INTERIM REPORT

Accession No. ____________

Contract Program or Project Title: SSC Code Validation

Subject of this Document: Comparative Studies of LMFBR System Codes: Part 2: FFTF Upper Plenum Mixing and Stratification

Type of Document: Informal Report

Author(s): J. W. Yang
Engineering & Advanced Reactor Safety Division
Department of Nuclear Energy
Brookhaven National Laboratory
Upton, New York 11973

Date of Document: August 1978

Responsible NRC Individual and NRC Office or Division: Dr. Robert T. Curtis, Chief
Analytical Advanced Reactor Safety Research Branch
Division of Reactor Safety Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

This document was prepared primarily for preliminary or internal use. It has not received full review and approval. Since there may be substantive changes, this document should not be considered final.

Brookhaven National Laboratory
Upton, NY 11973
Associated Universities, Inc.
for the
U.S. Department of Energy

Prepared for
U.S. Nuclear Regulatory Commission
Washington, D. C. 20555
Under Interagency Agreement EY-76-C-02-0016
NRC FIN No. A-3018

INTERIM REPORT

LIMITED DISTRIBUTION

BNL-NUREG 24856

INFORMAL REPORT

COMPARATIVE STUDIES OF LMFBR SYSTEM CODES: PART 2: FFTF UPPER PLENUM MIXING AND STRATIFICATION

J. W. YANG

ENGINEERING AND ADVANCED REACTOR SAFETY DIVISION

POOR ORIGINAL

DATE PUBLISHED - AUGUST 1978

DEPARTMENT OF NUCLEAR ENERGY BROOKHAVEN NATIONAL LABORATORY

UPTON, NEW YORK 11973

NRC Research and Technical Assistance Report

Prepared for the U.S. Nuclear Regulatory Commission

Office of Nuclear Regulatory Research

Contract No. EY-76-C-02-0016

POOR ORIGINAL

BNL-NUREG-24856
INFORMAL REPORT
LIMITED DISTRIBUTION

COMPARATIVE STUDIES OF LMFBR SYSTEM CODES:

PART 2: FFTF UPPER PLENUM MIXING AND STRATIFICATION

J. W. Yang

Engineering and Advanced Reactor Safety Division
Department of Nuclear Energy
Brookhaven National Laboratory
Upton, New York 11973

August 1978

Prepared for
U.S. Nuclear Regulatory Commission
Washington, D. C. 20555
Under Interagency Agreement EY-76-C-02-0016
NRC FIN No. A-3018

ABSTRACT

The upper plenum mixing and stratification model of SSC-L has been used to simulate the 1/15-scale test model at Argonne National Laboratory (ANL) and the upper plenum of the Fast Flux Test Facility (FFTF). SSC-L calculations were compared with test data and results obtained with the MIX and IANUS codes. Comparisons between SSC-L results and ANL's test data of the effective mixing volume agree well. Comparisons between predictions of SSC-L and the MIX code indicate the impact of two-dimensional analysis on transport delay and flow stratification. Recommendations for relevant modifications to the one-dimensional code are made. Calculations made with SSC-L and IANUS agree very well, in spite of differences in modeling.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

This report presents preliminary results of comparative analyses of mixing and stratification in the upper plenum of the Fast Flux Test Facility (FFTF). The ability to predict the transient thermal response in the outlet plenum is an important problem area for the overall safety analysis. Treatment of the thermal regime in the upper plenum can strongly affect the buoyancy-induced flow redistribution in the vessel and the onset of natural circulation through the primary loop system. In addition, transient states of sodium and cover gas in the upper plenum dictate the thermal-hydraulic state at the outlet nozzle, which is the inlet boundary condition for transient loop analysis. Verification of the mixing model used to predict the transient response in the upper plenum is therefore required. In the present study, verification of the SSC-L mixing model is carried out in two parts. The first part contains the simulation of ANL's 1/15-scale test model of FFTF. Comparisons with the test data and results of ANL's two-dimensional MIX code were made. The second part includes simulation of the FFTF upper plenum with comparisons between the predictions of SSC-L and IANUS. IANUS is a one-dimensional system code specifically developed for FFTF.

2. ANALYTICAL MODELING OF MIXING AND STRATIFICATION IN THE UPPER PLENUM

The basic model in predicting the thermal response in the upper plenum is the simple lumped-parameter approach in which mixing is characterized as occurring in a well-stirred chamber within the plenum. This model is known to be satisfactory if the temperature of the exiting core flow is higher than the average temperature of the fluid in the upper plenum. It is believed that the momentum of the core flow aided by the positive buoyancy force is sufficient to provide full penetration and results in complete mixing in the plenum. However, recent experiments have shown that this idealistic model is inadequate under certain off-normal and accident conditions. The first evidence of stratification was discovered at Combustion Engineering in 1973.[1] The experiments performed indicated that the large increase in the density of fluid entering the upper plenum following a normal scram coupled with the coastdown of flow in the primary loop caused fluid stratification within the plenum. Since then, various experiments on small scale models of FFTF have been conducted at Battelle-Columbus Laboratory, Argonne National Laboratory and Westinghouse Advanced Reactors Division. A review of these experiments is given in Reference 1.

Fluid stratification is the consequence of a normal scram transient of an LMFBR. During the transient, a density interface is created within the reactor outlet plenum. The interface lies between two distinct zones: an upper zone of relatively warm (light) quiescent fluid and a lower zone of relatively cool (heavy) fluid actively mixing with the core exit flow. The position of the hot-cool interface varies during the transient according to the penetration of core flow, and the heat and mass transfer at the interface. The temperature at the outlet nozzle of the plenum (an important parameter

for loop analysis), therefore, depends on the relative position of the two zones and the mean temperatures of each zone. In order to treat the complexity of the mixing process, a two-zone model was developed for the SSC-L code.[2]

The physical model used in SSC-L is shown in Figure 1. The upper plenum contains a large volume of sodium, the upper section of the bypass channel, a small region occupied by the cover gas and three sections of metal. Fluids leaving the reactor core and the leakage flow of the lower section of the bypass channel enter the plenum from the bottom section, while a small percentage of cold bypass overhead-flow enters the plenum through the annular space formed by the thin thermal liner and the vessel wall. The outlet flow is represented by an exit nozzle. The support columns, chimney of the outlet module, control rod drive mechanism, vertex suppressor plate, control assembly, cellular flow collector, baffle, and all other structures are lumped together and represented by a section of mass (m1) immersed in fluids, the cylindrical thermal liner is indicated as m2, and the vessel closure head and other metals above the cover gas region are considered as mass m3. The cover gas region is connected to a large reservoir which represents all its connections, such as the overflow tank, equalization line header and gas region of the loop pumps. The sodium region is divided into two zones according to the maximum penetration distance of core flow.

Penetration of core flow is determined from a detailed analysis of turbulent jet flow with negative buoyancy.[3] According to the analysis, the flow is characterized by the Froude number defined by the core exit condition. The Froude number represents the ratio of momentum flux to the buoyancy force. The governing equations for the mixing model, solution technique and numerical results of test cases are given in Reference 2.

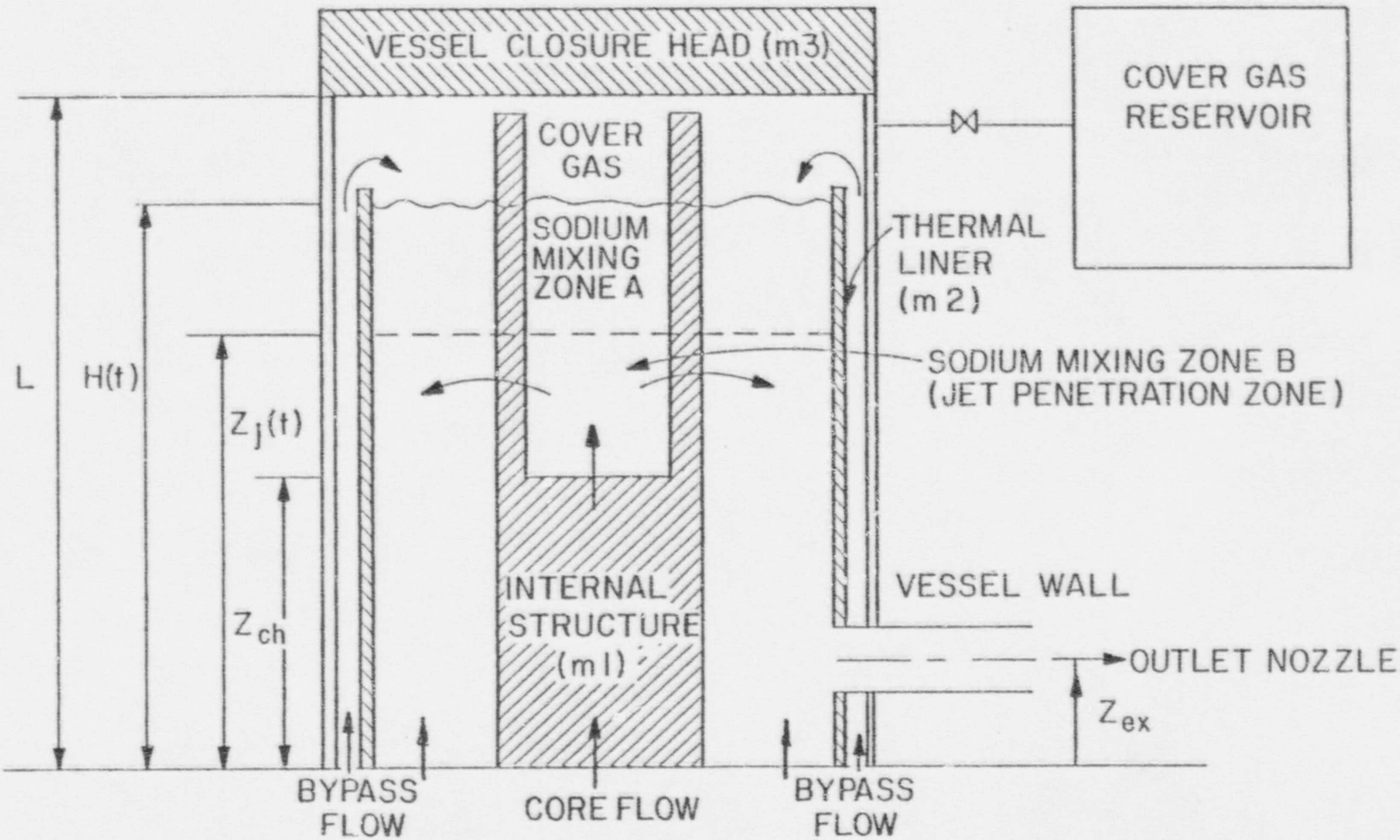


Figure 1: Schematic Diagram of SSC-L Model for Mixing in the Upper Plenum.

