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Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D. C. 20555

License No. DPR-35
Docket No. 50-293 P

Pilgrim Suppression Pool Temperature Transients

Reference 1) Letter from Don K. Davis
to G. Carl Andognini
dated 12/12/77

Dear Sir:

Reference 1) requested plant-specific information for the Pilgrim Power Station Unit #1 related to suppression pool temperature transients and to suppression pool temperature monitoring. Attachment 1 provices the results of a detailed analysis of suppression pool temperature response to a number of events.

The analyses indicate that when a 150^{o} bulk pool temperature at a ramshead mass flux in excess of 40 $lb/sec/ft^2$ is utilized as a steam quenching instability limit, there are no cases at Pilgrim when this limit is exceeded. Therefore, Boston Edison Company concludes that, in the event of the inadvertent opening of a safety relief valve, no adverse consequences will be experienced in either the suppression pool or the reactor pressure vessel.

We trust that this submittal satisfies your request of Reference 1). Should you require additional information with regards to this subject, please contact us.

Very truly yours,

G. Carl Andognini

6 copies

Attachment

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Attachment 1

Analysis of Suppression Pool Temperature Transients

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1. Introduction

The suppression pool at Pilgrim Station Unit #1 is designed to absorb the energy associated with a design basis loss-of-coolant accident and thus help to control peak transient containment pressures. Coincidentally, the suppression pool also provides a heat sink to absorb the energy released from the safety/relief valves during reactor pressurization transients, from the Automatic Depressurization System (should it be activated during the course of a LOCA event), and from the discharge of the RCIC and HPCI turbines. The existing pool temperature limits found in the technical specifications are based upon the analysis in the FSAR. In reference 1, the NRC requested plant-specific information regarding suppression pool temperature transients based on the current technical specifications. This report is the response to that request.

2. Discussion and Results

2.1 Steam Condensation Instability

The mechanisms of steam condensation instability are not well understood. It is known that high amplitude pressure oscillations can occur when a submerged pipe vent discharges steam at flow rates higher than critical flow with a sufficiently high pool temperature. The temperature at which this occurs is partly dependent on the type of steam discharge device used. Pilgrim 1 has 11.65 inch ramshead discharge devices for each of the four (4) safety/relief valves (SRV's). General Electric has recommended that the steam condensation instability limits associated with this type of device are, for steam discharge mass velocities greater than 40 lbm/ft^2 - sec, a suppression pool temperature limit of 160^oF local (150^oF bulk) (Reference 2).

The 10^oF differential between "local" and "bulk" temperature limits are based on actual measurements of temperatures from full scale plant tests as described in the attachment to Reference 2. Local temperatures refer to those temperatures at locations close (within a few feet) to the discharge device. The bulk temperature is the pool average temperature, or the temperature that would occur if instantaneous and perfect mixing of the entire pool volume were to occur during a relief valve discharge event. Since the bulk temperature response of the suppression pool can be relatively easily obtained by calculations, the remainder of the report will be concerned with the bulk temperature response of the suppression pool unless specifically stated otherwise.

2.2 Events Resulting in High Suppression Pool Temperatures

The NRC has requested evaluation of a number of events which would result in relatively high suppression pool temperatures. These included:

a) a stuck-open S/RV during power operation,

b) a stuck-open S/RV during hot standby conditions,

c) Automatic Depressurization System (ADS) actuation following a LOCA, and

d) primary system isolation and cooldown at $100^{o}F$ per hour

Each of these events will be considered in detail in the following sections. First, however, a general review of the problems and how they were solved will be given in order to put the detailed evaluations in perspective.

The suppression pool will be heated by the condensation of the steam generated in the reactor vessel and released to the suppression pool through the S/RV(s). The principal sources of energy available to generate steam include:

a) nuclear fission (prior to scram),

b) fission product decay (following scram),

c) sensible heat of the fuel,

d) sensible heat of structures (reactor vessel, piping, internals),

e) sensible heat of the reactor coolant.

In order to accurately evaluate the reactor's response to stuck-open relief valve events, given the multiplicity of energy sources, a one-dimensional thermal-hydraulic reactor system model was set up using the RETRAN computer code (Reference 3); the nodalization scheme used to model the reactor is shown on Figure 1.

This detailed model was used to evaluate the stuck-open S/RV during power operation and during hot standby transients. The results of these analyses were checked through comparison with simplified hand calculations. The steam flow rates obtained from both the computer model and the hand calculations were then used in another RETRAN submodel (Reference 4). This submodel has one control volume which represents the suppression pool and has one junction or flow path which represents a positive fill used for adding steam to the pool. A primary side temperature dependent non-conducting heat exchanger was used to represent the heat exchange between pool water and service water.

The key assumptions used in the analyses are listed on Table 1.

2.2.1 Stuck-open S/RV during Power Operation

A stuck-open S/RV during power operation is an unlikely event to occur at Pilgrim 1 based on past experience. It could only be initiated by a downward drift in the S/RV actuation setpoint or a failure in the electrical circuits causing a raise "open" signal to be sent to the valve actuator. This event has been evaluated by assuming the reactor is operating at 100% of the licensed power level when, for some reason, one of the four Target Rock S/RVs opens. The resulting transient can be described as follows:

a) S/RV opens
b) Reactor steam dome pressure drops
c) The turbine control valves shut in an attempt to maintain reactor pressure at its normal operating pressure.
d) The reactor steam dome pressure recovers to a new steady state value.

As soon as the reactor operator scrams the plant, the reactor begins to depressurize. As the reactor depressurizes, the steam flow to the suppression pool decreases because steam flow through the S/RV's is directly dependent on reactor pressure. The reactor pressure and S/RV steam flow transients are shown on Figures 2 and 3, respectively. It should be noted that on these and subsequent figures, the scram occurred at 10 seconds. This was done to save computer time and it has no effect on the course of the transient following scram. The steam flow to the suppression pool used to calculate the pool temperature response included the additional 10 minutes worth of steam flow prior to reactor scram. It was assumed the reactor operator would maintain reactor water level around its initial value (Figure 4). Feedwater flow was modeled as on-off actuations of the feedwater system at 200 lbm/sec (Figure 5) (Feedwater flow would not be manipulated in exactly this manner, but the impact on the transient of any variation in feedwater flow would be minimal). The variation in enthalpy of the water in the feedwater system was also accounted for in the analysis (Figure 6).

The computer run was carried to 1370 sec following scram. Running the transient further on the computer would not have been cost effective; therefore, a hand calculation technique was used to determine, for example, when the reactor pressure would fall below the value that gives a ramshead discharge mass flux of 40 lbm/sec ft^2. The hand calculation was fitted to the computer results and then extended beyond 1370 sec. The results are shown on the following table.

Time after scram (sec)	RETRAN Calculated Pressure (psia)	Hand Calculated Pressure (psia)
Ø	1024.9	1024.9
100	868.6	870.91
200	791.5	796.77
300	710	729
400	645	647
600	537	537.36
800	440	451.8
1000	387	385.3
1370	296	297

The good agreement between the computer results and the hand calculated results gives confidence that the hand calculated values beyond 1370 sec. are reasonably accurate.

The pool temperature response was based on the steam flow rates directly calculated by RETRAN out to 1370 seconds. Beyond that time, the hand calculated pressures were converted to a steam flow rate assuming Moody critical flow and a calculated S/RV throat area of 0.107 ft^2. This throat area was back-calculated by assuming the capacity of the S/RV is 10% above its rated nameplate capacity of 800,000 lbs/hr at 1090 psig.

The resulting suppression pool temperature transients for a 10 minute scram, and assuming the operator would actuate one residual heat removal heat exchanger 10 minutes after the scram, are shown on Figure 7. The initial conditions were assumed to be worst case, i.e., minimum pool volume 84,000 ft^3, maximum pool temperature (80^oF), and "fully-fouled" design heat exchanger capacity.

By plotting the bulk suppression pool temperature versus the ramshead mass flux, the margin to the steam condensation instability limits during the transients can be visualized. Figure 8 shows the results. The minimum margin to the 150^oF bulk temperature limit occurs when the mass flux is 40 lbm/ft^2 sec.

The analyses assumes 10 minutes to scram and another ten minutes to initiate operation of one RHR heat exchanger. However based upon the calculations at 10 minutes the suppression pool temperature is 109.5^{O}F. Thus the instability criteria can safely be said to be met for a case where the reactor was scrammed when the pool temperature reached 110^{O}F and one RHR train was operable 10 minutes thereafter.

The above analysis assumes the operator takes no actions other than scramming the plant and starting RHR in the suppression chamber cooling mode. There are other actions the operator is instructed to take, such as alternately opening each of the remaining three S/RVs, one at a time to distribute the heat load. The operator is instructed to continue such action until the relief valve closes.

2.2.2 Stuck-open S/RV During Hot Standby Conditions

Hot standby is assumed to be a condition where the reactor has been shutdown, but maintained near rated pressure and temperature. In practice, this is usually at about 600 psia. However, the analysis was done conservatively by assuming the initial reactor pressure was 1048 psig. The reactor blowdown following a stuck-open S/RV event was partially calculated by RETRAN. Figure 9 shows the reactor pressure transient. On the plot, the S/RV was assumed to stick-open at 50 seconds after shutdown. This is an arbitrary and conservative assumption.

