TECHNICAL MEMORANDUM

ANL-CT-78-30

OUTLET PLENUM MIXING FOR TRANSIENT OVERPOWER CONDITIONS OF A ONE-EXIT NOZZLE LMFBR

by

Paul A. Howard
Components Technology Division

ARGONNE NATIONAL LABORATORY
U of C-AUA-USDOE

BASE TECHNOLOGY

April 1978

MASTER

TECHNICAL MEMORANDUM

ANL-CT-78-30
LMFBR Reactor Core
Systems (UC-79e)

MN ONLY

OUTLET PLENUM MIXING FOR TRANSIENT OVERPOWER CONDITIONS OF A ONE-EXIT NOZZLE LMFBR

by

Paul A. Howard
Components Technology Division

ARGONNE NATIONAL LABORATORY

U of C-AUA-USDOE

BASE TECHNOLOGY

April 1978

TABLE OF CONTENTS

ABSTRACT

Two types of transient tests were employed to model a one-exit nozzle LMFBR outlet plenum. Water was used as a test fluid in the simulation of constant flowrates, Transient Overpower (TOP) conditions. In the first test, simulated fuel flow was 85% and blanket flow was 15%, whereas in the second test, the fuel flow was 100%. This allowed the assessment of the mitigating effects of blanket flow upon the exit nozzle temperature transient. The flow field was clearly three-dimensional, and a less active, though not stagnant, region was observed diametrically opposite the exit nozzle. During steady state, oscillations above the fuel-blanket interface were found to be small. This is attributed to the existence above the reactor core of a recirculating flow field, which served as an effective mixing agent. A simple lumped-parameter model, EXIT1, was developed to simulate TOP transient conditions for the test with both fuel and blanket flows. The predicted temperature profiles for various regions in the plenum were in good agreement with the experimental profiles, except for the region immediately above the reactor blanket. In devising the computer model, the temperature in this region was assumed to remain constant throughout the transient. However, this constant temperature did not prevail owing to the mixing that occurred in this region as a result of the recirculating flow field above the reactor core. The computer model can be readily modified to take into account the mixing due to this recirculation.

In the test without blanket flow, good agreement between predictions and data was again obtained. In comparing results of the two tests, it was found

that the blanket flow had only a small mitigating influence on the transient at the exit nozzle. The computer model can easily be extrapolated to reactor conditions.

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Andy Levine of Tufts University for performing most of the set-up work for this test and all of the analysis. Thanks are also given to Robert Morris and Roger Stern who assisted in the test and computer operation. The help of J. Royal for editing this report and Pat Williams for typing it is much appreciated.

1.0 INTRODUCTION

Mixing performance of outlet plenums is important to LMFBR designers for both steady state and transient conditions. Reactor power transients can result in changing flow patterns and temperature fields within the outlet plenum. The exit nozzles, pumps, intermediate heat exchangers, and other downstream components will be subjected to the resultant temperature changes. If poor mixing of ambient sodium within the plenum and sodium leaving the reactor core occurs, a severe thermal shock to downstream components is possible. Another area of interest to LMFBR designers is concerned with steady state temperature oscillations near the junction of blanket and fuel flows. Whenever two jets of different temperatures collide, thermal oscillations in the fluid are transported downstream. If the temperature difference is great enough, thermal fatigue and cracking can develop in any exposed structure. Both of these mixing processes are investigated here for a one-outlet nozzle LMFBR system.

Several outlet plenum mixing studies have been performed[1-4] in which it has been shown that small-scale water tests can accurately simulate large sodium outlet plenums. The balance between density changes and inertia determine the resulting flow pattern. For Transient Overpower (TOP) conditions, good mixing would be expected in the outlet plenum. In this case, the core outlet flow would be buoyant and would rise into the bulk of the ambient fluid and mix. However, if a stagnant region, or a preferred flow path within the plenum exists, good transient mixing is not assured. In an effort to simulate these conditions, a small-scale single-outlet nozzle plenum was fabricated and tested, Fig. 1. Although no actual reactor of the type simulated here exists, by employing similitude, the results obtained in these studies are applicable to several different size systems. At 1/4 scale these results apply to a LMFBR with a flow of 0.85 m^3/sec (13500 gpm) and a temperature rise of 83°C (150°F). Such a reactor would have a power of 75 MWt, but a more common temperature rise across the core is 150°C (270°F) with a reactor power of 135 MWt.

In the study of the one-exit nozzle plenum, the specific transient conditions to be simulated were as follows. The fuel flow temperature increases from 750°F to 1175°F in 15 seconds, corresponding to control rod withdrawal in the hypothetical reactor. The reactor is then scrammed and the fuel flow cools to 600°F in

4 seconds. A constant fuel flow of 11695 gpm is maintained throughout the transient. During this entire period, a constant blanket flow of 1805 gpm at 750°F is maintained.

1.1 Similitude Considerations

The simulation testing was done at 1/4 scale with water used as the test fluid. Earlier work at ANL has shown that water can be used as a test fluid for simulation studies of sodium under conditions of LMFBR operation provided that certain criteria of similitude are met.[1-3] The principal criterion was found to involve the ratio of the Froude number for the model to that for the prototype.[3] To achieve similitude, the ratio of these two Froude numbers must equal unity. Consideration of the Reynolds number indicated that similitude requires only that turbulent flows in both the model and prototype are present.[2] In addition, it was found that the Prandtl number, under conditions of turbulent flow in the two systems, has a negligible effect on similitude.[4]

In the present study, the criterion of turbulent flow was met by maintaining a Reynolds number on the order of 10^6. Thus, the principal concern in achieving similitude was to ensure the equality of the Froude numbers for the two systems.

A modified Froude number is used in this study and is defined as:

$$Fr = \frac{\Delta\rho g \ell}{\rho u^2}$$

where

$\Delta\rho$ = difference in density between fuel flow and blanket flow

g = acceleration due to gravity

ℓ = a characteristic length

ρ = density of fuel flow

u = velocity of fuel flow.

To achieve similitude, the Froude number ratio, Fr_r, for model and prototype must equal unity:

$$Fr_r = \frac{Fr\ (model)}{Fr\ (prototype)} = 1 = \frac{\Delta\rho_r\ \ell_r\ g_r}{\rho_r\ u_r^2}$$

where the subscript r denotes ratio. By rearranging terms:

$$\rho_r \, u_r^2 = \Delta\rho_r \, \ell_r \quad (1a)$$

and

$$u_r = \dot{Q}_r/\ell_r^2 \quad (1b)$$

where $\dot{Q}_r$ is the volumetric flowrate ratio. Since the length ratio is equal to 1/4 and the density ratio is 1.18 for the water/sodium system,

$$\dot{Q}_r = (\ell_r^5/\rho_r)^{1/2} \, (\Delta\rho_r)^{1/2}$$

$$= 0.0288 \, (\Delta\rho_r)^{1/2} \quad (2)$$

The final ratio that needs to be considered for the simulation is the time ratio, which is defined as:

$$t_r = \frac{\text{duration of an event in the model}}{\text{duration of the same event in the prototype}}$$

$$t_r = \ell_r^3/\dot{Q}_r \quad (3)$$

From the foregoing, it is evident that for a given set of high and low prototype transient temperatures, the solution of $\Delta\rho_r$ defines all the other parameters required for the simulation study. The high and low temperatures of the fuel flow during the transient are 1175 and 600°F. For maximal utilization of the model, the corresponding high and low water temperatures are 185 and 70°F. The blanket flow during the transient remains constant at 750°F.

The $\Delta\rho_r$ ratio is defined as:

$$\Delta\rho_r = \frac{(\rho_b - \rho_f) \text{ model}}{(\rho_b - \rho_f) \text{ prototype}}$$

with the subscripts b and f denoting blanket and fuel flow, respectively.

For proper simulation of fuel flow at 1175°F and blanket flow at 750°F, the preceding equation becomes:

$$\Delta\rho_r = \frac{\rho_{H2O}(\text{blanket}) - \rho_{H2O}(185°F)}{\rho_{Na}(750°F) - \rho_{Na}(1175°F)}$$

$$= \frac{\rho_{H2O}(\text{blanket}) - 60.47}{3.33} \qquad (4)$$

Similarly, for proper simulation of fuel flow at 600°F and blanket flow at 750°F, the equation becomes:

$$\Delta\rho_r = \frac{\rho_{H2O}(\text{blanket}) - \rho_{H2O}(70°F)}{\rho_{Na}(750°F) - \rho_{Na}(600°F)}$$

$$= \frac{\rho_{H2O}(\text{blanket}) - 62.26}{-1.25} \qquad (5)$$

The sodium densities used in Eqs. 4 and 5 were obtained from the following linear approximation of the change in sodium density with temperature:

$$\rho_{Na} = -0.008324 * T + 59.51 \qquad (T = °F) \qquad (6)$$

The water densities used in Eqs. 4 and 5 were taken from the plot of water densities vs. temperature shown in Fig. 2. A linear approximation of this plot was obtained by using the two endpoints of the figure:

at 185°F, $\rho_{H2O} = 60.47\ lb_m/ft^3$

at 70°F, $\rho_{H2O} = 62.26\ lb_m/ft^3$

The derived equation is:

$$\rho_{H2O} = -0.0156 * T + 63.36 \qquad (7)$$

where T is the temperature in °F.

To obtain the density of the blanket flow in the model, Eqs. 4 and 5 are set equal to one another and solved:

$$\rho_{H2O} \text{ (blanket)} = 61.77 \ lb_m/ft^3$$

From Eq. 7, the temperature corresponding to a density of 61.77 lb_m/ft^3 is 101.4° F. This is the temperature of the blanket flow to be used in the model.

To obtain the change in the density difference ratio, $\Delta\rho_r$, the value of ρ_{H2O} (blanket) is substituted in either Eq. 4 or 5:

$$\Delta\rho_r = 0.3904$$

By substituting this value in Eq. 2, the flowrate ratio, $\dot{Q}_r$, is obtained:

$$\dot{Q}_r = 0.0288 \ (\Delta\rho_r)^{1/2} = 0.0180$$

Since the fuel and blanket flowrates in the prototype are known, the flowrates to be used in the model can now be calculated:

$$\text{Fuel} \quad \dot{Q}_m = \dot{Q}_p * \dot{Q}_r = 11{,}695 * 0.0180 = 210.5 \text{ gpm}$$

$$\text{Blanket} \quad \dot{Q}_m = \dot{Q}_p * \dot{Q}_r = 1{,}805 * 0.0180 = 32.5 \text{ gpm}$$

where the subscripts m and p denote model and prototype, respectively. These flowrates are well within the capabilities of the test facility.

Finally, the solution of Eq. 3 sets the time ratio:

$$t_r = \ell_r^3/\dot{Q} = 0.86$$

Thus, an event that occurs in one second in the prototype reactor would occur in 0.86 seconds in the model.

2.0 EXPERIMENT

2.1 Test Section

The test section consisted of a 1/4-scale outlet plenum model with a single exit nozzle, Fig. 1. The outlet plenum was housed in a pressure vessel that is part of the test facility described later in subsection 2.4. The reactor core comprised 115 fuel elements and 365 blanket elements. A central structure, equivalent in area to that of seven fuel elements, was included in the simulated core. A schematic of the outlet plenum is shown in Fig. 3. The plate used to simulate the core (with the central structure removed) is shown in Fig. 4.

Blanket flow enters through six hoses, Fig. 5, and flows upward through an anular passage surrounding the simulated core. The position of contact between the hexagonal separator and the simulated core may be seen in Fig. 6.

Preliminary tests showed that backward flow had occurred through the blanket region of the core plate. This problem was attributed to an insufficient pressure drop across the blanket region. This allowed circulating water above the core plate to flow downward through the holes in the blanket region. To avoid this problem, stoppers with a single 3-mil hole were placed in the holes in the blanket region. The stoppers were placed on the upstream side of the core plate and penetrated roughly 1/16 inch into the holes. Although the stoppers served to increase the pressure drop across the blanket region, they did not appreciably affect the flow velocity on the downstream side. The stoppers can be seen in Fig. 4. (The "halo" around the blanket region is a reflection of part of the core plate by the stainless steel wall of the core barrel.)

2.2 Instruments

The instruments within the test section consisted of 59 thermocouples. Other instruments used in the experiment were three turbine flowmeters and three pressure transducers. All the data were recorded with a digital data acquisition system (a Hewlett Packard 21MX machine).

All of the thermocouples were chromel-constantan, 10-mil wire, with a time response of $\sim$ 10 ms. The accuracy of the thermocouples was found to be $\pm$ 1°C.

The three turbine flowmeters were found to be accurate within $\pm$ 5%.

The three pressure transducers were calibrated prior to the tests, with the computer providing a calibration curve for each instrument. These curves were stored for use during the test.

2.3 Thermocouple Locations

The locations of the 59 thermocouples are given in Table 1. The locations of 52 of these thermocouples are shown in Fig. 7. (Seven of the 59 thermocouples were located in the hexagonal separator.) Thermocouple 58 was placed inside the core plate. Thermocouple 43 was placed at the junction of the fuel and blanket. Three thermocouples (37, 39, and 41) were located near the exit nozzle, and three others (38, 40, and 41) were placed inside the nozzle. The location of all the thermocouples was fixed throughout the experiment.

2.4 Test Facility

The facility is shown schematically in Fig. 8. The test loop consists of a 2000-gallon tank, a 320-gallon tank and two 80-gallon hot-water heaters. The two larger vessels are made of stainless steel and are connected to the pressure vessel mainly by 4-in. copper piping. The hot-water heaters are connected to the pressure vessel mainly by 1-in. piping. The test section can be viewed from above through a clear Lexan top and from the front through a window that is also constructed of Lexan. Fuel flowrates of up to 300 gpm and blanket temperatures of 60 gpm can be attained.

The digital acquisition system is used to activate all of the electric and pneumatic valves on the test facility.

Figure 9 is a photograph of a portion of the facility and shows the pressure vessel, the 2000-gallon tank, and some of the valves and piping.

2.5 Procedure

Two types of tests were carried out. In the first type, in which transient overpower conditions were simulated using both fuel and blanket flows, the general procedure was as follows. The three tanks were filled with water and brought to the desired temperature: 70°F for the 2000-gallon tank, 180°F for the 320-gallon tank, and 101°F for the two hot-water tanks. The water in these reservoirs was recirculated to ensure uniform conditions. After the recirculation had been completed, the test procedure was initiated by using the computer to execute the timetable shown in Table 2. First, a steady state condition was established, with the blanket flow being supplied by the two hot-water heaters, and the fuel flow, by mixing water from the two large tanks. Next, the transient was begun by simultaneously opening the bypass valve while closing the 4-in valve (Fig. 8). This was immediately followed by the simultaneous opening of the 4-in. valve and the closing of the 3-in. valve. The 4-in. valve was kept open for about one minute to ensure the attainment of a steady state condition. The volumetric flowrates required for the transient are shown in Fig. 10.

As previously indicated, the specific conditions required to simulate TOP conditions are set by the need to achieve a Froude number ratio of unity. The simulated transient involves increasing the fuel temperature from 750°F to 1175°F in 15 seconds and then decreasing the temperature to 600°F in 4 seconds. The conditions required for the simulation of this transient in the model are shown in Fig. 11.

To assess possible ameliorating effects of the blanket flow, a second simulation of the temperature transient was carried out with fuel flow only, i.e., without blanket flow.

Dye was injected during some of the steady state tests to gain visual perception of the flow patterns. Movies were taken of these patterns to allow further study.

3.0 RESULTS

For purposes of analysis, the outlet plenum was divided into nine different volumes as shown in Fig. 12. Hence, the data obtained in the study are presented in terms of these nine volumes. The analysis of the data, which is described in Section 4, refers to these nine volumes and the temperature calculated for each case. Thus, Figs. 13-32 not only show the experimental results, but also the calculated results. The temperatures given in these figures have been normalized as follows:

$$T' = \frac{T - T_c}{T_h - T_c}$$

where T is the measured temperature, and T_c and T_h are, respectively, the lowest and highest temperatures attained during the transient.

In the test with fuel and blanket flows, an effort was made to simulate a constant blanket temperature of 750°F. In the simulation, however, the blanket temperature was 680°F and rising toward 690°F.

Thus, the data are normalized from 0.0 to 1.0, with the former representing the reactor core inlet temperature, and the latter representing the peak fuel outlet temperature. Hence, in order to relate data obtained here to various TOP conditions, one can make a direct comparison for various temperature changes. Also the abscissa for all the data presented here is for experimental time and, in order to relate to reactor time, one must apply the time ratio. This ratio is defined in Eq. 3 and for 1/4-scale it would be 0.86.

3.1 Steady State Temperature Oscillations

Several thermocouples (No. 15, 17, 20, 21, and 23) were located above the blanket region, as may be seen in Fig. 7. Data obtained at these locations revealed only very limited temperature fluctuations. It is possible, however, that some significant oscillations may have occurred at locations other than those being monitored. The lack of significant fluctuations in the region above the blanket is most likely related to the relative velocities of the fuel and blanket flows. The velocity of the fuel flow is 16 times greater than that of the blanket flow, and, hence, the fuel flow totally dominates the flow field. A recirculating flow field above the reactor core apparently results in highly effective mixing. The strength of the recirculating flow was demonstrated in the preliminary runs that indicated the occurence of backward flow through the blanket region (see Section 2.1).

3.2 Experimental Results of Tests with Fuel and Blanket Flows

Of the several tests that were carried out with both fuel and blanket flows, the test that most closely simulated the desired transient yielded the data set SR15. These data are shown in Figs. 13-22, where percent normalized temperature is plotted against time. Figure 13 shows the simulated transient temperature profile at the plenum inlet. Figures 14, 15, and 16 show the simulated transient temperature profiles for volumes V1, V2, and V3, respectively. Figures 17 and 18 show the temperature profiles for volumes V4I and V4A; Figs. 19 and 20, for volumes V5I and V5A; and Figs. 21 and 22, for volumes V6I and V6A.

3.3 Experimental Results of Test with Fuel Flow Only

In this test, only fuel flow was used. The blanket flow was omitted to allow better assessment of the mitigating effects of blanket flow. The results of this test are shown in Figs. 23-32. Figure 23 shows the simulated transient temperature profile at the plenum inlet. Figures 24, 25, and 26 show the transient temperature profiles for volumes V1, V2, and V3, respectively. Figures 27 and 28 show the temperature profiles for volumes V4I and V4A; Figs. 29 and 30, for volumes V5I and V5A; and Figs. 31 and 32, for volumes V6I and V6A.

4.0 ANALYSIS

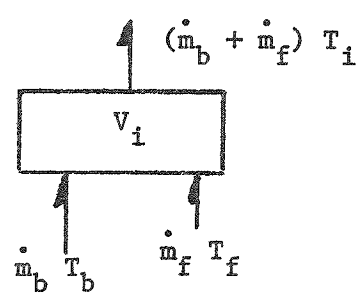
4.1 Computer Model

A simple one-dimensional computer model, EXIT1, was devised to simulate the temperature transient in the one-exit outlet plenum. The first step in the modeling procedure was to divide the outlet plenum into a number of volumes, based on uniformity of temperature. To locate volumes of uniform temperature, the data from SR15 were used. Six such volumes were located, and three of these were divided further into active and inactive regions to take into account differences in mixing in the region near the nozzle and the region diametrically opposite. In the active regions, the flowrates were high; in the inactive regions, the flowrates were low, but no stagnant region was observed. Visual inspection of the flow pattern through the Lexan top of the pressure vessel indicated that a good approximation would result by assigning 30% of the three divided volumes to the inactive region and 70% to the active region. The choice of the nine volumes and their locations dictated the flow pattern used in the computer model. Computer trials indicated that the best simulation of the temperature transient would be achieved by assigning 20% of the total flow to the inactive region and 80% to the active region for each of the three volumes. The nine volumes are shown in Fig. 12.

For each of these volumes, an energy-balance equation was written, based on the first law of thermodynamics:

$$\sum \dot{E}_{in} - \sum \dot{E}_{out} = \frac{dEv}{dt}$$

In writing the equations, it was assumed that all energy transfers are due to mass transfer:



where T_b and T_f are the temperatures of the blanket and fuel flows, respectively, and $\dot{m}_b$ and $\dot{m}_f$ are the respective mass flowrates for the blanket and fuel flows. Thus the energy equation for volume V_i may be written as:

$$\dot{m}_b\ C_p\ T_b + \dot{m}_f\ C_p\ T_f - (\dot{m}_b + \dot{m}_f)\ C_p\ T_i = m_i\ C_p\ \Delta T_i/\Delta t$$

Assuming a constant specific heat at constant pressure, C_p, the equation becomes:

$$\frac{\dot{m}_b\ (T_b - T_i) + \dot{m}_f\ (T_f - T_i)}{m_i}\ \Delta t = \Delta T_i$$

and, since

$$\dot{m}_b = \dot{Q}_b\ \rho_b \text{ and } \dot{m}_f = \dot{Q}_f\ \rho_f$$

$$\frac{\dot{Q}_b\ (\rho_b\ T_b - \rho_i\ T_i) + \dot{Q}_f\ (\rho_f\ T_f - \rho_i\ T_i)}{V_i\ \rho_i}\ \Delta t = \Delta T_i$$

where $\dot{Q}_b$ and $\dot{Q}_f$ represent the volumetric flowrates of the blanket and fuel flows; and ρ_b, ρ_f, and ρ_i are the densities of the fluid when its temperatures are T_b, T_f, and T_i, respectively.

In writing the equations for the nine selected volumes, the mixing flows shown in Fig. 33 were adopted. The fuel flow enters volume V1 and mixes perfectly with the fluid already in V1. The blanket flow enters volume V2 and mixes perfectly with the fluid in V2. All of volume V1 enters V3. Volume V2, on the other hand, mixes with V1, V3, V4I, V4A, V5I, and V5A. Volume V3 mixes with V4I and V4A. Cross-flow mixing occurs between V5I and V5A and between V6I and V6A, but not between V4I and V4A.

The nine equations based on this flow pattern are listed in Appendix A. The computer model, EXIT1, is given in Appendix B.

To simulate the temperature profiles obtained experimentally, data from SR15 were used in obtaining input for the computer model. Linear approximations of the SR15 profile of the temperature transient were used as input to EXIT1 for T_{in}.

Similar approximations were carried out for the total flow, GPS, and the fuel flow, GPSC. Blanket flow, GPSB was constant at 32.5 gpm.

4.2 Discussion of Results

Very good agreement between prediction and data can be seen in most of the figures. It should be noted that the exit nozzle transient is the most important transient as it determines the temperature transient to components downstream of the plenum. In both tests, SR15 and SR16, good agreement can be seen. The computer code EXIT1 was based upon actual flow observations and, thus, fundamentally describes the flow conditions. However, the simplicity of the code does not allow for some of the complexities of the mixing processes. The largest deficiency is in the handling of V2. In this case, the assumed flow enters from the blanket assemblies only. In the real case, a recirculating region exists and flow from V4A and V4I also enters V2. The reverse flow through the core plate testifies to this. Currently EXIT1 does not allow recirculation, but if further development is dictated, this feature could be included. Figure 15 shows data and prediction for V2. A nearly constant temperature for V2 is predicted resulting from a nearly constant blanket temperature. However, changes were measured which probably resulted from the recirculating flow field. Also shown are strong temperature fluctuations of approximately 35% of the total TOP temperature change at about the time the TOP occurred in V1. Part of these fluctuations resulted from pressure pulses being propagated downstream. These pressure changes, Fig. 34, may have caused a bulging of Region 1 into Region 2 with resulting temperature changes. It should be noted that these pressure fluctuations are a result of the experimental method employed in this test and are not prototypic of any reactor. Also shown in Fig. 34 is the measured total flowrate which was used in the computer code as input data.

Prediction and data for V2 during test SR18 are shown in Fig. 25 even though there was no blanket flow (this figure is included for completeness). A constant temperature is predicted and again a recirculating flow from V4I and V4A enters volume V2 and alters its temperature.

