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TITLE: TRAC Analysis of Coincident Main Steamline Break, Steam Generator Tube Rupture and a Small Primary-Coolant Piping Break

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TRAC ANALYSIS OF COINCIDENT MAIN STEAM-LINE BREAK, STEAM GENERATOR TUBE RUPTURE, AND A SMALL PRIMARY-COOLANT PIPING BREAK

I. INTRODUCTION

This report summarizes the results of four TRAC-PD2[1] calculations for a pressurized water reactor modeled after Zion-I. The calculations simulate transients induced by a hypothesized main steam-line break (MSLB) with various additional coincident failures. The specific initiating combinations of events are:

Case 1

- Main steam-line break (double-ended)
- Rupture of one steam generator tube (double-ended)
- A 0.002027-m^2 (2 in. diam.) break in the primary-coolant hot leg

Case 2

- Main steam-line break (double-ended)
- Rupture of one steam generator tube (double-ended)
- A 0.002027 m^2 (2 in. diam.) break in the primary-coolant cold leg

Case 3

- Main steam-line break (double-ended)
- Rupture of one steam generator tube (double-ended)

Case 4

- Main steam-line break (double-ended)
- Rupture of five steam generator tubes (double-ended).

Several control measures were modeled in all four cases. A reactor scram signal was produced by 60% excess steam flow in the broken steam line. This signal occurred at 1.82 s into the transient. Simultaneously, the feedwater flow rate to each of the steam generators was reduced to 50% of the auxiliary feedwater system capacity. At a primary coolant system pressure of 11.7 MPa (1700 psia), the emergency core-cooling system (ECCS) was started, and concurrently, power to the primary coolant pumps was switched off with a subsequent pump coastdown. This signal was encountered at 18 s.

The reactor power as a function of time is shown in Fig. 1. This power history consists of two components, fission product decay heat and residual fissions. The decay heat is taken from the standard ANS curve.[2] The residual fission contribution is computed by TRAC from a point neutron kinetics model with provision for temperature-reactivity feedback effects.

Figure 2 shows a schematic diagram of the TRAC system model used in the calculations. The steam generator tube rupture (SGTR) was simulated with a valve (component 36) connected between the steam generator primary outlet and secondary inlet. The hot-leg break (HLB) was located between the reactor vessel and the pressurizer, while the cold-leg break (CLB) was placed between the pump and the vessel. All breaks, including the MSLB, were assumed to be in the pressurizer loop. The other three intact loops were combined in the model into a single loop to reduce complexity and computing time. All physical dimensions, pump characteristics, and initial fluid conditions were taken from the Zion FSAR.[3] Figure 3 shows the TRAC noding in the reactor vessel. Eight axial levels were used, with levels 3 through 6 comprising the core region. Two radial segments were used, the outer one corresponding to the downcomer region. Azimuthally, two divisions were used, the smaller (90°) segment containing the inlet and outlet for the single coolant loop, and the larger (270°) segment corresponding to the combined loop.

II. RESULTS

All four transients were qualitatively similar. Because of the MSLB, there was a rapid blowdown of the secondary side of the affected steam generator. During this blowdown, there was overcooling and partial depressurization of the primary coolant system, with consequent activation of the ECCS. Within several minutes, the ECCS flow became sufficient to compensate for primary coolant losses from the breaks, and the system was essentially stabilized. The primary pressure never fell enough to activate the accumulators or the low-pressure injection system. The core always remained covered with liquid, and the primary system remained subcooled except for a nearly stagnant region in the vessel upper head.

More detailed results are given below for the four cases.

Results for Case 1: MSLB + SGTR + HLB.

The blowdown of the steam generator secondary in the MSLB loop took place in about 100 s. The voiding of the secondary side of the steam generator is shown in Fig. 4 and the depressurization down to a secondary pressure of 0.153 MPa is shown in Fig. 5. This blowdown produced an overcooling of the primary coolant system to 510 K as shown in Fig. 6 and a partial depressurization to 5.0 MPa as shown in Fig. 7. The minimum in the core average liquid temperature at about 120 s lagged the steam generator dryout because of the mixing time for the liquid from the loops in the reactor vessel. Figure 8 shows that the core coolant remained subcooled at all times.

The primary coolant loss rates through the HLB and the SGTR are shown in Figs. 9 and 10, respectively, while the ECCS injection flows are given in Figs. 11 and 12. (The negative values of the ordinates in Figs. 11 and 12 are due to the choice of positive direction in the calculation. These flows are into the primary system.) All of these primary system inflows and outflows are summed in Fig. 13 to give the net outflow rate. The ECCS balanced the break losses, giving zero outflow, at about 225 s, and for a short time thereafter actually overcompensated, giving a small net inflow. The core liquid inventory (Fig. 14) shows a relative minimum at 225 s, and subsequently increases due to both the small net inflow and because of gradual cooling by the auxiliary feedwater flow in the three intact steam generators. These effects are also reflected by the relative maximum in the core average liquid temperature shortly after 200 s as seen in Fig. 6.

In summary, after about four minutes, the ECCS was able to compensate for break losses, primary system pressure and temperatures were stabilized, and the accident was under control.

Two additional features of the calculation are worthy of mention. Figure 15 shows that the pressurizer emptied very early in the transient and did not refill. Also, Fig. 16 shows the TRAC prediction that the vessel upper head region attained a very high vapor fraction during the transient. This is a region of relatively stagnant fluid, especially after the primary coolant pumps were tripped. The onset of voiding is coincident with the pump trip at 18 s. This phenomenon apparently had no detrimental effect on the course of this accident. However, had the accident been sufficiently severe to void the upper plenum, the natural circulation of the primary coolant would have been lost and could have had severe consequences.

Results for Case 2: MSLB + SGTR + CLB.

Case 2 differs from Case 1 only in the location of the primary system piping break in the cold leg instead of the hot leg. The results are therefore quite similar. Comparison of Figs. 17 and 7 shows that the early history of the primary system pressure is slightly different, with the cold-leg break producing a somewhat more rapid depressurization. However, in both cases, the system stabilizes at about 5 MPa within 200 s.

The core liquid temperatures were also very similar in the two cases, as shown by a comparison of Figs. 18 and 6. The temperature was a few degrees higher in the cold-leg-break case. This is attributable to diversion of some of the relatively cool ECCS water out the cold leg break before reaching the vessel. However, Fig. 19 shows that the core coolant remains subcooled in this case also.

Results For Cases 3 and 4: MSLB + SGTR

Results for the calculations without a primary system piping break are shown in Figs. 20-22. Curves are given for both one steam generator tube rupture, and for five broken tubes. The primary system depressurization (Fig. 20) took longer in the latter case, because the larger primary-to-secondary leakage rate somewhat delayed the dryout of the steam generator secondary in the loop with the broken steam line. The primary pressure for a single ruptured steam generator tube stabilized at a higher level than any of the other cases because of the smaller total primary system break area and consequently smaller loss in coolant inventory.

Figure 21 shows that the core coolant temperature responded in a manner qualitatively similar to the previous cases. The five-tube rupture case produced lower temperatures because of larger ECCS delivery rates.

Finally, as shown in Fig. 22, the pressurizer emptied and did not refill in the five-tube rupture case, whereas it did refill in the one-tube break case. In fact, it appears that in the latter instance, the pressurizer may overfill and "go solid" if the calculation is continued.

III. SUMMARY AND CONCLUSIONS

All the transients reported exhibit qualitatively similar behavior. In all cases, the main steam-line break produces overcooling and partial depressurization of the primary coolant system. The high-pressure portion of the ECCS is required to compensate for coolant losses. However, in all cases, the high-pressure injection system is adequate, with neither the accumulator nor the low-pressure injection system being used. The core remains covered with liquid, and the primary coolant remains subcooled, except in the vessel upper head.

There appears to be nothing in the response of the primary and/or secondary systems which will indicate uniquely to the operator whether there is a primary piping break in addition to a steam generator tube rupture following a main steam line break. If the total break area is known, there are minor differences in the responses which, if properly interpreted, might permit this assessment. However, the differences are small, and occur only for a few minutes. Also, the operator could not have knowledge of the break size. In short, these TRAC calculations revealed no operationally useful accident "signature" which unequivocally identifies a tube rupture plus a piping break as contrasted with pure tube ruptures of comparable total area.

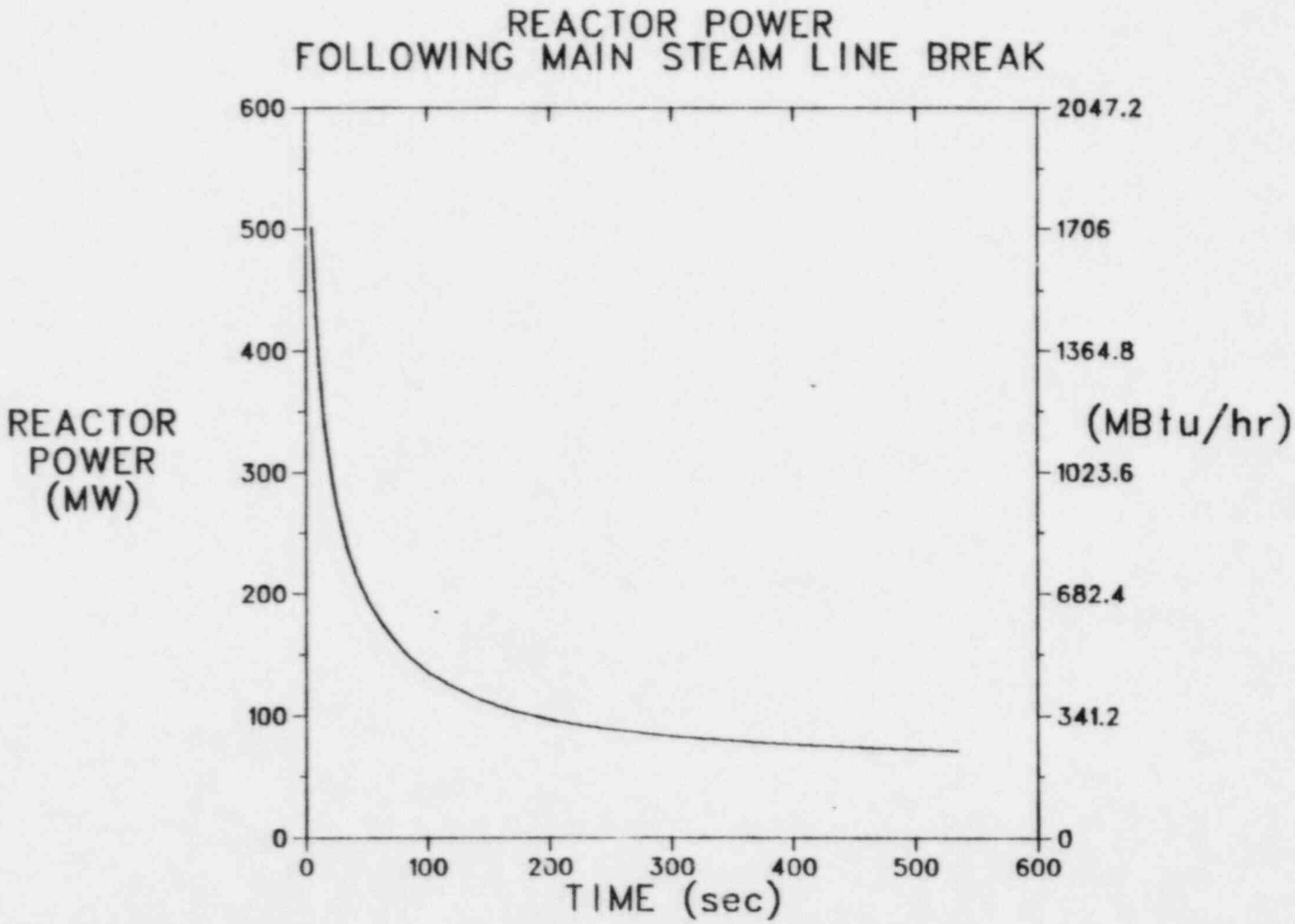
If the main steam line break were located outside the containment, the containment response would aid in identifying the specific accident. A primary piping break will always result, of course, in coolant and radiation leaks to the containment, whereas tube ruptures plus a MSLB outside containment would not. A MSLB inside containment provides no such immediate resolution.

