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TITLE: Steam Generator Tube Rupture Analysis for Zion-1

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STEAM GENERATOR TUBE RUPTURE ANALYSIS FOR ZION-1

by

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ABSTRACT

Steam generator tube ruptures are investigated for the ZION Unit-1 plant. The goal of these analyses is to provide thermodynamic and flow conditions to determine iodine transport to the environment and to provide accident evaluations demonstrating the adequacy of the plant safety systems. The automatic safety systems of the plant were found to be adequate for the mitigation of these transients. Sufficient time was afforded by these safety systems for the operators to identify the problem and to take appropriate measures.

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*Work performed under the auspices of the US Nuclear Regulatory Commission.

I. INTRODUCTION

This work represents the continuation of an effort, funded by the Office of Nuclear Reactor Regulations, to investigate steam generator tube ruptures for all of the generic-type Pressurized Water Reactors (PWR). Documents describing previous work performed are listed in References 3 and 4.

Steam generator tube ruptures for a Westinghouse four-loop PWR (Zion-1) are discussed in this paper. The goal of these analyses is to provide thermodynamic and flow conditions to determine radionuclide transport to the environment and to provide accident evaluations demonstrating the adequacy of the plant safety systems.

Information in the Appendix is included to provide the thermodynamic conditions for the calculation of the radionuclide releases to the atmosphere.

II. MODEL DESCRIPTION AND ASSUMPTIONS

TRAC-PD2 (Ref. 1) was used for the analysis of steam generator tube ruptures (SGTR) in the Zion-1, four-loop PWR. The noding diagram of the Zion-1 TRAC model is shown in Fig. 1. Information for this model was obtained from the Zion-1 FSAR.[2]

The three intact loops (A, C, and D) are modeled as one loop for computational efficiency. The remaining loop (Loop B) contains the plant's pressurizer and steam generator tube rupture. Included in this model are the hot and cold legs, vessel, pressurizer, U-tube steam generator (SG), safety injection (SI), pumps, steam lines, and atmospheric relief valves (ARVs). Turbine bypass is not modeled; all steam relief is assumed to be through the ARVs for consistency with previous analyses. A total of 172 mesh cells are used for this TRAC model.

The operating assumptions for these transients are outlined in Table I. These postulated responses simulate the actual responses of the plant during a SGTR event.

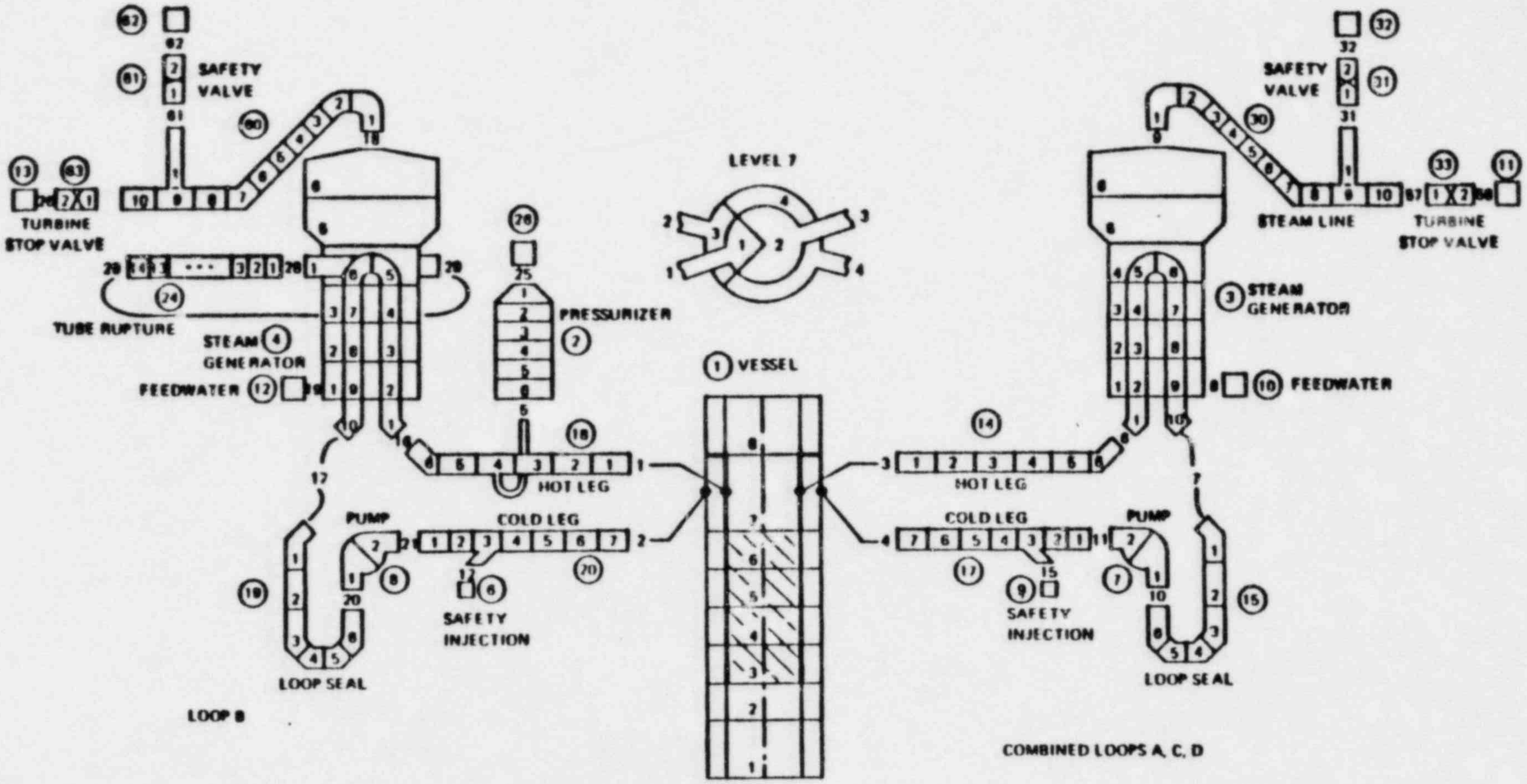

Fig. 1. Zion-1 TRAC noding diagram.

TABLE I
STEAM GENERATOR TUBE RUPTURE FOR ZION-1

	Event	Trip	Comment
1.	SGTR (Loop B).	Time = 0.0.	1, 5 and 10 tubes rupture, double-ended break.
2.	Reactor scram.	Low pressurizer pressure (13.1 MPa).	3-1/2% shutdown margin, 1-s insertion time.
3.	Close turbine stop valves.	Concurrent with reactor trip.	Turbine bypass can relieve 40% of total steam flow if available.
4.	Main feedwater coastdown, initiate AFW.	Concurrent with reactor trip.	AFW throttled to maintain operating level (top of U-tubes).
5.	HPI initiation.	Low system pressure (11.7 MPa).	HPI flow increases as pressure decreases.
6.	Main coolant pumps tripped.	1 min after HPI initiation.	Assumed operator action.
7.	Open intact loop ARVs to initiate controlled blowdown of SG; throttle SI flow.	SG-B full of liquid.	Operator action to decrease primary pressure.

III. RESULTS OF STEAM GENERATOR TUBE RUPTURES

A. General Results

The system response for the rupture of 1, 5, and 10 steam generator tubes was essentially the same. The SI flow was adequate to equilibrate with the leakage flow and prevent the primary inventory from decreasing. Operator action involving opening of the intact loop ARVs and throttling of the SI flow led to termination of leakage within approximately 500 s for all cases. The amount of liuqid out the ARV and tube rupture is shown in Table II.

B. Detailed Results

The rupture of 1, 5, and 10 steam generator tubes was assumed to be the initiating event of these transients. The tube ruptures occurred at the top of the U-tubes on the B-loop side and were modeled as double-ended breaks. The sequence of events for these transients is summarized in Table III.

1. One-SGTR. Initially, the pressurizer heaters and primary system makeup flow turned on in response to the decreasing primary pressure and pressurizer water level. This was insufficient, however, to prevent the primary depressurization and a reactor trip signal was generated due to low system pressure. Figures 2 and 3 show the primary system pressure and pressurizer water level, respectively. When the safety injection flow initiated at 650 s, the primary began repressurizing and the pressurizer began refilling. The SI flow continued until the pressurizer refilled, at which time the SI flow was throttled as shown in Fig. 4. The SI flow was adjusted so that it equilibrated with the flow out the ruptured tube. Figure 5 shows this leakage flow, which leveled at a value of approximately 28 kg/s. the system, therefore, reached a quasi-equilibrium state.

The net flow into the system was zero and the decay energy was removed by the SI flow and by natural circulation to the steam generators. Because the turbine stop valves were closed upon reactor scram, the ARVs cycled open to accommodate decay energy removal, as shown in Fig. 6.

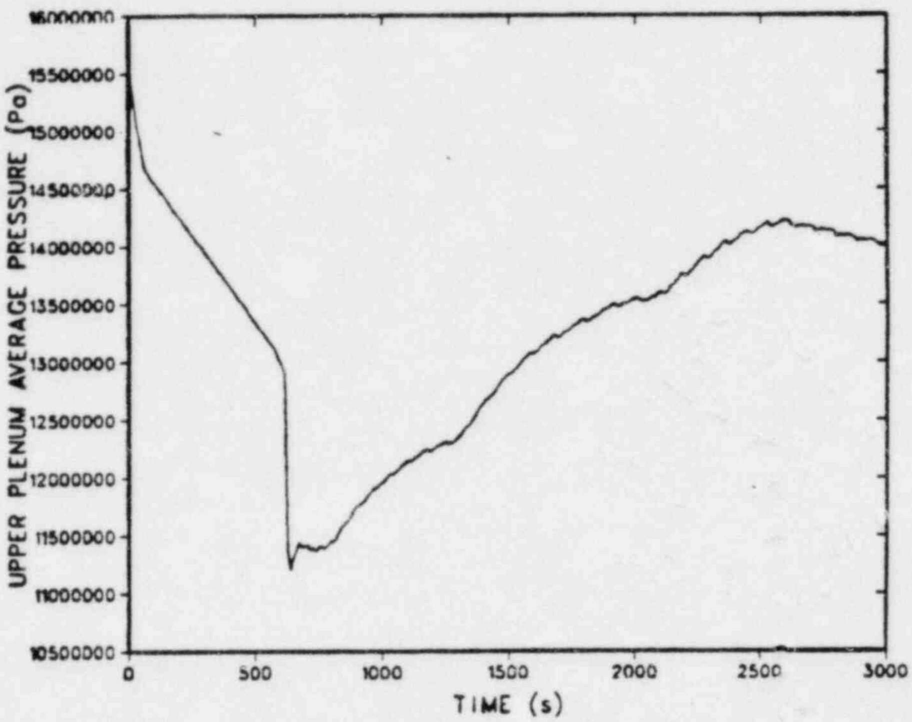

Fig. 2. System pressure levels when SI equilibrates with leakage.

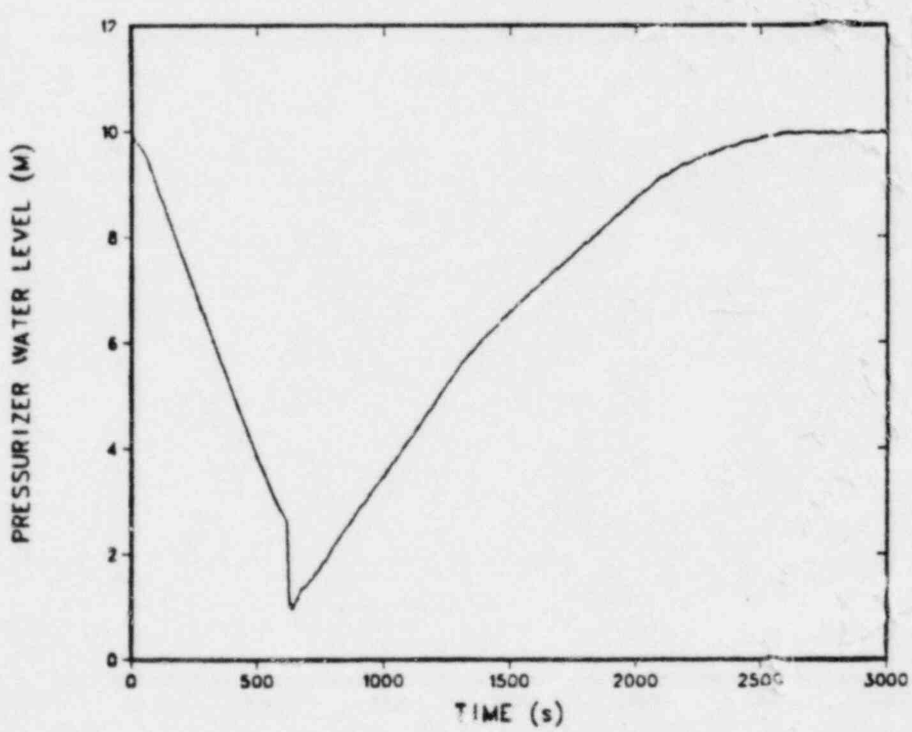

Fig. 3. Pressurizer water level recovers.