5.0 CONCLUSIONS

Steady state temperature oscillations were measured above the fuel-blanket interface and very small fluctuations were found. It was observed during flow visualization that a recirculating flow field above the core existed and acted as an effective mixing agent. Significant temperature fluctuations may exist at locations which were not monitored, such as near the top of the core barrel. At this location, hot recirculating fluid could collide with cold blanket flow.

Comparison of SR15 (fuel and blanket flow) and SR18 (fuel flow only) reveals the influence of blanket flow upon the mixing process. For the case simulated here, blanket flow had a small mitigating influence because it amounted to only 1/7 of the fuel flow. Data shown in Fig. 22 when related to a 75 MWt plant would have a 32.7°F/sec upramp and a 53.9°F/sec downramp for the TOP conditions described in Section 1. It should be noted that the actual TOP simulated was slightly more severe than the desired transient. For the case of no blanket flow, Fig. 32, a simulated upramp of 37°F/sec and a downramp of 59.7°F/sec was obtained.

The geometry tested here had no mixing enhancement devices. If a baffle were installed near the core barrel, the ratio of active to inactive flow could be changed to provide more uniform mixing. This would result in a milder exit transient than currently reported.

Since both cases were predicted with good accuracy by EXIT1, some confidence in this as a modeling tool can be assumed. However, incorporation of a recirculating region is recommended. As a first attempt, something like 40% of the flow from V4A and V4I could be allowed to enter V2. This modification would allow V2 to have some response and also to reduce the temperature rise in V3 and V4.

REFERENCES

1. J. J. Lorenz and P. A. Howard, A Study of CRBR Outlet Plenum Thermal Oscillations During Steady State Conditions, ANL-CT-76-36, July 1976.

2. P. A. Howard, Steady-State CRBR Outlet Plenum Mixing with an AFMS Core, ANL-CT-77-14, April 1977.

3. P. A. Howard, The Influence of Heterogeneous Core Geometry upon Outlet Plenum Mixing, ANL-CT-78-8, Nov. 1977.

4. J. J. Lorenz, R. D. Carlson, and P. A. Howard, The Influence of Scale Size and Fluid Thermal Properties in Simulating LMFBR Outlet Plenum Behavior, AIChE Paper 35, National Heat Transfer Conference and AIChE Symposium Series No. 164, Vol. 73 (1977).

TABLE 1. Locations of Thermocouples

WORD(TC)	CHANNEL	DESCRIPTION
1		*
2		ALL DIMENSIONS ARE PROTOTYPIC
3		EBR2-SRM
4		115 CORE HOLES, 365 BLANKET HOLES
5		CENTER TEST VEHICLE COVERS 7 CORE HOLES
6		NO BAFFLES
7		ONE EXIT NOZZLE. LOCATED AT Ø DEGREES
8		ALL ANGLES ARE AS MARKED ON CORE BARREL
9		*
1Ø		*
11		*
12	2ØØ	*
13	2Ø2	*
14	2Ø4	*
5	6	
16	1Ø	*
17	212	*
18	214	*
9	6	
2Ø	2Ø	GPMT-1ØØ.
21	222	[illegible]BC-CALCULATED TOTAL BRINE FLOW
22	224	MICROSWITCH
23	6	5Ø - 5ØØ GPM TURBINE - COLD WATER
24	23Ø	5 - 5Ø GPM TURBINE - BLANKET
25	232	VELOCITY PROBE #1
6	4	VELOCITY PROBE #2
27	236	DPT (LEAKAGE FLOW)
28(1)	24Ø	CENTER 1Ø1.6 CM, HEIGHT 221.Ø CM, AT Ø'
29(2)	2	CENTER 111.8 CM, HEIGHT 2ØØ.7 CM, AT Ø'
3Ø(3)	244	CE TER 111.8 CM, HEIGHT 18Ø.Ø CM, AT Ø'
31(4)	246	CENTER 1Ø1.6 CM, HEIGHT 21Ø.8 CM, AT Ø'
2(5)	5Ø	CENTER [illegible] CM, HEIGHT 19Ø.5 CM, AT Ø'
33(6)	252	91.4 CM, HEIGHT 84.5 CM
34 7	254	CENTER 91.4, HEIGHT 221.Ø CM, AT Ø'
35(8)	6	ENTER 91. CM, HEIGHT 2ØØ.7 CM, AT Ø'
36(9)	26Ø	CE TER 91.4 CM, HEIGHT 18Ø.Ø CM, AT Ø'
37(1Ø)	262	CENTER 81.3 CM, HEIGHT 21Ø.8 CM, AT Ø'
8(1)	4	CENTER [illegible] CM, HEIGHT 19Ø.5 CM, AT Ø'
39(12)	266	BROK N TC
4Ø(13	27Ø	CENTER 71.1 CM, HEIGHT 221.Ø CM, AT Ø'
41(14)	2	NTER 71.1 CM, HEIGHT 2ØØ.7 CM, AT Ø'
42(15)	274	CE E 71.1 CM, HEIGHT 18Ø.Ø CM, AT Ø'
3 6	6	CENTER 6 .Ø CM, HEIGHT 21Ø.8 CM, AT Ø'
44(17)	3ØØ	NT R 61.Ø CM, HEIGHT 19Ø.5 CM, AT Ø'
45(18)	3Ø2	CEN E 91.4 CM, HEIGHT 147.3 CM
46(19	3 4	CENTER 5Ø.8 CM, HEIGHT 221.Ø CM, AT Ø'
47(2Ø)	3Ø6	ENT R 5Ø.8 CM, HEIGHT 2ØØ.7 CM, AT Ø'
48(21)	31Ø	CENTER 5Ø.8 CM, HEIGHT 18Ø.Ø CM, AT Ø'
9(2)	2	CENTER 4 .6 CM, HEIGHT 21Ø.8 CM, AT Ø'
5Ø(23)	314	CENTER 4Ø.6 CM, HEIGHT 19Ø.5 CM, AT Ø'
51(24)	316	CENTER 91.4 CM, HEIGHT 177.8 CM

TABLE 1. Locations of Thermocouples (Contd.)

52(25)	320	CENTER 30.5 CM, HEIGHT 221.0 CM, AT 0'
53(26)	322	CENTE 30.5 CM, HEIGHT 200.7 CM, AT 0'
54(7	4	CENTER 30.5 CM, HEIGHT 180.0 CM, AT 0'
55(28)	6	NT R 20.3 CM, HEIGHT 210.8 CM, AT 0'
56(29)	330	CE TE 20.3 CM, HEIGHT 190.5 CM, AT 0'
57(30	332	CENTER 91.4 CM, HEIGHT 206.4 CM
58(1)	334	CENTER 10.1 CM, HEIGHT 221.0 CM, AT 0'
59(32)	336	CENTE 10.1 CM, HEIGHT 200.7 CM, AT 0'
60(3)	40	CENTER 1 .1 CM, HEIGHT 180.0 CM, AT 0'
61(34)	342	NT R 0.0 CM, HEIGHT 210.8 CM, AT 0'
62(35)	344	CE 0.0 CM, HEIGHT 190.5 CM, AT 0'
3(6	6	CENTER 91.4 CM, HEIGHT 236.9 CM
64(37)	350	TER 94.0 M, T 37.6 CM
65(38)	352	CENTER 129.5 CM, HEIGHT 37.6 CM
6(9)	4	CENTER 94.0 CM, HEIGHT 30.5 CM, AT 0'
67(40)	356	T 129.5 CM, HEIGHT 30.5 CM, AT 0'
68(41	360	CENTER 94,0 CM, HEIGHT 23.4 CM
9(2)	2	ENTER 129.5 CM, HEIGHT 23.4 CM
70(43)	364	ON CO E PLATE (BLANKET REGION)
71(4)	6	*
2(5)	70	*
73(6)	3 2	*
74(47)	374	*
75(8	376	
6(9	400	CENTER 94 CM, HEIGHT 0 CM, AT 180'
77(50)	402	T R 94 M, E T 30.5 CM, AT 180'
78(51	404	CENTER 94 CM, HEIGHT 86.4 CM, AT 180'
9(2,	- 6	CENTER CM, HEIGHT 106.7 CM, AT 180'
80(53)	410	94 C , HEIGHT 137.2 CM, AT 180'
81(54	412	CENTER 94 CM, HEIGHT 167.6 CM, AT 180'
2(5)	4	LNTER M, HEIGHT 182.9 CM, AT 180'
83(56)	416	CE E 94 CM, HEIGHT 201.9 CM, AT 180'
84(7	20	CENTER 94 CM, HEIGHT 226.1 CM, AT 180'
85(58)	422	CORE TEMPERATURE (IN CORE PLATE)
86(59)	424	CENTER 52.0 CM, HEIGHT 81.3 CM, AT 10'
87(60	4 6	CENTER 52.0 CM, HEIGHT 81.3 CM, AT 70'
88(61)	430	ENT R 52.0 CM, HEIGHT 81.3 CM, AT 130'
89(62)	432	CENTER 52.0 CM, HEIGHT 81.3 CM, AT 190'
90(3)	4	CENTER 5 .0 CM, HEIGHT 81.3 CM, AT 250'
91(4)	436	NT R 52.0 CM, HEIGHT 81.3 CM, AT 310'
92(65)	440	*
3(6)	2	*
94(67)	444	*
95 68	446	*
6(9)	50	*
97(0)	452	*
98(71)	454	*
9(2)	6	
100(73)	460	*
101(74	462	*
2 5	4	
103(6)	6	*
104(77)	470	*

TABLE 1. Locations of Thermocouples (Contd.)

105(78)	472	*
1 6(9.	4	[illegible]
107(80)	476	*
108 81	500	TEST SECTION INLET TEE
1 9(2	2	TEMPERATURE OF THE 320 RESERVOIR
110(3)	504	T80 AT TEST SECTION INLET
111(84)	506	80 RECIRCULATE AND DORIC
2(5)	10	HEAT EXCHANGE INLET TEMPERATURE
113(6)	512	T X OUTLET TEMPERATURE
114 87	514	WATER TEMPERATURE FROM 2000 RESERVOIR
115(8)	6	SPARE TC CHANNEL
116	520	TEST SECTION ENTRANCE PRESSURE
117	522	BAD MPX CHANNEL
8	4	PRESSURE OF 320 RESERVOIR
119	526	SSUR O THE 2000 RESERVOIR
120	530	SPARE CHANNEL
121	2	TOTAL FLOW (GPMT)
122	534	INNER BLANKET FLOW (GPMB)
123	536	SPARE (OLD GPM80)
4		LAST PNEUMATIC RELAY WORD
125		AST EL CTRIC RELAY WORD
126		TRACK NUMBER
127		MINUTES
128		SECONDS

TABLE 2. Experimental Timetable Executed by Computer

THE TIME TABLE FILE NAME IS TIME4

THE NEW TIME TABLE IS:

EVENT NUM	MIN-HSEC TIME	CONTROL WORD PNEU	CONTROL WORD ELEC	RELAYS 8 2TSST	7 2TSOP	6 2TKST	5 2TKOP	4 82ST	3 82OP	2 STMST	1 STMOP	8 BYPA	7 32ØV	6 32ØP	5 2ØØOV	4 2ØØCP	3 4INCH	2 3INCH	1 2INCH
1	[illegible] Ø	[illegible]16[illegible]	[illegible]222	1	Ø	Ø	1	1	Ø	1	Ø	Ø	1	Ø	1	Ø	Ø	Ø	Ø
2	1[illegible]	[illegible]Ø5	[illegible]3[illegible]	1	[illegible]	[illegible]	1	1	[illegible]	1	[illegible]	Ø	Ø	1	Ø	1	Ø	Ø	[illegible]
3	1 2[illegible]	[illegible]	[illegible]Ø226	1	Ø	Ø	1	Ø	1	1	Ø	Ø	Ø	1	Ø	1	1	1	Ø
4	2 [illegible]	[illegible]	[illegible]	1	Ø	[illegible]	1	Ø	1	1	Ø	1	Ø	1	Ø	1	1	1	Ø
5	[illegible]	[illegible]2	[illegible]	1	[illegible]	[illegible]	1	Ø	1	1	Ø	1	Ø	1	Ø	1	Ø	1	[illegible]
6	[illegible] 16[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	Ø	1	[illegible]	Ø	1	Ø	1	Ø	1	Ø	Ø	Ø
7	[illegible] 17[illegible]	[illegible]4	[illegible]	1	Ø	Ø	1	Ø	1	1	Ø	1	Ø	1	Ø	1	1	Ø	[illegible]
8	3 3[illegible]	[illegible]	[illegible]32	1	[illegible]	[illegible]	1	1	Ø	1	Ø	Ø	Ø	1	Ø	1	Ø	Ø	Ø
9	7 [illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	Ø	1	[illegible]	[illegible]	Ø
10	1[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	1	1	[illegible]	1	Ø	Ø	[illegible]	1	Ø	1	Ø	Ø	Ø
11	17	[illegible]	[illegible]2	1	Ø	[illegible]	1	1	Ø	1	Ø	Ø	Ø	1	Ø	1	Ø	Ø	Ø
12	2[illegible]	[illegible]	[illegible]	1	Ø	Ø	1	1	Ø	1	Ø	Ø	Ø	1	Ø	1	Ø	Ø	Ø
13	[illegible]	[illegible]	[illegible]	1	Ø	Ø	1	1	Ø	1	Ø	Ø	Ø	1	Ø	1	Ø	Ø	Ø
14	[illegible]7	12[illegible]	[illegible]2	1	[illegible]	[illegible]	1	1	Ø	[illegible]	[illegible]	Ø	1	Ø	1	Ø	Ø	Ø	[illegible]
15	3[illegible]	[illegible]	[illegible]	1	Ø	Ø	1	1	[illegible]	1	Ø	Ø	1	Ø	1	Ø	Ø	Ø	Ø
16	[illegible]7	[illegible]	[illegible]	1	Ø	Ø	1	1	[illegible]	1	Ø	Ø	1	Ø	1	Ø	Ø	Ø	Ø

