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UPDATED NUREG-0619 FEEDWATER NOZZLE FATIGUE CRACK GROWTH ANALYSIS

ENRICO FERMI NUCLEAR POWER PLANT, UNIT 2

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ABSTRACT

This report provides a plant specific fracture mechanics assessment of the Fermi 2 feedwater nozzle. The results presented herein are an update to those documented in report KH1-0619-001 (Reference 1) based on actual plant data collected during 1990-1991. The intent of this report is to show compliance with NRC requirements regarding feedwater nozzle crack growth, as specified in NUREG-0619 (Reference 2) and amended by NRC Generic Letter 81-11 (Reference 3). The evaluation considered the effects of reactor water cleanup (RWCU) system mixing with one feedwater loop. The results show that the growth of an assumed initial 0.25-inch crack would propagate to an allowable depth of one inch in 38.3 years based on the 1989 ASME Code, Section XI fatigue crack growth relationships. This analysis includes conservatism inherent to strip chart data evaluation and conservative thermal cycle projections based on the early years of plant operation. It is expected that updated projections done after several more years of operation will compensate for "learning curve" effects, and provide results which demonstrate full compliance with the requirements of NUREG-0619 (e.g., final crack depth of less than one inch after the 40 year design life of the plant).

1.0 INTRODUCTION

The Reference 1 report provided a plant specific feedwater nozzle fracture mechanics assessment for Enrico Fermi Nuclear Power Plant, Unit 2 (hereafter called Fermi 2) based on the existing low flow feedwater controller in conjunction with anticipated plant operating history. That assessment was generated in response to Nuclear Regulatory Commission (NRC) requirements regarding feedwater nozzle crack growth. These requirements are contained in NUREG-0619 (Reference 2), as amended by NRC Generic Letter 81-11 (Reference 3), which states that a fracture mechanics evaluation must predict an end-of-design life crack size of one inch or less. The results of the Reference 1 report demonstrated that the growth of an assumed, initial 0.25-inch crack would propagate to greater than one inch 8.9 years after the initial plant startup using ASME Code, Section XI methods.

The purpose of this analysis is to document an updated crack growth analysis using actual plant duty in place of the previously assumed, conservative thermal duty and controller characteristics. As recommended in Reference 1, actual plant duty was obtained from available plant records in an effort to provide a more realistic definition of the Fermi 2 cycling and controller characteristics. The cycling characteristics and temperature magnitudes used for the current analysis were obtained from strip chart recorder records for eleven (11) startup, shutdown and SCRAM events which occurred during the 1990-1991 time frame. Actual cycle counts were extracted from 1986-1990 annual operating reports and used to project the thermal duty out to 40 years. This information was used together with the previously determined thermal and pressure stress profiles to again assess the postulated growth of an assumed 0.25-inch crack as specified in NUREG-0619.

2.0 THERMAL CYCLE DEFINITION

The crack growth predictions made in Reference 1 were based on *assumed* thermal cycling as derived from the actual low flow controller system design at Fermi 2, since the plant had been in operation for only a short period of time and actual thermal cycling histories were not yet available. The projected thermal cycling histories used in Reference 1 were not intended to be a substitute for actual operating plant data, but rather as a basis for conducting a preliminary analysis of crack growth.

Feedwater nozzle thermal duty can occur as a result of some 50 different normal and upset events defined for the feedwater system. As explained in Reference 1, a review of these events revealed that they could be condensed down to three basic types which conservatively envelope them from the standpoint of feedwater nozzle low cycle fatigue duty. The enveloping events are:

(1) Startup/shutdown cycles.
(2) SCRAMs to low pressure hot standby followed by a return to full power.
(3) SCRAMs to high pressure hot standby followed by a return to full power.

In the Reference 1 analysis, definitions for these three events were assumed consistent with those found on the Fermi 2 Thermal Cycle Diagram (Reference 4).

For the current analysis, thermal cycle definitions based on operating data from eleven startup, shutdown and SCRAM events which occurred during 1990-1991 were used. These definitions were based on a review of plant recorder strip charts providing feedwater and reactor water cleanup (RWCU) system temperatures and flow rates. Representative definitions of these startup, shutdown and SCRAM events were developed which consisted of a series of temperature differentials and a corresponding number of occurrences for each of these differentials. As in Reference 1, since the thermal cycle definition with the RWCU injection is conservative when compared to the definition with the non-RWCU injection, definitions were only developed for the one feedwater loop which has RWCU injection.

Strip chart data for three SCRAM events and eight startup/shutdown events were made available (Reference 5) for the current crack growth assessment. These eleven (11) events were summarized by the following ten traces:

Trace No.	Event Date	Event Description
1	April 10-15, 1990	SCRAM, Shutdown and Startup
2	Sep. 29 - Oct. 9, 1990	Shutdown and Startup
3	Nov. 25, 1990	Shutdown
4	Jan. 1, 1991	Startup
5	March 12, 1991	SCRAM, Shutdown and Startup
6	March 30, 1991	Shutdown
7	June 10, 1991	Startup
8	June 15-16, 1991	Shutdown to 500 psi and Startup
9	June 17-19, 1991	Shutdown from 10% and Startup
10	June 27-29, 1991	SCRAM, Shutdown and Startup

Data for another event (June 30 - July 6, 1990 Shutdown and Startup) were also provided, but were discarded from consideration because of erroneous strip chart pen behavior.

The following plant flow and temperature signals were provided on the strip charts for each event:

Signal ID	Signal Description	Scaling
F084	Reactor Feed Pump Startup Bypass Flow	-0.5 - 1.5 Mlb/hr
F083	Reactor Feed Pump Suction Temperature	50.0 - 550.0 °F
B048	RWCU Water Outlet Temperature	50.0 - 435.0 °F[1]
B024	RWCU Water Inlet Flow	0.0 - 0.198 Mlb/hr

(1) The initial data transmittal (Reference 5) which showed the RWCU strip chart temperature range of 50 - 550°F was subsequently corrected by the Reference 17 transmittal to be 50 - 435°F.

These temperature and flow signals were digitized into computer form for subsequent reduction and use in the crack growth analysis. This was accomplished by picking off X, Y coordinates for all points during each given transient where a significant fluctuation was encountered. A significant fluctuation was defined as any fluctuation where the measured parameters changed by more than approximately 2-3% of full (100%) scale on the strip charts. Fluctuations below this level were assumed to be attributed to instrument noise, and their effect on the final crack growth estimates were considered to be insignificant. The results of this digitization are shown in graphical form in Appendix A for all signals and all events. For those events which had flow rates less than zero, a minimum value of zero was used in the crack growth evaluation to eliminate non-conservatism (e.g., negative flows which would tend to cancel out other flows involved in the mixing calculations were eliminated).

For the crack growth assessment, the temperature of the fluid flowing through the feedwater nozzle is needed. Since the plant signals provided are measured at locations away from the feedwater nozzles and before mixing of the RWCU and feedwater systems takes place, mixing calculations were performed to determine the required fluid temperatures. These calculations were based on an energy balance of the affected flows, as follows:

$$\text{Input Enthalpy} = \text{Output Enthalpy}$$

$$\dot{m}_{RWCU}\, h_{RWCU} + \dot{m}_{FW}\, h_{FW} = \dot{m}_{MIX}\, h_{MIX}$$

$$\dot{m}_{RWCU}\, c\, T_{RWCU} + \dot{m}_{FW}\, c\, T_{FW} = \dot{m}_{MIX}\, c\, T_{MIX}$$

$$\dot{m}_{RWCU}\, T_{RWCU} + \dot{m}_{FW}\, T_{FW} = \dot{m}_{MIX}\, T_{MIX}$$

or: $$T_{MIX} = (\dot{m}_{RWCU}\, T_{RWCU} + \dot{m}_{FW}\, T_{FW})/\dot{m}_{MIX}$$

where:
$\dot{m}_{RWCU}$ = RWCU flow rate.
h_{RWCU} = RWCU enthalpy.
$\dot{m}_{FW}$ = Feedwater flow rate for one loop = $\dot{m}_{strip\ chart}/2$.
h_{FW} = Feedwater enthalpy.
$\dot{m}_{MIX}$ = Mixed (nozzle) flow rate = $\dot{m}_{RWCU} + \dot{m}_{FW}$.
h_{MIX} = Mixed (nozzle) fluid enthalpy.
c = Specific heat of water (assumed constant).
T_{RWCU} = RWCU temperature.
T_{FW} = Feedwater temperature.
T_{MIX} = Mixed (nozzle) fluid temperature.

The assumption of the specific heat of water remaining constant with temperature introduces insignificant errors since the variation of this property with temperature is small.

The final, mixed (nozzle) temperature variations for the ten traces (or 11 events) identified above are shown in Figures 2-1 through 2-10. The data shown in these figures were reduced into a series of temperature differentials grouped according to severity in 25°F increments. The temperature differentials consisted of starting at some temperature, T_1, and proceeding to a final temperature, T_2, where a change in direction of temperature occurred. The starting temperature, T_1, was chosen based on the lowest temperature observed for each 25°F grouping to ensure bounding results. A full cycle is defined in the crack growth analysis as initially starting at some value T_i, changing to some other value T_f, and then returning to T_i. Therefore, the result of this data reduction was a series of half-cycles of different magnitudes. The results of this data reduction are given for the ten traces identified above in Tables 2-1 through 2-10.

Since pressure data was not provided, the temperature cycling described in Tables 2-1 through 2-10 was assumed to occur at a constant reactor pressure of 1,050 psi. Pressure cycling between 0 psi and 1,050 psi was included as appropriate for each event as noted in Table 2-1 through 2-10. Although conservative, this treatment of pressure cycling does not cause significant over-predictions of crack growth.

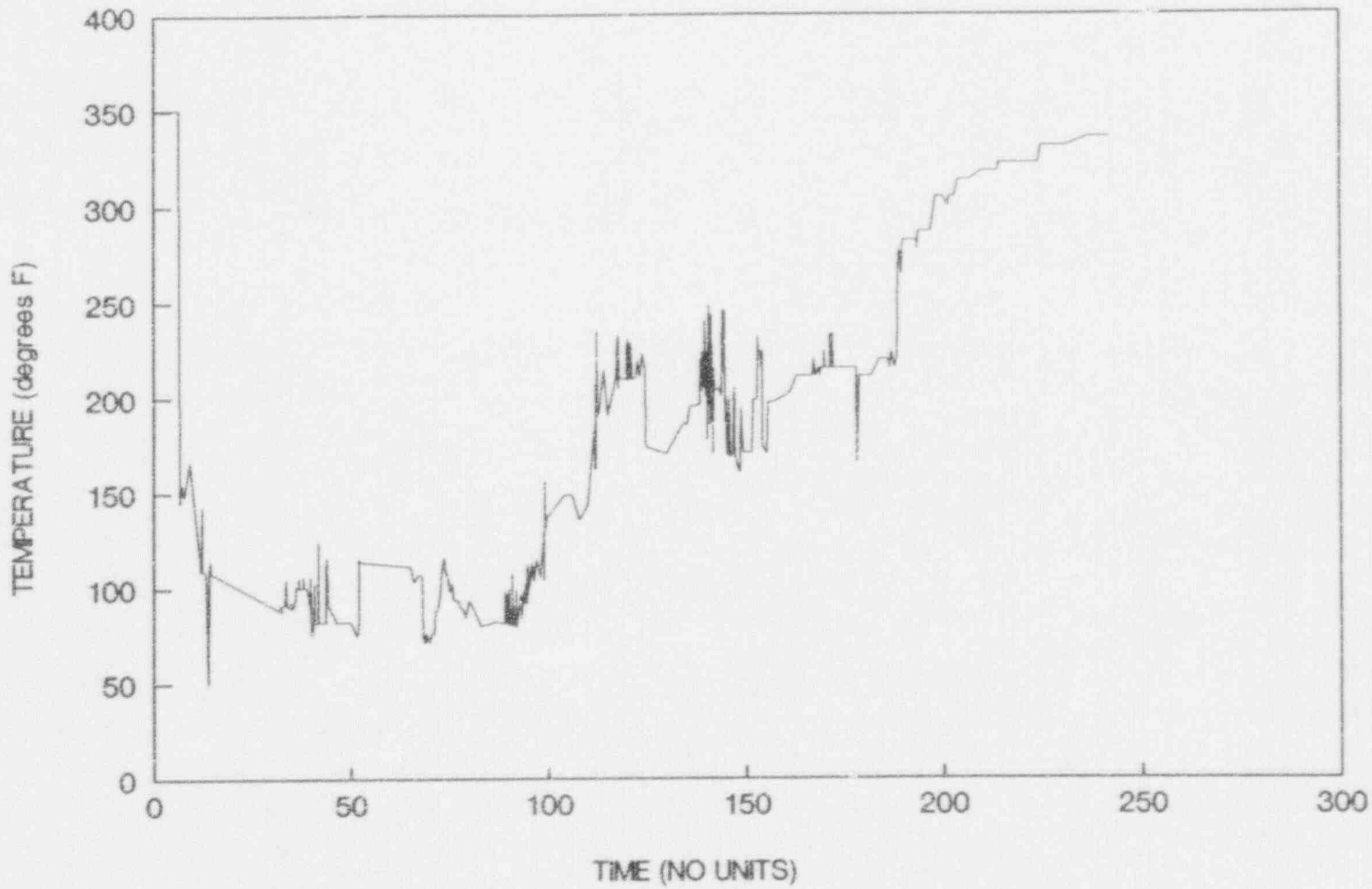


Figure 2-1: Mixed (Nozzle) Fluid Temperature for the April 10-15, 1990 SCRAM, Shutdown and Startup Event

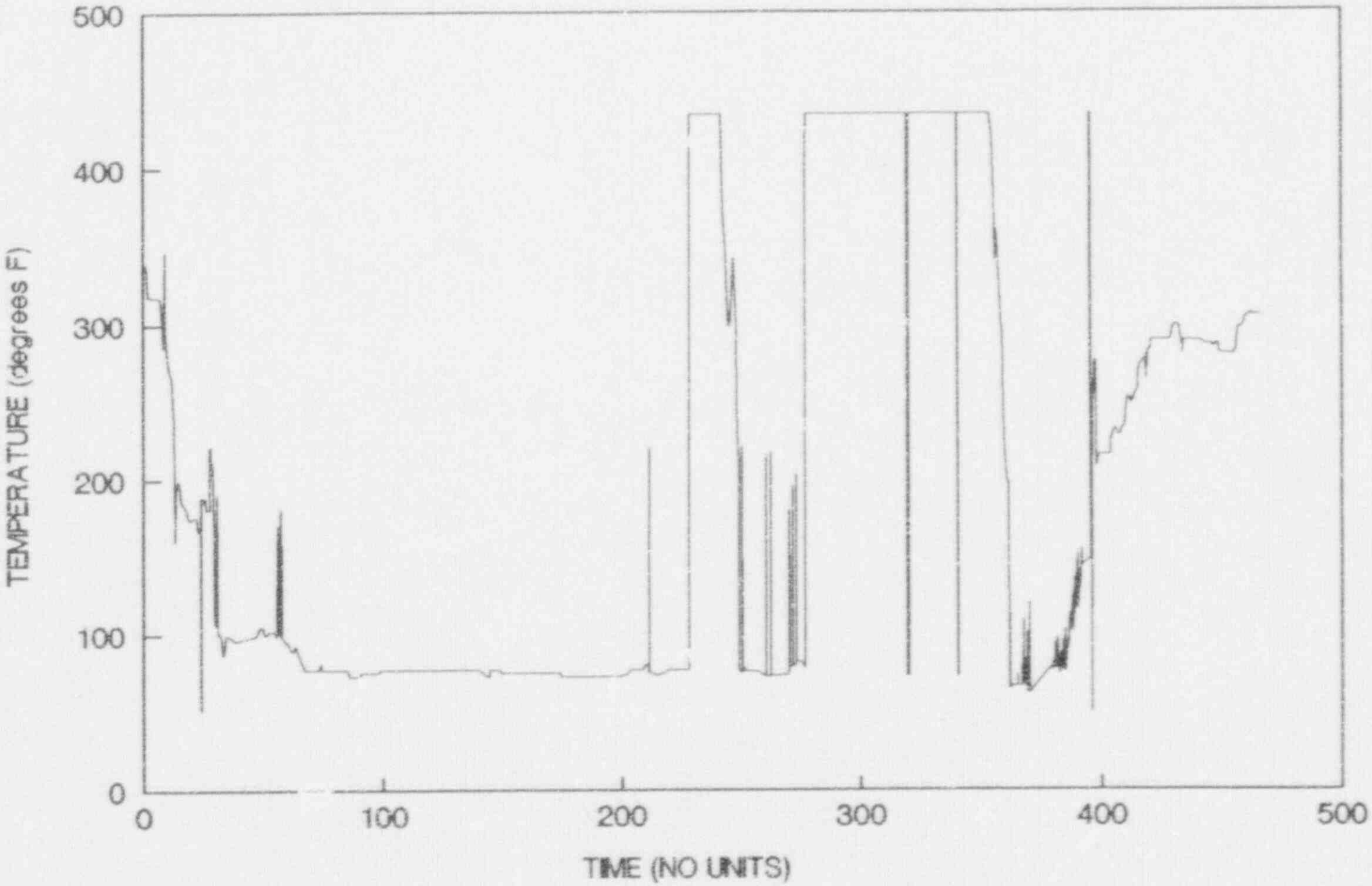


Figure 2-2: Mixed (Nozzle) Fluid Temperature for the
September 29 - October 9, 1990 Shutdown and Startup Event