IANUS[4] is a transient system code developed to model LMFBR loop-type reactor plants. It has been used extensively for the reactor-plant design of FFTF. Computation of the transient boundary conditions for the primary loop hot leg components is done with a simple empirical mixing model developed for the IANUS code. The key features of the model are[4,5]:

(1) The upper plenum is represented by a variable number of perfectly-mixed regions with effective volumes chosen through input.

(2) For the case of normal scram, the effective volume is approximated based on HEDL's isothermal hydraulic tests:

(a) The effective mixing volume at the moment of power scram is 30 percent of the total plenum volume;

(b) The effective mixing volume increases linearly from 30 percent to 100 percent of the total volume in 2000 seconds after the scram.

(3) For cases other than normal scram, the effective mixing volume has not yet been reported.

(4) Heat exchange between plenum fluid and metal structure including vessel thermal baffle can be included as an option.

(5) Fluid stream from core subassemblies and core peripheries is assumed to be perfectly mixed before entering the plenum.

Both SSC and IANUS are one-dimensional system codes and, therefore, can predict only the average temperature of each mixing zone. There are two two-dimensional codes (VARR-II and MIX) capable of predicting the axial and radial temperature variations in the plenum and the impact of the two-dimensional effect on fluid stratification. The computer code VARR-II,[6] developed at Los Alamos Scientific Laboratory (LASL)/Science Applications Incorporated

(SAI), performs a detailed computation of time-dependent turbulent flows with slight density variation. In addition to the basic time-averaged Navier-Stokes equations, it includes the turbulent kinetic energy and turbulent kinematic viscosity as two more variables in its model. The code has been used as a design tool by WARD. In a recent study, Chen and Golay[7] performed an experimental validation of the turbulence model used in VARR-II for LMFBR upper plenum flows. The study concluded that VARR-II provides a good prediction of the observed behavior in the CRBR geometry, but poor agreement was observed in the FFTF geometry. The VARR-II code was therefore not used in the comparative studies of this program.

The MIX[8] code developed at ANL adopted a different approach. It solves the vorticity-stream function equations and a coupled energy equation to account for buoyancy. Turbulence is treated by a modified laminar approach assuming constant effective Reynolds and Peclet numbers. This simple treatment avoids the complexity in the computation of the turbulence model used in VARR-II and provides flexibility to adjust the effective Reynolds and Peclet numbers to fit experimental data. Extensive studies of the MIX code and its applications to CRBR and FFTF models were reported and are available in literature. The MIX code was used in this comparative study.

3. SIMULATION OF ANL 1/15-SCALE FFTF MODEL

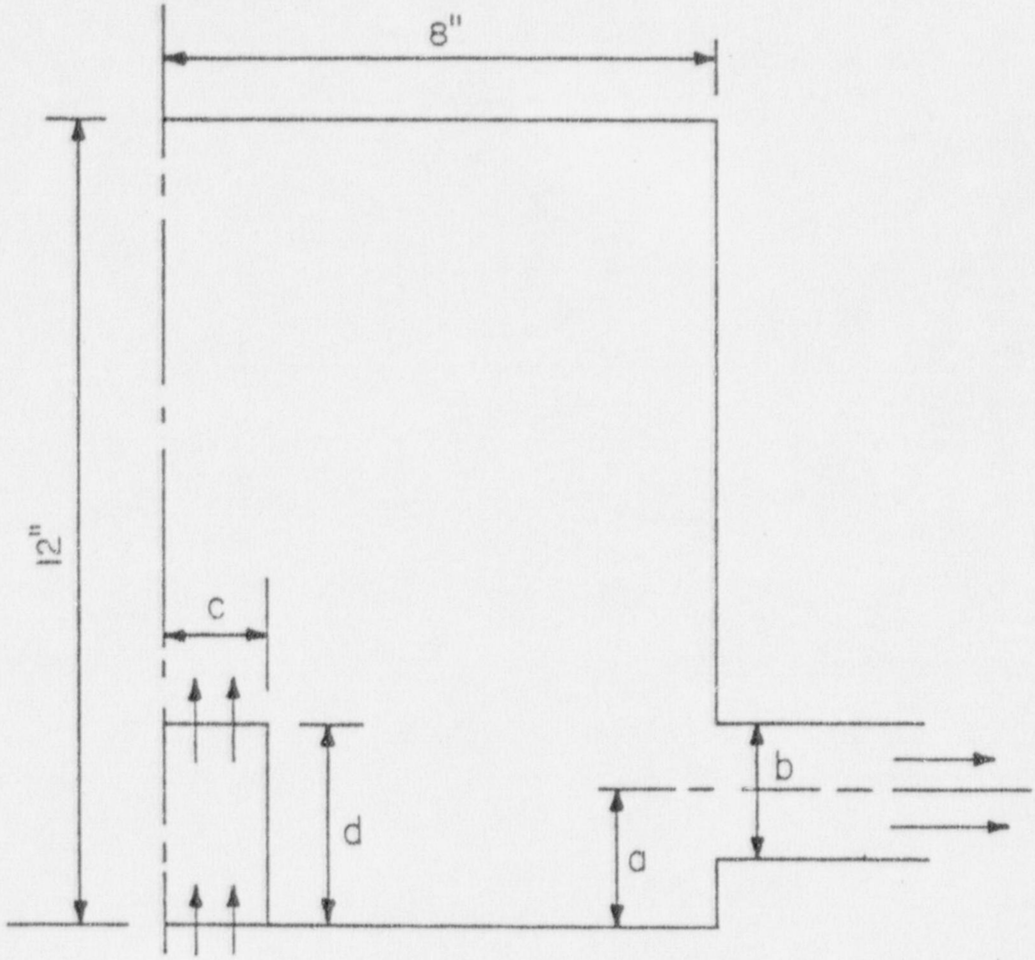
Argonne National Laboratory has conducted a series of tests with their 1/15-scale model of the FFTF outlet plenum using water and sodium as test fluids. Two objectives of the tests are:

(1) The study of the temperature response within the plenum during normal (and constant flow) reactor scrams, with emphasis on the exit nozzle transients;

(2) The study of the vertical propagation of the jet head (penetration of core flow) and the characteristics of the hot-cool interface.

These objectives coincide with that of SSC-L and the test results are directly comparable with SSC-L predictions. A schematic diagram of the test model is shown in Figure 2. The fluid enters the plenum through the inlet module located on the bottom and exits through three outlet nozzles. There are four different configurations of the inlet and outlet nozzles which permit a systematic study of the effects of inlet boundary structures on the mixing process in the plenum. The internal structures and bypass channel contained in the prototype of FFTF upper plenum are not included.

The measured effective mixing volume of nine representative runs was reported in Reference 9. Test conditions of these runs are given in Table 1. These conditions were simulated by the jet penetration model of SSC-L, and the computed values were compared with the measured ones in Figure 3. It is evident that there is good agreement between the measured and computed results. Furthermore, Figure 3 reveals that complete mixing in FFTF cannot be achieved at a Froude number less than 10. Thus, as indicated in the analysis,[3] the Froude number can be used as the indicator for selecting either the complete or the partial mixing model in a system code. Recently, Howard and Carbajo[10]



CONFIGURATION	a	b	c	d	
1A	2.0	2.0	1.5	3.0	20% INLET FLOW AREA
1B	2.0	2.0	1.5	3.0	100% INLET FLOW AREA
2A	2.3	2.75	1.62	2.75	NON-PROTOTYPICAL OUTLET
2B	1.6	1.7	1.62	2.75	PROTOTYPICAL OUTLET

Figure 2: Sketch of ANL 1/15-Scale FFTF Upper Plenum Geometry.