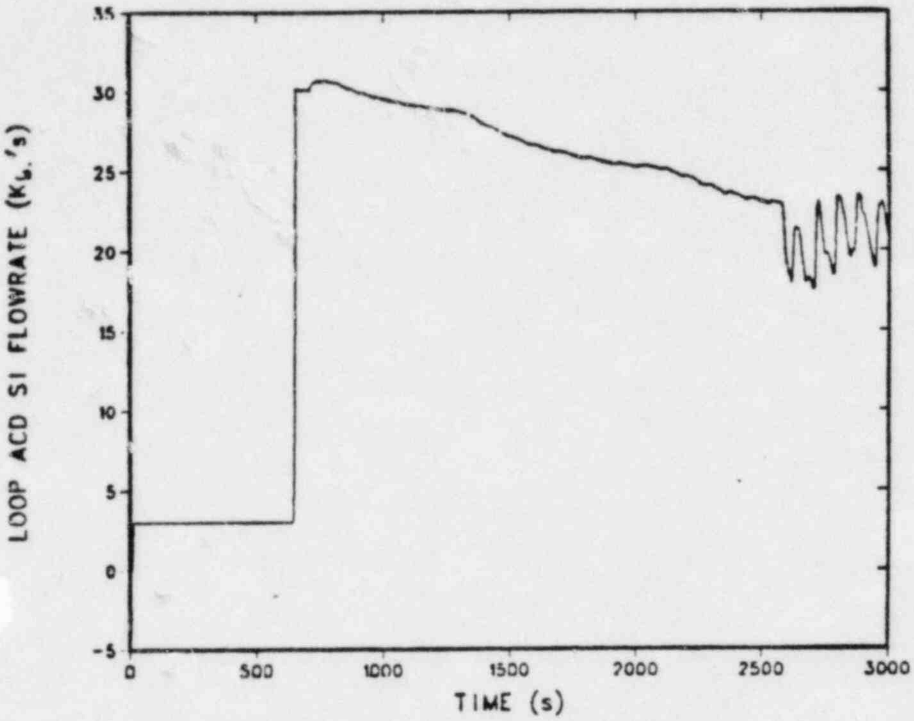

Fig. 4. SI flow throttled when pressurizer fills.

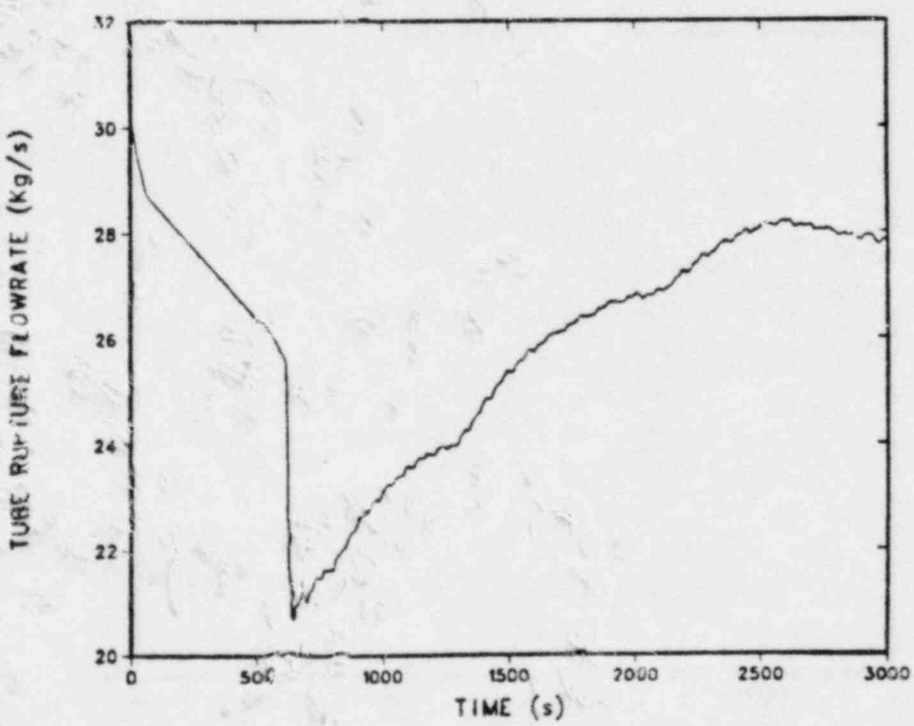

Fig. 5. Leakage flow levels when SI flow throttled.

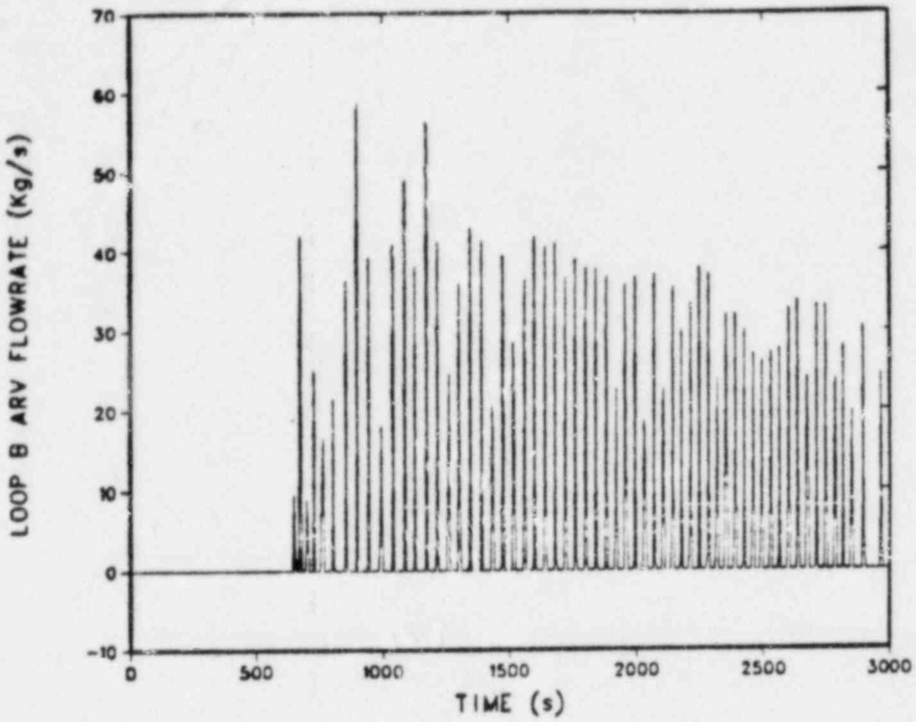

Fig. 6. ARVs open to accommodate decay energy removal.

TABLE II
INTEGRATED LEAKAGE FLOWS

Number of Tubes	Time	Total ARV Flow (kg)	Total Tube Rupture Flow (kg)
1	3000[a]	11650	78140
5	3000	5160	85620
10	1078	5207	58210

[a]Primary system not yet depressurized to stop leakage flow.

TABLE III
SGTR SEQUENCE OF EVENTS

Event	Time (s) 1-SGTR	5-SGTR	10-SGTR
SGTR	0.0	0.0	0.0
Reactor scram, close turbine stop valves.	616.1	76.0	37.7
MFW coastdown, initiate AFW (level control).	645.4	105.4	67.1
Initiate HPI.	649.6	108.6	68.9
Trip main pumps.	709.5	168.6	128.9
Primary leakage ends.	-	~1500	~850.

2. Five-Tube Rupture. The response for this case was essentially the same as the one-tube case except the trips occurred sooner due to the faster primary depressurization. The SI flow was sufficient to make up for the primary liquid being lost out the tube rupture and the primary pressure, shown in Fig. 7, leveled at a value of about 8.5 MPa.

At 1000 s, it was assumed that the operators would have diagnosed the accident and would then proceed to depressurize the primary by initiating a controlled blowdown at the intact SG secondaries. This blowdown, shown in Fig. 8, concurrent with throttling of the SI flow, led to primary depressurization and subsequent tube leakage flow termination, as shown in Fig. 9. Natural circulation was redistributed to the intact loop SGs only and the loop-B ARV closed as shown in Fig. 10. This ended the primary leakage to the environemnt and would allow the operators to proceed to cold shutdown.

3. 10-SGTR. Except for the timing, the results for the 10-SGTR case are the same as the 5-SGTR case. The plant trips occured slightly earlier due to the higher initial leakage, as shown in Fig. 11. The leakage rate rapidly decreased as the primary pressure dropped. The operator action of opening the intact-loop ARVs and throttling the SI flow was taken at about 420 s. At about 900 s, the leakage ended and the transient terminated.

IV. CONCLUSIONS

The existing safety systems for Zion-1 plant were found to be adequate for the mitigation of SGTR transients of up to 10 tubes. Operator action is required to terminate the primary leakage; however, the safety systems automatically respond in such a way as to bring the system to a stable condition, allowing the operators sufficient time to assess the accident and take appropriate steps. Natural circulation and the injection of liquid were sufficient at all times to remove the core decay energy, ensuring complete coverage of the core.

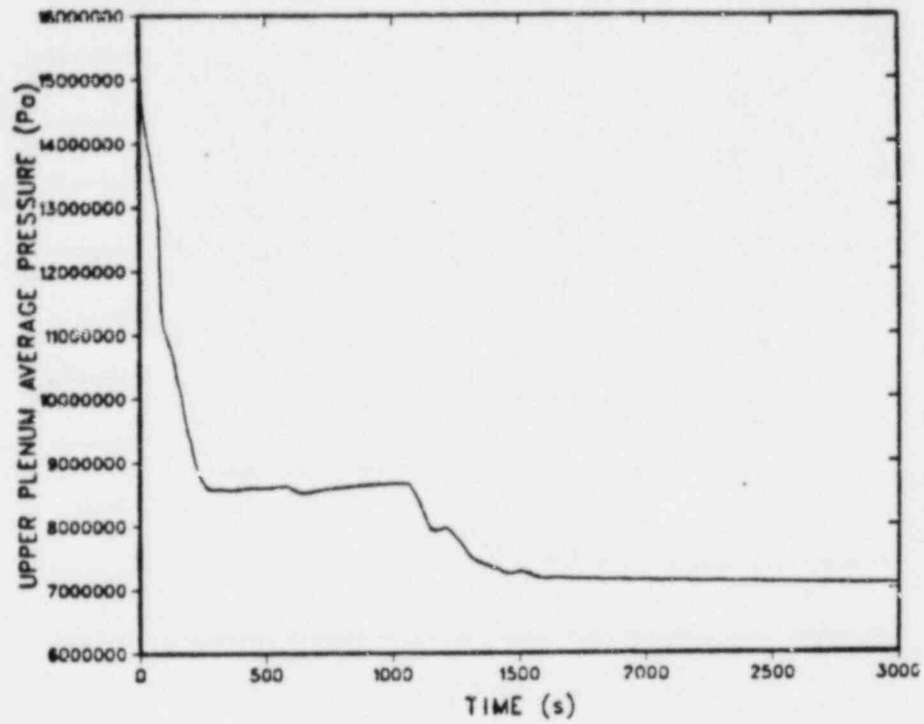

Fig. 7. Pressure levels when SI and leakage equilibrate.