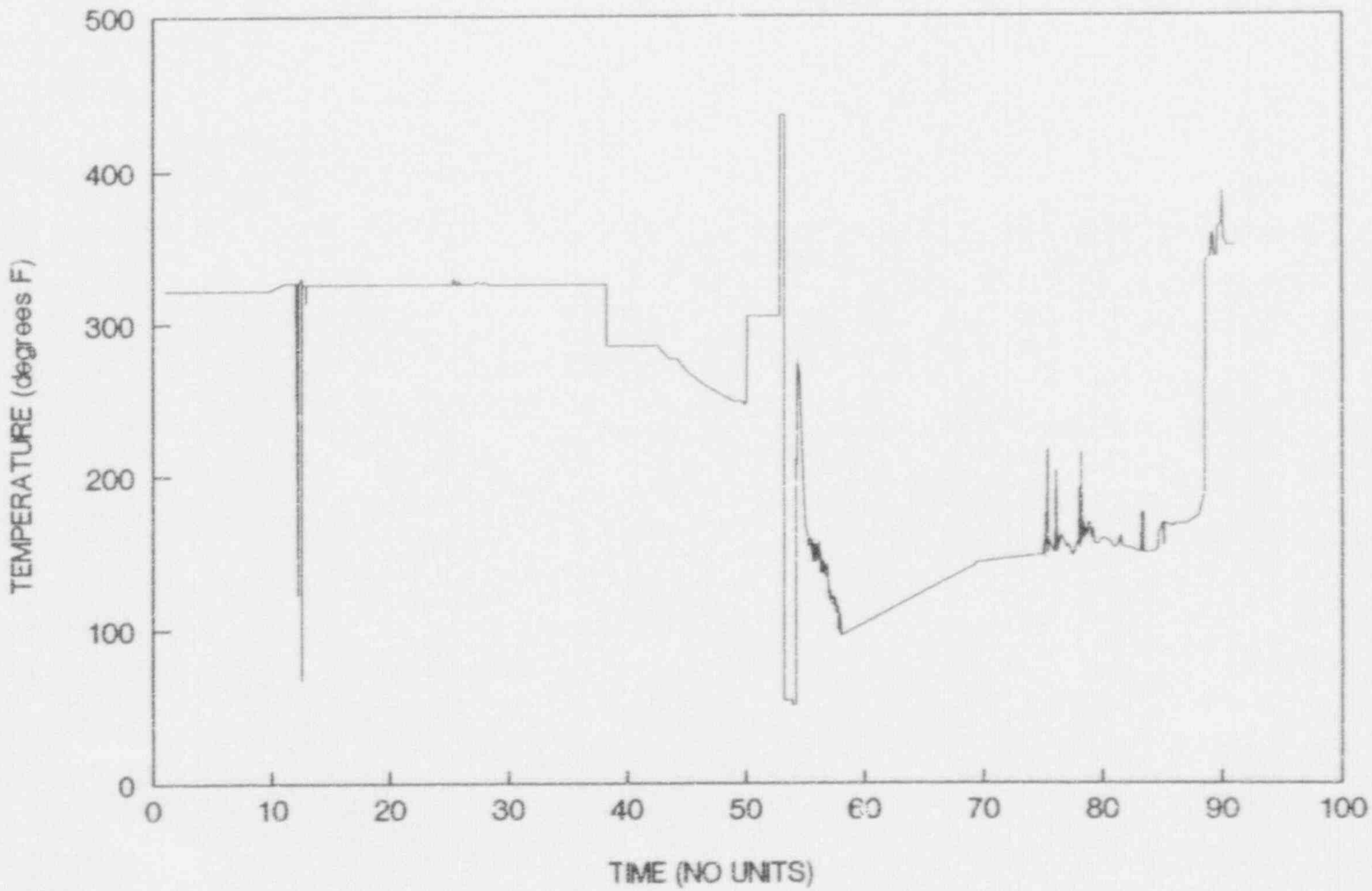


Figure 2-3: Mixed (Nozzle) Fluid Temperature for the November 25, 1990 Shutdown Event

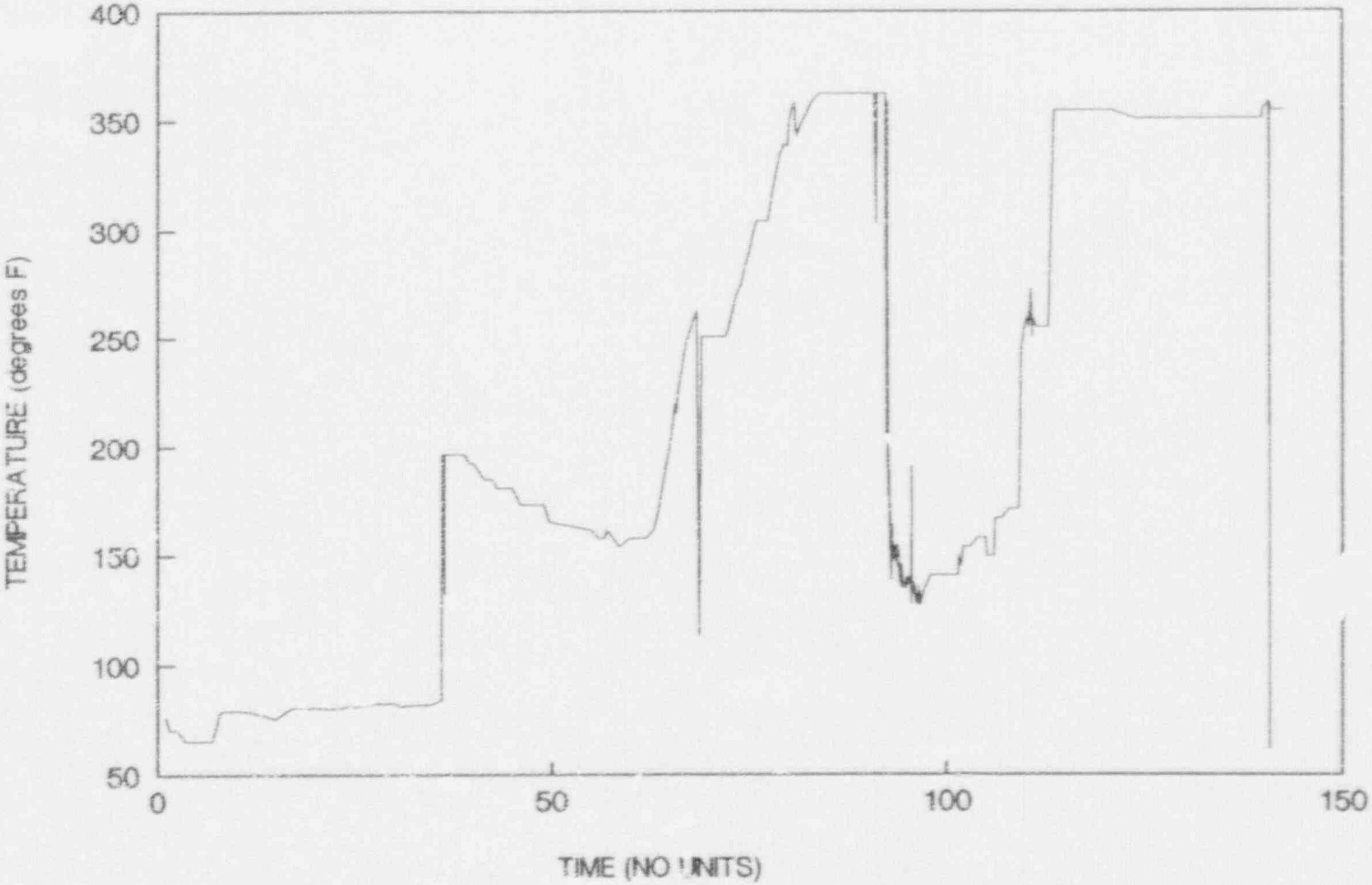


Figure 2-4: Mixed (Nozzle) Fluid Temperature for the January 1, 1991 Startup Event

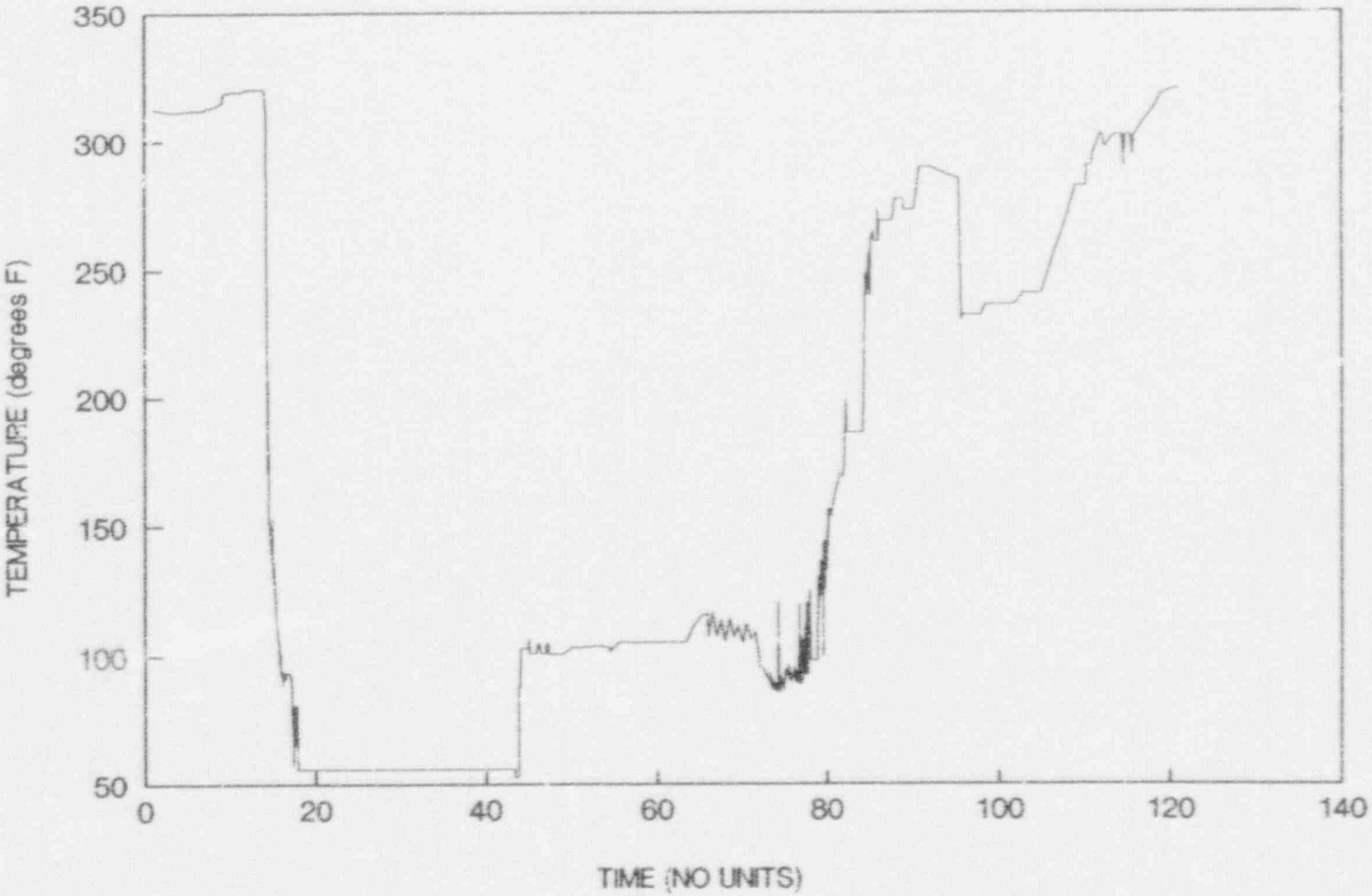


Figure 2-5: Mixed (Nozzle) Fluid Temperature for the March 12, 1991 SCRAM, Shutdown and Startup Event

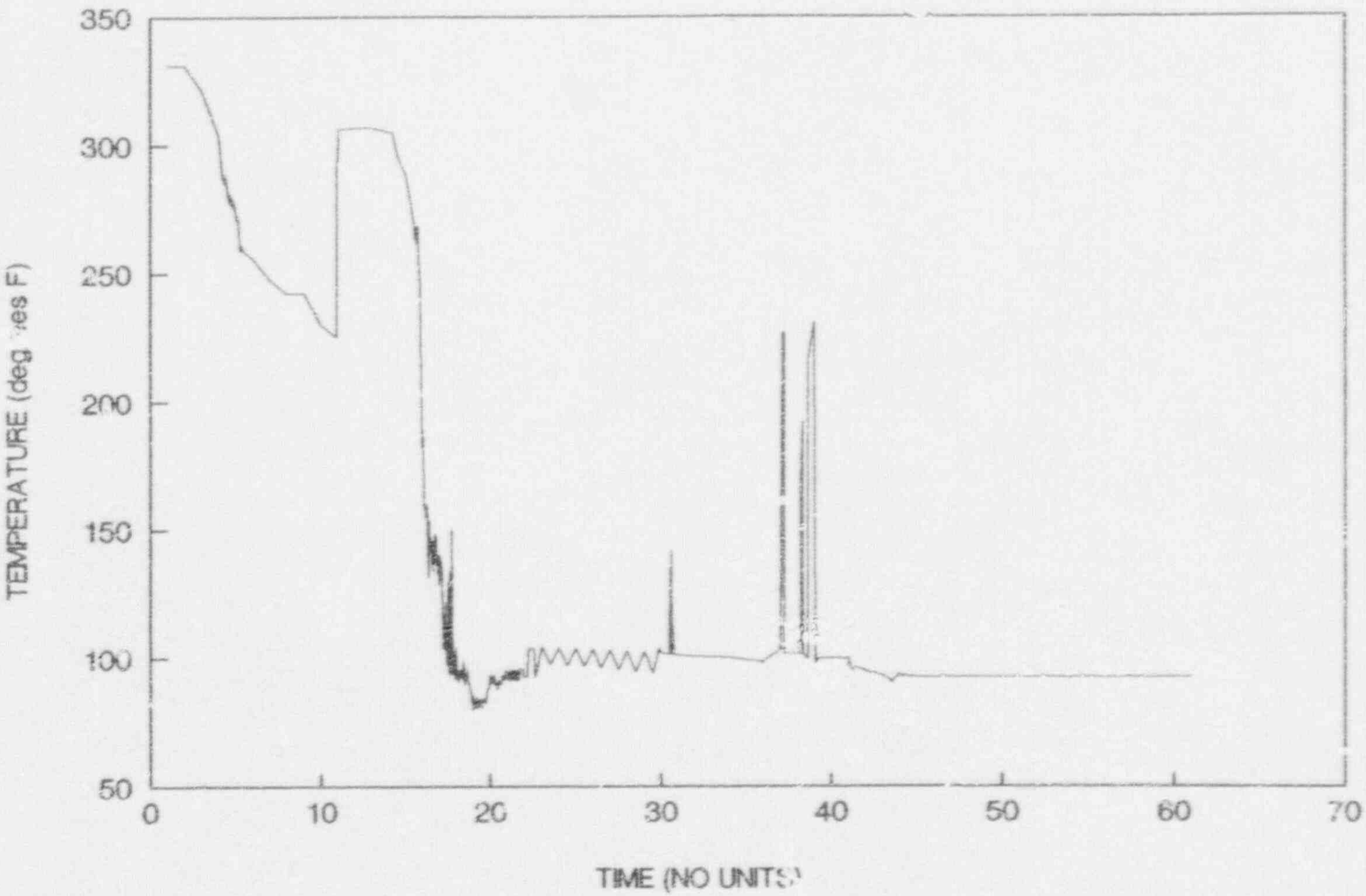


Figure 2-6: Mixed (Nozzle) Fluid Temperature for the March 30, 1991 Shutdown Event

