Enclosure to
LD-83-074

COMPUTER SIMULATION OF A NATURAL CIRCULATION COOLDOWN

COMBUSTION ENGINEERING SYSTEM 80™

NUCLEAR POWER SYSTEMS DIVISION
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1.0 INTRODUCTION

1.1 Purpose

This report provides the results of a computer simulation of a natural circulation cooldown of a Combustion Engineering System 80 NSSS from hot standby to conditions that permit initiation of the shutdown cooling system. The simulation was performed using Long Term Cooling (LTC) computer simulation code which uses a node and flow path type network to model the reactor coolant system and rigorously accounts for steam bubble formation in the reactor vessel upper head. The simulation was performed assuming the restrictions of Branch Technical Position (BTP) RSB 5-1, i.e., only safety-grade equipment was used in the analysis concurrent with a loss of offsite power and a single failure. Table I (p. 2) lists the operational status of certain key systems and equipment assumed in the analysis.

1.2 Scope

This report contains a computer simulation of a full, natural circulation cooldown from hot standby conditions to temperatures and pressures that permit the initiation of the shutdown cooling system. All systems, equipment, and components used in the simulation conform to the requirements of BTP RSB 5-1, i.e., the simulation was conducted using only safety-grade equipment concurrent with a loss of offsite power and an assumed single failure. The analysis was performed for the C-E System 80 NSSS. Values of certain key System 80 plant parameters pertinent to the natural circulation cooldown process are shown in Table II (p. 3).

2.0 COMPUTER SIMULATION

2.1 Methodology and Assumptions

The LTC computer simulation code that was used to perform the analysis contained in this report is described in Reference 1. However, the code is modified to provide an improved flow path modeling for the reactor

TABLE I

Operational Status of Key Systems and Equipment During Simulation

SYSTEM/COMPONENT	STATUS
Letdown	Unavailable.
Charging pumps	One pump available initially, two pumps only after thirty minutes.
Auxiliary spray	Available.
Pressurizer heaters	Unavailable.
Emergency diesel generators	One available only.
Steam bypass control system	Unavailable.
Atmospheric dump valves	Available.
Main feedwater system	Unavailable.
Auxiliary feedwater system	Available.
Seismic Category I condensate storage tank (300,000 gallons)	Available.
Reactor protective system	Available, all rods fully inserted following reactor trip.
Refueling water tank	Available with a boron concentration Technical Specifications of 4000 ppm.
Reactor vessel upper head vent system	Available.
Offsite power	Unavailable.
Reactor coolant pumps	Unavailable.
Pressurizer pressure control system	Unavailable, operator has manual control of pressure via auxiliary spray and charging flow.
Pressurizer level control system	Unavailable, operator has manual control of pressurizer level via charging and system contraction during plant cooldown.

TABLE II

Key System 80 Parameters
Pertinent to the Natural Circulation
Cooldown Process

PARAMETER	VALUE
Rated thermal power	3800 Mw
Reactor vessel upper head volume	2019 ft^3
Normal system pressure	2250 psia
Charging pump flowrate, per pump	44 gpm
Main steam safety valve setpoint	1270 psia
Atmospheric dump valve capacity, per valve (steam at 1070 psia)	9.59×10^5 lbm/hr
Atmospheric dump valve effective flow area	0.122 ft^2
Number of atmospheric dump valves per steam generator	2
RCS water volume	12097 ft^3
Pressurizer volume	1800 ft^3
Normal, no load, steam generator pressure	1170 psia

vessel upper head (RVUH). Previously only one flow path was used to connect the RVUH with the reactor vessel outlet plenum; in this version two flow paths, representing the normal flow of heated water into and out of the RVUH region, were used to connect the RVUH to the reactor vessel outlet plenum. The hydraulic data used by the code for the two flow paths is design data which allows the code to mechanistically calculate the normal flow under forced circulation into and out of the region. Code initialization is such that the initial RVUH water temperature is equal to the weighted average of the hot and cold leg fluid temperatures entering the region. For System 80 this temperature is 599°F.

The normal pumped flowrates representing the design calculated flows into and out of the RVUH region are shown in Figure 1. [All figures for this report are contained together at the end of this section (p. 11).] In contrast with the pumped flowrates, i.e., reactor coolant pumps running, the flowrates under natural circulation are very small. Therefore, following a loss of all forced flow the RVUH can remain relatively hot and thermally lag behind the remainder of the reactor coolant system (RCS) during a cooldown. In addition since the RVUH is at a higher elevation than the RCS, natural circulation induced flow into and out of the region is unlikely. As a result the RVUH must be cooled by either a heat conduction process or by first draining and then flushing cooler loop water into the region.

Nodalized heat conduction calculations in conjunction with a normal RCS cooldown indicate that a conduction related cooldown of the RVUH to shutdown cooling system initiation conditions, i.e., a cooldown and subsequent depressurization without forming a steam bubble in the upper head, will require about 55 hours for System 80. This cooldown rate precludes entrance into the shutdown cooling system within the capacity of the condensate storage system, therefore, an analysis using the deliberate draining and refilling of the upper head region via steam bubble formation is credited. Previous analyses (Reference 2), credited full pressurizer heaters to displace fluid via heater action from the pressurizer into a drained RVUH in order to effect cooling in

that region. In the analysis performed for this report the reactor vessel upper head vent system was used to assist in depressurizing the upper head. Although the orifice size is small (7/32" diameter), the use of the head vent system allows adequate depressurization of the upper head which in turn allows cooler RCS loop water, augmented by charging flow, to preferentially enter and cool the region.

Table I (p. 2) shows the status of key systems and components assumed for this report. The analysis was performed using the restrictions of BTP RSB 5-1, i.e., only safety-grade equipment was used concurrent with a loss of offsite power and a single failure. The single failure assumed was a failure of one diesel generator to start which disables one entire emergency power train. Additional assumptions and initial conditions are listed in Table III (p. 6).

2.2 Results

Immediately following the loss of offsite power, flow through the core decreases rapidly as reactor coolant pumps begin to coast down. A reactor trip is assumed to occur essentially concurrent with the loss of offsite power and full natural circulation is establish in the RCS in approximately ten minutes (Figure 2). Secondary pressures and temperatures (Figure 3 through Figure 6) are rapidly stabilized at hot zero power conditions by manual control of the atmospheric dump valves (ADVs). Pressurizer level (Figure 7) stabilizes at about 43% and is maintained relatively constant via manual control of charging (Figure 8). Loop temperatures (Figure 9 and Figure 10) rapidly stabilize with cold leg temperatures approximately equal to steam generator secondary temperatures. RVUH temperature, initially 599°F (Figure 11) is essentially constant throughout the beginning portions of the simulation.

The plant is maintained in hot standby for four hours, consistent with BTD RSB 5-1. During this period, RCS pressure gradually decreases due to pressurizer ambient heat losses (Figure 12). As noted previously, heaters are assumed to be unavailable. At four hours following reactor

<u>TABLE III</u>

Additional Assumptions and Initial
Conditions Used in Analysis

1. RCS initially stable at 100% power.

2. 1.0 1971-ANS decay heat.

3. Initial steam generator pressure approximately 1070 psia. Operator opens ADVs immediately following trip to maintain secondary pressure below main steam safety valve setpoint.

4. Transient initiated at time zero via a loss of offsite power. One emergency diesel generator fails to start.

5. Unless otherwise stated, operator actions per Reference 3 assumed.

6. Operator takes manual control of charging following trip to control pressurizer pressure and level.

7. Operator takes manual control of auxiliary feedwater system following trip to slowly regain steam generator levels and prevent overcooling.

trip, a 50°F/hour RCS cooldown is commenced by increasing flow through the ADVs. Pressurizer level is allowed to decrease via loop contraction by operating only one charging pump during the initial part of the cooldown (Figure 7). This action is taken in anticipation of RCS pressure decreasing to saturation pressure in the RVUH with subsequent steam bubble formation. Pressure is about 1700 psia at the start of the RCS cooldown (Figure 12) and decreases fairly rapidly to 1500 psia until pressurizer level reaches 30%, at which time, level is maintained constant and pressure decreases due to ambient losses only. At about 5.6 hours, system pressure has fallen to saturation pressure for the RVUH, approximately 1400 psia as shown in Figure 12. A steam bubble then begins to form and then slowly expands, displacing fluid into the pressurizer (Figure 7). At this point one charging pump is secured and the steam bubble continues to expand (Figure 13) as fluid is displaced from the upper head into the RCS loops as loop fluid contracts due to the cooldown. By 8.2 hours the steam bubble in the RVUH has increased in size to about 1000 ft^3 and pressurizer level has increased to about 42%. Using this size steam bubble in the RVUH as an arbitrary limit and recognizing the need to flush cooler RCS loop water into the upper head region, the reactor vessel head vent is opened, (Figure 14).

The result of opening the head vent and charging to the RCS is to preferentially force cooler loop water into the RVUH; as the subcooled RCS water now mixes with the saturated water in the RVUH it removes the subcooling from that water causing the RVUH thermodynamic state to be saturated steam over subcooled water. Under these conditions the depressurization due to the vent is more effective since the negative feedback of boiling the previously saturated water (in the RVUH) is no longer present. The depressurization thus effected in the RVUH is such that pressurizer level falls due to the relative pressure difference between the RVUH and the pressurizer. At 8.9 hours the RCS cooldown is stopped (Hot leg temperature = 350°F) and pressurizer level reaches 30%. At this point the second charging pump is used to control pressurizer level at 30%, and the cool RCS water continues to surge into the RVUH region. This insurge is allowed to continue until the steam bubble size

in the RVUH is reduced to approximately 100 ft^3 at 10.0 hours. The collapse of the steam bubble is then halted by closing the vent; at this point RCS pressure has dropped to about 900 psia.