Table 1: Experimental Conditions of ANL Tests for Effective Mixing Volume Study

ANL Test Number	Geometry (Fig. 2)	Flow Rate (gpm)		Temperature °F		Comments
		Initial	Final	Initial	Final	
5/20-4	2A	25.1	2.4	168	76	Normal Scram
5/29-1	2B	25.7	3.0	180	72	Normal Scram
5/20-8	2A	25.0	4.9	170	72	Higher Shutdown Flow Rate
5/29-7	2B	25.7	5.5	154	70	Higher Shutdown Flow Rate
5/20-6	2A	24.8	9.9	180	65	Higher Shutdown Flow Rate
5/29-6	2B	25.7	9.5	152	68	Higher Shutdown Flow Rate
5/20-7	2A	25.0	14.2	174	65	Higher Shutdown Flow Rate
5/29-5	2B	25.7	14.0	153	66	Higher Shutdown Flow Rate
5/20-5	2A	25.1	25.1	172	66	Constant Flow Scram

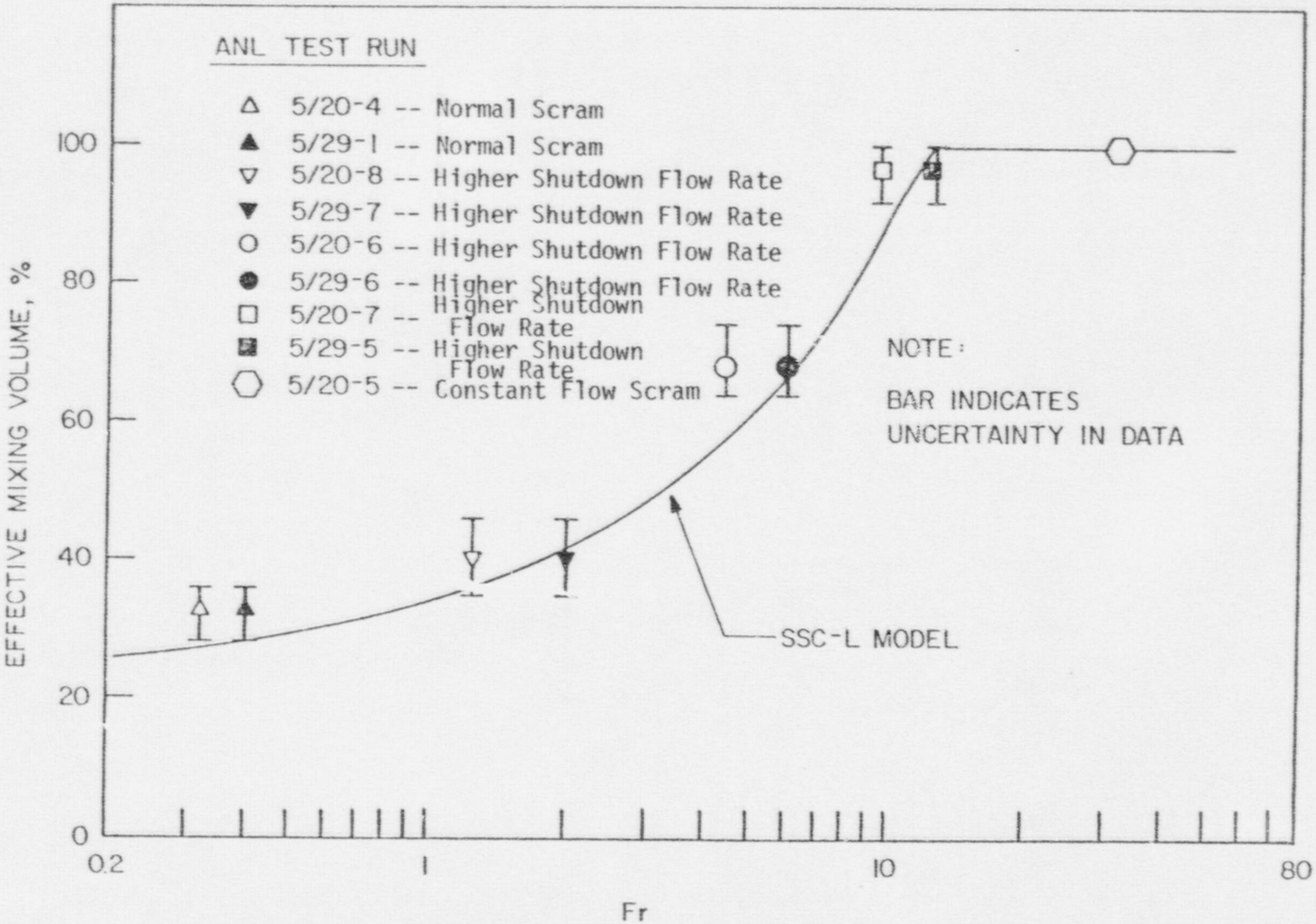


Figure 3: Comparison Between Effective Mixing Volume Calculated by SSC-L Model and ANL Experimental Values.

of ANL have conducted an experimental study of the transient behavior in a generalized outlet plenum model and confirmed the validity of the jet penetrating model developed for SSC-L. Their test results and comparisons are included in the Appendix for reference.

Two of the ANL test runs representing the case of constant flow (Run 9/12-7) and the case of normal scram (Run 9/11-6) were selected for the study of transient temperature response. Both runs were compared with the two-dimensional MIX predictions and are in good agreement. The test conditions of the two runs are given below:

Run Number	Geometry (Fig. 2)	GPM		Temperature ^{o}F		Fluid
		Initial	Final	Initial	Final	
9/12-7	1B	27.3	27.3	75	133	Water-Brine
9/11-6	1B	30.0	3.1	116	70	Hot-Cool Water

It is noted that water-brine or hot-cool water was used in the experiments. Since the SSC-L code cannot simulate these fluids, sodium at 838 K and with the same ΔT was used in the computation for both SSC-L and MIX.

For the case of constant flow (Run 9/12-7), both experimental visualization and MIX prediction show that the mixing in the plenum is characterized by a toroidal recirculating flow pattern (i.e., 100 percent effective mixing volume). The complete mixing is also predicted in SSC-L as shown in Figure 4. According to the SSC-L model, the large flow rate (i.e., high momentum flux of the core exit flow) permits a full penetration in the plenum regardless of the negative buoyancy imposed on the entering flow due to scram of power. Comparisons of the plenum outlet temperature are included in Figure 4. For the outlet

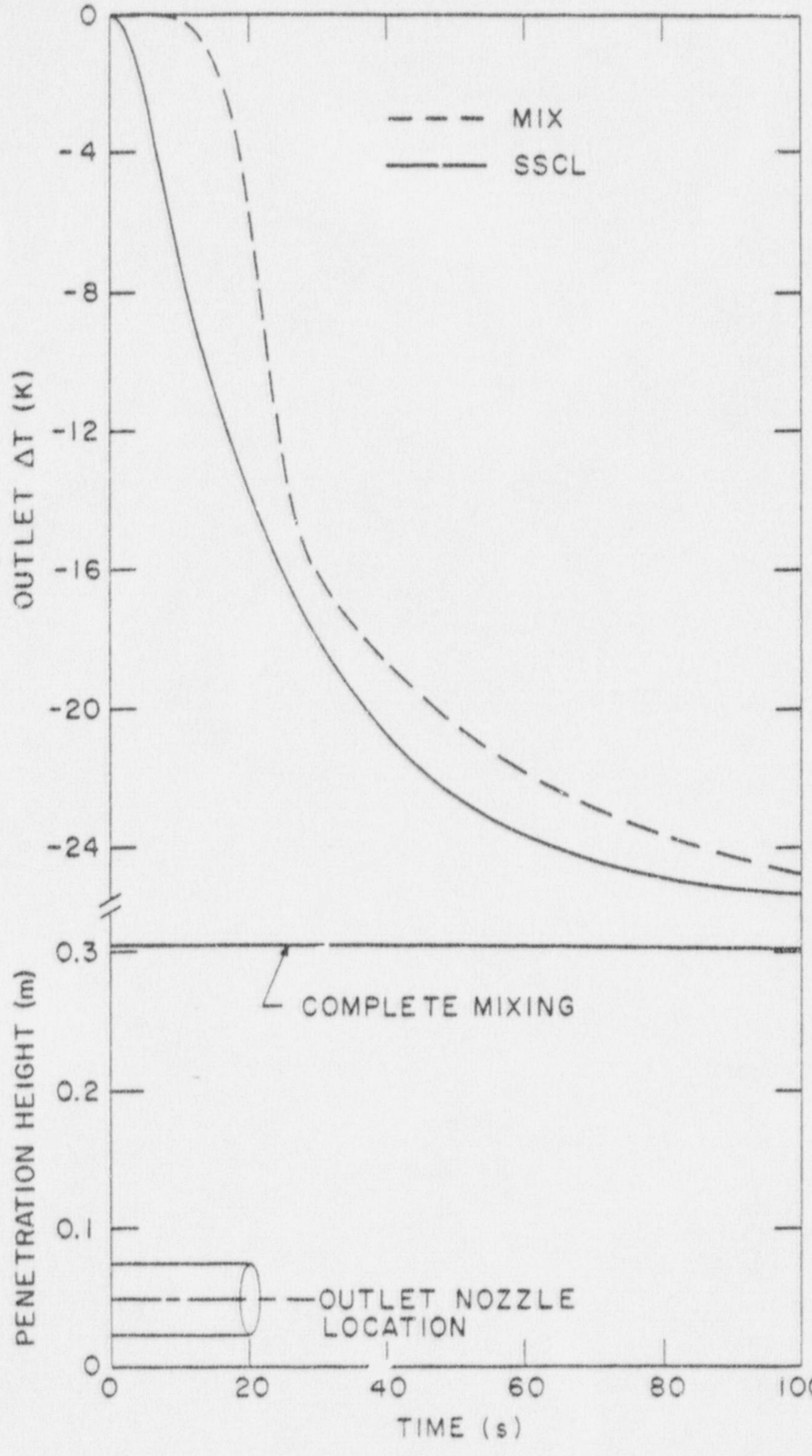


Figure 4: Predicted Penetration Height and Outlet Temperature for ANL Run 9/12-7.

temperature, SSC-L predicts an instant response to the reduction of the core temperature as a result of the one-dimensional lumped-parameter approach. The two-dimensional MIX code which computes the stream-lines of fluid particles indicates a transport delay of about 10 seconds. After the initial period of delay, as the cold entering flow reaches the outlet nozzle, the outlet temperature decreases rapidly as indicated by the dotted line in Figure 4. After about 30 seconds, the predicted temperatures from the two codes agree reasonably well with each other.

