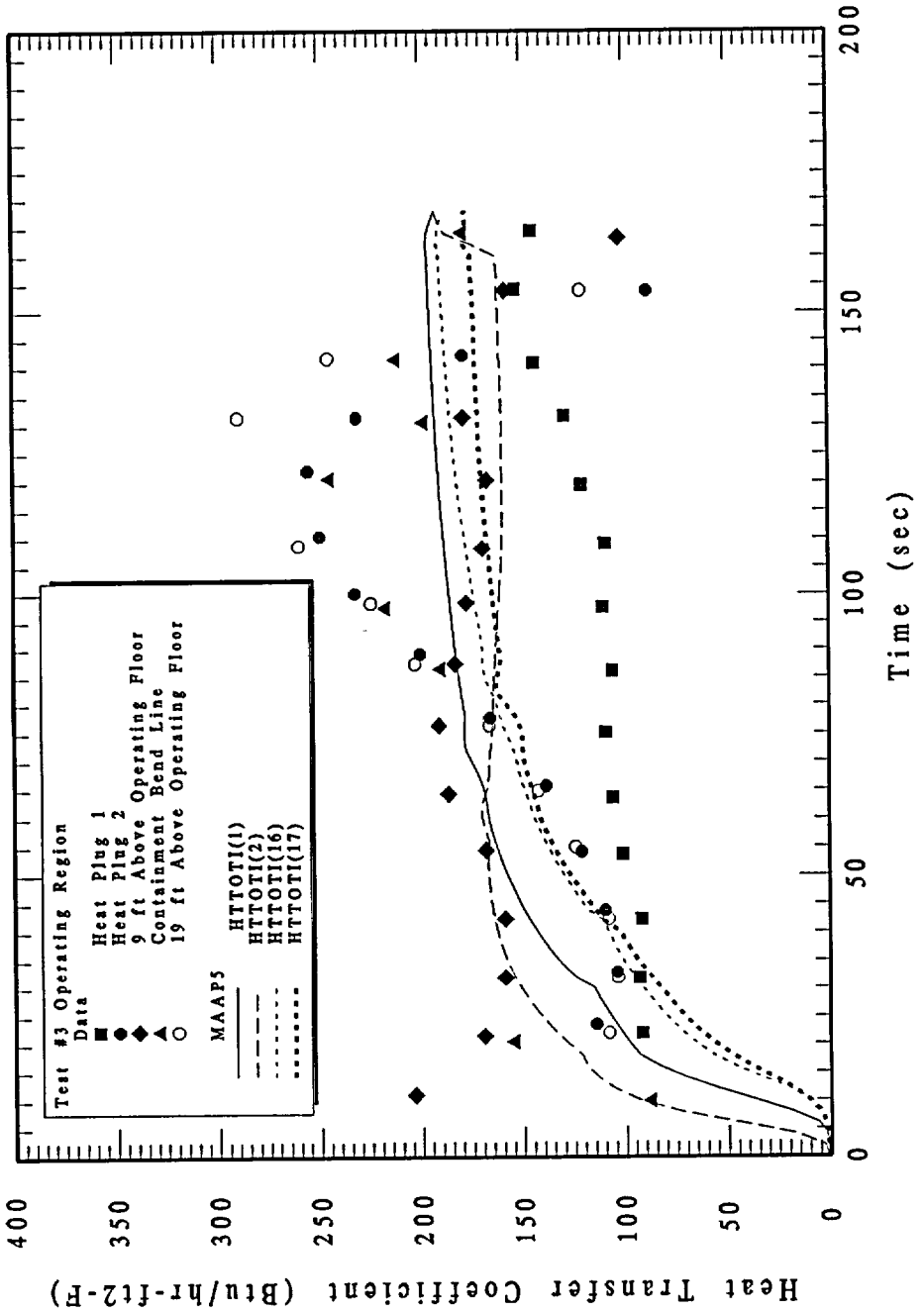


Figure 4: Comparison of the calculated and measured heat transfer coefficients above the operating deck when the steam is discharged simultaneously into nodes 2 and 6.