Now that the upper head has been essentially refilled and the pressurizer is relatively empty with the RCS pressure still too high to enter shutdown cooling (≤ 400 psia), auxiliary spray is used to further reduce the system pressure. This occurs from 10.1 hours to 10.3 hours (Figure 15). The resulting depressurization is rapid, with RCS pressure falling to about 500 psia during this time frame (Figure 12). Auxiliary spray is halted when the pressurizer level reaches about 80%. Following the auxiliary spray action, the vent is again opened but charging is not used this time to preferentially force cooler loop water into the RVUH. If charging had been used, the results would have been as previously described and an RCS pressure below 400 psia would have been reached very shortly. Instead, after opening the vent, nothing more was done in order to demonstrate the effect of the combined depressurization rate due to RCS heat losses and steam venting in the absence of charging. As seen in Figure 12, this rate is adequate to depressurize the system to 400 psia in a fraction of an hour, but as expected, a slightly larger steam bubble is formed in the RVUH since the process used is not one of collapsing the bubble.

Figure 16 shows loop subcooling throughout the simulation. Even though a steam bubble was formed in the RVUH, adequate loop subcooling was maintained throughout the analysis to ensure proper natural circulation flow. Figure 17 shows the feedwater usage for the evolution as calculated by the simulation code. Note that approximately 220,000 gallons of condensate water was required, well within the 300,000 gallons available per plant Technical Specifications.

2.3 Conclusions

The total time required to take the plant from hot standby conditions to temperatures and pressures that permit use of the shutdown cooling system was approximately 10.5 hours. This time assumes the restrictions

contained in BTP RSB 5-1 which includes maintaining the plant in hot standby for four hours prior to commencing a cooldown. Significant aspects of the analysis are as follows:

1. A steam bubble in the RVUH began to form approximately two hours into the plant cooldown when pressurizer pressure decreased to saturation pressure for that region as a result of ambient losses. Once the steam bubble formed, it continued to increase in size as fluid was displaced from the upper head into the loops, partially accommodating for the contraction due to cooldown.

2. Steam bubble growth is halted and reversed as the RVUH is refilled. Depressurization continues when the vent is used in conjunction with charging flow once cooldown has produced hot leg temperatures sufficiently less than upper head water temperature.

3. Use of auxiliary spray resulted in a relatively rapid pressure decrease. During this period pressurizer level increased significantly concurrent with an increase in RVUH steam bubble size. Loop subcooling was maintained.

4. Significant depressurization could be achieved, once a steam bubble was formed by the use of the head vent alone with ambient losses and without the use of charging. In the absence of charging, the steam bubble continues to increase in size due to flashing in the RVUH as steam flows out the head vent.

4.0 REFERENCES

1. "Response of Combustion Engineering Nuclear Steam Supply System to Transients and Accidents", CEN-128, April 1980

2. Letter from A. E. Scherer to D. G. Eisenhut dated 8 Sept 1982, LD-82-078, Docket No. STN-50-470F, Subject: CESSAR SER Confirmatory Item Number 9

3. "Combustion Engineering Emergency Procedure Guidelines", CEN-152, Rev. 01, November 1982