REFERENCES

1. Safety Code Development Group, "TRAC-PD2, An Advanced Best-Estimate Computer Program for PWR Loss-of-Coolant Accident Analysis," Energy Division, Los Alamos National Laboratory report (to be published).

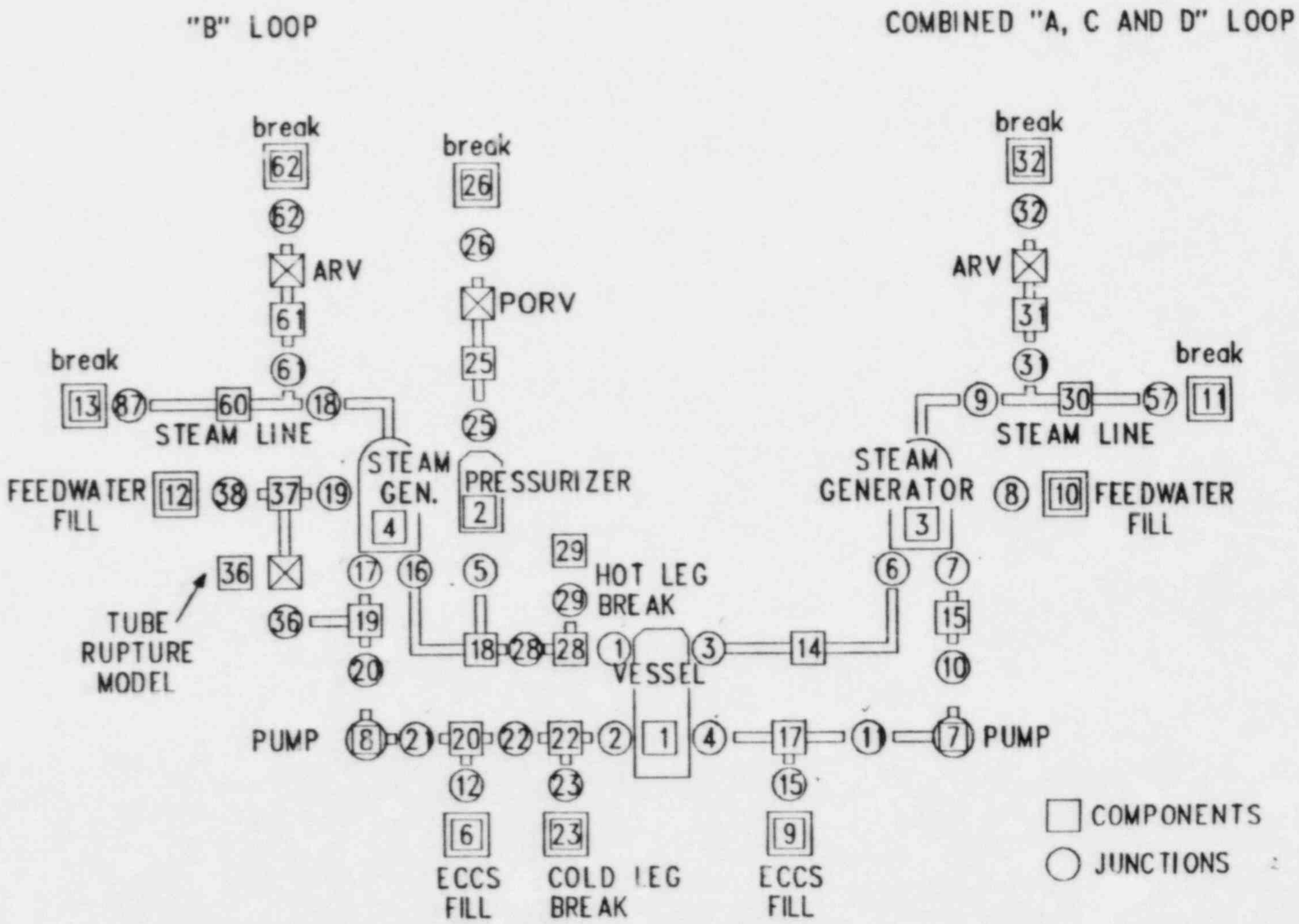
2. American Nuclear Society Proposed ANS 5.1 Standard, "Decay Heat Power in Light Water Reactors," (June 1978, Rev. September 1978).

3. Commonwealth Edison Co., "Zion Station, Final Safety Analysis Report, Chicago, Illinois.



REACTOR POWER
FOLLOWING MAIN STEAM LINE BREAK
REACTOR POWER (MW)
(MBtu/hr)
TIME (sec)
0
100
200
300
400
500
600
0
341.2
682.4
1023.6
1364.8
1706
2047.2

Fig. 1.



SCHEMATIC OF TRAC MODEL

Fig. 2

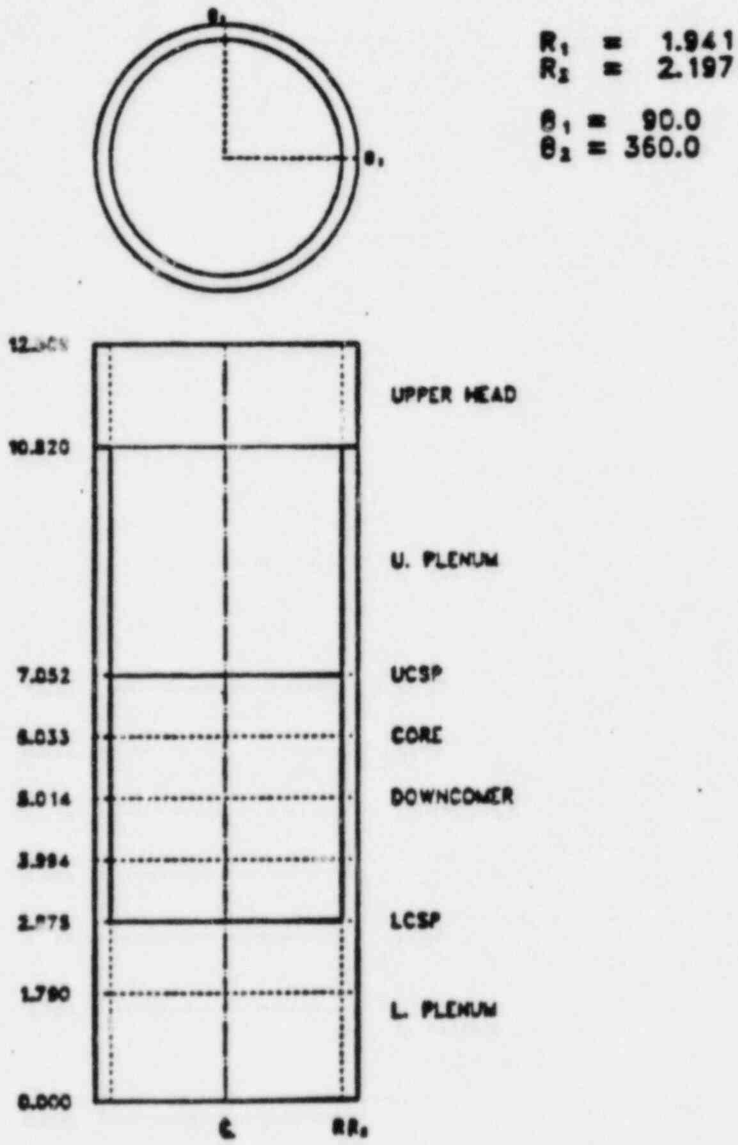


Fig. 3.
Vessel noding diagram.

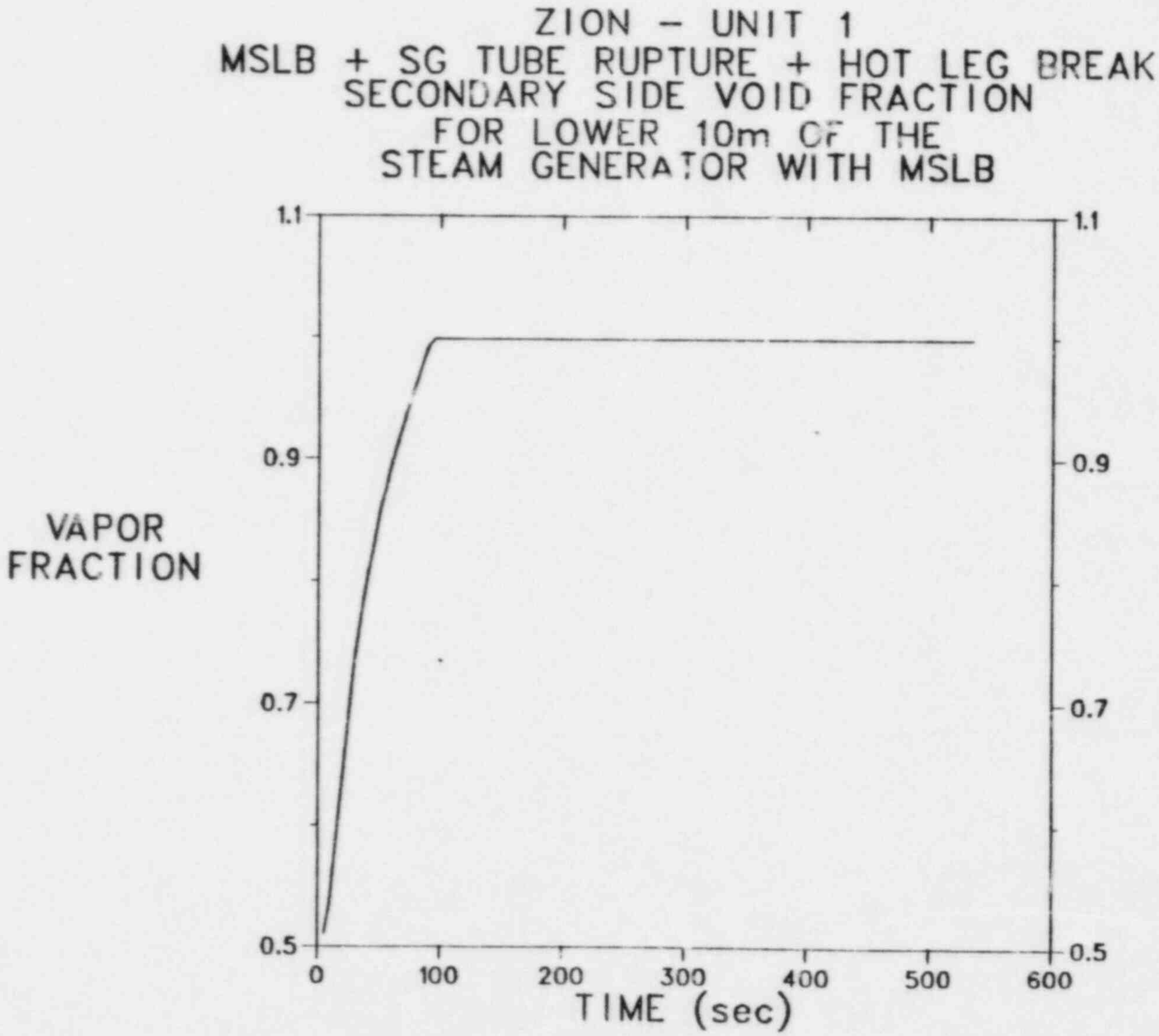

ZION - UNIT 1
MSLB + SG TUBE RUPTURE + HOT LEG BREAK
SECONDARY SIDE VOID FRACTION
FOR LOWER 10m OF THE
STEAM GENERATOR WITH MSLB
VAPOR FRACTION
1.1
0.9
0.7
0.5
0
100
200
300
400
500
600
TIME (sec)

Fig. 4.