The second case, Run 9/11-6, represents a different transient in which normal scram is simulated by reducing the flow rate to 10.334 percent within 10 seconds. For this case, both experimental visualization and MIX prediction indicate a rapid decay of the toroidal recirculating flow pattern and a partial mixing in the lower portion of the plenum. Similar effects are indicated by the SSC-L computations which show that stratification starts at about 7 seconds and the effective mixing volume decreases to 34.8 percent at 11 seconds as illustrated by the penetration height in Figure 5. The penetration height (i.e., effective mixing volume) increases slowly during the later stage of the transient as the negative buoyancy vanishes slowly due to the cooling of the fluid stored in the plenum. The comparison of outlet temperatures for this case is plotted in the upper portion of Figure 5. Again, SSC-L predicts an instant response of the outlet temperature to the reduction of temperature of the entering flow; while MIX gives a transport delay of about 10 seconds. However, the differences of the two predictions are larger than that of the first case (Run 9/12-7). The response of the outlet temperature by the MIX code is governed by the large axial and radial variation of fluid temperature in the plenum. Four representative graphs of the transient temperature distribution within the plenum are illustrated in Figures 6 through 9.

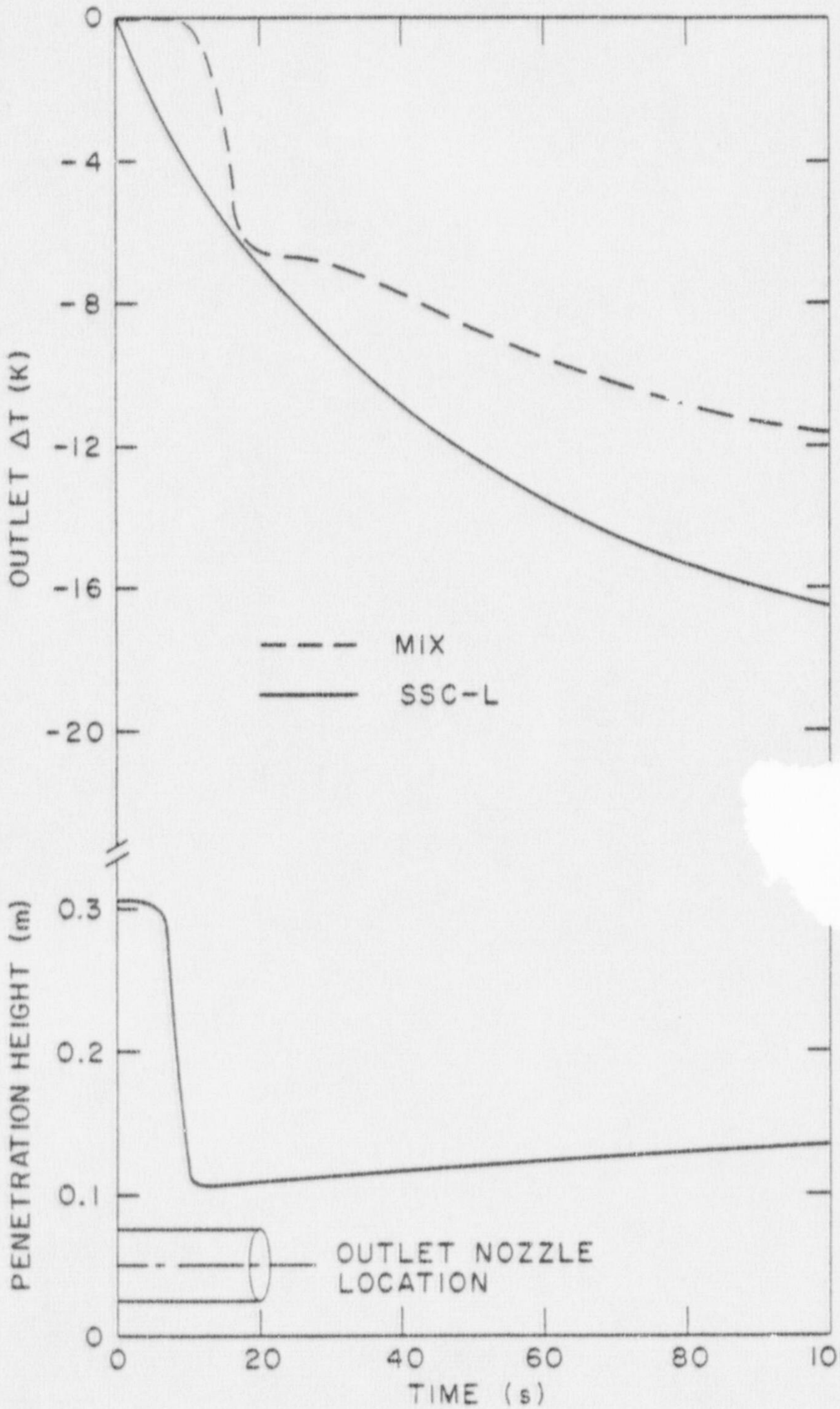
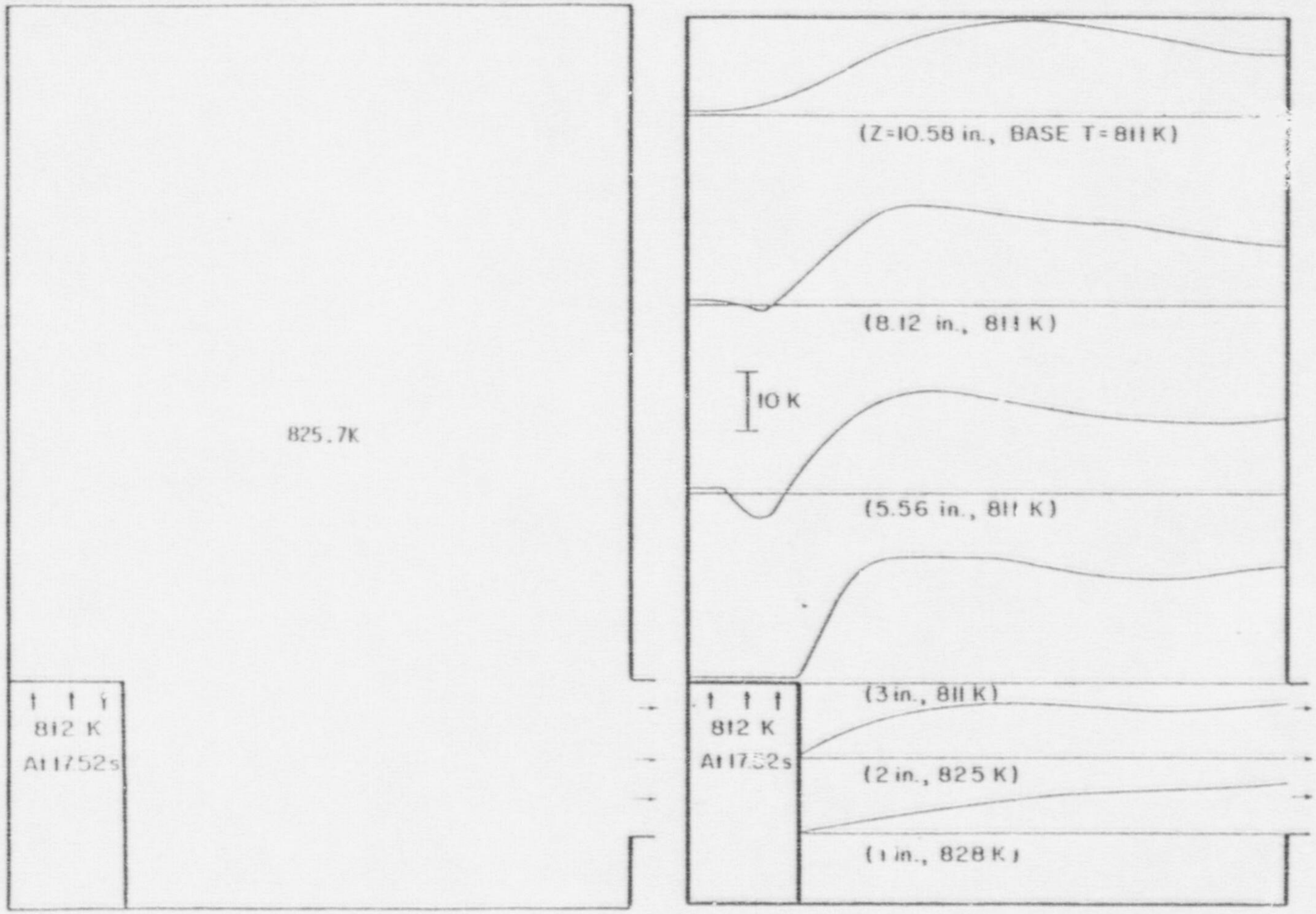
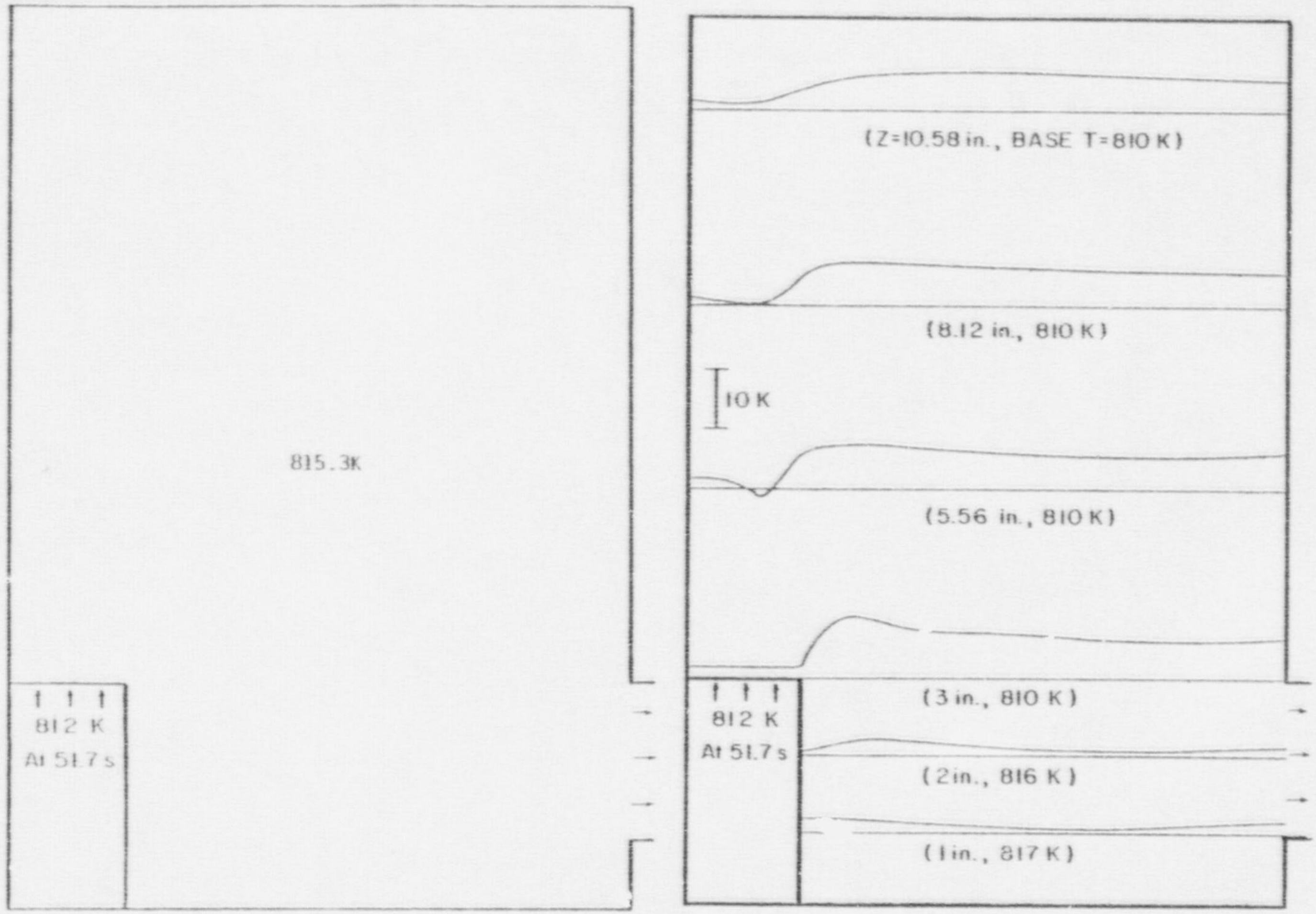