Since an initial pool temperature of 120°F (the technical specification limit for reactor isolation) would not be reached until about one hour of shutdown and isolation conditions (making the unrealistic assumption that no pool cooling heat exchangers were in use. the decay heat rate used in the analysis assumed the reactor was for one hour shutdown before the transient was initiated.

2.2.3 ADS Actuation Following a LOCA

Automatic Depressurization System (ADS) actuation following a LOCA will occur provided the following conditions are satisfied:

a) reactor water level is less than 78.5 inches above the top of the active fuel, and

b) drywell pressure is greater than or equal to 2.0 psig, and

c) conditions a) and b) exist for more than 120 seconds to satisfy the timer delay.

The most limiting conditions, i.e., highest bulk suppression pool temperature at the time of ADS actuation, would occur for the particular break size that resulted in the maximum amount of energy addition to the suppression pool with the minimum reduction in reactor pressure. A bounding case was constructed by assuming all the water in one recirculation loop plus all the water outside the core shroud (downcomer region) and all the water inside the core shroud to an elevation equal to the top of the jet pumps was discharged through a break in the lowest part of the recirculation piping directly to the suppression pool. None of the energy thus released was assumed to be added to any other part of the containment. The break was assumed to be that particular liquid break which would thus result in the maximum mass loss with the minimum reactor depressurization just prior to actuation of the ADS. Thus, using the trip level of the ADS, and Moody critical flow for saturated liquid, the break size was calculated to be .14 ft^2. From this the time at which the ADS actuated was calculated to be 233.20 seconds. The pool temperature at the time the ADS actuated was calculated by adding the blowdown mass and energy, plus the fuel relaxation energy (10 full power seconds), plus the decay energy over 233.20 seconds (6.3 full power seconds). The pool temperature thus calculated was 109.10°F assuming an initial temperature of 80°F.

The subsequent reactor depressurization due to the ADS actuation (the ADS is made up of 4 S/RV's) was conservatively calculated by assuming normal full-power reactor pressure and mass as the initial conditions. Therefore, any intermediate condition was bounded by assuming on one hand the maximum possible energy addition to the suppression pool and on the other hand the maximum energy conditions in the reactor at the time the ADS was initiated.

The reactor depressurization for this case is shown on Figure 11. The plot of bulk suppression pool temperature vs. ramshead mass flux is shown on Figure 12. The margin to the instability limit of 40 lbm/sec ft^2 is 24°F. This conservative evaluation already shows that the steam condensation instability region will be avoided in the unlikely event of an ADS actuation following a LOCA.

2.2.4 Primary System Isolation and Cooldown at 100°F/hr

The reactor was assumed to be cooled down at 100°F per hour, starting from hot standby conditions, with the reactor isolated, i.e., the only heat sink available is the suppression pool. Since the cooldown rate is specified to be 100°F per hour, the reactor pressure rate will follow the temperature directly according to the saturation curve. The steam flow to the suppression pool can be calculated by setting up a simple mass and energy balance on the reactor system. The energy input to the system includes decay energy, energy released by the reactor structures (vessel, piping internals, and fuel), and the energy of the makeup water. The only energy flow out of the system is steam through the S/RV's. Also the mass of steam discharged through the relief valves was added to the initial suppression pool mass this resulted in elevating the pool temperature to an initial temperature of 120°F. It was conservatively assumed that structural temperatures would directly follow fluid temperatures. The resulting reactor pressure and suppression pool temperatures (assuming an initial pool temperature of 120°F) for one RHR heat exchanger in operation are shown on Figures 13 and 14. A plot of ramshead mass flux versus bulk suppression pool temperatures is shown on Figure 15.

2.3 Operator Response to a Stuck Open S/RV

If the reactor is operating at full power and an S/RV suddenly sticks open, there are a number of unmistakable indicators which would almost immediately tell the reactor operator what was happening. An immediate indicator would be the sound of the steam discharging through the S/RV. At the same time, there would be an immediate drop of 12 to 15% in reactor steam flow and main generator output. Correspondingly, the turbine control valves would partially close to maintain set point. Within a few seconds, the thermocouple in the S/RV discharge line would sense the increased temperature and display increased temperature on panel 921 in the control room and cause an audible alarm on process computer and panel annunciator.

The Suppression Pool Temperature Monitoring System at Pilgrim Unit #1 consists of two temperature element resistance bulbs which are directly affected by suppression pool temperature. Both resistance bulbs are combined to provide an average or bulk temperature indication of the entire suppression pool. The temperature element resistance bulbs are the single-element type and are protected by a stainless steel tube. Temperature indication from these temperature resistance bulbs can be read on panel C7.

There are a number of other indications and alarms, located on control room panels C7, 903 and 904 which may be tripped by the stuck open S/RV event. These include (a) torus vacuum breaker open, (b) HPCI torus high level, (c) drywell to torus low differential pressure, and high torus air temperature.

By far, however, the most compelling signals to the operator are those previously mentioned, i.e.:

a) the unmistakable sound of steam discharging from an S/RV,

b) the immediate drop in steam flow and generator output of 12% to 15%, and the corresponding partial closure of the turbine control valve,

c) within 10 seconds, annunciation on the S/RV discharge line temperature increase,

d) within a few seconds to a few minutes, annunciation on suppression pool high temperature.

Reactor operators have been instructed to recognize these signals as indications of a stuck open S/RV. They have been given specific instructions on how to deal with the situation. Their first action will be to attempt to close the open S/RV, as this is the most direct way of terminating the transient. If unsucessful, they are instructed to scram the plant within five minutes of the first indication. Subsequent actions of the operators will be to alternately open each of the three remaining S/RV's one at a time at frequent intervals to help distribute the heat load. Also, the operators are instructed to establish suppression chamber cooling using both RHR heat exchangers.

If an S/RV should stick open at full power, it is important that the operator scram the plant in a reasonably short period of time after initiation of the event. The operators are instructed to scram in five minutes or less if attempts to close the open S/RV are unsuccessful. It was shown in Section 2.2.1 that the operator could wait 10 minutes until bulk suppression pool temperature reached 110°F and still be below the 150°F limit. However his ability to react in five minutes is reasonable based on actual plant experience.

Of course, operators will not have to scram the plant if an S/RV sticks open under hot standby conditions. In this case, and after the scram for the full power case, the operator is required to either open the bypass valves or another S/RV. He is also required to actuate the RHR system in the pool cooling mode using both heat exchangers if it is not already operating.

3. Summary and Conclusions

Of all the cases considered, there were none that exceeded a 150°F bulk suppression pool temperature for a ramshead mass flux of 40 lbm/sec-ft^2 or greater using the current technical specification pool temperature limits as initial conditions.

All technical specification limits were found to be adequate to keep bulk suppression pool temperatures below 150°F when the ramshead discharge mass flux was 40 lbm/sec-ft^2 or greater.

4. References

1. Letter, USNRC to Boston Edison Company, Dated December 12, 1977.
2. Letter, E. D. Fuller, GE, to O. D. Parr, USNRC, MFN 343-77 September 6, 1977.
3. RETRAN - A Program for One-Dimensional Transient Thermal-Hydraulic Analysis of Complex Fluid Flow Systems, Volume 1: Equations and Numerics, EPRI NP-408, January, 1977.

4. Ansari, A. A. F., - A RETRAN model to Predict BWR Suppression Pool Temperature Response to a specific heat load as a Function of time; calculation for VY, 1978, YAECo.

TABLE 1

INITIAL CONDITIONS

Parameter	Value	Comment
Reactor Power, MWt	1998	Licensed Power Level
Initial Pressure, psia	1020	FSAR
Initial Fluid Mass, lbm	458,756	Calculated
Initial Steam Flow, 10^6 lbm/hr	7.983	FSAR
S/RV capacity at 1080 psig	880,000	10% above nameplate capacity
Decay Heat	-	ANS + actinides, infinite irradiation
Suppression Pool Vol, ft^3	84,000	Tech. Spec. Minimum
RHR Heat Exchanger		
Cap., Btu/sec^{o}F	177 each	FSAR (fully fouled condition)
Service Water Temp., ^{o}F	70	