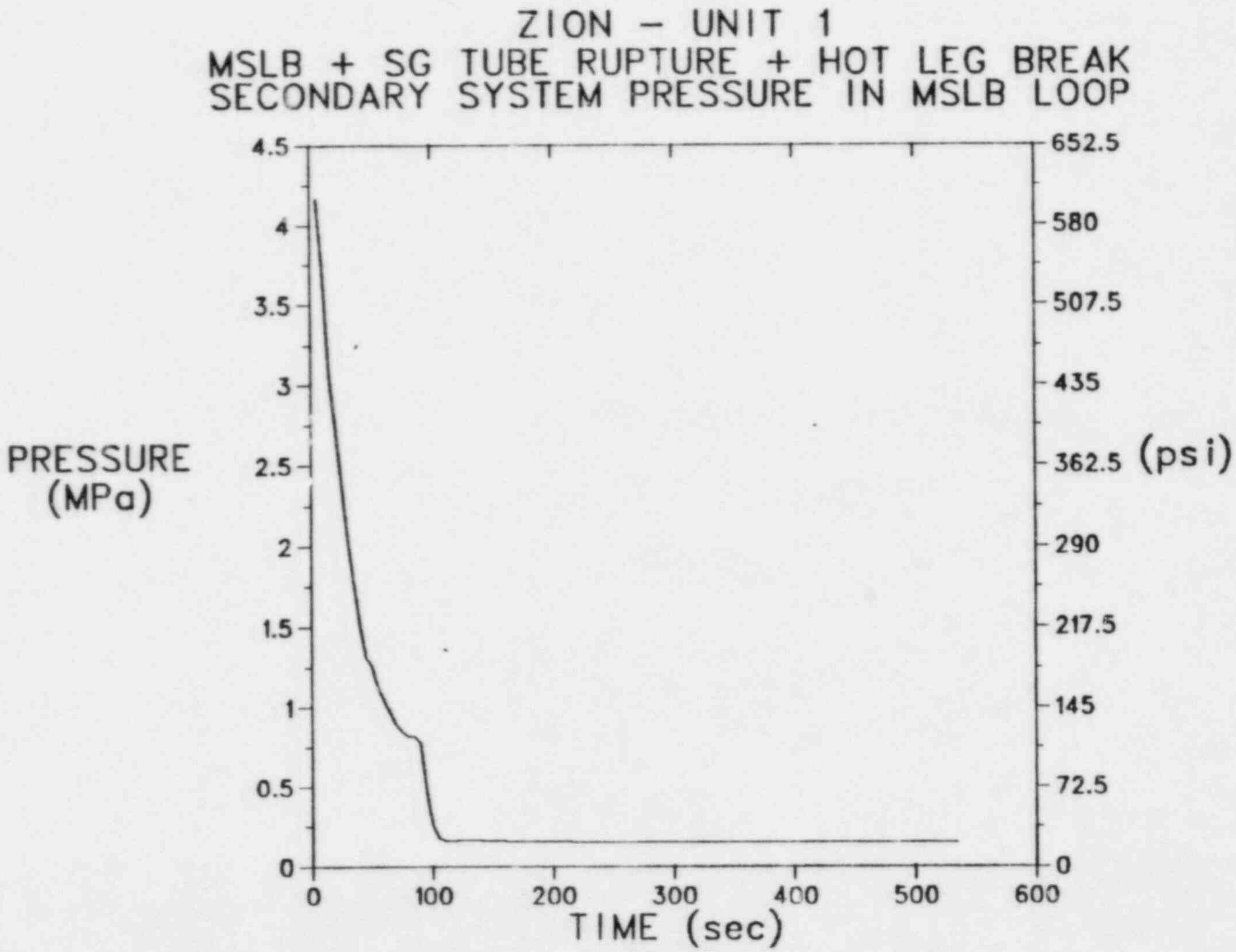

ZION - UNIT 1
MSLB + SG TUBE RUPTURE + HOT LEG BREAK
SECONDARY SYSTEM PRESSURE IN MSLB LOOP
PRESSURE (MPa)
(psi)
TIME (sec)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
652.5
580
507.5
435
362.5
290
217.5
145
72.5
0
100
200
300
400
500
600

Fig. 5.

