TEST PREDICTION OF THE
SEVENTH SEMISCALE MOD-1 TESTS
STEAM GENERATOR TUBE RUPTURE TESTS
TEST S-28-3

SEMISCALE PROGRAM

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STEAM GENERATOR TUBE RUPTURE TESTS

TEST S-28-3

by

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SEMISCALE PROGRAM

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SUMMARY

This document contains a pretest prediction of the Semiscale Mod-1 system thermal-hydraulic response for Test S-28-3. Test S-28-3 will be the third integral blowdown reflood test to be performed in the steam generator tube rupture test series. The primary objectives of this test are to aid in defining the core temperature response for small numbers of steam generator tube ruptures and to probe into the range of steam generator tube ruptures indicated by the analysis used in the specification of Test Series 28 to result in high peak cladding temperatures.

The initial conditions for Test S-28-3 will be as specified in Appendix 28 of the Semiscale Experimental Operating Specification (EOS)[1]. Injection from an accumulator into the intact loop hot leg just upstream of the steam generator inlet plenum will begin at 40 seconds after rupture to simulate the steam generator tube ruptures. The test will be run with an injection rate of 0.104 kg/s to simulate the rupture of approximately 12 steam generator tubes.

The break configuration will represent a full size (200%) double-ended offset shear cold leg break. The test will be initiated at an initial core power of 1.44 MW (with 36 powered rods) and the ANS power decay curve will be used during the reflood portion of the test. Emergency core coolant (ECC) from the intact loop high pressure injection system (HPIS), the accumulator, and the low pressure injection system (LPIS) will be injected into the intact loop cold leg. Accumulator, HPIS, and LPIS injection will also be used in the broken loop pump simulator discharge. The pressure suppression system pressure will be maintained at about 241 kPa during the blowdown and the reflood portions of the test.

The predictions for Test S-28-3 were developed from Test S-04-6 test data (the baseline test) and from calculations performed with the FLOOD4 computer code. The system response during the first 40 seconds of Test S-28-3 is expected to be the same as the system response in Test S-04-6. Also, the results of a study completed as part of the preliminary analysis for EOS Appendix 28 (see Reference 1) indicated the small flow rates used to simulate the rupture of a small number of tubes had little affect on the refill response (40 to 58 seconds). Therefore, Test S-04-6 data is provided to give an indication of the expected system thermal-hydraulic response for the first 58 seconds of Test S-28-3. The FLOOD4 computer code was used to provide predictions for the reflood portion of the transient. Since the heat transfer and entrainment correlations used in the FLOOD4 code have not been extensively tested against data, the prediction is expected to follow the trends of the data, but may not exactly calculate the oscillating flows and the rod temperatures. Also, the calculation of quench times is strongly dependent on the rod temperature distribution and system pressure at the initiation of reflood. Small differences in these parameters can significantly affect the reflood calculations. In addition, the FLOOD4 code does not account for downcomer wall heat transfer during the reflood transient. Previous test data indicates that liquid depletion in the downcomer, which is due to downcomer wall heat transfer, can also significantly affect the core response during reflood.

Since the initial conditions for Test S-28-3 and Test S-04-6 are the same and the tube rupture flow rate is small, the system response should be essentially the same in these two tests until 58 seconds after rupture. The temperature at the peak power location should be about 1011 K when reflood from the bottom begins. However, data from previous

tests in Series 28 have shown that some of the rods may quench during blowdown. If quenching during blowdown does occur in Test S-28-3, lower cladding temperatures in the core may occur during reflood than were predicted because the temperatures at the start of refill would be lower. Test S-04-6 data indicates the system pressure should reach 241 kPa (containment pressure) by 40 seconds. Fluid saturation conditions at 6 MPa and 549 K should be present in the steam generator secondary at 40 seconds.

Reflood of the core is expected to start at approximately 58 seconds after rupture. The peak temperature during reflood is expected to reach 1158 K before temperature turnover occurs. When the FLOOD4 calculation ended at 600 seconds after the beginning of reflood, the core hot spot had not yet quenched. The temperature at the hot spot had declined to 1055 K at this time. This delay in the quenching of the core is thought to be due to steam binding in the intact loop and upper plenum. The steam binding in the loop and upper plenum tends to retard the core reflood rate and hence causes poor heat transfer. The calculation was not continued beyond this point because the experimental data systems cannot record beyond this point in time (658 seconds after rupture) without compromising the quality of the data.

I. INTRODUCTION

This report contains the predictions of the Semiscale Mod-1 system thermal-hydraulic response for Test S-28-3 which will be the third integral blowdown-reflood test in the steam generator tube rupture test series. The report identifies the prerupture system conditions and presents the expected behavior of key variables with particular emphasis placed on the predicted response of the electrically-heated core. Test S-04-6 data[2] (the baseline test for Test S-28-3) was used to indicate the expected system blowdown and refill response, since the response in Test S-28-3 should be the same during these periods. The FLOOD4[3] model used to predict the system reflood response is described.

The test conditions for Test S-28-3 are identical to those of the baseline Test S-04-6 except for the introduction of accumulator injection into the intact loop hot leg just upstream of the steam generator inlet plenum to simulate the steam generator tube ruptures. The test will be run with an injection rate of 0.104 kg/s to simulate the rupture of approximately 12 steam generator tubes. The change in heat transfer potential of the steam generator will be simulated by discharging the steam generator secondary fluid during the simulated tube rupture period. The water in the accumulator will be near saturation conditions at 547 K (approximately the average temperature of the pressurized water reactor (PWR) steam generator secondary fluid at rated load) and 5.9 MPa. The total volume of water injected to simulate the tube rupture flow is 0.144 m^3, which is core area scaled from three PWR steam generators at rated load. The injection will begin at 40 seconds after the cold leg break to simulate the steam generator tube ruptures. During steam generator liquid injection, the accumulator pressure will be maintained by a nitrogen supply. The injection will be terminated before the accumulator

water is completely exhausted to prevent nitrogen injection into the primary system. The initiation of the tube ruptures at 40 seconds was selected (although the analysis indicated no dependency on time of steam generator tube rupture for small numbers of tubes) because preliminary analysis (see Reference 1) showed that when a large number of tube ruptures (50 to 125) occurred at this time the highest peak cladding temperatures occurred (see Figure 1). The initiation of tube ruptures at 40 seconds for Test S-28-3, which will simulate the rupture of approximately 12 steam generator tubes, was not changed in order to maintain consistency with the other tests.

Emergency core coolant (ECC) for Test S-28-3 will be injected into the intact loop cold leg and broken loop pump simulator discharge. The Mod-1 ECC systems in operation in both loops will include the accumulator injection system (AIS), the high pressure injection system (HPIS), and the low pressure injection system (LPIS).

The operating conditions for Test S-28-3 are summarized in Table I. The test will be conducted at an initial core power of 1.44 MW and an initial flow rate of 9.5×10^{-3} m^3/s. The radial core power profile will be peaked for this test. The three high power rods will have a peak power density of 39.7 kW/m and the other 33 low power rods will have a peak power density of 37.7 kW/m. Four rods will be unpowered with their locations chosen to give the same core configuration as in Test S-04-6. The fluid temperature at the core inlet will be 558 K and the core outlet fluid temperature will be 594 K. The axial power profile will be skewed toward the bottom of the heated core as shown in Figure 2. The power decay will follow the electrical power decay curve shown in

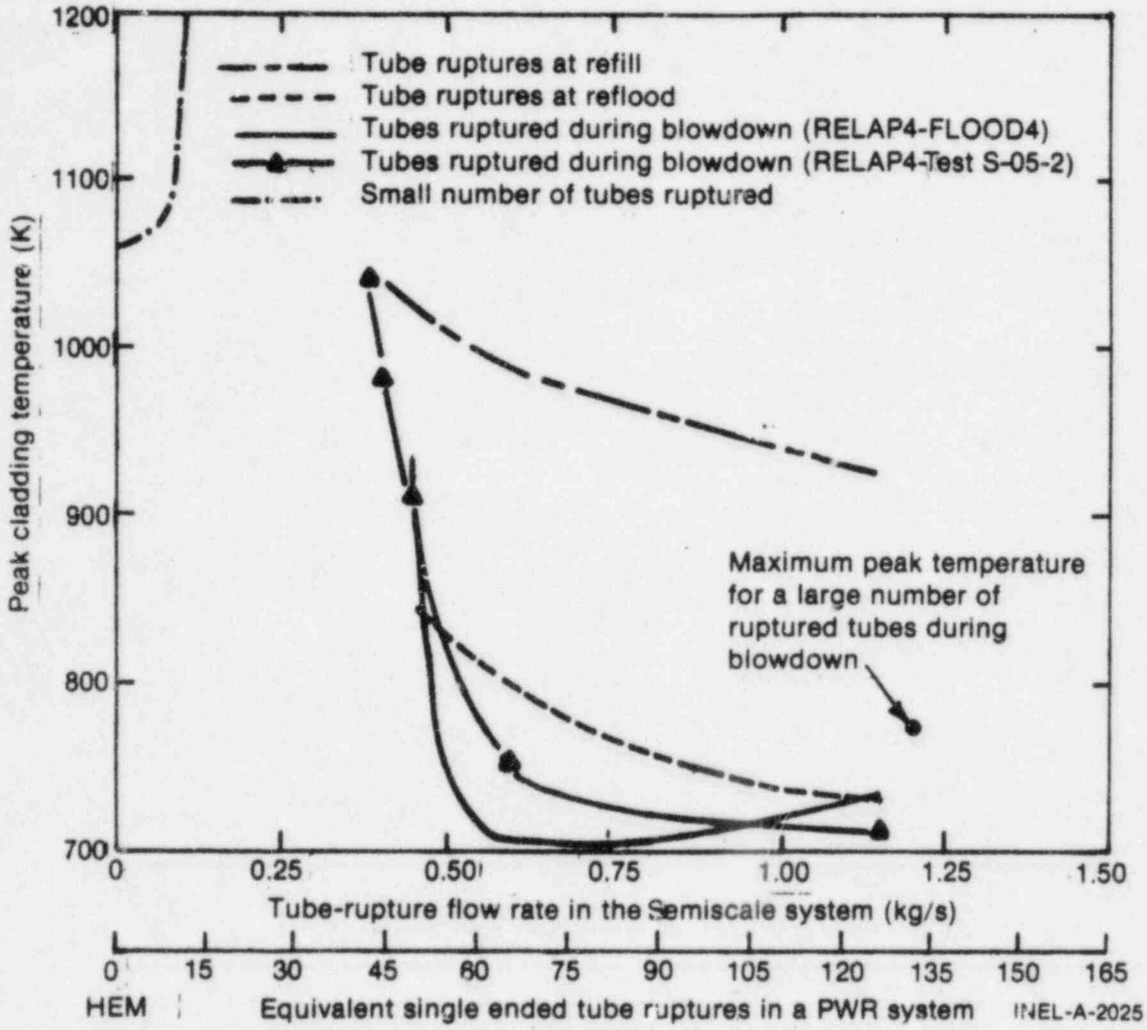

Figure 1. The Influence of the Tube Rupture Flow Rate or the Number of Ruptured Tubes on the Peak Cladding Temperature

Table I

Test S-28-3 Description and Initial Conditions

Parameter	Initial Value
Break Size	200%[a]
Break Type	Cold Leg
Intact Loop Resistance	Low[b]
Nominal Initial System Pressure	15.5 MPa
Hot Leg Fluid Temperature	594 K
Cold Leg Fluid Temperature	558 K
Core Temperature Difference	36 K
Core Power	1.44 MW
Core Initial Inlet Flow Rate	7.1 kg/s
Power Decay	Figure 3
Pump Speed Control	Allowed to coast down to approximately 61% of initial rpm, then maintain at 61% of initial rpm.
ECC Injection	
Accumulator	
Location	Intact Loop Cold Leg
Actuation Pressure	4.1 MPa
Liquid Volume	0.08 m^3
Gas Volume	0.053 m^3
Line Resistance	659 $\frac{MPa\ sec^2}{kg\ m^3}$
Injection Rate	$1.45 \times 10^{-3}\ m^3/s$
Nitrogen Valve	Open for 24 seconds after accumulator empty of water

Table I (contd)

Test S-28-3 Description and Initial Conditions

Parameter	Initial Value
HPIS	
Location	Intact Cold Leg
Actuation Pressure	12.4 MPa
Injection Rate	1.96×10^{-5} m^3/s
LPIS	
Location	Intact Cold Leg
Actuation Pressure	1.03 MPa
Injection Rate	2.52×10^{-4} m^3/s
Tube Rupture Simulator	
Steam Generator Accumulator	
Location	Just Upstream From The Intact Loop Steam Generator Inlet Plenum
Actuation Time	40.0 Seconds
Closure Time	Open during remainder of test
Liquid Volume	0.144 m^3
Gas Volume	4.8×10^{-2} m^3
Temperature	547 K
Injection Rate	1.37×10^{-4} m^3/s

(a) 200% break refers to a simulated double-ended offset shear break in the broken loop with each break nozzle having an area of 0.000243 m^2. The 200% break has a break area-to-system volume ratio equivalent to that ratio for a double-ended offset shear break in the cold leg of one loop of a four-loop pressurized water reactor.