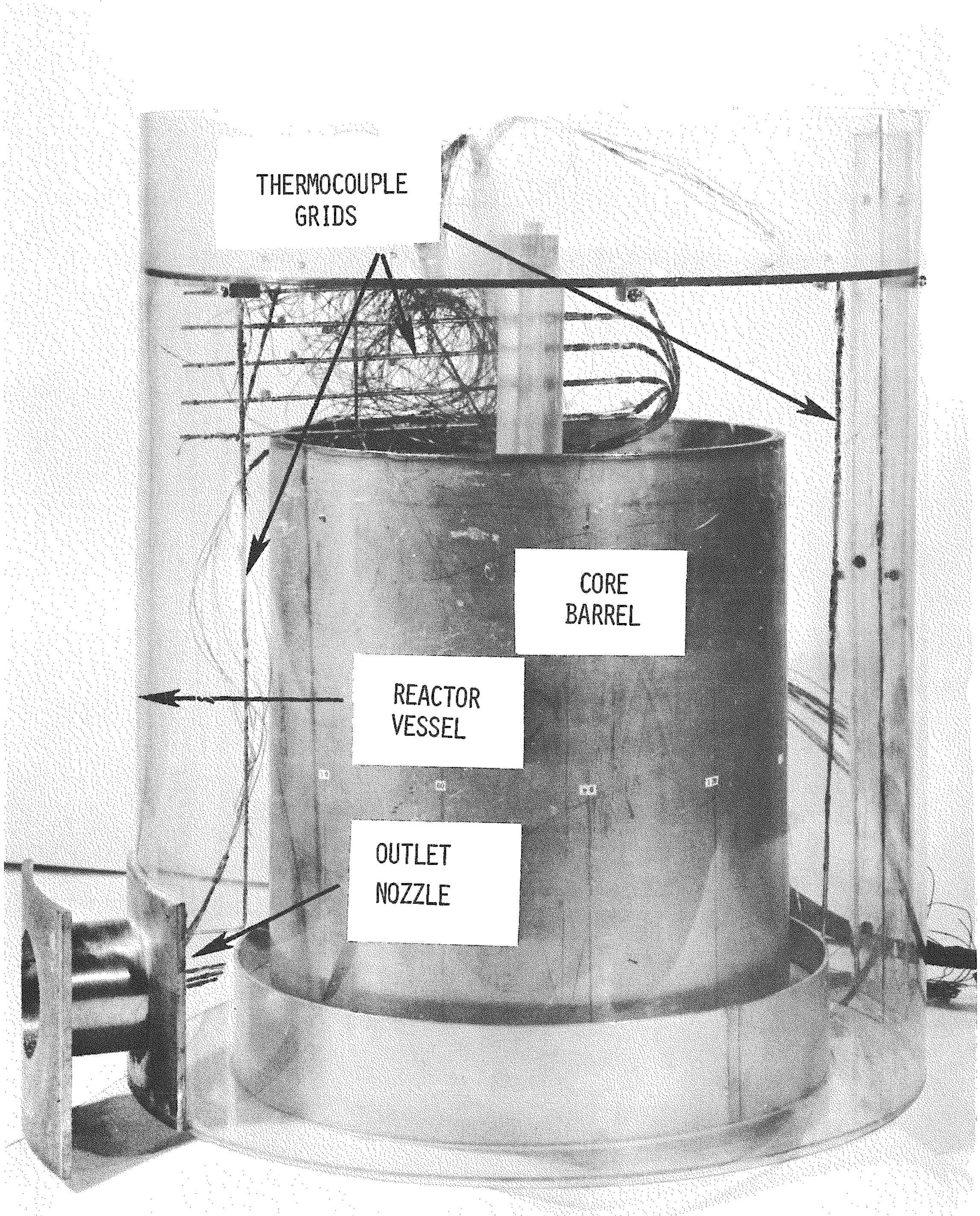


Fig. 1. Outlet Plenum with One-Exit Nozzle

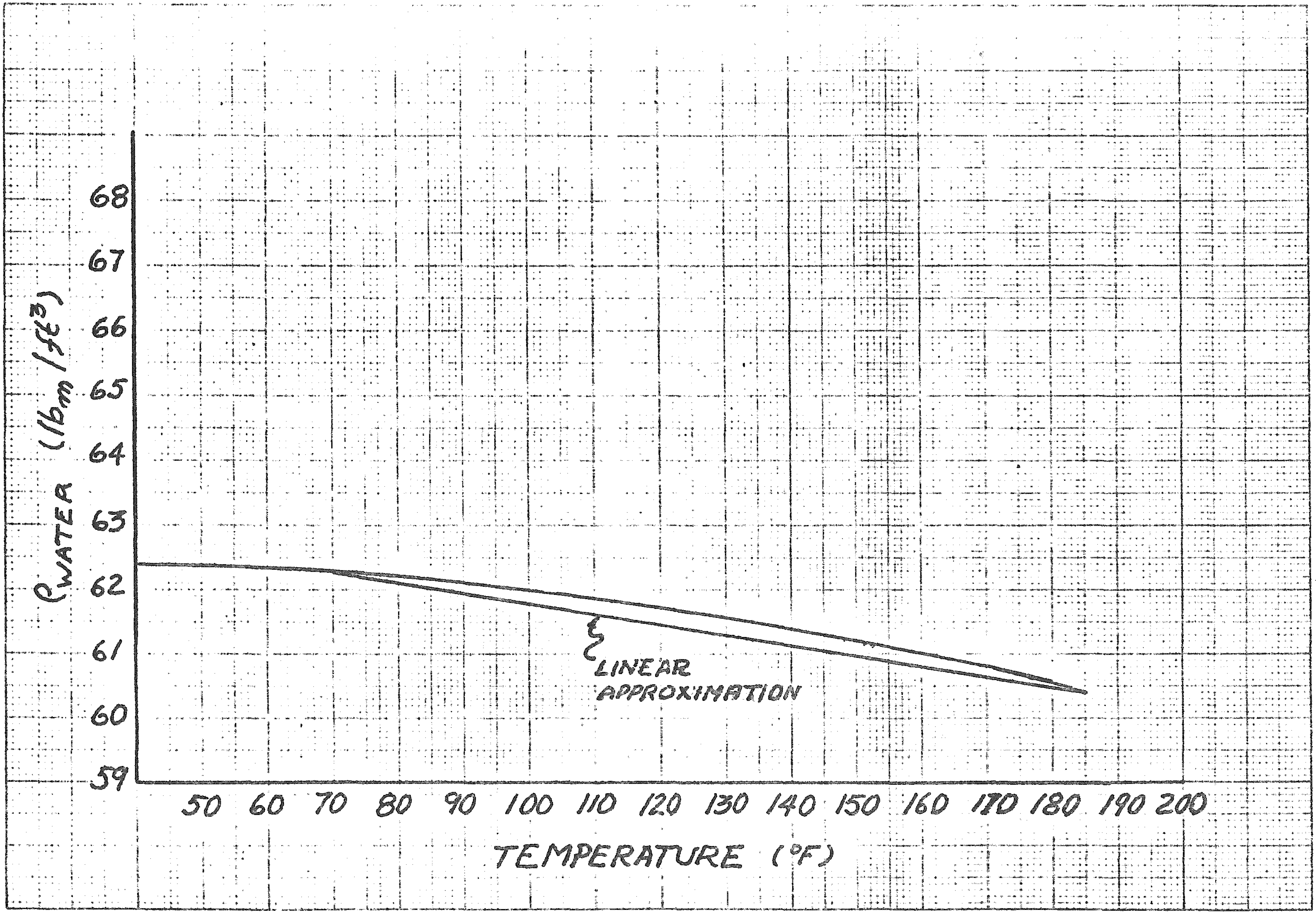


Fig. 2. Density of Water vs. Temperature

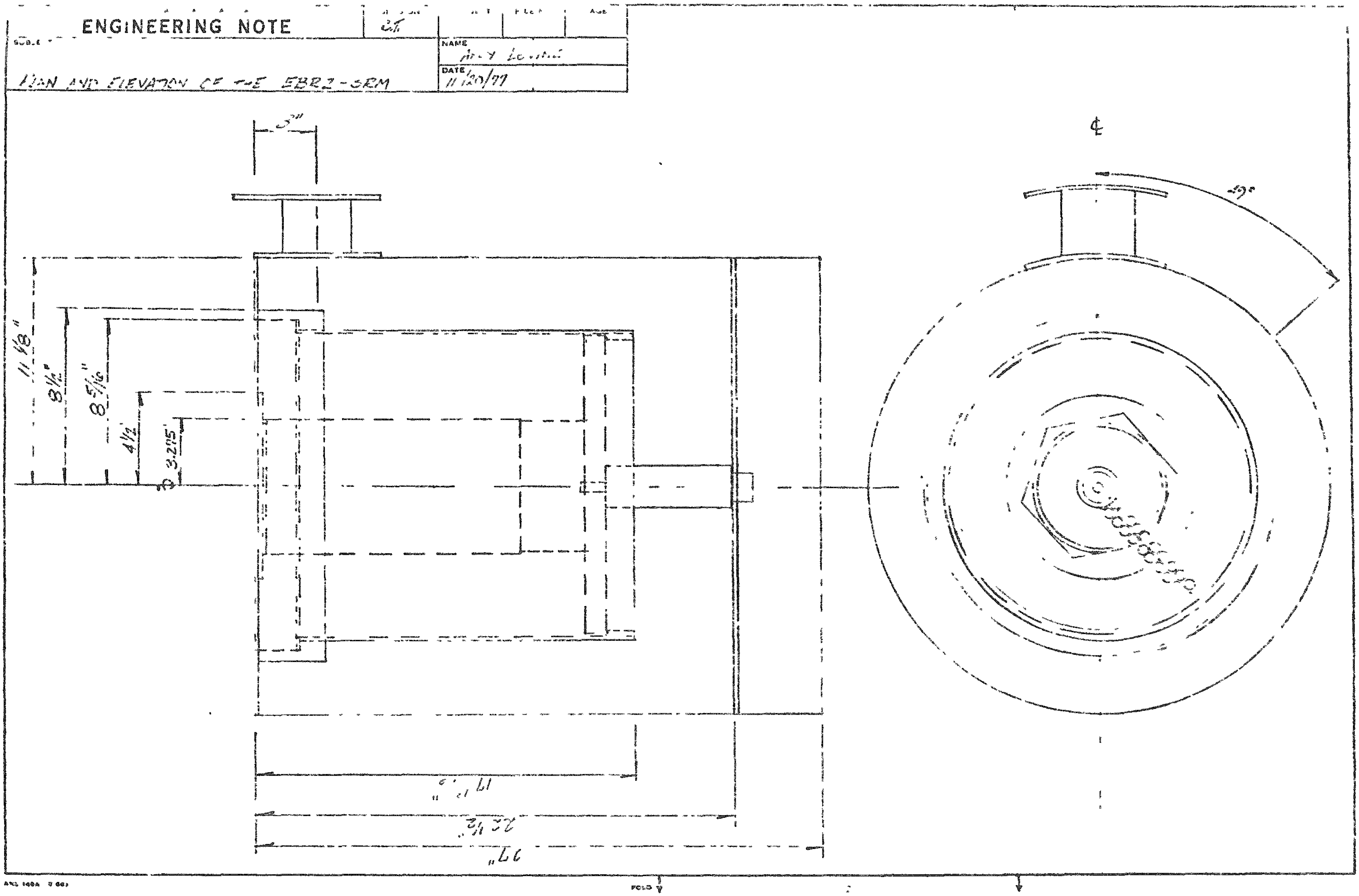


Fig. 3. Schematic of Outlet Plenum

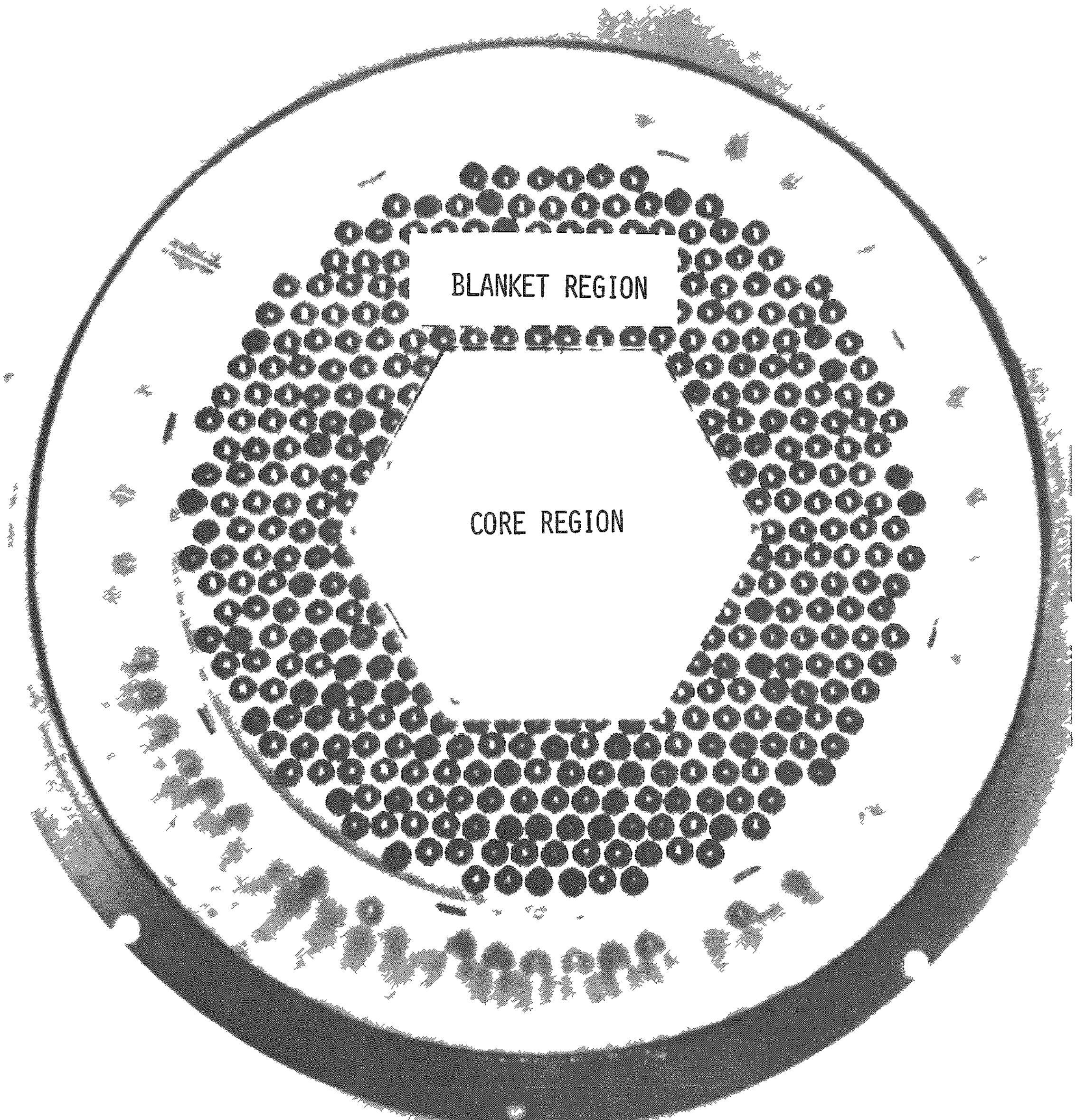


Fig. 4. Core Plate

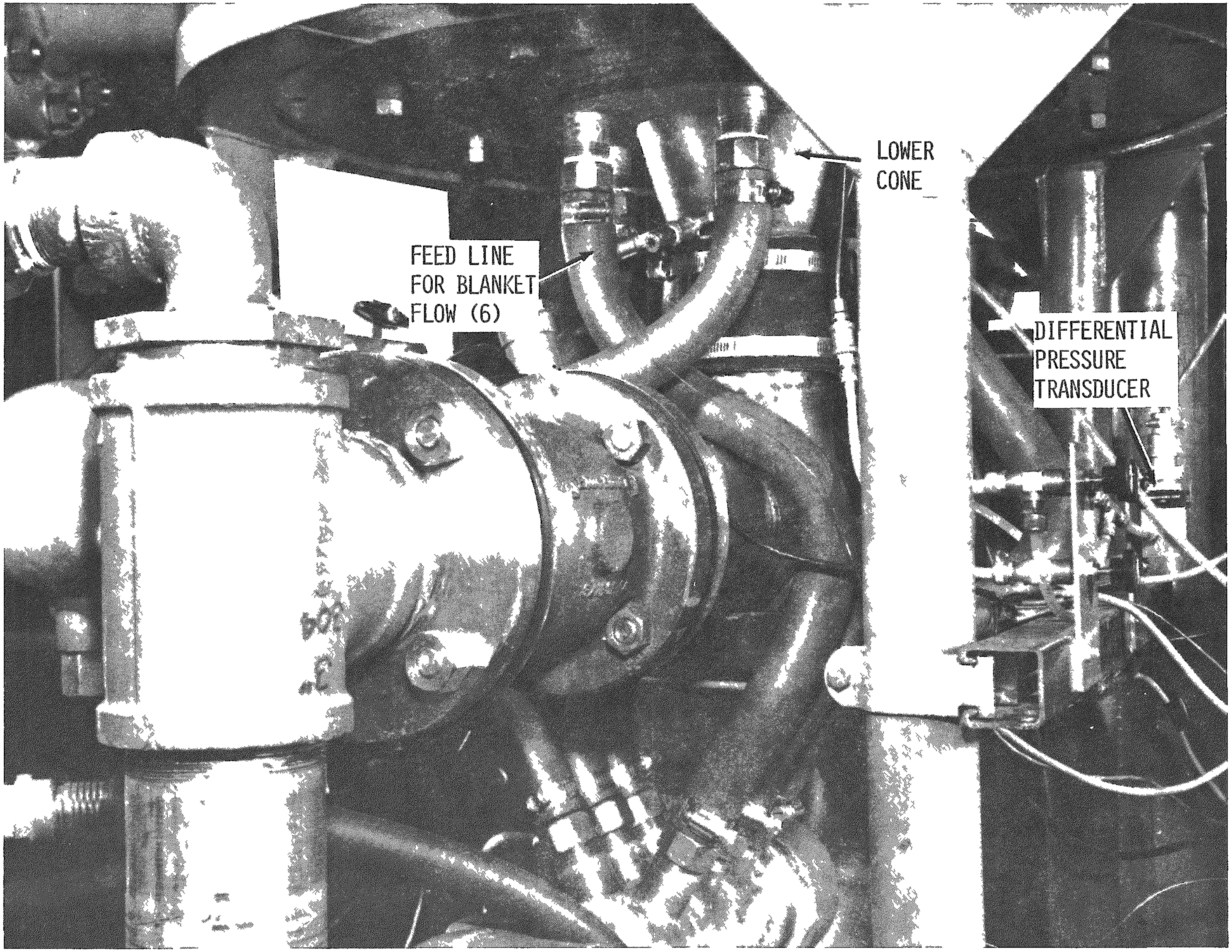


Fig. 5. Test Section Inlet Piping

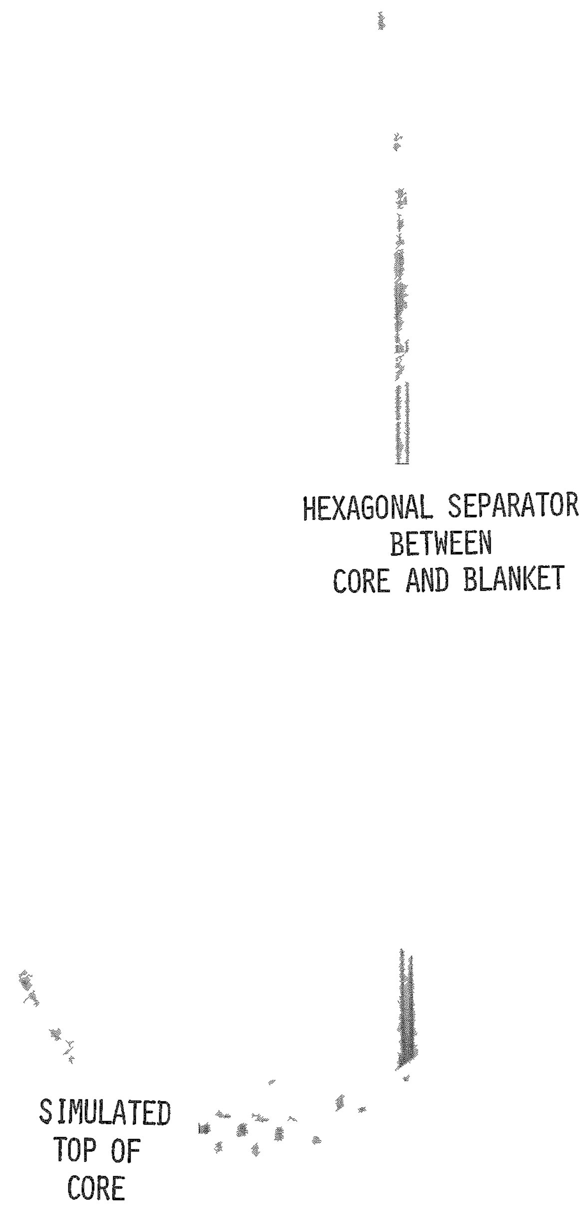


Fig. 6. Core Plate and Hexagonal Can

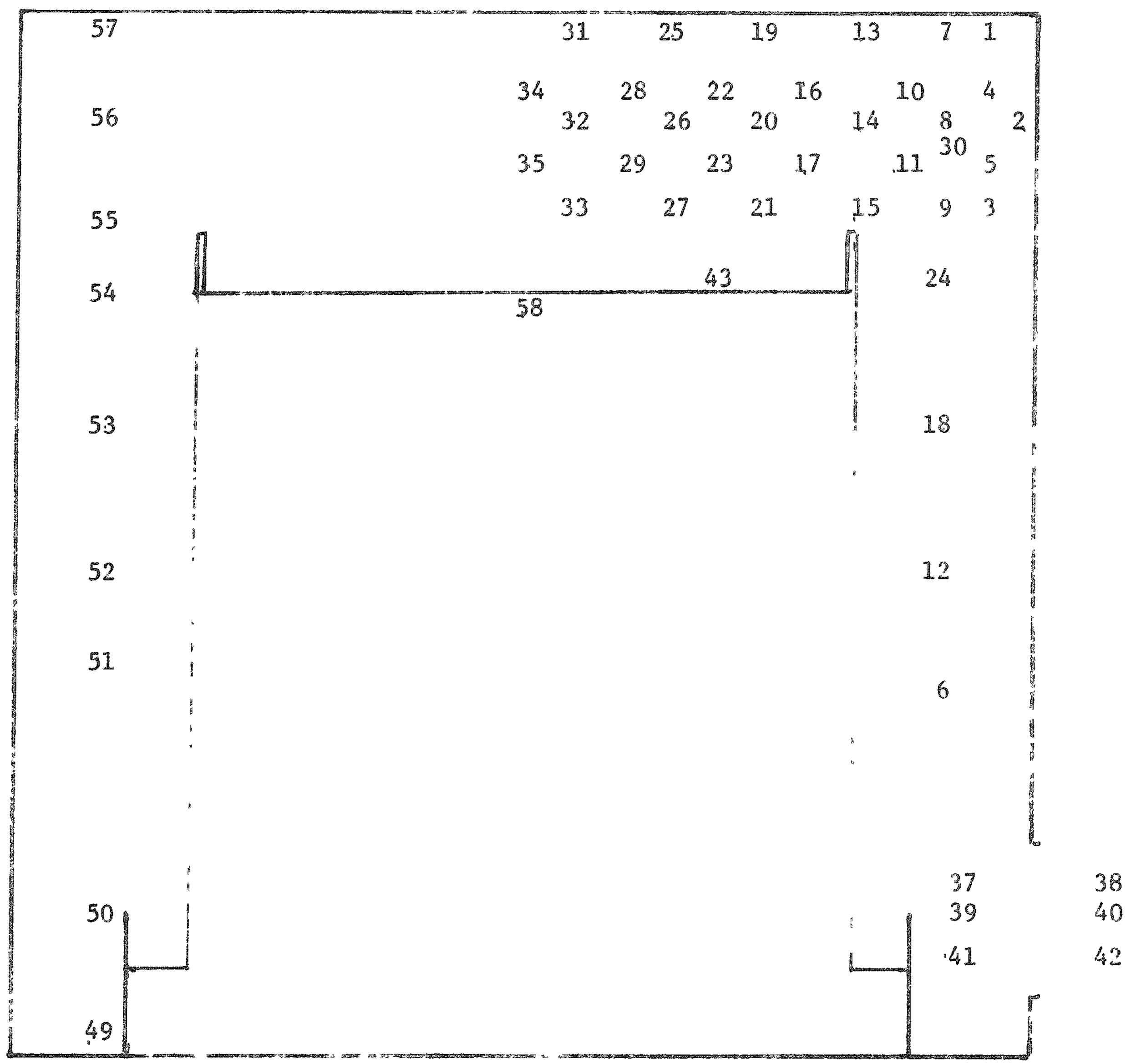


Fig. 7. Thermocouple Locations

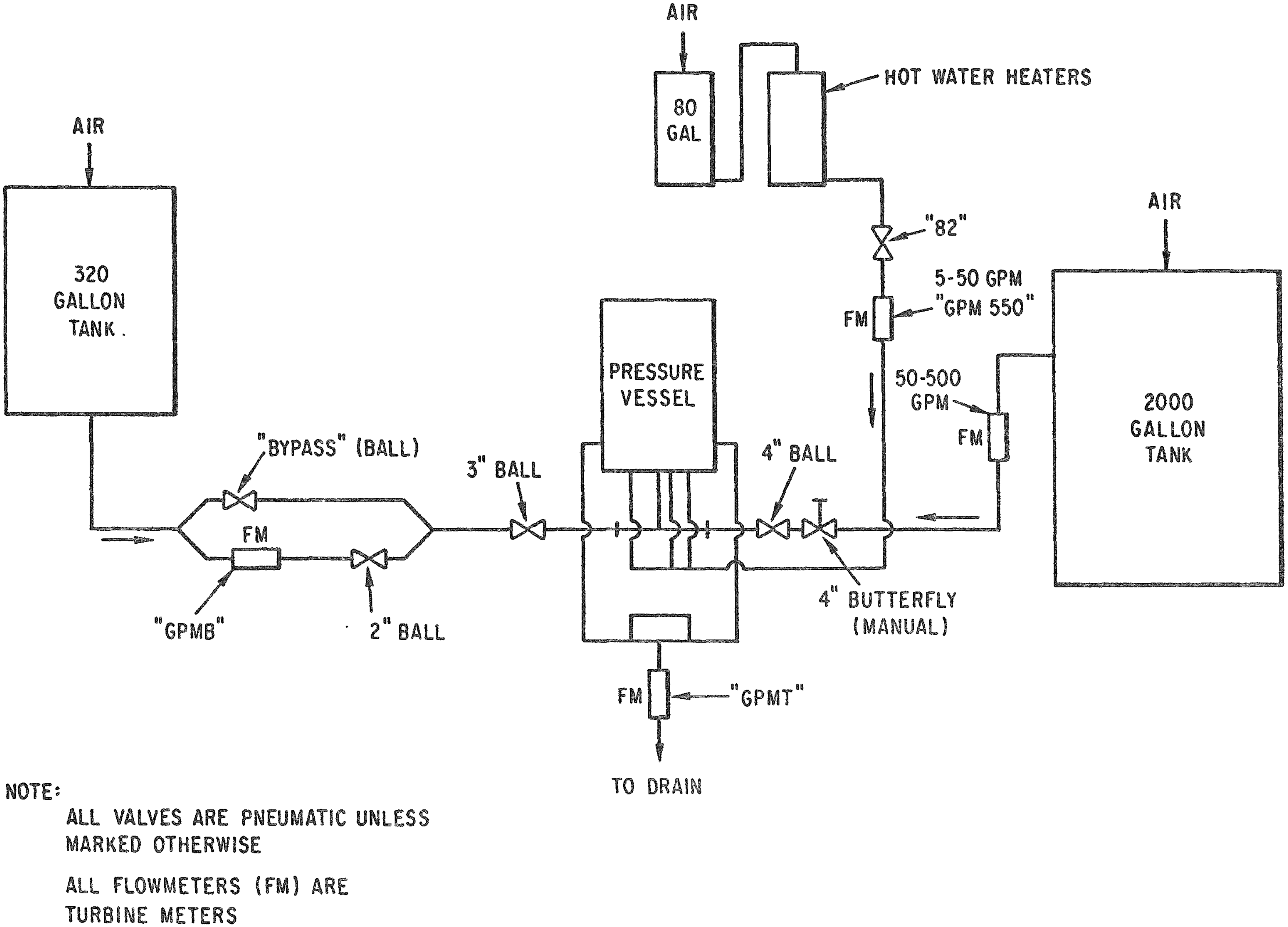


Fig. 8. Schematic of Test Facility

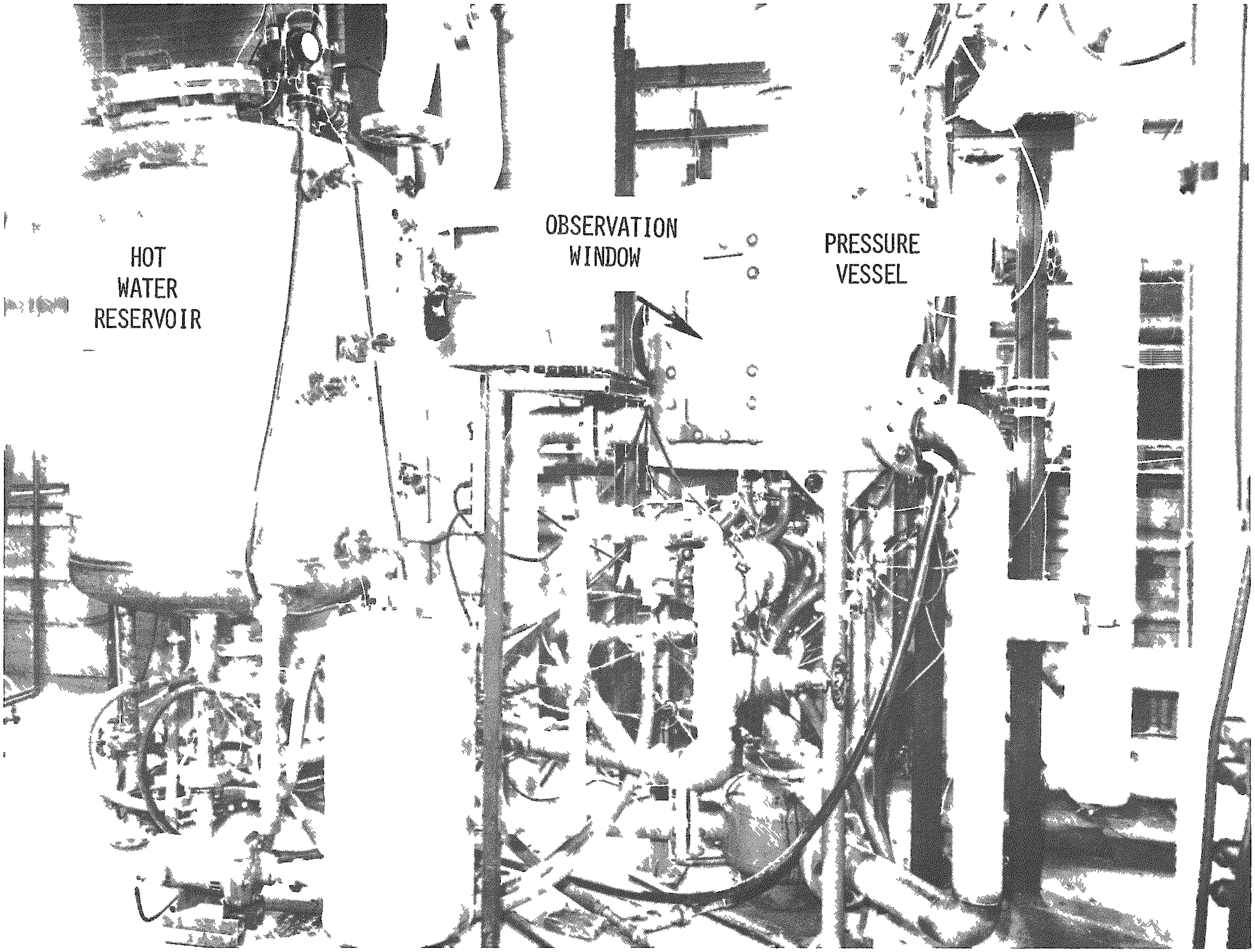


Fig. 9. Portion of Test Facility

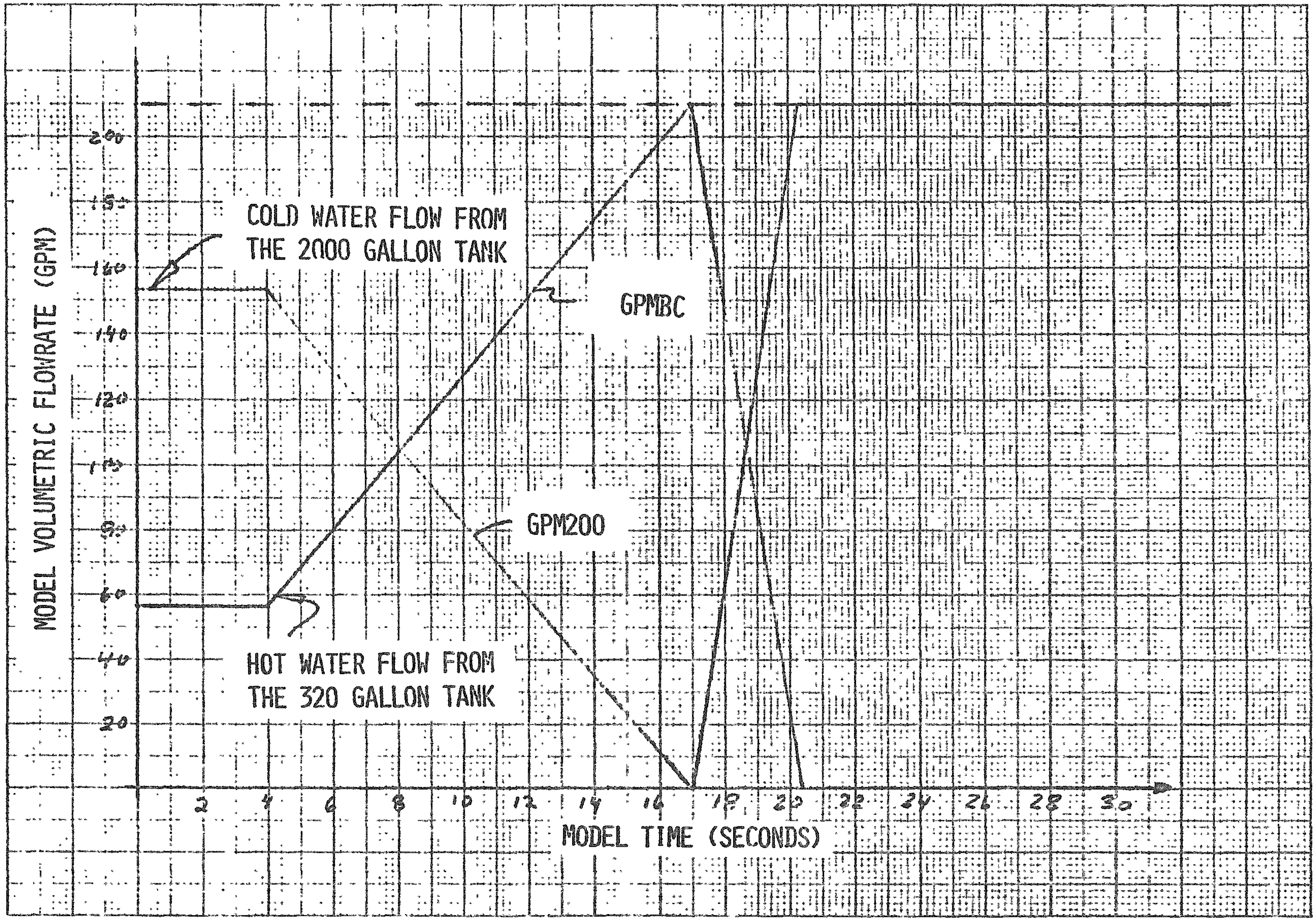


Fig. 10. Volumetric Flowrates Required to Simulate Temperature Transient.