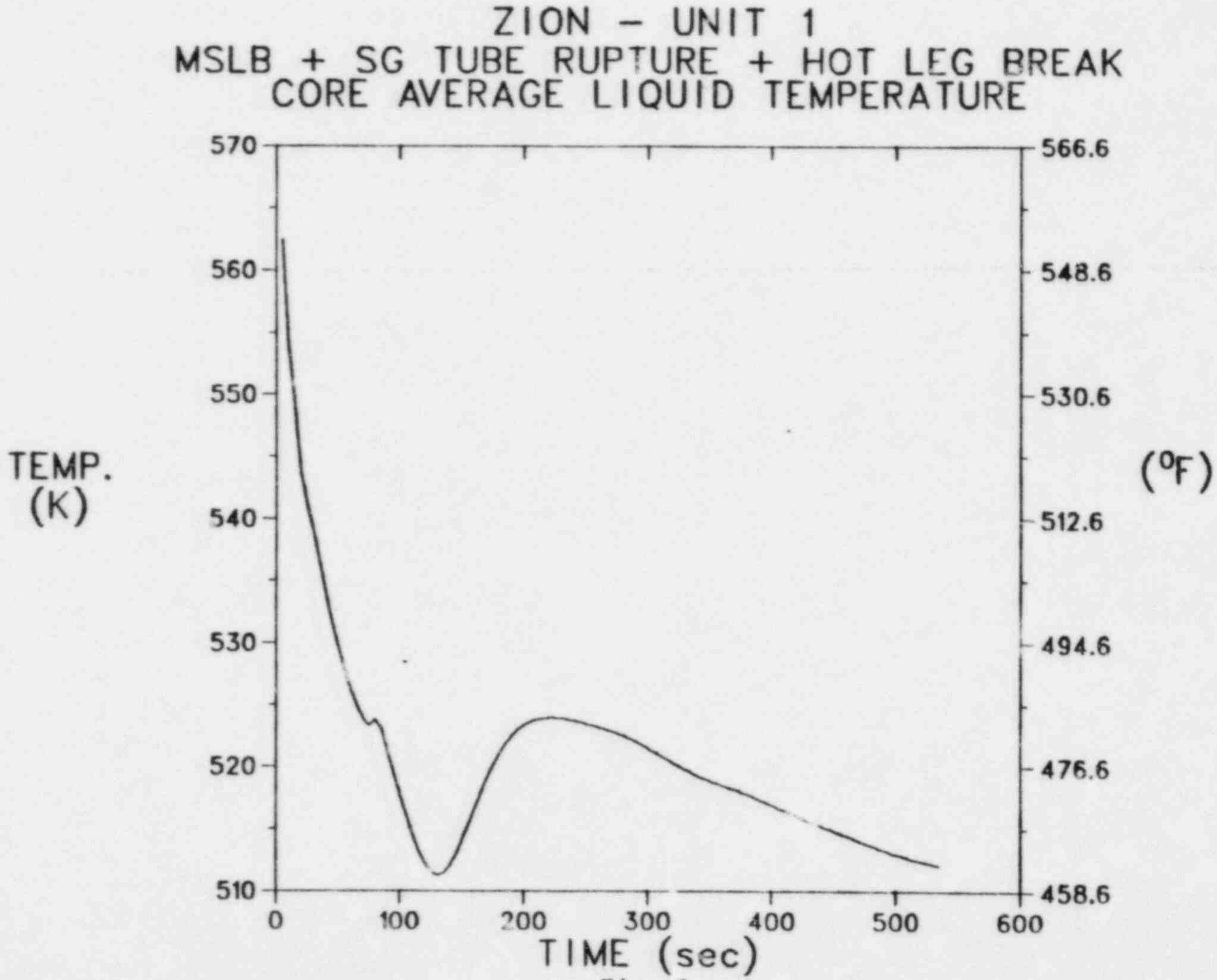
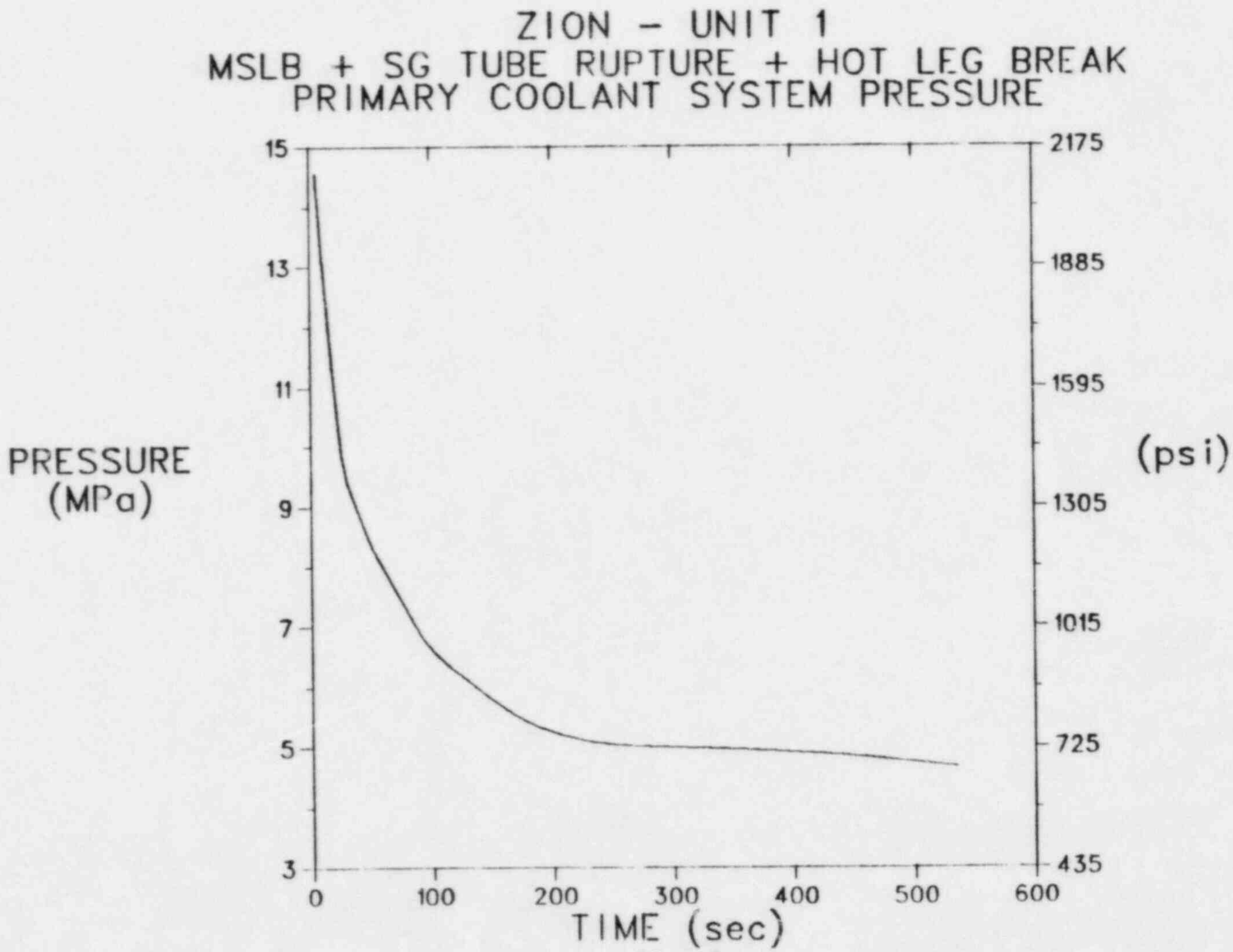
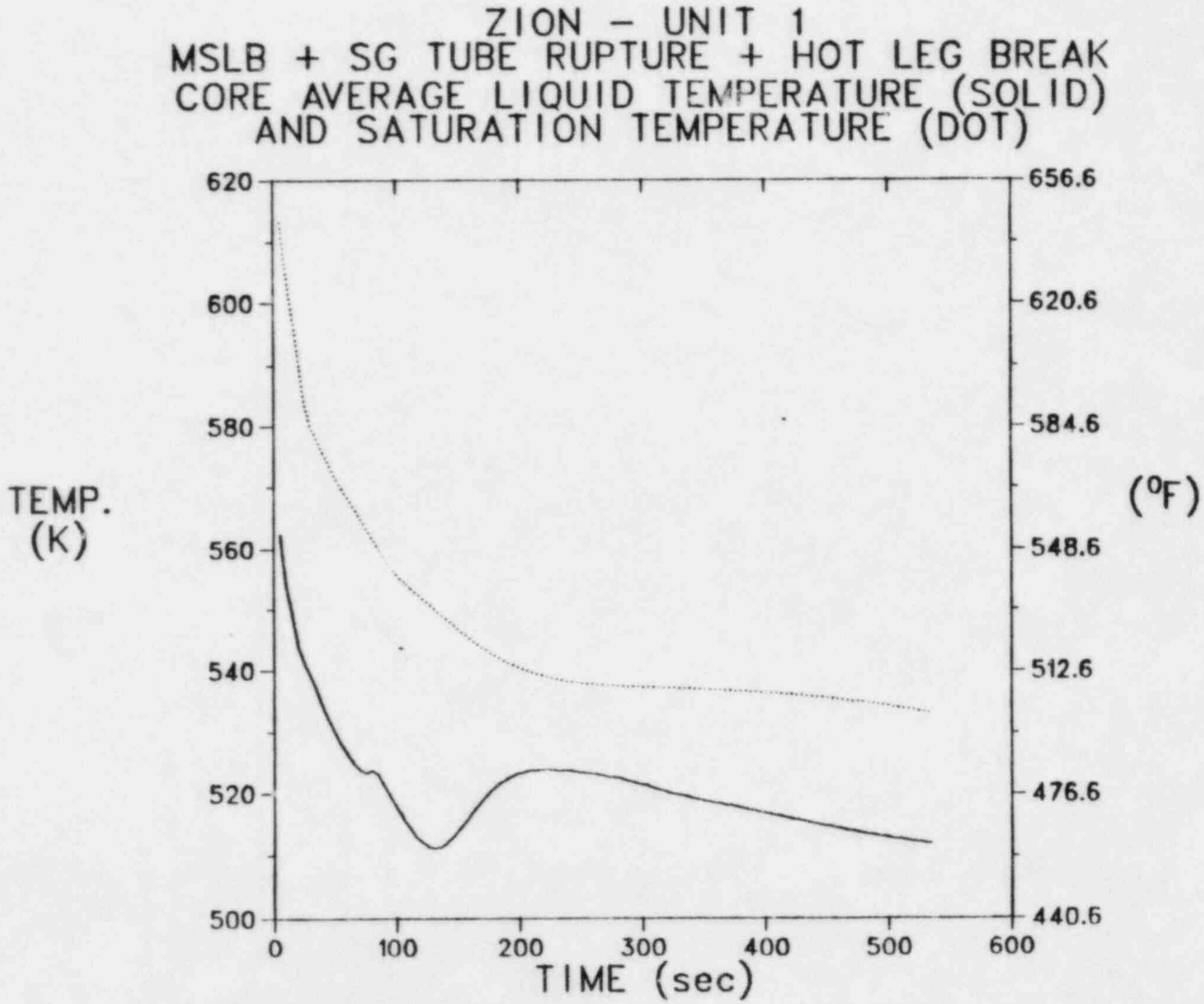
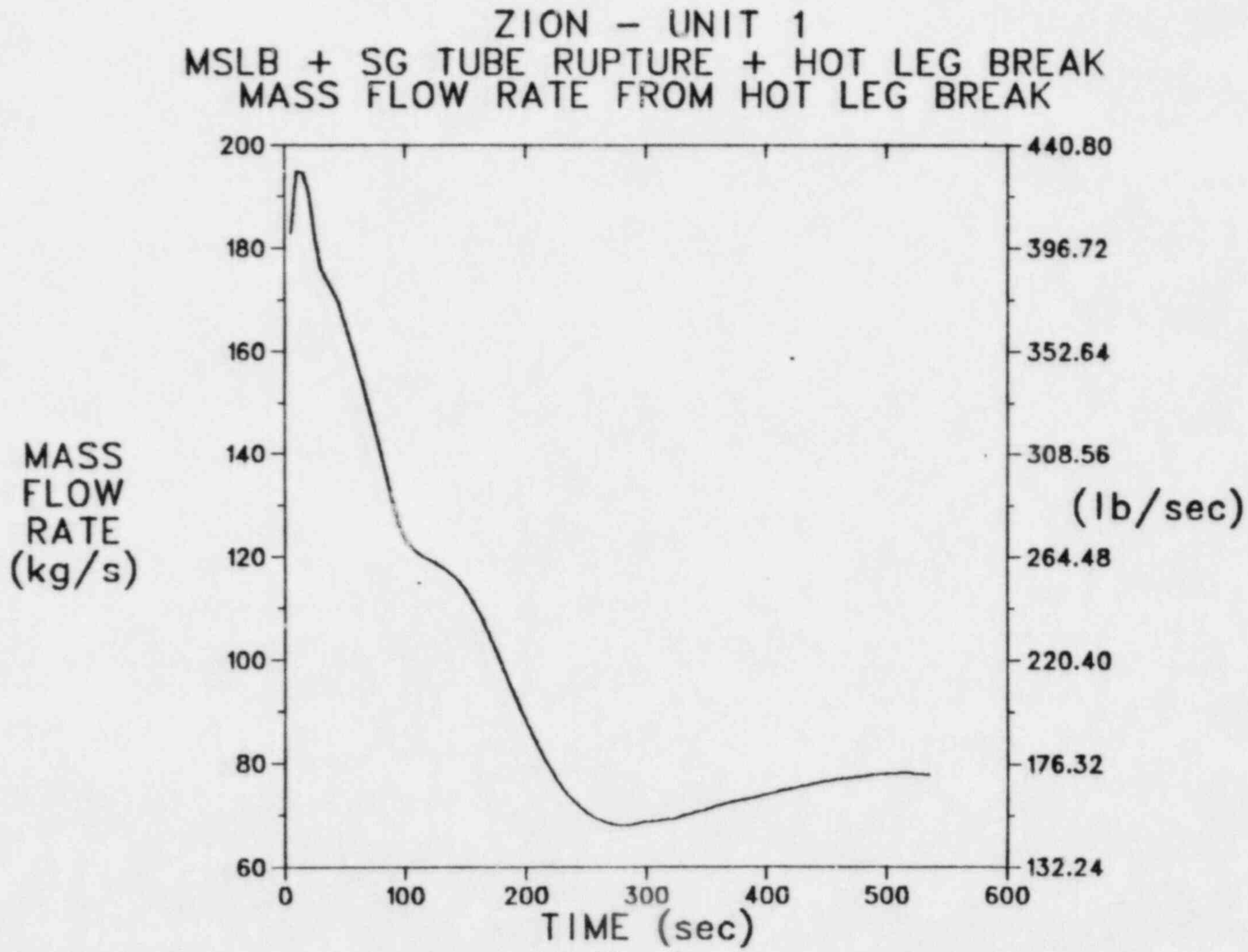

ZION - UNIT 1
MSLB + SG TUBE RUPTURE + HOT LEG BREAK
CORE AVERAGE LIQUID TEMPERATURE
TEMP.
(K)
570
560
550
540
530
520
510
(°F)
566.6
548.6
530.6
512.6
494.6
476.6
458.6
0
100
200
300
400
500
600
TIME (sec)

Fig. 6.


ZION - UNIT 1
MSLB + SG TUBE RUPTURE + HOT LEG BREAK
PRIMARY COOLANT SYSTEM PRESSURE
PRESSURE
(MPa)
(psi)
15
13
11
9
7
5
3
2175
1885
1595
1305
1015
725
435
0
100
200
300
400
500
600
TIME (sec)
Fig. 7.


ZION - UNIT 1
MSLB + SG TUBE RUPTURE + HOT LEG BREAK
CORE AVERAGE LIQUID TEMPERATURE (SOLID)
AND SATURATION TEMPERATURE (DOT)
TEMP.
(K)
(^{0}F)
620
600
580
560
540
520
500
656.6
620.6
584.6
548.6
512.6
476.6
440.6
0
100
200
300
400
500
600
TIME (sec)
Fig. 8.



ZION - UNIT 1
MSLB + SG TUBE RUPTURE + HOT LEG BREAK
MASS FLOW RATE FROM HOT LEG BREAK
MASS FLOW RATE (kg/s)
(lb/sec)
TIME (sec)
200
180
160
140
120
100
80
60
440.80
396.72
352.64
308.56
264.48
220.40
176.32
132.24
0
100
200
300
400
500
600

Fig. 9.