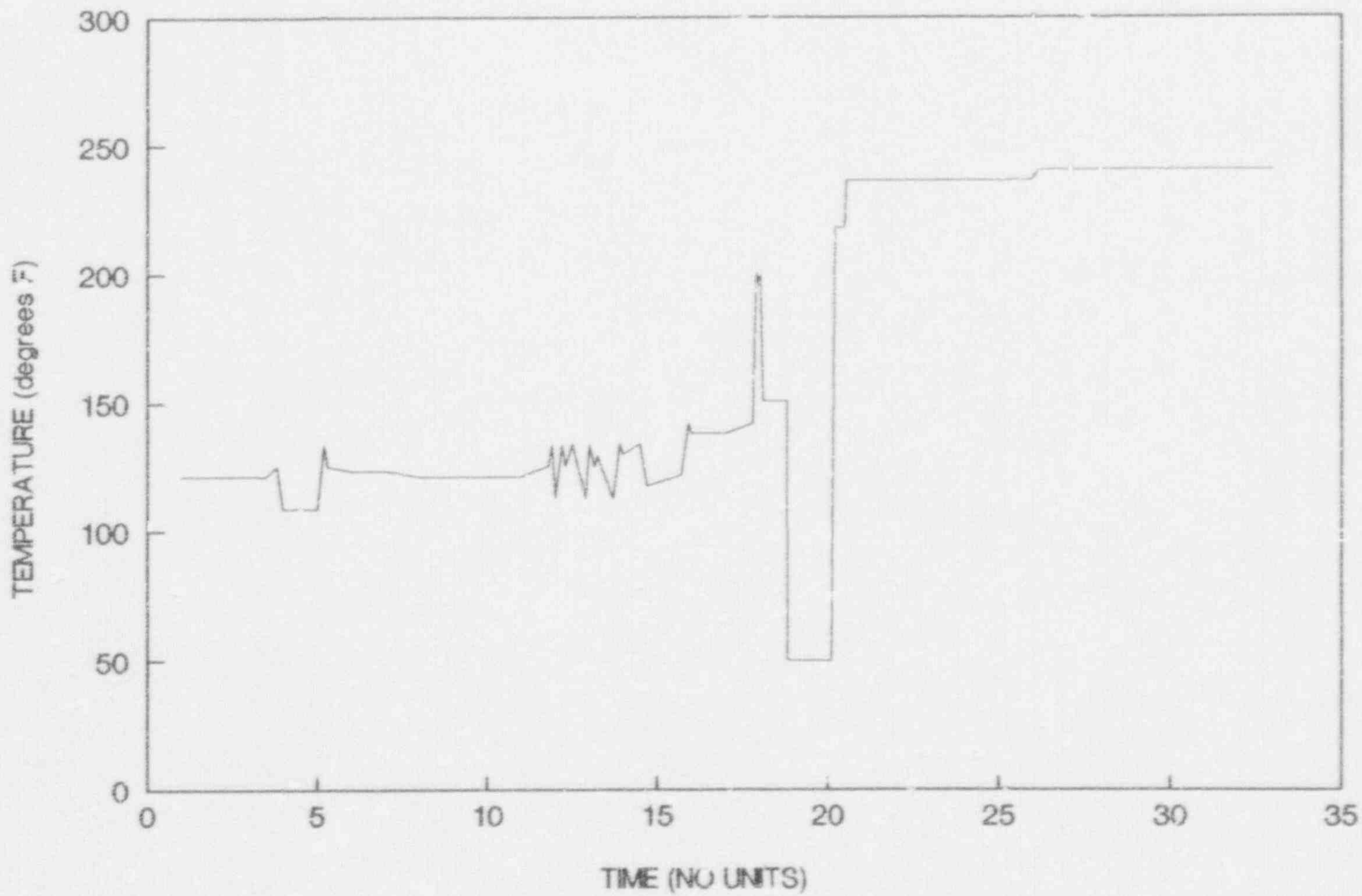


Figure 2-7: Mixed (Nozzle) Fluid Temperature for the June 10, 1991 Startup Event

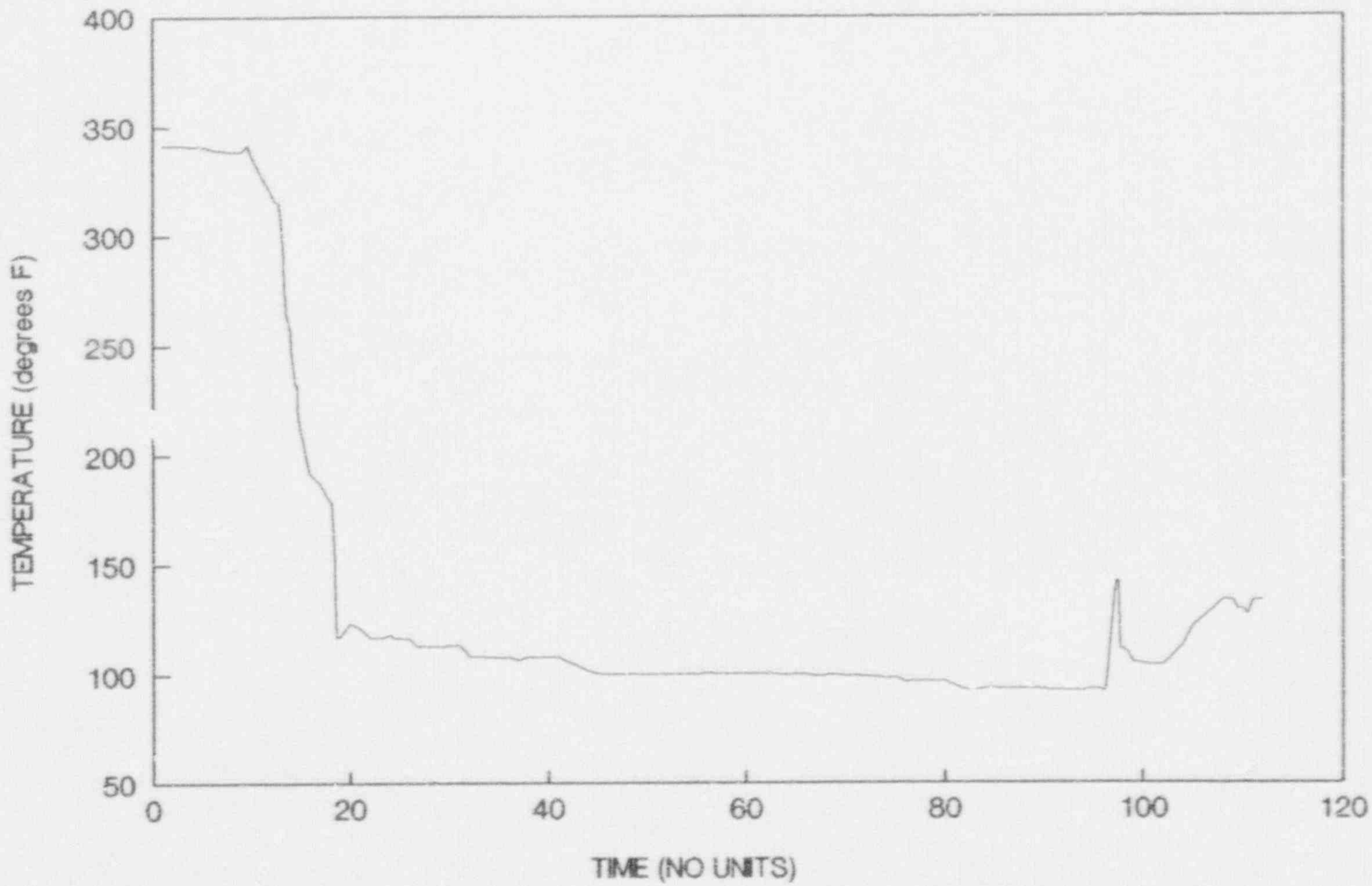


Figure 2-8: Mixed (Nozzle) Fluid Temperature for the June 15-16, 1991 Shutdown to 500 psi and Startup Event

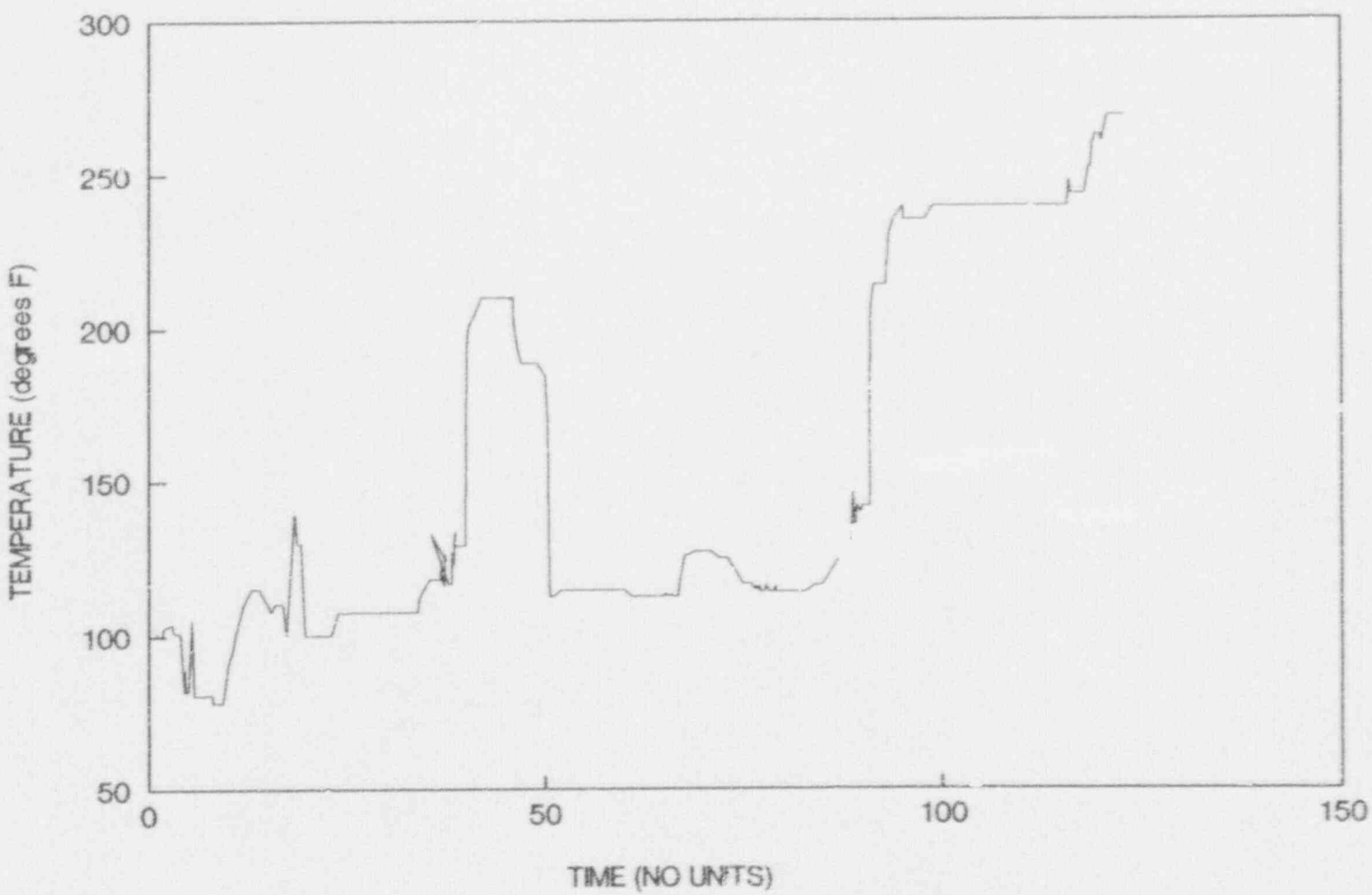


Figure 2-9: Mixed (Nozzle) Fluid Temperature for the
June 17-19, 1991 Shutdown from 10% and Startup Event

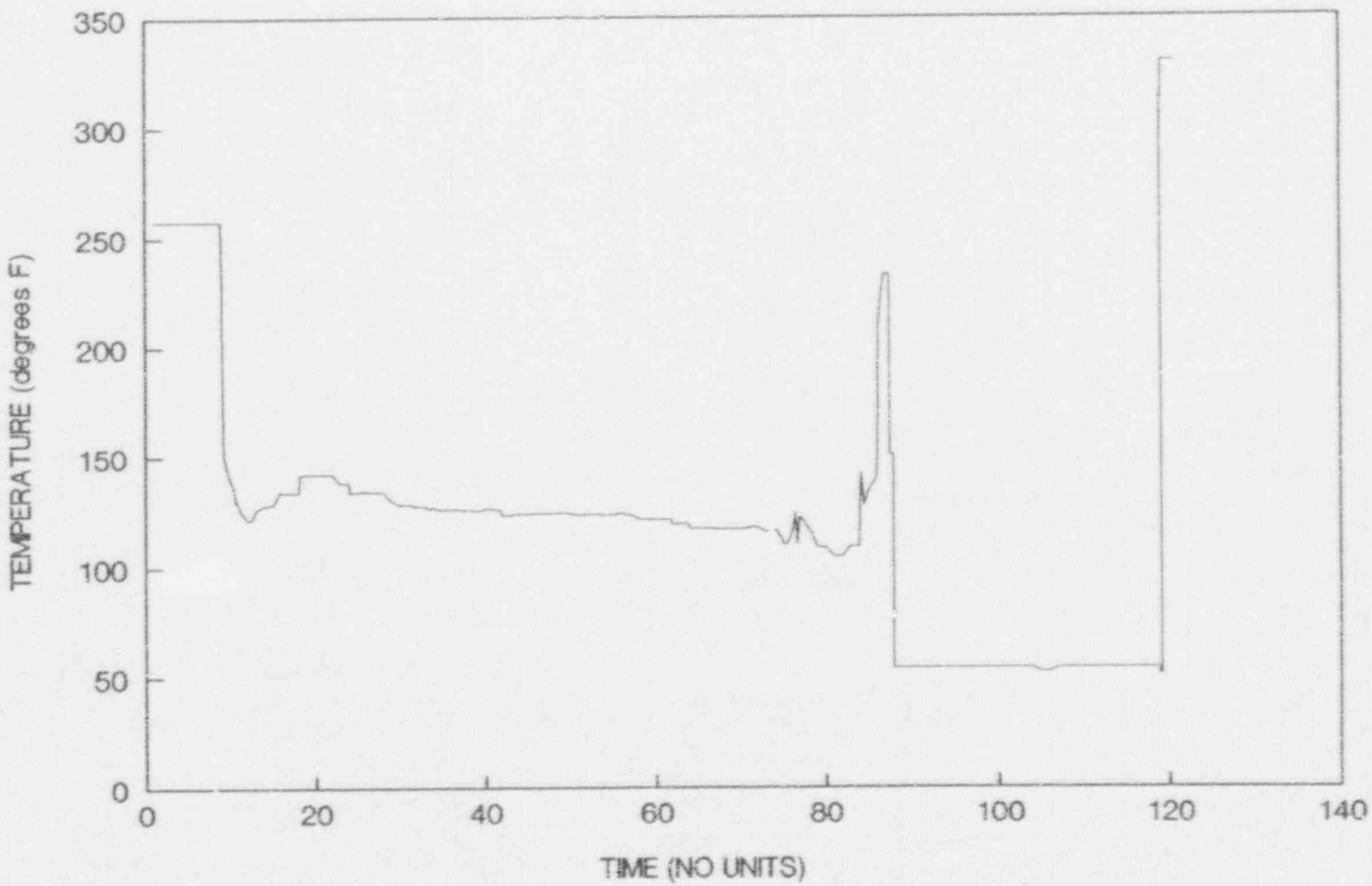


Figure 2-10: Mixed (Nozzle) Fluid Temperature for the June 27-29, 1991 SCRAM, Shutdown and Startup Event