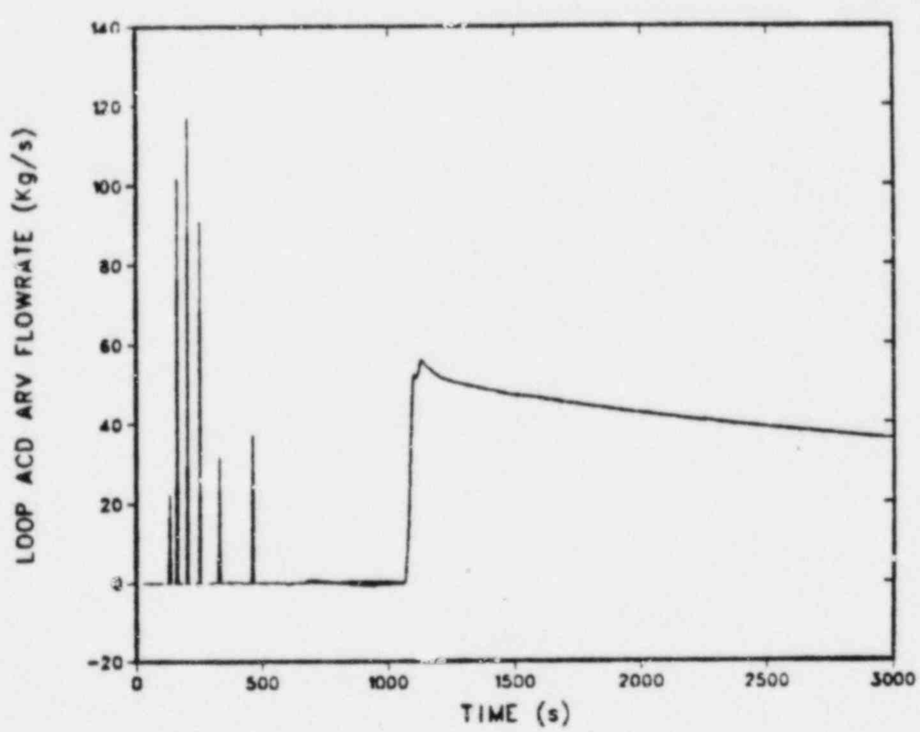

Fig. 8. Intact-loop ARVs opened to allow primary depressurization.

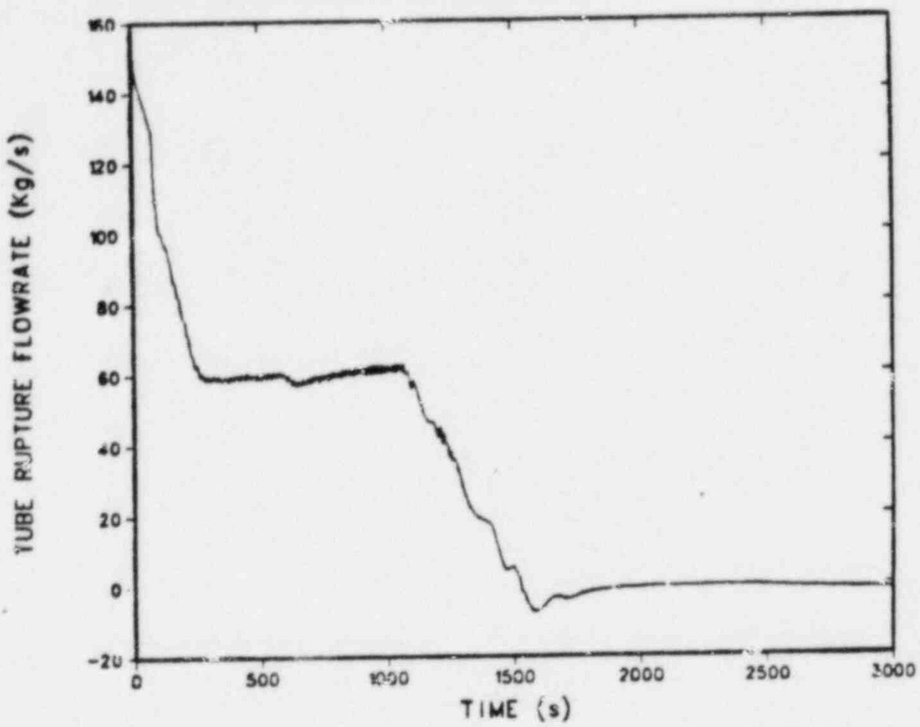

Fig. 9. Leakage ends when primary is depressurized.

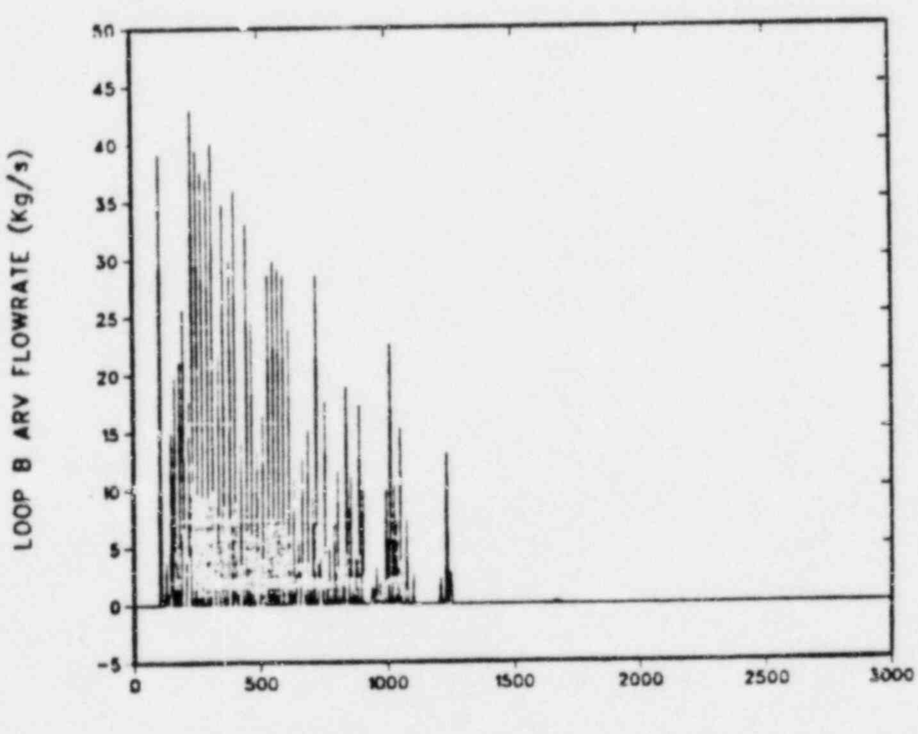

Fig. 10. ARVs close upon primary depressurization.

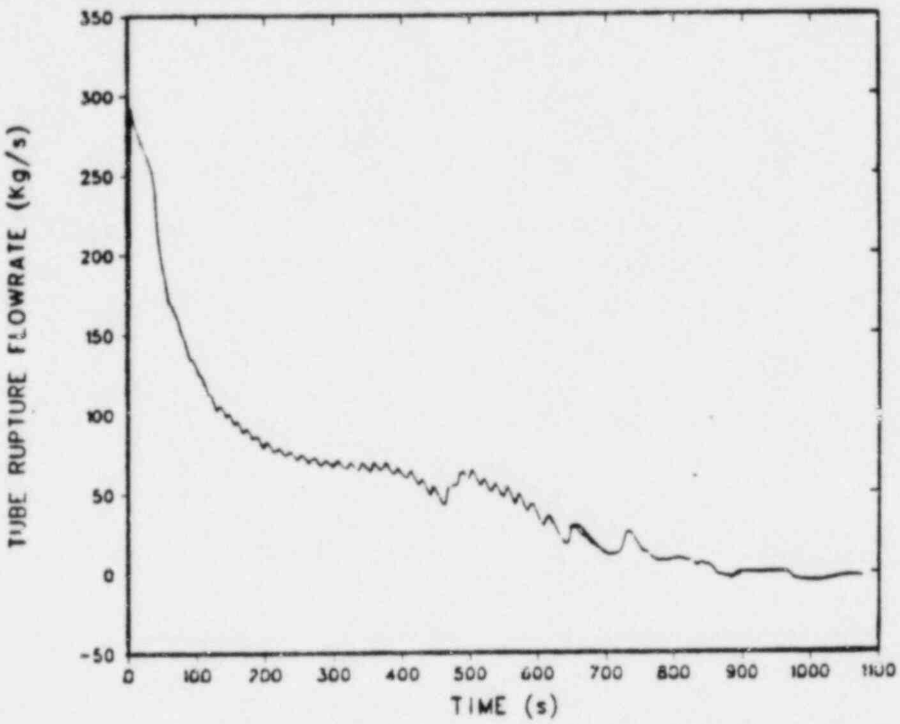

Fig. 11. Leakage terminates after primary depressurization.

REFERENCES

1. Safety Code Development Group, "TRAC-PD2, An Advanced Best-Estimate Computer program for Pressurized Water Reactor Loss-of-Coolant Accident Analysis," Los Alamos National Laboratory report LA-8709-MS (May 1981).

2. "Zion Station Final Safety Analysis Report," Commonwealth Edision Company (1973).

3. "Analysis of Steam-Line-Break-Induced Steam Generator Tube Rupture," Los Alamos National Laboratory report LA-UR-80-3682 (June, 1981).

4. "Steam Generator .ube Rupture Analysis for TMI-1," Los Alamos National Laboratory report (to be published).

APPENDIX

A primary goal of these analyses was to provide thermodynamic source conditions for the determination of iodine transport to the environment. The following tables and graphs are intended to supply additional information necessary for that analysis.

Selected initial conditions are given in Table 1A. These represent values given in FSAR data. Plots are not duplicated if they are included in the main text. When there is more than one curve on a plot, the solid curve is the first curve listed on the ordinate label. The plots of SG primary flow indicate negative flow because of the way the system is noded. This represents flow in the normal, steady-state direction. Additional information, if required, can be obtained from the ZION FSAR.

TABLE 1A
ZION-1 STEADY-STATE DATA

Power	3250. Mw
Cold-leg temperature	549.9 K
Hot-leg temperature	585.5 K
Coolant flow rate (per loop)	4250. kg/s
System pressure	15.5113 MPa
Vessel ΔP	0.358 MPa
Pump ΔP	0.631 MPa
Secondary pressure	5.0 MPa
Secondary exit temperature	537.1 K
Total primary coolant volume	360. m^3
Total pressurizer volume	51.0 m^3

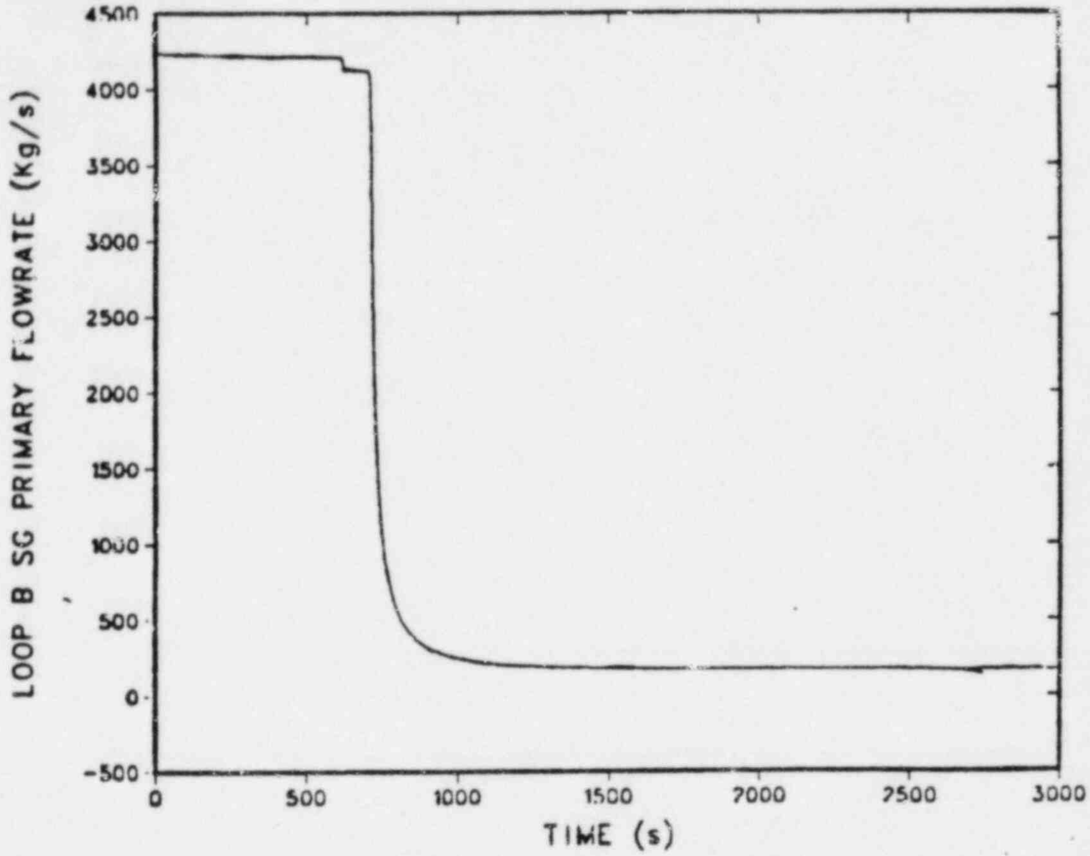

Fig. 1A. Primary temperatures; one-SGTR.