(b) Low system resistance refers to the size of orifices located at the inlet and outlet of the intact loop steam generator. The low system resistance orifices have an approximate 4.06 cm diameter hole. The total system resistance with the low resistance orifices is properly scaled to the LOFT system.

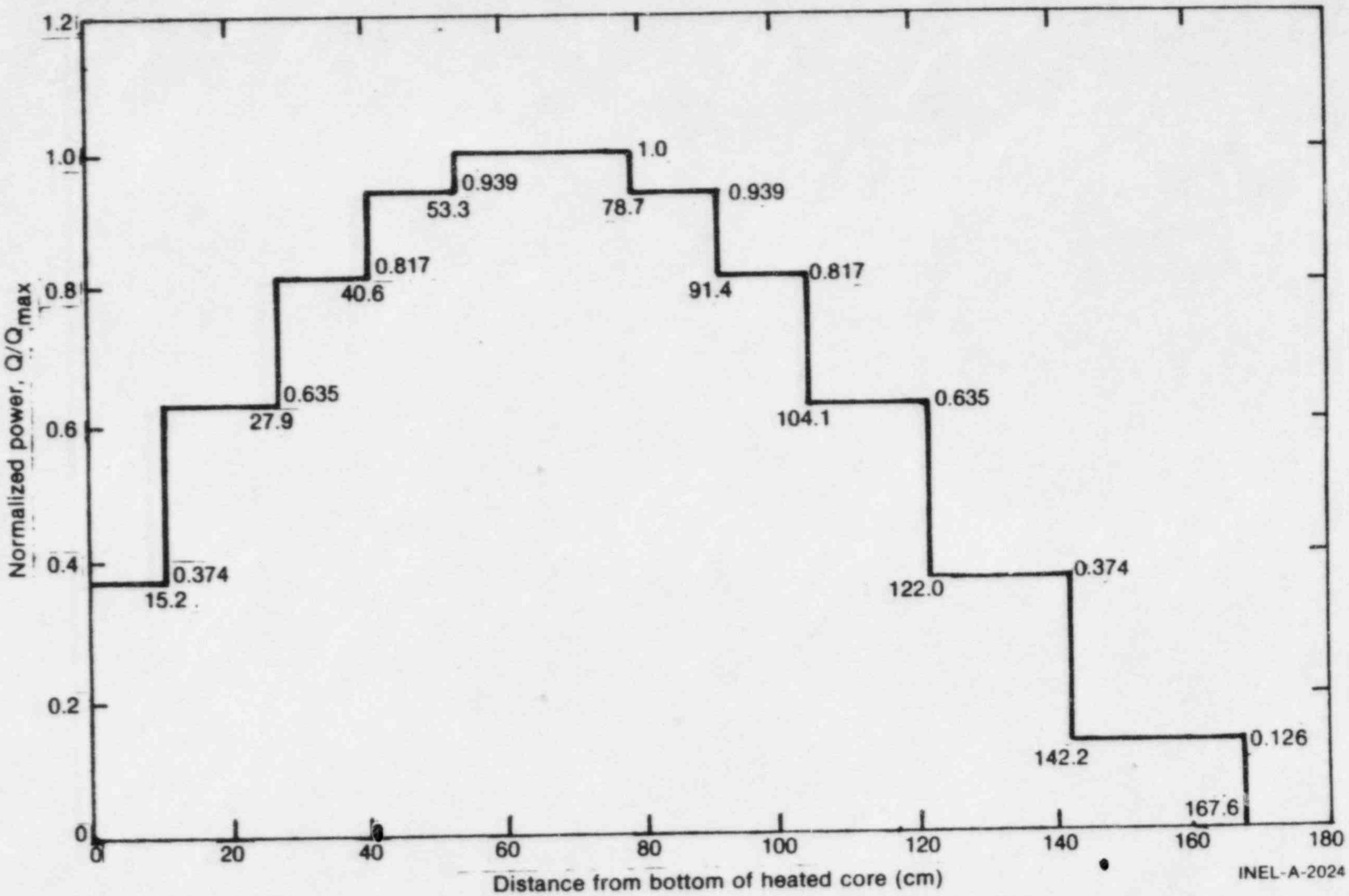

Figure 2. Normalized Axial Power Profile for Test S-28-3

Figure 3. The pressure suppression system for Test S-28-3 will be controlled to maintain a containment pressure of 241 kPa throughout the blowdown and the reflood portions of the test.

Section II of this report presents a brief description of the analysis methods and FLOOD4 model used in these predictions, and the results of the calculations. Section III presents the more significant conclusions arising from the predictions. A more detailed discussion of the FLOOD4 model is included in Appendix A.

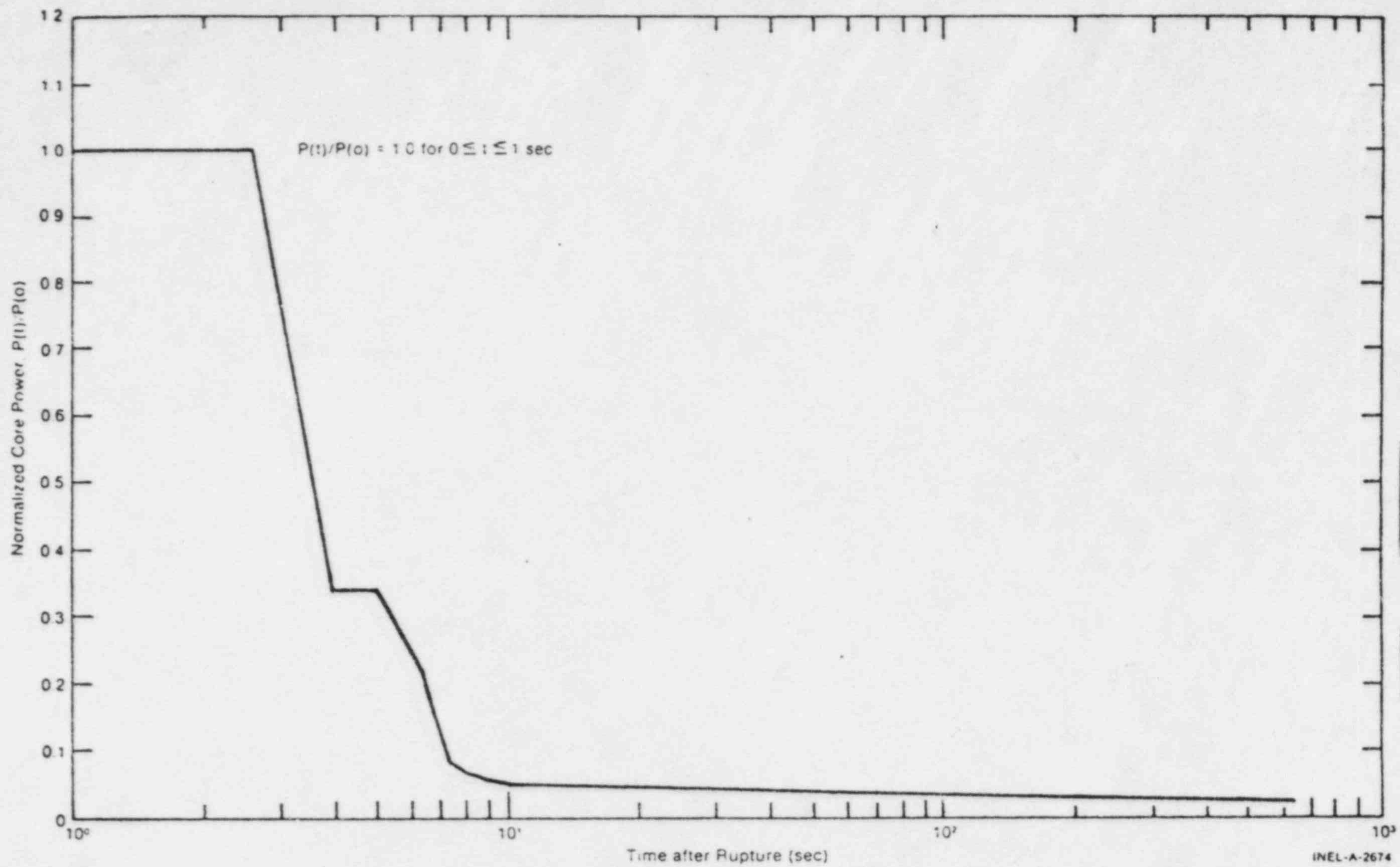

Figure 3. Decay Heat Curve for Test S-28-3

II. PREDICTIONS OF STEAM GENERATOR TUBE RUPTURE TEST S-28-3

1. METHOD OF ANALYSIS

Because of the similarity expected between Tests S-04-6 and S-28-3 during the blowdown (0 to 40 seconds) and refill (40 to 58 seconds) periods, it was decided not to use the analysis methods of previous pretest predictions. These consisted of using RELAP4 to predict the blowdown and refill response and FLOOD4 to predict the reflood response of the system. Instead, it was decided to use the method developed for the scoping analysis described in EOS Appendix 28, Addendum 28-A (see Reference 1). This method is described below.

The blowdown response for Test S-28-3 is expected to be the same as Test S-04-6 because the initial conditions for both tests are the same. Test S-28-3 will differ from Test S-04-6 only in that Test S-28-3 will include accumulator injection into the intact loop hot leg just upstream of the steam generator inlet plenum beginning at 40 seconds after rupture to represent the flow from the ruptured tubes. Thus, the Mod-1 system response during the first 40 seconds of the transient of Test S-28-3 should be the same as the system response in Test S-04-6. Because of the similarity expected between the tests, Test S-04-6 data was used to indicate the expected system thermal-hydraulic response prior to 40 seconds.

The refill response during Test S-28-3 is also expected to be similar to the response recorded during Test S-04-6. This is based on a study completed as part of the preliminary analysis for EOS Appendix 28 (see Reference 1). This study showed the system refill response to be relatively insensitive to the small flow rates used to simulate the rupture of a small number of steam generator tubes. For this reason,

Test S-04-6 data is also used to indicate the expected system response from 40 to 58 seconds after rupture. At 58 seconds, reflood from the bottom began in Test S-04-6.

To determine the system response during reflood, the FLOOD4 code (load module FLOOD4/103[a]) was used in the following manner. The system conditions at the initiation of reflood (58 seconds) were taken from Test S-04-6 data and input into the FLOOD4 code. The initial axial temperature profile was calculated from the peak temperature in the core (1011 K) using a cosine curve fit. The flow from the steam generator secondary was modeled to flow into the upper plenum since this is the same as the hot leg in the FLOOD4 model. The fraction of the mass flow from the steam generator that flashes to steam in the primary system is also required as input for the FLOOD4 model. Based on an isenthalpic calculation for typical conditions, it was calculated that about 30% of the mass from the steam generator would be flashed to steam. This percentage was used in the FLOOD4 calculation. The FLOOD4 code was then used to provide predictions of the system response during the reflood period from 58 to 658 seconds after rupture.

2. FLOOD4 MODEL DESCRIPTION

The FLOOD4/103 computer code was used to predict the reflood portion of the test (58 to 658 seconds after rupture). The FLOOD4 code is a recently developed reflood analysis tool and, therefore, is undergoing

[a] For the purpose of historical configuration control FLOOD4/103 is referenced as program number, HB00121IB.

evaluation and improvement as more test data becomes available. Figure 4 shows the FLOOD4 model of the Semiscale system. A more detailed discussion of the code and a listing of the input to the model is contained in Appendix A.

The flow rate from the ruptured tubes and the fraction of the flow which flashes to steam on entering the primary system are entered in the model as the parameters WTUBE and SFRACT, respectively. The tube rupture flow is assumed in the model to flow into the upper plenum since the model does not allow injection into the hot legs. The part of the flow which flashes to steam and the part which remains liquid are added to the steam and liquid mass in the system. The total steam and liquid mass are then handled by the model in the same manner as the liquid and steam entering the upper plenum from the core. The steam must flow out the break to escape from the system, and the liquid mass is entrained from the upper plenum. Since Test S-04-6 data is used to indicate the system response until the beginning of reflood, no FLOOD4 heat up calculation was required. The initial rod axial temperature profile used at the start of reflood is shown in Figure 5. This temperature profile was calculated using the peak temperature in the core at the beginning of reflood (1011 K) in Test S-04-6 and a cosine curve fit. Table II lists the initial conditions used in the FLOOD4 model at the start of reflood for Test S-28-3. The FLOOD4 calculation for Test S-28-3 provides a prediction of the thermal-hydraulic response for the reflood process over the time period from 58 seconds to 658 seconds following rupture. The calculation was not continued beyond 600 seconds after reflood because the data acquisition system cannot record experimental data beyond this point.