FIGURE 1

REACTOR VESSEL FLOW PATHS

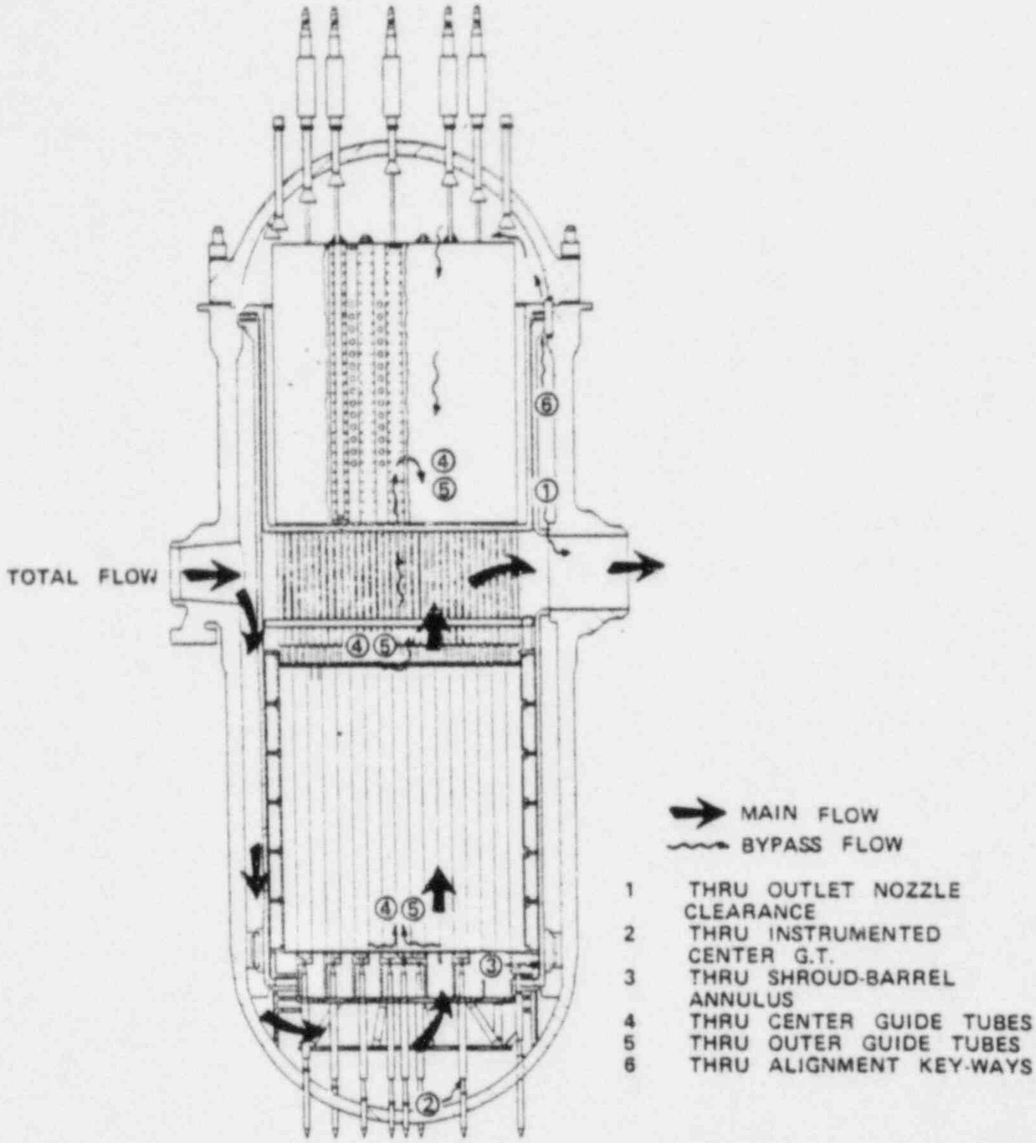

FIGURE 2
SYSTEM 80 BTP RSB 5-1 SIMULATION
CORE FLOW

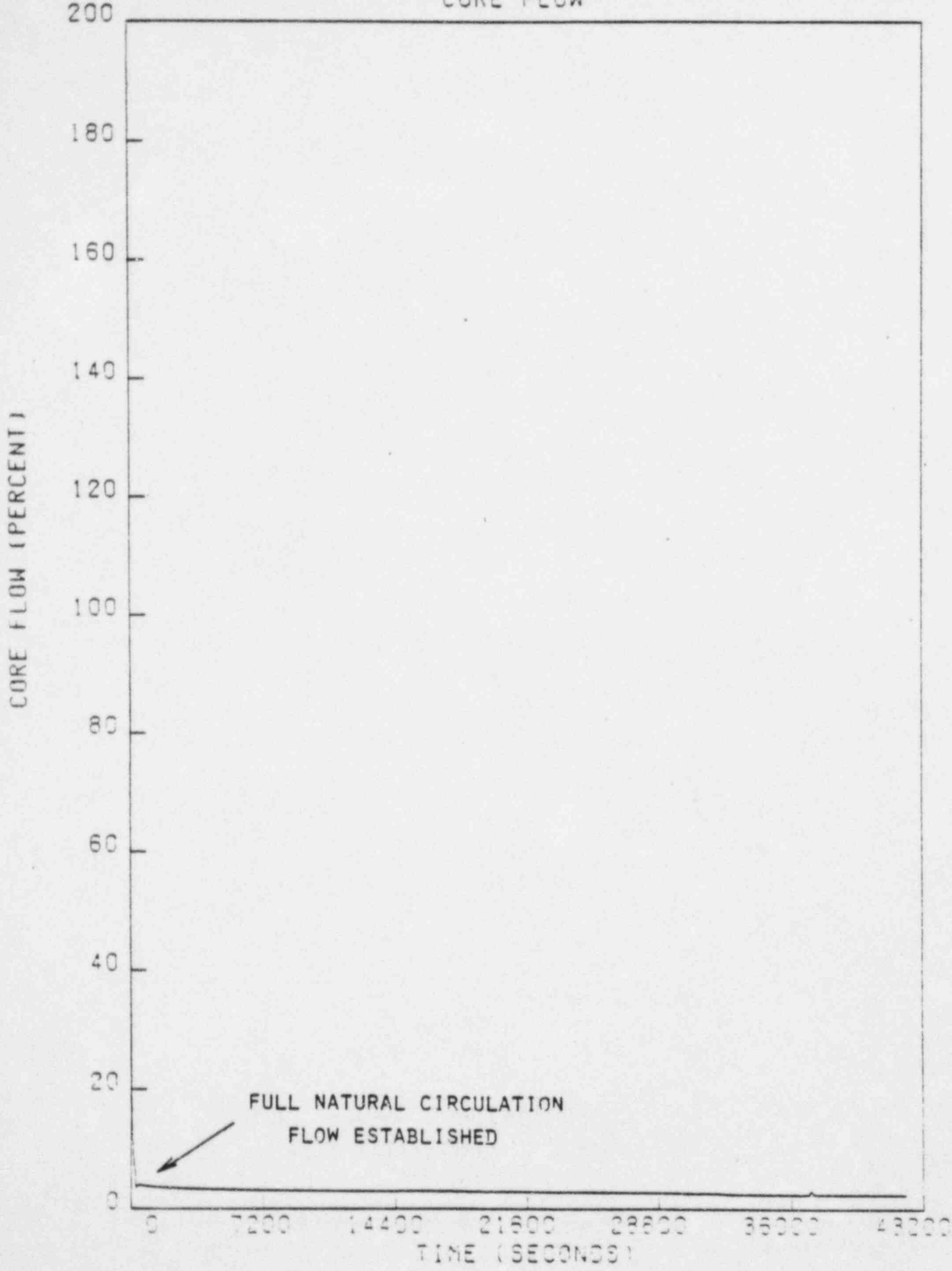

FIGURE 3
SYSTEM 80 BTP RSB 5-1 SIMULATION
STM GEN A PRESSURE

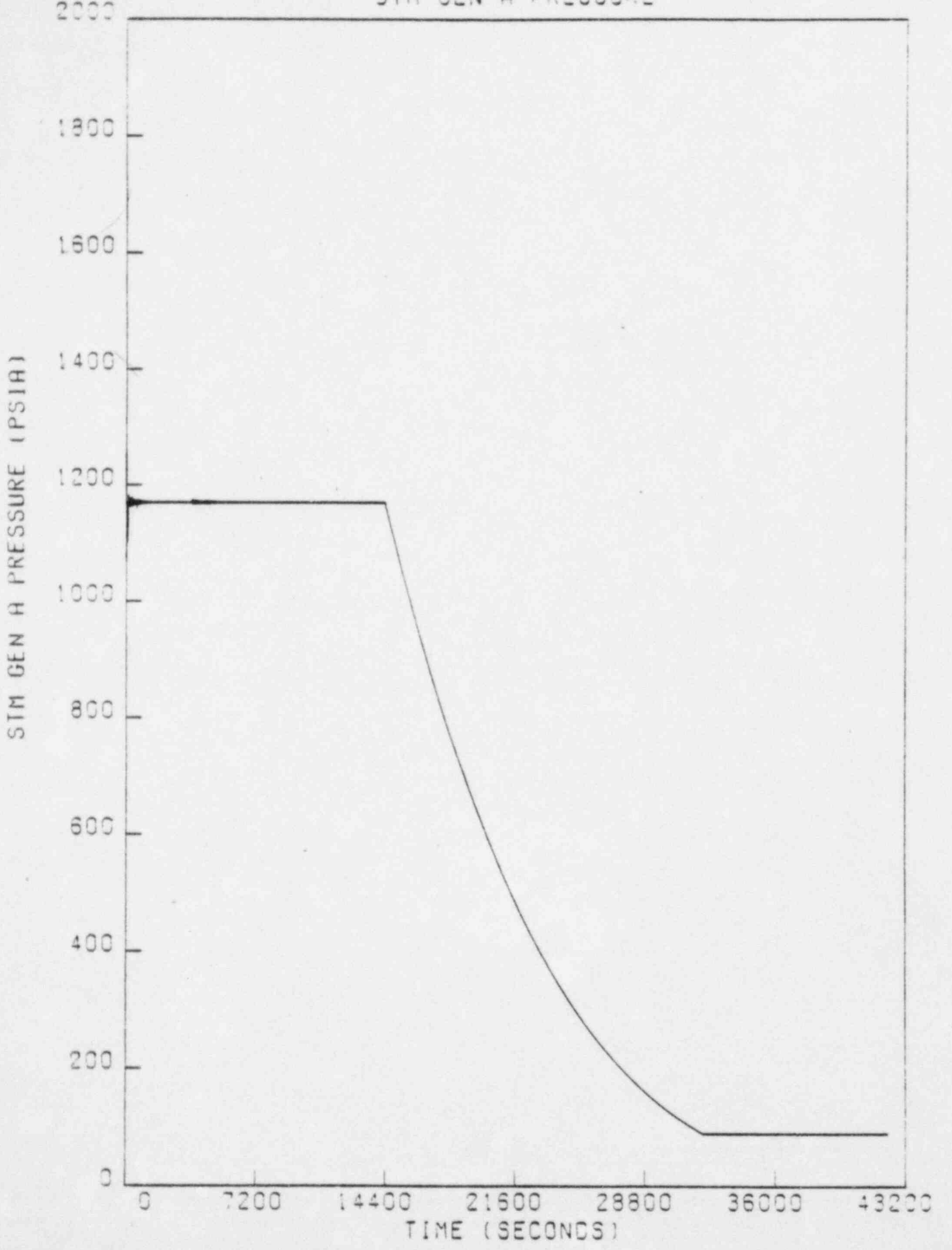