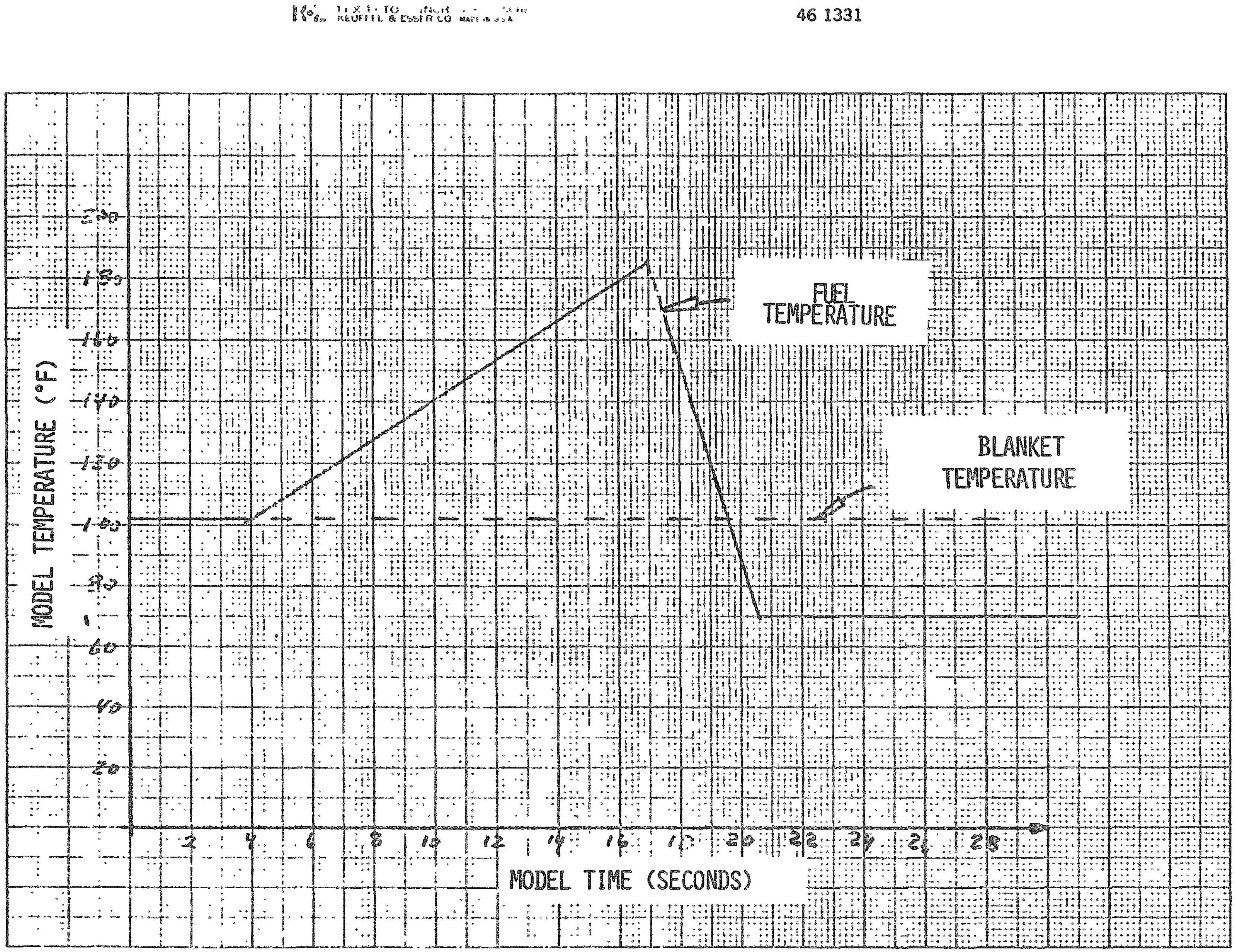


Fig. 11. Temperature Profile Required in Simulation of TOP Transient Conditions.

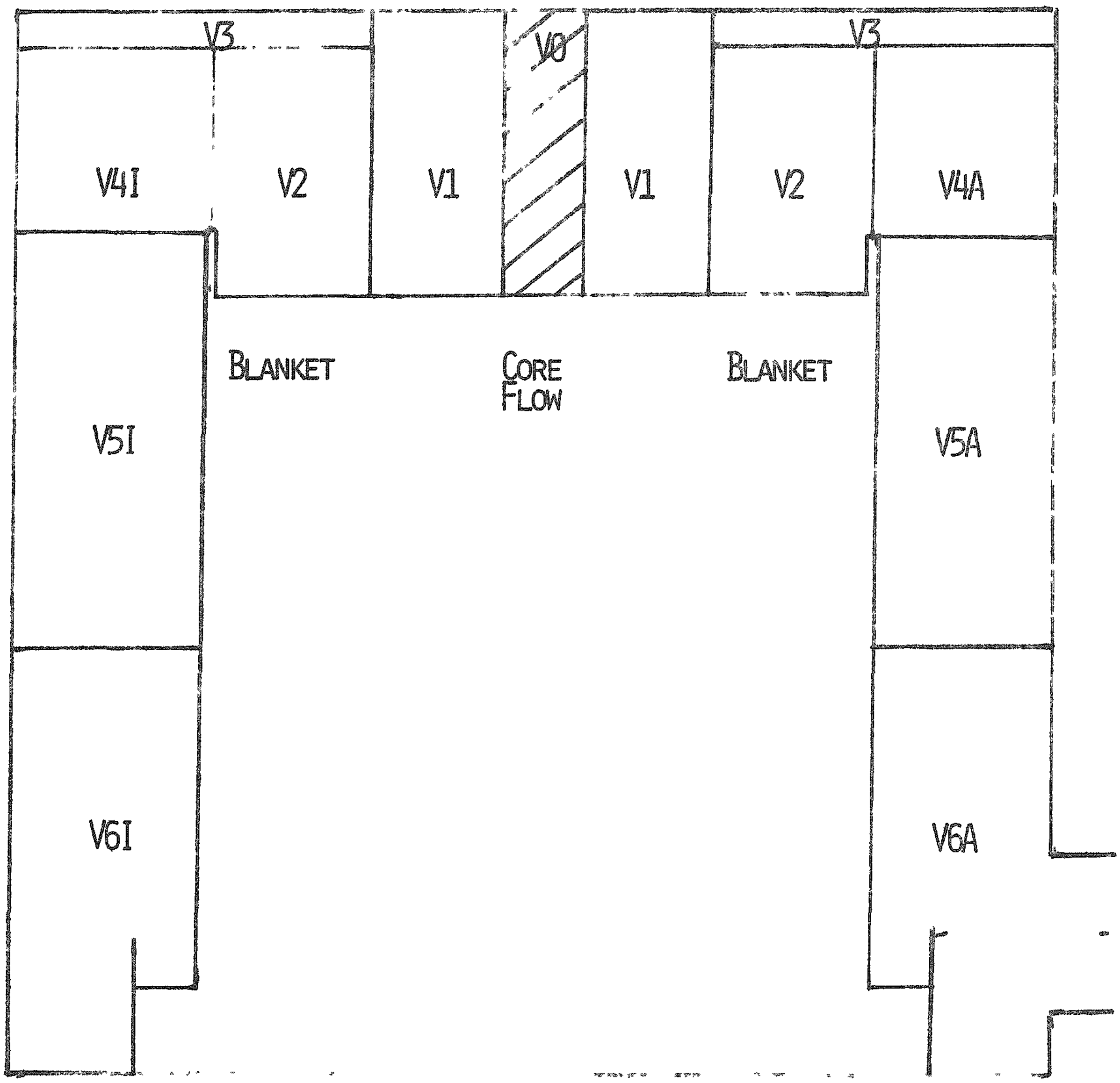


Fig. 12. Nine Regions Used in Developing Computer Model, EXIT1

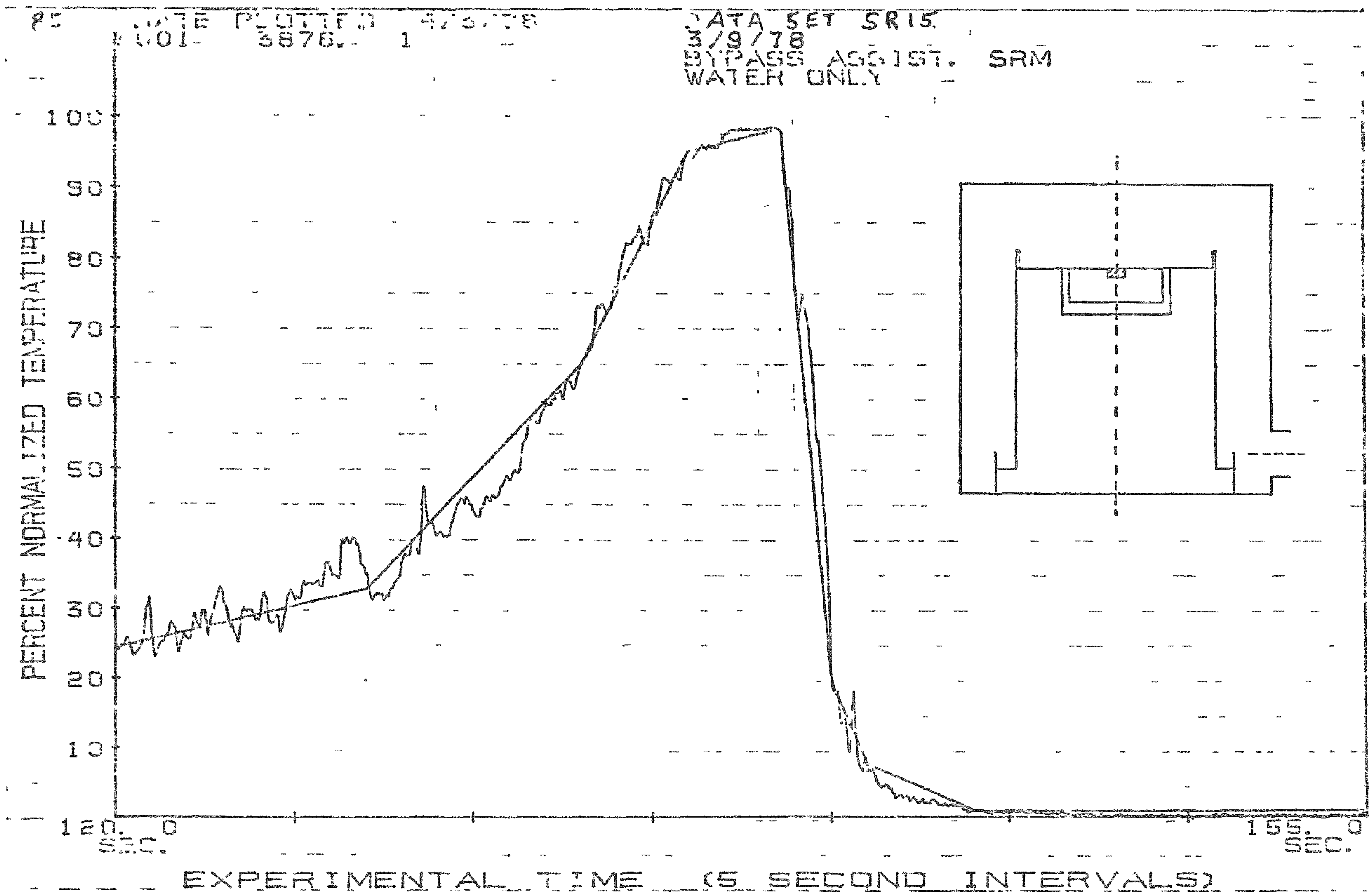


Fig. 13. Prediction and Data of Fuel Inlet for Simulated Transient with Fuel and Blanket Flows.

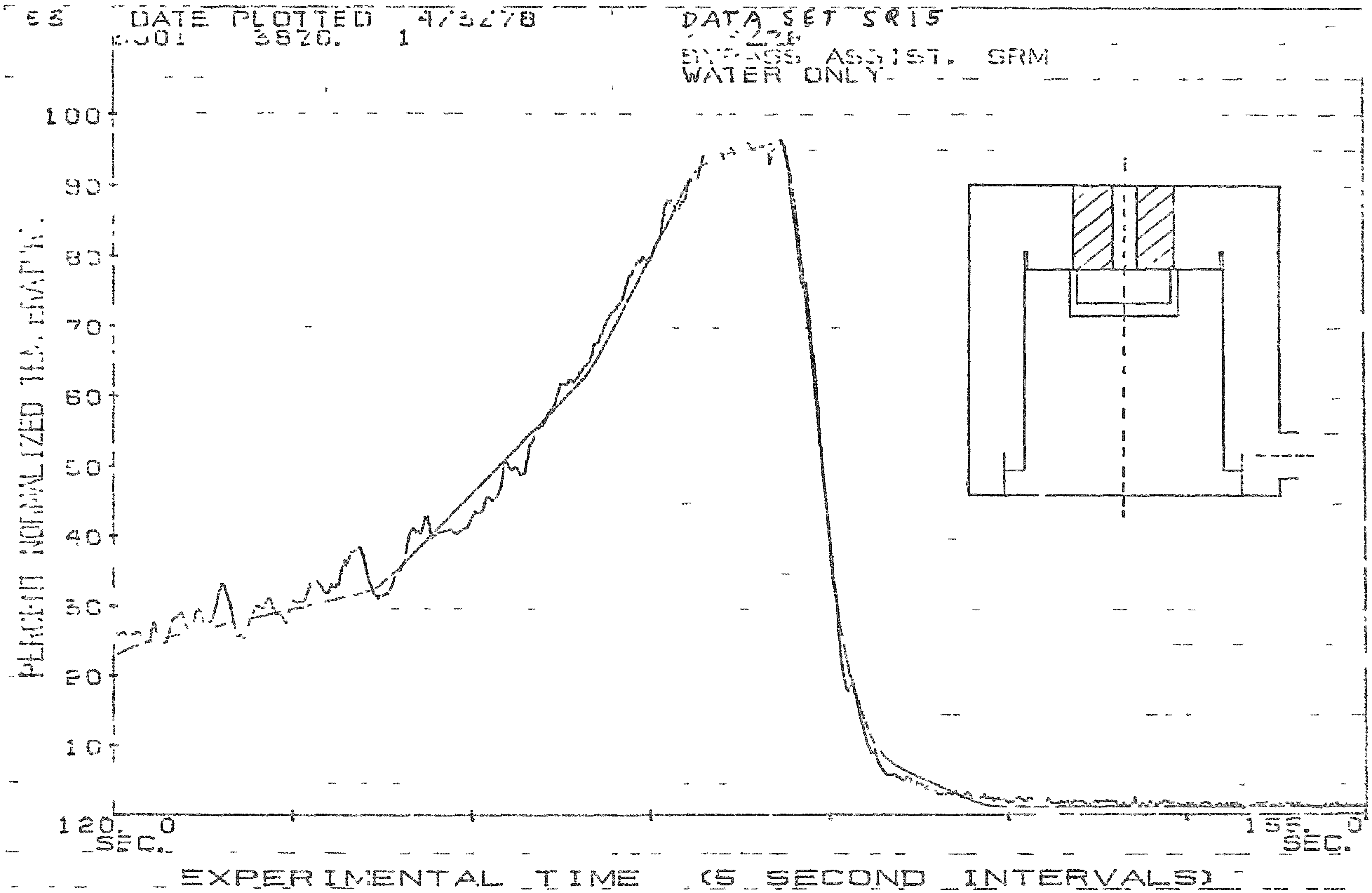


Fig. 14. Prediction and Data for Volume V1 for Simulated Transient with Fuel and Blanket Flows.

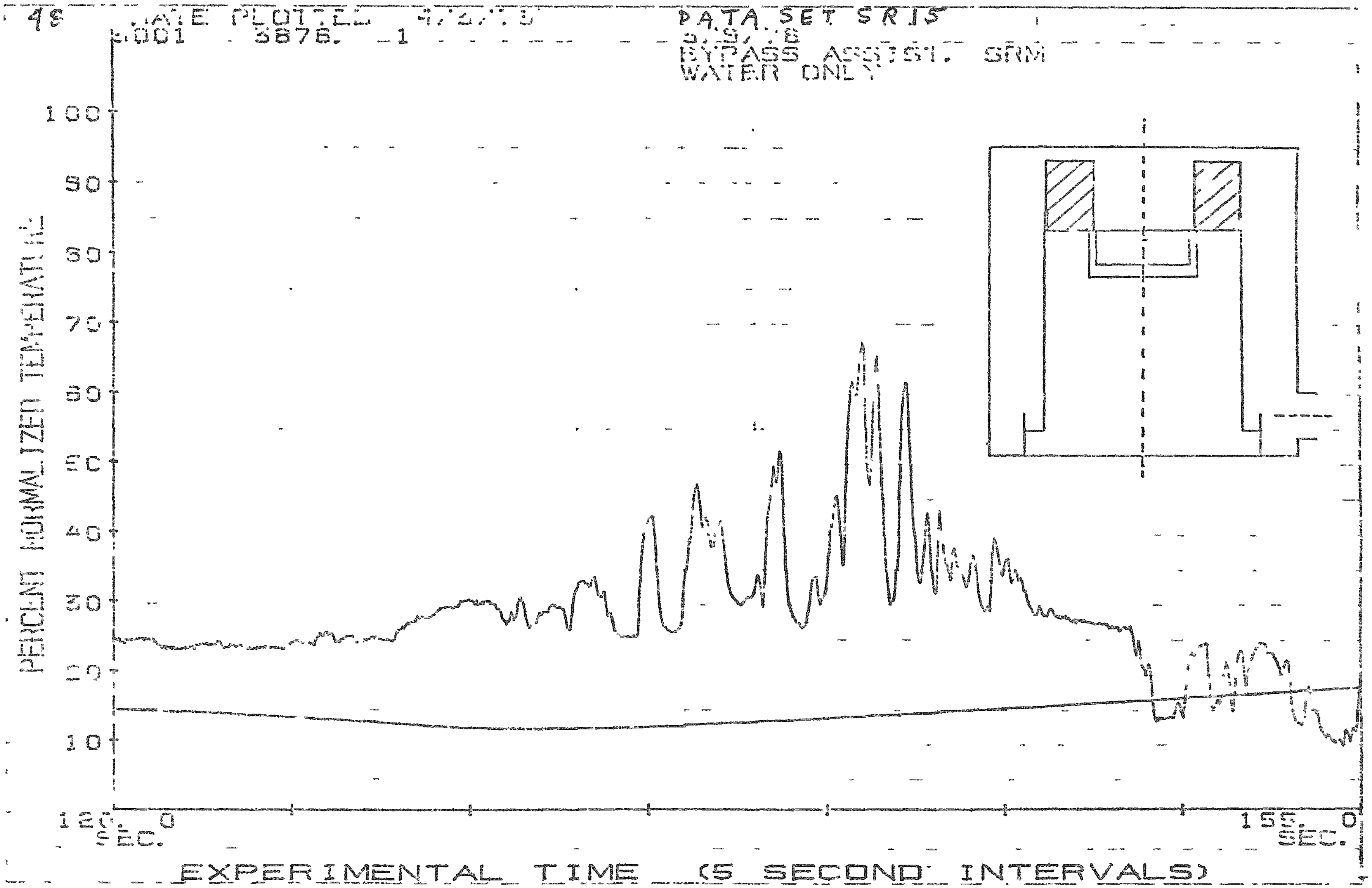


Fig. 15. Prediction and Data for Volume V2 for Simulated Transient with Fuel and Blanket Flows.

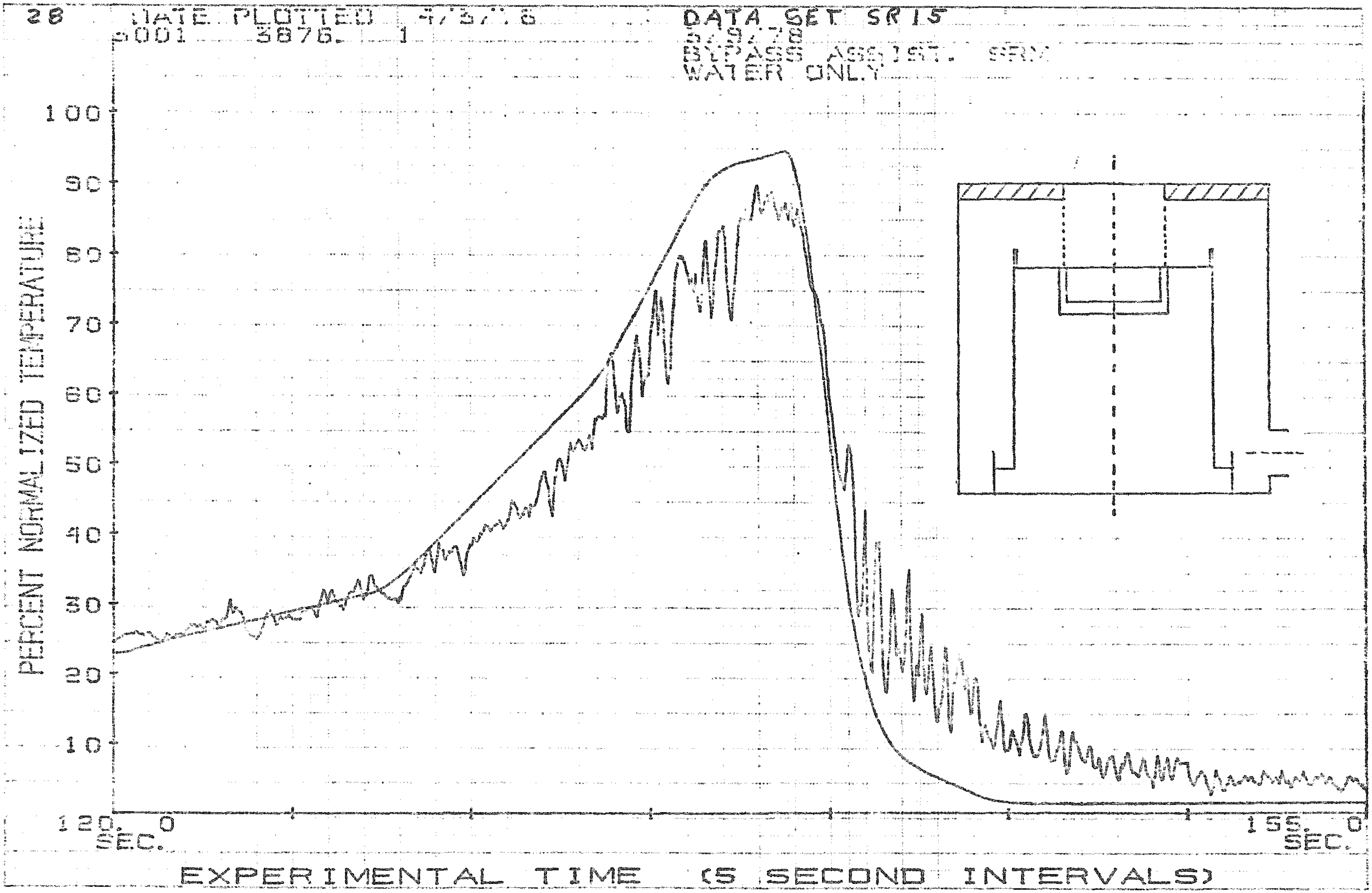


Fig. 16. Prediction and Data for Volume V3 for Simulated Transient with Fuel and Blanket Flows.