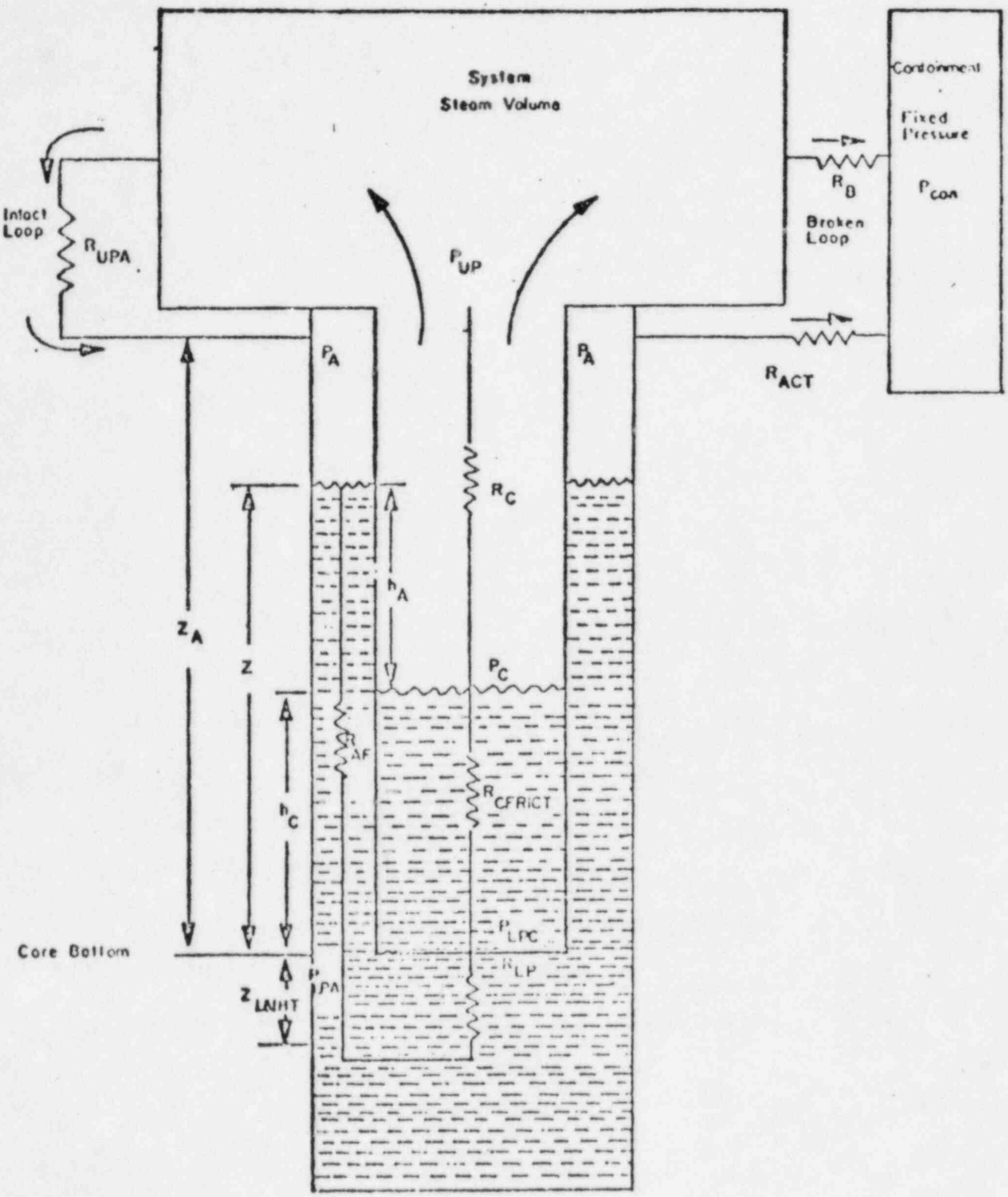

Figure 4. FLOOD4 Model of Semiscale System

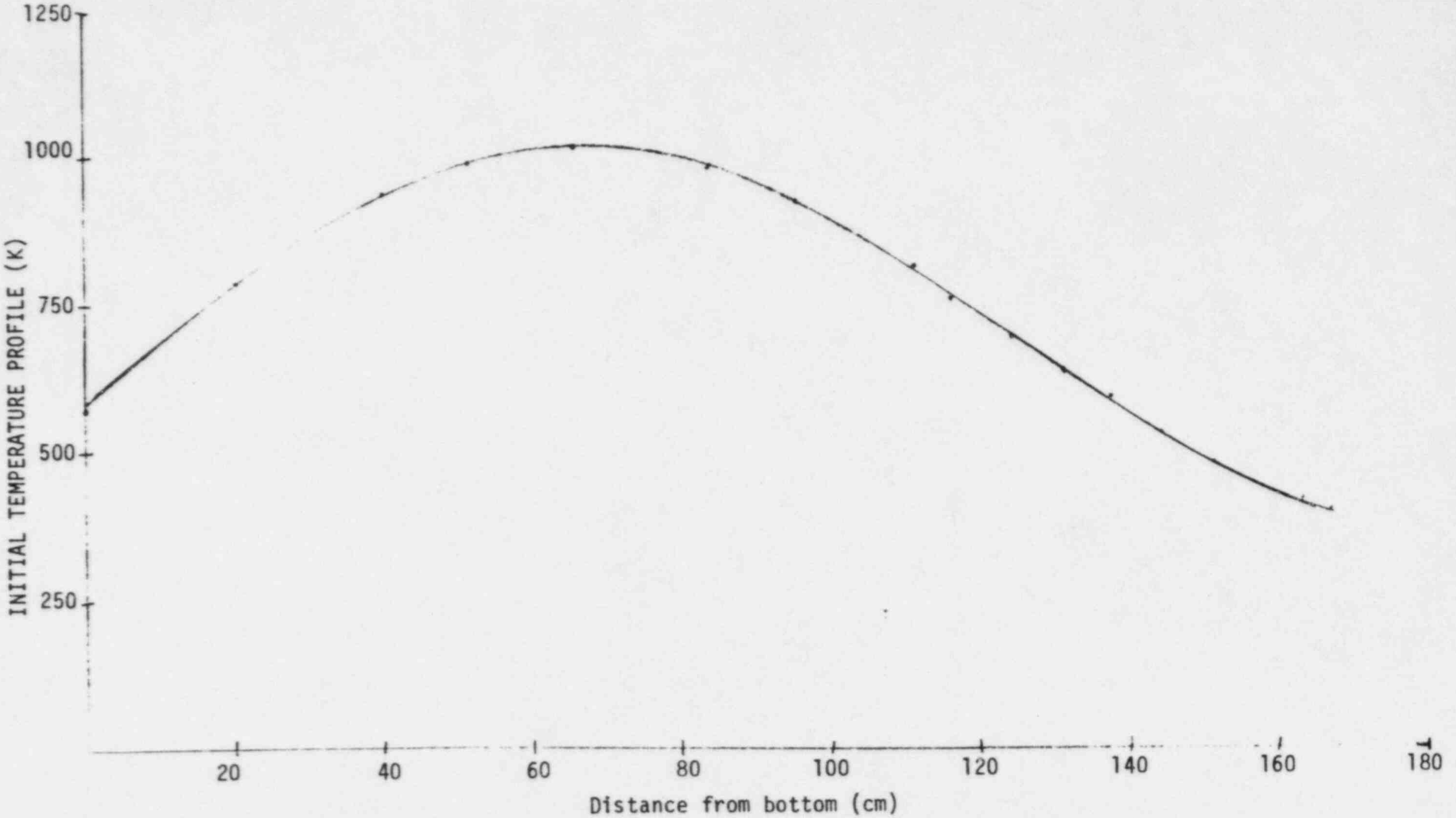

Figure 5. Rod Axial Temperature Profile at Start of Reflood

Table II

Semiscale Mod-1 Initial Conditions At The Start of Reflood for Test S-28-3

Parameter	Initial Value
Containment Pressure	241 KPa
Temperature of ECC	
At Bottom of Heated Length	411 K (saturated)
ECC Injection Rate Cold Leg Intact Loop	
58 Seconds to 70 Seconds	1.72×10^{-3} m^3/s
70 Seconds to Completion	2.72×10^{-4} m^3/s
Peak Rod Power Density	1.39 kW/m
Power Profile	Stepped (Figure 2)
Power Decay	Refer to Figure 3
Peak Initial Rod Temperature	1011 K
Temperature Profile	Refer to Figure 5

3. PREDICTIONS OF THE SEMISCALE MOD-1 SYSTEM RESPONSE

Predicted behavior of key system parameters for Test S-28-2 are presented and discussed in this section.

3.1 Blowdown Response Prior to Steam Generator Tube Rupture and Refill Response

Since the initial conditions for Tests S-04-6 and S-28-3 are the same, the system response in Test S-28-3 should be essentially the same as in Test S-04-6 until steam generator injection into the intact loop between the pressurizer and the steam generator inlet plenum begins at 40 seconds after rupture. Also, the refill response for Test S-28-3 after the tube rupture flow begins is expected to be similar to the refill response in Test S-04-6. This is based on a study made in the analysis completed for EOS Appendix 28 (see Reference 1), which showed the system refill response to be relatively insensitive to the small flow rates used to simulate the rupture of a small number of tubes. Thus Test S-04-6 data is also used to indicate the refill response (40 to 58 seconds) for Test S-28-3. A detailed discussion of the system thermal-hydraulic response in Test S-04-6 is contained in Reference 2 and, therefore, only a brief discussion is included here. Several results from the blowdown and refill period of Test S-04-6 which are of interest in Test S-28-3 are included below.

The peak temperature in the core during the blowdown period of Test S-04-6 occurred on a rod located on the perimeter of the core and reached approximately 1075 K at 8 seconds after rupture. Test data shows this temperature declined to 1011 K at 58 seconds as shown in Figure 6. Test S-04-6 data indicated the system pressure had reached containment pressure (241 kPa) at 40 seconds after rupture (Figure 7).

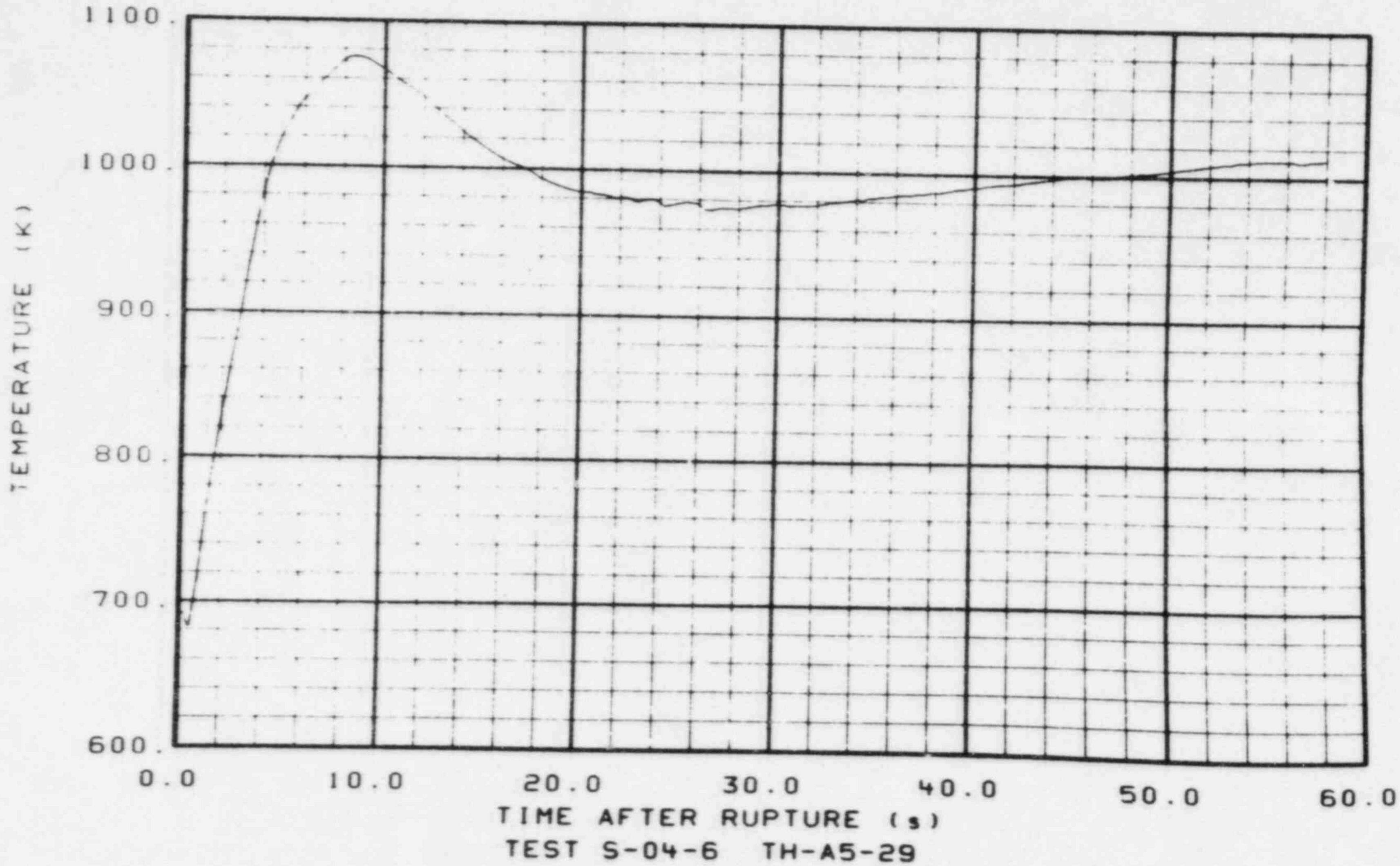

Figure 6. Measured Cladding Temperature Rod A5 (74 cm Elevation) During Blowdown and Refill in Test S-04-6