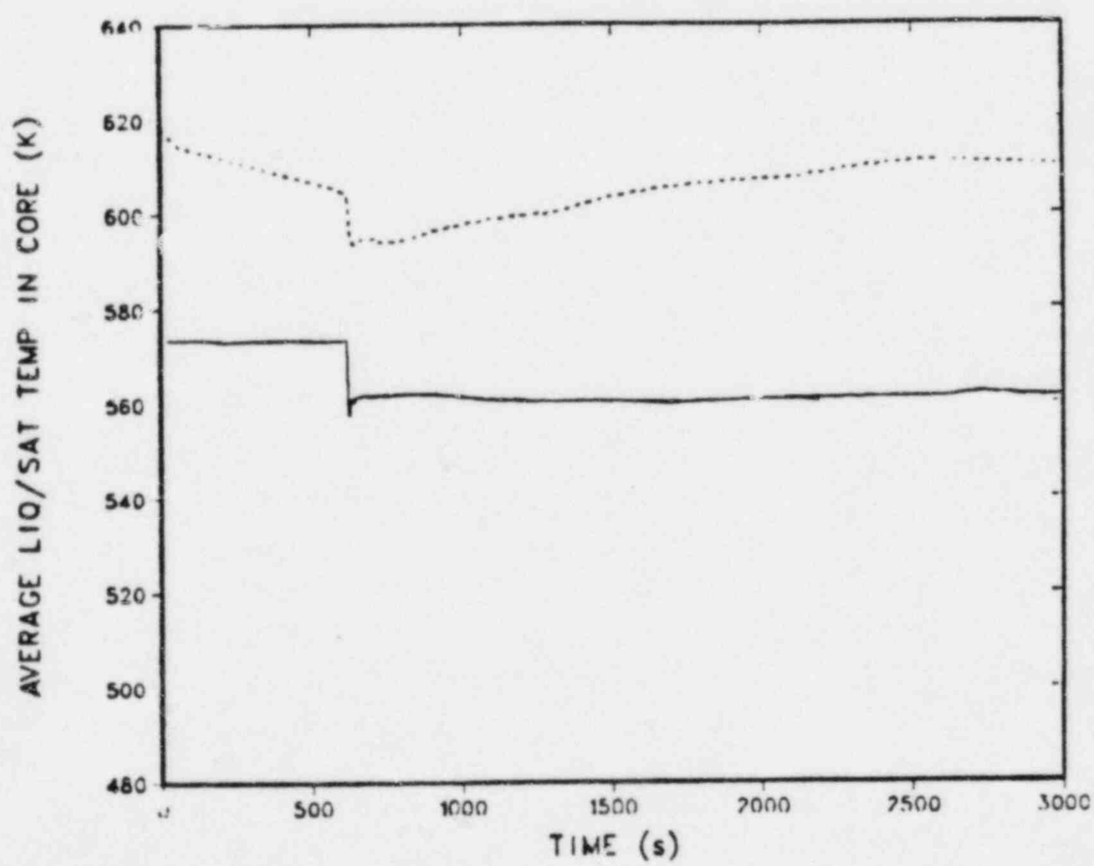

Fig. 2A. Loop-B flow rate; one-SGTR.

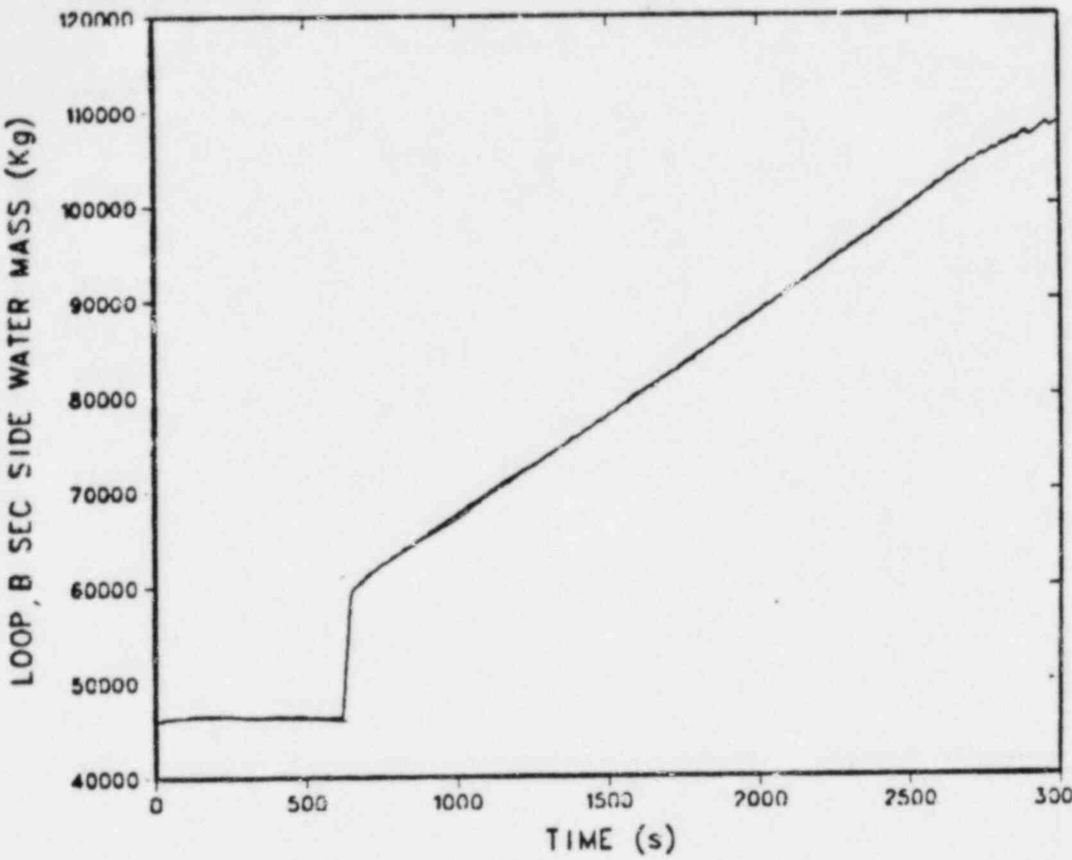

Fig. 3A. Steam generator secondary water mass; one-SGTR.

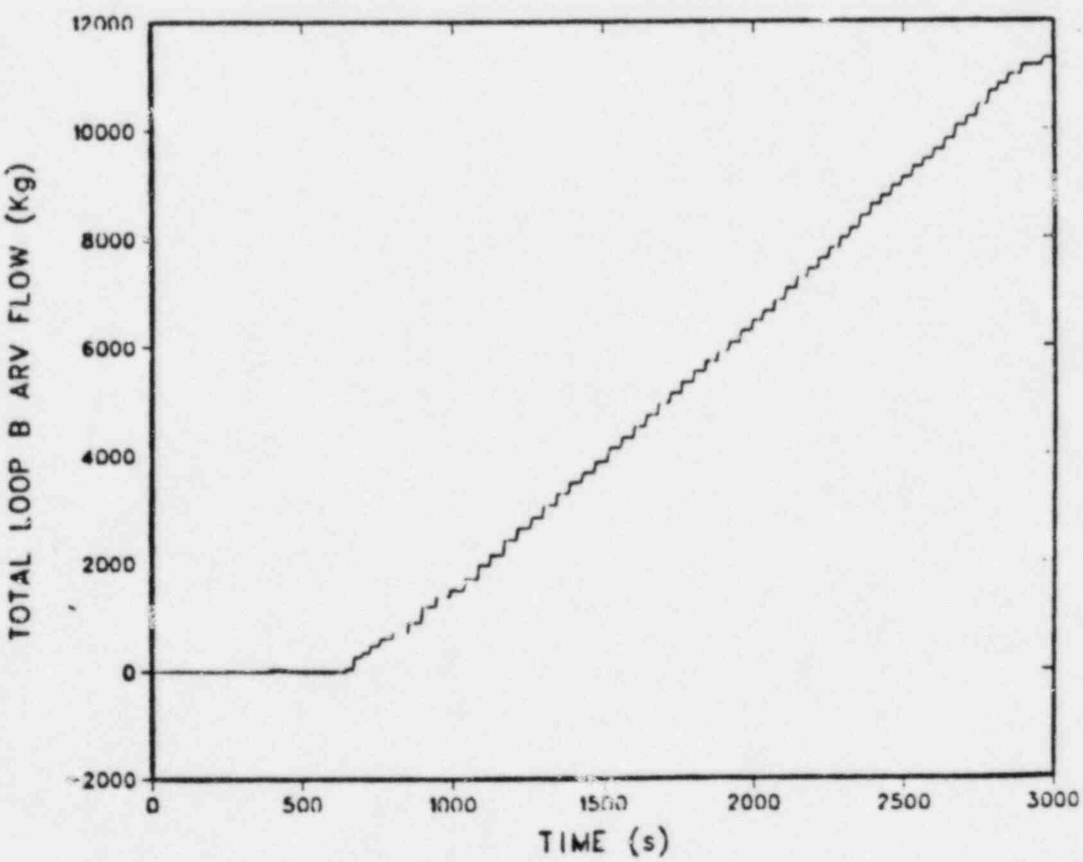

Fig. 4A. Total flow out ARV; one-SGTR.

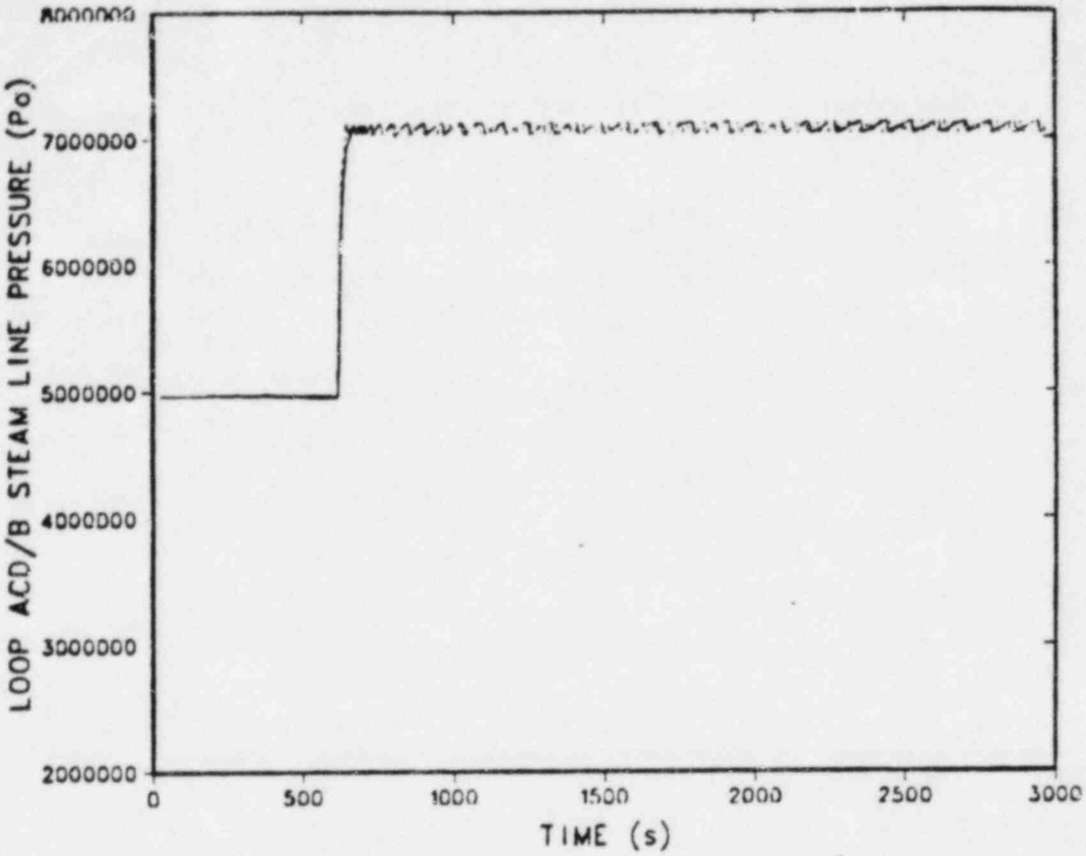

Fig. 5A. Secondary pressures; one-SGTR.