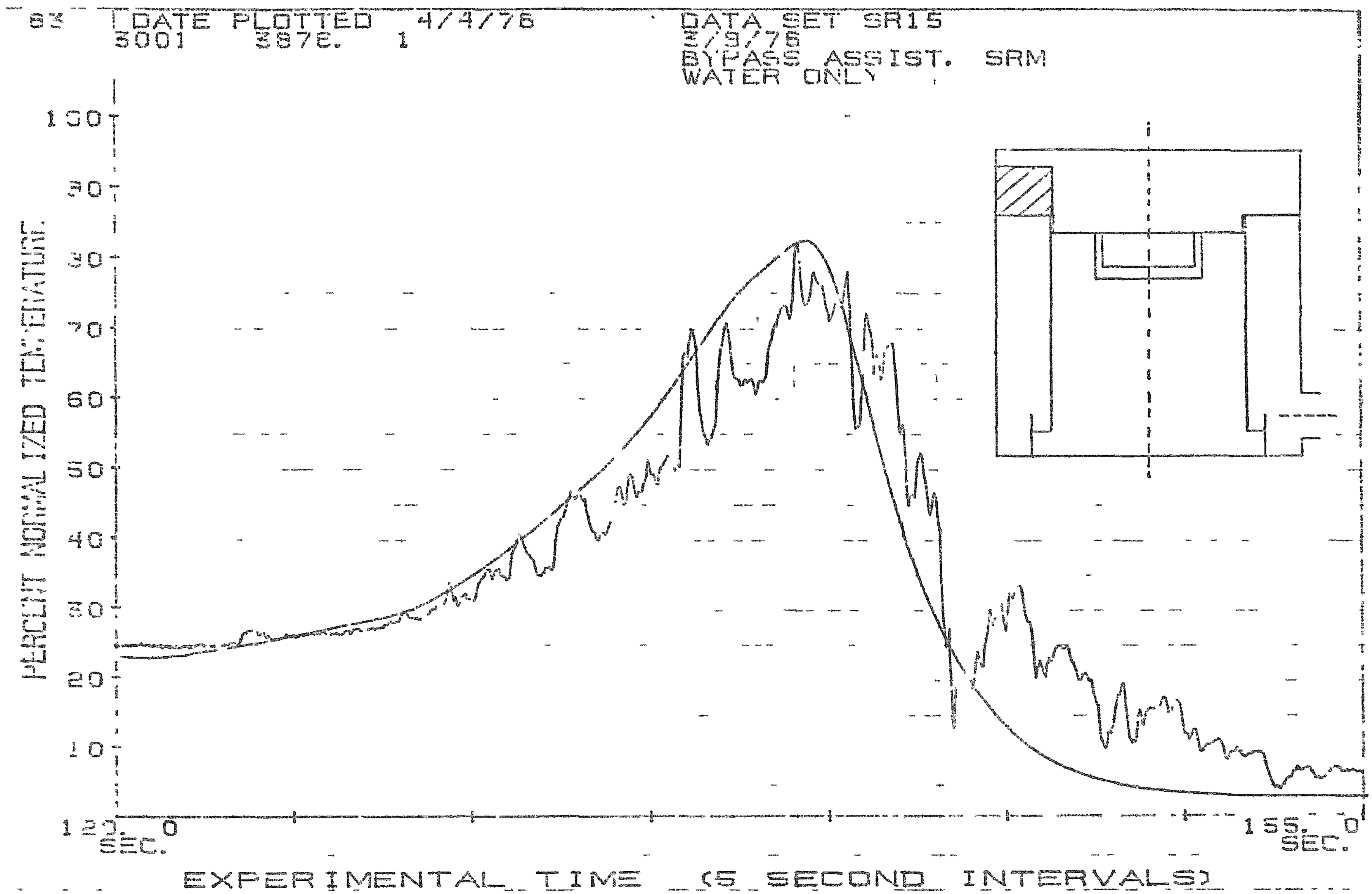


Fig. 17. Prediction and Data for Volume V4I for Simulated Transient with Fuel and Blanket Flows.

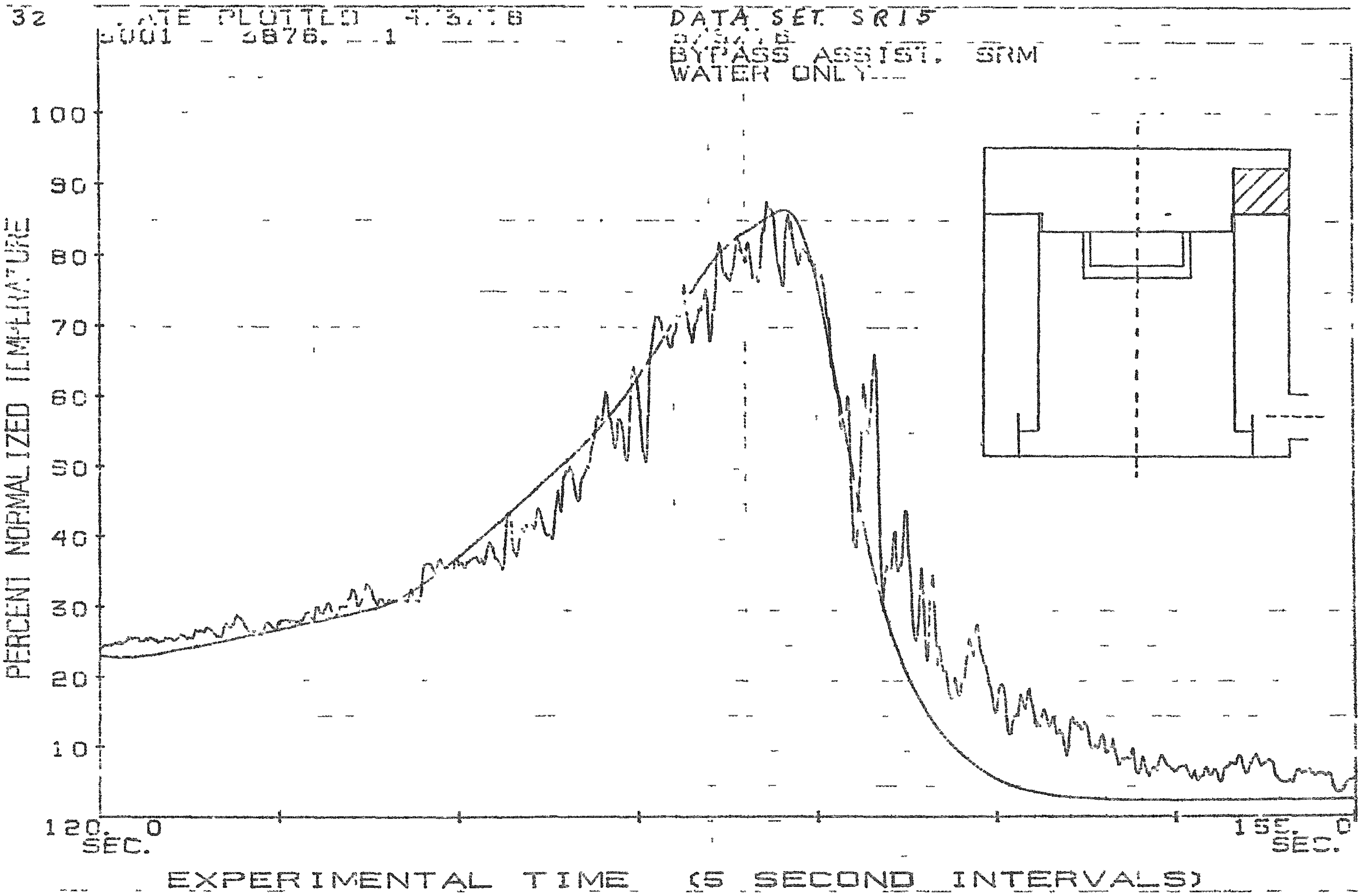


Fig. 18. Prediction and Data for Volume V4A for Simulated Transient with Fuel and Blanket Flows.

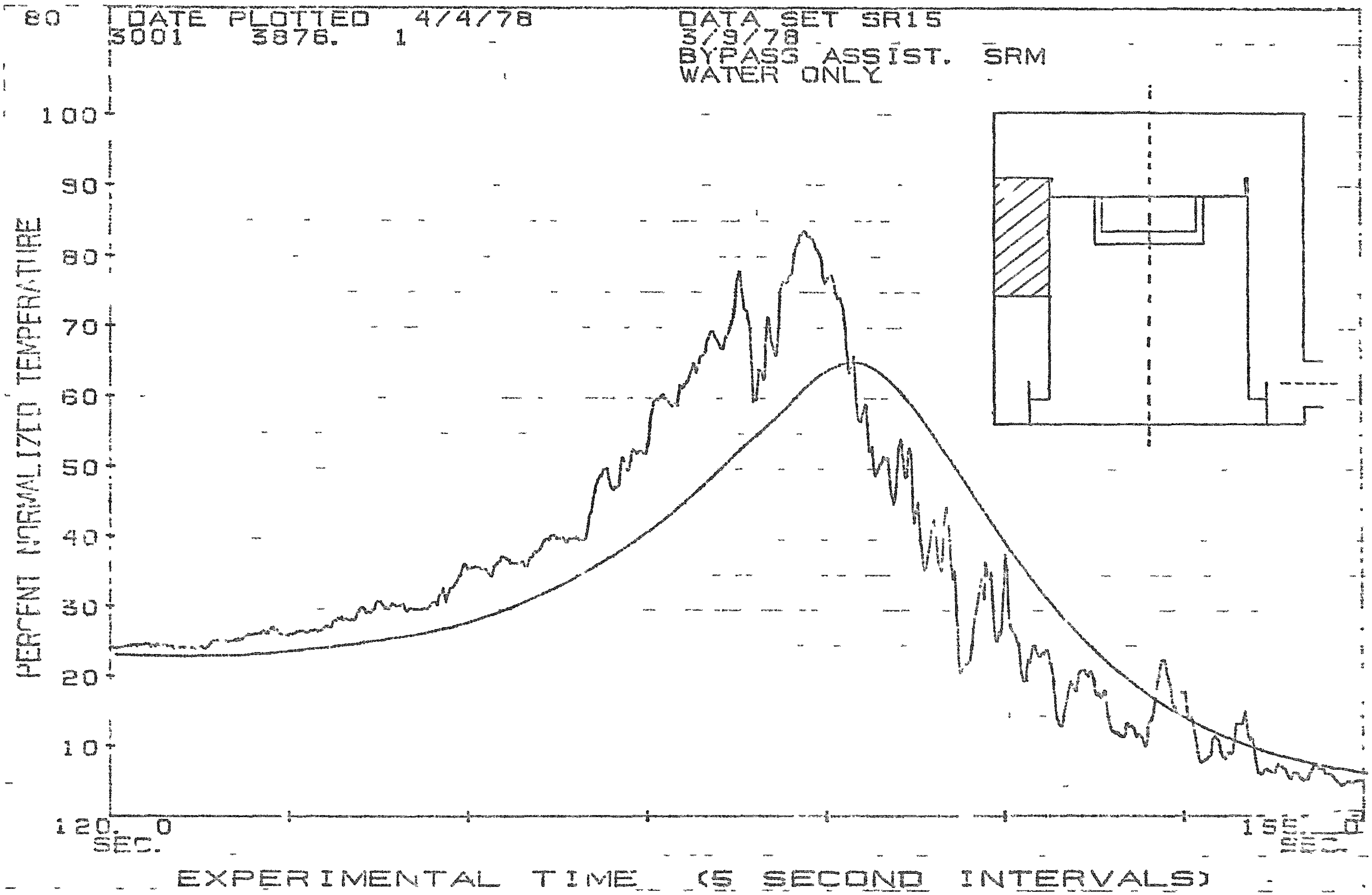


Fig. 19. Prediction and Data for Volume V5I and Simulated Transient with Fuel and Blanket Flows.

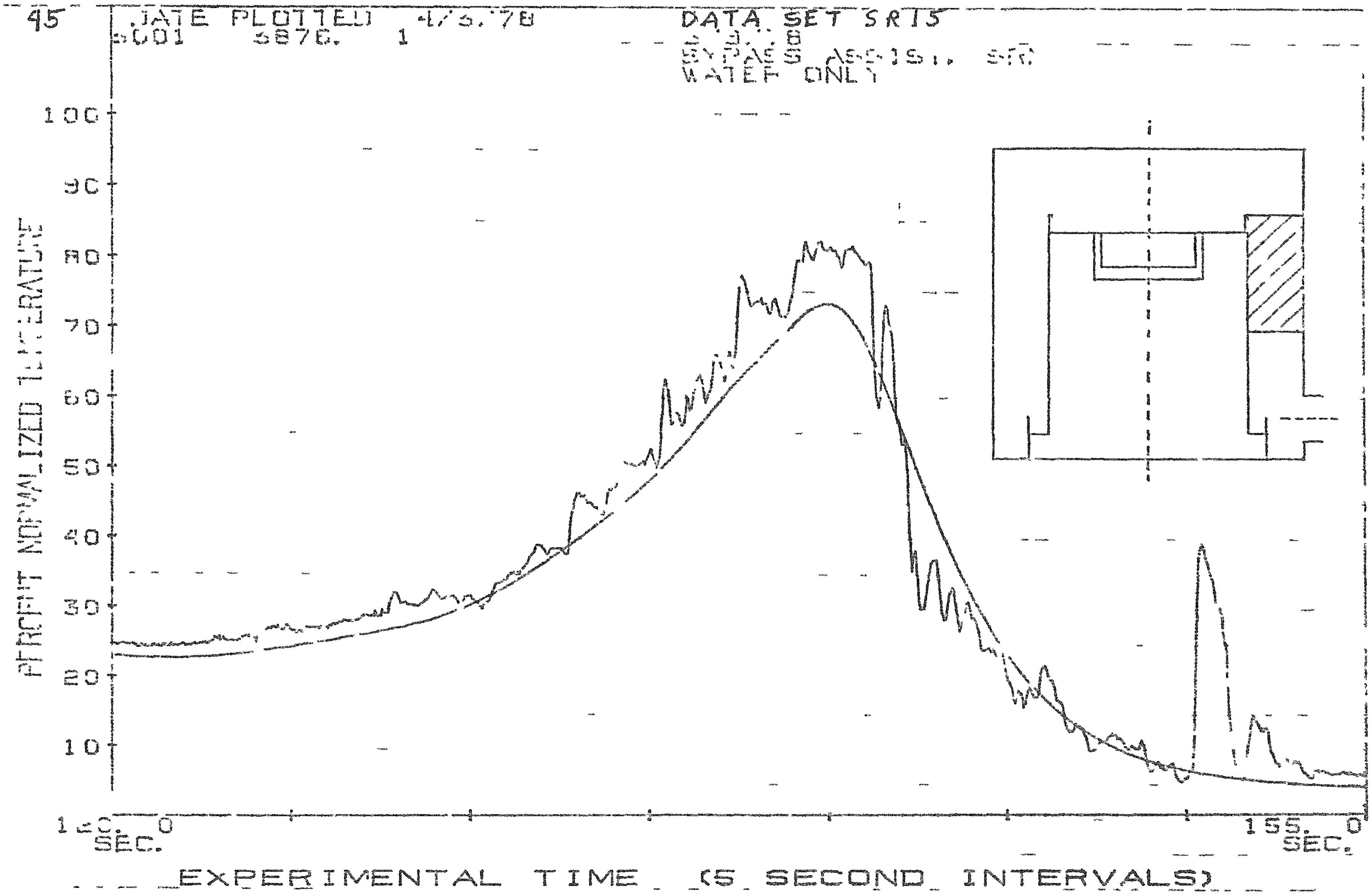


Fig. 20. Prediction and Data for Volume V5A and Simulated Transient with Fuel and Blanket Flows.

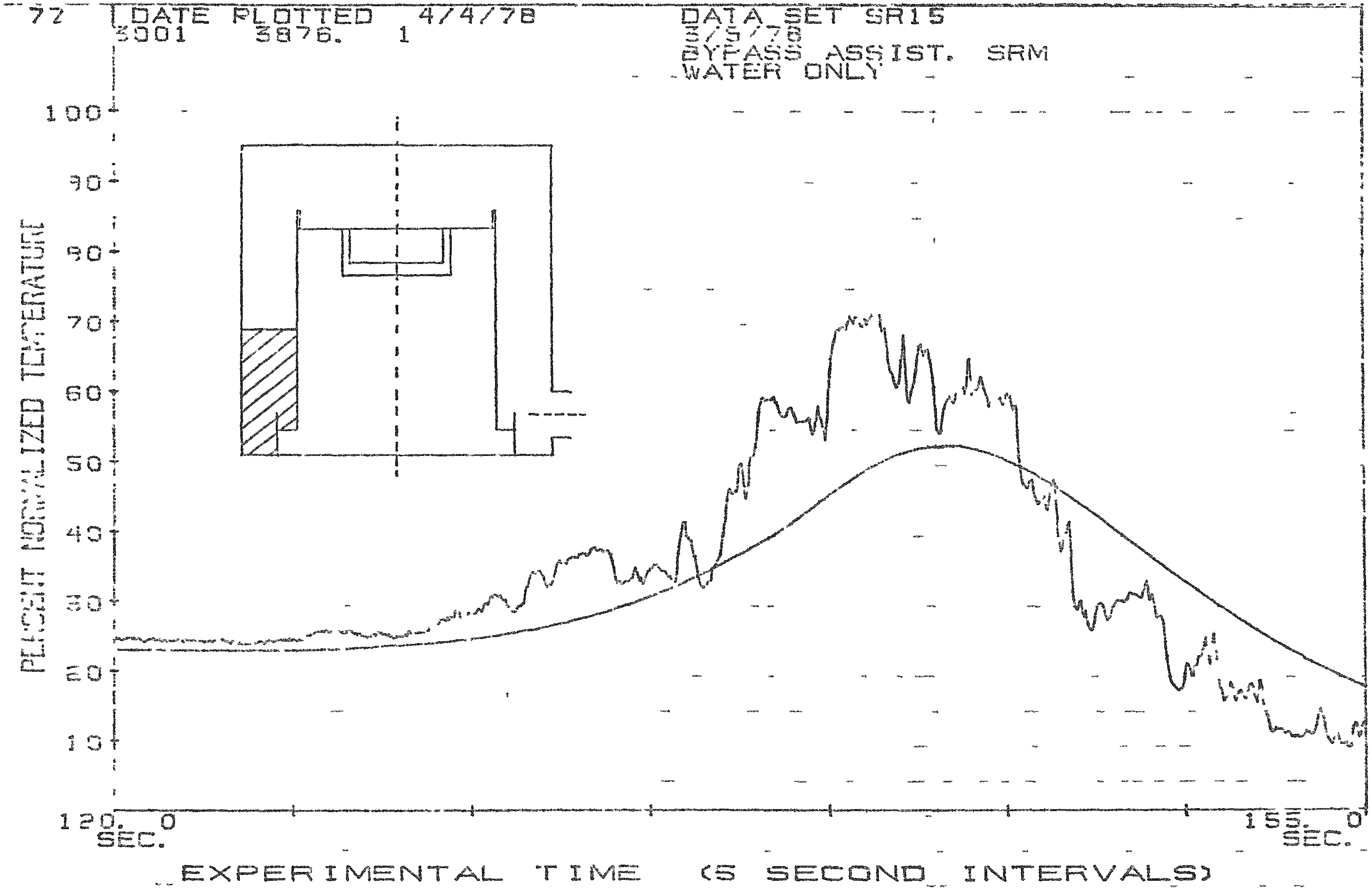


Fig. 21. Prediction and Data for Volume V6I and Simulated Transient with Fuel and Blanket Flows.

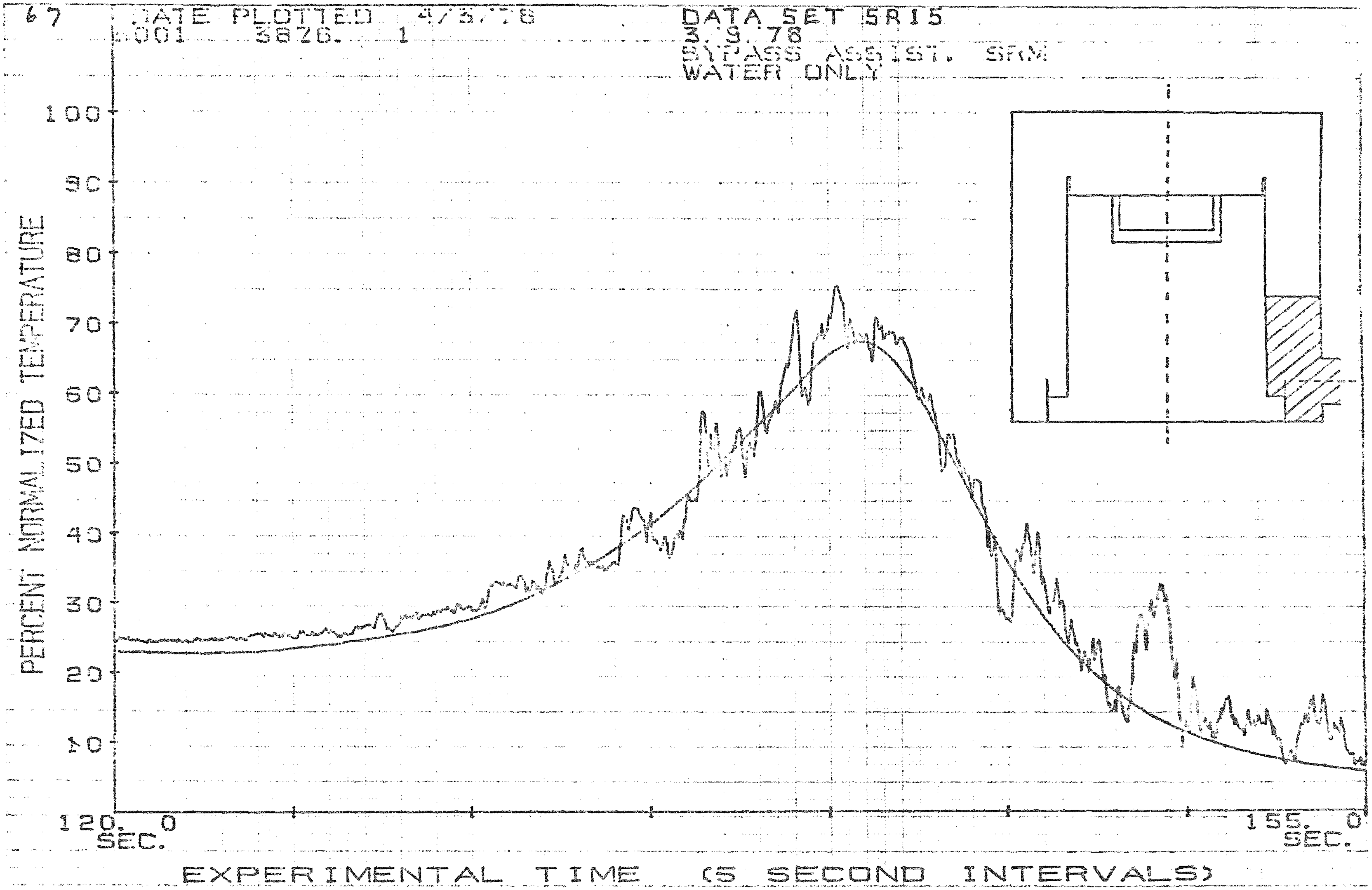


Fig. 22. Prediction and Data for Volume V6A and Simulated Transient with Fuel and Blanket Flows.