Figure 1

PILGRIM RETRAN MODEL
OPTIMIZED VERSION
FOR SUPPRESSION POOL STUDY

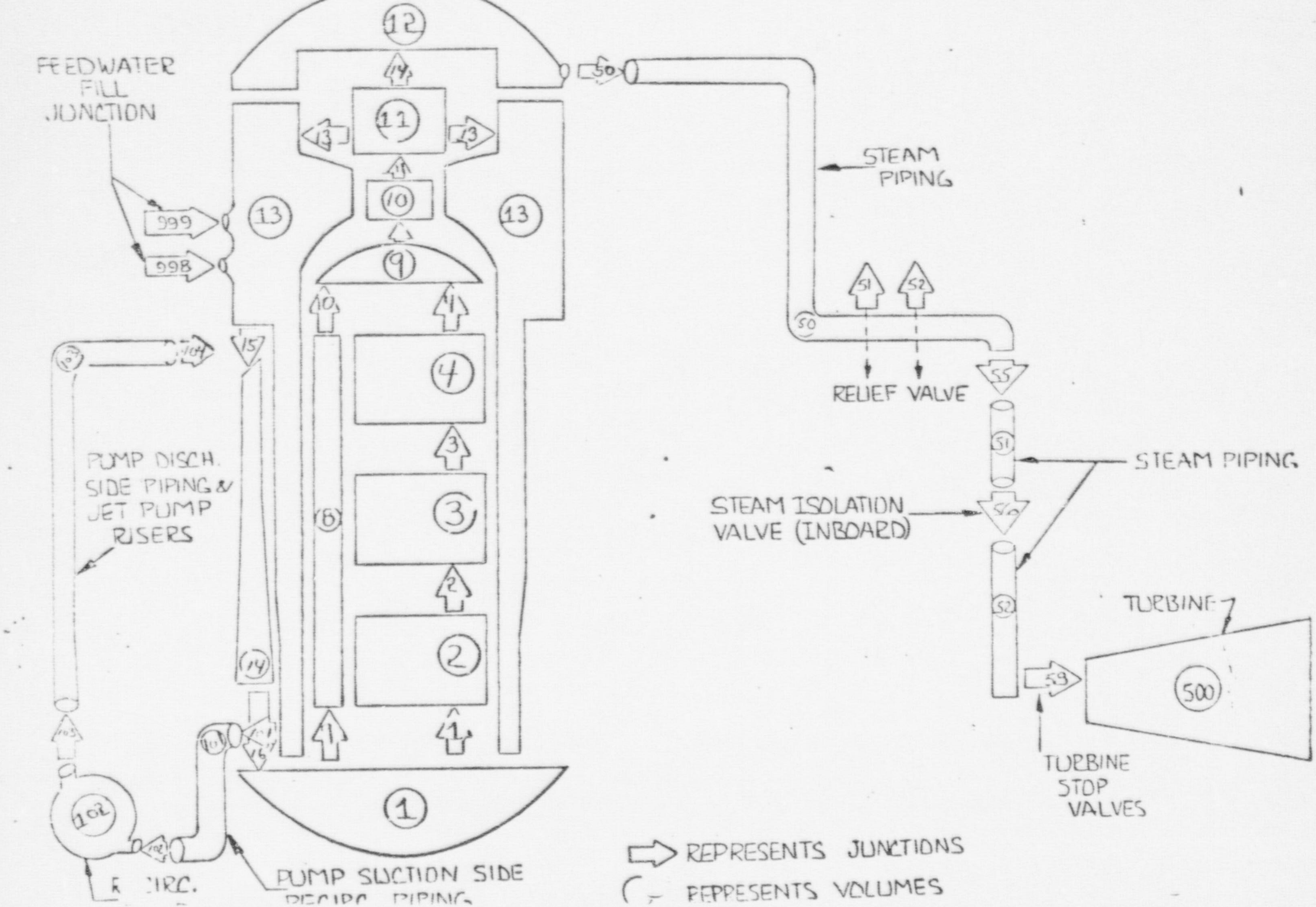
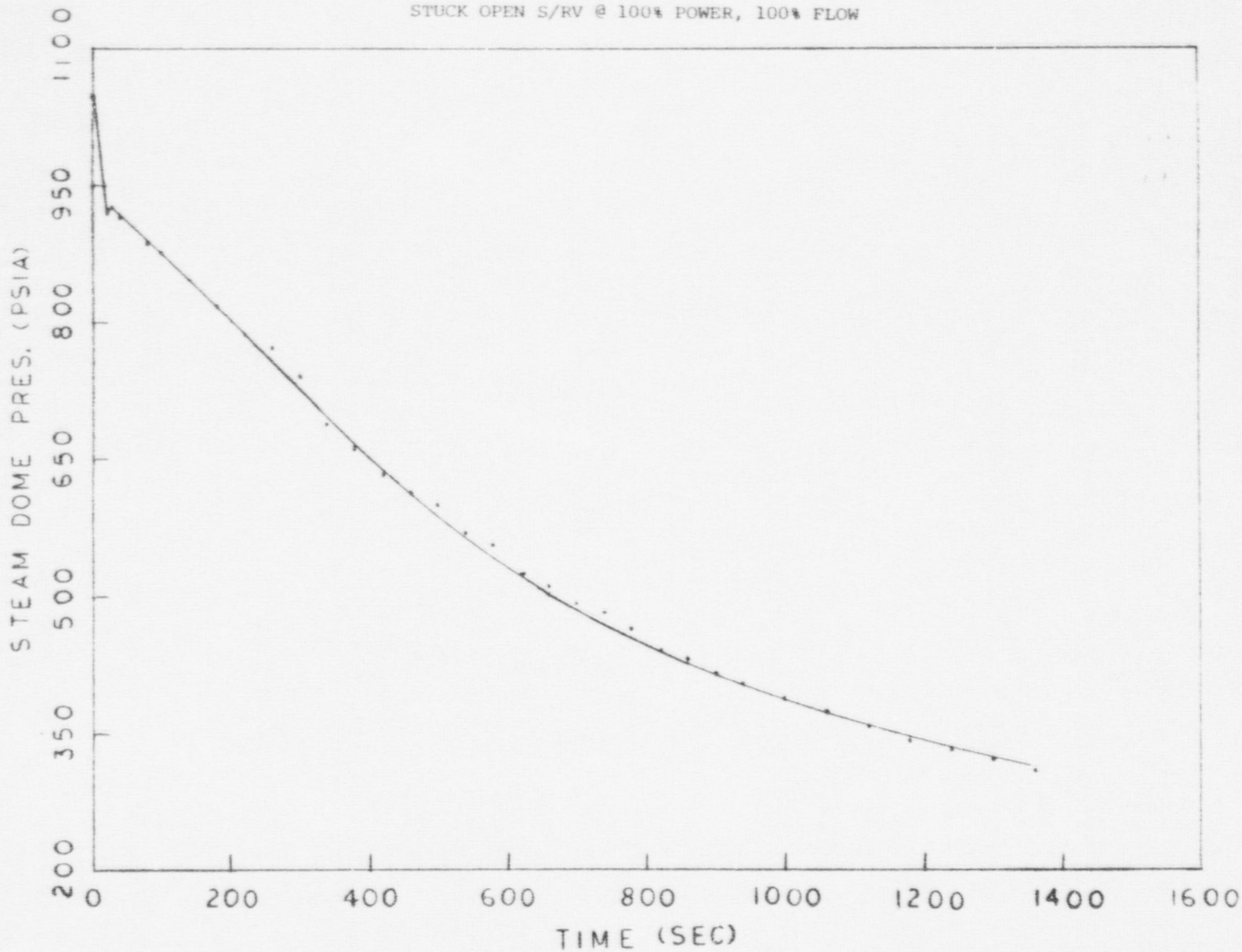