Table 2-1

Thermal and Pressure Cycle Definition

for the April 10-15, 1990

SCRAM, Shutdown and Startup Trace (Figure 2-1)

ΔT (°F)	Number of Half-Cycles	Lowest Temperature (°F)
ΔT ≤ 25	482	71.5
25 < ΔT ≤ 50	35	74.0
50 < ΔT ≤ 75	14	50.0
75 < ΔT ≤ 100	1	50.0
100 < ΔT ≤ 125	0	---
125 < ΔT ≤ 150	0	---
150 < ΔT ≤ 175	0	---
175 < ΔT ≤ 200	0	---
200 < ΔT ≤ 225	1	144.8
225 < ΔT ≤ 250	0	---
250 < ΔT ≤ 275	0	---
275 < ΔT ≤ 300	0	---
300 < ΔT ≤ 325	0	---
325 < ΔT ≤ 350	0	---
350 < ΔT ≤ 375	0	---
375 < ΔT ≤ 400	0	---
400 < ΔT ≤ 425	0	---
425 < ΔT ≤ 450	0	---
450 < ΔT ≤ 475	0	---
475 < ΔT ≤ 500	0	---
500 < ΔT ≤ 525	0	---
525 < ΔT ≤ 550	0	---
550 < ΔT	0	---
Total =	533	

Notes:

(1) A half-cycle is defined as a change in temperature from T_1 to T_2 only (e.g., no return to T_1 associated with a full cycle).

(2) All temperature cycles were assumed to occur at a constant pressure of 1,050 psi.

(3) One full cycle (2 half-cycles) of ΔT = 300.7°F and ΔP = 1050 psi was also included to account for the overall temperature and pressure changes associated with this event.

(4) The lowest temperature identified above for each ΔT range was used as a reference point for computing thermal stresses from the thermal stress polynomial stress distribution.

Table 2-2

Thermal and Pressure Cycle Definition for the September 29 - October 9, 1990 Shutdown and Startup Trace (Figure 2-2)

ΔT (°F)	Number of Half-Cycles	Lowest Temperature (°F)
0 < ΔT ≤ 25	1263	62.7
25 < ΔT ≤ 50	193	62.7
50 < ΔT ≤ 75	24	62.7
75 < ΔT ≤ 100	6	99.2
100 < ΔT ≤ 125	6	53.8
125 < ΔT ≤ 150	12	51.4
150 < ΔT ≤ 175	0	---
175 < ΔT ≤ 200	1	160.3
200 < ΔT ≤ 225	0	---
225 < ΔT ≤ 250	1	50.0
250 < ΔT ≤ 275	1	75.9
275 < ΔT ≤ 300	101	65.1
300 < ΔT ≤ 325	0	---
325 < ΔT ≤ 350	0	---
350 < ΔT ≤ 375	10	73.1
375 < ΔT ≤ 400	1	50.0
400 < ΔT ≤ 425	0	---
425 < ΔT ≤ 450	0	---
450 < ΔT ≤ 475	0	---
475 < ΔT ≤ 500	0	---
500 < ΔT ≤ 525	0	---
525 < ΔT ≤ 550	0	---
550 < ΔT	0	---
	Total = 1619	

Notes:

(1) A half-cycle is defined as a change in temperature from T_1 to T_2 only (e.g., no return to T_1 associated with a full cycle).

(2) All temperature cycles were assumed to occur at a constant pressure of 1,050 psi.

(3) One full cycle (2 half-cycles) of ΔT = 300°F and ΔP = 1050 psi was also included to account for the overall temperature and pressure changes associated with this event.

(4) The lowest temperature identified above for each ΔT range was used as a reference point for computing thermal stresses from the thermal stress polynomial stress distribution.

Table 2-3

Thermal and Pressure Cycle Definition
for the November 25, 1990
Shutdown Trace (Figure 2-3)

ΔT (°F)	Number of Half-Cycles	Lowest Temperature (°F)
0 < ΔT ≤ 25	105	95.9
25 < ΔT ≤ 50	9	147.2
50 < ΔT ≤ 75	459	95.9
75 < ΔT ≤ 100	1	245.5
100 < ΔT ≤ 125	1	157.4
125 < ΔT ≤ 150	0	---
150 < ΔT ≤ 175	1	50.7
175 < ΔT ≤ 200	2	168.7
200 < ΔT ≤ 225	2	123.2
225 < ΔT ≤ 250	0	---
250 < ΔT ≤ 275	2	67.3
275 < ΔT ≤ 300	0	---
300 < ΔT ≤ 325	0	---
325 < ΔT ≤ 350	0	---
350 < ΔT ≤ 375	0	---
375 < ΔT ≤ 400	1	50.7
400 < ΔT ≤ 425	0	---
425 < ΔT ≤ 450	0	--
450 < ΔT ≤ 475	0	---
475 < ΔT ≤ 500	0	---
500 < ΔT ≤ 525	0	---
525 < ΔT ≤ 550	0	---
550 < ΔT	0	---
Total =	583	

Note. (1) A half-cycle is defined as a change in temperature from T_1 to T_2 only (e.g., no return to T_1 associated with a full cycle).

(2) All temperature cycles were assumed to occur at a constant pressure of 1,050 psi.

(3) One half-cycle of ΔT = 275°F and ΔP = 1050 psi was also included to account for the overall temperature and pressure changes associated with this event.

(4) The lowest temperature identified above for each ΔT range was used as a reference point for computing thermal stresses from the thermal stress polynomial stress distribution.

Table 2-4
Thermal and Pressure Cycle Definition
for the January 1, 1991
Startup Trace (Figure 2-4)

ΔT (°F)	Number of Half-Cycles	Lowest Temperature (°F)
0 < ΔT ≤ 25	78	65.2
25 < ΔT ≤ 50	5	138.6
50 < ΔT ≤ 75	8	128.4
75 < ΔT ≤ 100	1	254.7
100 < ΔT ≤ 125	2	81.3
125 < ΔT ≤ 150	1	113.8
150 < ΔT ≤ 175	4	188.8
175 < ΔT ≤ 200	1	177.2
200 < ΔT ≤ 225	1	113.8
225 < ΔT ≤ 250	0	---
250 < ΔT ≤ 275	0	---
275 < ΔT ≤ 300	2	61.5
300 < ΔT ≤ 325	0	---
325 < ΔT ≤ 350	0	---
350 < ΔT ≤ 375	0	---
375 < ΔT ≤ 400	0	---
400 < ΔT ≤ 425	0	---
425 < ΔT ≤ 450	0	---
450 < ΔT ≤ 475	0	---
475 < ΔT ≤ 500	0	---
500 < ΔT ≤ 525	0	---
525 < ΔT ≤ 550	0	---
550 < ΔT	0	---
	Total = 103	

Notes:

(1) A half-cycle is defined as a change in temperature from T_1 to T_2 only (e.g., no return to T_1 associated with a full cycle).

(2) All temperature cycles were assumed to occur at a constant pressure of 1,050 psi.

(3) One half-cycle of ΔT = 300.4°F and ΔP = 1050 psi was also included to account for the overall temperature and pressure changes associated with this event.

(4) The lowest temperature identified above for each ΔT range was used as a reference point for computing thermal stresses from the thermal stress polynomial stress distribution.

Table 2-5

Thermal and Pressure Cycle Definition
for the March 12, 1991
SCRAM, Shutdown and Startup Trace (Figure 2-5)

ΔT (°F)	Number of Half-Cycles	Lowest Temperature (°F)
$0 < \Delta T \leq 25$	315	57.7
$25 < \Delta T \leq 50$	20	52.7
$50 < \Delta T \leq 75$	5	52.7
$75 < \Delta T \leq 100$	0	---
$100 < \Delta T \leq 125$	0	---
$125 < \Delta T \leq 150$	1	171.2
$150 < \Delta T \leq 175$	0	---
$175 < \Delta T \leq 200$	0	---
$200 < \Delta T \leq 225$	0	---
$225 < \Delta T \leq 250$	0	---
$250 < \Delta T \leq 275$	0	---
$275 < \Delta T \leq 300$	0	---
$300 < \Delta T \leq 325$	0	---
$325 < \Delta T \leq 350$	0	---
$350 < \Delta T \leq 375$	0	---
$375 < \Delta T \leq 400$	0	---
$400 < \Delta T \leq 425$	0	---
$425 < \Delta T \leq 450$	0	---
$450 < \Delta T \leq 475$	0	---
$475 < \Delta T \leq 500$	0	---
$500 < \Delta T \leq 525$	0	---
$525 < \Delta T \leq 550$	0	---
$550 < \Delta T$	0	---
	Total = 341	

Notes:

(1) A half-cycle is defined as a change in temperature from T_1 to T_2 only (e.g., no return to T_1 associated with a full cycle).

(2) All temperature cycles were assumed to occur at a constant pressure of 1,050 psi.

(3) One full cycle (2 half-cycles) of ΔT = 267.6°F and ΔP = 1050 psi was also included to account for the overall temperature and pressure changes associated with this event.

(4) The lowest temperature identified above for each ΔT range was used as a reference point for computing thermal stresses from the thermal stress polynomial stress distribution.

Table 2-5
Thermal and Pressure Cycle Definition
for the March 30, 1991
Shutdown Trace (Figure 2-6)

ΔT (°F)	Number of Half-Cycles	Lowest Temperature (°F)
0 < ΔT ≤ 25	568	79.8
25 < ΔT ≤ 50	38	93.7
50 < ΔT ≤ 75	2	93.7
75 < ΔT ≤ 100	4	99.5
100 < ΔT ≤ 125	1	101.6
125 < ΔT ≤ 150	3	97.6
150 < ΔT ≤ 175	0	---
175 < ΔT ≤ 200	0	---
200 < ΔT ≤ 225	0	---
225 < ΔT ≤ 250	0	---
250 < ΔT ≤ 275	0	---
275 < ΔT ≤ 300	0	---
300 < ΔT ≤ 325	0	---
325 < ΔT ≤ 350	0	---
350 < ΔT ≤ 375	0	---
375 < ΔT ≤ 400	0	---
400 < ΔT ≤ 425	0	---
425 < ΔT ≤ 450	0	---
450 < ΔT ≤ 475	0	---
475 < ΔT ≤ 500	0	---
500 < ΔT ≤ 525	0	---
525 < ΔT ≤ 550	0	---
550 < ΔT	0	---
	Total = 616	

Notes:

(1) A half-cycle is defined as a change in temperature from T_1 to T_2 only (e.g., no return to T_1 associated with a full cycle).

(2) All temperature cycles were assumed to occur at a constant pressure of 1050 psi.

(3) One half-cycle of ΔT = 251.2°F and ΔP = 1050 psi was also included to account for the overall temperature and pressure changes associated with this event.

(4) The lowest temperature identified above for each ΔT range was used as a reference point for computing thermal stresses from the thermal stress polynomial stress distribution.

Table 2-7

Thermal and Pressure Cycle Definition
for the June 10, 1991
Startup Trace (Figure 2-7)

ΔT (°F)	Number of Half-Cycles	Lowest Temperature (°F)
0 < ΔT ≤ 25	23	108.4
25 < ΔT ≤ 50	0	---
50 < ΔT ≤ 75	1	137.7
75 < ΔT ≤ 100	0	---
100 < ΔT ≤ 125	0	---
125 < ΔT ≤ 150	1	50.0
150 < ΔT ≤ 175	0	---
175 < ΔT ≤ 200	1	50.0
200 < ΔT ≤ 225	0	---
225 < ΔT ≤ 250	0	---
250 < ΔT ≤ 275	0	---
275 < ΔT ≤ 300	0	---
300 < ΔT ≤ 325	0	---
325 < ΔT ≤ 350	0	---
350 < ΔT ≤ 375	0	---
375 < ΔT ≤ 400	0	---
400 < ΔT ≤ 425	0	---
425 < ΔT ≤ 450	0	---
450 < ΔT ≤ 475	0	---
475 < ΔT ≤ 500	0	---
500 < ΔT ≤ 525	0	---
525 < ΔT ≤ 550	0	---
550 < ΔT	0	---
	Total = 26	

Notes:

(1) A half-cycle is defined as a change in temperature from T_1 to T_2 only (e.g., no return to T_1 associated with a full cycle).

(2) All temperature cycles were assumed to occur at a constant pressure of 1,050 psi.

(3) One half-cycle of ΔT = 131.7°F and ΔP = 1050 psi was also included to account for the overall temperature and pressure changes associated with this event.

(4) The lowest temperature identified above for each ΔT range was used as a reference point for computing thermal stresses from the thermal stress polynomial stress distribution.

Table 2-8

Thermal and Pressure Cycle Definition
for the June 15-16, 1991
Shutdown to 500 psi and Startup Trace (Figure 2-8)

ΔT (°F)	Number of Half-Cycles	Lowest Temperature (°F)
0 < ΔT ≤ 25	43	92.3
25 < ΔT ≤ 50	4	104.4
50 < ΔT ≤ 75	2	92.3
75 < ΔT ≤ 100	1	117.1
100 < ΔT ≤ 125	0	---
125 < ΔT ≤ 150	0	---
150 < ΔT ≤ 175	0	---
175 < ΔT ≤ 200	0	---
200 < ΔT ≤ 225	0	---
225 < ΔT ≤ 250	0	---
250 < ΔT ≤ 275	0	---
275 < ΔT ≤ 300	0	---
300 < ΔT ≤ 325	0	---
325 < ΔT ≤ 350	0	---
350 < ΔT ≤ 375	0	---
375 < ΔT ≤ 400	0	---
400 < ΔT ≤ 425	0	---
425 < ΔT ≤ 450	0	---
450 < ΔT ≤ 475	0	---
475 < ΔT ≤ 500	0	---
500 < ΔT ≤ 525	0	---
525 < ΔT ≤ 550	0	---
550 < ΔT	0	---
	Total = 50	

Notes:

(1) A half-cycle is defined as a change in temperature from T_1 to T_2 only (e.g., no return to T_1 associated with a full cycle).

(2) All temperature cycles were assumed to occur at a constant pressure of 1,050 psi.

(3) One full cycle (2 half-cycles) of ΔT = 249.1°F and ΔP = 550 psi was also included to account for the overall temperature and pressure changes associated with this event.

(4) The lowest temperature identified above for each ΔT range was used as a reference point for computing thermal stresses from the thermal stress polynomial stress distribution.