Figure 5: Predicted Penetration Height and Outlet Temperature for ANL Run 9/11-6.



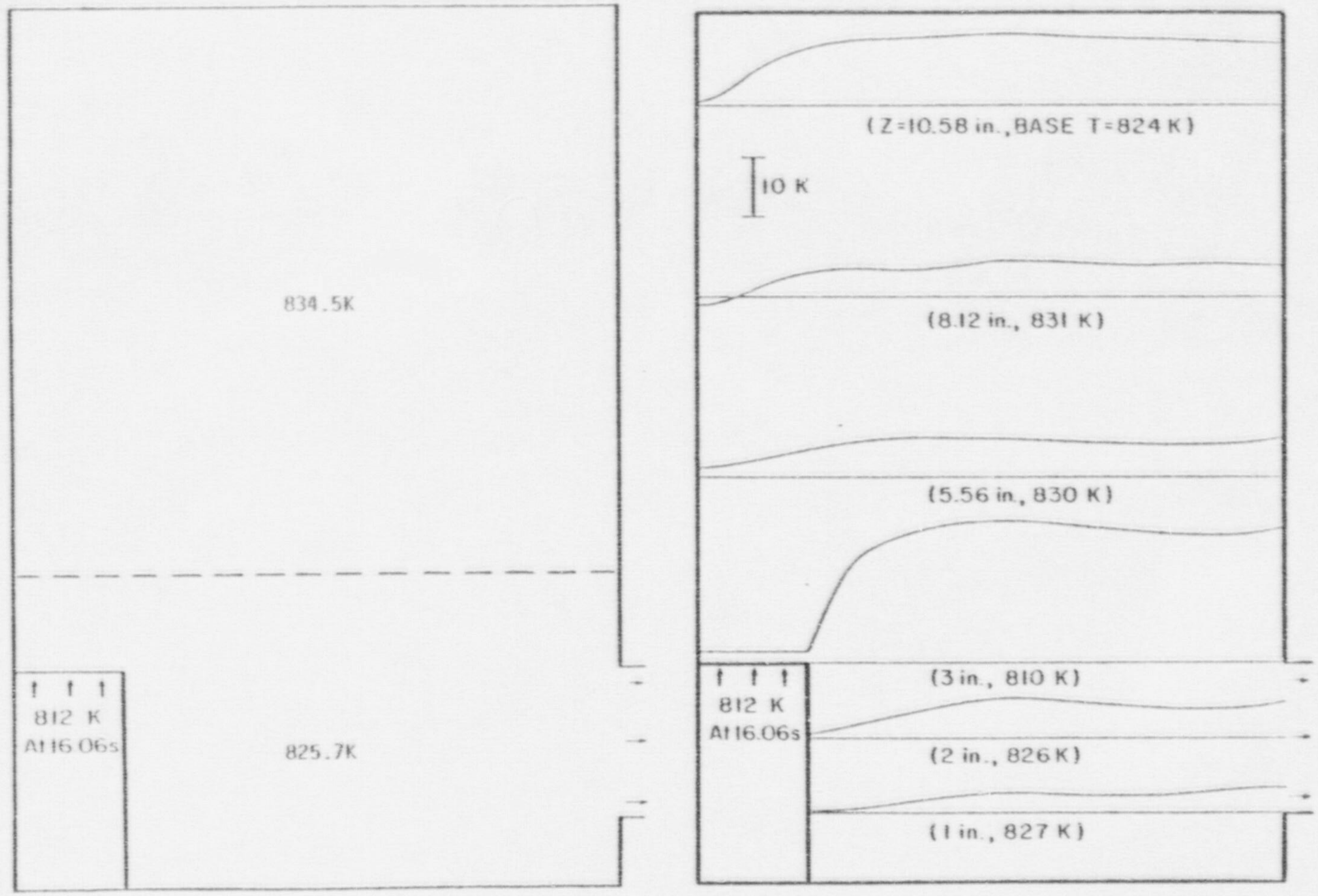
(a) SSC-L (b) MIX

Figure 6: Predicted Transient Temperature Distribution in Upper Plenum for Run 9/12-7 at 17.52 Seconds.



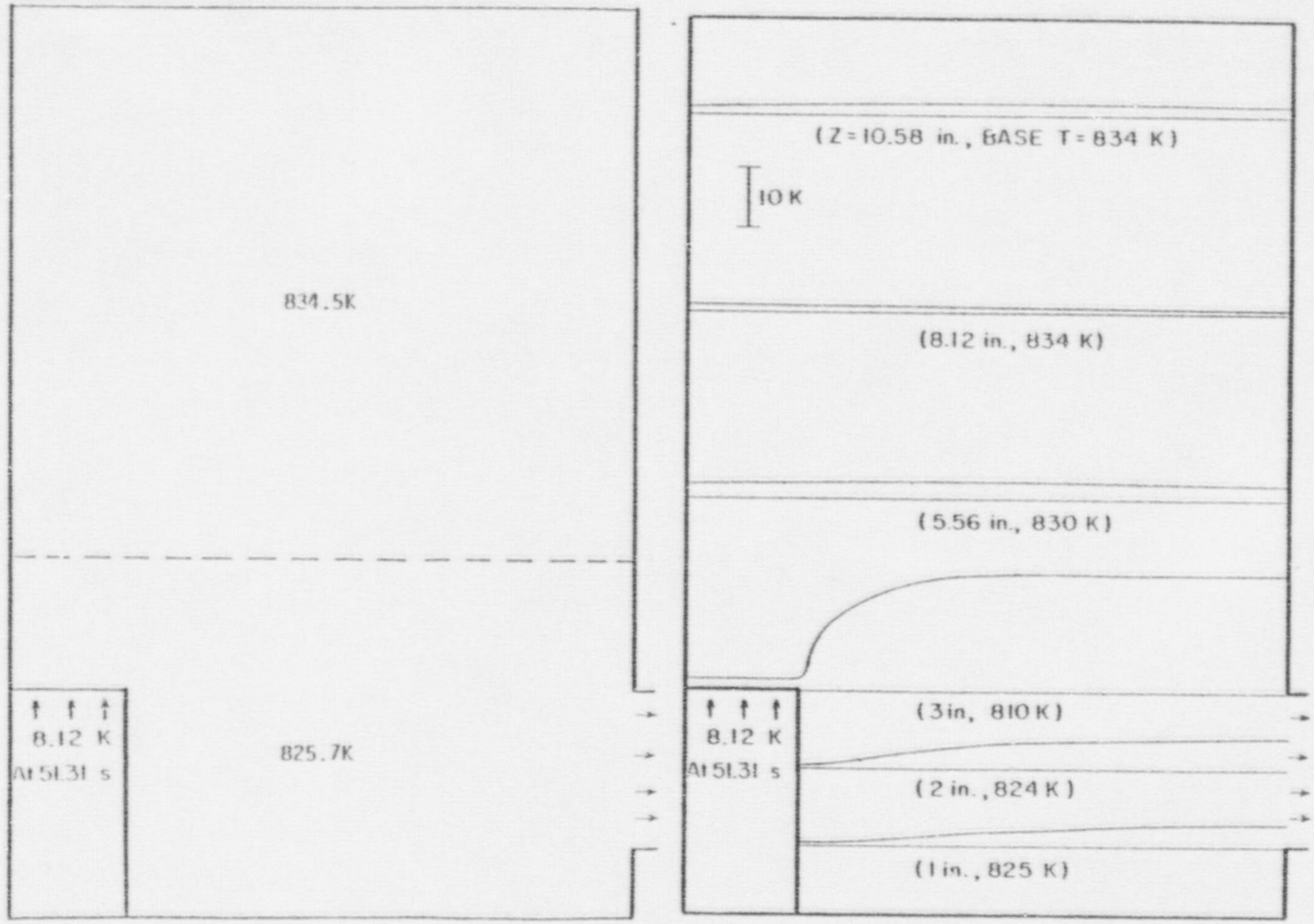
(a) SSC-L (b) MIX

Figure 7: Predicted Transient Temperature Distribution in Upper Plenum for Run 9/12-7 at 51.7 Seconds.