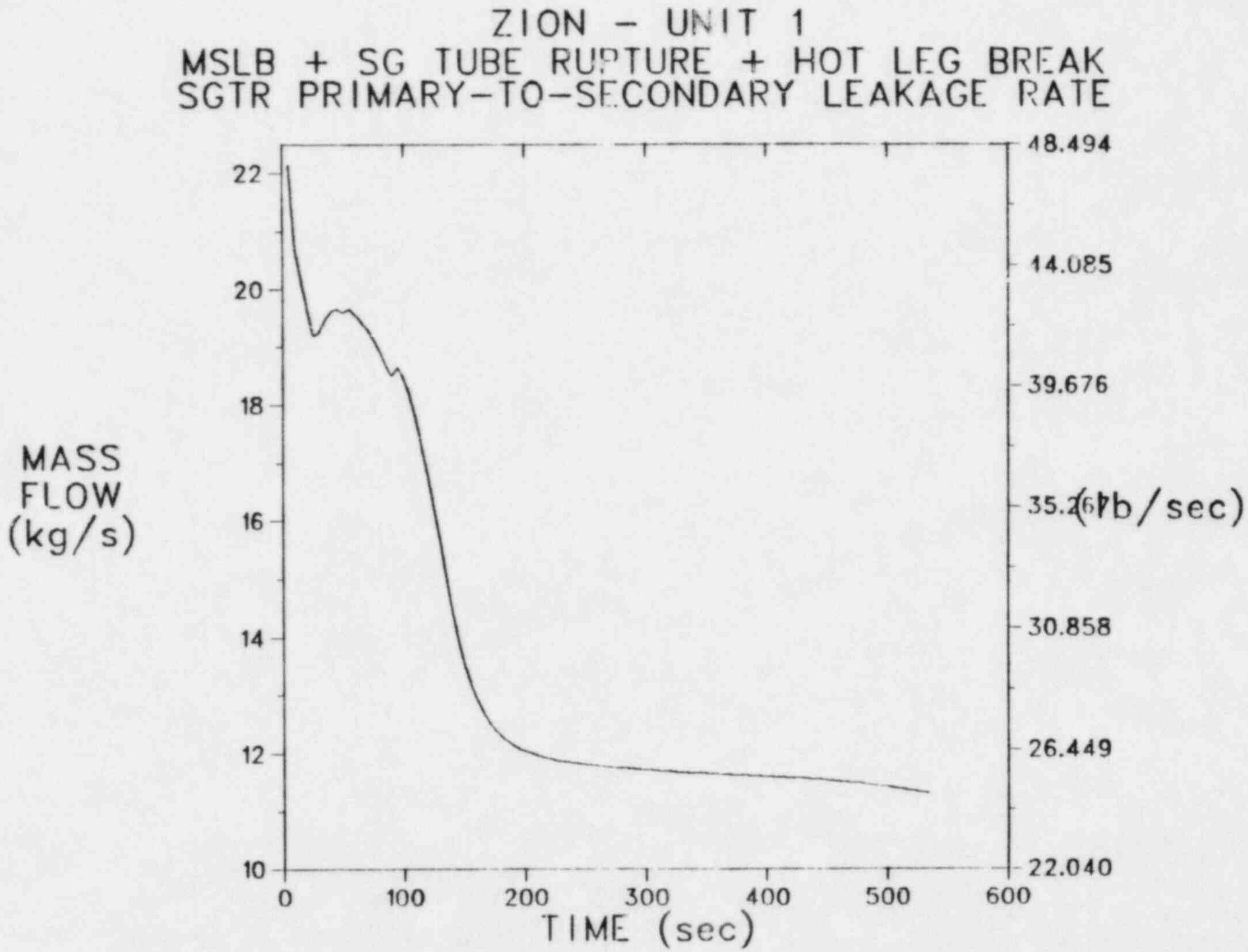

ZION - UNIT 1
MSLB + SG TUBE RUPTURE + HOT LEG BREAK
SGTR PRIMARY-TO-SECONDARY LEAKAGE RATE
MASS FLOW (kg/s)
22
20
18
16
14
12
10
48.494
14.085
39.676
35.267
(lb/sec)
30.858
26.449
22.040
0
100
200
300
400
500
600
TIME (sec)

Fig. 10.

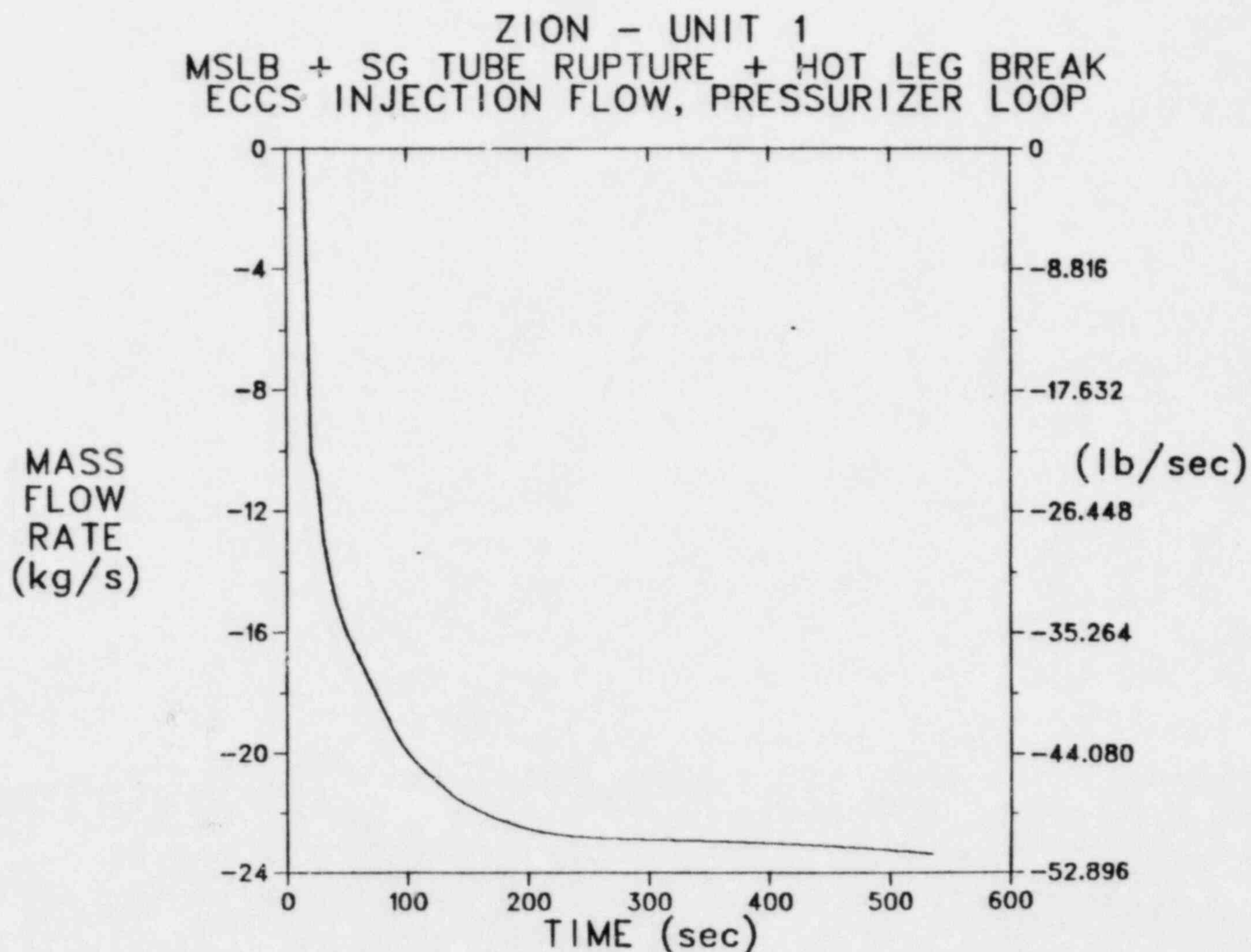

ZION - UNIT 1
MSLB + SG TUBE RUPTURE + HOT LEG BREAK
ECCS INJECTION FLOW, PRESSURIZER LOOP
MASS FLOW RATE (kg/s)
(lb/sec)
TIME (sec)
0
-4
-8
-12
-16
-20
-24
0
-8.816
-17.632
-26.448
-35.264
-44.080
-52.896
0
100
200
300
400
500
600

Fig. 11.