FIGURE 2

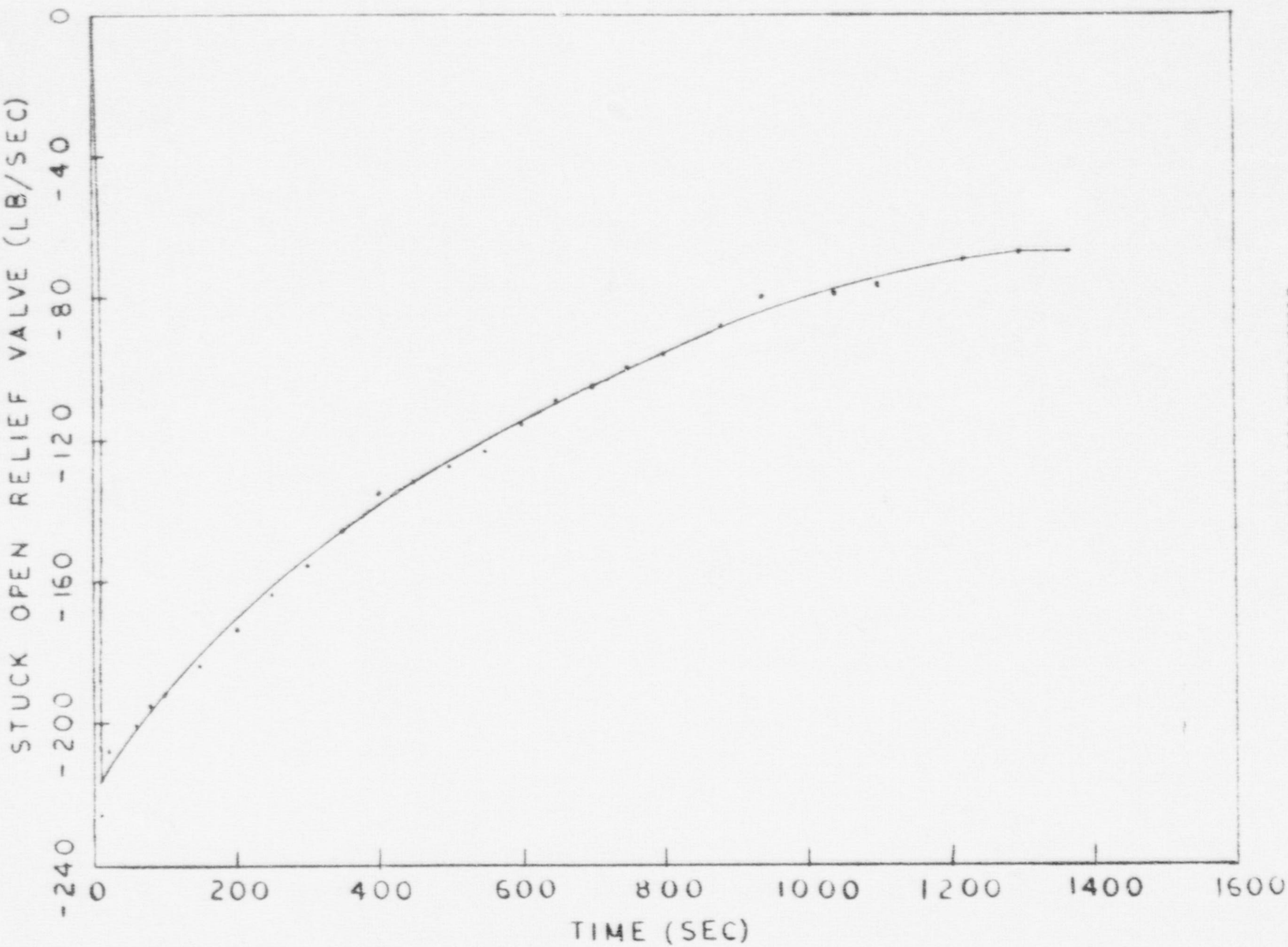
STUCK OPEN S/RV @ 100% POWER, 100% FLOW



PRESSURE vs. TIME

FIGURE 3

STUCK OPEN S/RV @ 100% POWER, 100%FLOW



STEAM FLOW VS. TIME

FIGURE 4

STUCK OPEN S/RV @ 100% POWER, 100% FLOW

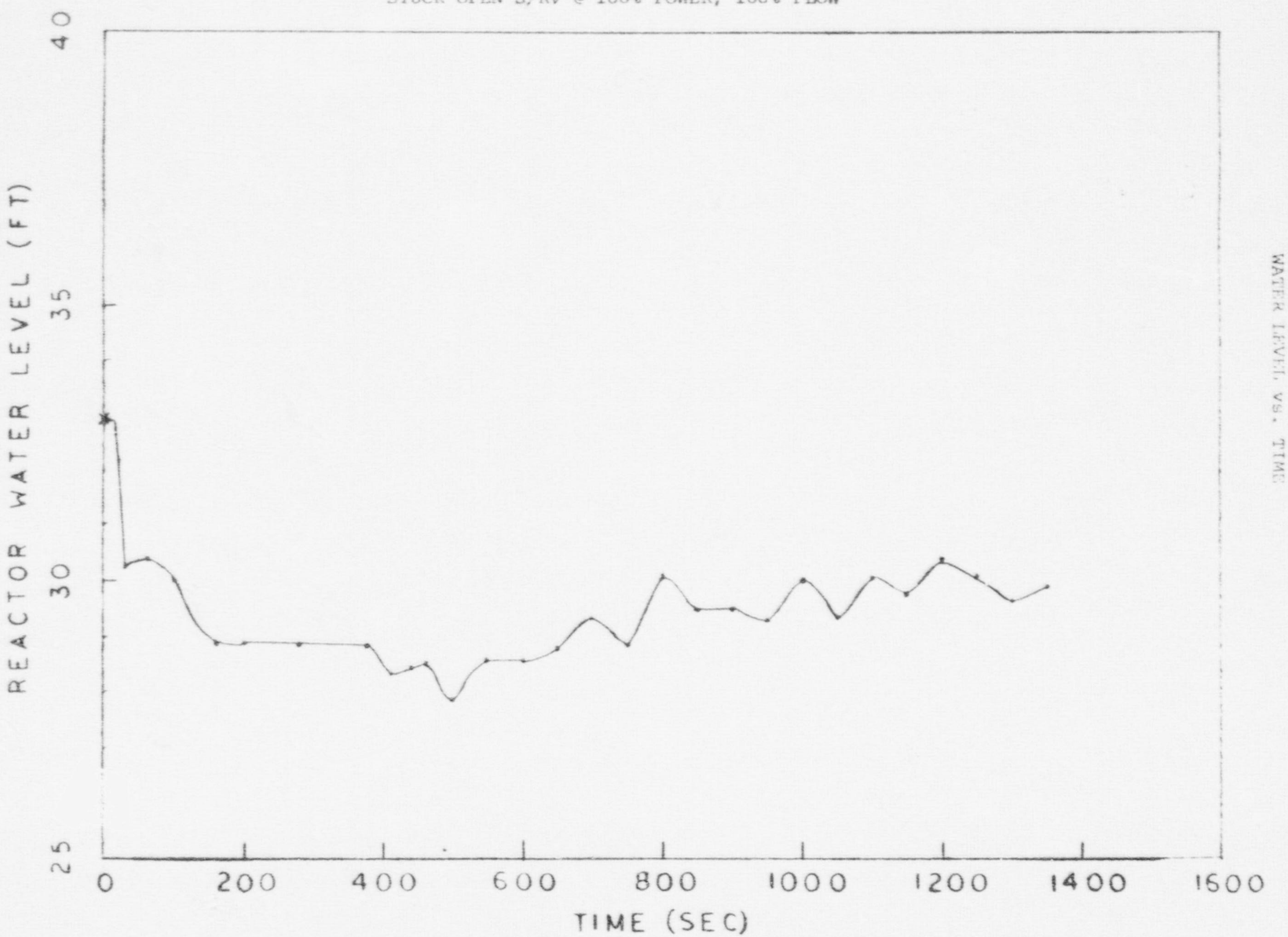
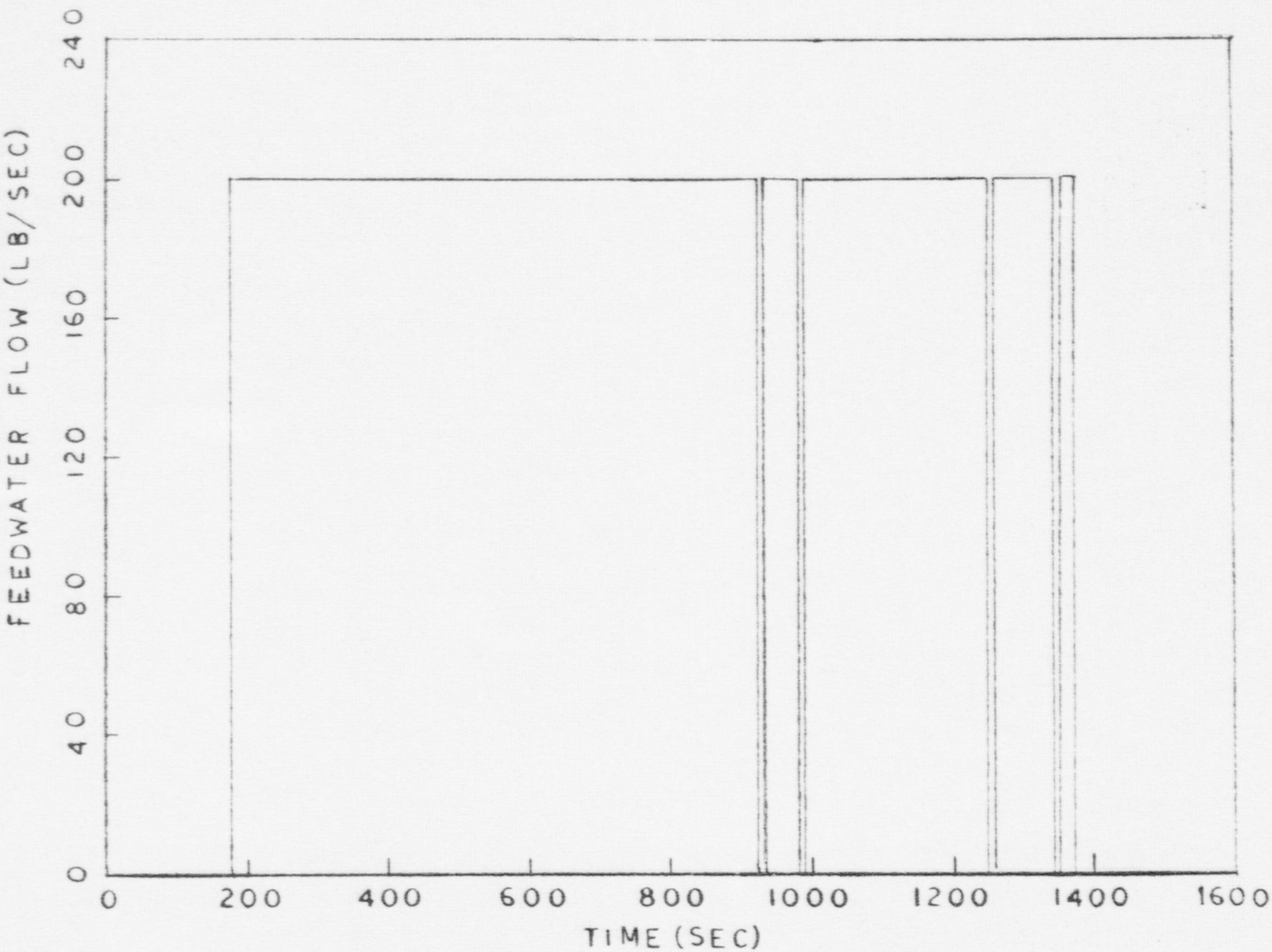