Table 2-9

Thermal and Pressure Cycle Definition
for the June 17-19, 1991
Shutdown from 10% and Startup Trace (Figure 2-9)

ΔT (°F)	Number of Half-Cycles	Lowest Temperature (°F)
0 < ΔT ≤ 25	59	78.0
25 < ΔT ≤ 50	4	78.0
50 < ΔT ≤ 75	0	---
75 < ΔT ≤ 100	3	112.5
100 < ΔT ≤ 125	0	---
125 < ΔT ≤ 150	0	---
150 < ΔT ≤ 175	0	---
175 < ΔT ≤ 200	0	---
200 < ΔT ≤ 225	0	---
225 < ΔT ≤ 250	0	---
250 < ΔT ≤ 275	0	---
275 < ΔT ≤ 300	0	---
300 < ΔT ≤ 325	0	---
325 < ΔT ≤ 350	0	---
350 < ΔT ≤ 375	0	---
375 < ΔT ≤ 400	0	---
400 < ΔT ≤ 425	0	---
425 < ΔT ≤ 450	0	---
450 < ΔT ≤ 475	0	---
475 < ΔT ≤ 500	0	---
500 < ΔT ≤ 525	0	---
525 < ΔT ≤ 550	0	---
550 < ΔT	0	---
	Total = 66	

Notes:

(1) A half-cycle is defined as a change in temperature from T_1 to T_2 only (e.g., no return to T_1 associated with a full cycle).

(2) All temperature cycles were assumed to occur at a constant pressure of 1,050 psi.

(3) One full cycle (2 half-cycles) of ΔT = 190.4°F and ΔP = 1050 psi was also included to account for the overall temperature and pressure changes associated with this event.

(4) The lowest temperature identified above for each ΔT range was used as a reference point for computing thermal stresses from the thermal stress polynomial stress distribution.

Table 2-10

Thermal and Pressure Cycle Definition

for the June 27-29, 1991

SCRAM, Shutdown and Startup Trace (Figure 2-10)

ΔT (°F)	Number of Half-Cycles	Lowest Temperature (°F)
0 < ΔT ≤ 25	57	50.7
25 < ΔT ≤ 50	1	104.4
50 < ΔT ≤ 75	0	---
75 < ΔT ≤ 100	0	---
100 < ΔT ≤ 125	1	127.4
125 < ΔT ≤ 150	1	129.3
150 < ΔT ≤ 175	0	---
175 < ΔT ≤ 200	1	51.9
200 < ΔT ≤ 225	0	---
225 < ΔT ≤ 250	0	---
250 < ΔT ≤ 275	0	---
275 < ΔT ≤ 300	1	50.7
300 < ΔT ≤ 325	0	---
325 < ΔT ≤ 350	0	---
350 < ΔT ≤ 375	0	---
375 < ΔT ≤ 400	0	---
400 < ΔT ≤ 425	0	---
425 < ΔT ≤ 450	0	---
450 < ΔT ≤ 475	0	---
475 < ΔT ≤ 500	0	---
500 < ΔT ≤ 525	0	---
525 < ΔT ≤ 550	0	---
550 < ΔT	0	---
	Total = 62	

Notes:

(1) A half-cycle is defined as a change in temperature from T_1 to T_2 only (e.g., no return to T_1 associated with a full cycle).

(2) All temperature cycles were assumed to occur at a constant pressure of 1,050 psi.

(3) One full cycle (2 half-cycles) of ΔT = 153.2°F and ΔP = 1050 psi was also included to account for the overall temperature and pressure changes associated with this event.

(4) The lowest temperature identified above for each ΔT range was used as a reference point for computing thermal stresses from the thermal stress polynomial stress distribution.

3.0 PLANT OPERATING HISTORY

The Reference 1 report utilized the projected number of events from Reference 4, and modified them to coincide with the Reference 6 updated thermal cycle diagram. As a result, 260 startup/shutdown cycles and 468 total SCRAM events were evaluated in Reference 1. For the current analysis, annual operating reports for Fermi 2 were made available (References 7-11) so that a more accurate cycle count projection could be made specific to Fermi 2. A summary of these reports along with the cycle count totals for this analysis are provided in Table 3-1.

The information shown in Table 3-1 was used to determine an updated projection for the number of events for the 40-year design life of the plant. This new projection is shown in Table 3-2.

It is seen that the extrapolated number of events for the 40-year design life of the reactor is nearly the same as that used in the Reference 1 analysis. This is as expected since the Reference 1 projections were modified to coincide with more recent thermal cycle diagrams. However, as documented in Reference 12, there are typically more thermal events during the initial years of plant operation because of "learning curve" effects. Therefore, the projections shown in Table 3-2 should improve as more operational experience is accumulated.

In addition, power reductions were conservatively counted as SCRAM events since no information was available to determine how low the reactor temperature reached during these events. For those events where a significant drop in reactor power was achieved, this assumption is probably reasonable. For other events where only a small drop in power level occurred, this assumption is conservative as more thermal cycling was probably included than was actually present. Therefore, for the two reasons described here, the projection shown in Table 3-2 is considered to be conservative for use in the current analysis.

Table 3-1

Fermi-2 Thermal Cycle Counting Results

Year	Date	Event	Startup	Shutdown	SCRAM	Comments
1986	1/01	Scheduled Shutdown	1	1	0	Scheduled outage which started on 10/11/85.
	8/07	Forced Shutdown	1	1	0	Shutdown after fire in Motor Control Center.
	8/29	Forced Shutdown	0	0	1	Reactor trip on high RPV pressure transient.
	9/03	Forced Shutdown	1	1	0	Tech. spec. required shutdown for isolation valve repair.
	9/23	Forced Shutdown	1	1	0	Shutdown to repair condenser tube leaks.
	10/01	Forced Shutdown	2	2	0	LER 86-035 + LER 86-036 during 9/23 shutdown.
	10/17	Forced Shutdown	0	0	1	Pressure regulator malfunction causing low water level trip.
	10/23	Forced Shutdown	1	1	0	Shutdown using remote shutdown panel.
	11/02	Forced Shutdown	1	1	0	Shutdown to repair excessive air in-leakage to condenser.
	12/01	Forced Shutdown	0	0	0	Continuation of 11/2 shutdown.
1987	1/02	Forced Shutdown	0	0	1	Reactor was not shutdown - only turbine-generator.
	1/05	Forced Shutdown	1	1	0	Reactor shutdown to repair welds on instrument taps.
	2/16	Forced Shutdown	0	0	1	Reactor was not shutdown - turbine-generator trip.
	2/17	Forced Shutdown	0	0	1	Reactor was not shutdown - generator shutdown only.
	2/18	Forced Shutdown	0	0	1	Reactor was not shutdown - generator shutdown only.
	2/23	Forced Shutdown	0	0	1	Reactor was not shutdown - generator automatically shutdown.
	2/26	Forced Shutdown	0	0	1	Turbine trip followed by reactor trip.
	3/01	Forced Shutdown	1	1	0	LER 87-008 in addition to 2/26 shutdown.
	3/16	Scheduled Outage	0	0	1	Reactor was not shutdown - turbine valve trip.
	3/16	Scheduled Outage	1	1	1	LER 87-007 SCRAM signal.
	4/01	Scheduled Outage	0	0	0	Continuation of 3/16 scheduled outage.

Table 3-1 (cont'd)

Fermi-2 Thermal Cycle Counting Results

Year	Date	Event	Startup	Shutdown	SCRAM	Comments
1987	4/06	Forced Shutdown	0	0	1	SCRAM due to personnel error.
	4/10	Forced Shutdown	0	0	1	Reactor was not shutdown - main turbine-generator tripped.
	4/11	Forced Shutdown	1	1	0	Cold shutdown after turbine-generator manual trip.
	5/01	Forced Shutdown	2	2	0	LER 87-017 + LER 87-018 in addition to 4/11 shutdown.
	6/16	Forced Shutdown	1	1	0	Reactor power was reduced.
	6/18	Forced Shutdown	0	0	1	Reactor was not shutdown - turbine-generator trip.
	6/24	Forced Shutdown	1	1	0	Tech. spec. required shutdown.
	7/20	Forced Shutdown	0	0	1	SCRAM after turbine valve fast closure.
	7/26	Forced Shutdown	1	1	0	Maintenance outage began.
	8/01	Forced Shutdown	0	0	0	Part of 7/26 forced shutdown.
	9/01	Forced Shutdown	0	0	0	Part of 7/26 forced shutdown.
	10/01	Forced Shutdown	0	0	0	Part of 7/26 forced shutdown.
	12/31	Forced Shutdown	0	0	1	Reactor trip due to turbine valve fast closure.
1988	1/01	Forced Shutdown	0	0	1	Part of 12/31/87 forced shutdown.
	1/10	Forced Shutdown	0	0	1	SCRAM due to reactor feed pump speed controller failure.
	2/27	Forced Shutdown	1	1	0	Emergency Diesel Generator procedure corrective actions.
	2/27	Scheduled Outage	0	0	0	Scheduled local leak rate testing outage.
	3/01	Scheduled Outage	0	0	0	Continuation of local leak rate outage.
	4/01	Scheduled Outage	0	0	0	Continuation of local leak rate outage.
	5/01	Scheduled Outage	0	0	3	3 SCRAMs prior to synchronizing turbine.
	5/28	Scheduled Reduction	0	0	1	Scheduled for routine surveillance test of RWCU system.
	7/23	Forced Shutdown	1	1	0	Unidentified drywell leakage.
	8/01	Forced Shutdown	0	0	0	Continuation of 7/23 outage.
	8/08	Forced Power Reduct.	0	0	1	Steam leak from separator seal tank.
	8/13	Forced Shutdown	0	0	1	Turbine bearing high vibration signal.

Table 3-1 (cont'd)

Fermi-2 Thermal Cycle Counting Results

Year	Date	Event	Startup	Shutdown	SCRAM	Comments
1988	8/21	Forced Shutdown	1	1	0	LPCI loop select logic declared inoperable.
	8/28	Forced Shutdown	1	1	0	Valve B13-F013B torque switch not properly reset.
	9/01	Forced Shutdown	0	0	0	Continuation of 8/28 outage.
	10/01	Forced Shutdown	0	0	0	Continuation of 8/28 outage.
	11/01	Scheduled Outage	1	1	0	MSIV closure test and remote shutdown.
1989	1/03	Shutdown	1	1	0	Excessive hydrogen inleakage into stator cooling system.
	1/26	Power Reduction	0	0	1	East heater feed pump seal failure.
	2/26	Shutdown	0	0	1	SCRAM caused by turbine overspeed reset.
	3/07	Shutdown	0	0	1	SCRAM caused by turbine bearing vibration.
	4/10	Power Reduction	0	0	1	Maintenance on feed pump minimum flow valve, etc.
	5/07	Power Reduction	0	0	1	Maintenance on feed pump minimum flow valve, etc.
	6/03	Power Reduction	0	0	1	Control rod sequence exchange.
	7/14	Power Reduction	0	0	1	Control rod drive and turbine valve operability testing.
	7/21	Power Reduction	0	0	1	Recirculation runback caused by lost heater drains.
	8/05	Power Reduction	0	0	1	Recirculation runback caused by lost heater drains.
	9/04	Shutdown	1	1	0	Shutdown for first refueling outage.
	10/01	Shutdown	0	0	0	Continuation of shutdown for first refueling outage.
	11/01	Shutdown	0	0	0	Continuation of shutdown for first refueling outage.
	12/19	Shutdown	0	0	1	SCRAM caused by operator error.
	12/23	Shutdown	0	0	1	Low pressure turbine lagging fire.
1990	1/08	Power Reduction	0	0	1	Reduced power to 38% in anticipation of ESF test shutdown.

Table 3-1 (cont'd)

Fermi-2 Thermal Cycle Counting Results

Year	Date	Event	Startup	Shutdown	SCRAM	Comments
1990	1/13	Power Reduction	0	0	1	Repair steam leaks; perform control rod pattern adjustment.
	2/11	Power Reduction	0	0	1	Plug tube leaks in condenser; repair feed pump seal leak.
	2/17	Power Reduction	0	0	1	Enable steam tunnel entry for valve repair.
	3/31	Power Reduction	0	0	1	Perform weekly turbine steam valve surveillance.
	4/10	Shutdown	1	1	1	RPS motor-generator relay coil burned up.
	4/24	Power Reduction	0	0	1	Replace leaking MSIV leakage control valve.
	5/01	Power Reduction	0	0	0	Continued power reduction from 4/24 - feedwater pump trip.
	5/19	Power Reduction	0	0	1	Perform turbine valve and CRD operability surveillance.
	6/26	Power Reduction	0	0	1	Repair tube leaks in condenser water box.
	6/30	Shutdown	1	1	1	Manual SCRAM; continued tube leak repairs.
	7/01	Shutdown	0	0	0	Continued tube leak repairs.
	7/07	Power Reduction	0	0	1	Repair feedwater heater relief valve.
	7/14	Power Reduction	0	0	1	Perform control rod pattern adjustment.
	7/28	Power Reduction	0	0	1	Cleaning of main generator hydrogen coolers.
	8/02	Power Reduction	0	0	1	Repair a feedwater heater vent line.
	8/04	Power Reduction	0	0	1	Enter single loop operation.
	9/29	Shutdown	1	1	0	Test and repair various feedwater heaters.
	10/01	Shutdown	0	0	1	Continued maintenance outage; SCRAM due to low water level.
	10/13	Power Reduction	0	0	1	Perform turbine valve and CRD surveillance tests.
	11/08	Power Reduction	0	0	1	Relieve stresses on main turbine blading.
	11/25	Shutdown	1	1	1	Continued stress relief on turbine blading; manual SCRAM.
	12/01	Shutdown	0	0	0	Continued repairs on low pressure turbine.

Table 3-2

Projected Number of Events for the 40-Year Design Life

Year	No. of Startups	No. of Shutdowns	No. of SCRAMs
1990	4	4	19
1989	2	2	11
1988	5	5	8
1987	9	9	13
1986	8	8	2
Totals:	28	28	53
40-Year Projections:	224	224	424

Note: (1) The 40-year projections were based on an extrapolation of 5 years of operating history (e.g., 1986-1990). For example:

startups = 28 x (40/5) = 224

4.0 FINITE ELEMENT ANALYSIS

A detailed finite element model of the Fermi 2 feedwater nozzle configuration was developed in the Reference 1 analysis in order to develop temperature distributions as well as thermal and pressure stresses for use in the crack growth analysis. Those results remain valid for use in the current analysis. As a result they are used without any modification herein, and are repeated here for convenience.

The finite element computer code ANSYS (Reference 13) was used to develop a two-dimensional (2-D), axisymmetric model which simulates the Fermi 2 feedwater nozzle. The isoparametric heat conduction element (STIF 55) was used to obtain temperature distributions, and the isoparametric stress element (STIF 42) was used for the thermal and pressure stress analyses. The finite element model is shown in Figure 4-1, and is based on the configuration defined in Reference 14.

The heat transfer coefficients are given in Reference 1, which provides overall heat transfer coefficients for a triple thermal sleeve sparger design with seal number 1 failed. The use of overall heat transfer coefficients removed the necessity of modeling the thermal sleeve in the finite element analysis.

A temperature "step" transient was modeled by varying the feedwater fluid temperature from 550°F down to 100°F over a 10-second interval. Vessel fluid temperature was maintained at 550°F for the duration of the event. The temperatures were maintained at this level until steady-state conditions were reached. The 10-second ramp was used rather than a perfect step change since it was more realistic and assured numerical stability in the finite element solution. Subsequent evaluation showed that steady-state conditions induced the most limiting thermal stresses with respect to crack growth.