ZION - UNIT 1
MSLB + SG TUBE RUPTURE + HOT LEG BREAK
ECCS INJECTION FLOW
COMBINED INTACT LOOP

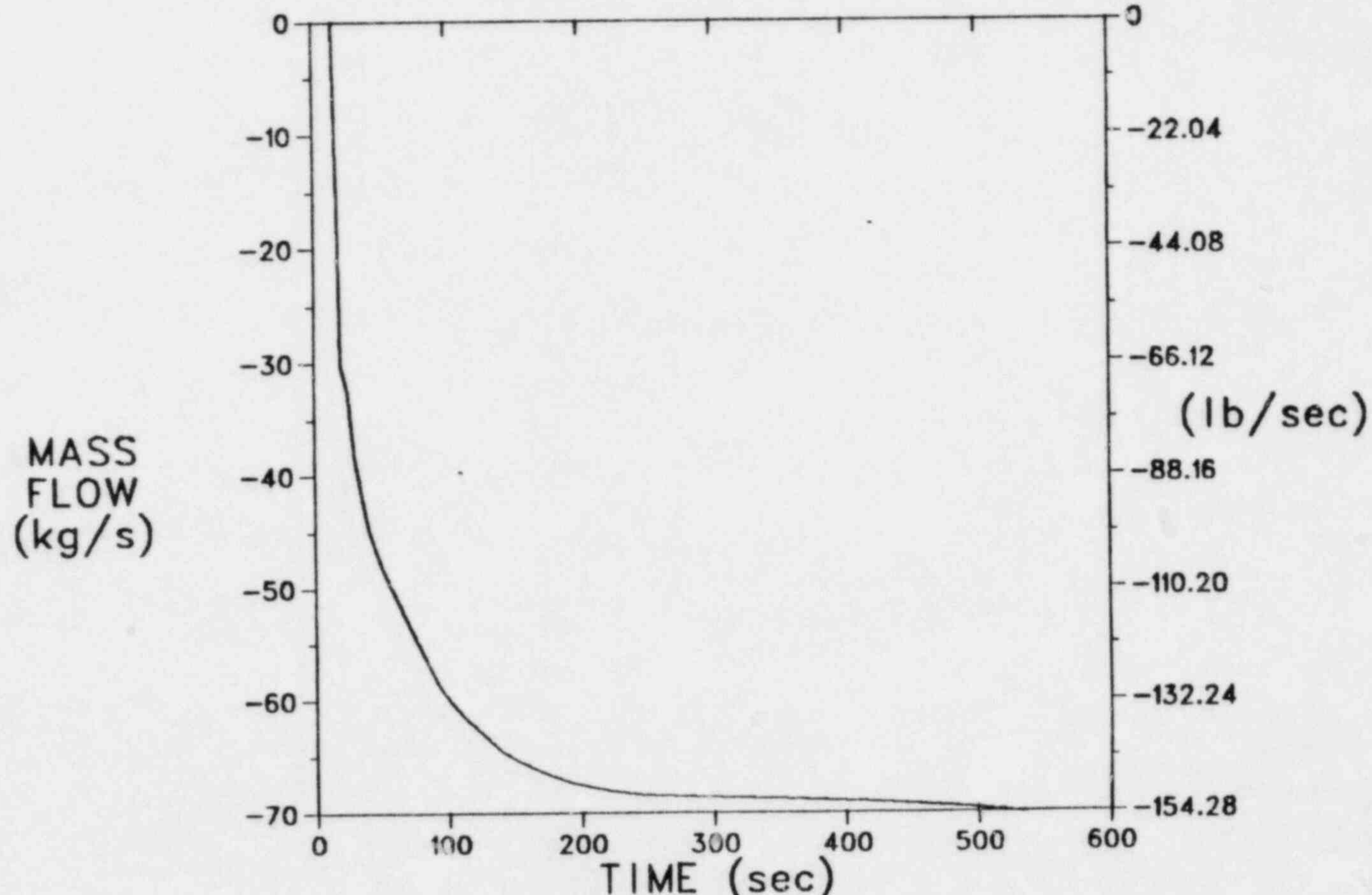
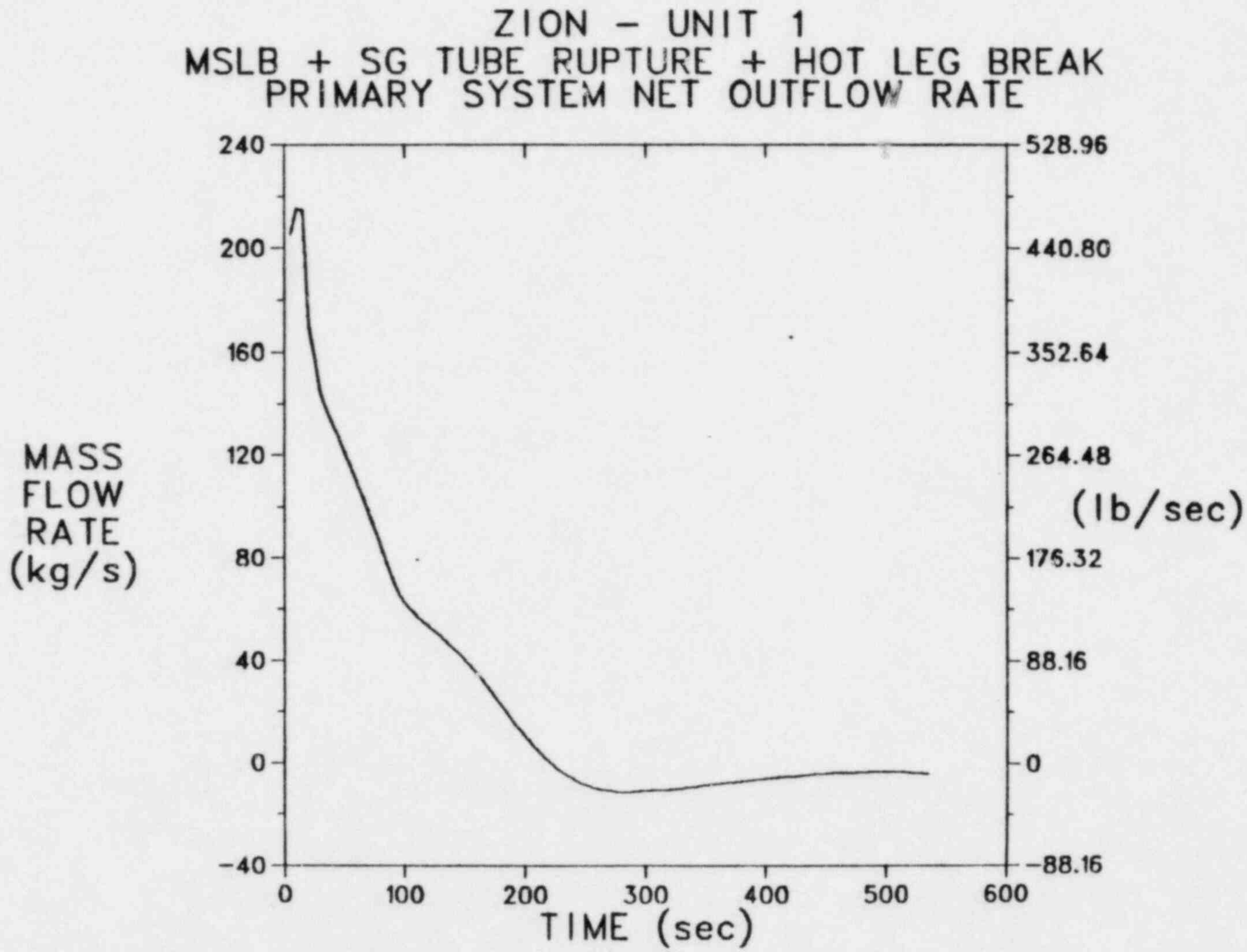
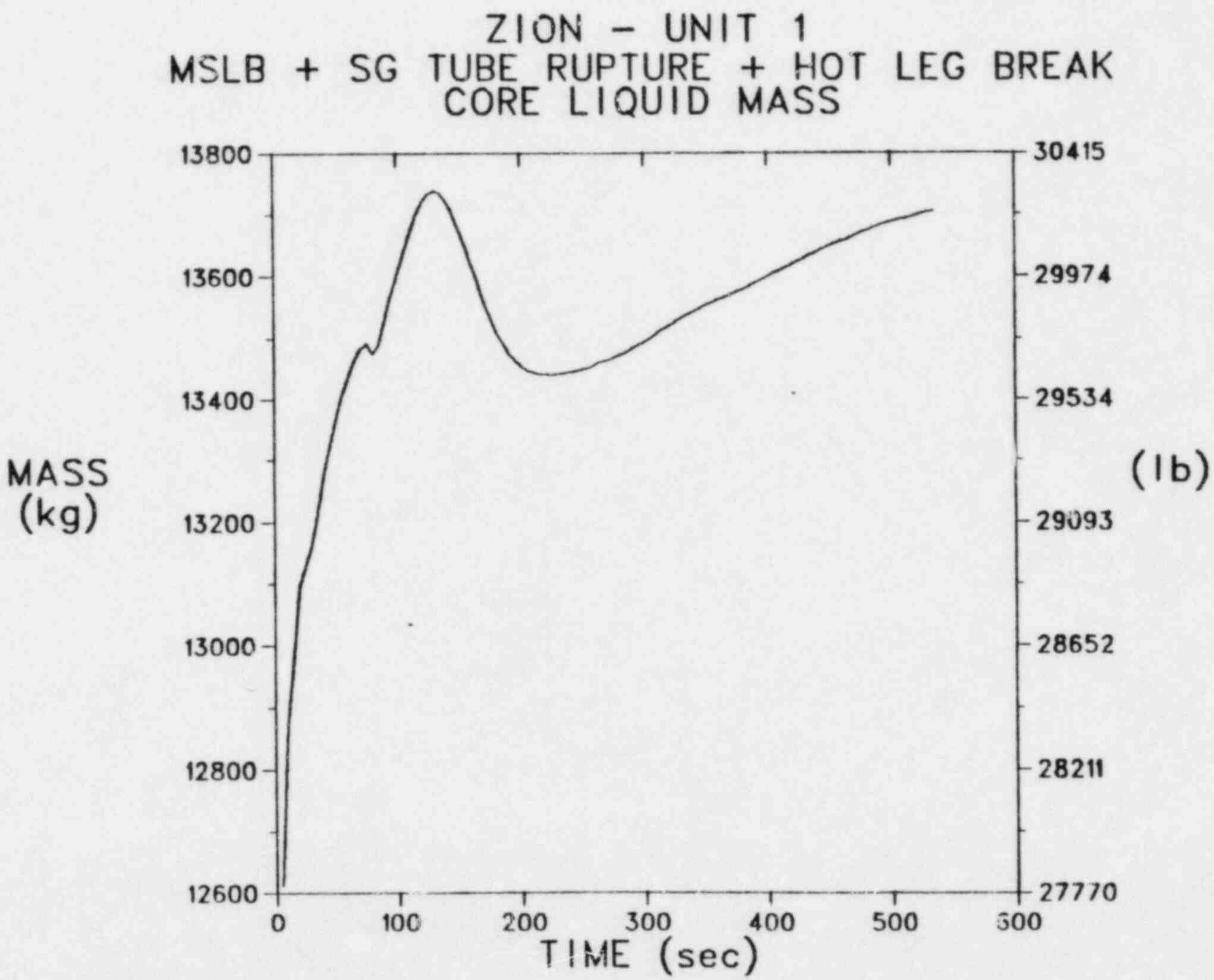


Fig. 12.



ZION - UNIT 1
MSLB + SG TUBE RUPTURE + HOT LEG BREAK
PRIMARY SYSTEM NET OUTFLOW RATE
MASS FLOW RATE (kg/s)
(lb/sec)
TIME (sec)
240
200
160
120
80
40
0
-40
528.96
440.80
352.64
264.48
176.32
88.16
0
-88.16
0
100
200
300
400
500
600

Fig. 13.


ZION - UNIT 1
MSLB + SG TUBE RUPTURE + HOT LEG BREAK
CORE LIQUID MASS
MASS (kg)
(lb)
13800
13600
13400
13200
13000
12800
12600
30415
29974
29534
29093
28652
28211
27770
0
100
200
300
400
500
600
TIME (sec)
Fig. 14.

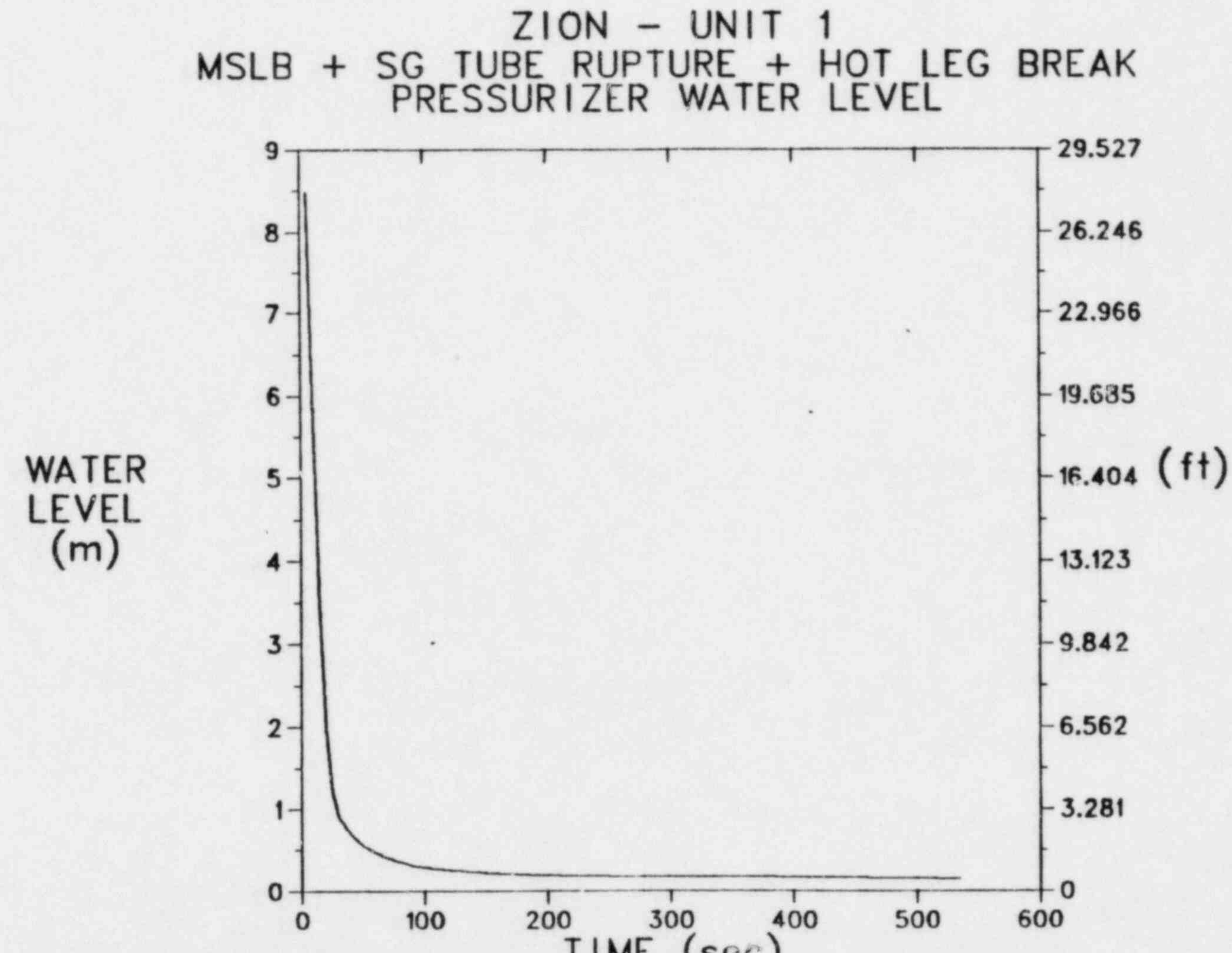

ZION - UNIT 1
MSLB + SG TUBE RUPTURE + HOT LEG BREAK
PRESSURIZER WATER LEVEL
WATER LEVEL (m)
(ft)
TIME (sec)
0
1
2
3
4
5
6
7
8
9
100
200
300
400
500
600
3.281
6.562
9.842
13.123
16.404
19.685
22.966
26.246
29.527

Fig. 15.