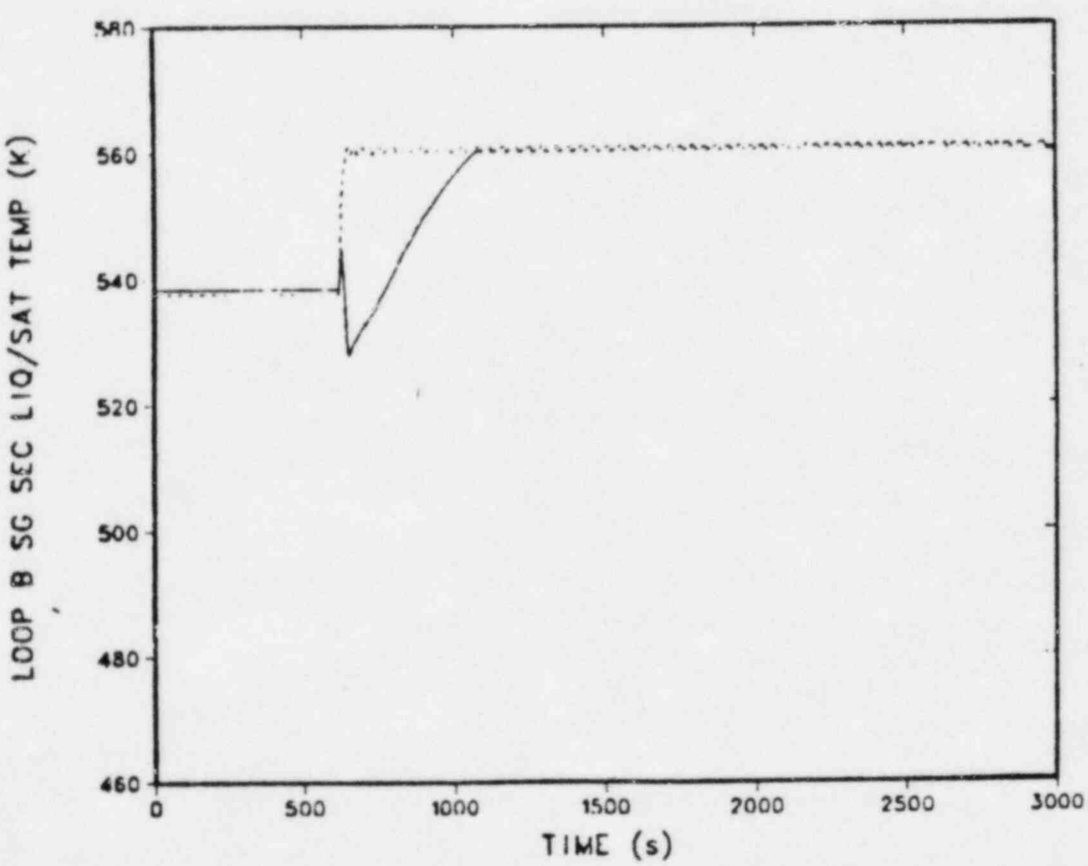

Fig. 6A. Secondary temperatures; one-SGTR.

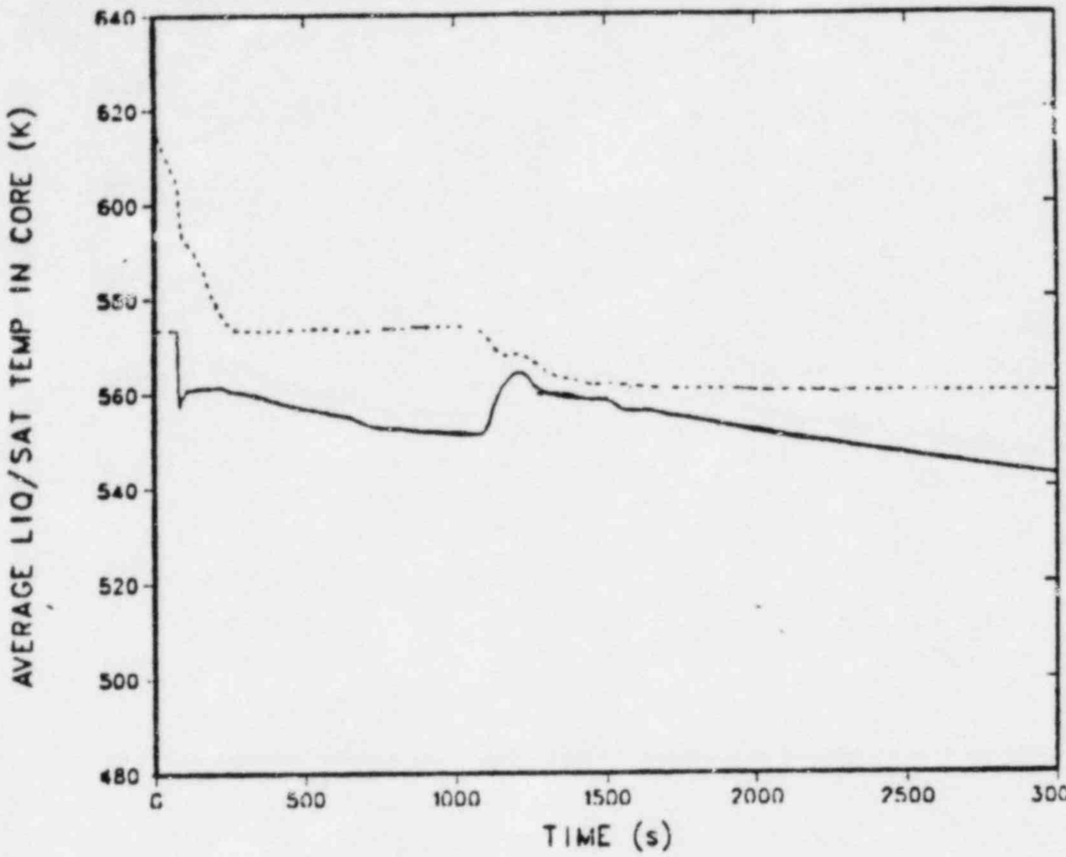

Fig. 7A. primary temperatures; five-SGTR.

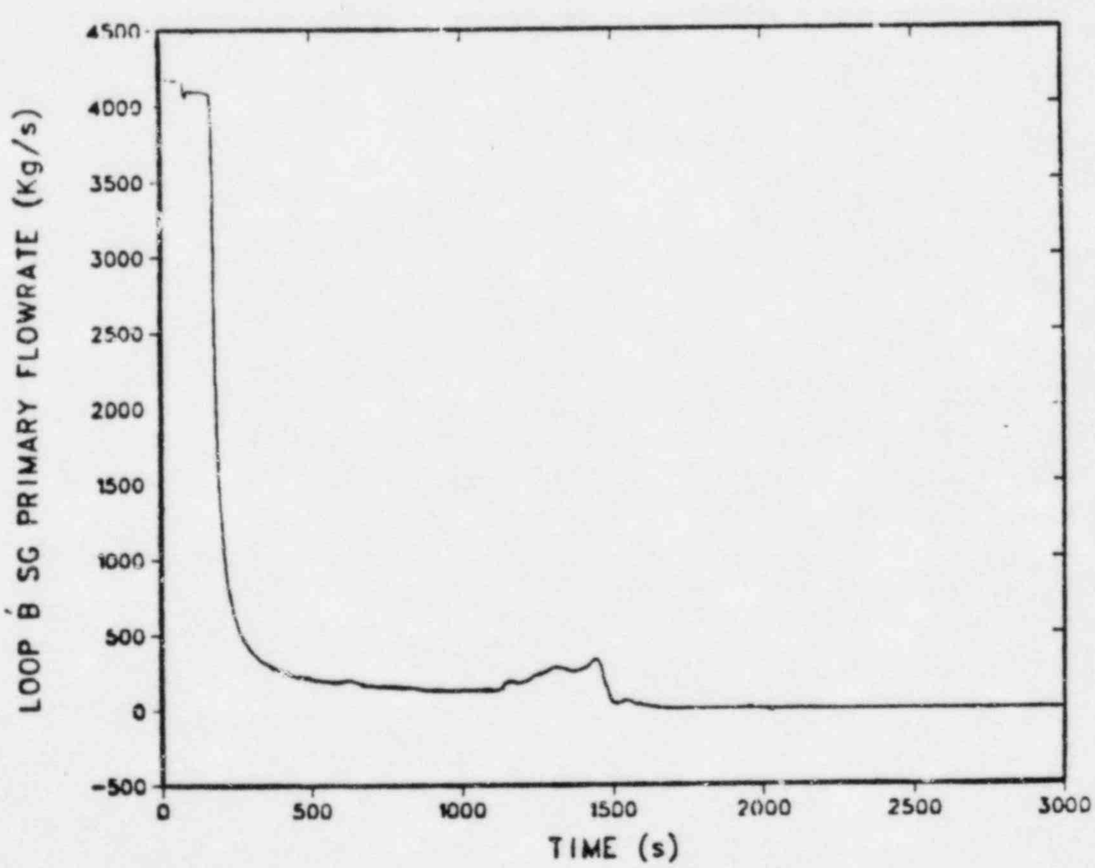

Fig. 8A. Loop-B flow rate; five-SGTR.

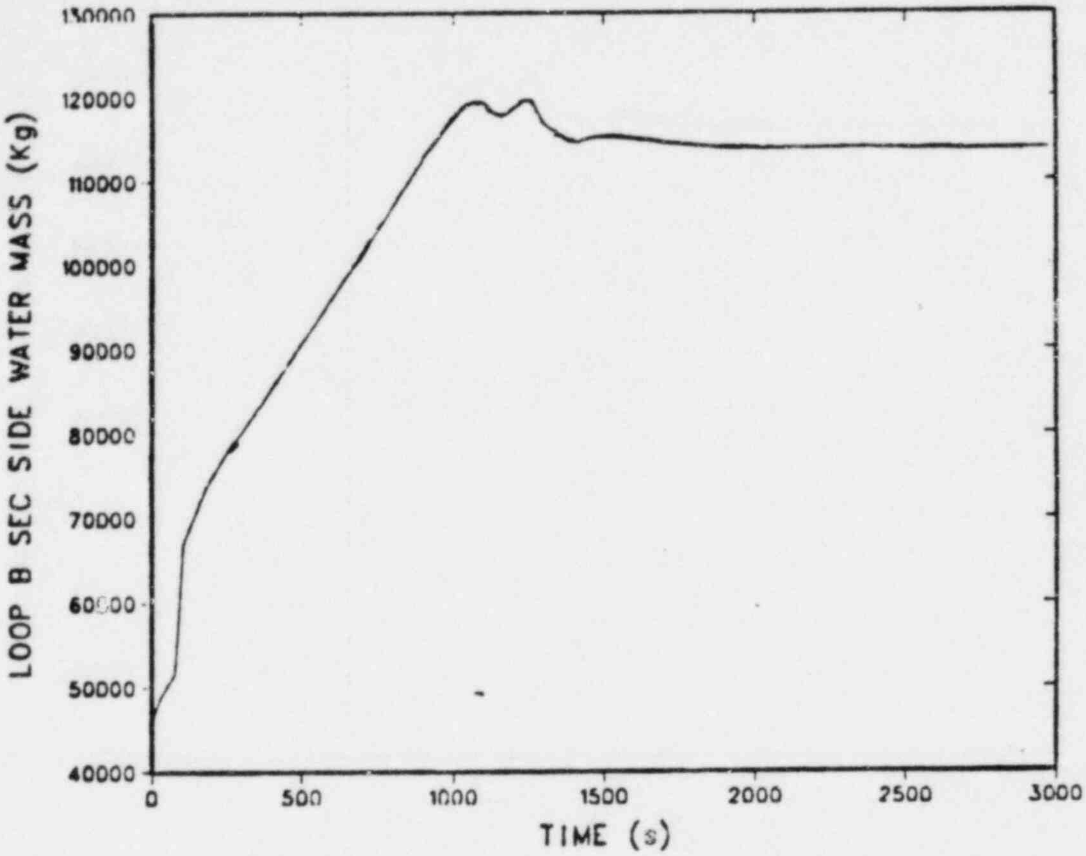

Fig. 9A. Secondary water mass; five-SGTR.