The results of the thermal analysis were applied to the finite element model to determine the thermal stresses. The nozzle was modeled by a 2-D, axisymmetric finite element mesh with the vessel being represented as a spherical shell. This approximation, commonly used in the stress analysis of a three-dimensional (3-D) nozzle configuration in a cylindrical shell, is adequate for thermal stresses but pressure stresses require a scaling factor based on a 3-D analysis. The lengths of the nozzle safe end and pressure vessel section were each modeled to at least $2.5\sqrt{Rt}$, where R is the radius and t is the thickness of the nozzle. This modeling assured that end effects did not influence the stresses in the nozzle corner region.

The stresses were evaluated during several time intervals, but the peak stresses were found to occur during the final, steady-state condition. The peak thermal stresses on the inside surface are presented in Table 4-1. Figure 4-2 is an ANSYS plot of the peak thermal stress for the steady state condition. The stresses which developed from a ΔT of 450°F were linearly scaled to the ΔT described in the thermal cycle definition (Section 2). The scaled stresses were subsequently used in the crack growth analysis.

Pressure stresses for the case of a 1000-psi vessel pressure were also calculated. These stresses, as mentioned earlier, required application of a scaling factor. This factor was necessary because the 2-D axisymmetric model cannot perfectly model the 3-D characteristics near the nozzle corner. To accurately determine the peak pressure stresses at the nozzle corner, a generic 3-D model developed by Gilman and Rashid (Reference 15) was used to scale the stress values calculated by ANSYS. The scaling factor for the pressure stress was given by the ratio of the peak pressure stress on the inside surface, as reported by Gilman and Rashid, to the peak pressure stress on the inside surface from the finite element model. The peak surface pressure stresses are presented in Table 4-1 and Figure 4-3.

The critical stress location was determined from the combined effect of the pressure and thermal stresses. Although the peak thermal stress was located at node 23, and the peak pressure stress was located at node 17, the peak combined stress was located at node 22, as shown in Table 4-1. The stress distribution across the nozzle thickness was taken at this location, as shown in Figure 4-4, in the polynomial curve fits used in the crack growth analysis of Section 5.

Table 4-1

Thermal and Pressure Surface Stresses

Node	Thermal Stress (psi) 1.7 min	Thermal Stress (psi) 8 min.	Thermal Stress (psi) St. State	Pressure Stress (psi) Model	Pressure Stress (psi) Scaled	SUM (psi) Steady State
15	18610	26370	35880	35610	43728	79608
16	19610	28770	37260	36290	44563	81823
17	20510	30820	37900	**36320**	**44600**	82500
18	21370	32530	37910	35620	43740	81650
19	23150	34750	38020	34070	41837	79857
20	25720	37690	39290	31900	39172	78462
21	31450	43650	43940	30720	37723	81663
22	36540	48800	47840	29290	35967	**83807**
23	39220	51430	**49130**	27850	34199	83329
24	40880	**52660**	48100	25350	31129	79229
25	**41160**	51990	45240	22690	27863	73102
26	40760	50180	41370	20080	24658	66027
27	39900	47490	36770	17440	21416	58186

Note: (1) The pressure stresses calculated by ANSYS were scaled so that the maximum pressure stress equaled the maximum pressure stress obtained from Reference 15, as follows:

Maximum pressure stress from FEM = 36,320 psi

Maximum pressure stress from 3-D model = 44,600 psi

Scaling factor = 44600/36320 = 1.22797

(2) Maximum stress values and the location chosen for crack growth analysis are shown in bold face.

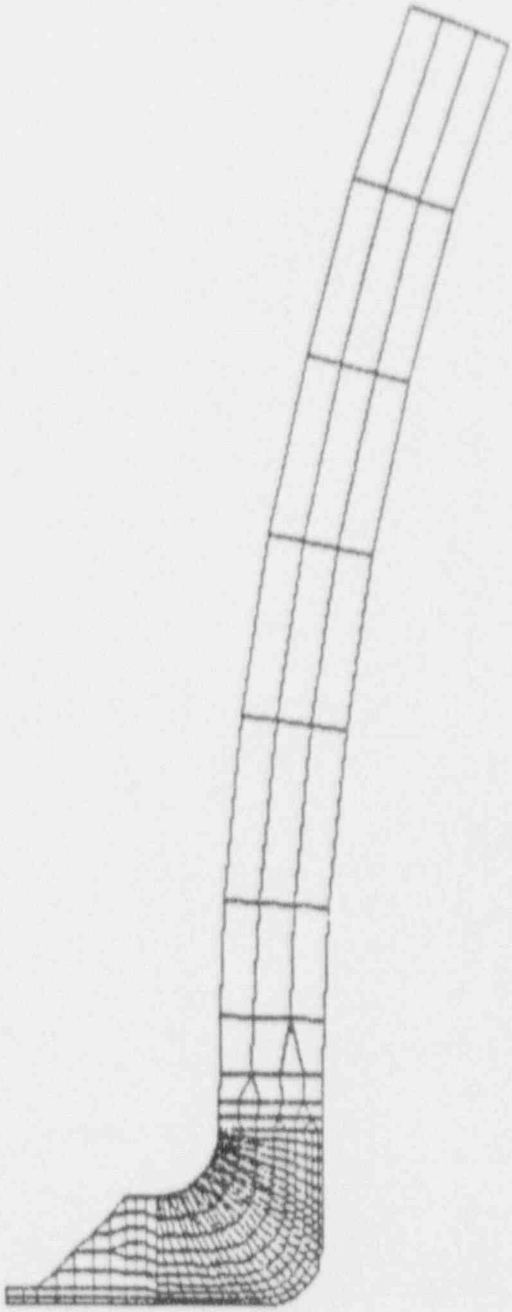


Figure 4-1: Finite Element Model

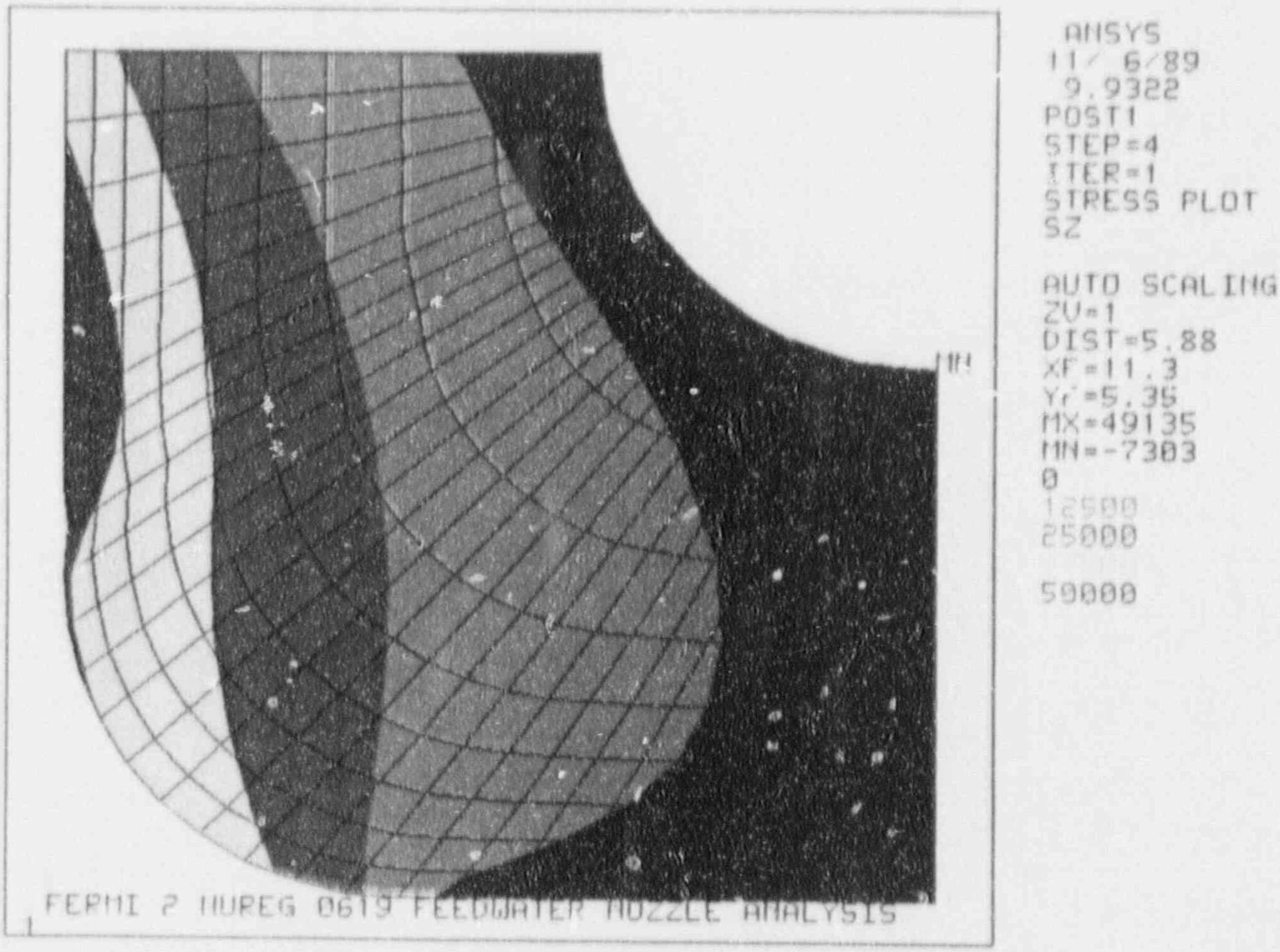


Figure 4-2: Peak Thermal Stresses at Steady State

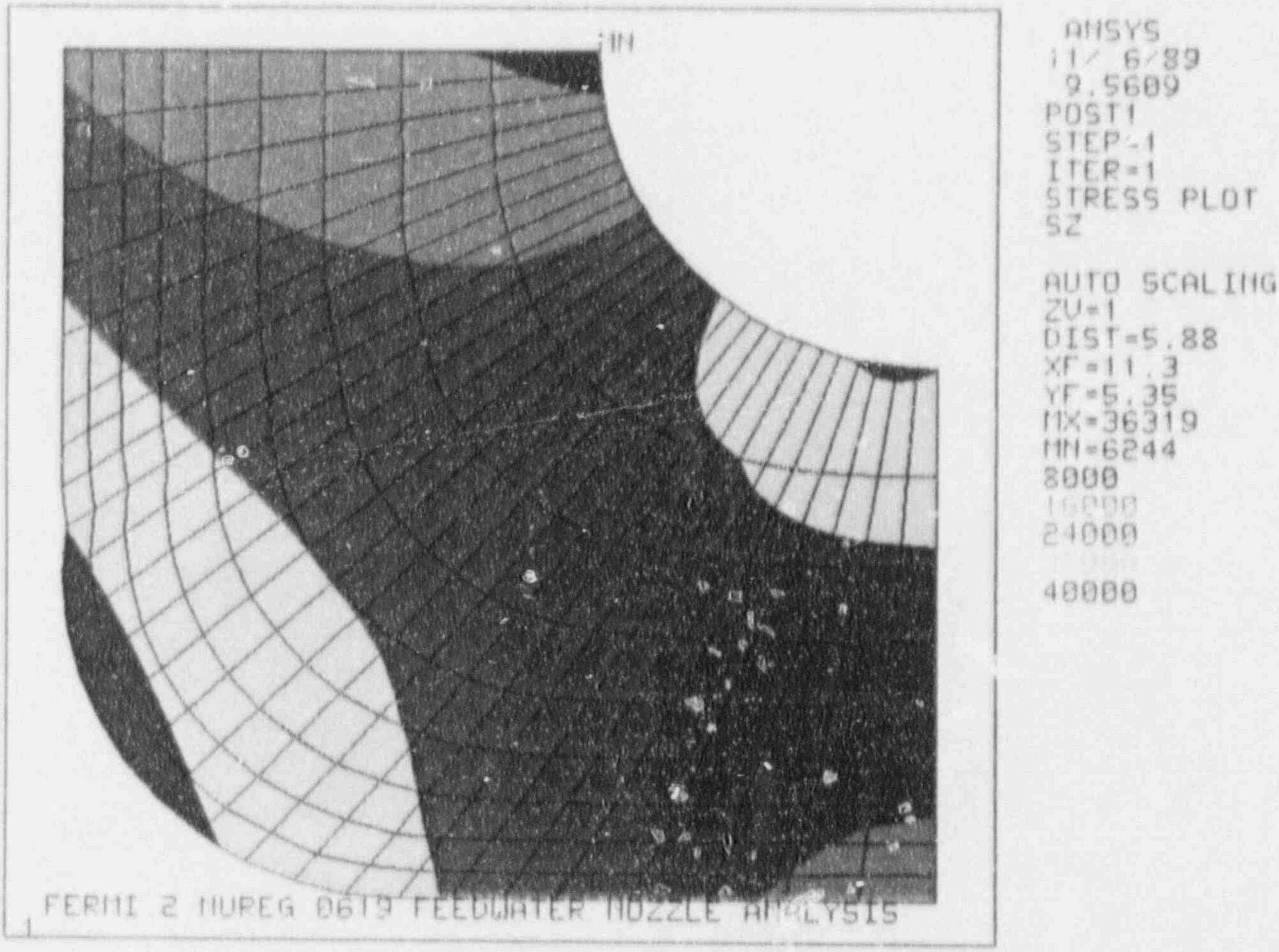


Figure 4-3: Peak Pressure Stresses

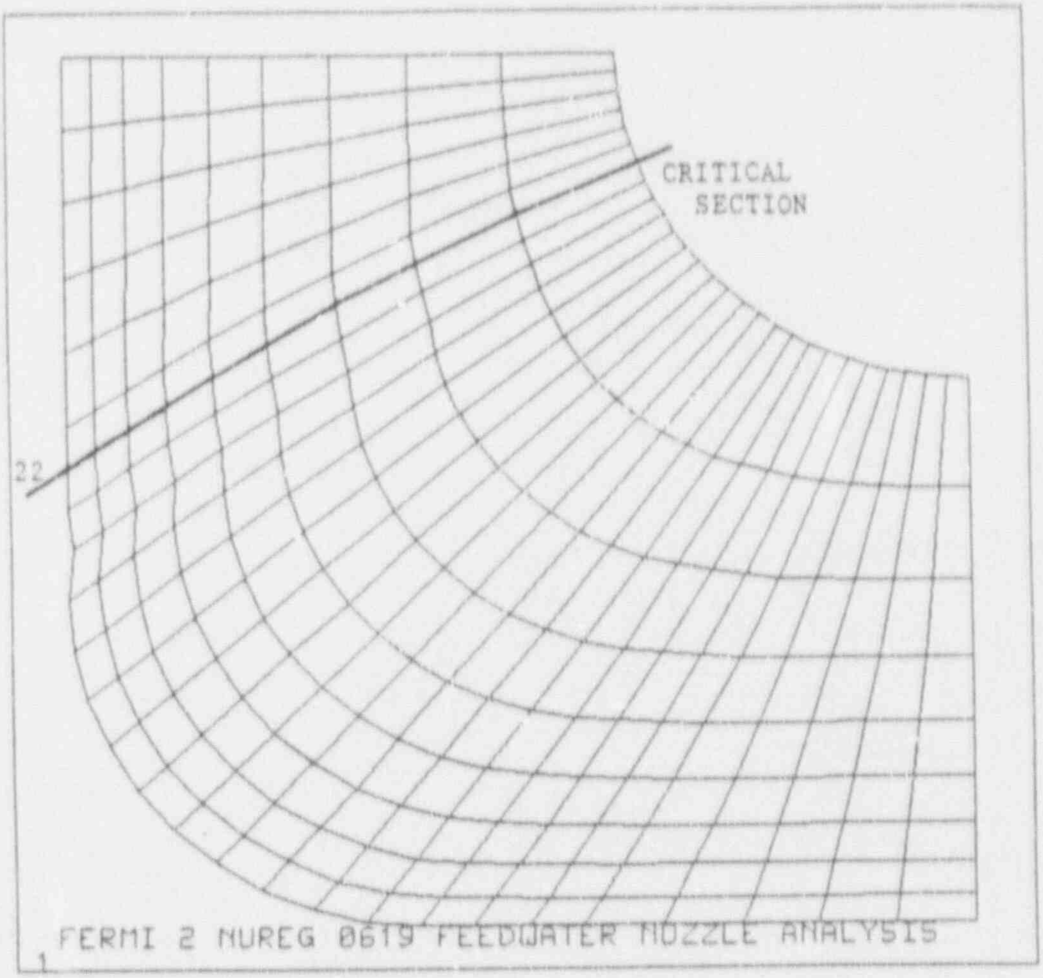


Figure 4-4: Critical Section Stress Distribution
(Sum of Pressure + Thermal Stresses)

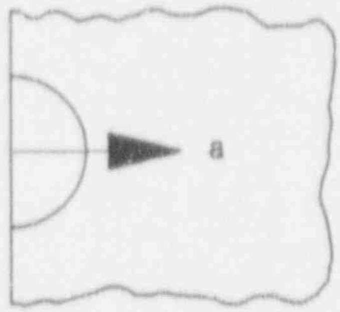
5.0 CRACK GROWTH ANALYSIS

A general purpose, polynomial curve-fit technique was used to generate stress intensity factors for the stress distributions determined in Section 4. Stress intensity factors were calculated using solutions for standard stress distributions in half and quarter space. Stress intensity solutions for specific crack geometries are shown in Figure 5-1. It was recognized that the solution for a 3-D nozzle corner crack lies in between the half and quarter space solutions, so those solutions were averaged to obtain the nozzle solution. The pressure and thermal stress distributions shown in Table 4-1 were fit to third order polynomials using a least squares procedure:

$$\sigma = A_0 + A_1x + A_2x^2 + A_3x^3$$

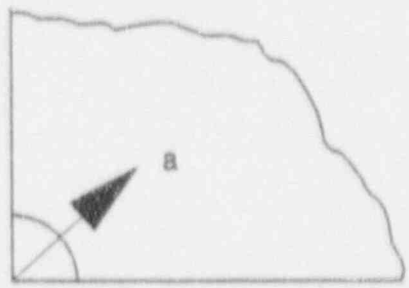
The polynomial fits are shown in Figures 5-2 and 5-3. For the region of interest (x = 0.0 to 1.5 inches), the accuracy of the polynomial fits is seen to be more than adequate.