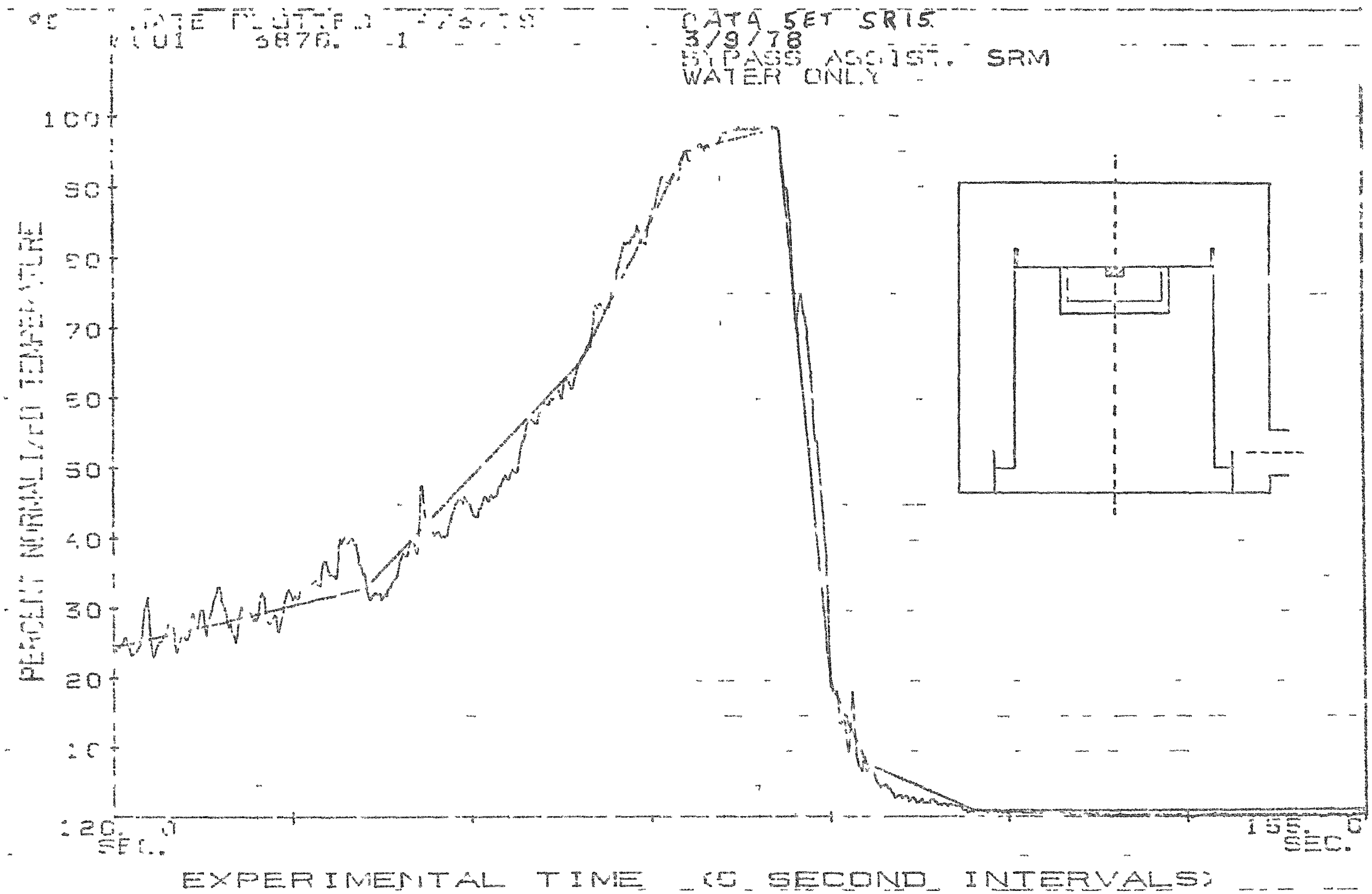


Fig. 23. Prediction and Data of Fuel Inlet for Simulated Transient with Fuel Flow Only.

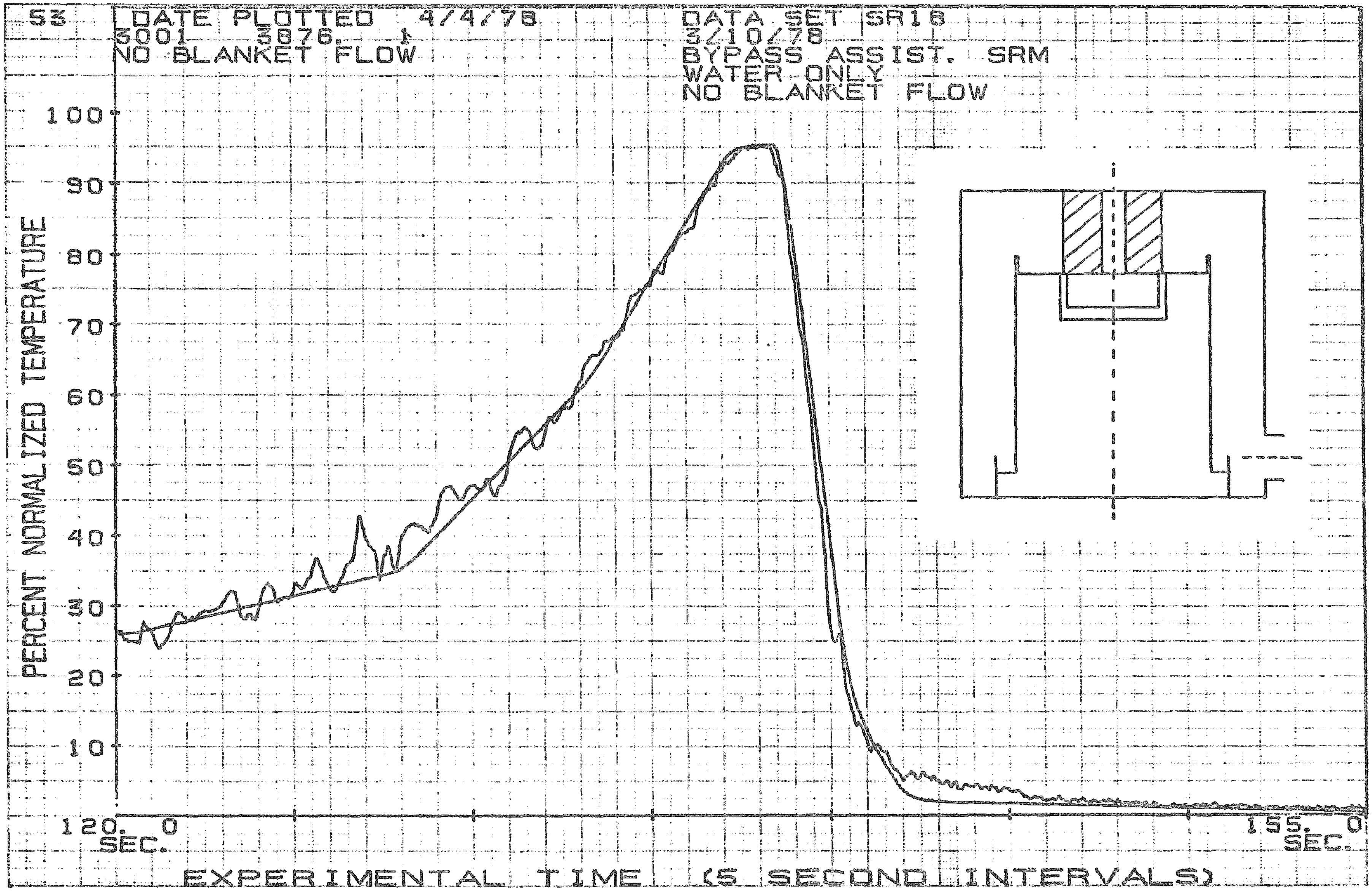


Fig. 24. Prediction and Data for Volume V1 for Simulated Transient with Fuel Flow Only.

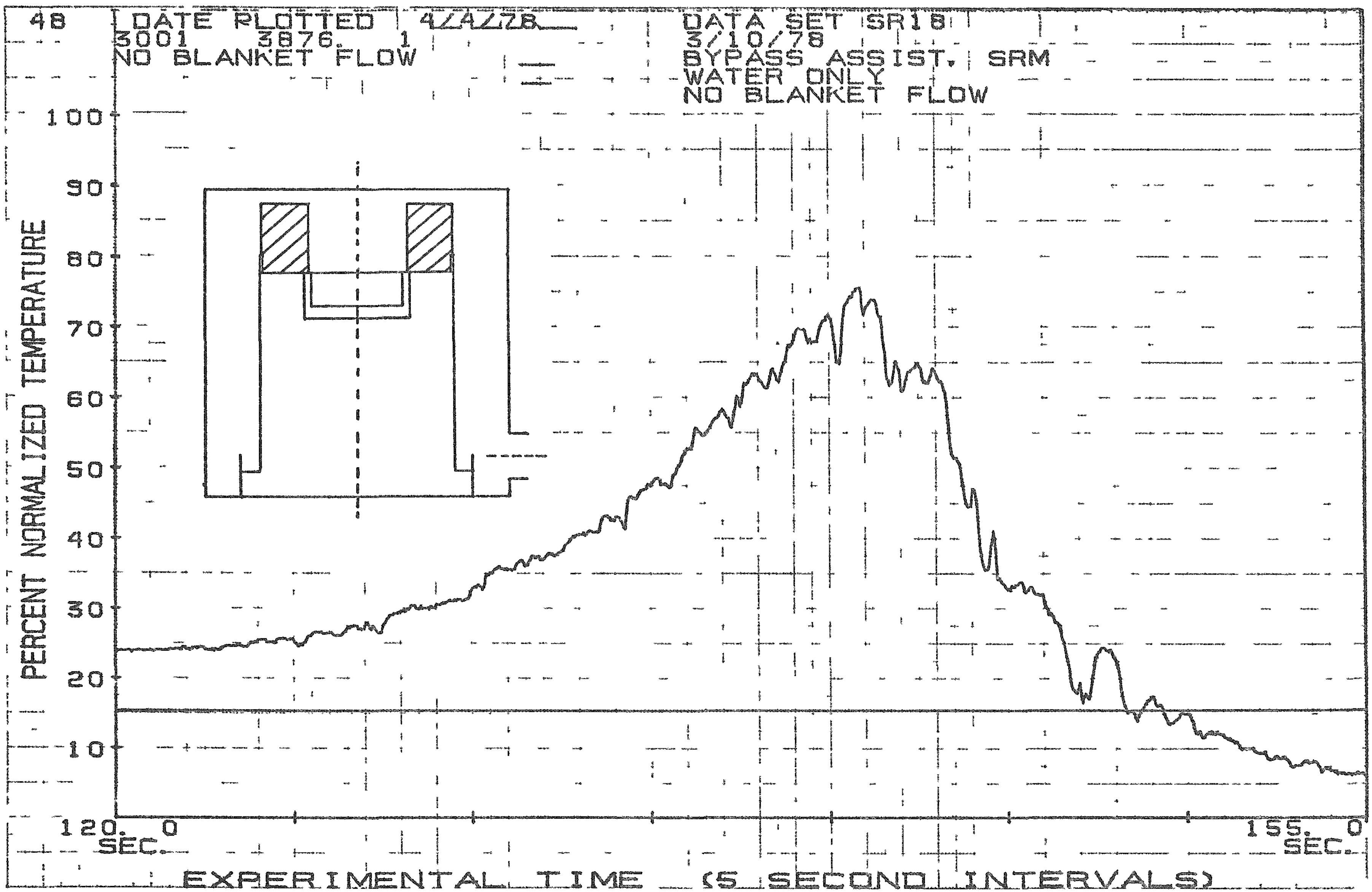


Fig. 25. Prediction and Data for Volume V2 for Simulated Transient with Fuel Flow Only.

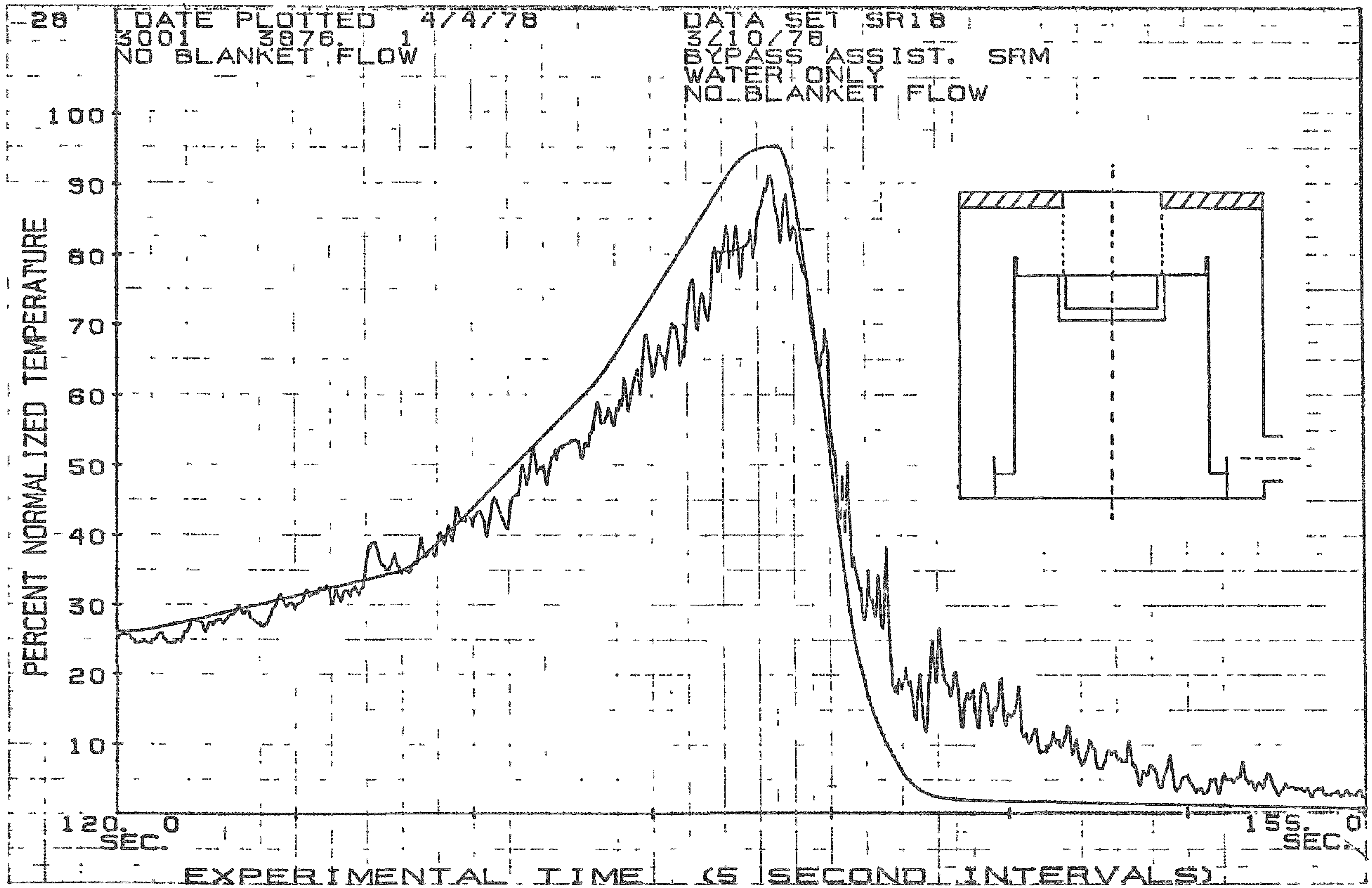


Fig. 26. Prediction and Data for Volume V3 for Simulated Transient with Fuel Flow Only.

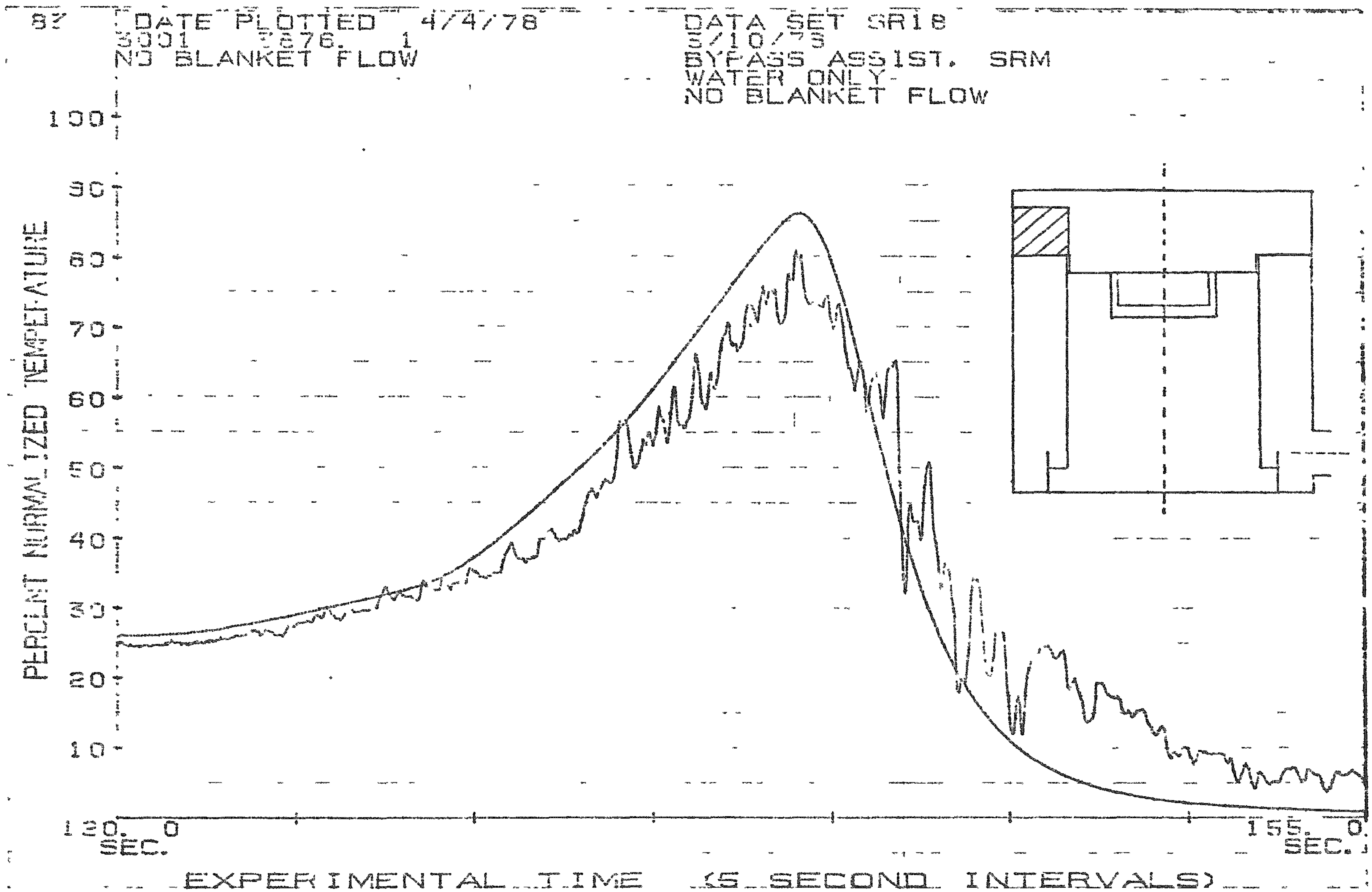


Fig. 27. Prediction and Data for Volume V4I for Simulated Transient with Fuel Flow Only.

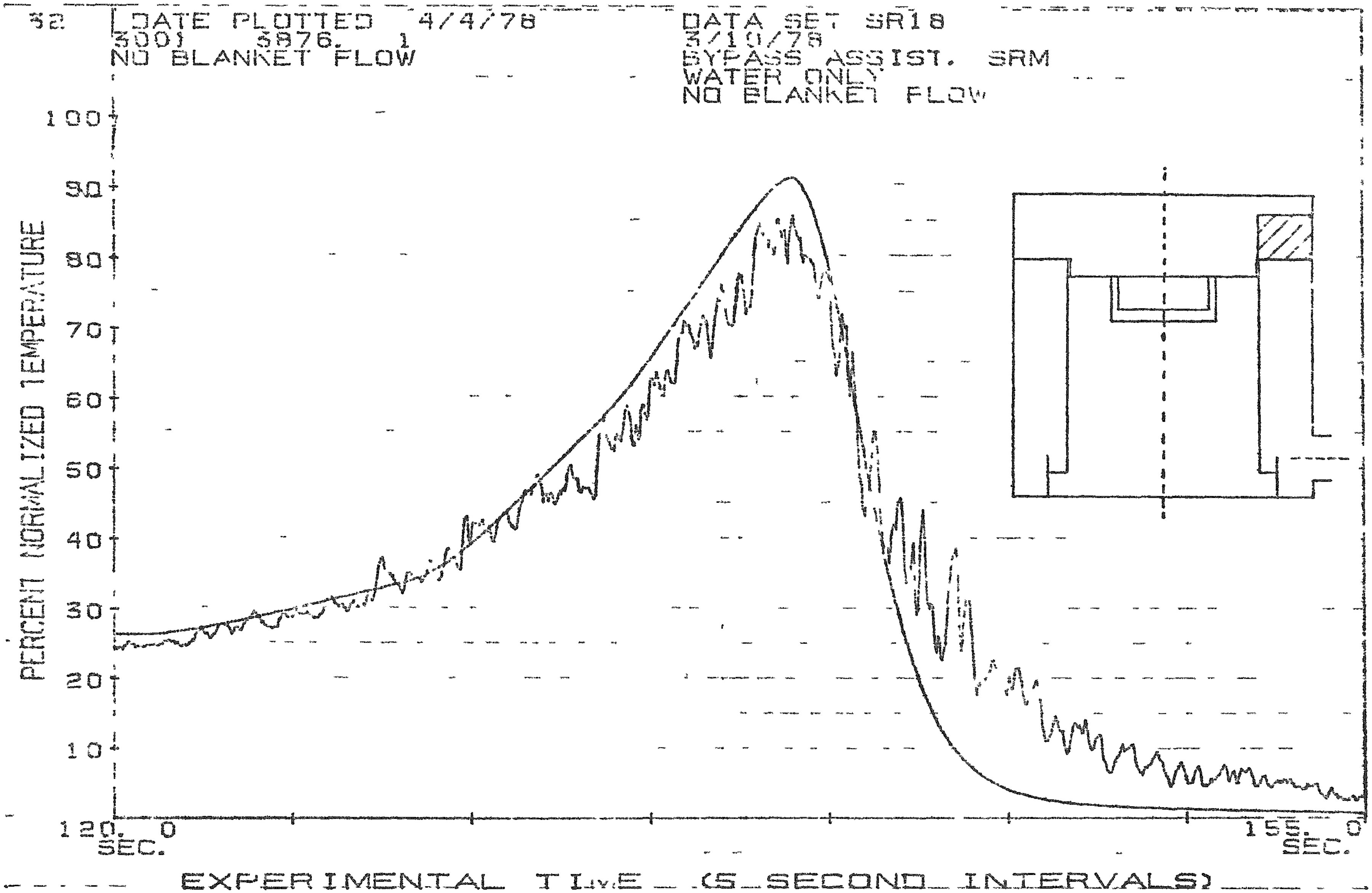


Fig. 28. Prediction and Data for Volume V4A for Simulated Transient with Fuel Flow Only.