FIGURE 5

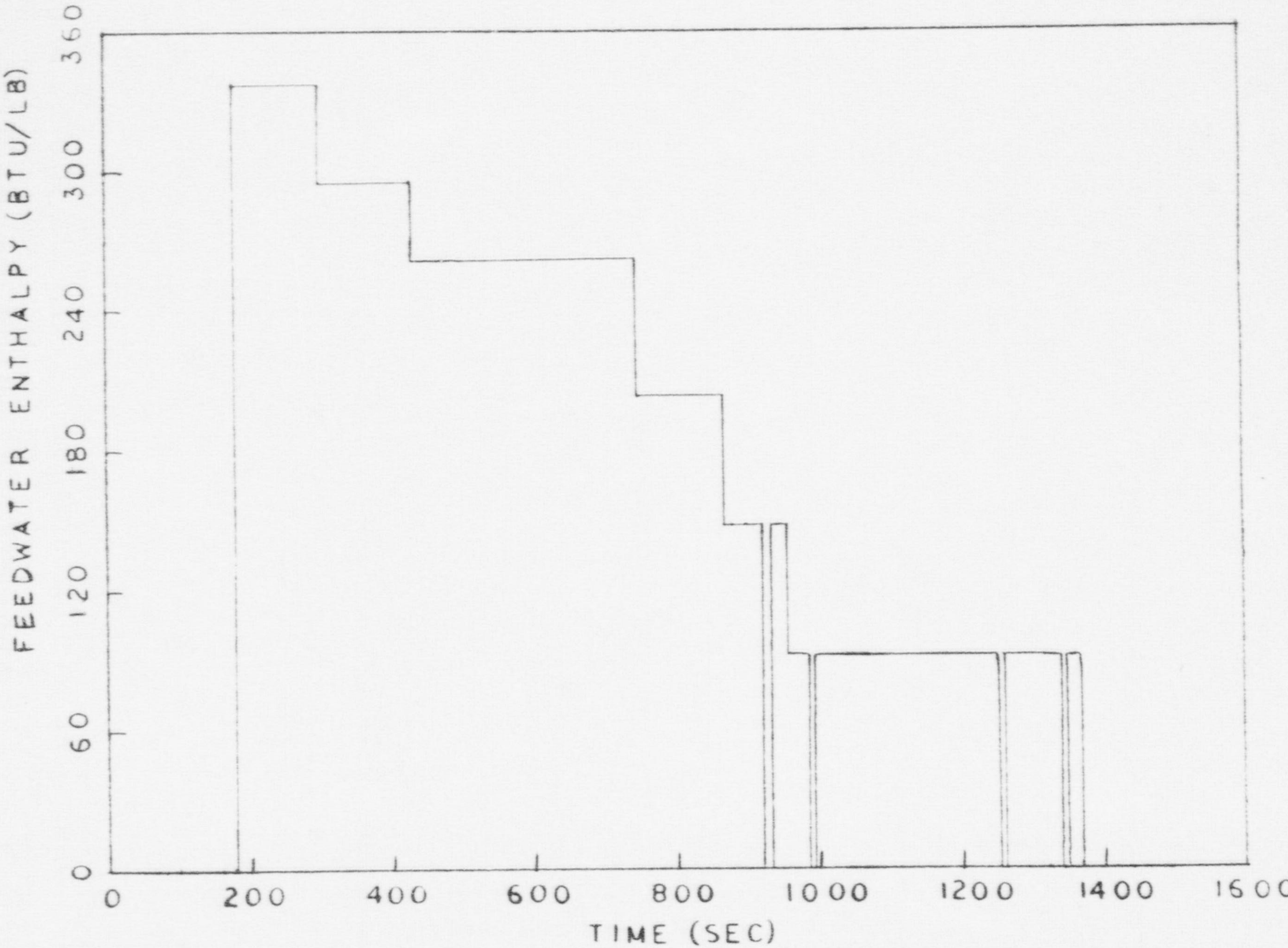
STUCK OPEN S/RV @ 100% POWER, 100% FLOW



FEEDWATER FLOW vs. TIME

FIGURE 6

STUCK OPEN S/RV @ 100% POWER, 100% FLOW



FEEDWATER ENTHALPY vs. TIME

FIGURE 7

STUCK OPEN S/RV @ 100% POWER, 100% FLOW

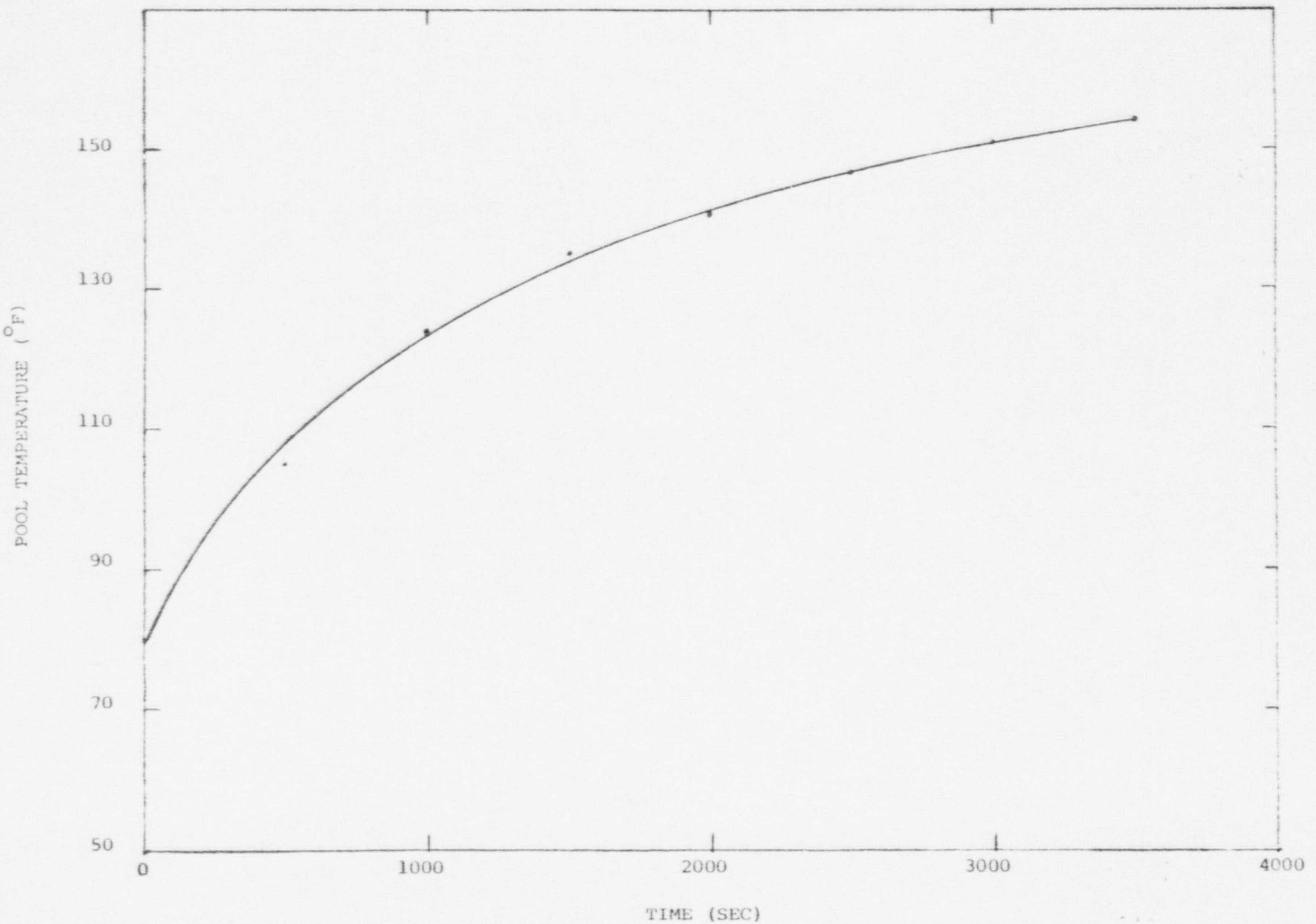