FIGURE 4

SYSTEM 80 BTP RSB 5-1 SIMULATION

STM GEN A TEMPERATURE

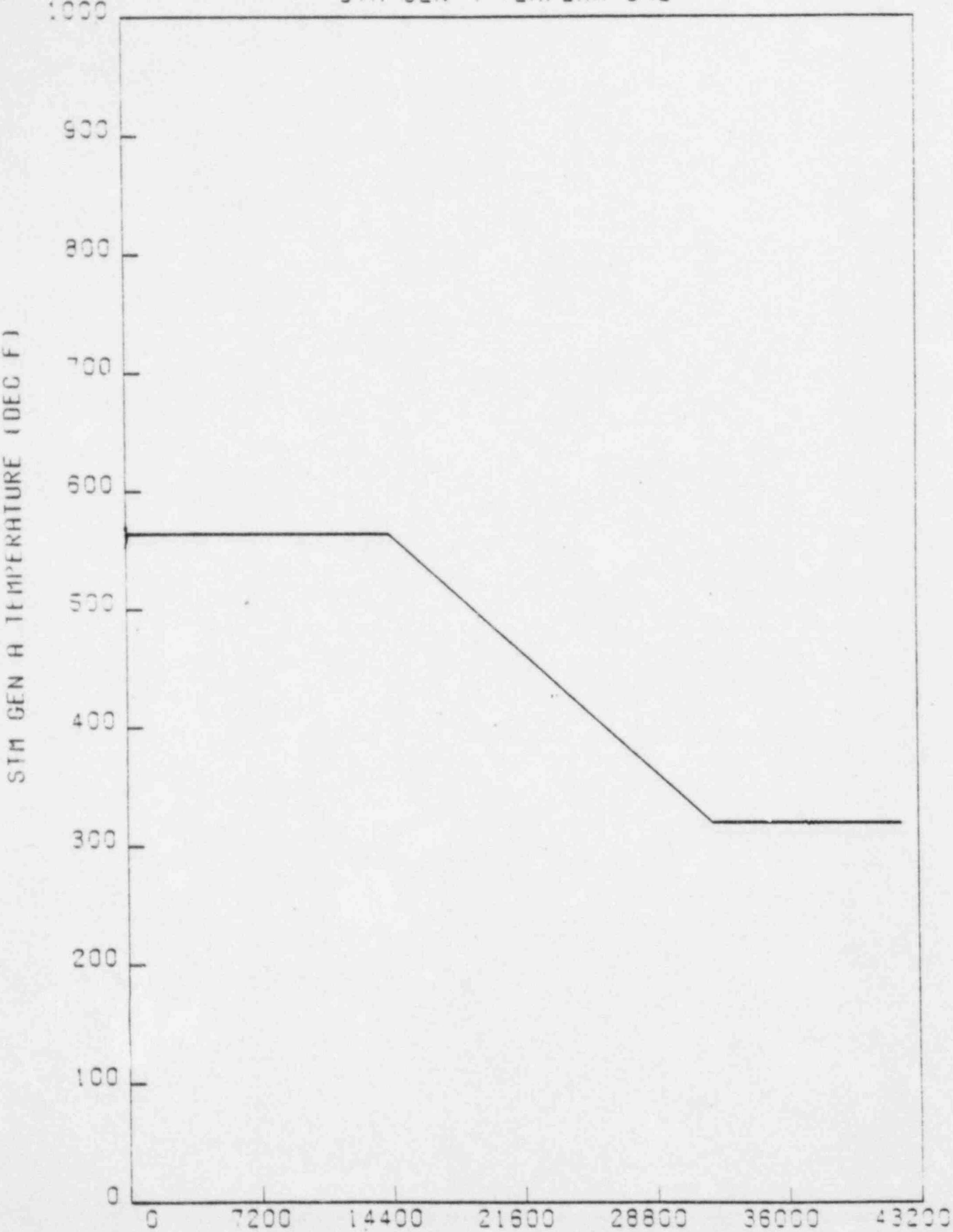

FIGURE 5
SYSTEM 80 BTP RSB 5-1 SIMULATION
STM GEN B PRESSURE

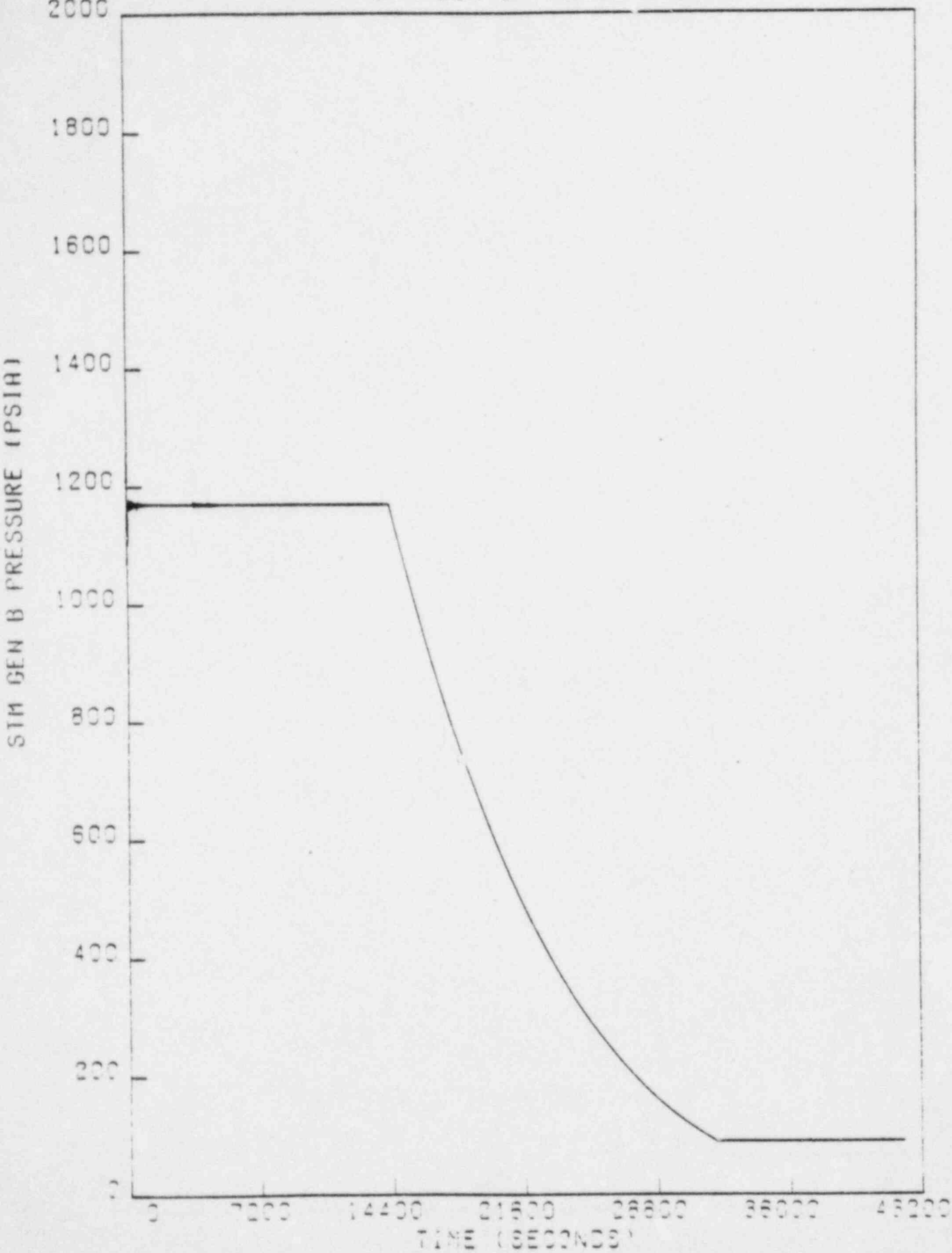

FIGURE 6
SYSTEM 80 STP RSB 5-1 SIMULATION