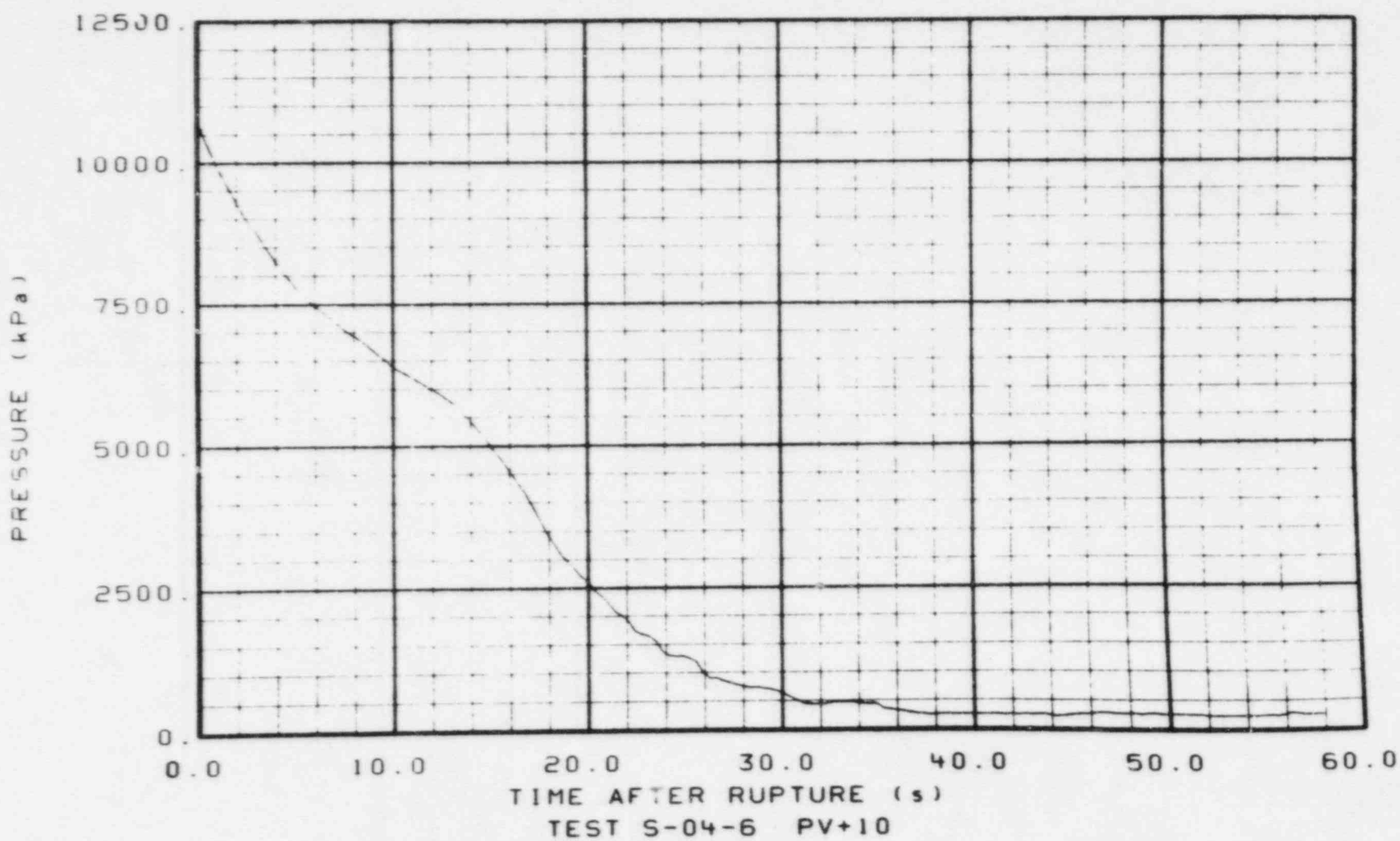

Figure 7. Measured Pressure in the Upper Plenum During Blowdown and Refill in Test S-04-6

The mass flow at the core inlet (see Figure 8) at 58 seconds is oscillatory in nature. The steam generator secondary pressure (Figure 9) at 40 seconds was approximately 6.0 MPa and the secondary fluid temperature (Figure 10) was 549 K (saturation conditions). The fluid density at the core inlet is presented in Figure 11 and shows reflood from the bottom began at 58 seconds after rupture.

3.2 System Response During Reflood

The FLOOD4 code was used to predict the system response during reflood for Test S-28-3. Test S-04-6 data was used to determine the time at which reflood would commence in Test S-28-3. The Test S-04-6 results indicated core reflood in Test S 28-3 would start at approximately 58 seconds. The calculated reflood results presented in this section were done assuming the rod power densities at the time of reflood were reflective of the high power rod power density.

Figure 12 shows that the FLOOD4 calculations predict that the core inlet flow oscillates both positively and negatively as for previous predictions. A comparison of the calculated differential pressure between the upper plenum and the inlet annulus (Figure 13), with the steam flow from the upper plenum (Figure 14), shows that the differential pressure between the upper plenum and the inlet annulus follows the steam generation in the core. The oscillations in the steam flow from the upper plenum are related to the oscillations in the core flow rate shown in Figure 12. A comparison of the data in these figures shows that the amplitude of the steam flow and differential pressures are directly related to the amplitude of the core flow oscillations as expected. The downcomer annulus liquid level shown on Figure 15 also shows oscillations. These

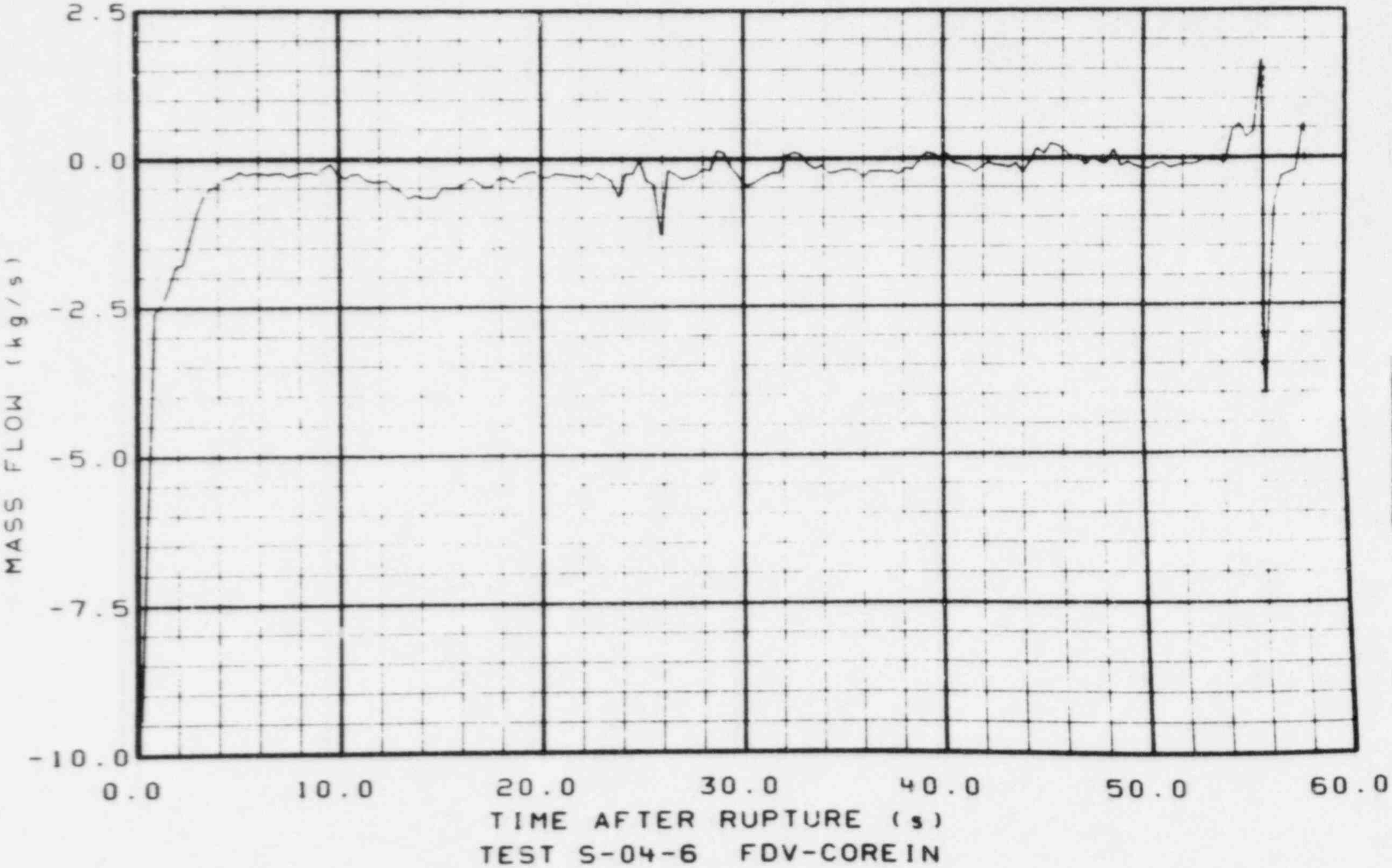

Figure 8. Measured Mass Flow at the Core Inlet During Blowdown and Refill in Test S-04-6

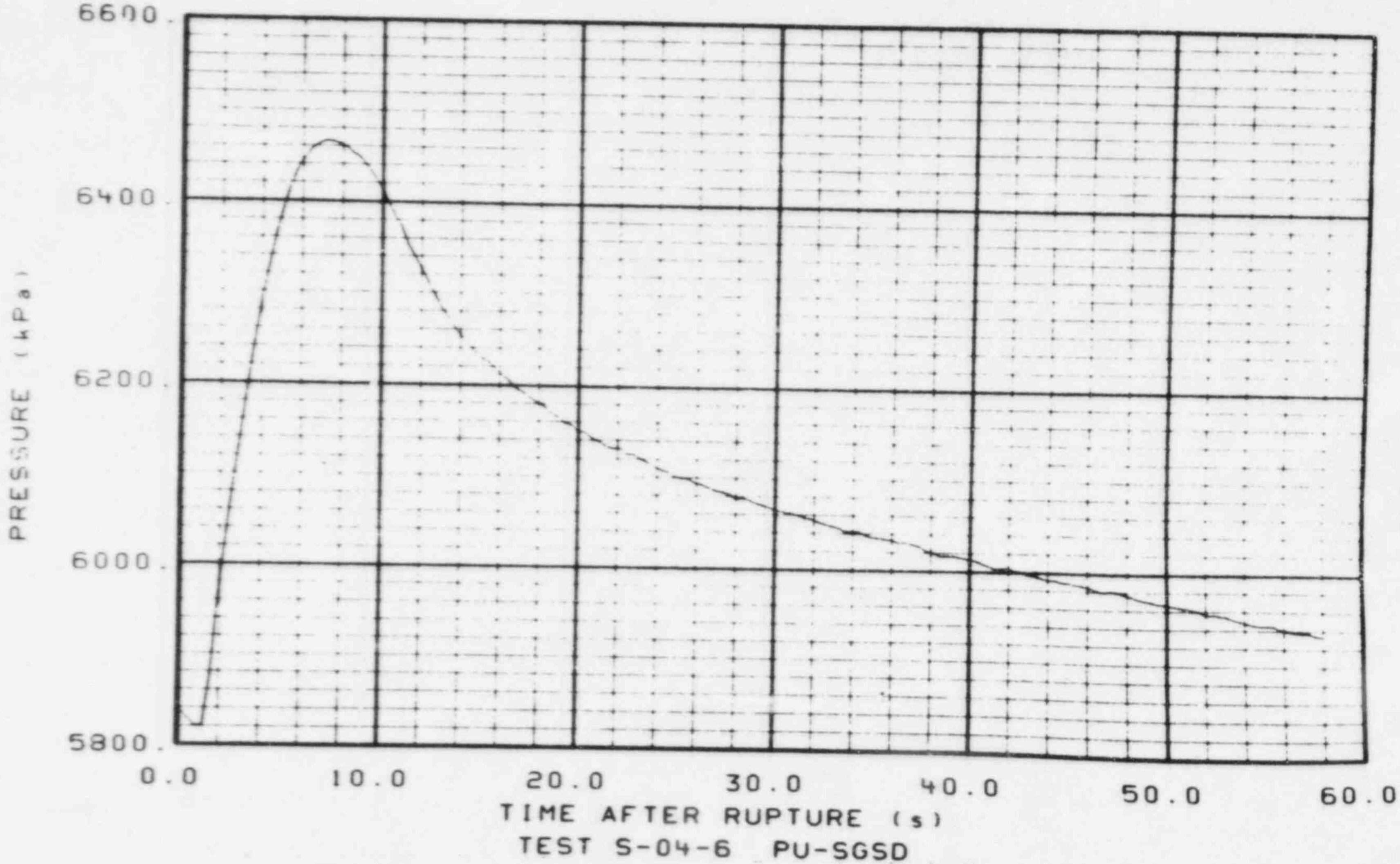

Figure 9. Measured Pressure in the Steam Generator Secondary During Blowdown and Refill in Test S-04-6