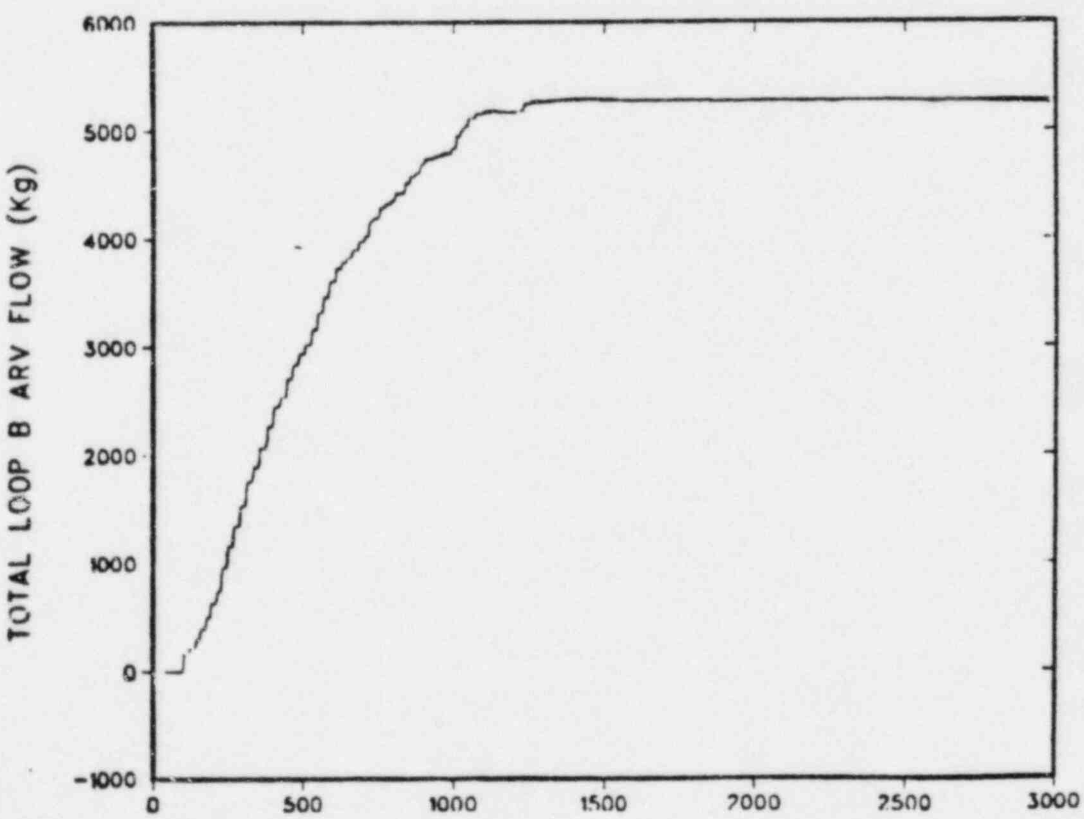

Fig. 10A. Total flow out ARV; five-SGTR.

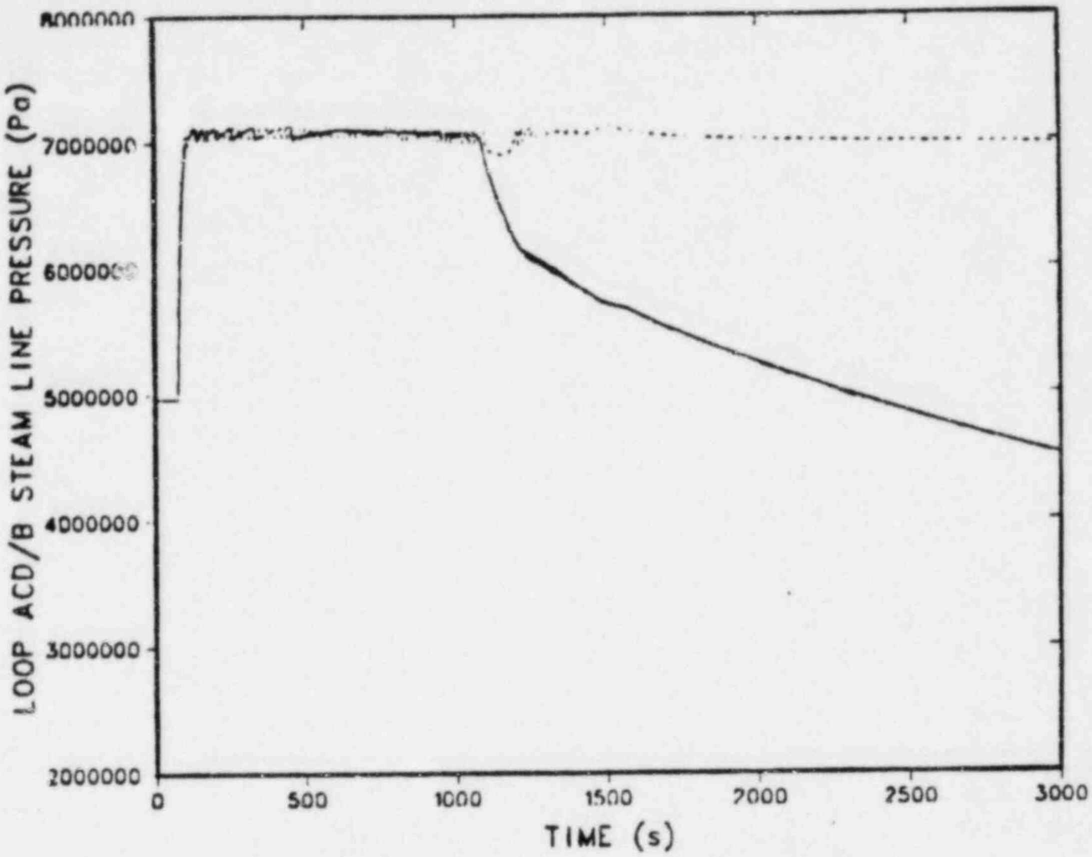

Fig. 11A. Secondary pressures; five-SGTR.

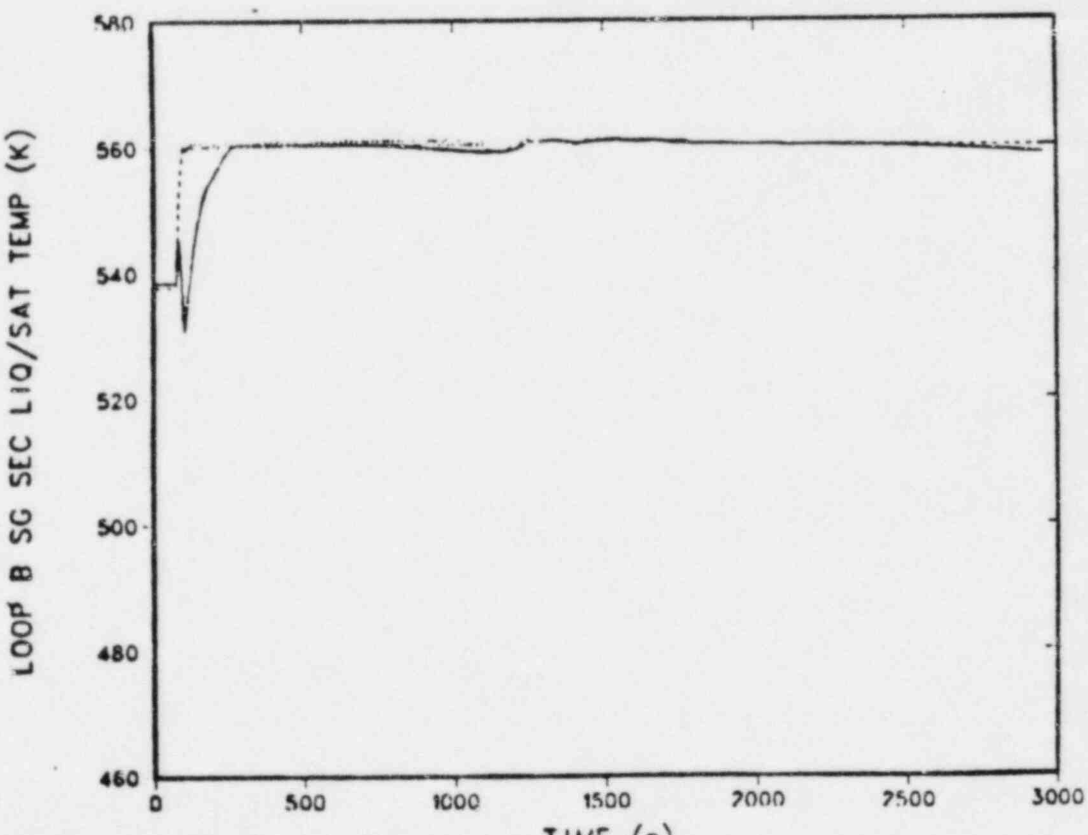

Fig. 12A. Secondary temperatures; five-SGTR.

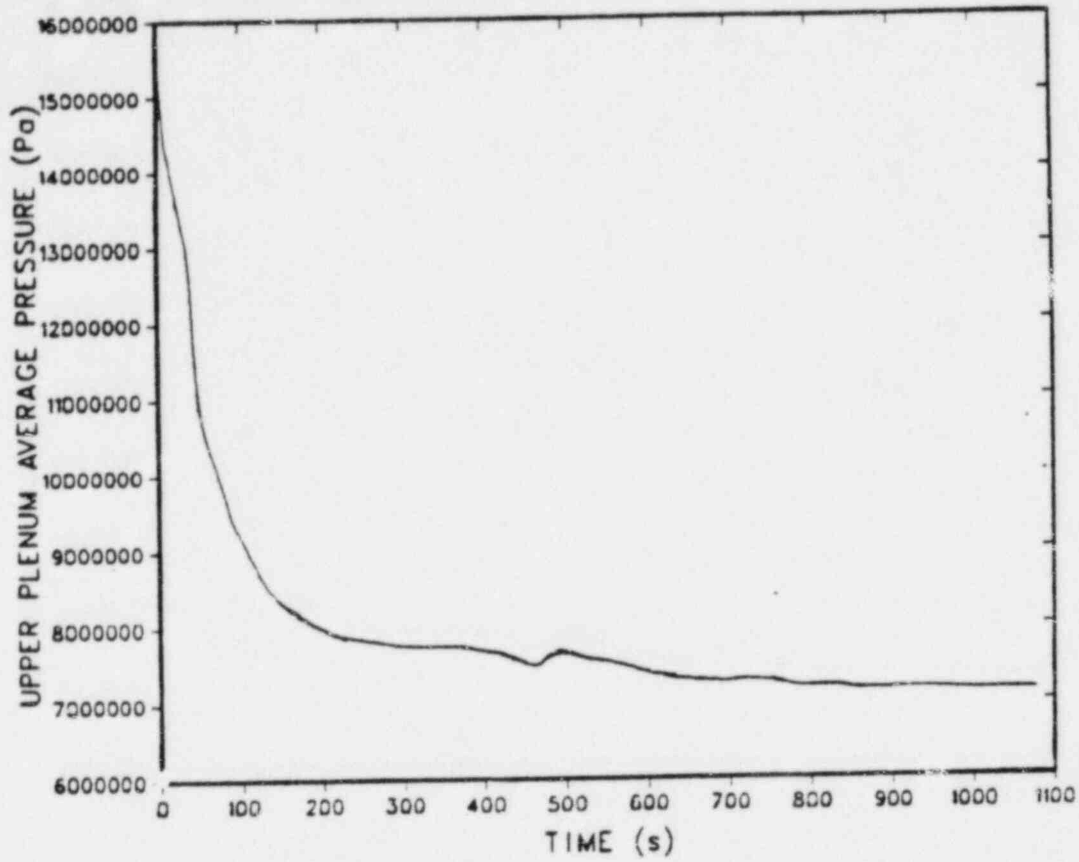

Fig. 13A. Primary pressure; 10-SGTR.