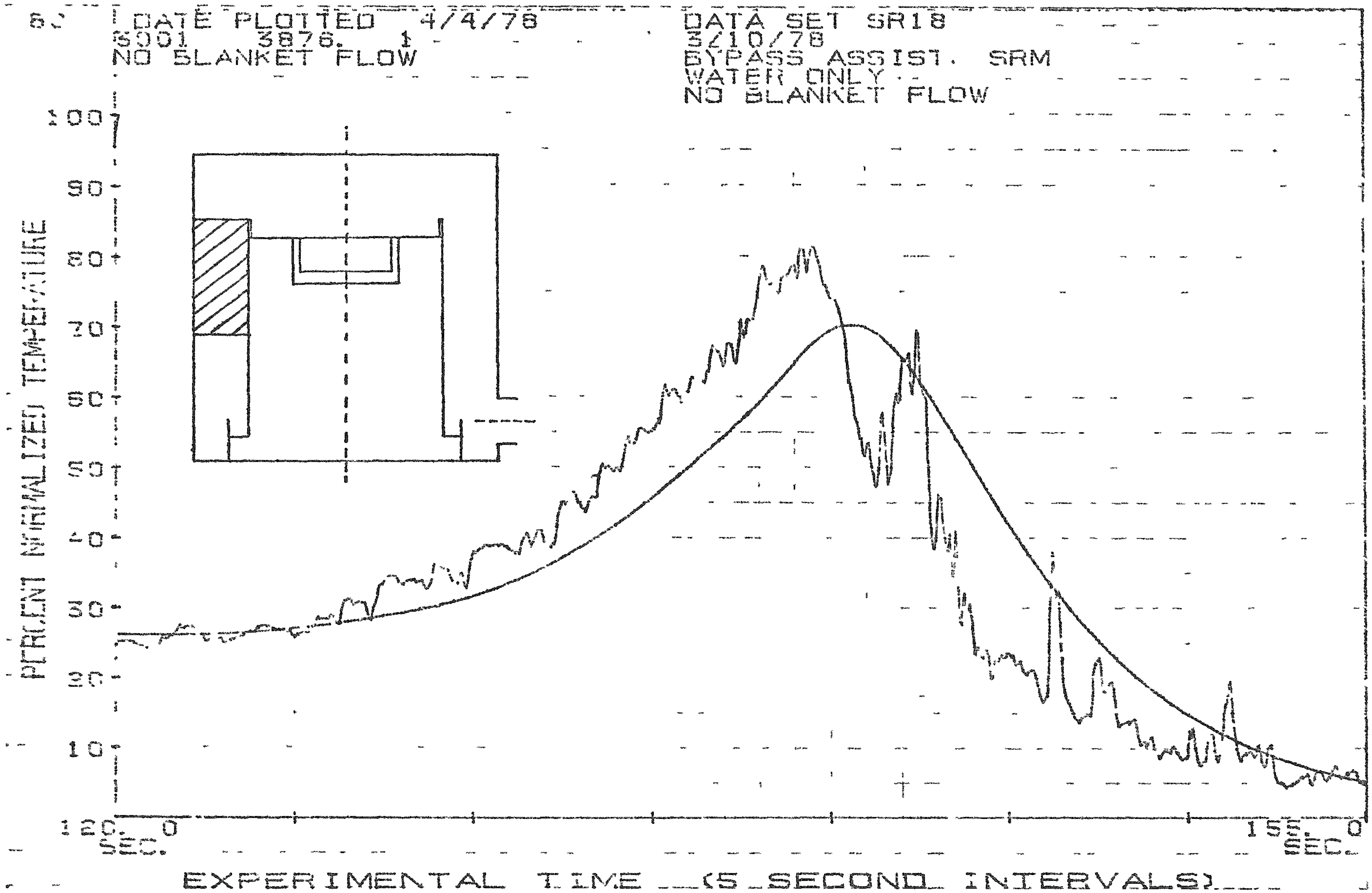


Fig. 29. Prediction and Data for Volume V5I for Simulated Transient with Fuel Flow Only.

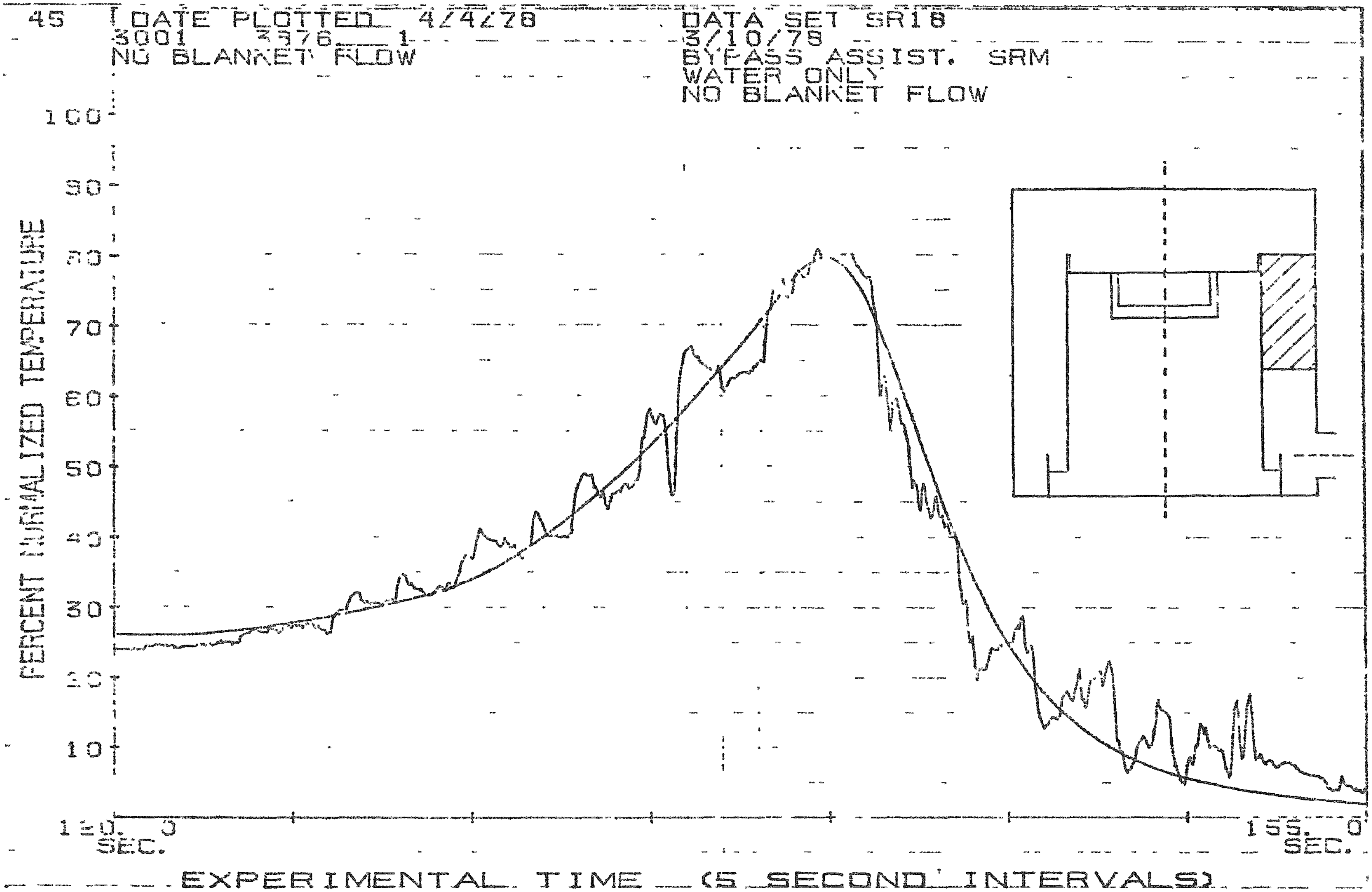


Fig. 30. Prediction and Data for Volume V5A for Simulated Transient with Fuel Flow Only.

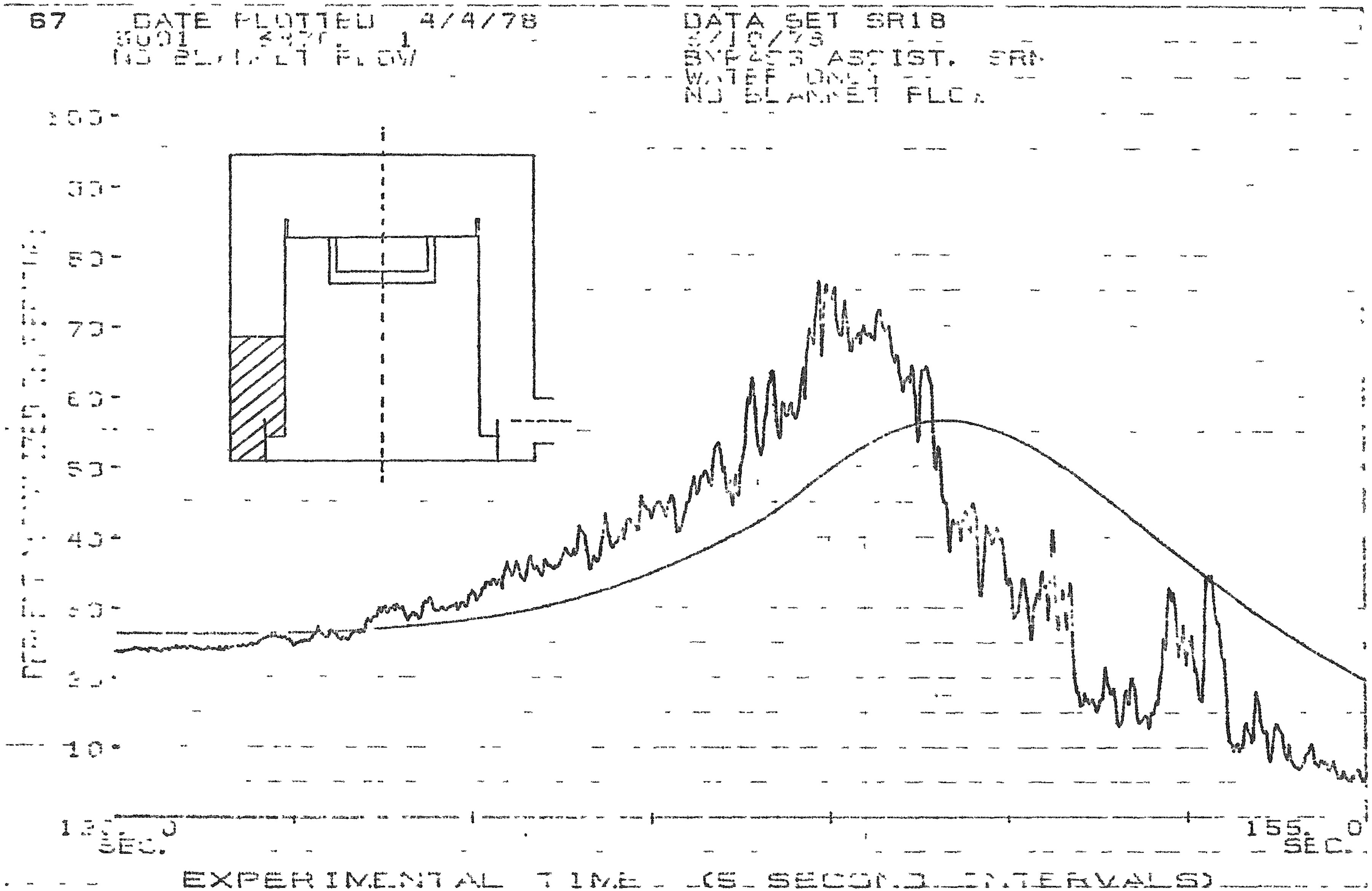


Fig. 31. Prediction and Data for Volume V6I for Simulated Transient with Fuel Flow Only.

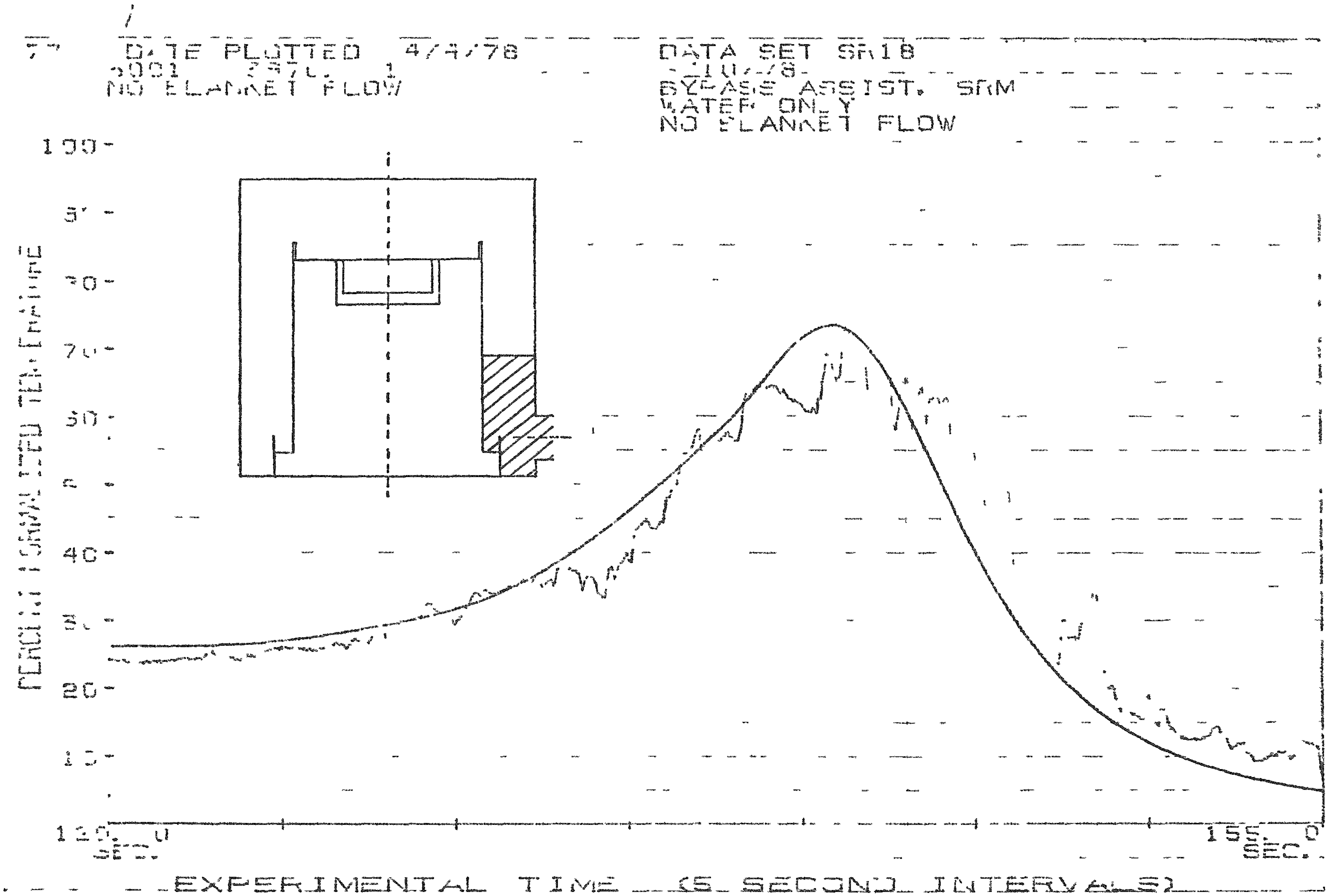


Fig. 32. Prediction and Data for Volume V6A for Simulated Transient with Fuel Flow Only.

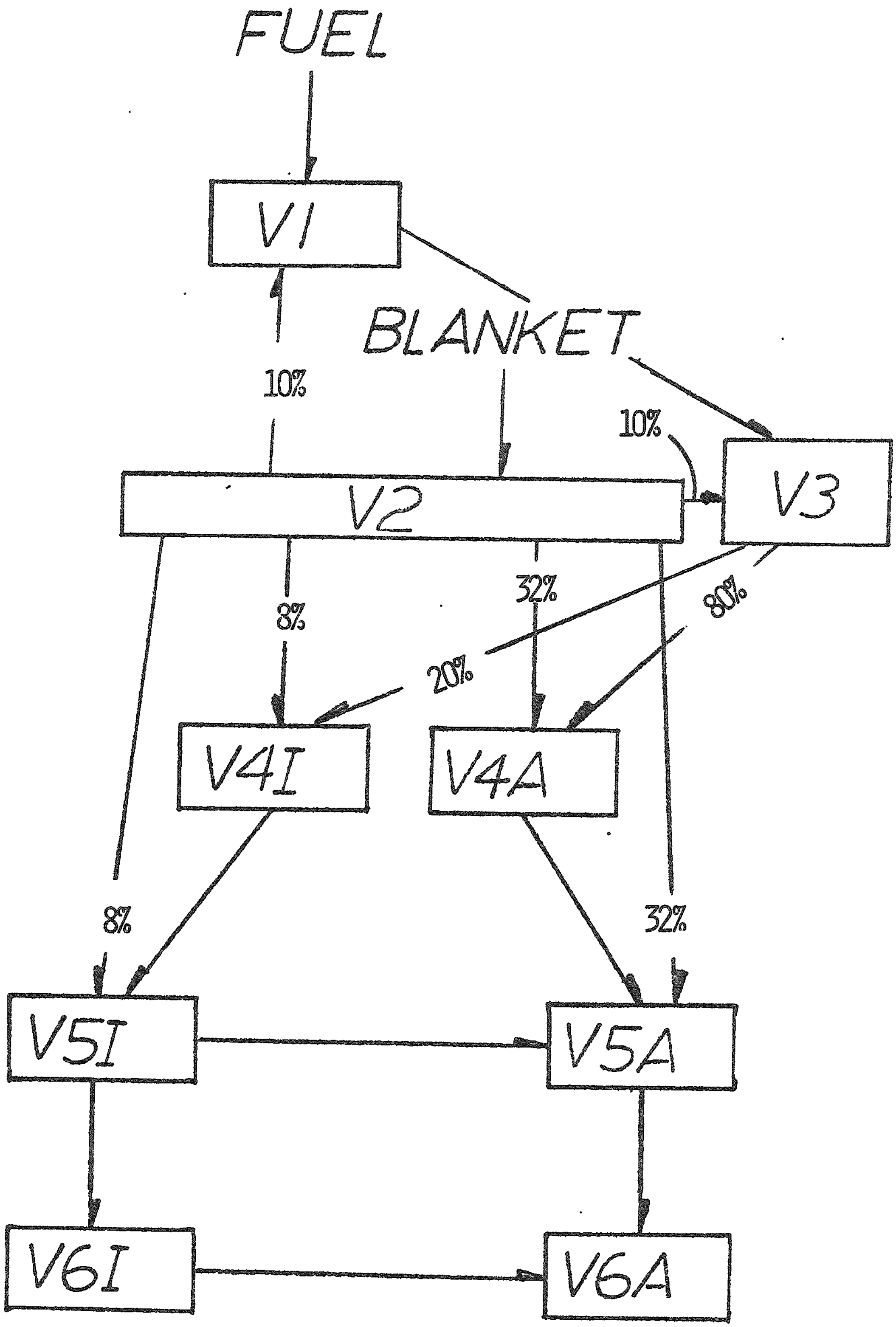


Fig. 33. Flow Pattern Used in EXIT1

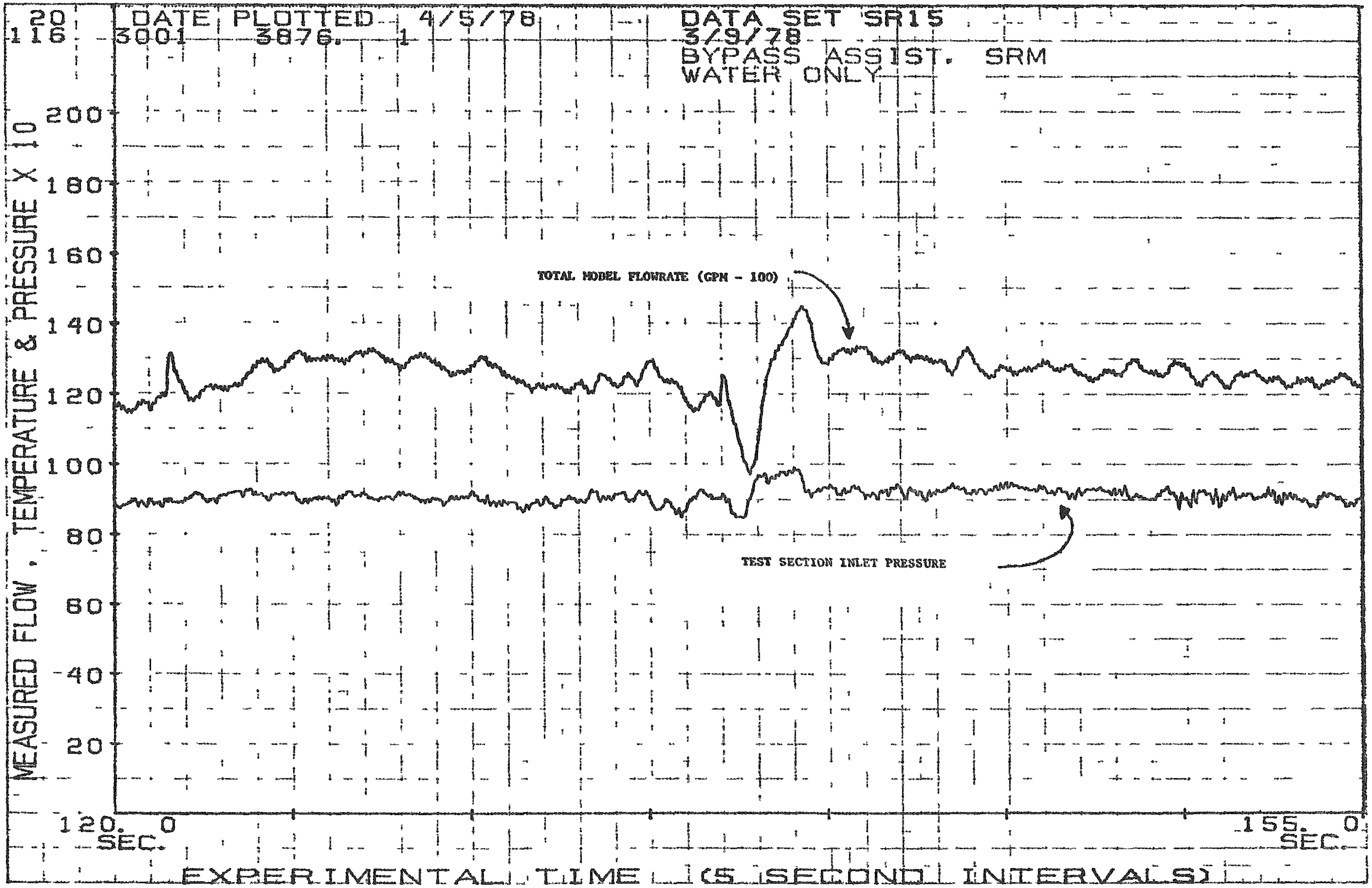


Fig. 34. Pressure and Flow Data for SR15

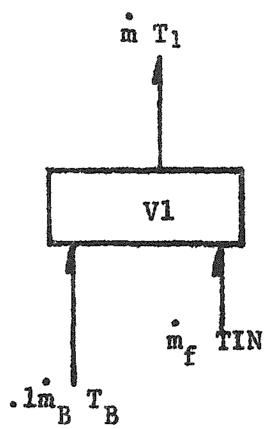
APPENDIX A

ENERGY ANALYSIS FOR PROGRAM EXIT1

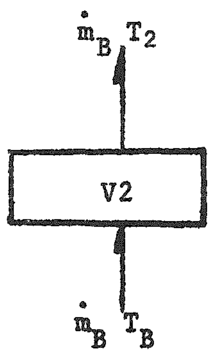
The equations used in devising the computer program had as their basis the first law of thermodynamics:

$$\sum \dot{E}_{in} - \sum \dot{E}_{out} = \frac{dE}{dt}$$

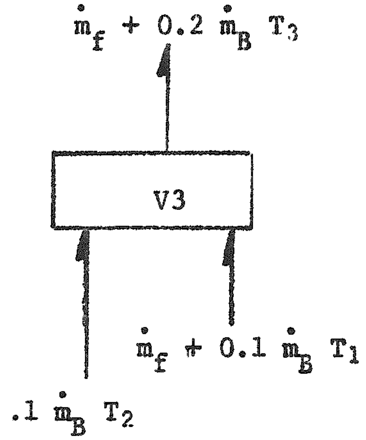
The nine equations for the nine volumes into which the outlet plenum was divided were as follows:



$$\Delta T_1 = \Delta t \left[\dot{V}_f \left(\rho_{IN} T_{IN} - \rho_1 T_1\right) + \dot{V}_B \, .1\left(\rho_B T_B - \rho_1 T_1\right) \right] \Big/ V_1 \rho_1$$