STM GEN B TEMPERATURE

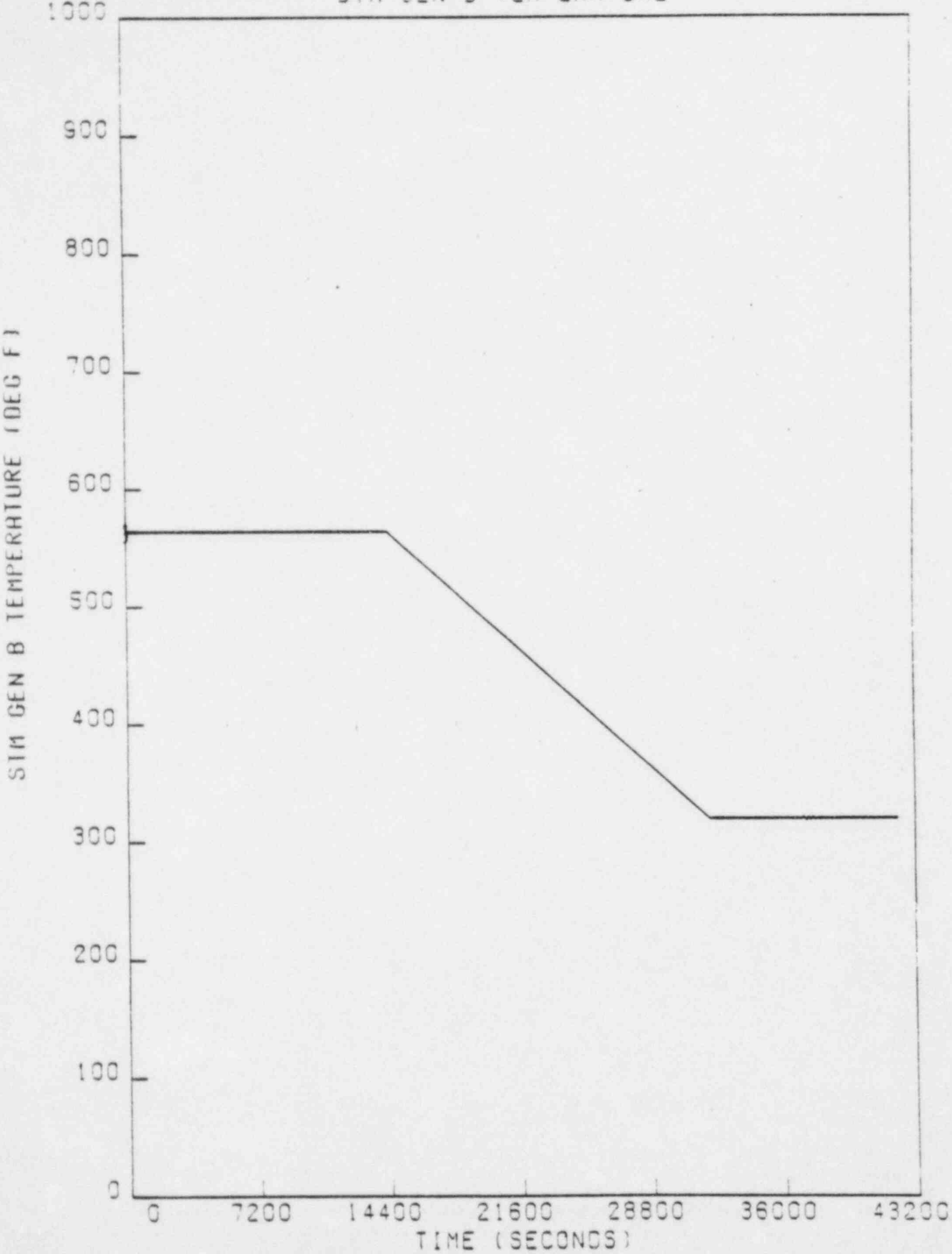

FIGURE 7
SYSTEM 80 BTP RSB 5-1 SIMULATION
PZR LEVEL

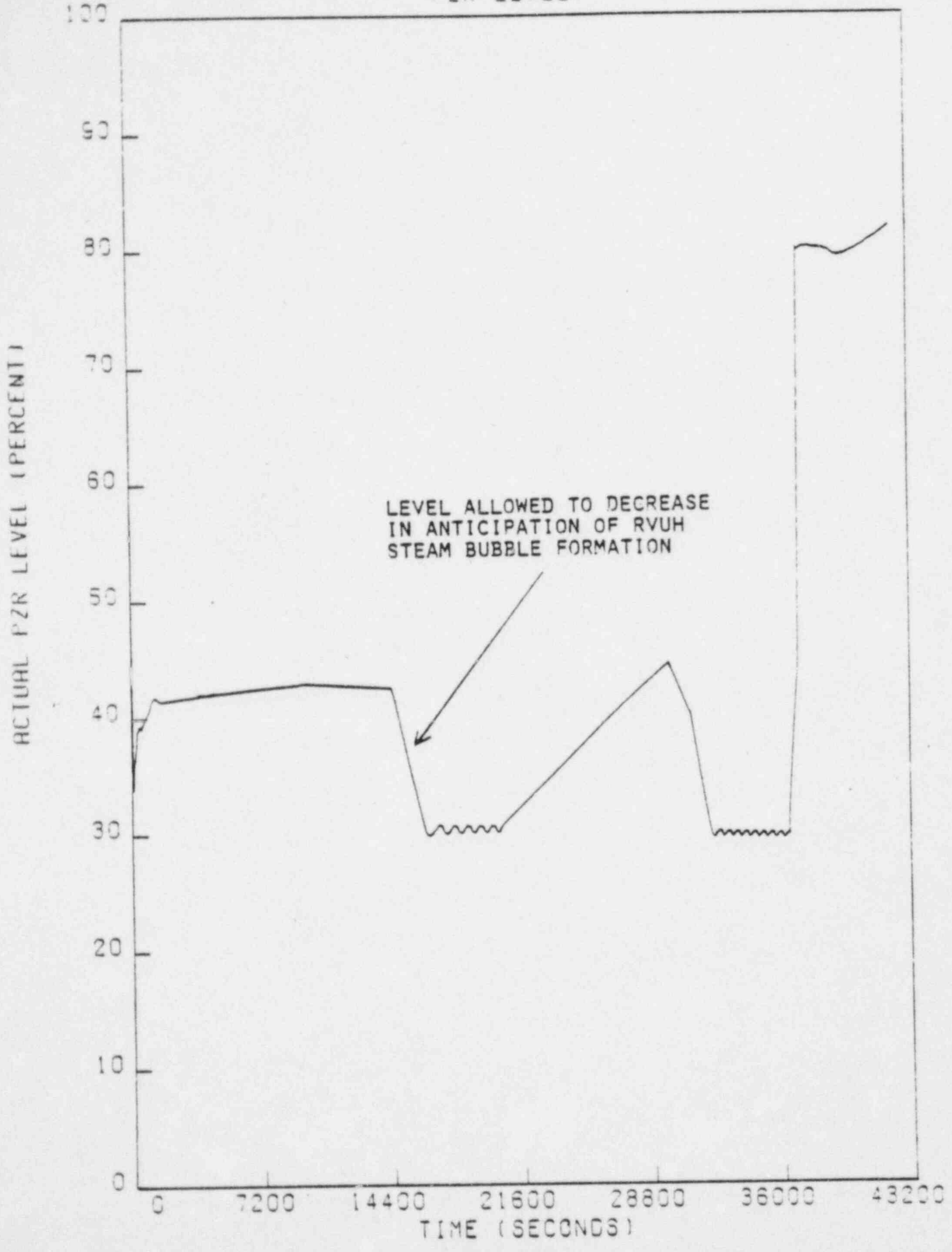

FIGURE 8
SYSTEM 80 BTP RSB 5-1 SIMULATION
CHARGING

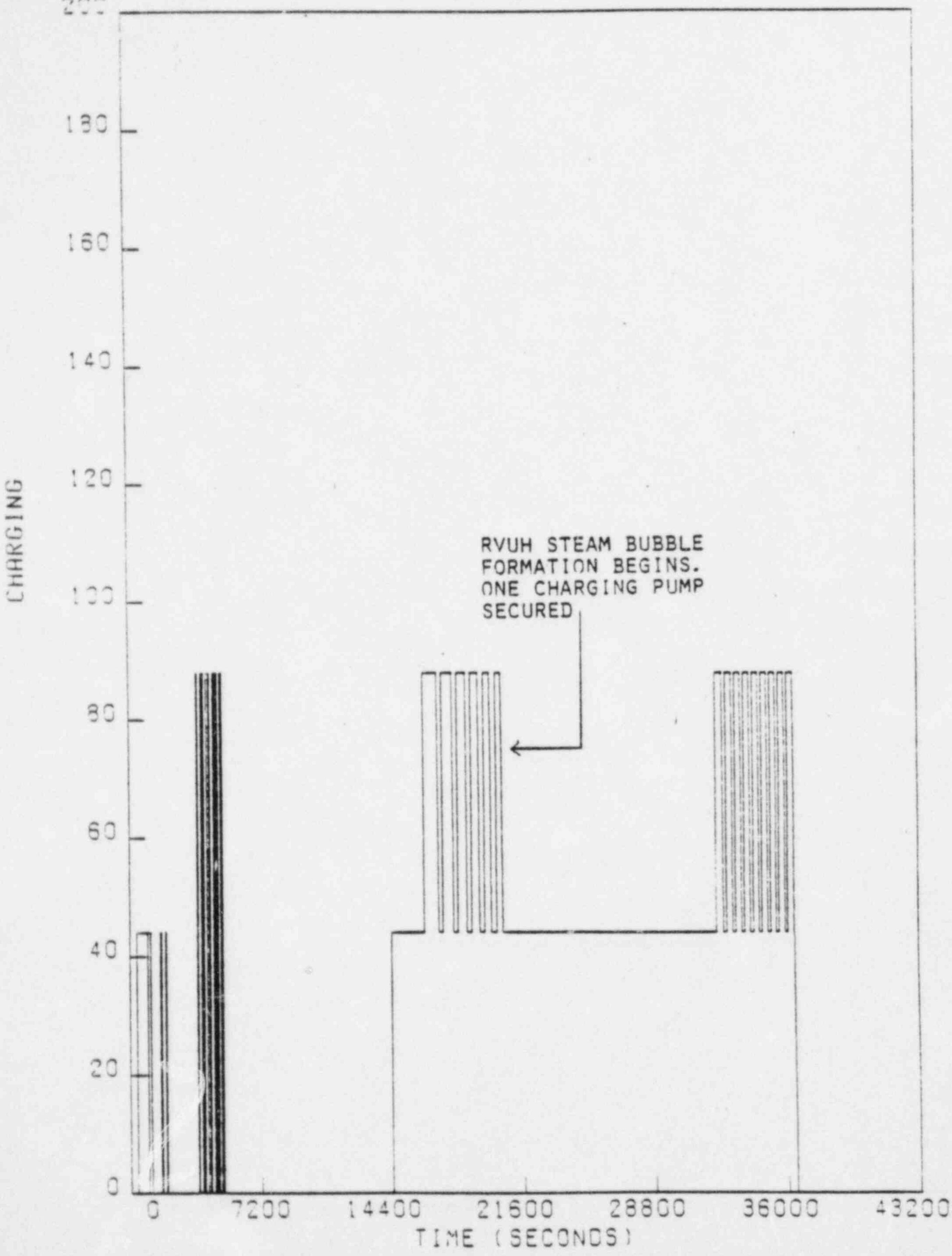

FIGURE 9
SYSTEM 80 STP RSB 5-1 SIMULATION