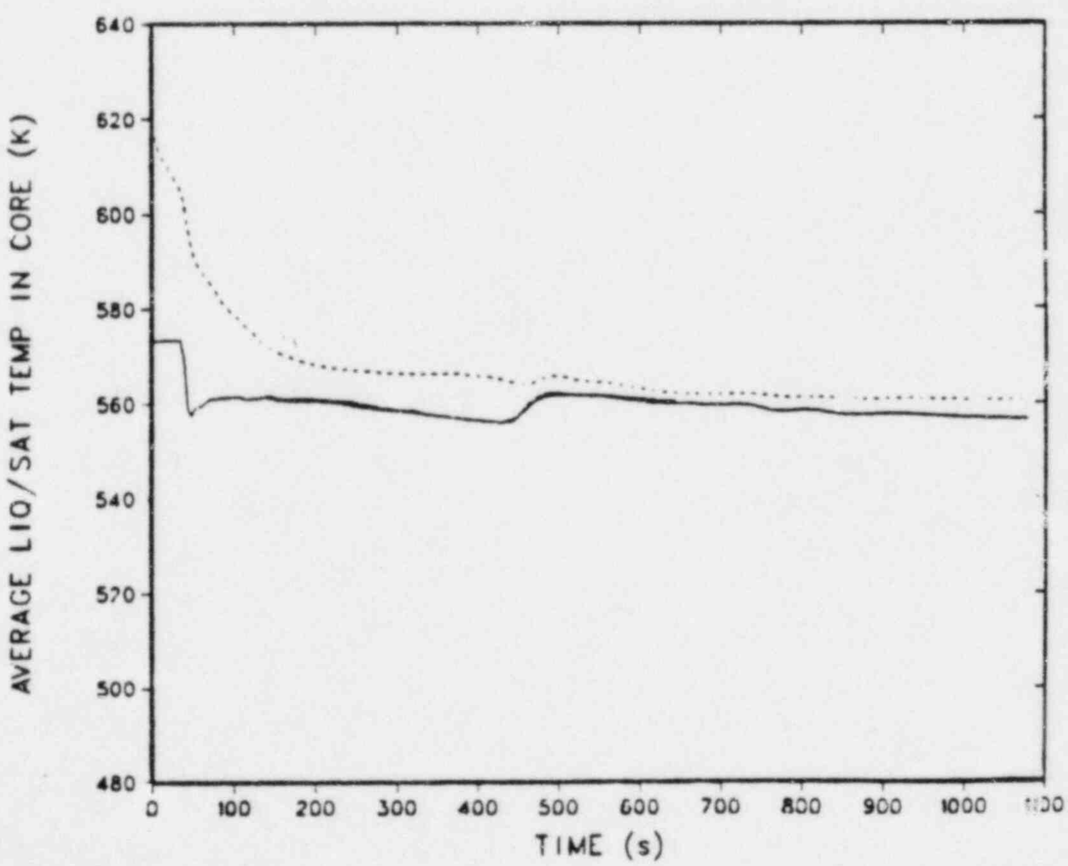

Fig. 14A. Primary temperatures; 10-SGTR.

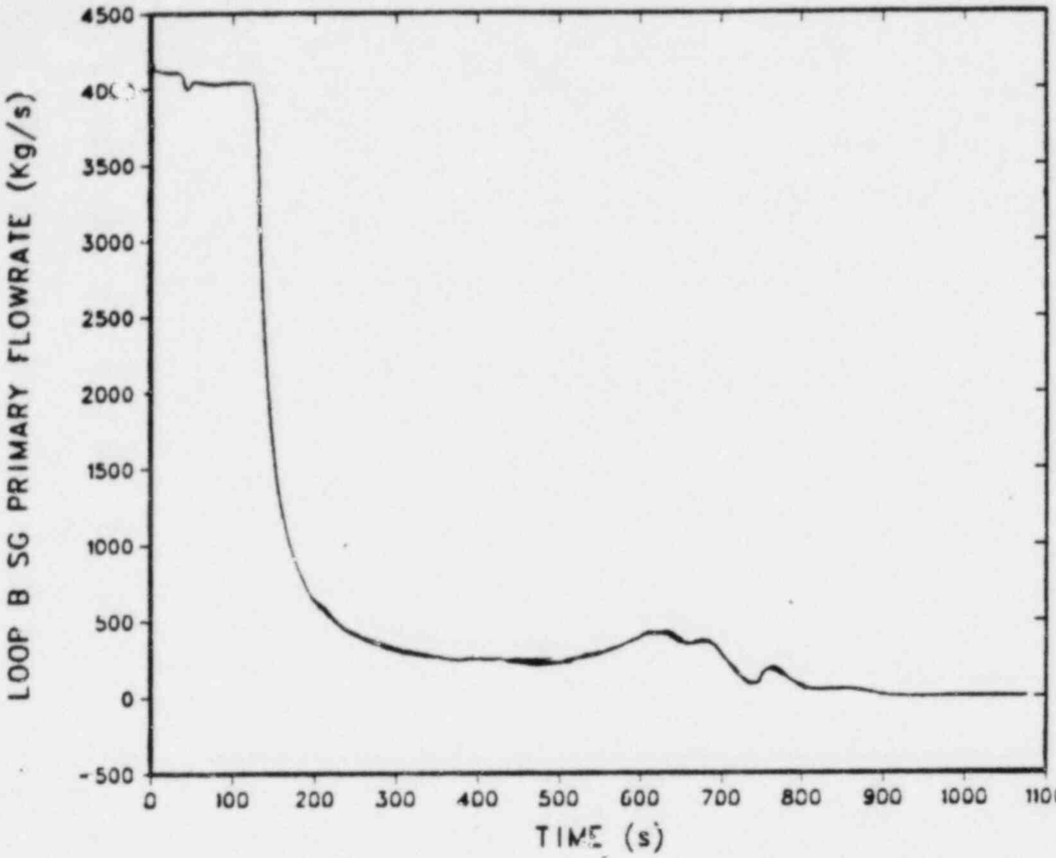

Fig. 15A. Loop-B flow rate; 10-SGTR.

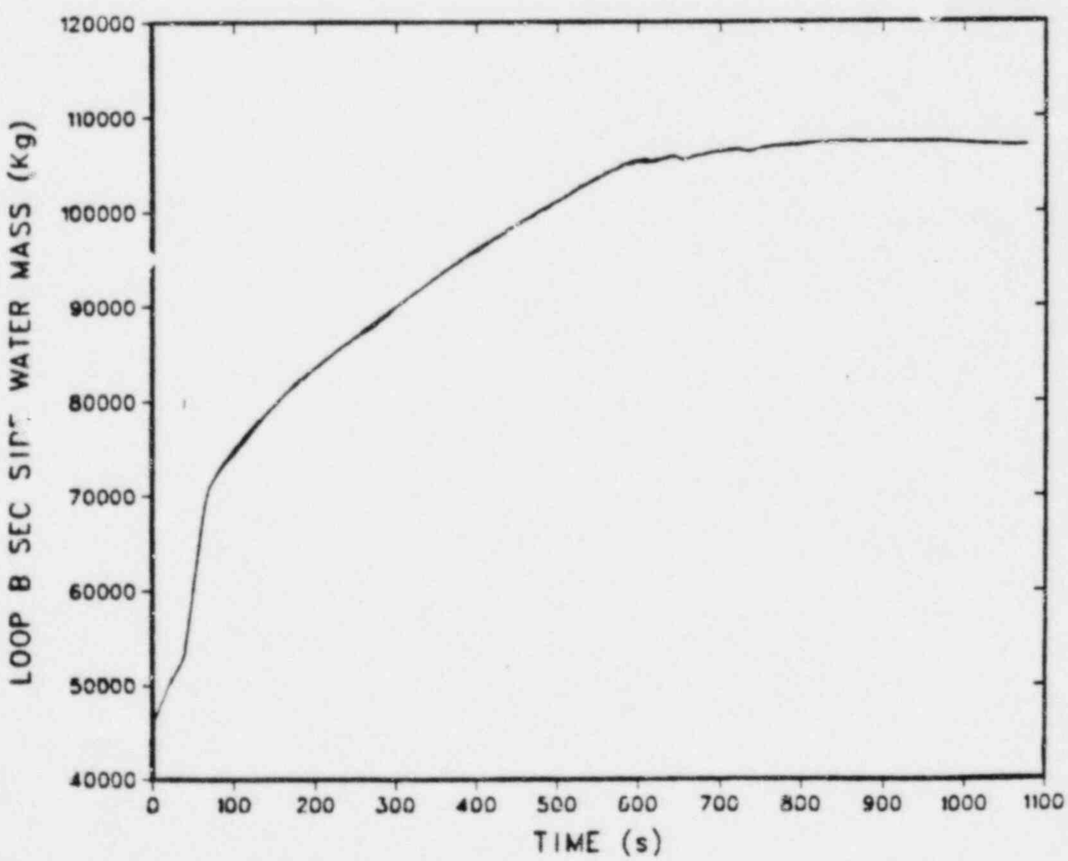

Fig. 16A. Secondary water mass; 10-SGTR.

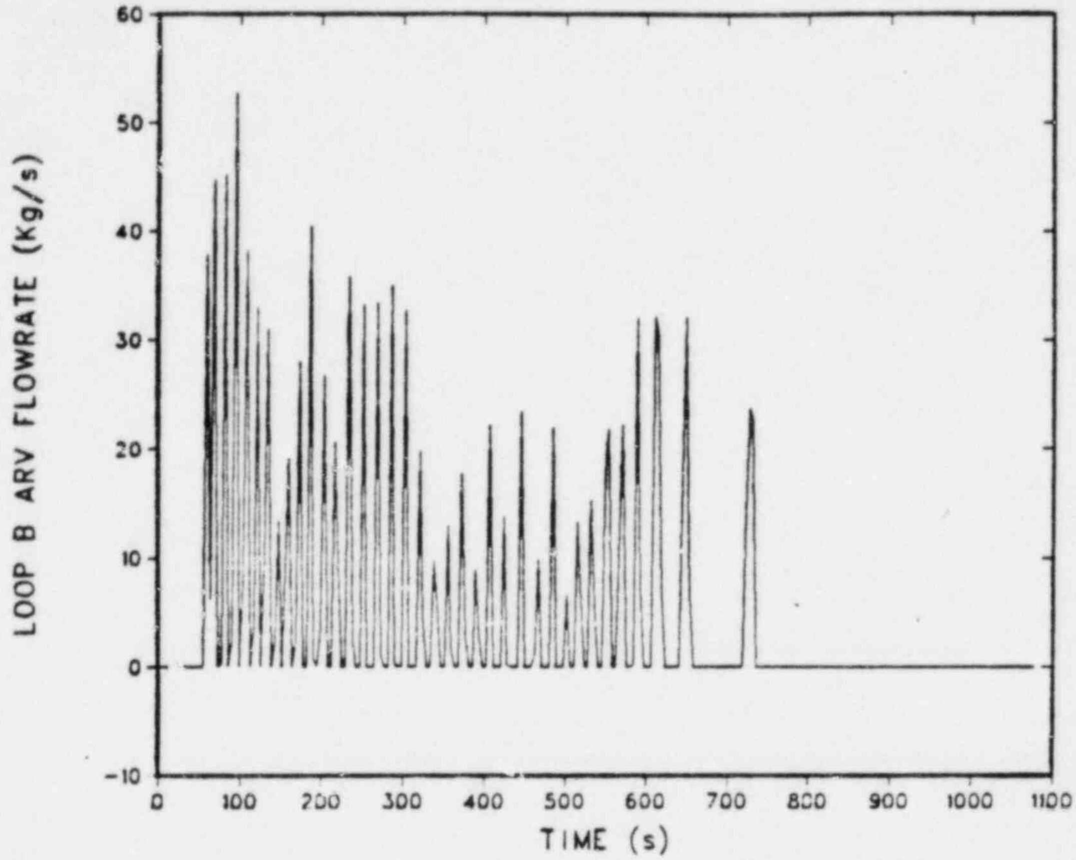

Fig. 17A. ARV flow rate; 10-SGTR.