FIGURE 8
BULK SUPPRESSION POOL TEMP. vs. RAMSHEAD MASS FLUX

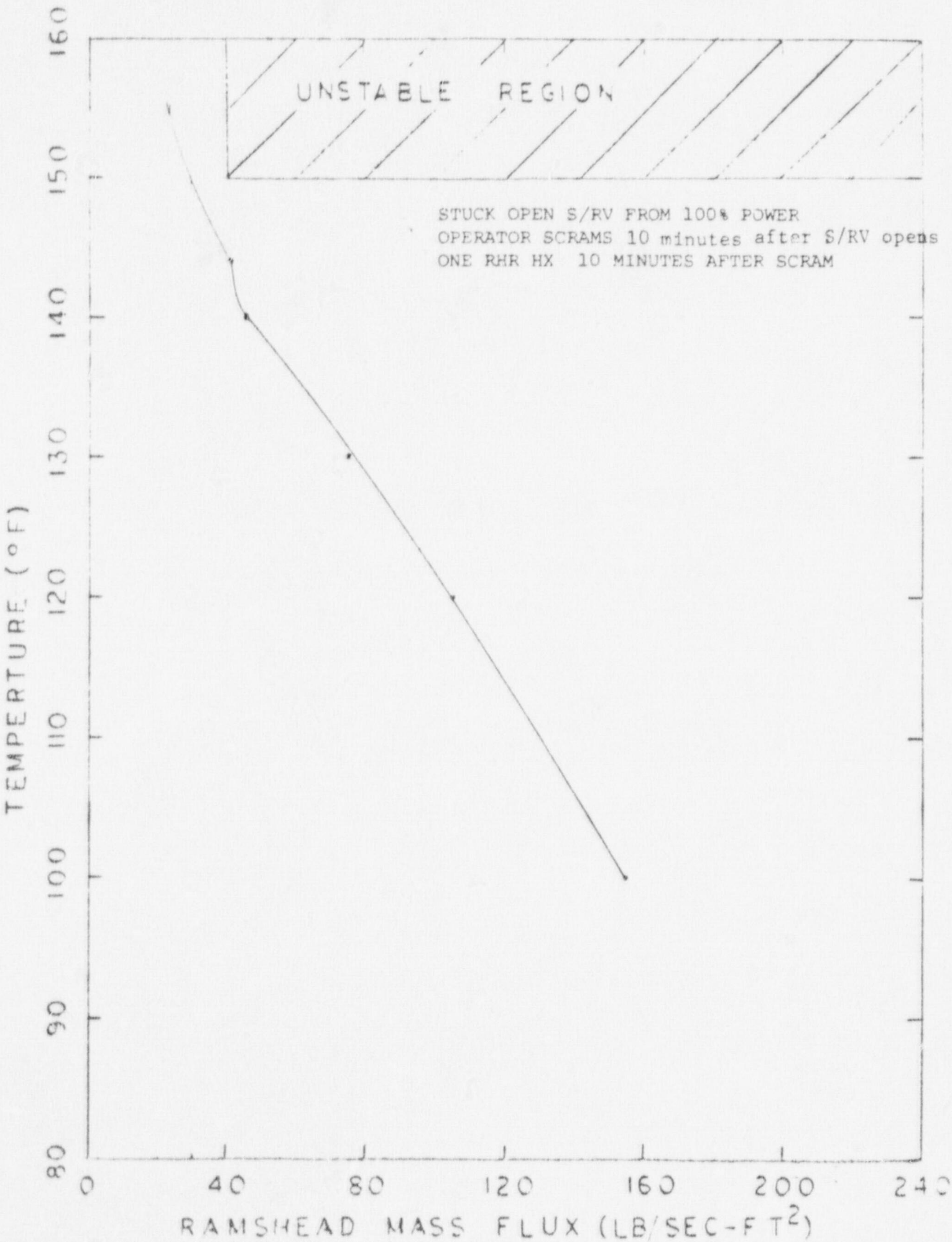


FIGURE 9

STUCK OPEN S/RV

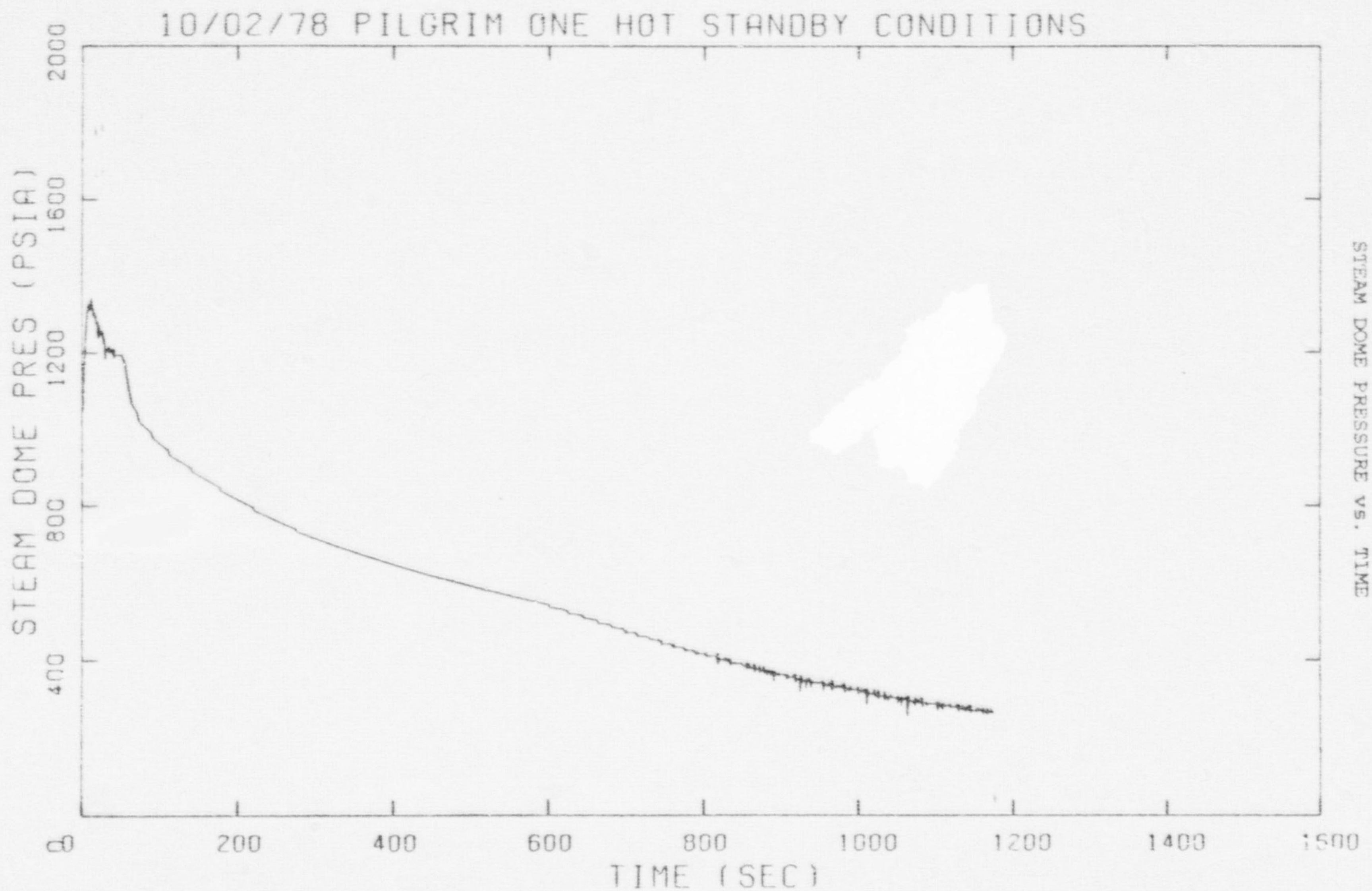


FIGURE 10

BULK SUPPRESSION POOL TEMPERATURE VS. RAMSHEAD MASS FLUX

STUCK-OPEN S/RV FROM HOT STANDBY CONDITIONS