LOOP A RCS WIDE RANGE TEMPERATURES

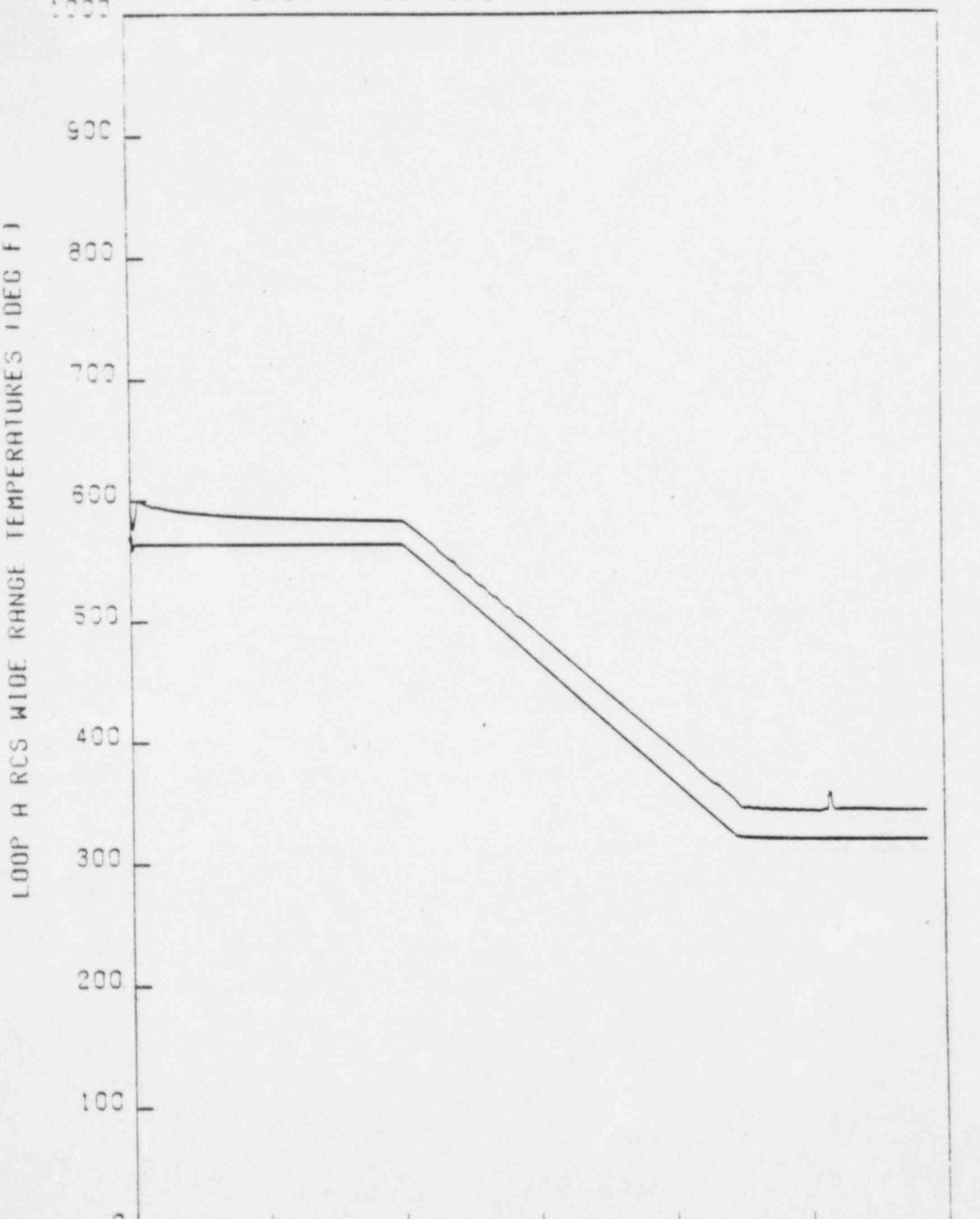

FIGURE 10
SYSTEM 80 BTP RSB 5-1 SIMULATION
LOOP B RCS WIDE RANGE TEMPERATURES

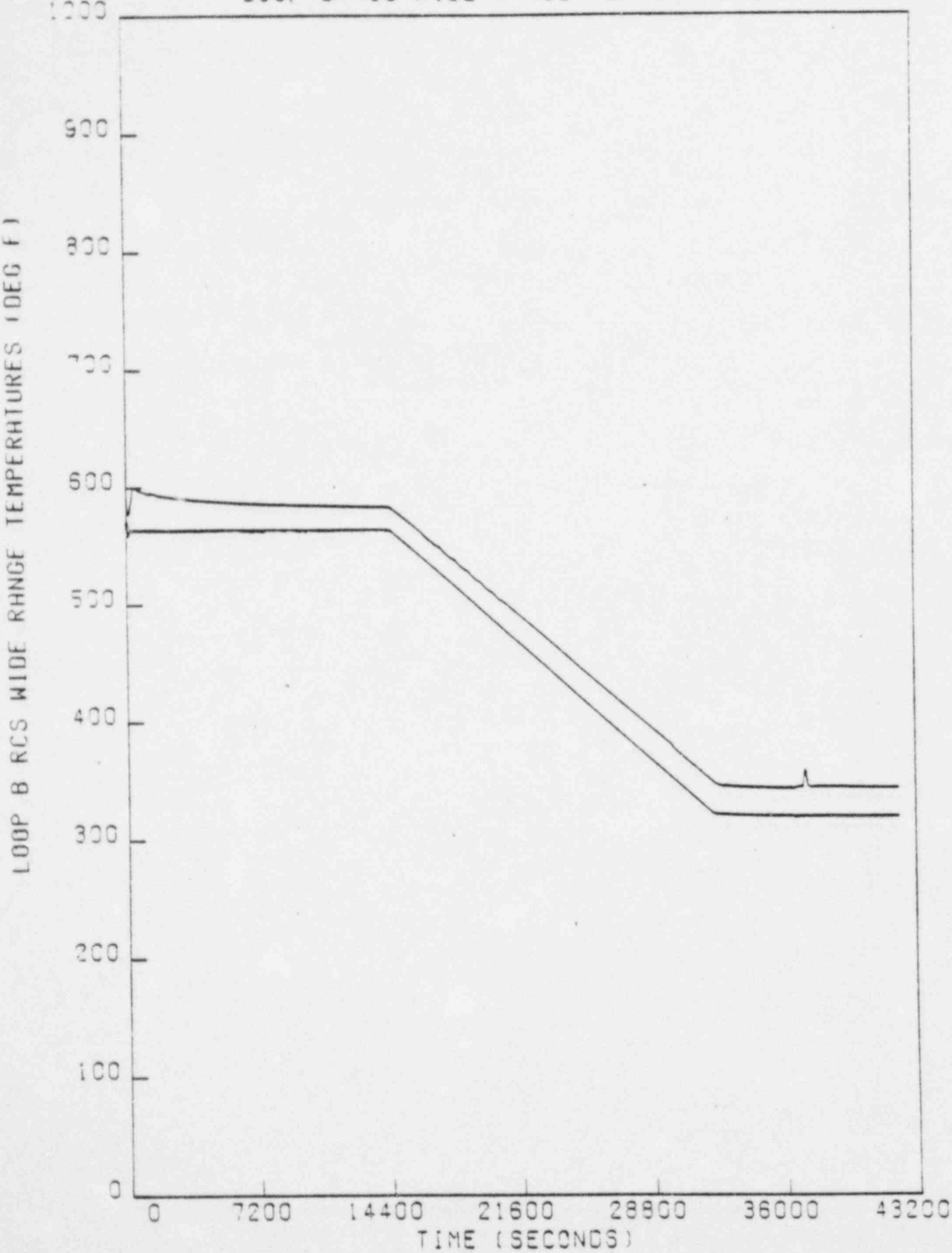

FIGURE 11
SYSTEM 80 BTP RSB 5-1 SIMULATION