(a) SSC-L (b) MIX

Figure 8: Predicted Transient Temperature Distribution in Upper Plenum for Run 9/11-6 at 16.06 Seconds.



(a) SSC-L (b) MIX

Figure 9: Predicted Transient Temperature Distribution in Upper Plenum for Run 9/11-6 at 51.31 Seconds.

Figures 6 and 7 show the temperature distribution at 17.52 and 51.7 seconds, respectively, for the case of complete mixing (Run 9/12-7). The radial temperature distribution at six axial elevations computed by MIX is compared with the single average temperature computed by SSC-L. Similar graphs are shown in Figures 8 and 9 for the case of stratification (Run 9/11-6). For this case, SSC-L provides two average temperatures for each of the mixing zones. It is noted that, according to MIX predictions, there is a large variation of temperature within the plenum.* The computed MIX outlet temperature (Figures 4 and 5) is the average of the axial temperatures at the opening of the outlet nozzle. The axial temperature distribution at the outlet nozzle is, in turn, determined by the instant flow pattern in the plenum. Figure 9 reveals an interesting point that, after stratification is fully estaplished, there is less temperature variation in the upper section of plenum according to MIX predictions. This agrees with the two-zone model of SSC-L, that above the penetration zone, the upper section is the undisturbed zone composed of quiescent fluid at uniform temperature.

---

*Temperatures at a few nodes directly above the chimney, Figures 6 and 7, are lower than the inlet temperature (which is physically impossible). According to Lorenz,[8] this is the consequence of the difficulty in modeling the rapid turning of the jet. Possibly flow continuity is slightly violated. However, numerical tests had shown that the problem is confined to these nodes and does not affect temperature elsewhere.

4. SIMULATION OF FFTF UPPER PLENUM

FFTF upper plenum simulation was performed for the event of a total loss-of-electrical power by the two one-dimensional system codes, IANUS and SSC-L. The simulation involves the coupling of upper plenum with the core region. Differences between the two codes in the thermal-hydraulic modeling of the core region[11] and of the upper plenum region were discussed in Section 2. In SSC-L, there are three flows entering the upper plenum: the core exit flow, the leakage flow and overhead flow of the bypass channel (indicated as 2, 3 and 4, respectively, in Figure 10). The three flows mix in the plenum according to the two-zone model. In IANUS, only the core exit flow and the leakage flow of the bypass channel are represented in its mixing model. Because of the differences of the in-vessel modeling,[11] the predicted temperatures of the core exit flow and leakage flow by the two codes are slightly different as illustrated in Figure 10. However, agreement between the two computed outlet temperatures (curve 1) is still good and both exhibit a small variation with time. Apparently, the large amount of sodium stored in the upper plenum reduces the temperature variations of the core flow and the leakage flow. Comparison of curves 1 and 2 reveals that the core exit temperature is less than the mean temperature of the upper plenum between 3 and 50 seconds. Stratification caused by negative buoyancy can only occur during this period. Figure 11 shows the computed penetration height by SSC-L. It is seen that stratification occurs only between 19 $\sim$ 45 seconds and the minimum mixing volume is about 63%. Thus, according to the present analysis, for the event of loss-of-total electrical power, severe stratification does not occur in the upper plenum of FFTF.

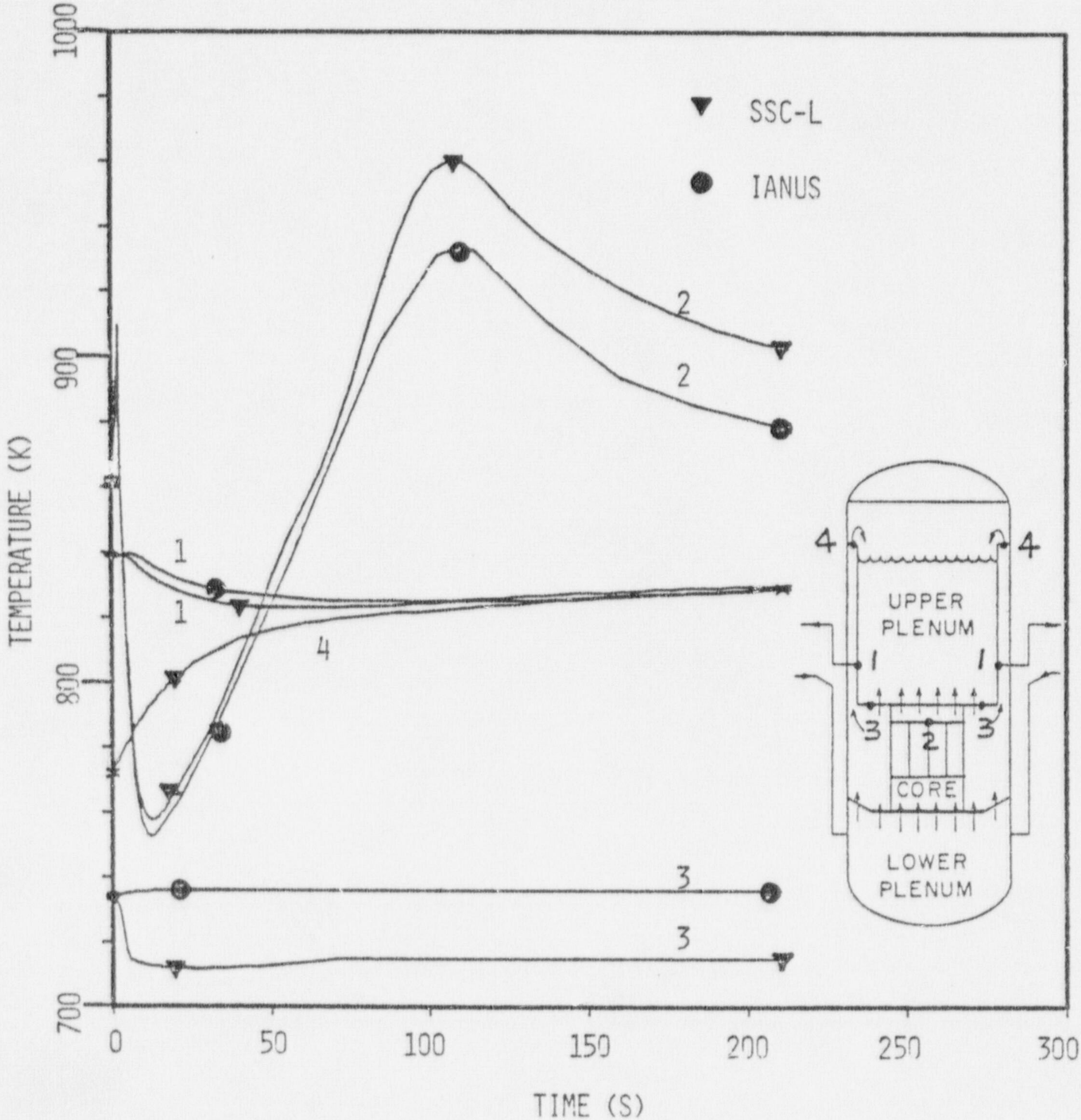


Figure 10: Comparison of SSC-L and IANUS Predictions of Outlet Plenum Temperatures.