INITIAL POOL TEMPERATURE = 120°F

ONE RHR HX OPERATING AT TIME OF INCIDENT

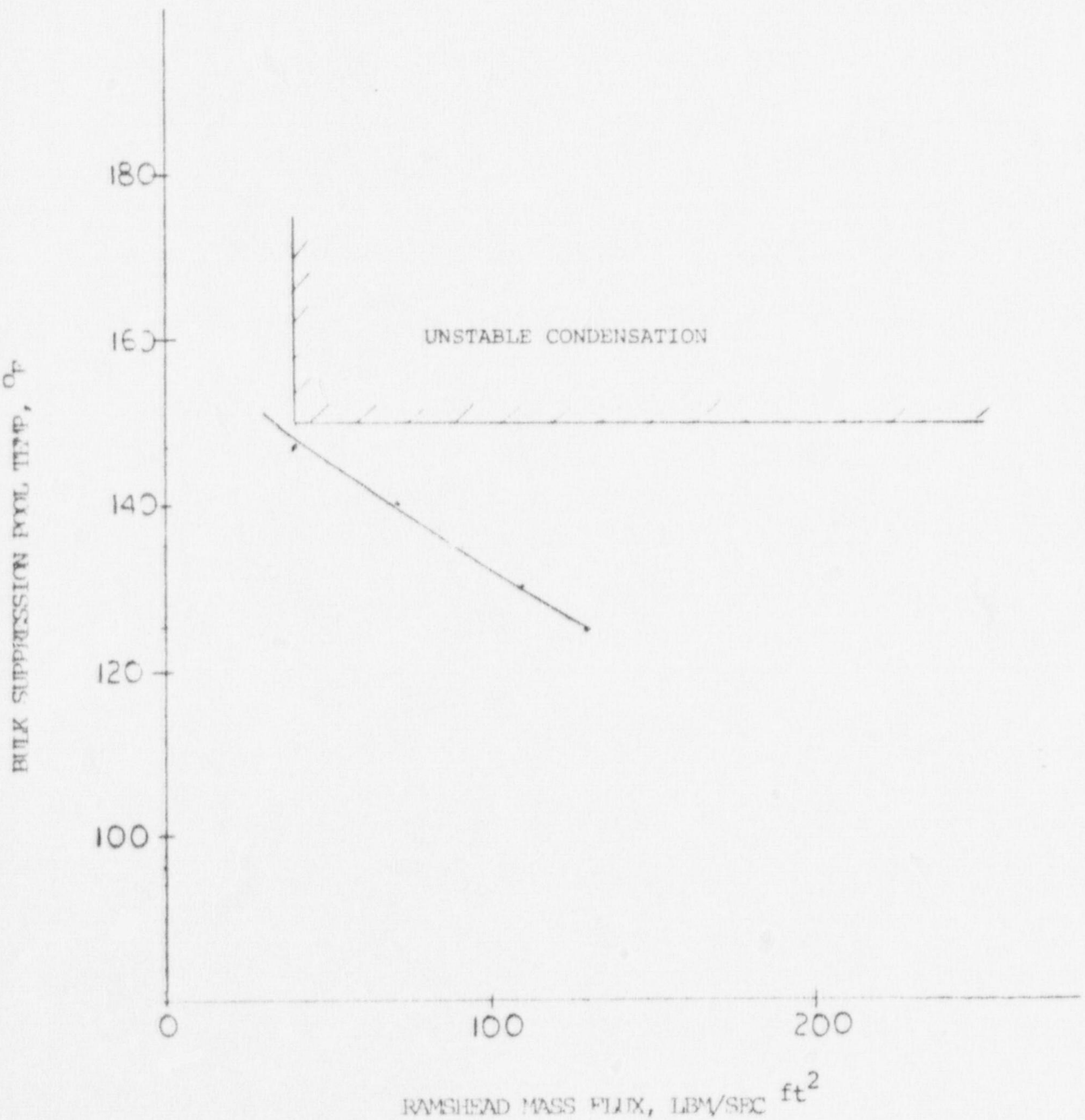


FIGURE 11

ADS ACTUATION FOLLOWING A LOCA, REACTOR PRESSURE VS. TIME

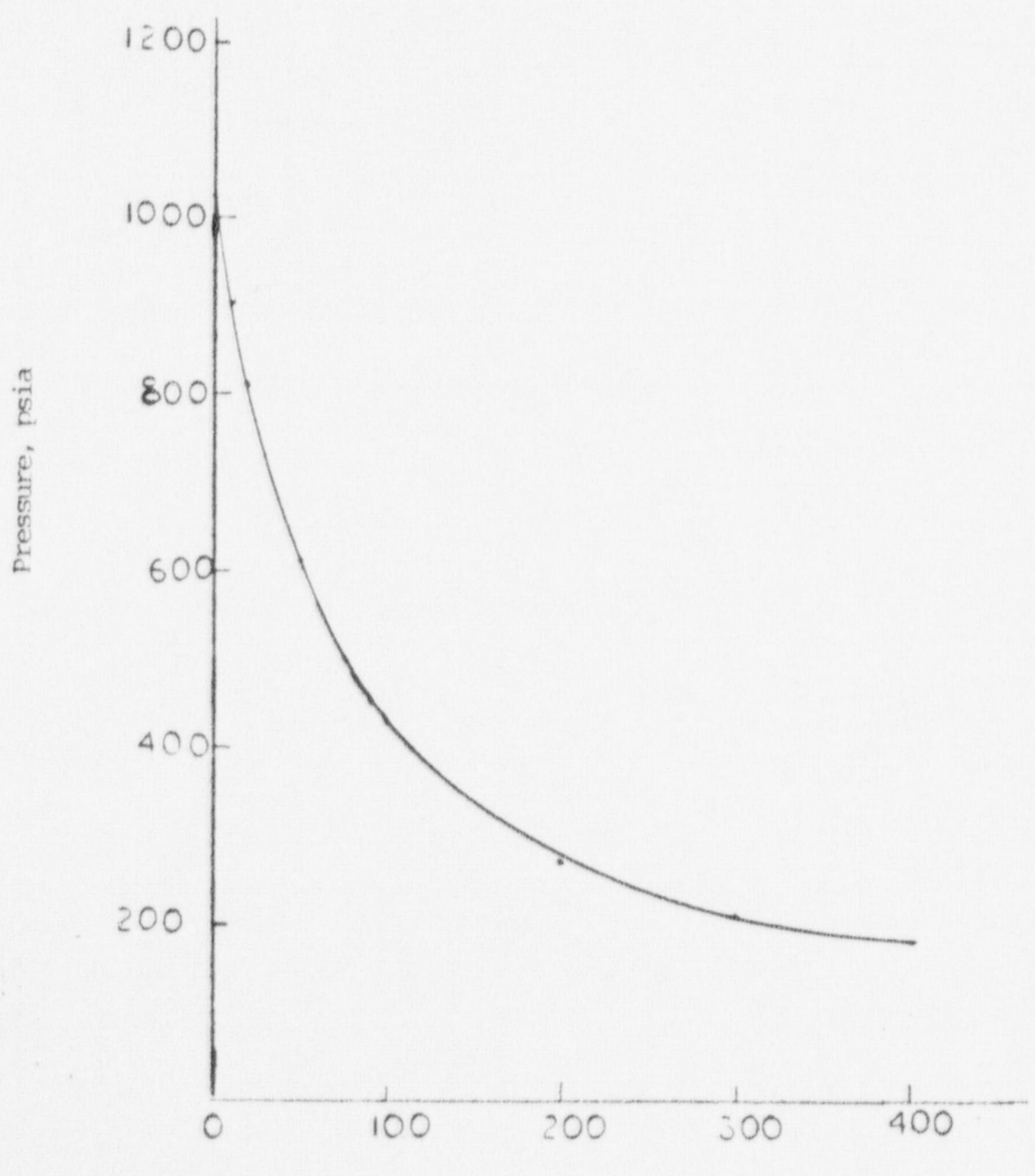
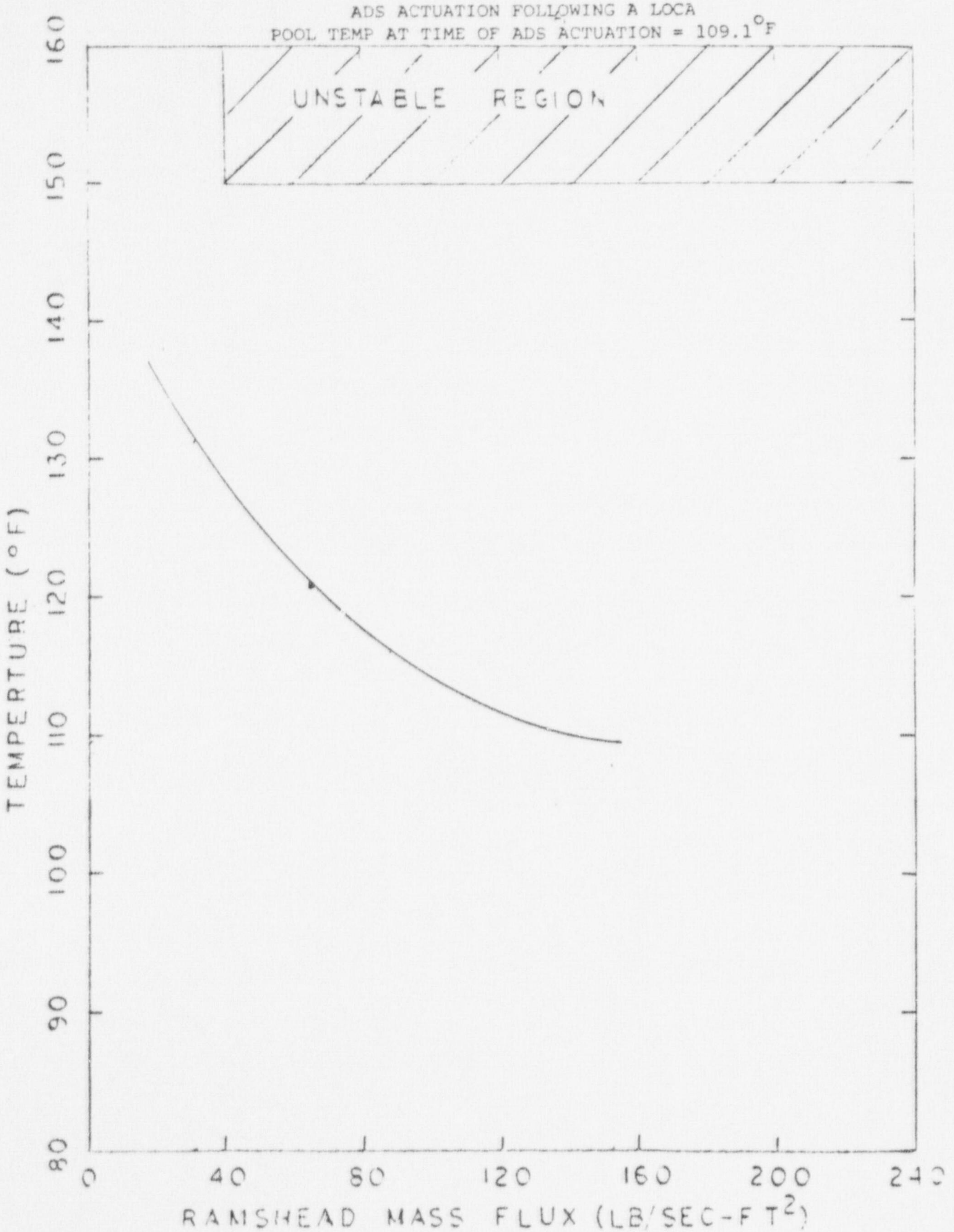