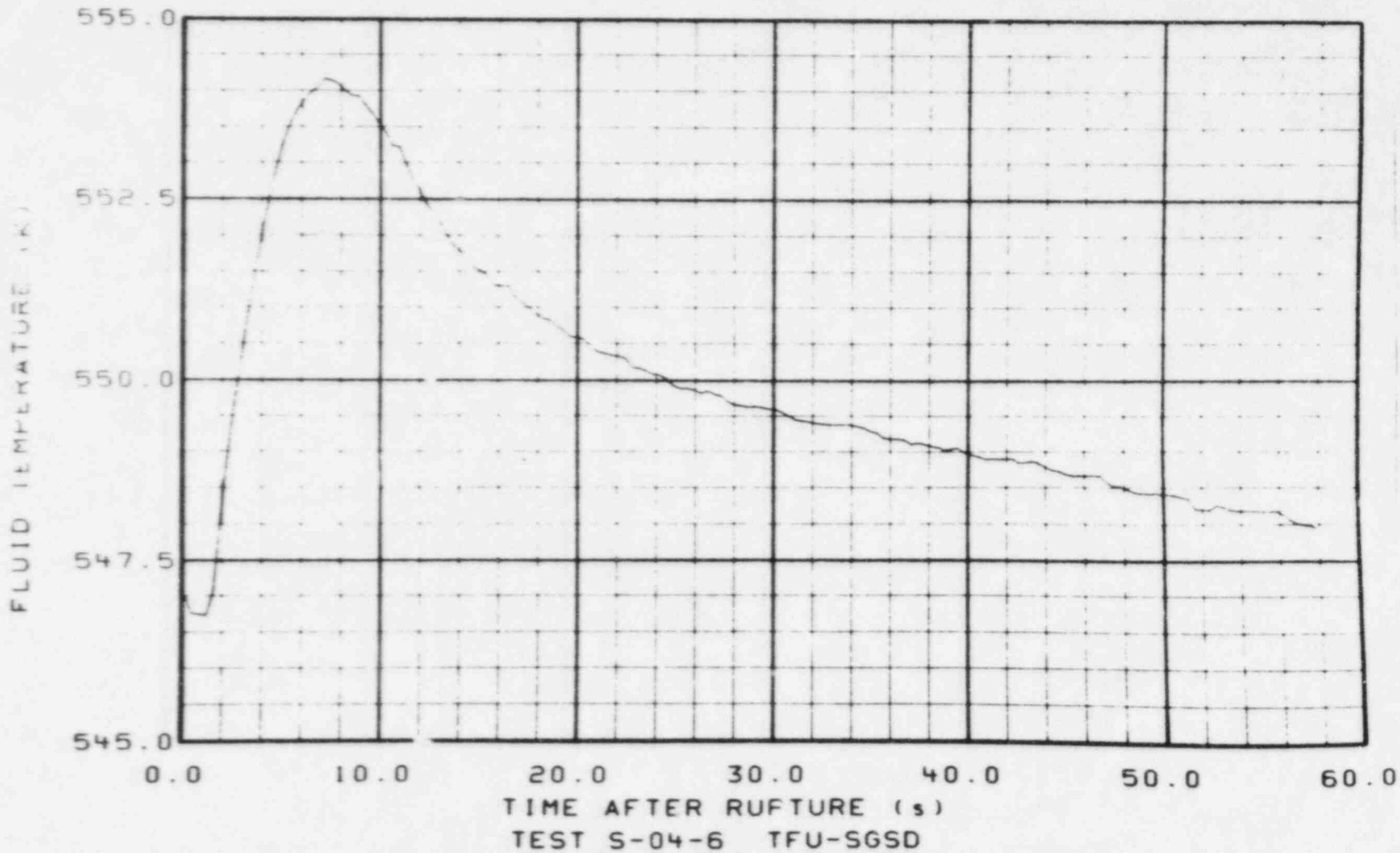

Figure 10. Measured Fluid Temperature in the Steam Generator Secondary During Blowdown and Refill in Test S-04-6

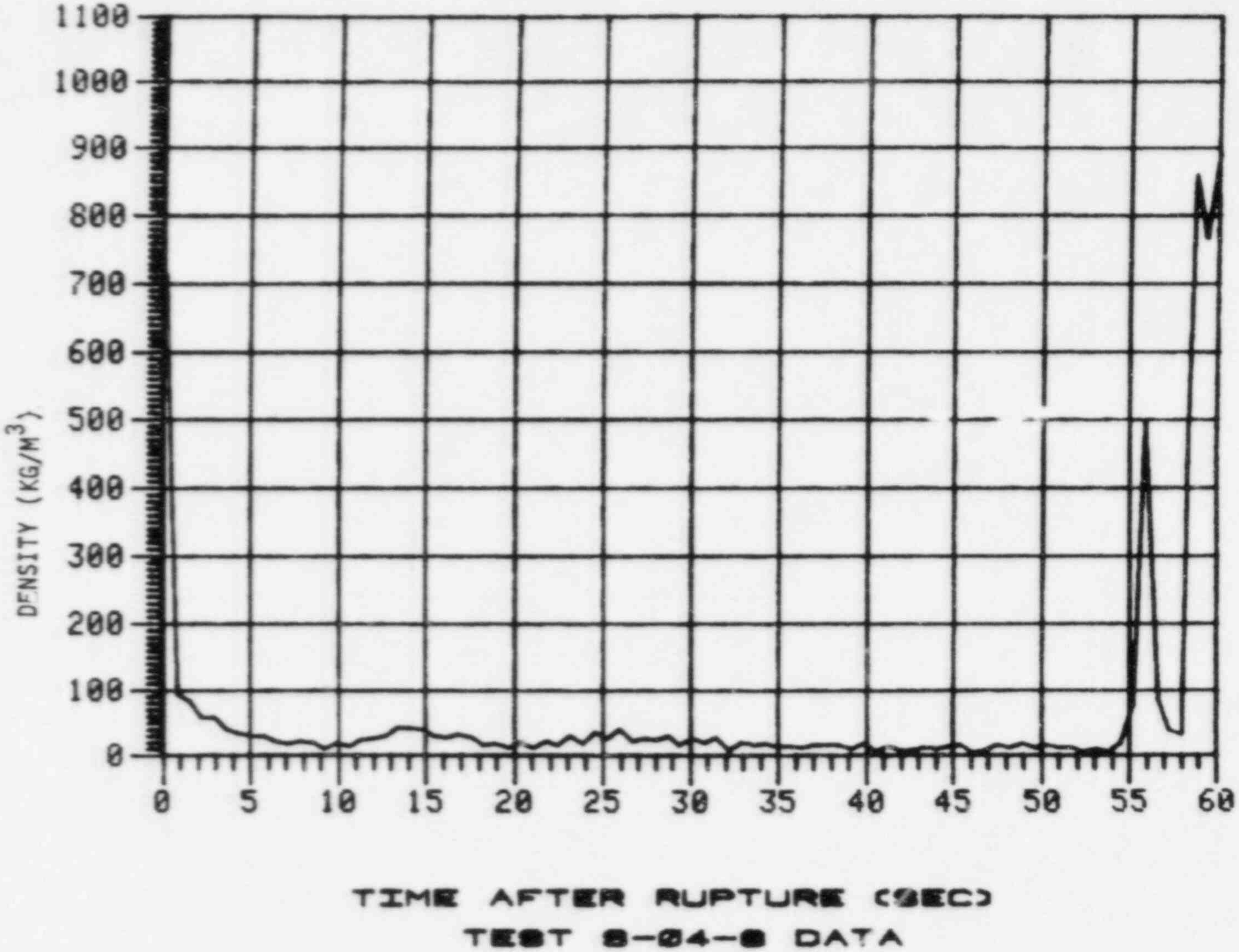

Figure 11. Measured Density at the Core Inlet During Blowdown and Refill in Test S-04-6