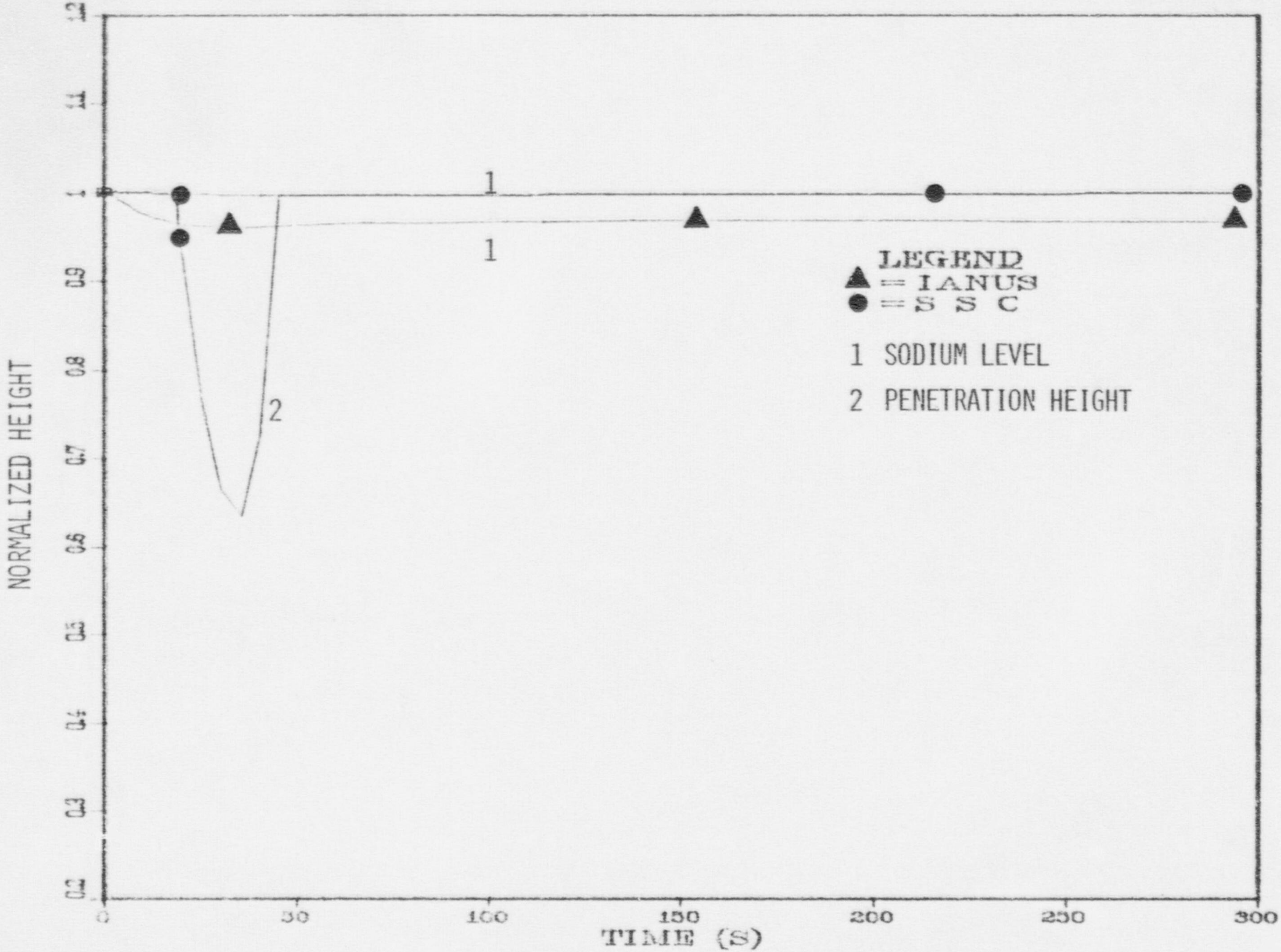


Figure 11: Comparison of SSC-L and IANUS Predictions of Sodium Level and Penetration Height.

F[illegible] 11 also includes the computed sodium level from both SSC-L and IA[illegible] there is no net mass flow in the plenum, the sodium level is onl[illegible] the thermal expansion effect. For the small change of sodium tem[illegible] igure 10), SSC-L predicts a nearly constant sodium level [illegible] negligible effect of thermal expansion. However, a decrease [illegible] out $3 \sim 4$ percent of sodium level is predicted by IANUS.

Finally, other calculated parameters in the SSC-L model are given in Figure 12 for reference. These are temperatures of sodium in the two mixing zones, temperatures of three sections of metal (internal structure, thermal liner and vessel head), and the temperature of cover gas. All temperatures are determined simultaneously by the model. Since IANUS does not compute these temperatures, no comparison could be made.

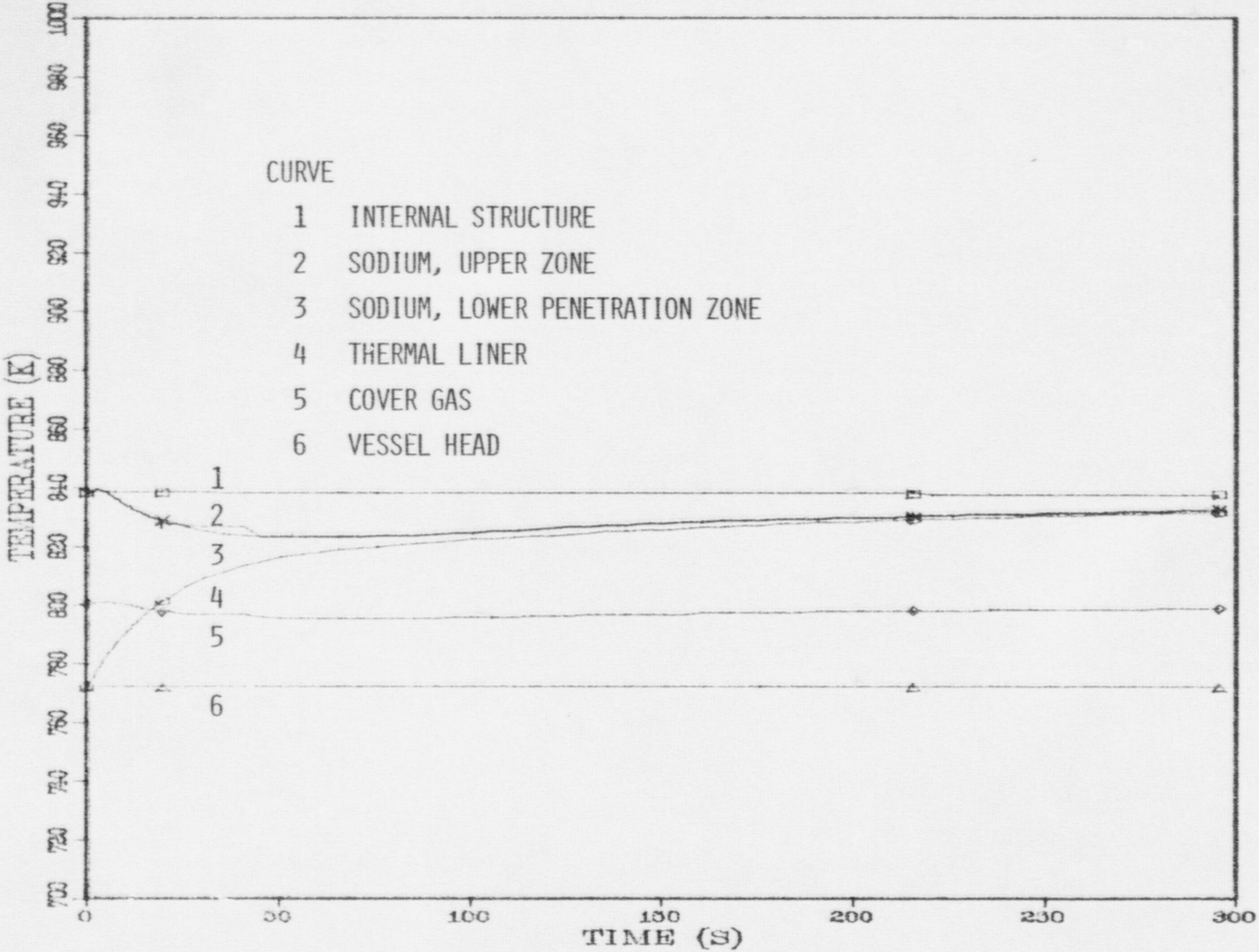


Figure 12: SSC-L Predictions of Transient Temperatures in Upper Plenum for the Event of Loss-of-Total-Electrical Power

5. CONCLUSIONS AND SUMMARY

Comparisons of the SSC-L, MIX and ANL test results give the following indications:

(1) The jet penetration model of SSC-L is adequate on predicting the effective mixing volume.

(2) The effect of transport delay on outlet temperature is not taken into account by the one-dimensional codes.

(3) There is a large axial variation of temperature at the outlet nozzle which may cause flow stratification in pipes of the primary loop; this situation is not indicated by the one-dimensional codes.

Predictions from SSC-L and IANUS were compared for the event of loss-of-total-electrical power. For this test case, no severe stratification occurs in the FFTF upper plenum and the predicted outlet temperatures from the two codes agree very well, despite the differences of modeling.

Based on this preliminary study, the following recommendations are made:

(1) The one-dimensional system code (SSC-L) should be modified to encounter the transport delay in the upper plenum.

(2) The temperature variation at the opening of the outlet nozzle may cause flow stratification in the heat transport piping system. The impact of this variation on the overall transient performance should be investigated.

(3) More comparisons between SSC-L and IANUS for transients with severe stratification should be performed.

ACKNOWLEDGEMENTS

I would like to thank Drs. J. J. Lorenz, P. A. Howard and J. J. Carbajo of Argonne National Laboratory for making their MIX code and test results available to us. I would also like to thank Drs. R. J. Cerbone and D. Majumdar for their valuable comments and Ms. L. Zaharatos for typing the manuscript.

REFERENCES

1. P. J. Wood, "FFTF Outlet Plenum Flow Stratification Summary," Westinghouse Advanced Reactors Division, FRT-1713 (June 30, 1975).

2. J. W. Yang, "An Analysis of Transient Thermal Response in the Outlet Plenum of an LMFBR," Brookhaven National Laboratory, BNL-NUREG-50521 (June 1976).

3. J. W. Yang, "Penetration of a Turbulent Jet with Negative Buoyancy into the Upper Plenum of an LMFBR," Nucl. Eng. Des. 40, 297 (1977).

4. C. F. Wolfe, "IANUS -- Application Information," WARD-FPC-1253 (Proprietary), Rev. 1 (May 1976).

5. S. L. Additon, T. B. McCall and C. F. Wolfe, "Simulation of the Overall FFTF Plant Performance," Hanford Engineering Development Laboratory, HEDL-TC-556 (March 1976).

6. J. L. Cook and P. I. Nakayama, "VARR-II. A Computer Program for Calculating Time Dependent Turbulent Fluid Flows with Slight Density Variation," WARD-D-0106 (July 1975).

7. Y. B. Chen and M. W. Golay, "Validation of Turbulent Models for LMFBR Outlet Plenum Flows," ASME Paper 77-HT-34 (1977).

8. J. J. Lorenz, "MIX -- A Computer Code for Transient Thermal-Hydraulic Analysis of LMFBR Outlet Plenums," Argonne National Laboratory, ANL-CT-75-41 (May 1975).