REACTOR VESSEL UPPERHEAD TEMPERATURE

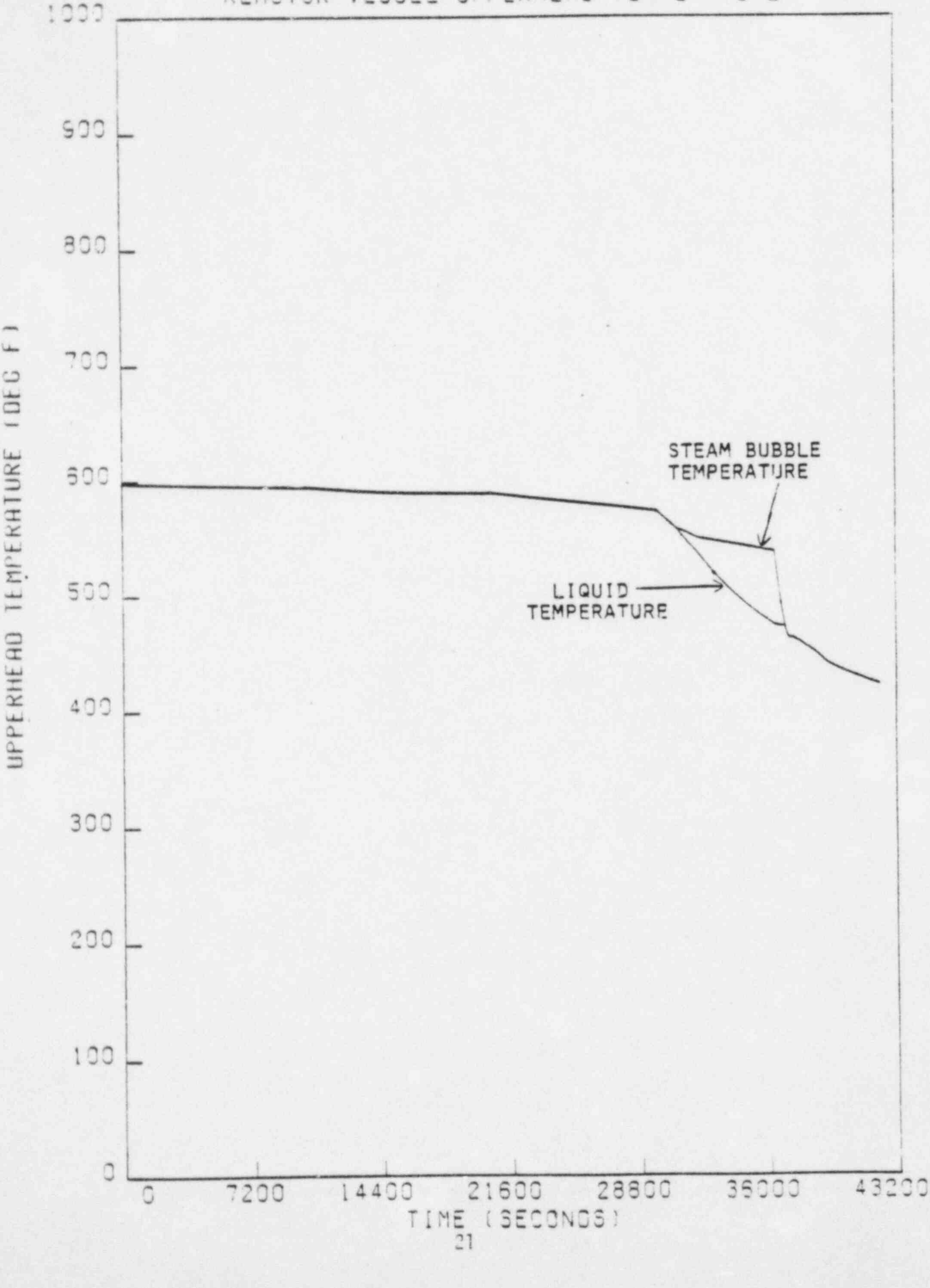

FIGURE 12
SYSTEM 80 BTP RSB 5-1 SIMULATION
PZR WIDE RANGE PRESSURE

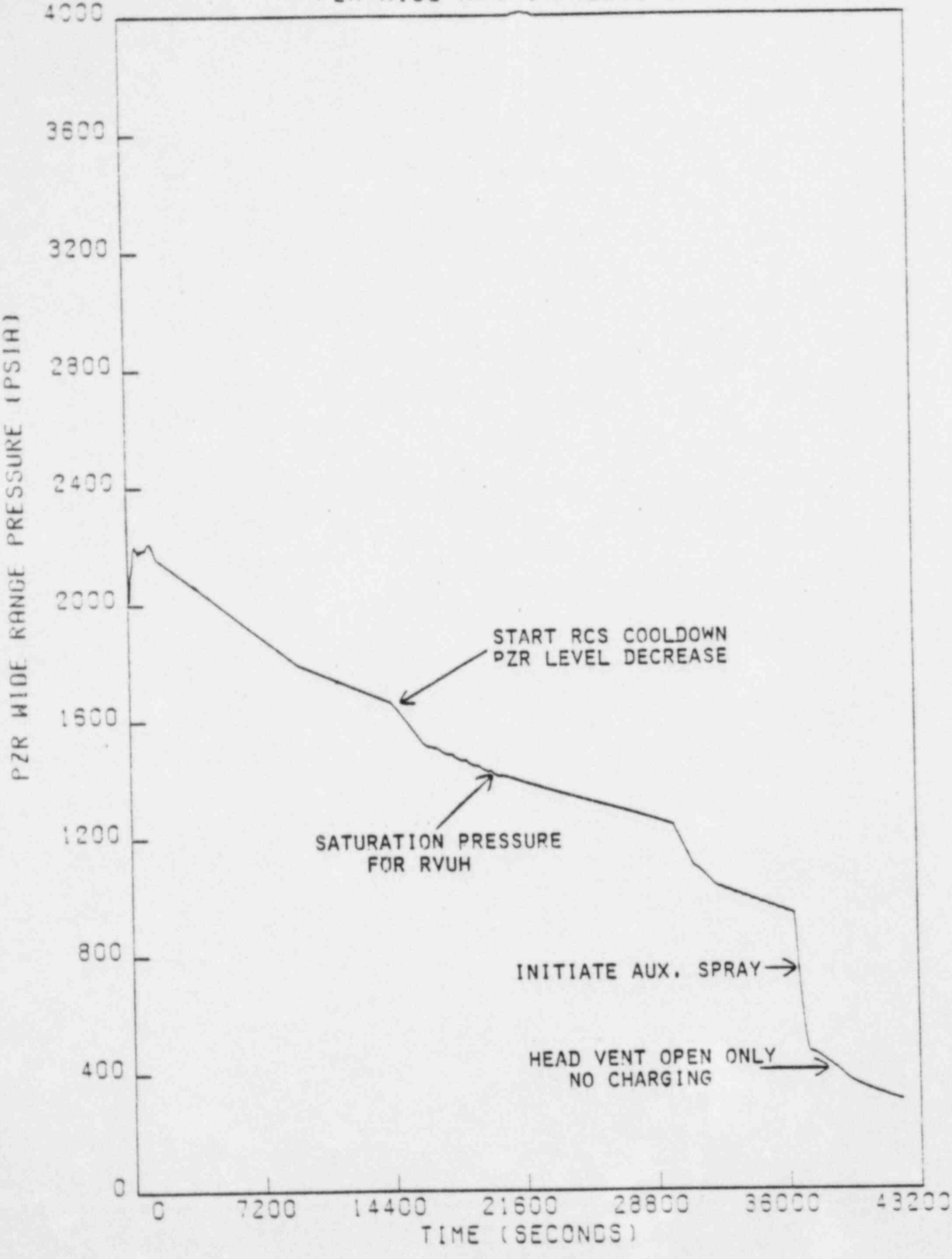

FIGURE 13
SYSTEM 80 BTP RSB 5-1 SIMULATION
WATER VOLUME IN REACTOR VESSEL UPPERHEAD (CU.FT.)