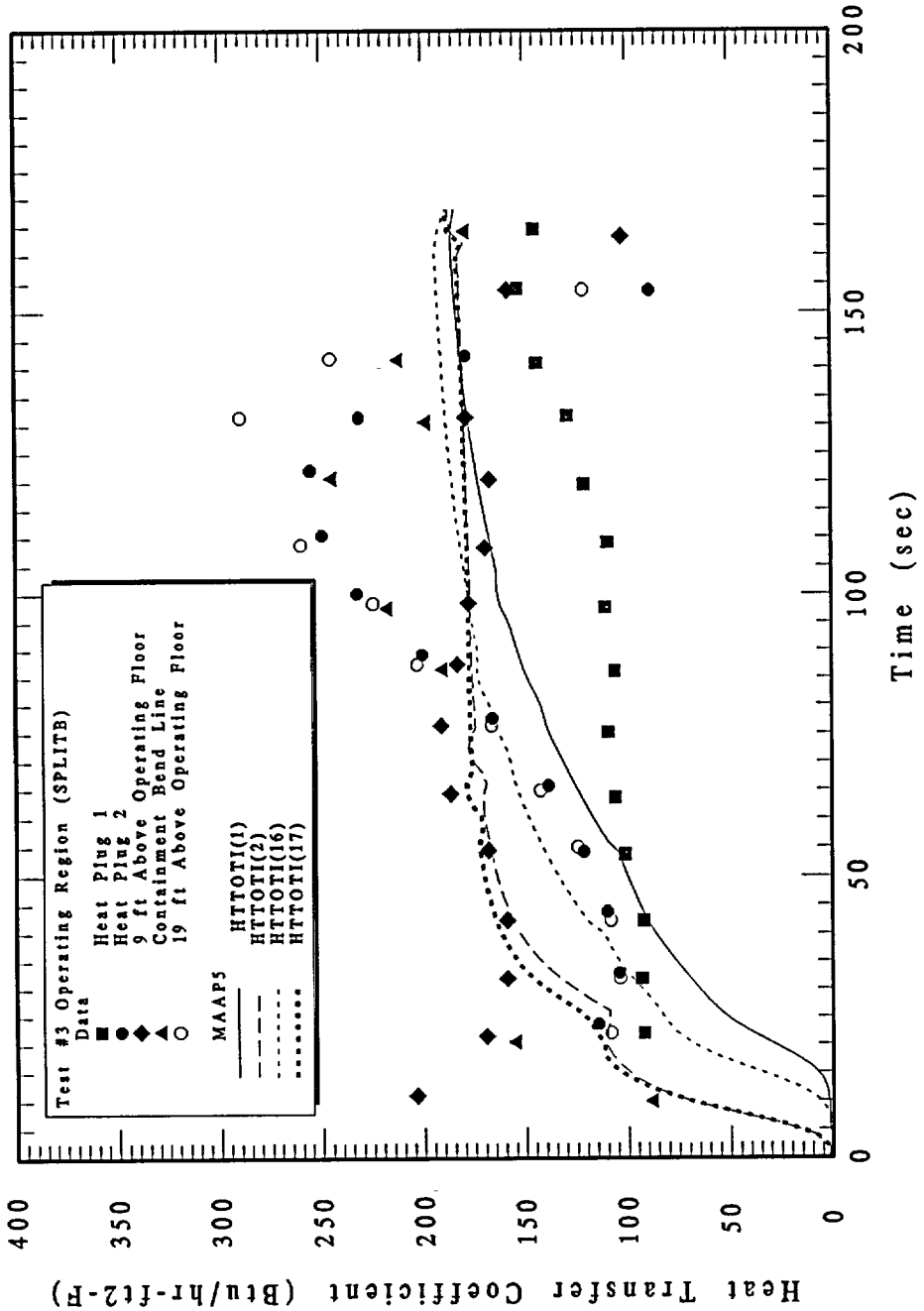
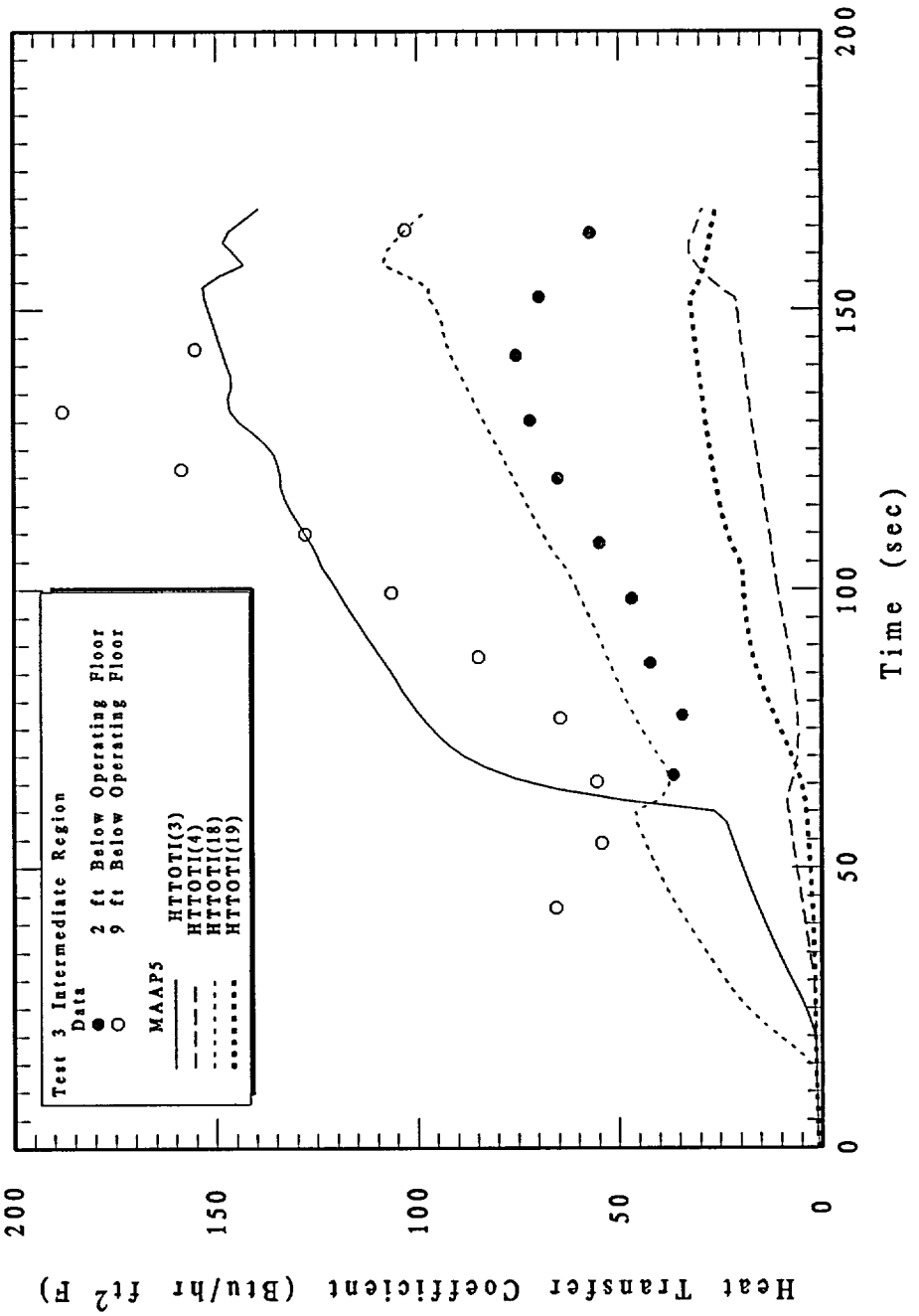


Figure 5: Comparison of the calculated and measured heat transfer coefficients for CVTR Test 3 in the region immediately below the operating floor.