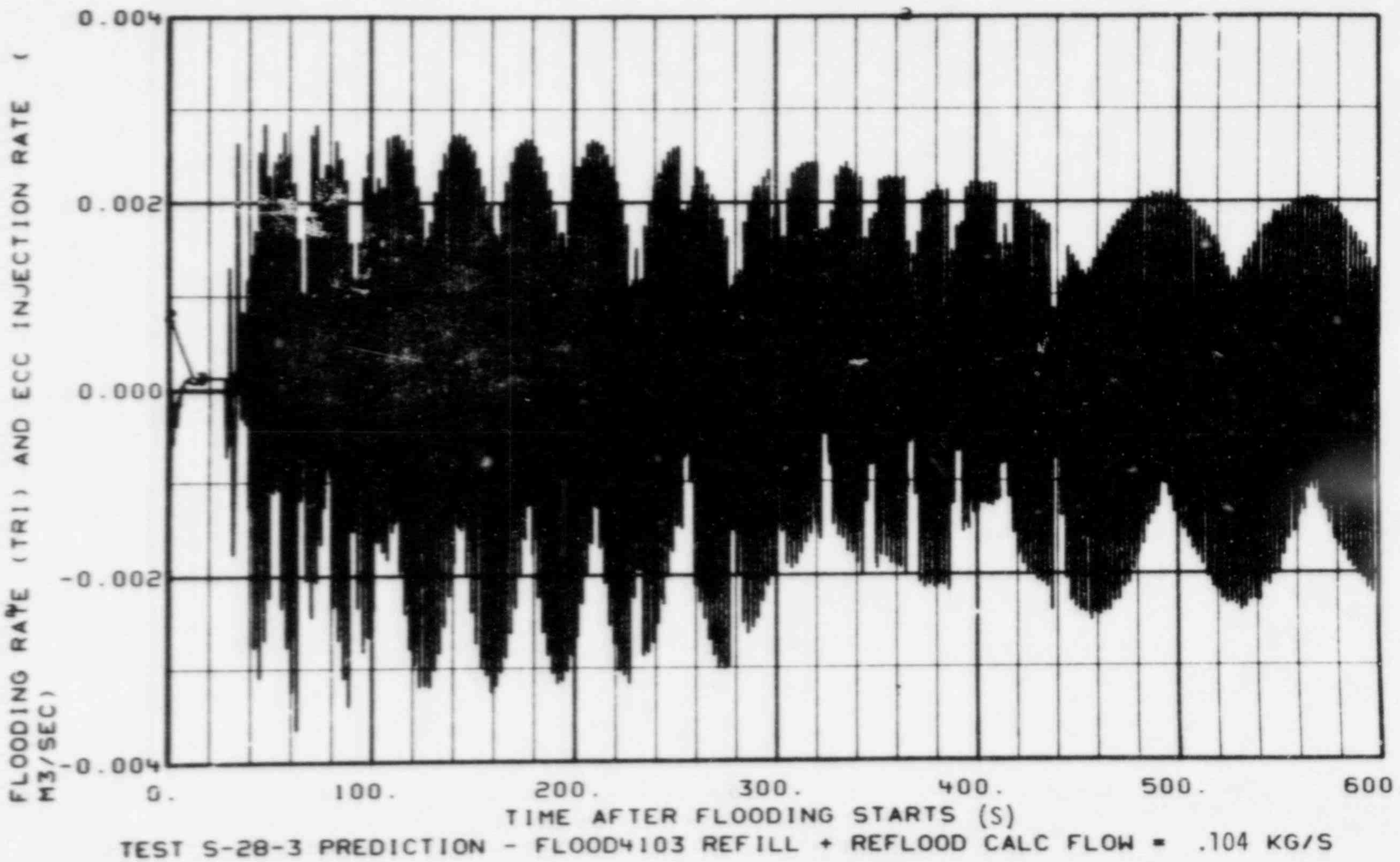

Figure 12. FLOOD4 Prediction of Core Inlet Volumetric Flow Rate

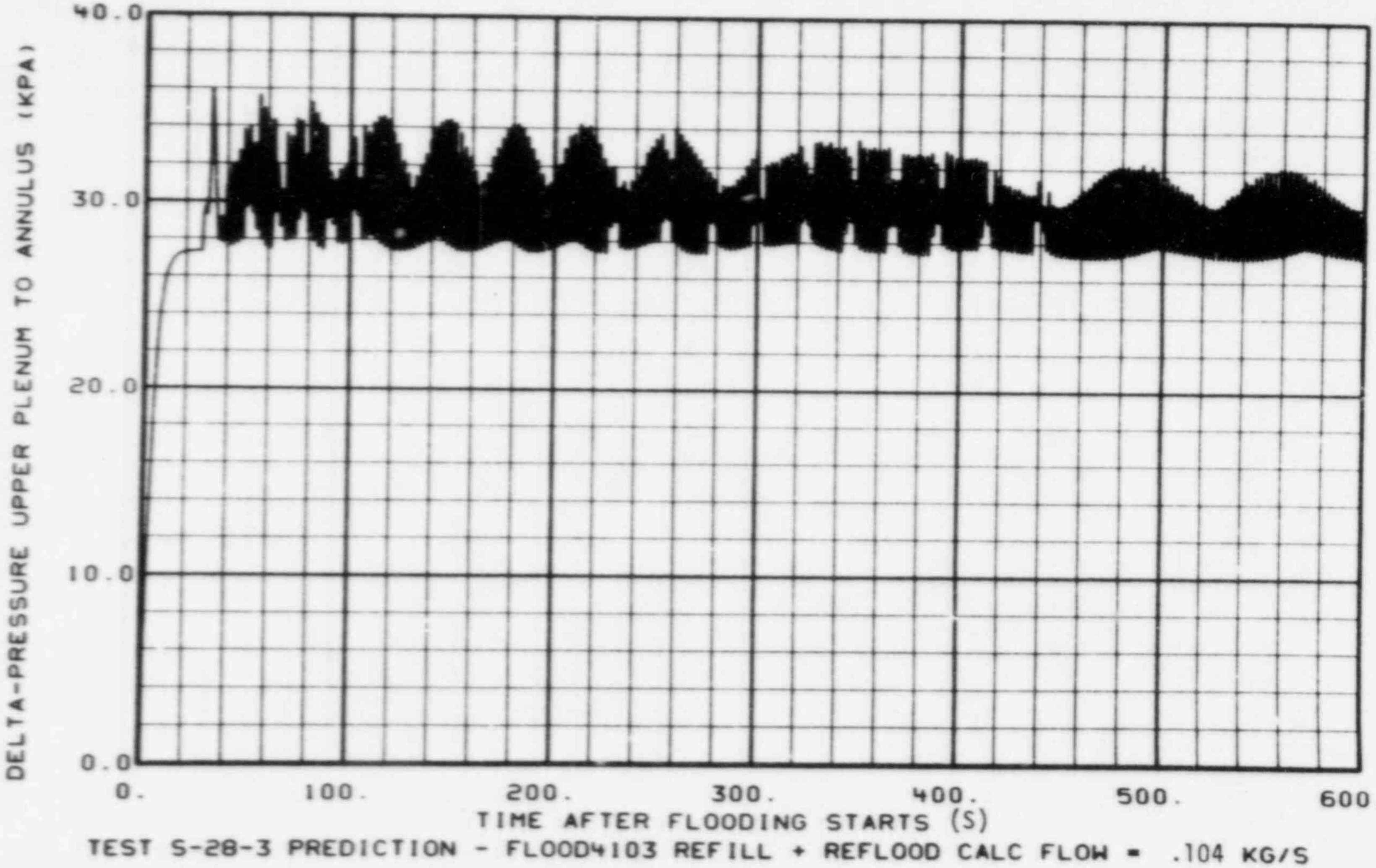

Figure 13. FLOOD4 Prediction of Differential Pressure Between the Upper Plenum and Inlet Annulus

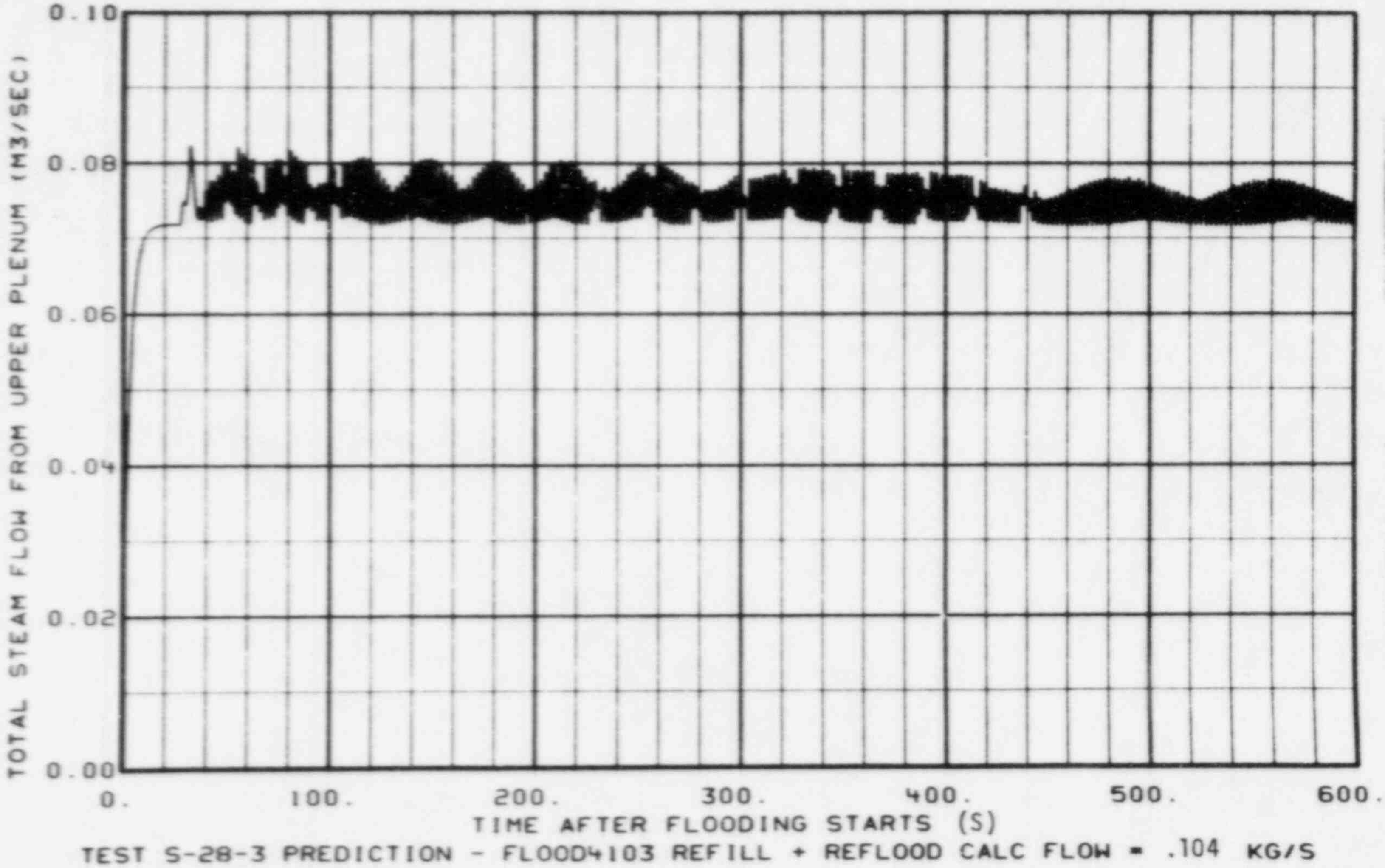

Figure 14. FLOOD4 Prediction of Total Steam Flow from the Vessel Upper Plenum During Reflood

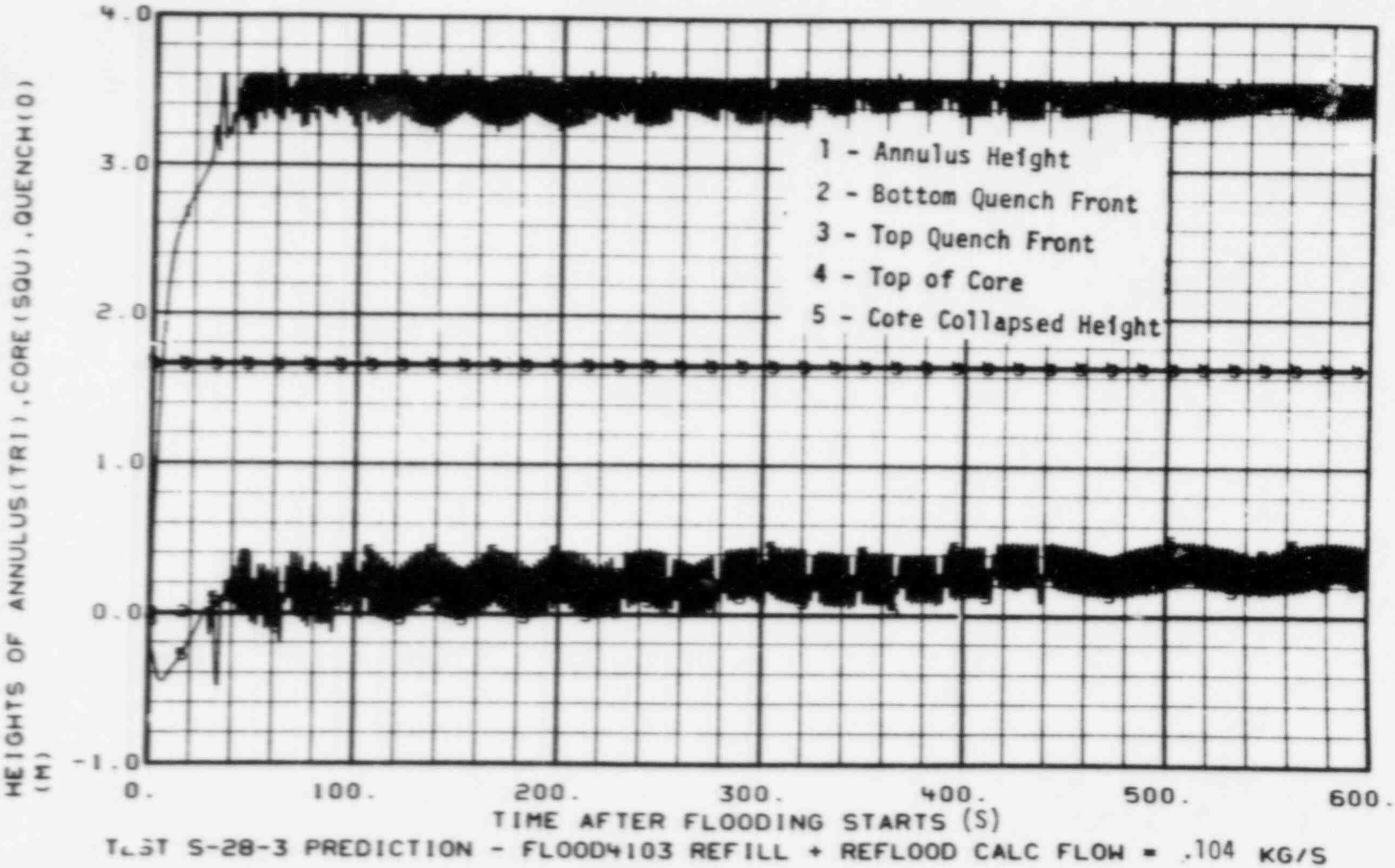

Figure 15. FLOOD4 Prediction of Water and Quench Front Heights During Reflood

oscillations are primarily responsible for the oscillations in the core flow and steam generation in the core. The manometer type oscillations result when the liquid level builds up in the downcomer and forces liquid into the core. Some of the liquid forced into the core is vaporized to steam on contact with the heater rods. This steam generation causes a small pressure increase which tends to force some fluid out of the core and also entrain some liquid up the core. The level in the downcomer then builds up again and the process is repeated causing the oscillatory flows and levels shown in Figures 12 through 15. The core quench level shown in Figure 15 indicates that the core quenched from the bottom only and that the quench front had only reached the 0.27 m elevation when the calculation ended. Although the downcomer annulus filled to a height of about 3.8 m, the core collapsed level remained below the 0.50 m elevation in the core. This difference in elevations is due to steam binding in the intact loop which prevents the water in the downcomer annulus from entering the core and thus retards core reflooding.

The FLOOD4 code cannot account for the downcomer mass depletion phenomena noted in previous Semiscale tests. This phenomena is a result of an excessively large amount of energy transfer from the downcomer walls to the fluid in the downcomer gap after the liquid is depleted from the accumulator. The mass depletion from the downcomer causes a reduction in the downcomer liquid head which in turn causes a reduction in the core reflood driving potential (the annulus water level shown in Figure 15 would be lower if mass depletion were taken into account). The depletion could cause the measured reflood phenomena to be somewhat different than the predicted reflood response.

The FLOOD4 predicted thermal response of the Semiscale Mod-1 core for the reflood portion of Test S-28-3 is presented in Figures 16 and 17. Core elevations of 20, 36, 53, 63.5, and 99 cm above the bottom of the heated length were chosen for presentation because they correspond to existing core heater rod thermocouple measurements. The predicted heat transfer coefficients oscillate between 0.03 and 0.15 kW/m^2-K during most of the reflood calculation. The only exception to this is the calculated heat transfer coefficient at the 20 cm elevation, because it is the only elevation below the quench front at the time the calculation ended. It shows a rapid rise at 320 seconds after reflood as the quench front approaches and the heat transfer regime predicted for that elevation switches to transition boiling. After the quench front passes the heat transfer regime is nucleate boiling and forced convection to liquid with a heat transfer coefficient of 2.3 kW/m^2-K. The predicted rod surface temperature response for various elevations is shown in Figure 17. The predicted temperature at the core hot spot (63.5 cm elevation) increases during reflood to 1158 K and remains at this temperature during the period from 180 to 270 seconds after reflood. After this time the temperature declined to 1055 K at 600 seconds after reflood when the calculation ended. The 99 cm elevation had the highest temperature (1089 K) when the calculation ended. The lower elevations show a continual decline from 40 seconds after reflood. The rapid drop in temperature at the 20 cm elevation at 320 seconds after rupture is the result of the prediction of transition boiling. The predicted surface heat flux at the rod hot spot (63.5 cm elevation) is shown in Figure 18, and fluctuates between 20 and 50 kW/m^2 during the entire reflood transient.