ZION - UNIT 1
MSLB + SG TUBE RUPTURE + HOT LEG BREAK
VESSEL UPPER HEAD VOID FRACTION

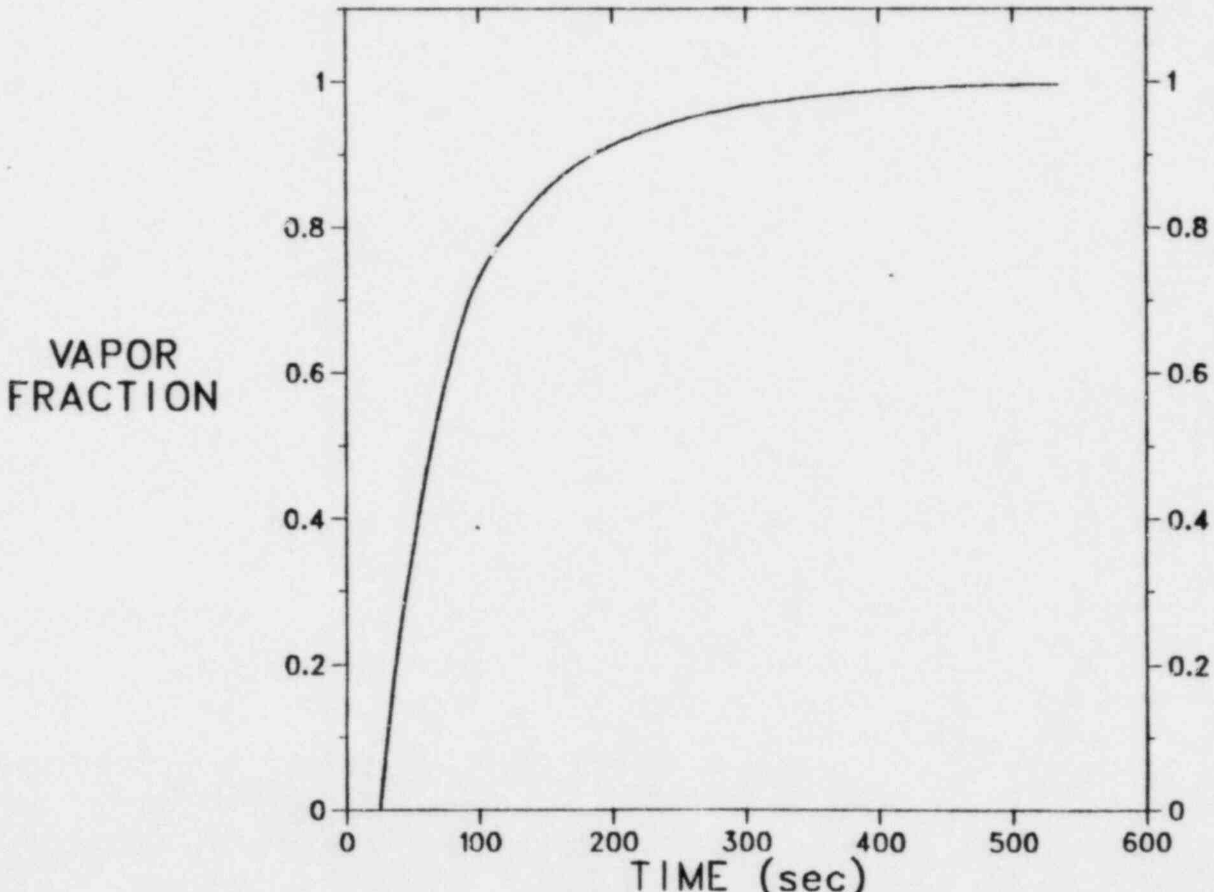


Fig. 16.

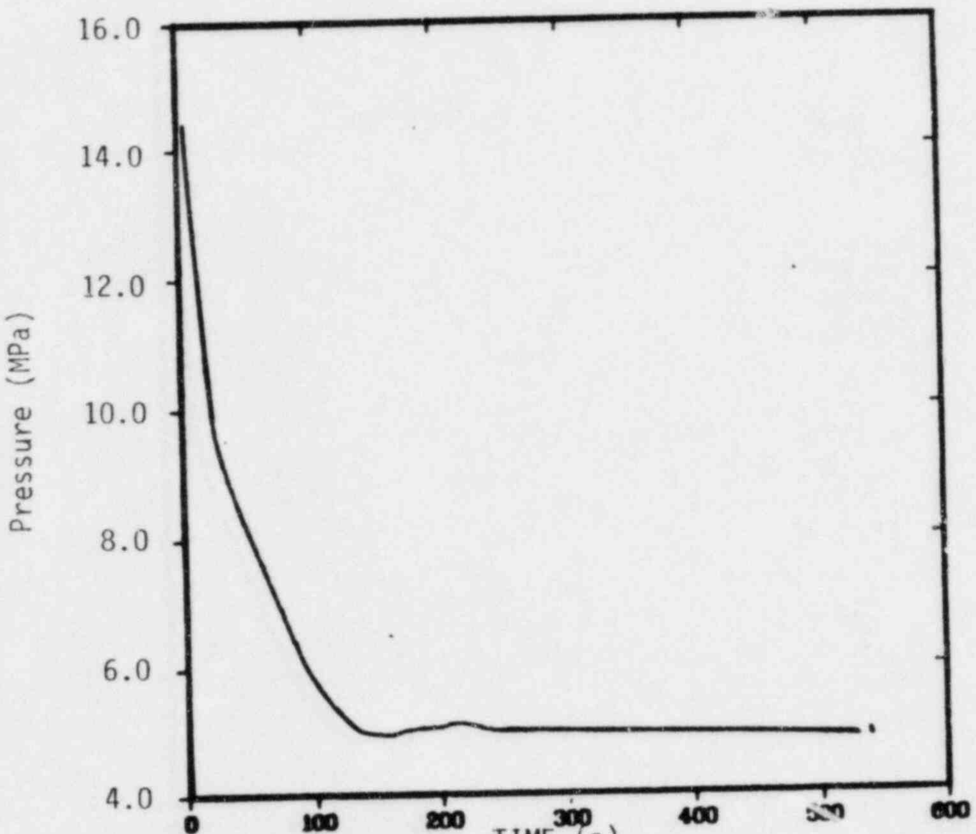


Fig. 17.
Zion - Unit 1
MSLB + SGTR + COLD Leg Break
Primary coolant system pressure.

ZION – UNIT 1

MSLB + SG TUBE RUPTURE + COLD LEG BREAK

Core average liquid temperature.

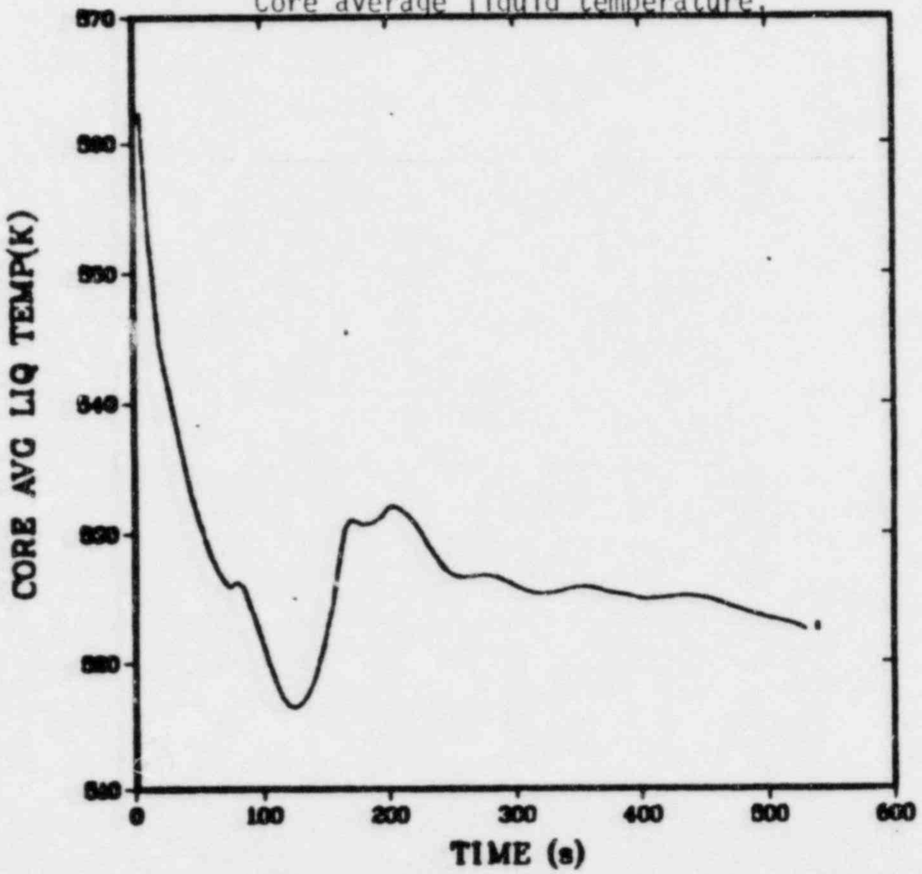


Fig. 18.

ZION - UNIT 1

MSLB + SG TUBE RUPTURE + COLD LEG BREAK

Core average saturation temperature.

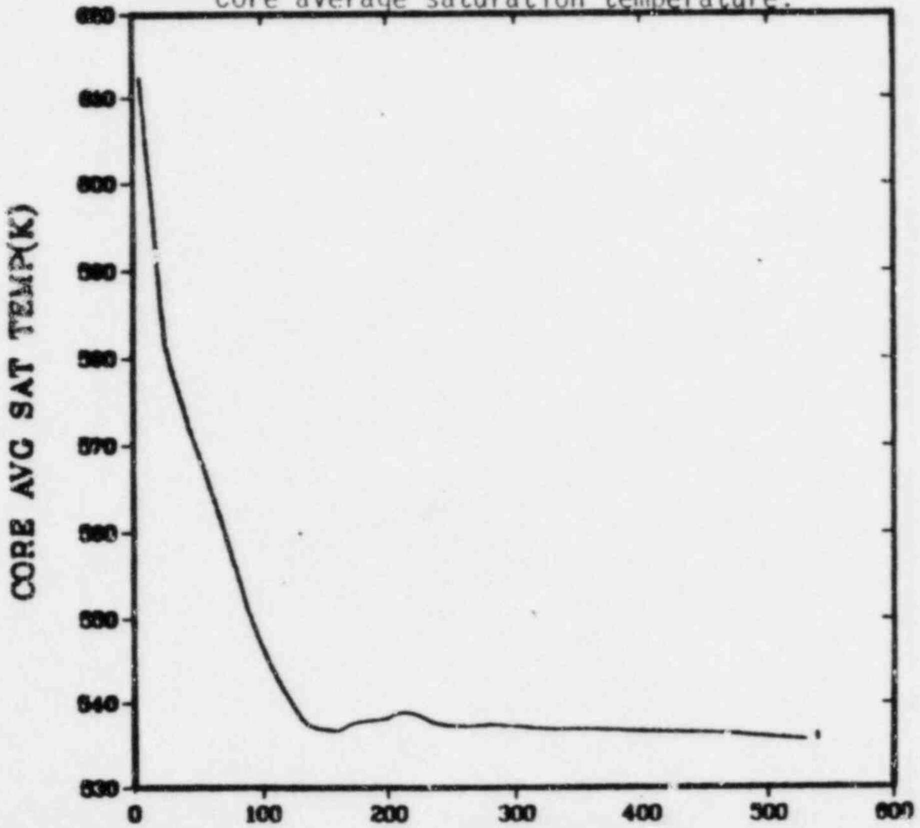


Fig. 19.