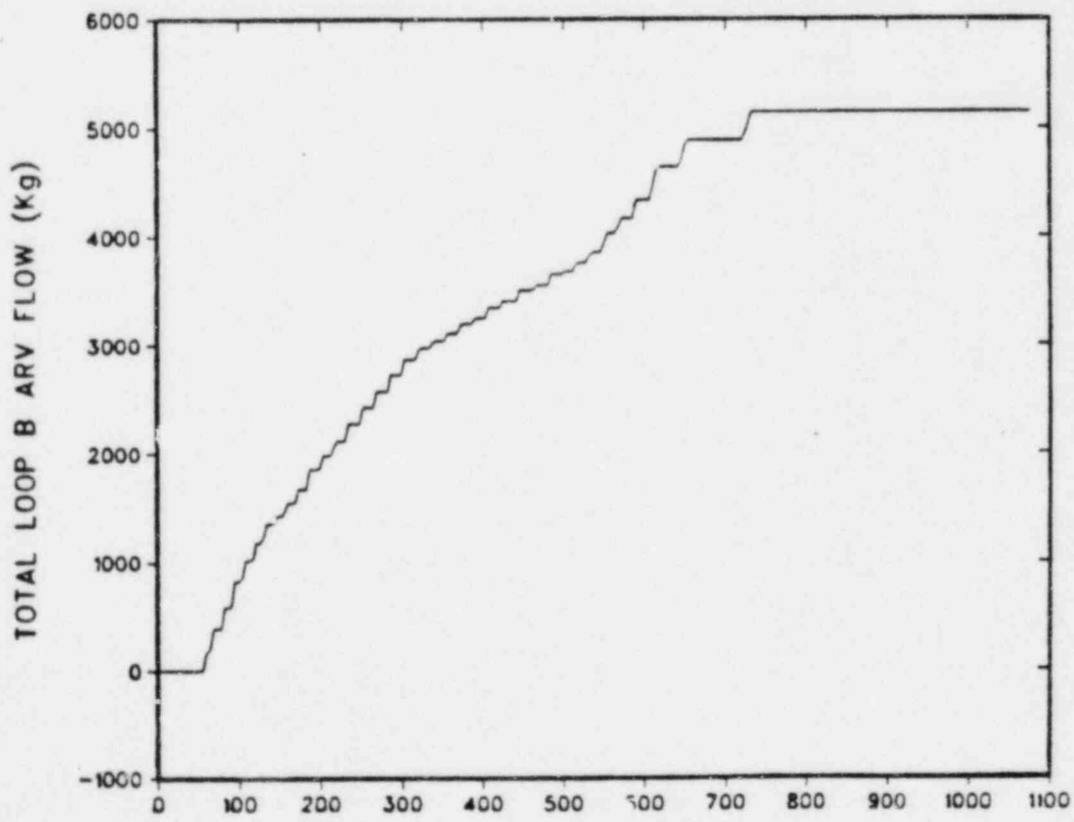

Fig. 18A. Total ARV flow; 10-SGTR.

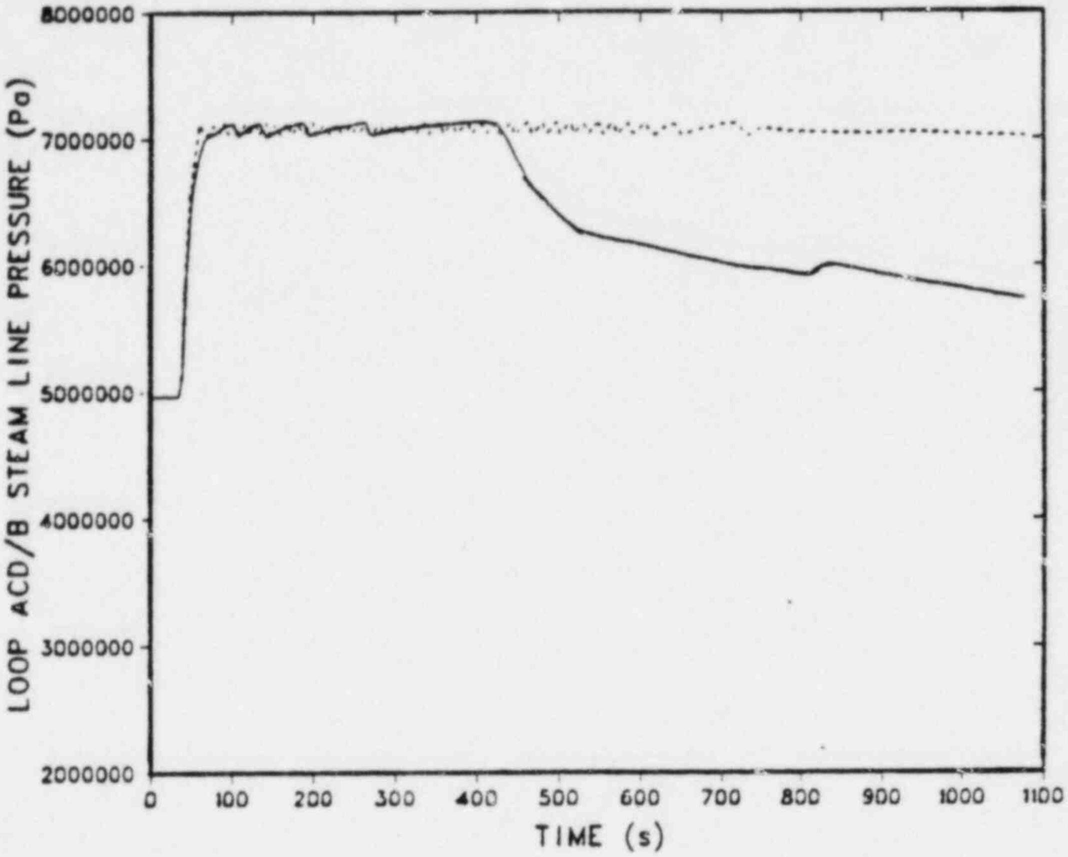

Fig. 19A. Secondary pressures; 10-SGTR.

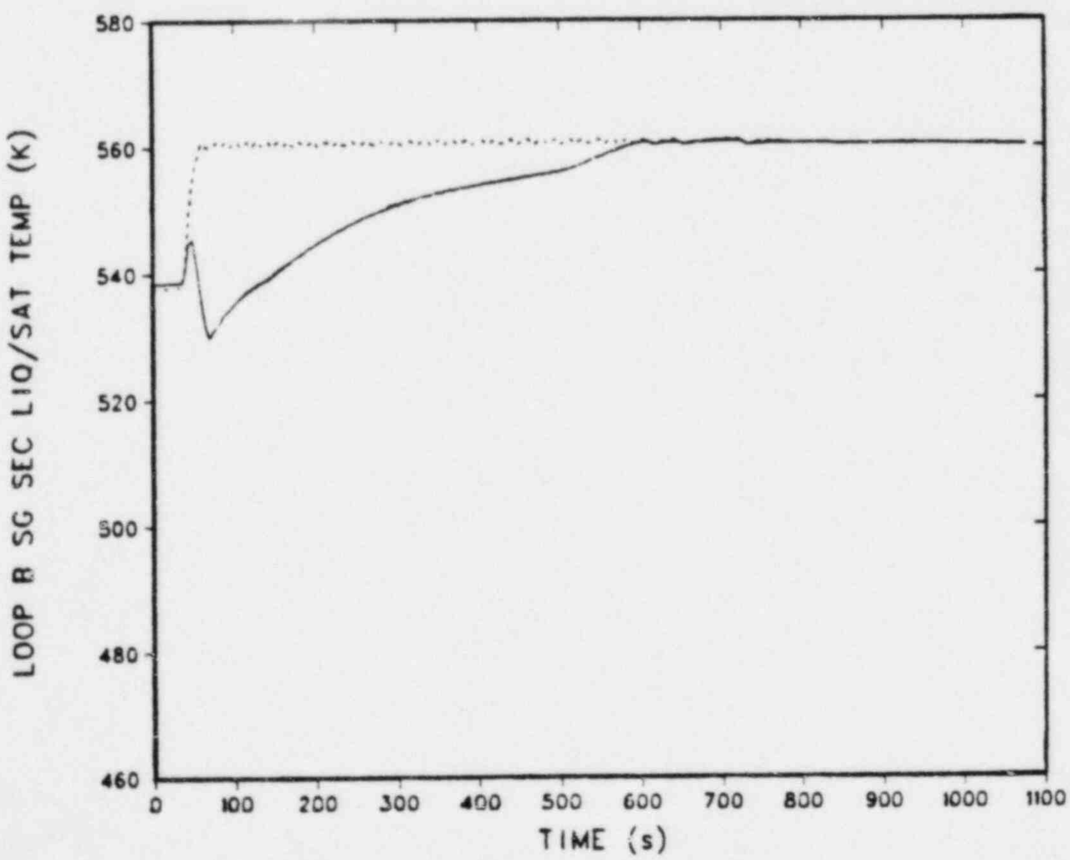

Fig. 20A. Secondary temperatures; 10-SGTR.

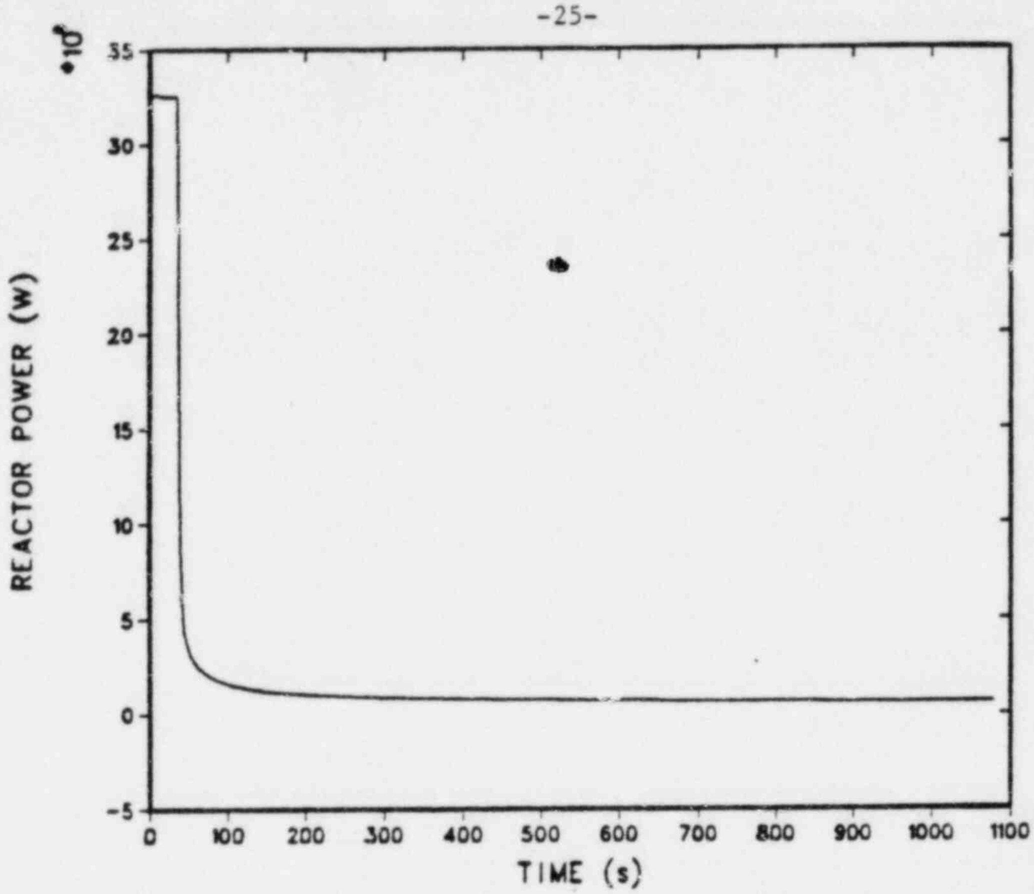

Fig. 21A. Reactor power; 10-SGTR.