FIGURE 12

BULK SUPPRESSION POOL TEMP vs. RAMSHEAD MASS FLUX
ADS ACTUATION FOLLOWING A LOCA
POOL TEMP AT TIME OF ADS ACTUATION = 109.1°F



REACTOR COOLANT @100°F/HR, REACTOR PRESSURE VS. TIME

FIGURE 13

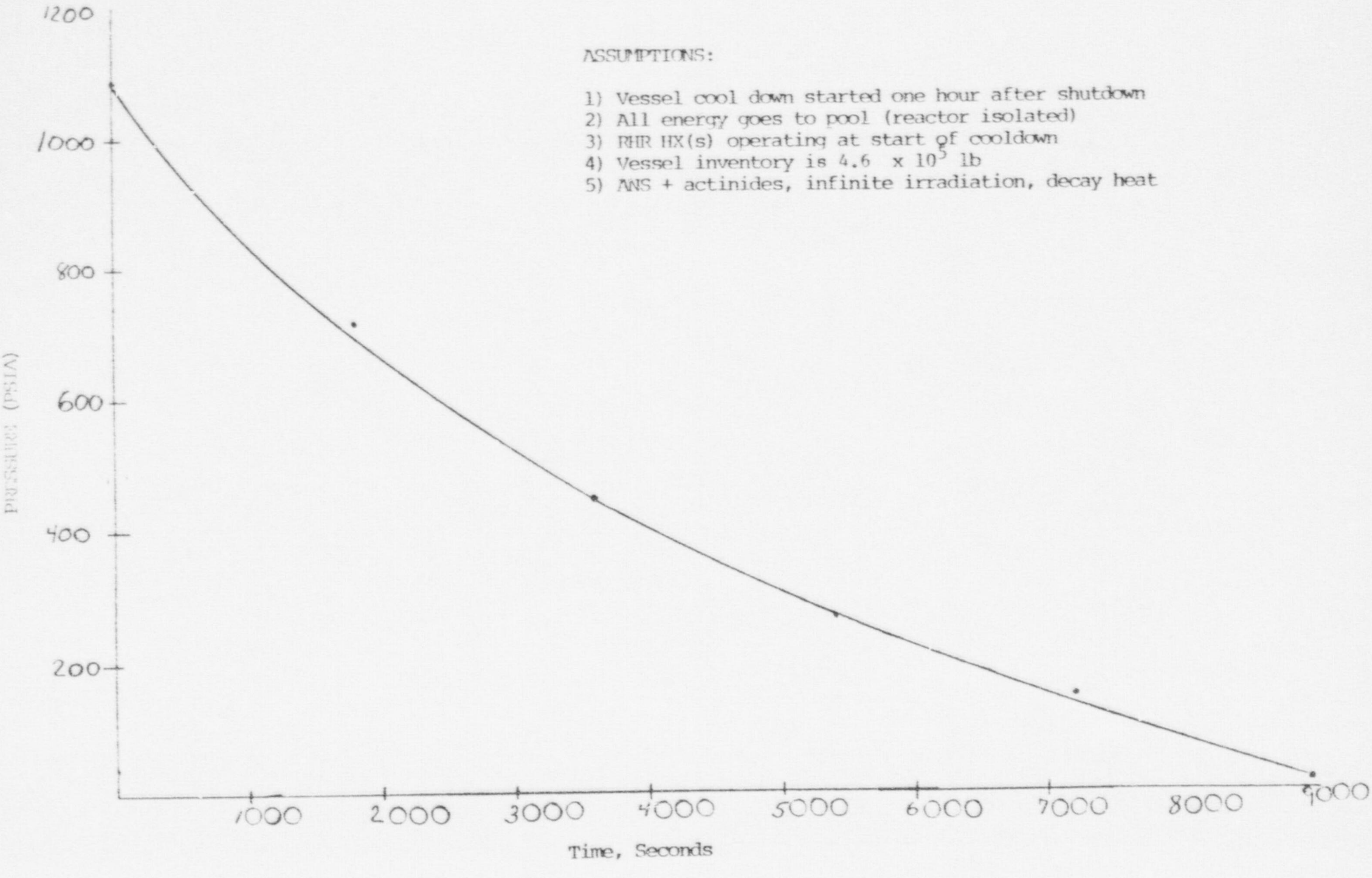


Figure 14

REACTOR COOLANT @100°F/HR, POOL TEMP. VS. TIME

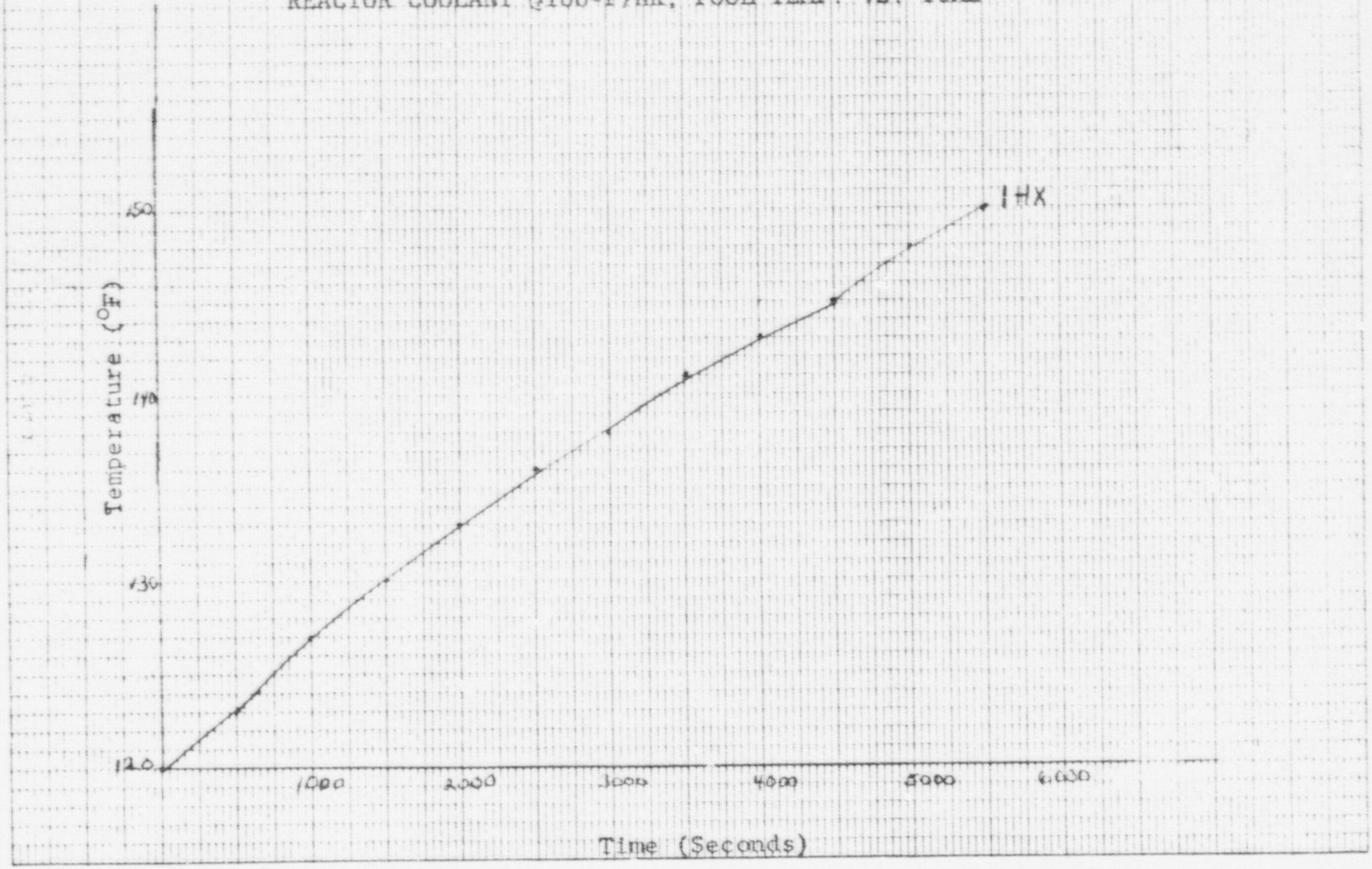


FIGURE 15

BULK SUPPRESSION POOL TEMPERATURE VS. RAMSHEAD MASS FLUX

REACTOR ISOLATED AN COOLED DOWN AT 100°F/HR