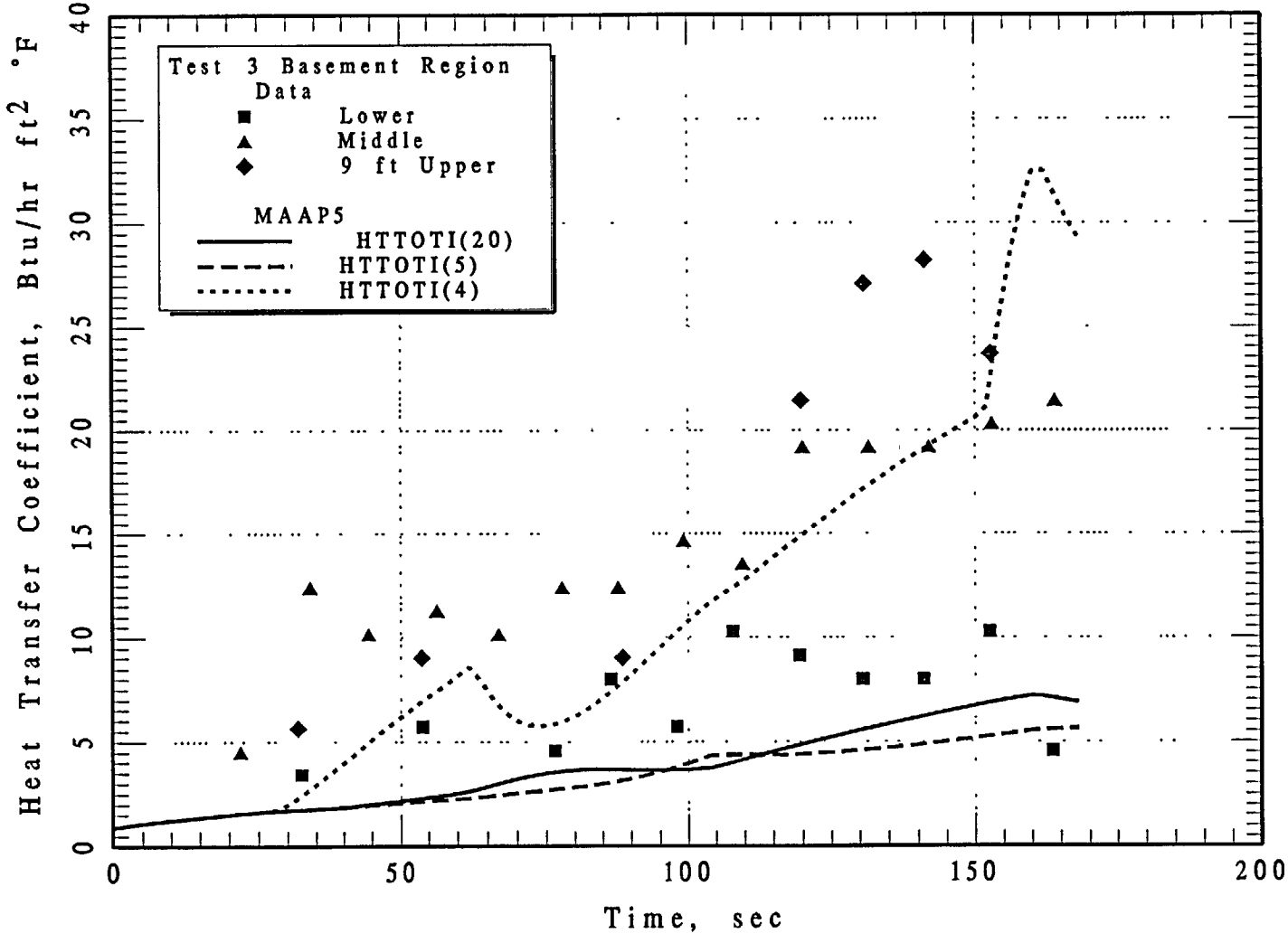


Figure 6: Comparison of the measured and calculated heat transfer coefficients for CVTR Test 3 in the basement region.