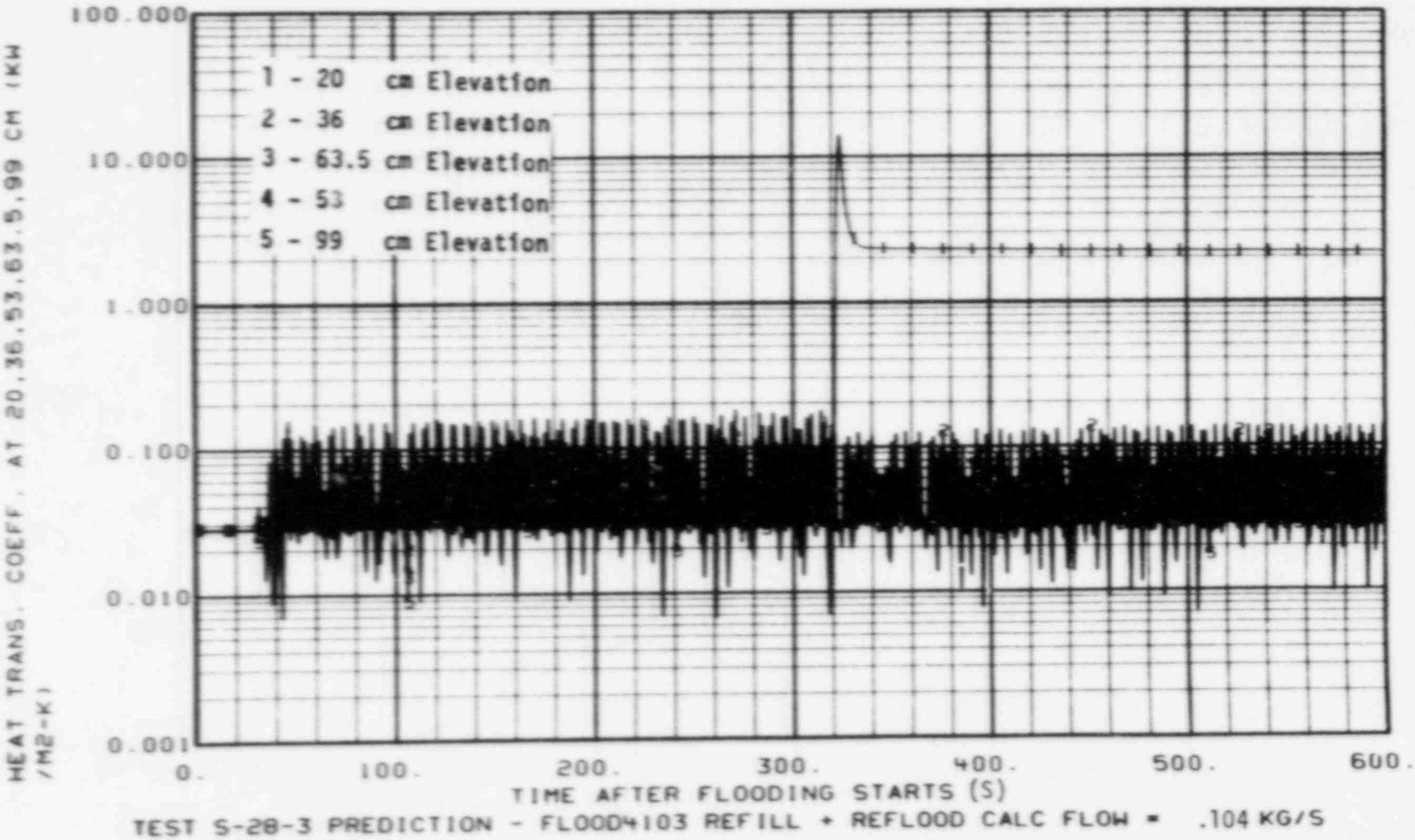

Figure 16. FLOOD4 Prediction of the Heat Transfer Coefficient at the 20, 36, 53, 63.5, and 99 cm Elevations

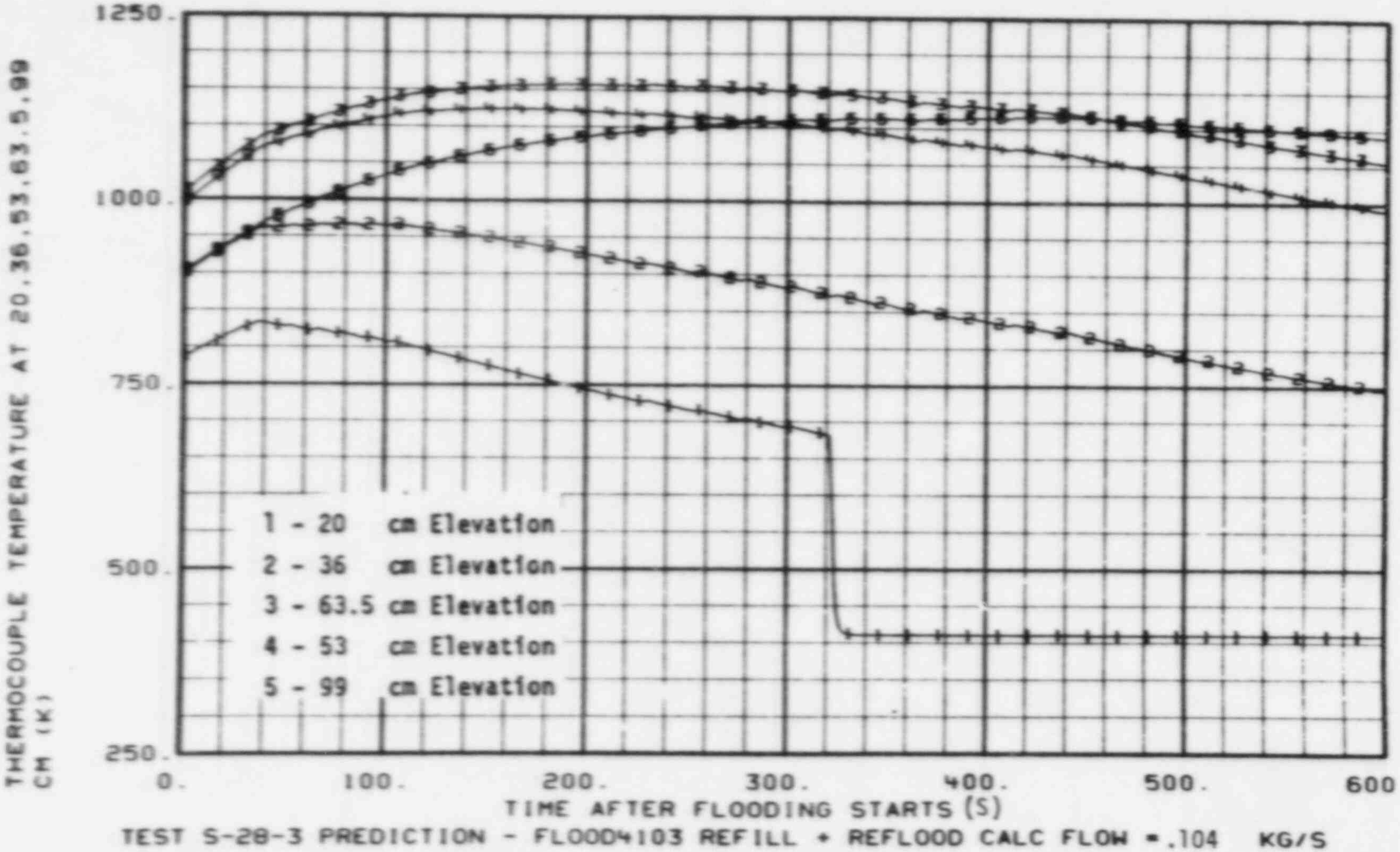

Figure 17. FLOOD4 Prediction of the Rod Temperatures at the 20, 36, 53, 63.5 and 99 cm Elevations During Reflood

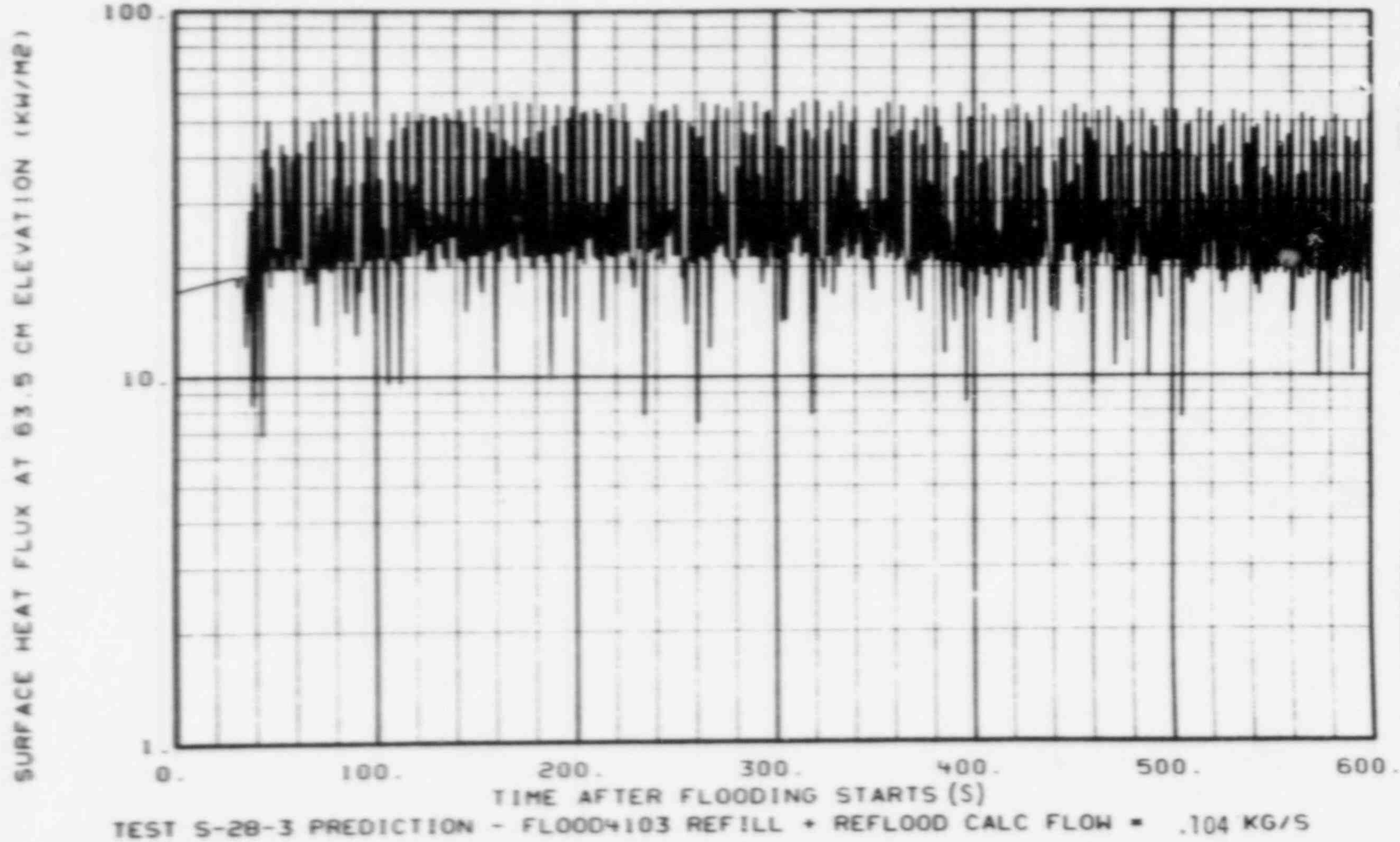

Figure 18. FLOOD4 Prediction of the Surface Heat Flux at the Rod Hot Spot (63.5 cm Elevation) During Reflood

III. CONCLUSIONS

The conclusions relative to the use of Test S-04-6 data to indicate the blowdown and refill response and the FLOOD4 predictions for the reflood portion of the transient for the Semiscale Mod-1 Test S-28-3 are as follows:

(1) The system and core thermal response should be essentially identical for Tests S-28-3 and S-04-6 until 40 seconds after rupture because the initial conditions for the two tests are the same.

(2) Little difference in the refill response (40 to 58 seconds) between Test S-28-3 and the baseline test, Test S-04-6, is expected because of the small tube rupture flow rate specified for this test.

(3) The peak temperature during blowdown should be approximately 1075 K at 8 seconds after rupture and should occur on a rod located on the core perimeter. This temperature should decline to 1011 K at 58 seconds after rupture.

(4) Previous tests in Series 28 have shown that some rods quench during blowdown. If this is the case in Test S-28-3, the cladding temperatures during the transient may be lower than presented in this document.