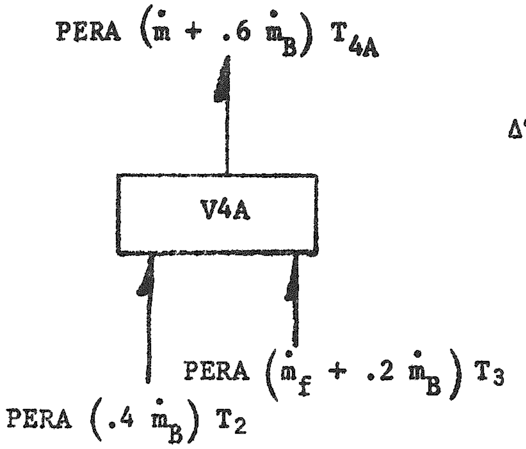


$$\Delta T_2 = \frac{\Delta t \, \dot{V}_B \left(T_B \rho_B - T_2 \rho_2\right)}{V_2 \rho_2}$$

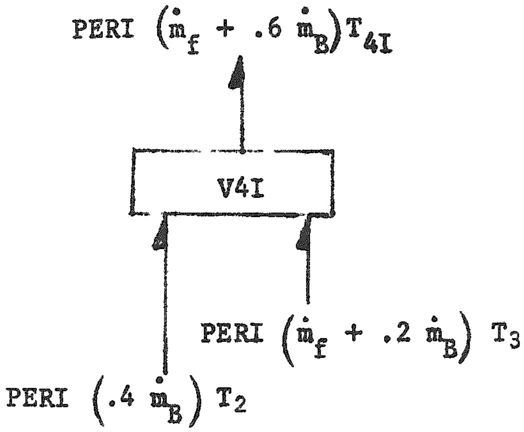


$$\Delta T_3 = \Delta t \left[\dot{V}_f \left(\rho_1 T_1 - \rho_3 T_3 \right) + \dot{V}_B \left(.1\ \rho_2 T_2 + .1\ \rho_1 T_1 - .2\ \rho_3 T_3 \right) \right] \Big/ V_3 \rho_3$$

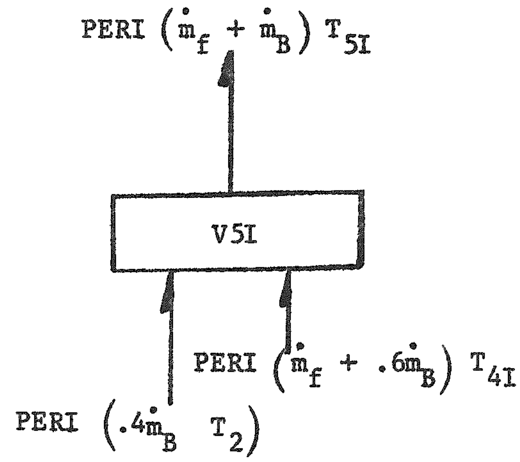
At this point, the volumes split into active and inactive regions. Thus, in the following, "PERI" is used to denote percent flow to the inactive volume, and "PERA" is used to denote percent flow to the active volume.



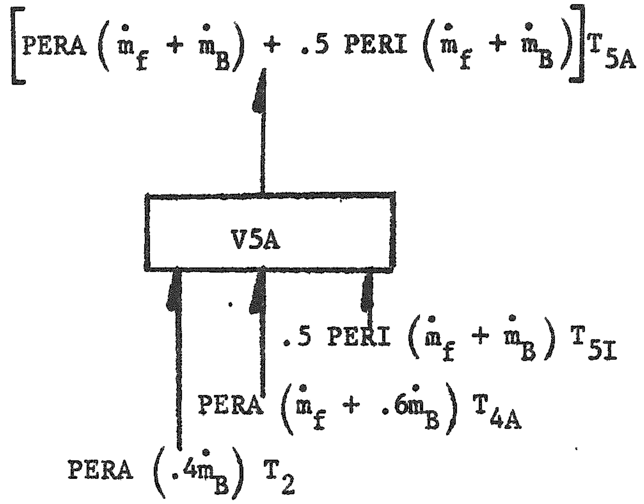
$$\Delta T_{4A} = \Delta t\ \mathrm{PERA} \left[\dot{V}_f \left(\rho_3 T_3 - \rho_{4A} T_{4A} \right) + \dot{V}_B \left(.4\ \rho_2 T_2 + .2\ \rho_3 T_3 - .6\ \rho_{4A} T_{4A} \right) \right] \Big/ V_{4A} \rho_{4A}$$



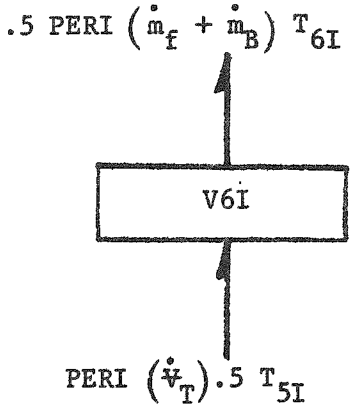
$$\Delta T_{4I} = \Delta t\ \mathrm{PERI} \left[\dot{V}_f \left(\rho_3 T_3 - \rho_{4I} T_{4I} \right) + V_B \left(.4\ \rho_2 T_2 + .2\ \rho_3 T_3 - .6\ \rho_{4I} T_{4I} \right) \right] \Big/ V_{4I} T_{4I}$$



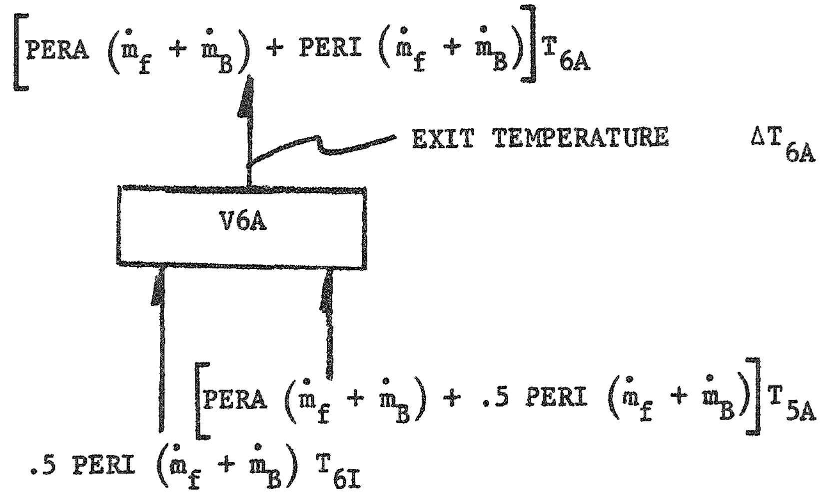
$$\Delta T_{5I} = \Delta t \text{ PERI } \Big[\dot{\forall}_f \left(\rho_{4I} T_{4I} - \rho_{5I} T_{5I}\right) + \dot{\forall}_B \left(.4\rho_2 T_2 + .6\rho_{4I} T_{4I} - \rho_{5I} T_{5I}\right)\Big] \Big/ V_{5I}\rho_{5I}$$



$$\Delta T_{5A} = \Delta t \Big[\dot{\forall}_f \big(\text{PERA } \rho_{4A} T_{4A} + .5 \text{ PERI } \rho_{5I} T_{5I} - \text{PERA } \rho_{5A} T_{5A} - .5 \text{ PERI } \rho_{5A} T_{5A}\big) + \dot{\forall}_B \big(.4 \text{ PERA } \rho_2 T_2 + .6 \text{ PERA } \rho_{4A} T_{4A} + .5 \text{ PERI } \rho_{5I} T_{5I} - \text{PERA } \rho_{5A} T_{5A} - .5 \text{ PERI } \rho_{5A} T_{5A}\big)\Big] \Big/ V_{5A}\rho_{5A}$$



$$\Delta T_{6I} = \Delta t\ PERI\ \dot{V}_T\ .5\ \left(\rho_{5I}T_{5I} - \rho_{6I}T_{6I}\right) \Big/ V_{6I}\rho_{6I}$$



$$\Delta T_{6A} = \Delta t\ \dot{V}_T\ \left(.5\ PERI\ \rho_{6I}T_{6I} + PERA\ \rho_{5A}T_{5A} + .5\ PERI\ \rho_{5A}T_{5A} - \rho_{6A}T_{6A}\right) \Big/ V_{6A}\rho_{6A}$$

APPENDIX B
EXIT1 COMPUTER PROGRAM

```
FTN4,L
      PROGRAM EXIT1
C
C     SOURCE = PRO84

      THIS CODE MODELS A SINGLE OUTLET NOZZEL OUTLET PLENUM.  IT IS
C     SET UP FOR PREDICTING TH E TEMPERATURE TRANSIENT FOR TWO DIFFERENT
C     DATA SETS WHERE WATER WAS USED AS A FLUID.  THE FIRST
      LAW OF THERMODYNAMICS IS USED TO CALCULATE THE TEMPERATURE IN
C     NINE CONTROL VOLUMES.  A CRUDE EULER INTERGRATION METHOD IS USED.
C      SSW(3) IS USED FOR DEBUGGING
C      IF SSW(4) ON IT PLOTS SR18
C      IF SSW(4) AND SSW(5) ARE ON IT PLOTS SR18 NORMALIZED
C
      DIMENSION AT1(350),AT2(350),AT3(350),AT4A(350),AT4I(350),
     $AT5A(350),AT5I(350),AT6A(350),AT6I(350)
      DIMENSION T(10),ATFUEL(350),ATBLAN(350)
      EQUIVALENCE(T(1),TIN),(T(2),T1),(T(3),T2),(T(4),T3),
     $(T(5),T4A),(T(6),T5A),(T(7),T6A),(T(8),T4I),(T(9),T5I),
     $(T(10),T6I)
      PI = 3.14159/4.
      WRITE(1,20)
   20 FORMAT("ENTER INACTIVE VOLUME AND FLOW TO INACTIVE ")
      READ(1,*)PORT,PERI
      PERA = 1.-PERI
      WRITE(1,21)
   21 FORMAT("ENTER START AND FINISH TIME")
      READ(1,*)START,FINISH
      DTIME = (FINISH-START)/3500.
C
      VOLUME DIMENSIONS IN FEET (MODEL)

      Z0 = 6.188/12.
      DO0 = .95/6.
      Z1 = [illegible]
      DO1 = 3.75/6.
      DI1 = .95/6.
      Z2 = 5.438/12.
      DO2 = 6.063/6.
      DI2 = 3.75/6.
      Z3 = .75/12.
      DO3 = 11./6.
      DI3 = 3.75/6.
      Z4 = 4.063/12.
      DO4 = 11./6.
      DI4 = 6.063/6.
      Z5 = 9.625/12.
      DO5 = 11.125/6.
      DI5 = 7.438/6.
      Z6 = 8.062/12.
      DO6 = 11.0/6.
      DI6 = 8./6.
C
```

```
C     CALCULATION OF MIXING VOLUMES (CUBIC FEET)
C
      V0 = PI*D00**2*Z0
       1 = PI*(DO1**2-DI1**2)*Z1
      V2 = PI (DO2 **2-DI2**2)*Z2
      V3   PI*( O3**  - I3**2)*Z3
      V4     *(   4**2-   4**2)*Z4
       5 = P  *(DO5**2-D 5**2)* 5
      V6 = PI  DO6   -DI6       Z6
      V4A = (1.-PORT)*V4
       5A = (1.-   T)*V5
       6A = (1.-     )* 6
      V4I   PORT*V4
      V5I - PORT*V5
       6  =      * 6
      WRITE(13,30)PORT,PERI,V1,V2,V3,V4A,V5A,V6A,V4I,V5I,V6I
   30 FORMAT(2X,"PORT=",F8.4,2X,"PERI=",F8.4,/,2X,"V1=",F8.4,2X,
     $"V2=",F8.4,2X,"V3=",F8.4,/,2X,"V4A=",F8.4,2X,"V5A=",F8.4,
     ,2X,"V6A=",F8.4,/,2X,"V4I=",F8.4,2X,"V5I=",F8.4,2X,"V6I=",F8.4)
      GPMB = 32.
       IF (ISSW(4) .LT. 0) GPMB=0
      TB = TINB(START)
      TM = (GPMB*TB+(GPMT(START)-GPMB)*TINF(START))/GPMT(START)
      T1 - TM
      T2 - TB
       3 =
      T4A = TM
      T5A   TM
       6  =
       4I =
      T5I = TM
      T6I   TM
      C1 = V1*7.481/DTIME
      C2 = 2*7.481/DTIME
      C3   V3        DTIME
       4A = V4A*7.481/DTIME
       4I =  4I*7.481/DTIME
      C5A =  5A 7.481/DTIME
        I   V I*        DTIME
       6    V6 *7.4 1/  T
      C6I =  6I*7.481/   IME
C
      DO 50 I=1,3500
      TIME = FLOAT(I)*DTIME+START
C
C     CALCULATION OF TEMP CHANGES

      TFUEL = TINF(TIME)
      BLANK = TINB(TIME)
      ROIN = ROWA(TFUEL)*TFUEL
      RO1 = ROWA(T1)*T1
        BLA = ROWA(TBLANK)*TBLANK
      RO2 = ROWA(T2)*T2
```

```
      RO3 = ROWA(T3)*T3
        4A = ROWA(T4A)*T4A
        5A = A(5A)*5A
      RO6A   ROWA(T6A)*T6A
      RO4I   ROW (T4I)*T4I
        5      (T5 )*T5
      RO6I =  O A T6I)*T6I
      GPSC   (GPMT(TIME)-GPMB)/60.
      GPSB = GPMB/60.
C
      DT1 = (GPSC*(ROIN-RO1)+GPSB*.1*(RO2-RO1))/C1/ROWA(T1)
      DT2     GPSB*(ROBLA-RO2))/C2/ROWA(T )
        3   (     C*(  1-RO3)+GPSB*(.1*RO2+.1*RO1-.2*RO3))
     $/C3/ROWA(T3)
      DT4A = PERA*(GPSB*(.4*RO2+.2*RO3-.6*RO4A)+GPSC*(RO3-RO4A))
     $/C  /ROWA(T4A)
       T5A = (GPSB*(.4*PERA*RO2+.6*PERA*RO4A+.5*PERI*RO5I-PERA*RO5A
     $-.5*PERI*RO5A)+GPSC*(PERA*RO4A+.5*PERI*RO5I-PERA*RO5A
     $-.  PERI*RO A))/C5A/ROWA(T5A)
      DT6A = ((GPSC+GPSB)*(.5*PERI*RO6I+PERA*RO5A+.5*PERI*RO5A-RO6A))
     $/C6A/ROWA(T6A)
      DT4I = PERI*(GPSB*(.4*RO2+.2*RO3-.6*RO4I)+GPSC*(RO3-RO4I))
     $/C I ROWA(T4I)
       T5  = PERI*(GPSB*(.4*RO2+.6*RO4I-RO5I)+GPSC*(RO4I-RO5I))
     $/C5I/ O A( 5I)
      DT6I = ((GPSC+GPSB)*.5*PERI*(RO5I-RO6I))/C6I/ROWA(T6I)
  127 CONTINUE
C
      T1 = T1+DT1
      T2 = T2+DT2
      T3   T3+ T3
       4A = T4A+DT4A
       5A =  5A+  5A
      T6A = T6A+DT6A
      T4I   T4I DT4I
       5I    5I+  5
       6I =   6I+  6I
C
  120 CONTINUE
      IF((  -1)/10*10.NE.(I-1))GOTO49
      ATFUEL(I/10+1) = TFUEL
      ATBLAN(I     ) = TBLANK
       T1(I/10+ ) = T1
        2( /10+1) =  2
      AT3 I/10+1  = T3
      AT4A(I/10+1) = T4A
       T4I( /10+1) = T4I
      A 5A  /10+1) =  5A
      AT I I       = T5I
       T6A       ) = T6A
       6 (  /10+1) =  6
   49 CONTINUE
      IF(ISSW(1).LT.0)WRITE(13,54)I,TIME,T1,T2,T3,T4A,T4I,T5A,T5I,
```

```
      $T6A,T6I,GPSC,TFUEL,TBLANK
   54 FORMAT("I=",I5," TIME=",F6.2," T1=",F7.2," T2=",F7.2," T3=",
      $F7.2," T4A=",F7.2," T4I=",F7.2,/,
      ."T5A=",F7.2," T5I=",F7.2," T6A=",F7.2," T6I=",F7.2," GPSC=",F7.3,
      $/,"TFUEL=",F7.2," TBLANK=",F7.2)
   50 CON INUE
   52 CON IN E
      WRITE(1,41)
   41 FORMAT("ENTER TRACE NUMBER",/,"1 = TFUEL",/,"2 = TBLANK",/,
      $"3 = 1",/,"4 = T2",/,"5 = T3",/,"6 = T4A",/,"7 = T4I",
      ./,
       "8 = T5A",/,"9 = T5I",/,"10 = T6A",/,"11 = T6I",/,"0 = QUIT")
      READ(1,*)INDEX
      IF(INDEX.EQ.0)GOTO40
      DO 53 I = 1,350
      IF(INDEX.EQ.1)T = ATFUEL(I)
        (     X.   .2)T =  TBLAN( )
      IF INDE  .EQ.3 T = AT1(I)
      IF INDEX EQ 4   T = AT2(I)
        (   X. Q.5)T = AT3(I)
        (     .   .6)  = AT4A(T)
      IF  INDEX.EQ.7 T = AT4I(I)
      IF(INDEX EQ 8 T = AT5A(I)
        (    X.   .9)   T5I( )
      IF(  DE  .E  .10)T = AT6A(I)
      IF INDEX.EQ. 1 T = AT I(I)
      I (ISSW(2).LT.0)T = (T-70.8)/(189.7-70.8)*200.
       IF (ISSW(5).LT.0) T=(T-69.6)/(189.5-69.6)*200.
      IX = FLOAT(I)/35 .*9210.+789.
      IY   T/200.*8000.+800.
       F(I.EQ.1)WRITE(9)-1,1,IX,IY
      WRITE(9)1,1,IX,IY
   53 CONTINUE
      GOTO52
   40  NTINUE
      STOP
      END
      FUNCTION ROWA(T)
      DIMENSION A(6,6),B(6,2),AA(6)
      DATA AA/70.,62.26,130.,61.55,190.,60.35/
       AT. IFLAG/0/
      IF(IFL G.EQ.1) GO TO 9
      DO 10 I=1,6
   10 A(I,1) = AA(I)
      CALL MATIN(A,B,3,DELTA)
      IF AG = 1
    9 CONTINUE
      ROWA = B(1,1)*T**2+B(2,1)*T+B(3,1)
      RETURN
      END
      FUNCTION GPMT(TIME)
      DIMENSION A(20),B(20)
C
```

```
C      ARRAY A HAS THE DATA FOR DATA SET SR15 WHILE ARRAY B DESCRIBES
C      DATA SET SR18.  THE DIFFERENCE BETWEEN THESE TWO DATA SETS IS
       THAT SR15 HAS BOTH FUEL AND BLANKET FLOW WHILE SR18 HAS ONLY FUEL
       FLOW.

       DATA A/217.,0.,217.,120.,232.,127.,222.,131.,225.,137.,
      $198.,137.8,244., 39.3,230.,140.,222.,155.,222.,200./
       DAT  B/20 .,0.,20 .,120.,212.,123.,230.,129.,220.,135.,
      $188.,137.5,241.,139.,211.,140.,208.,155.,208.,200./
       IF (ISSW(4).LT.0) GO TO 3
       DO 1 I = 1,17,2
       IF(TIME.GT.A(I+3))GOTO1
       GPM  = A(I)+(A(I+2)-A(I))/(A(I+3)-A(I+1))*(TIME-A(I+1))
       IF(TIME.GE.A I+1))RETURN
     1 CONTINUE
     3 D  2 J=1,17,2
       IF (TIME.GT.B(J+3)) GO TO 2
       GPMT = B(J)+(B(J+2)-B(J))/(B(J+3)-B(J+1))*(TIME-B(J+1))
       IF (TIME.GE.B(J+1)) RETURN
     2 CONTINU
       WRI E(1,1000)
  1000 FORMAT("ERROR IN GPMF, STOP")
       STOP
       END
       FUNCTION TINF(TIME)
       DIMENSION A(20),B(20)
C
C      ARRAY A IS FOR SR15 AND ARRAY B IS FOR SR18

       DATA A/100.,0.,100.,120.,110.,127.,148.,133.,184.,136.,188.,138.6,
      $94.,140.,80.,141.,72.,144.,72.,200./
         B/101.,0.,101.,120.,112.,127.7,145.,133.,185.,137.,
      $184.,138.4,87.,140.2,72.,141.8,70.,155.,70.,200./
       IF (ISSW( ).LT.0) GO TO 3
       DO 1 I = 1,1 ,2
       IF(TIME.GT.A(I+3))GOTO1
       TINF = A(I)+(A(I+2)-A(I))/(A(I+3)-A(I+1))*(TIME-A(I+1))
       IF(TIME.GE.A(I+1))RETURN
     1 CON  NUE
     3 D  2 J=1,17,2
       IF (TIME.GT.B(J+3)) GO TO 2
       TINF = B(J)+(B(J+2)-B(J))/(B(J+3)-B(J+1))*(TIME-B(J+1))
         (TIM . E. (J+1)) RETURN
     2 CONTINUE
       WRITE(1,1000)
  1000 FORMAT("ERROR IN TINF  STOP")
       STOP
       END
       FUNCTION TINB(TIME)
       DIMENSION A(20)
       ATA A/90.,0.,88.,120.,84.,129.,93.,155.,93.,200./
       DO 1 I = 1,17,2
       IF(TIME.GT.A(I+3))GOTO1
```

```
      TINB = A(I)+(A(I+2)-A(I))/(A(I+3)-A(I+1))*(TIME-A(I+1))
      IF(TIME.GE.A(I+1))RETURN
    1 CONTINUE
      WRITE(1,1000)
 1000 FORMAT("ERROR IN TINB  STOP")
      STOP
      END
       N $
**** LIST END ****
```