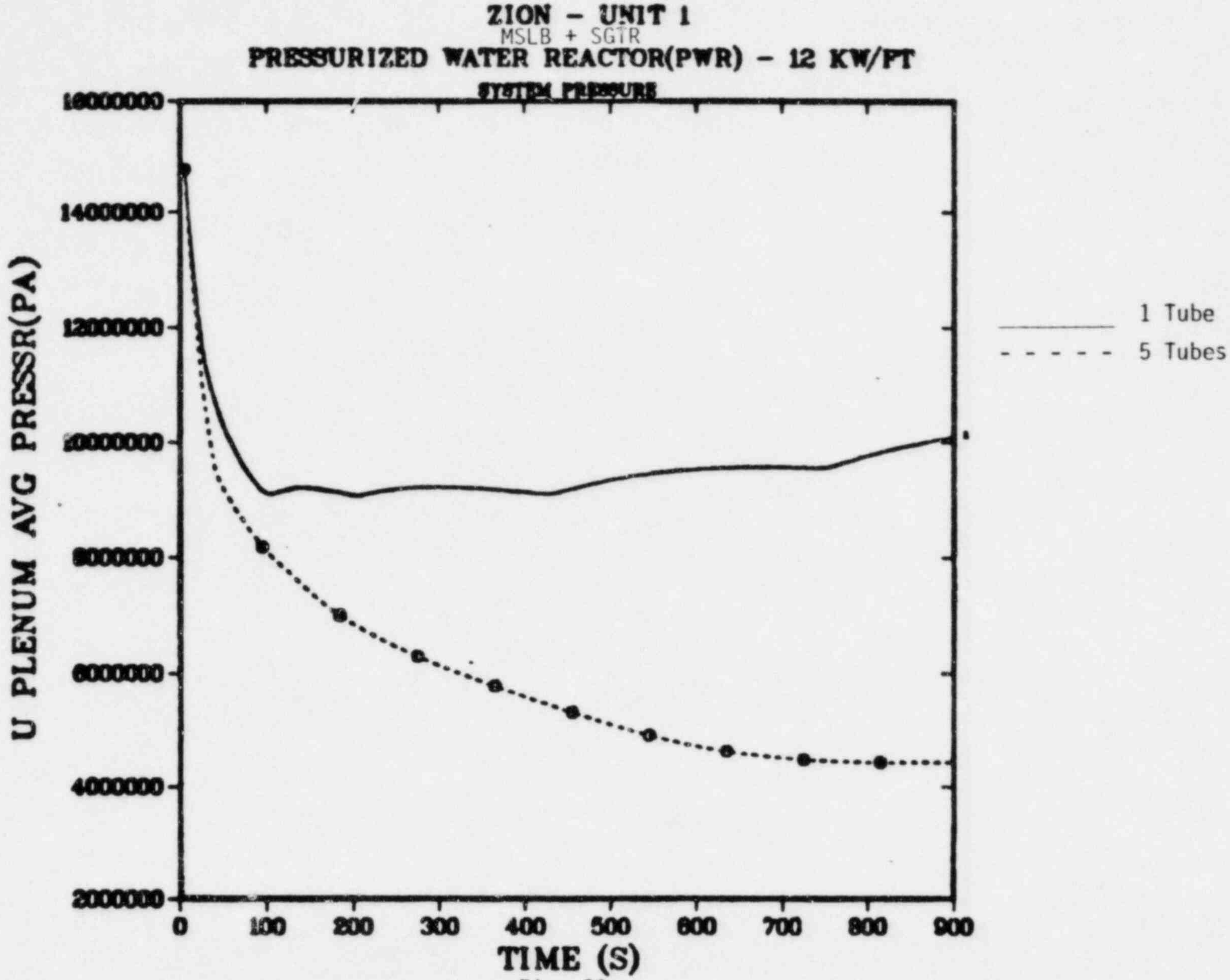
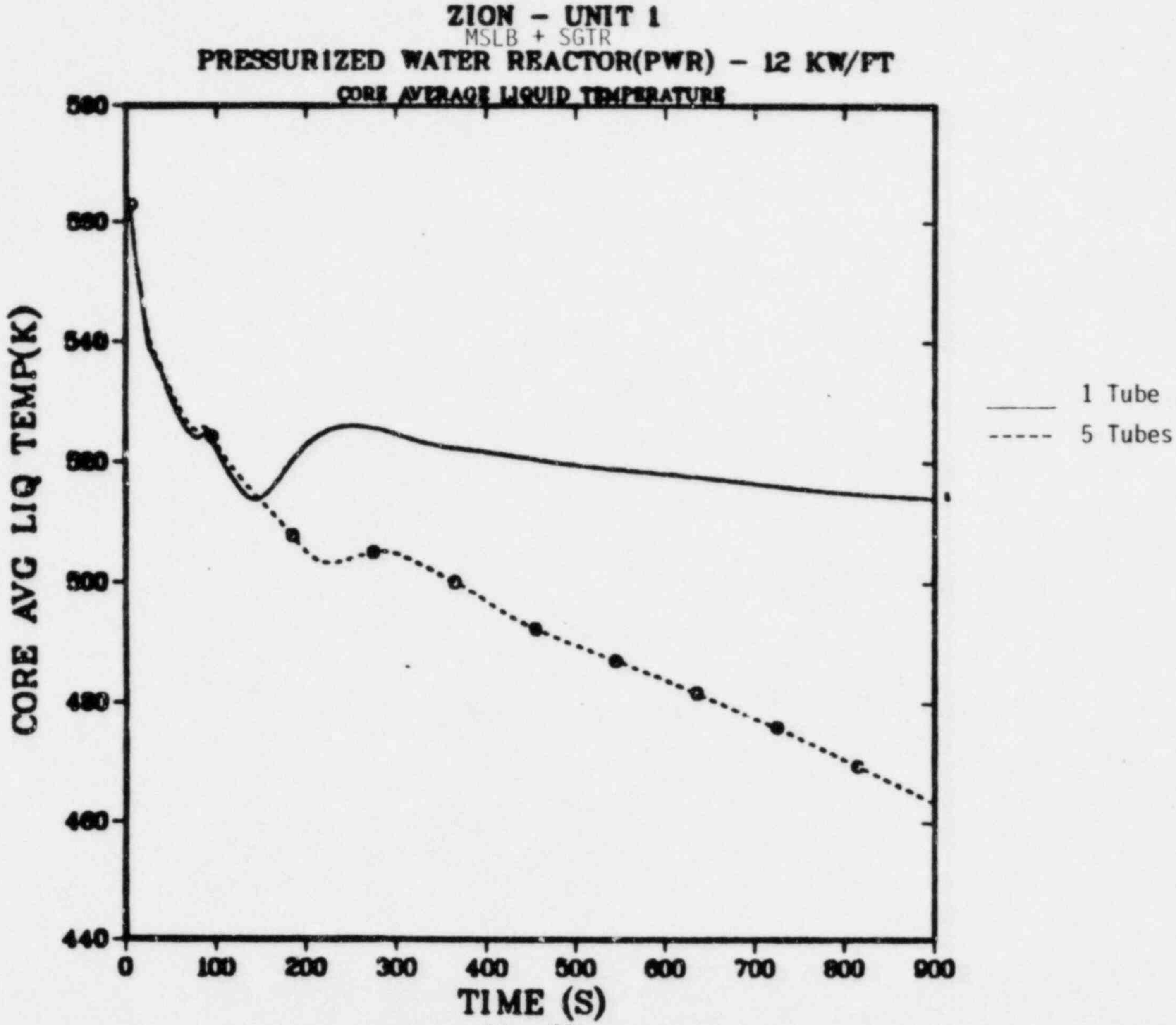

ZION - UNIT 1
MSLB + SGTR
PRESSURIZED WATER REACTOR(PWR) - 12 KW/FT
SYSTEM PRESSURE
U PLENUM AVG PRESSR(PA)
16000000
14000000
12000000
10000000
8000000
6000000
4000000
2000000
0
100
200
300
400
500
600
700
800
900
TIME (S)
1 Tube
5 Tubes

Fig. 20



ZION - UNIT 1
MSLB + SGTR
PRESSURIZED WATER REACTOR(PWR) - 12 KW/FT
CORE AVERAGE LIQUID TEMPERATURE
CORE AVG LIQ TEMP(K)
TIME (S)
1 Tube
5 Tubes

Fig. 21.

ZION - UNIT 1
MSLB + SGTR
PRESSURIZED WATER REACTOR(PWR) - 12 KW/FT

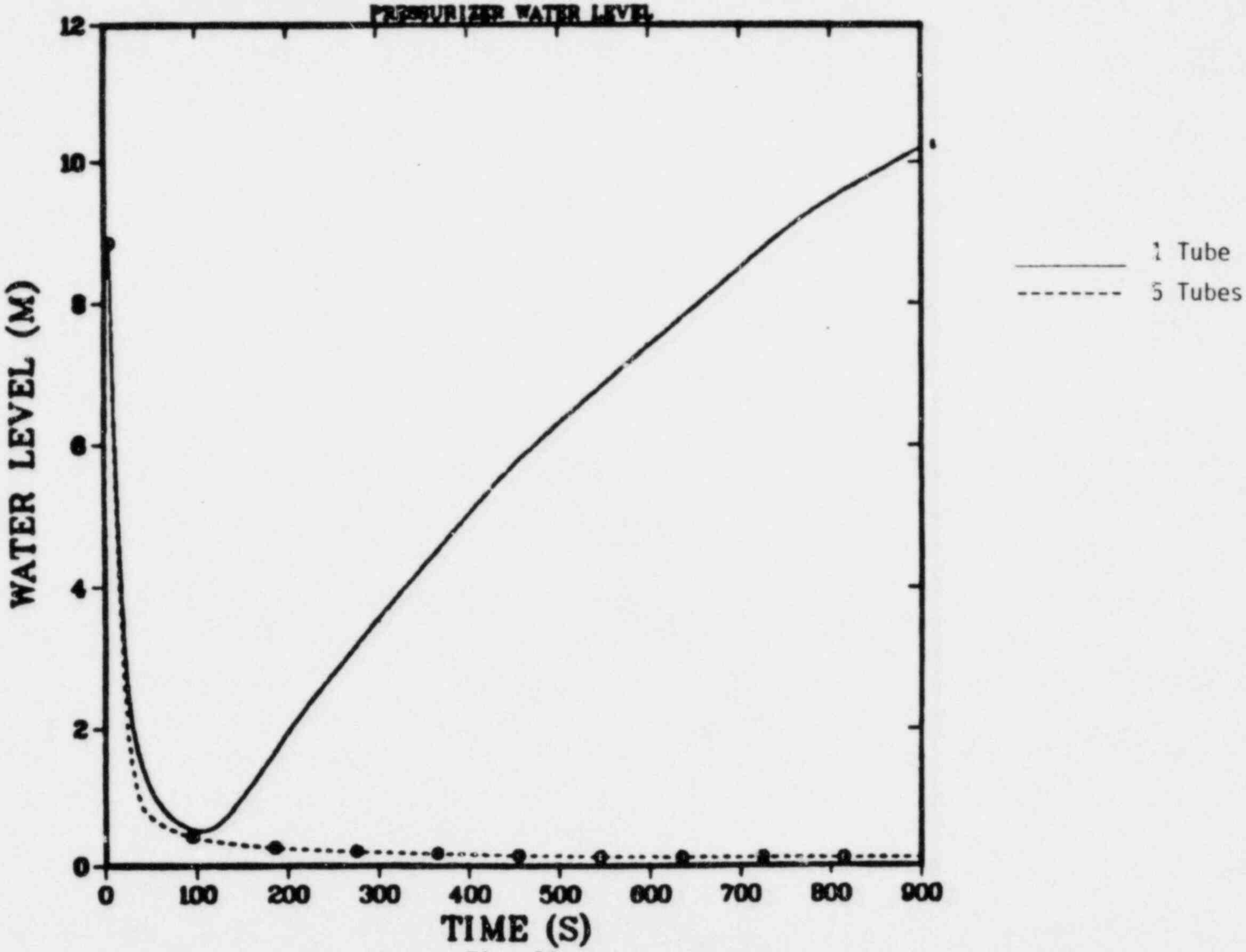


Fig. 22.