9. J. J. Lorenz et al., "FFTF Upper Plenum Mixing Studies," Argonne National Laboratory, ANL-CT-75-45 (June 1975).

10. P. A. Howard and J. J. Carbajo, "Plenum-2: A Two-Region Outlet Plenum Model," Argonne National Laboratory, ANL-CT-78-16 (March 1978).

11. J. W. Yang, D. Majumdar and H. Ludewig, "Comparative Studies of LMFBR System Codes, Part 1: FFTF In-Vessel Coolant Dynamics and Fuel Heat Transfer," Brookhaven National Laboratory, BNL-NUREG-24452 (June 1978).

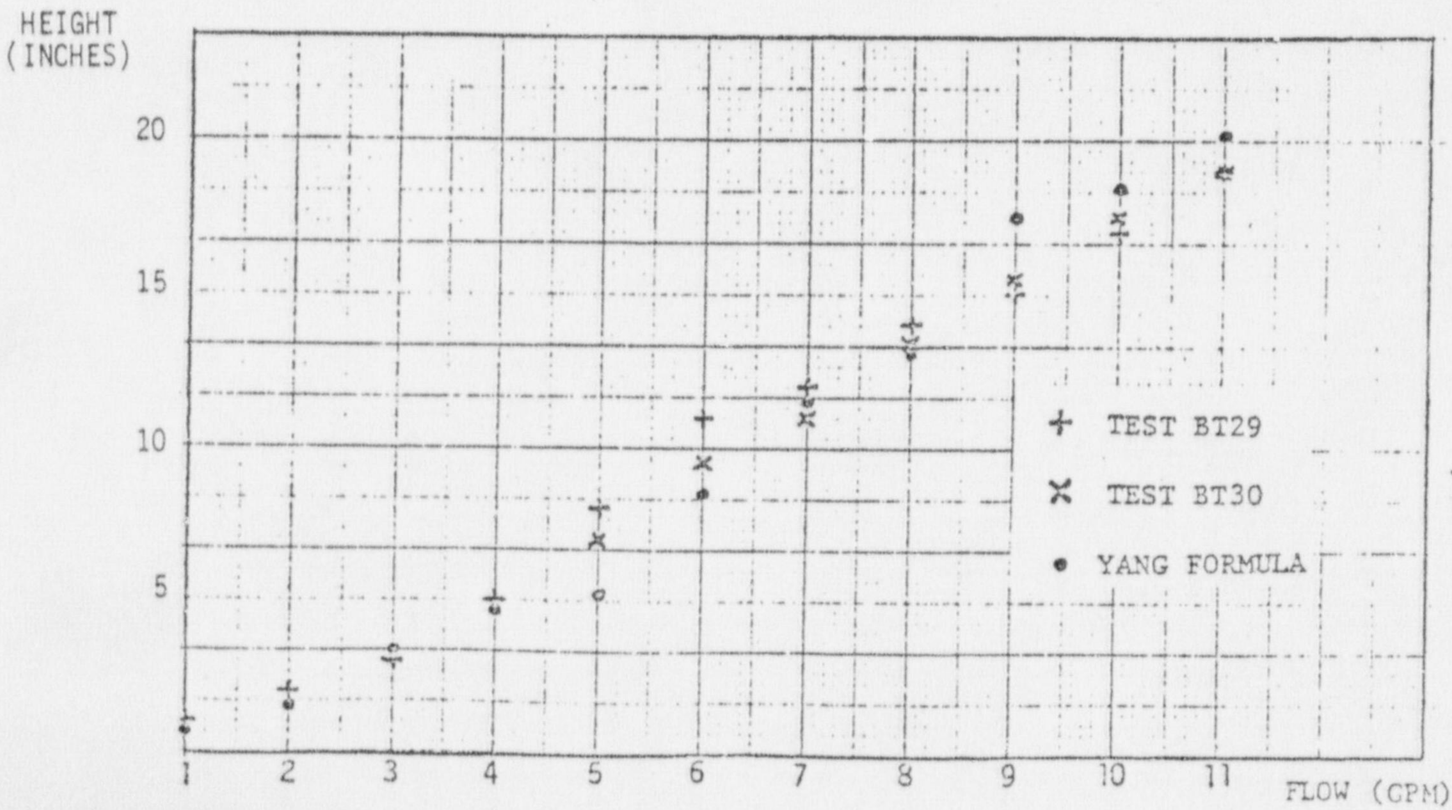
APPENDIX

EXPERIMENTAL VERIFICATION OF THE CORRELATION OF JET PENETRATION BY ANL

Howard and Carbajo have conducted an experimental study of the transient behavior in a generalized outlet plenum model. Different conditions of flow rate, temperature and geometries were used in the study. Two of their tests were conducted where the only purpose was to estimate the height of the penetrating jet. Experimental values were compared with correlations available in the literature and good agreement was found with BNL's correlation. Hence, BNL correlation was used in their new PLENUM-2 code and is considered verified by these experimental tests. Since this is an independent verification of the SSC-L model, ANL's test results and comparisons are included for reference.

Table A-1: Comparison Between Plume Heights Calculated by Yang Formula and Experimental Values.

FLOW (GPM)	FLOW $m^3/sec \times 10^{-3}$	EXPERIMENTAL Z (inches) BT29	EXPERIMENTAL Z (inches) BT30	For BT29 Calculated Z (inches) YANG
1	.063	1		.60
2	.126	2		1.52
3	.189	3		3.16
4	.252	5		4.80
5	.315	8	7	5.06
6	.378	11	9.5	8.58
7	.441	12	11.0	11.80
8	.505	14	13.5	13.12
9	.568	15	15.5	17.5
10	.631	17	17.5	18.40
11	.694	19	19.0	20.12



REPORT DISTRIBUTION

Mr. Harry Alter, Chief (1)
Safety Analysis Branch
Division of Reactor Development
and Demonstration
U.S. Department of Energy
Washington, D. C. 20545

Mr. Rene Audette (1)
Division of Systems Safety
U.S. Nuclear Regulatory Commission
Washington, D. C. 20555

Dr. Robert Avery, Director (1)
Reactor Analysis and Safety Division
Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

Mr. Demetrios L. Basdekas (1)
Experimental Fast Reactor Safety
Research Branch
Division of Reactor Safety Research
U.S. Nuclear Regulatory Commission
Washington, D. C. 20555

Central Mail & Files (1)
U.S. Nuclear Regulatory Commission
Public Document Room
Washington, D. C. 20555

Dr. R. Curtis, Chief (1)
Analytical Advanced Reactor
Safety Research Branch
Division of Reactor Safety Research
U.S. Nuclear Regulatory Commission
Washington, D. C. 20555

Dr. Carl A. Erdman (1)
Department of Nuclear Engineering
University of Virginia, Thornton Hall
Charlottesville, Virginia 22901

Mr. William P. Gammill, Assistant Director (1)
for Standardization and Advanced Reactors
Division of Project Management
U.S. Nuclear Regulatory Commission
Washington, D. C. 2,,55

Dr. R. Ferguson, Director (1)
Fast Flux Test Facility Project Office
U.S. Department of Energy
P.O. Box 550
Richland, Washington, 99352

Dr. Harry Hummel (1)
Applied Physics Division
Argonne National Laboratory
Building 208
9700 South Cass Avenue
Argonne, Illinois 60439

Dr. William Kastenberg (1)
Department of Chemical, Nuclear
and Thermal Engineering
University of California
at Los Angeles
Los Angeles, California 90024

Dr. C. N. Kelber, Assistant Director (2)
for Advanced Reactor Safety Research
Division of Reactor Safety Research
U.S. Nuclear Regulatory Commission
Washington, D. C. 20555

Dr. James F. Meyer (1)
Advanced Reactors Branch
Division of Project Management
U.S. Nuclear Regulatory Commission
Washington, D. C. 20555

Dr. David Okrent (1)
Department of Chemical, Nuclear
and Thermal Engineering
University of California
at Los Angeles
Los Angeles, California 90024

Dr. P. D. O'Reilly (1)
Advanced Reactors Branch
Division of Project Management
U.S. Nuclear Regulatory Commission
Washington, D. C. 20555

Dr. Peter F. Riehm (1)
Advanced Reactors Branch
Division of Project Management
U.S. Nuclear Regulatory Commission
Washington, D. C. 20555

Secretary, Advisory Committee on
Reactor Safeguards
U.S. Nuclear Regulatory Commission
Washington, D. C. 20555 (5)

Dr. Arkal S. Shenoy, Manager
Systems & Safety Analysis Branch
Gas Cooled Fast Breeder Reactor
General Atomic Company
P.O. Box 81608
San Diego, California 92138 (1)

Mr. Brian Sheron
Division of Systems Safety
U.S. Nuclear Regulatory Commission
Washington, D. C. 20555 (1)

Mr. M. Silberberg, Chief
Experimental Fast Reactor
Safety Research Branch
Division of Reactor Safety Research
U.S. Nuclear Regulatory Commission
Washington, D. C. 20555 (1)

Dr. Themis P. Speis, Chief
Advanced Reactors Branch
Division of Project Management
U.S. Nuclear Regulatory Commission
Washington, D. C. 20555 (1)

Dr. Michael Stevenson
Los Alamos Scientific Laboratory
P.O. Box 1663
Los Alamos, New Mexico 97545 (1)

Technical Information Center
U.S. Nuclear Regulatory Commission
P.O. Box 62
Oak Ridge, Tennessee 37830 (1)

Dr. Theo G. Theofanous
132 Pathway Lane
Lafayette, Indiana 47906 (1)

Mr. Phillip M. Wood
Analytical Advanced Reactor
Safety Research Branch
Division of Reactor Safety Research
U.S. Nuclear Regulatory Commission
Washington, D. C. 20555 (1)

BNL DISTRIBUTION

DNE Chairman	(1)
RSP Associate Chairman	(1)
RSP Division Heads & Group Leaders	(18)
E & ARS Division	(12)
RSP Library	(2)