The polynomial coefficients (A_0, A_1, A_2 and A_3) were then substituted into the simulated 3-D nozzle corner crack stress intensity factor expression of Figure 5-1. The resulting stress intensity factor versus crack depth results are plotted in Figure 5-4. The stress intensity relationships used to generate these figures are used in the updated crack growth analysis contained herein.



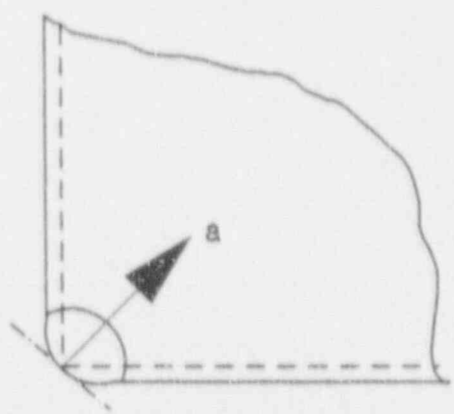
SEMI-CIRCULAR CRACK IN HALF-SPACE

$$K_I = \sqrt{\pi a}\,[0.688A_0 + 0.522(2a/\pi)A_1 + 0.434(a^2/2)A_2 + 0.377(4a^3/3\pi)A_3]$$



QUARTER-CIRCULAR CRACK IN QUARTER SPACE

$$K_I = \sqrt{\pi a}\,[0.723A_0 + 0.551(2a/\pi)A_1 + 0.462(a^2/2)A_2 + 0.408(4a^3/3\pi)A_3]$$



SIMULATED 3-D NOZZLE CORNER CRACK

$$K_I = \sqrt{\pi a}\,[0.706A_0 + 0.537(2a/\pi)A_1 + 0.448(a^2/2)A_2 + 0.393(4a^3/3\pi)A_3]$$

Figure 5-1: Stress Intensity Magnification Factors

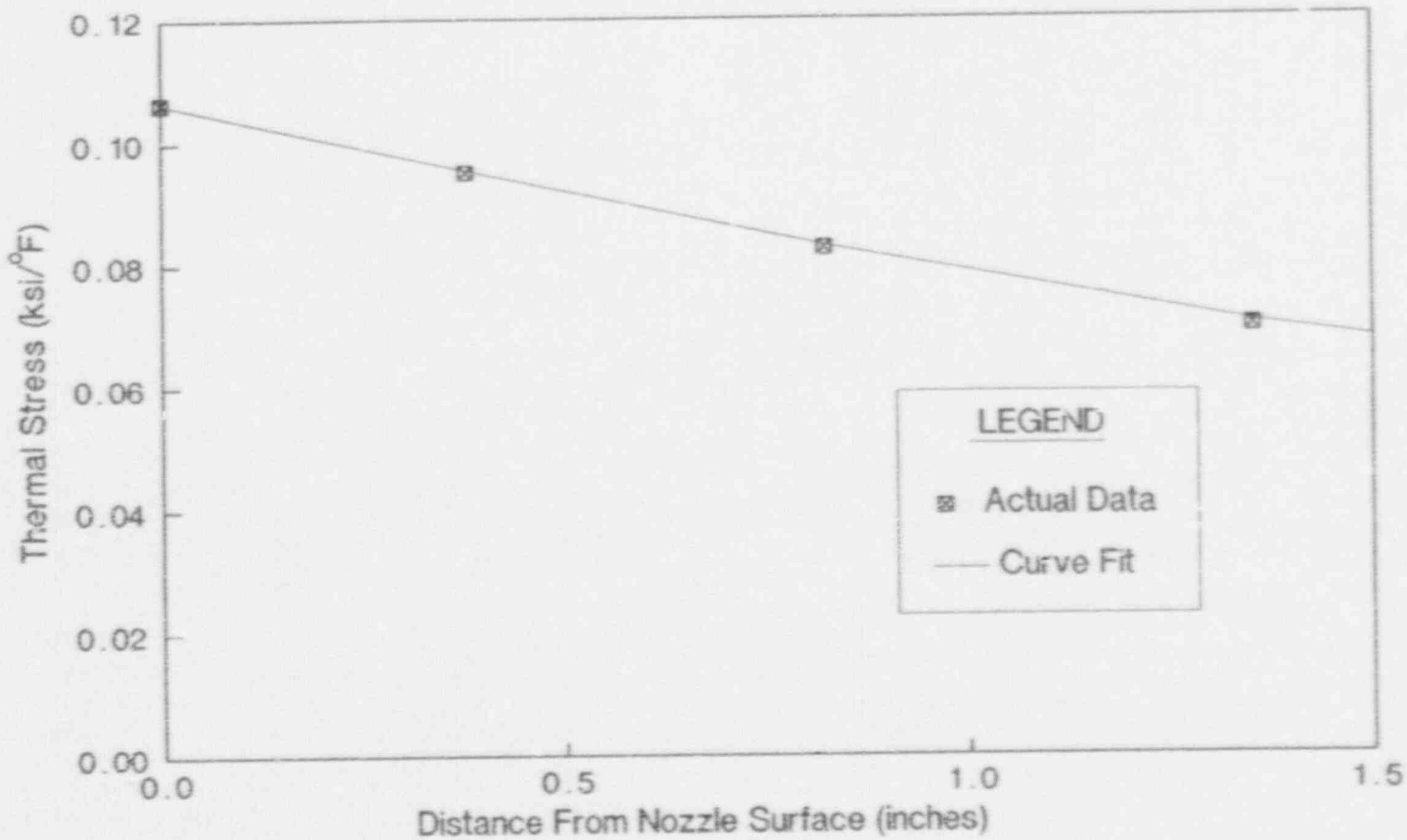


Figure 5-2: Thermal Stress Polynomial Curve Fit

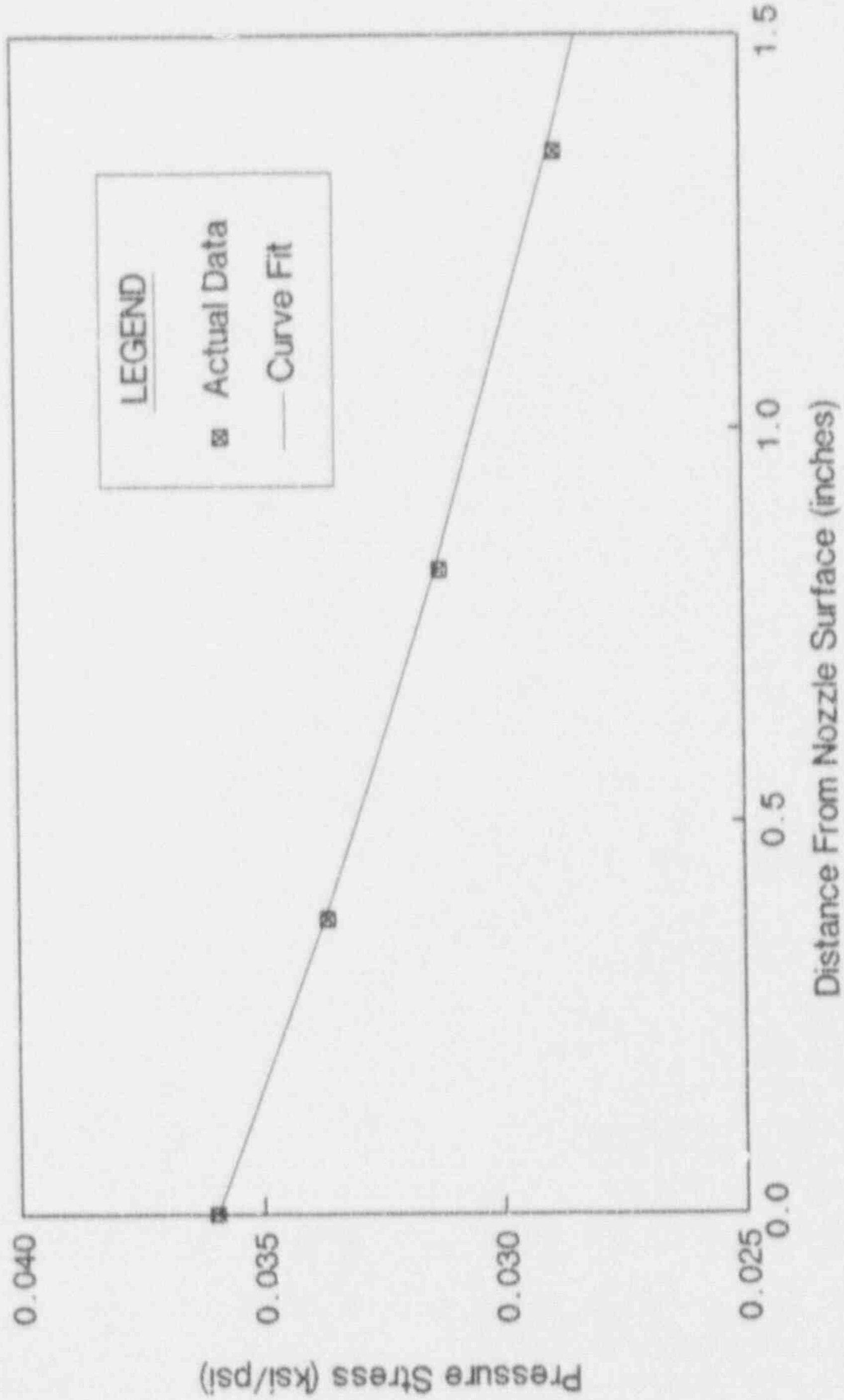


Figure 5-3: Pressure Stress Polynomial Curve Fit

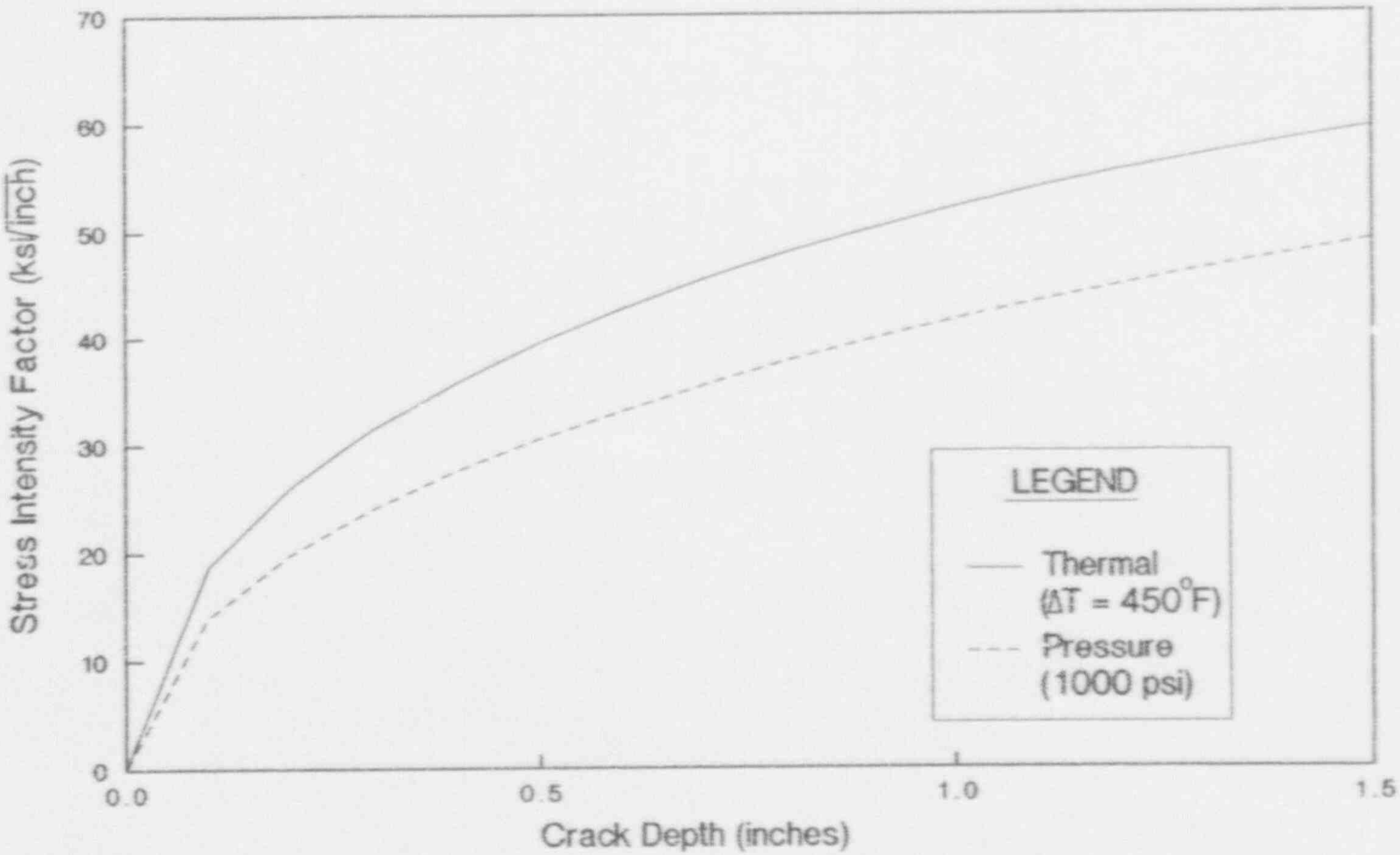


Figure 5-4: Stress Intensity Factor Versus Crack Depth

6.0 CRACK GROWTH RESULTS

The fatigue crack growth rate data for low alloy steel from the 1989 edition of Section XI of the ASME Code (Reference 16) were used for the crack growth analysis. This curve is the same as was used in the Reference 1 report. In the Reference 1 report, a best-fit relationship was also used in the crack growth analysis. The best fit results were reported for information and comparative purposes only, and provided improved results over those obtained from an ASME Code, Section XI approach (13.5 years versus 8.9 years). Nevertheless, the best-fit relationship was not considered herein since the ASME Code curves are the accepted criteria for analyses of this type. Therefore, the ASME crack growth relationships are used exclusively in the updated crack growth analysis contained herein.