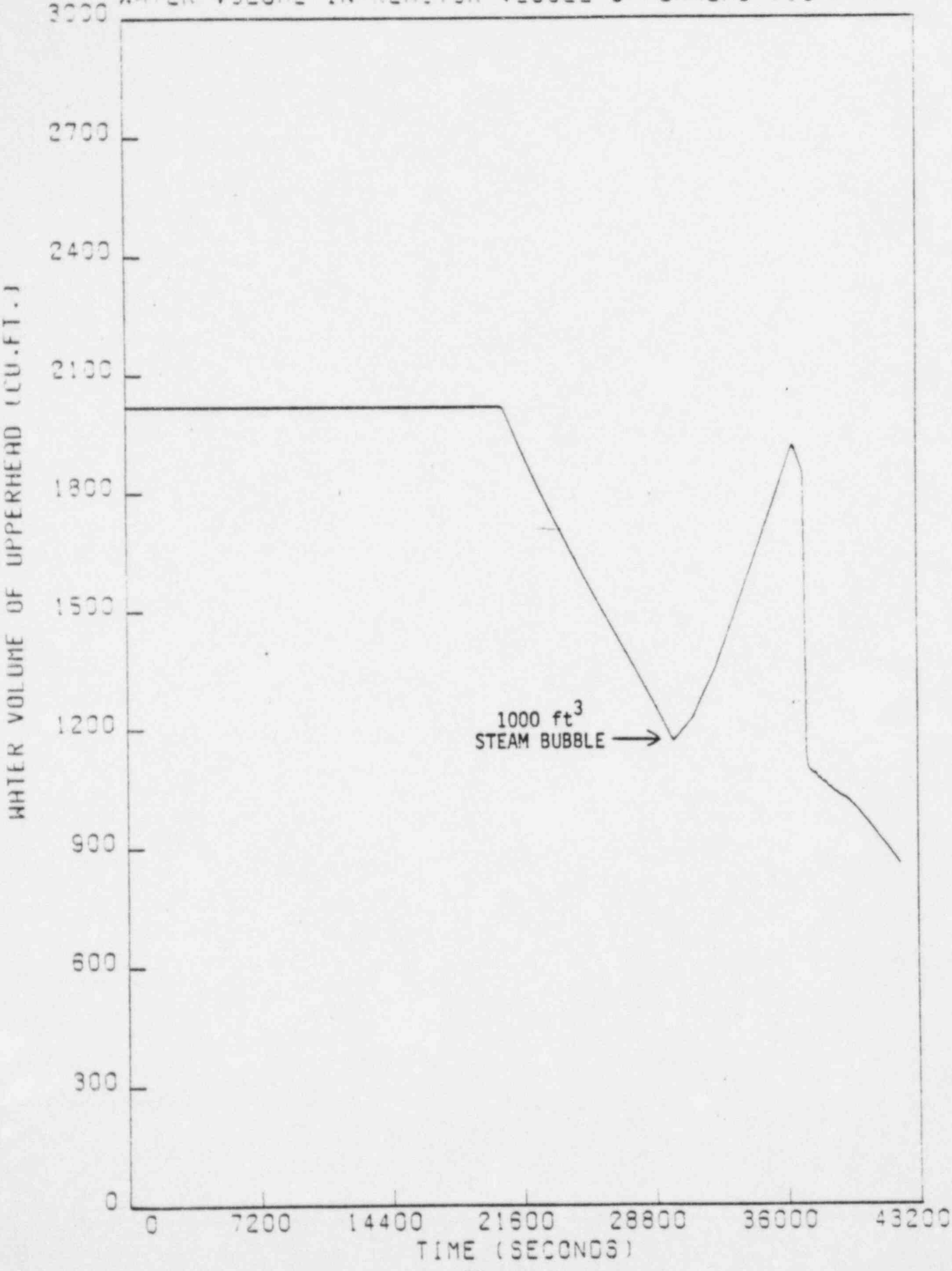

FIGURE 14
SYSTEM 80 STP RSB S-1 SIMULATION
UPPERHEAD VENT FLOW

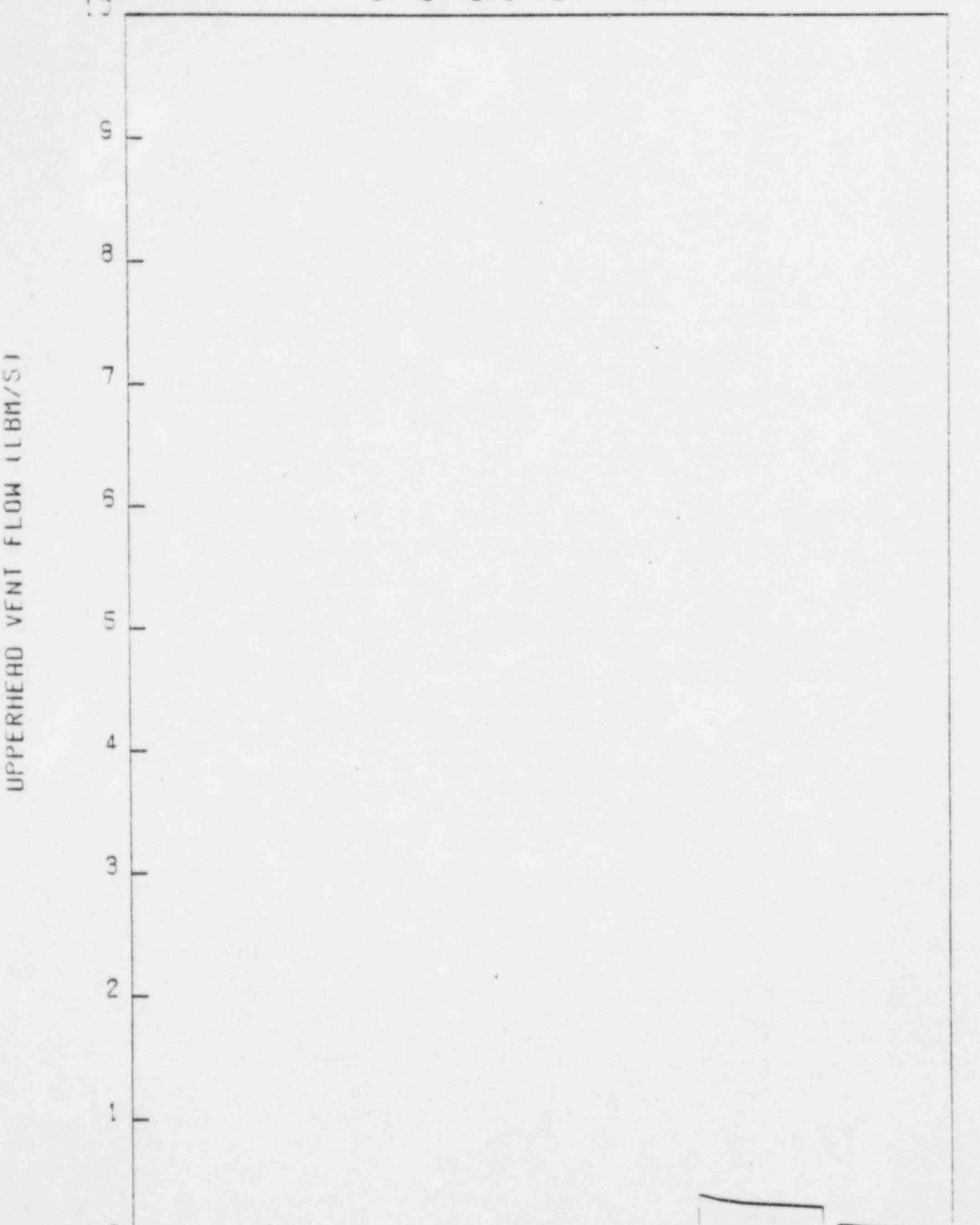

FIGURE 15

SYSTEM 80 BTP RSB 5-1 SIMULATION

PZR SPRAY FLOW

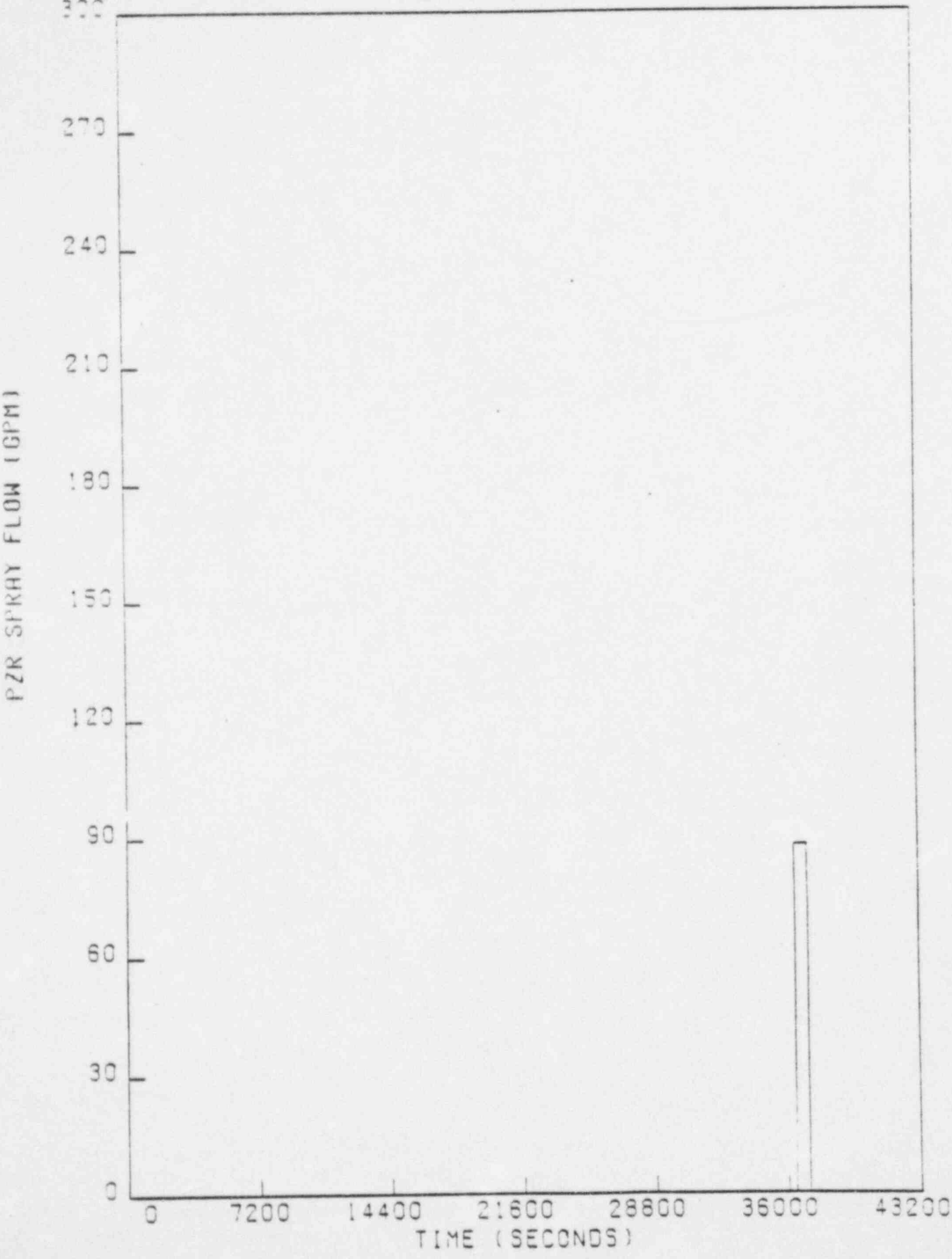

FIGURE 16
SYSTEM 80 BTP RSB 5-1 SIMULATION
DELTA T SUBCOOLING

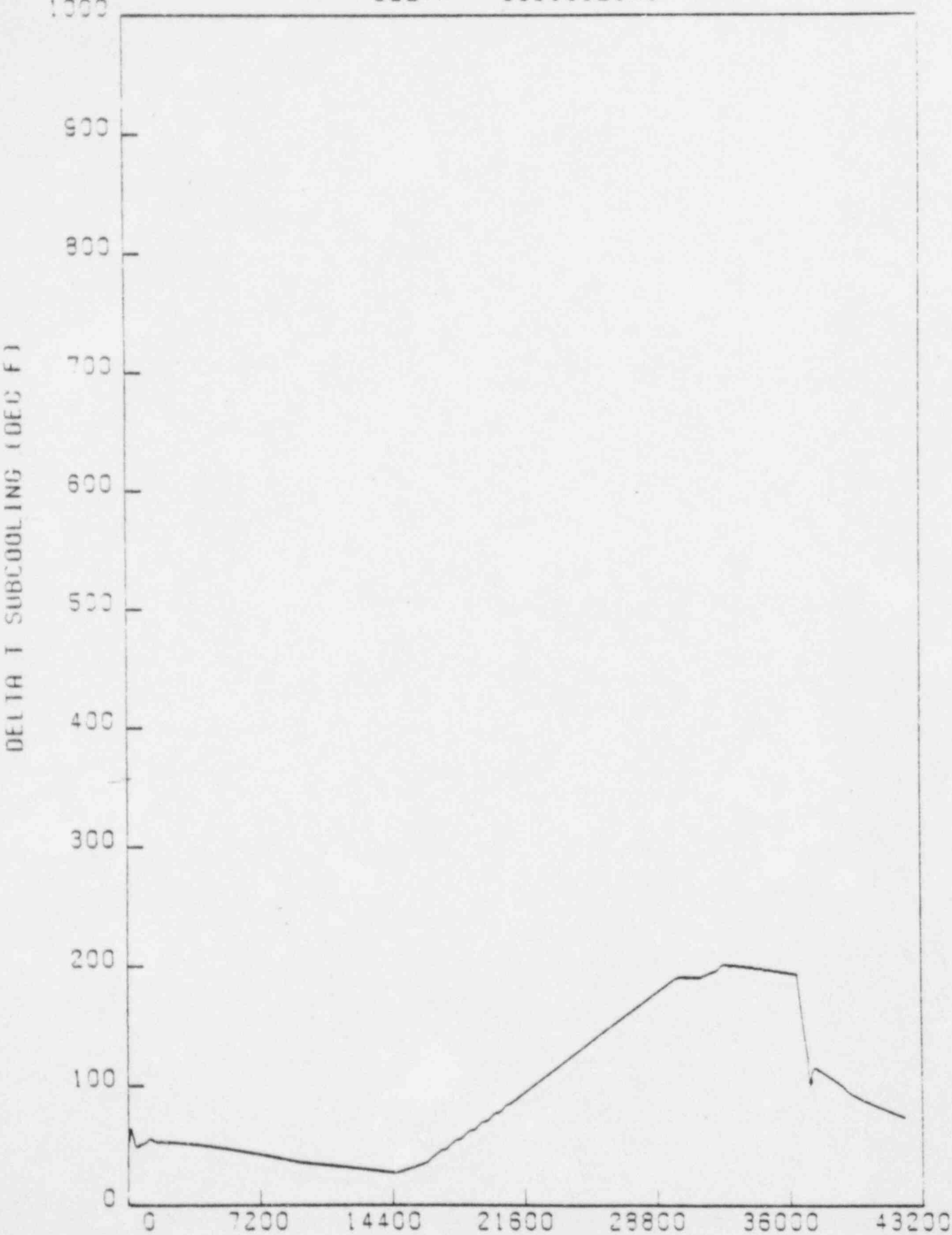

FIGURE 17

INTEGRATED AUXILIARY FEEDWATER USAGE