(5) The start of reflood from the bottom is estimated to begin at 58 seconds after rupture.

(6) Results from this calculation indicate that the core peak power location had not quenched when the FLOOD4 calculation ended at 600 seconds after reflood (658 seconds after rupture).

However, after reaching a maximum temperature of 1158 K during reflood, the rod temperatures turned over and declined to 1055 K when the calculation ended. Steam binding in the intact loop and upper plenum appears to be the reason that the core did not quench. The calculations indicate that the rupture of about 12 steam generator tubes results in sufficient steam binding to severely retard the core reflood rate and hence produce poor core heat transfer.

IV. REFERENCES

(1) D. J. Olson Ltr to P. E. Litteneker, DJO-125-77, Transmittal of EOS Appendix 28, June 3, 1977.

(2) J. O. Zane Ltr to P. E. Litteneker, Zan-250-76, Transmittal of Quick Look Report for Semiscale Mod-1 Integral Blowdown Reflood Tests S-04-5 and S-04-6, October 15, 1976.

(3) J. O. Zane Ltr to R. E. Swanson, Zan-235-75, Test Prediction of the Third Mod-1 Semiscale Test Series, Reflood Heat Transfer Tests, Tests S-03-1, S-03-2, and S-03-3, November 19, 1975.

APPENDIX A

FLOOD4 COMPUTER CODE

APPENDIX A

FLOOD4 COMPUTER CODE

The FLOOD4 computer code is a recently developed analysis tool used to predict core reflood behavior in water reactors. The methods and models used in FLOOD4 are currently undergoing evaluation and improvement.

The FLOOD4 code couples the system hydraulics using the momentum equation for the core, lower plenum, and downcomer with the heat transfer and steam generation in the core region. Liquid which rises in the downcomer to a height greater than the cold leg is assumed to be lost from the system. The steam within the system is lumped into one gas volume and the perfect gas law is used to calculate the relationship between the steam pressure, mass, volume, and temperature. Figure A-1 illustrates the hydraulic coupling of the Semiscale system used in the FLOOD4 model. The core is represented in FLOOD4 by a series of axially stacked conduction nodes which have a specified initial temperature and energy generation rate. The heat transfer coefficient applied to a node depends on the mode of heat transfer which is determined from the elevation of the node, the elevation of the water, and the temperature of the node. Four different heat transfer modes are used to define the boiling curve and one mode is defined for forced convection to single-phase liquid below the quench level. The reference temperature used for the heat transfer calculation is T_{sat} for nodes above the water level in the core and T_{bulk} for nodes below the quench level core.

The fluid entering the upper plenum is a mixture of the steam generated in the core and entrained water. The amount of steam is determined from the heat flux at the nodes above the quench front and

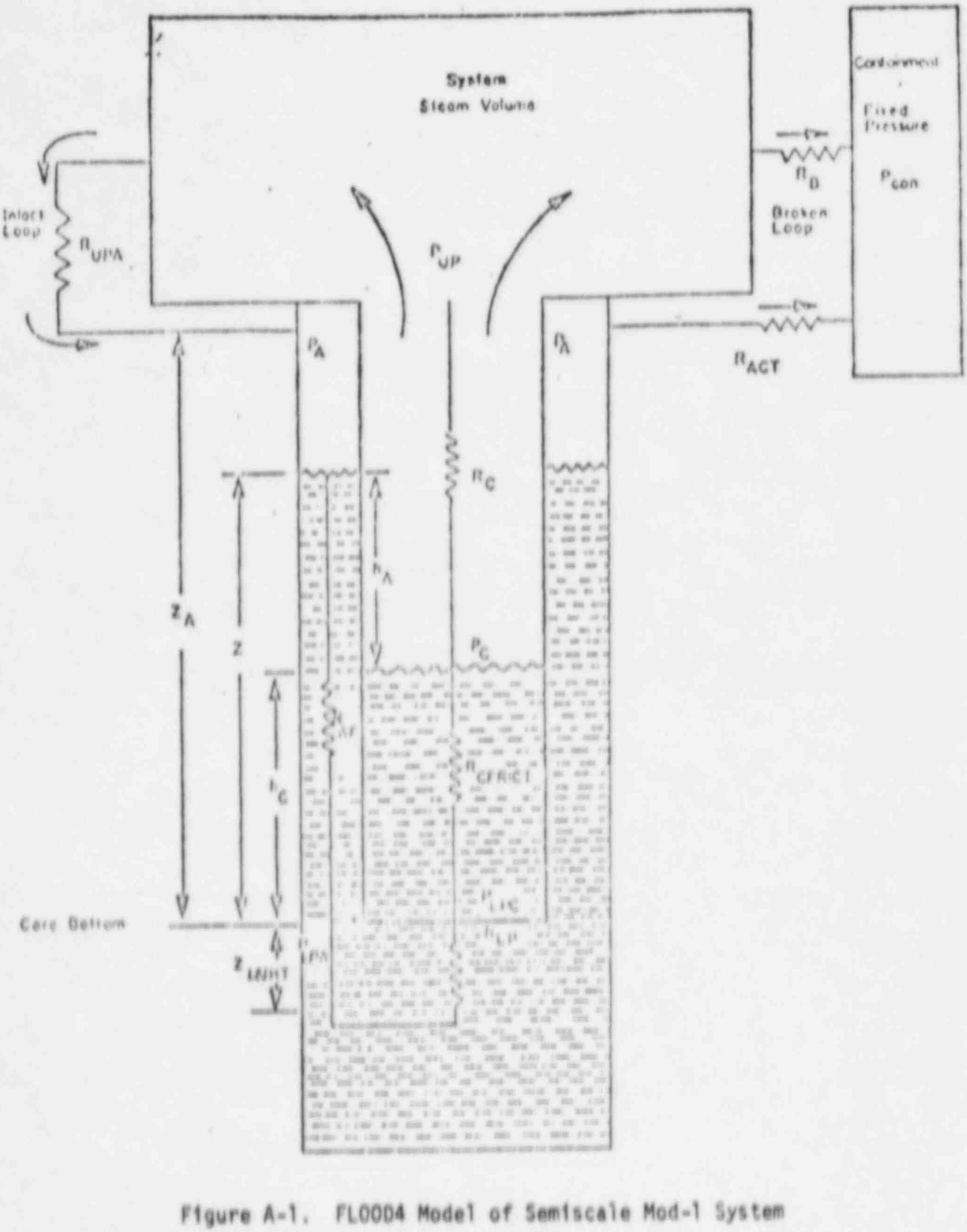

Figure A-1. FLOOD4 Model of Semiscale Mod-1 System

the amount of entrained water is a function of the steam flow rate, the collapsed water level above the quench front, the pressure, and the core hydraulic diameter. Since all of the rods are assumed to be identical, the calculation is performed for one subchannel and rod and then multiplied by the number of rods in the core to obtain the total steam flow. The axial temperature distribution at the start of reflood (58 seconds) was determined by using the peak temperature in the core at that time and using a cosine curve fit to determine the temperature distribution.

FLOOD4 has several new features which are still experimental and include: (1) capability for upper plenum injection which include a condensation mode, (2) capability to have liquid fall back from the upper plenum if the core steam velocity goes below a certain value, and (3) vaporization of entrained liquid in the intact loop steam generator. Future predictions will attempt to include these features where applicable in an effort to better simulate expected behavior.

Table A-1 is a copy of the input to the FLOOD4 calculation for the reflood calculation for Test S-28-3.

Table A-I. FLOOD4 Input Listing for the Reflood Calculation

```
0000000001111111111222222222233333333334444444444555555555566666666667777777778
1234567890123456789012345678901234567890123456789012345678901234567890123456789O

        TEST S-28-3 PREDICTION - FLOOD4103 REFLOOD CALCULATION 12 TUBES
    1   TIME AFTER FLOODING STARTS (SEC)
    2   FLOODING RATE(TRI) AND ECC INJECTION RATE (IN/SEC)     -100.,     100.
    3   HEIGHTS OF ANNULUS(TRI),CORE(SQU),QUENCH(O) (FT)       -2.        12.0
    4   TOTAL STEAM FLOW FROM UPPER PLENUM (GPM)
    5   DELTA-PRESSURE UPPER PLENUM-ANNULUS (PSI)               0.0        2.0
    6   THERMOCOUPLE TEMPERATURE AT 8,14,21,25,39 IN. (F)      0.         2200.
    7   SURFACE HEAT FLUX AT 25 INCH ELEVATION (BTU/HR-FT2)    1000.      1000000.
    8   HEAT TRANS.COEFF.AT 8,14,21,25,39 IN. (BTU/HR-FT2-F)   1.         10000.
    9   DISTANCE FROM BOTTOM (IN)                              0.         70.
   10   INITIAL TEMPERATURE PROFILE (F)                        0.         1600.
   11   FLOODING RATE(TRI) AND ECC INJECTION RATE (GPM)
   12   LIQUID LEVEL AND CORE EXIT QUALITY                      0.0        1.0
   13   LIQUID LEVEL AND CORE EXIT STEAM FLOW (LBS/SEC)
   14   CORE EXIT LIQUID VAPORIZED IN STEAM GENERATOR (LB/SEC)
   15   CORE EXIT AND COLLAPSED LEVEL STEAM VELOCITY (FT/SEC)
-1
       3.65      0.58       12.       0.58      600.00
     .0513        .05     .0589       35.0          6.      58.4  .0001408      264.0
      11.8       2.63      1.67      .0445       .085
   0           .00376       .05         1.       .760        .6       .23       0.3
       5.5        0.0      -1.0        .07    1.0E+06       3.5       3.0
      .002       500.  200      .002      500.  200      .002      500.  200   100
     266.6       11.0
-1
       9.6       11.0
-1
      5.63       11.9
-1
      0.52       11.0
-1
   2           .00468      0.00       175.       940.       1.0      0.00
       0.6       0.25    75380.        0.0       264.      38.0      264.      1360.
   0     1   0              0.0        0.5       58.0       .05      2.00       0.2
     36.       940.         1.0       1.0        1.0      .995
   1     1   2       .055         0.
   2     2   4       .045         1.
   3     4   2       .036         0.
   5     5   1       .010         0.
   6     6   1       .029         0.
-1
  17    28   50   43   78    4    2    2   10    5    5
   1    12        0.5     0.374     711.
  13    22        0.5     0.635     786.
  23    32        0.5     0.817     829.
  33    42        0.5     0.939     842.
  43    62        0.5     1.000     808.
  63    72        0.5     0.939     726.
  73    82        0.5     0.817     644.
  83    96        0.5     0.635     544.
  97   112        0.5     0.374     414.
 113   132        0.5     0.126     364.
-1
0000000001111111111222222222233333333334444444444555555555566666666667777777778
1234567890123456789012345678901234567890123456789012345678901234567890123456789O
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EG&G Idaho, Inc.

P. O. Box 1625
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June 30, 1977

Mr. R. E. Tiller, Director
Reactor Operation and Program Division
Idaho Operations Office - ERDA
Idaho Falls, Idaho 83401

TEST PREDICTION OF SEMISCALE MOD-1 INTEGRAL TEST S-28-4 - DJO-147-77

Reference: D. J. Olson Ltr to P. E. Litteneker, DJO-125-77
Transmittal of Semiscale EOS Appendix 28,
June 3, 1977

Dear Mr. Tiller:

Enclosed is the test prediction document for Test S-28-4 of the steam generator tube rupture test series. Details of the system description and initial test conditions were transmitted in the referenced letter.

The objectives of Test S-28-4 are to aid in defining the core temperature response for large numbers of steam generator tube ruptures and to probe into the range of steam generator tube ruptures shown in the analysis used to specify Test Series 28 to result in high peak cladding temperatures. Test S-28-4 will be a 200% double-ended cold leg break simulation. The rupture of 30 steam generator tubes will be simulated by a flow rate of 0.272 kg/s from accumulator injection into the intact loop hot leg between the pressurizer and the steam generator inlet plenum. The injection will begin at 40 seconds after the initiation of the cold leg break to simulate the steam generator tube ruptures. The change in heat transfer potential of the steam generator will be simulated by discharging the steam generator secondary fluid during the simulated tube rupture period. The system initial conditions and emergency core coolant injection parameters are the same as Test S-04-6, the baseline test for Test Series 28.

The blowdown response should be the same as Test S-04-6 until 40 seconds after rupture. The predictions for the remainder of the transient were performed with the FLOOD4 code. Experimental results from Test S-04-6 indicate the peak rod temperature during blowdown should occur at 8 seconds after rupture when a maximum of 1075 K was achieved. Initiation of the simulated tube ruptures at 40 seconds after rupture should delay the beginning of refill until about 444 seconds after the initiation of the cold leg break and the beginning of reflood until 518 seconds. Both refill

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and reflood must be accomplished by the high pressure injection system and the low pressure injection system alone. The peak temperature during reflood was calculated to be 1175 K. The core hot spot is predicted to quench at 633 seconds after rupture and the whole core is expected to quench by 648 seconds.

Very truly yours,

D. J. Olson, Manager
Semiscale Program

CPF:klj

Enclosure

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