As described in Section 2, the feedwater nozzle thermal duty was obtained from actual plant data for a total of ten traces (as depicted in Figures 2-1 through 2-10) covering eleven (11) SCRAM, startup and shutdown events. This duty was considered to be representative of actual plant operations, and is therefore valid for use on a long-term average basis. The thermal duty of the feedwater nozzle used in this crack growth evaluation therefore consisted of:

11 total events from Section 2 which consisted of:

8 startup/shutdowns
3 SCRAMS

Since there was no way to determine which portion of the duty for some of the events was caused by SCRAM and which portion was caused by startup/shutdown, all events were treated as equal. Thus, from Table 3-2, the amount of times the above duty had to be repeated was:

Total, projected number of events for 40 years:

224 startup/shutdowns

<u>424</u> SCRAMs

Total = 648 startup/shutdown or SCRAM events

Repeat factor = 648/11 ≈ 59

The entire plant design life was therefore assumed to be a repetitive combination of the 11 startup/shutdown and SCRAM events identified in Section 2.

The procedure for calculating the crack propagation was as follows: For each cycle, the maximum and minimum stress intensity and the number of occurrences were calculated. From this, the stress intensity factor range and the corresponding R-ratio were calculated for each cycle. Using this information and the ASME Code crack growth relationships, the incremental crack growth was calculated for each cycle. The crack size was updated and the procedure was repeated for all cycles until all events had been analyzed. This process was repeated 59 times to project crack growth out over the entire 40-year plant life. Since this calculation involved numerous repetitive operations, a computer program was developed to perform the calculations.

The results of the crack growth analysis are shown in Figure 6-1. These results show that, using the ASME Code, Section XI fatigue crack growth relationships, a postulated 0.25-inch initial depth crack (as specified in NUREG-0619) reaches the allowable depth of 1.0 inch 38.3 years after initial plant startup.

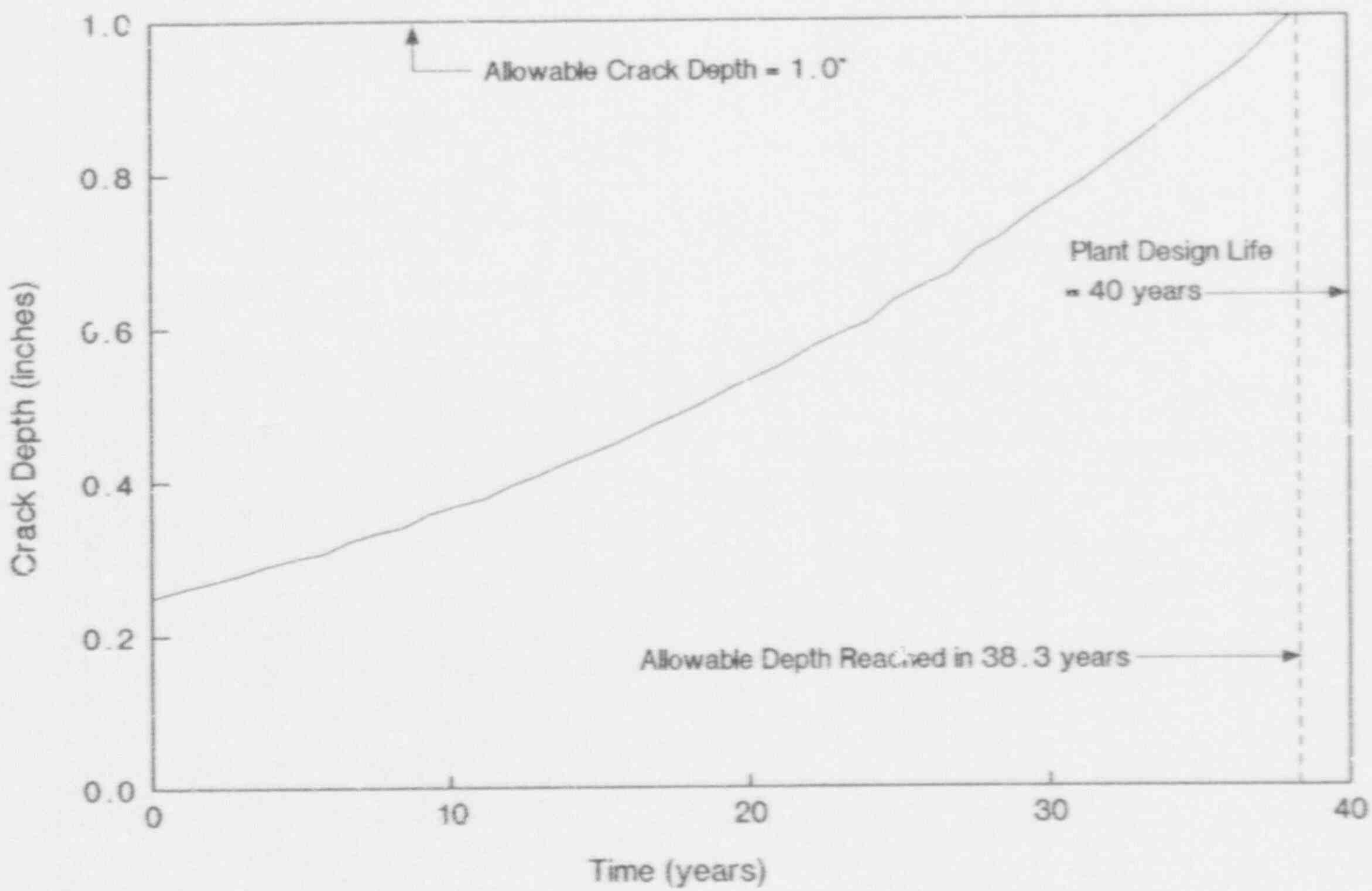


Figure 6-1: Updated Crack Growth Results

7.0 SUMMARY

The Reference 1 crack growth analysis for Fermi 2 was reevaluated using updated cycle count projections and thermal duty based on actual plant data obtained during 1990-1991. Application of the 1989 ASME Code, Section XI crack growth rate relationships resulted in a crack growth greater than the acceptance criterion of one inch for a 40-year plant life. The analysis yielded a crack depth of one inch 38.3 years after initial plant startup.

This analysis is conservative for the following four reasons:

(1) **"Step" temperature changes assumed.**
Due to inadequacies of the strip chart recording devices, conservative assumptions had to be made during the data reduction and digitization process. Because of the compressed time scale on the strip chart records, a transient which takes minutes would be recorded as a step change. As a result, a worst-case "step" change had to be assumed for calculating stresses for these scenarios, and no benefit for a slower, "ramped" rate of change could be taken into account. This scenario is schematically depicted in Figure 7-1(a).

(2) **Steady state thermal stress profiles assumed.**
Again because of the compressed time scale on the strip chart records, no determination could be made of the time between adjacent temperature changes. As a result, a bounding case of using the final, steady state thermal stress had to be assumed. As demonstrated by the thermal stress results of Table 4-1, this can lead to significantly higher thermal stresses than other stress states taken earlier in the transient. This scenario is schematically depicted in Figure 7-1(b).

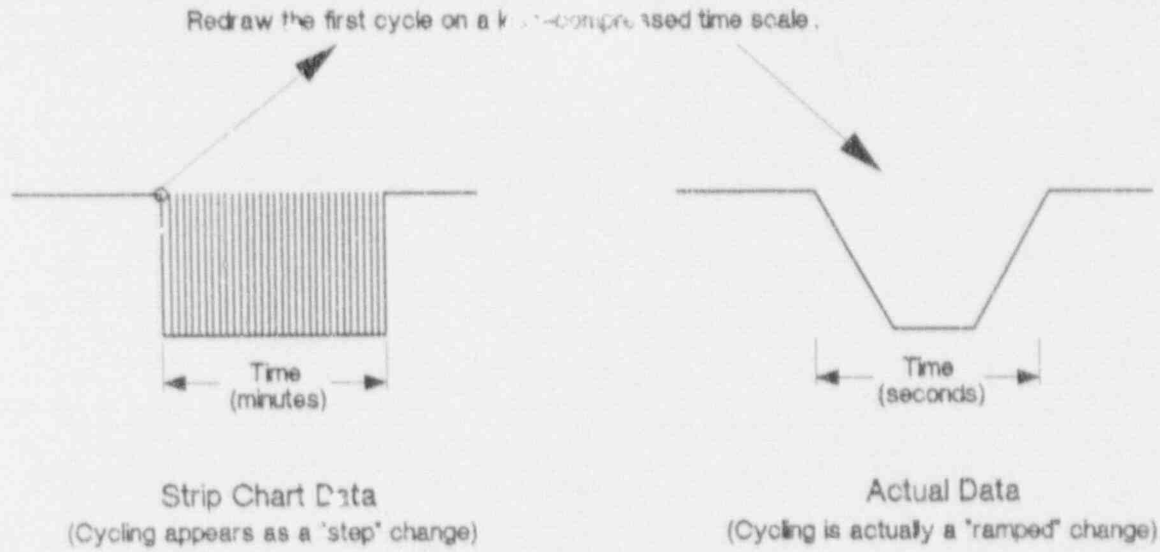
(3) **Low flow condition assumptions.**
Fluctuations which occur during low flow conditions (which contribute significantly to crack growth), are difficult to accurately identify from the strip charts as the recording devices lose sensitivity for low-scale readings. Here again, bounding

assumptions had to be made in order to substantiate the analysis.

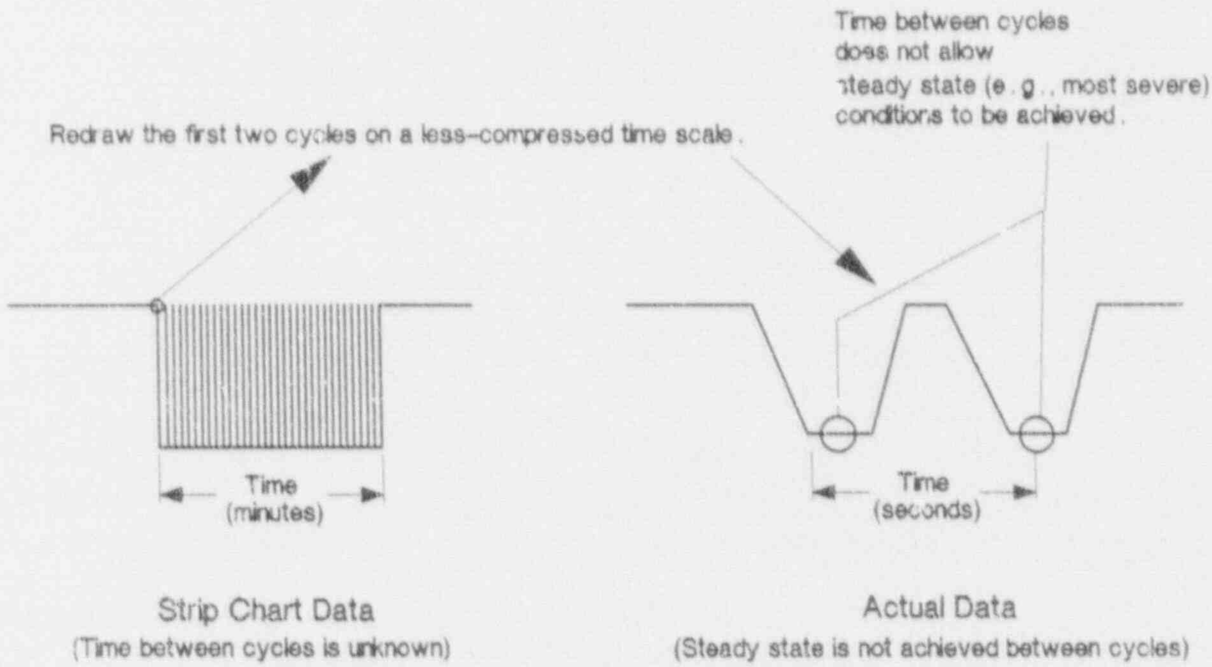
(4) **Conservative cycle count projections.**

A total of 648 startup/shutdown or SCRAM events were projected for Fermi 2 over the 40-year design life of the plant, as shown in Table 3-2. As described in Section 3, this projection is considered to be conservative because of "learning curve" effects which are typically experienced during the initial years of plant operation.

Of the four items identified above, item (4) allows the most direct method of showing compliance with NUREG-0619. Experience with other analyses of this type for other BWRs suggest that future operating experience should improve to the point where the 40-year projected number of events should decrease significantly. Such a decrease would easily contribute to improving the crack growth estimates provided here such that the requirements of NUREG-0619 could be met. Other measures might also be implemented, if plant life extension beyond the 40-year design life of the reactor is a consideration.



(a) Schematic of "Step" Temperature Change Conservatism



(b) Schematic of Steady State Stress Conservatism

Figure 7-1: Conservatism Present in Crack Growth Analysis

8.0 REFERENCES

[1] Report #KH1-0619-001, DRF B11-00484, "Feedwater Nozzle Fracture Mechanics Analysis to Show Compliance with NUREG-0619 for Enrico Fermi Unit 2," GE Nuclear Energy, October 1989.

[2] NUREG-0619, "BWR Feedwater Nozzle and Control Rod Drive Return Line Nozzle Cracking," Office of Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission, November 1980.

[3] Generic Letter 81-11 to all Power Reactor Licensees from Darrell Eisenhut, Office of Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission, February 28, 1981.

[4] GE Drawing 761E246, "Reactor Thermal Cycles, Reactor Vessel," Jan. 1970.

[5] Letter NE-PJ-91-0535, File 0801.05, Kenneth E. Howard (DECo) to G.L. Stevens (GE), "Feedwater Nozzle Crack Growth Analysis," October 15, 1991.

[6] GE Drawing 795E949,"Reactor Cycles," July 1981.

[7] Letter NRC-91-0007, DECo to U.S. NRC, "1990 Annual Operating Report for Fermi 2," February 28, 1991.

[8] Letter NRC-90-0034, DECo to U.S. NRC, "1989 Annual Operating Report for Fermi 2."

[9] Letter NRC-89-0036, DECo to U.S. NRC, "1988 Annual Operating Report for Fermi 2," February 21, 1989.

[10] Letter NRC-88-0030, DECo to U.S. NRC, "1987 Annual Operating Report for Fermi 2," February 29, 1988.

[11] Letter NRC-87-0064, DECo to U.S. NRC, "Annual Operating Report," 6/15/87.

[12] Services Information Letter (SIL) Number 318, "BWR Reactor Vessel Cyclic Duty Monitoring," GE Nuclear Energy, December 1979.

[13] G.J. DeSalvo and R.W. Gorman, <u>ANSYS Engineering Analysis System User's Manual</u>, Swanson Analysis Systems, Inc., Houston, PA, Revision 4.4, 5/1/89.

[14] Design Specification 22A5536AD, Rev. 1,"Feedwater Nozzle and Replacement Safe End Details", GE Nuclear Energy, June 1978.

[15] Y.R. Rashid and J.D. Gilman, "Three Dimensional Analysis of Reactor Pressure Vessel Nozzles," Proc. 1st Int. Conf. on Structural Mechanics in Reactor Technology (SMIRT), Vol. 4, Part G., September 1971.

[16] ASME Boiler and Pressure Vessel Code, Section XI, 1989 Edition.

[17] Letter NEPJ-92-0139, File 0801.05, Kenneth E. Howard (DECo) to Gary Stevens (GE), "RWCU Return Temperature Used in the Feedwater Nozzle Crack Growth Analysis," May 4, 1992.

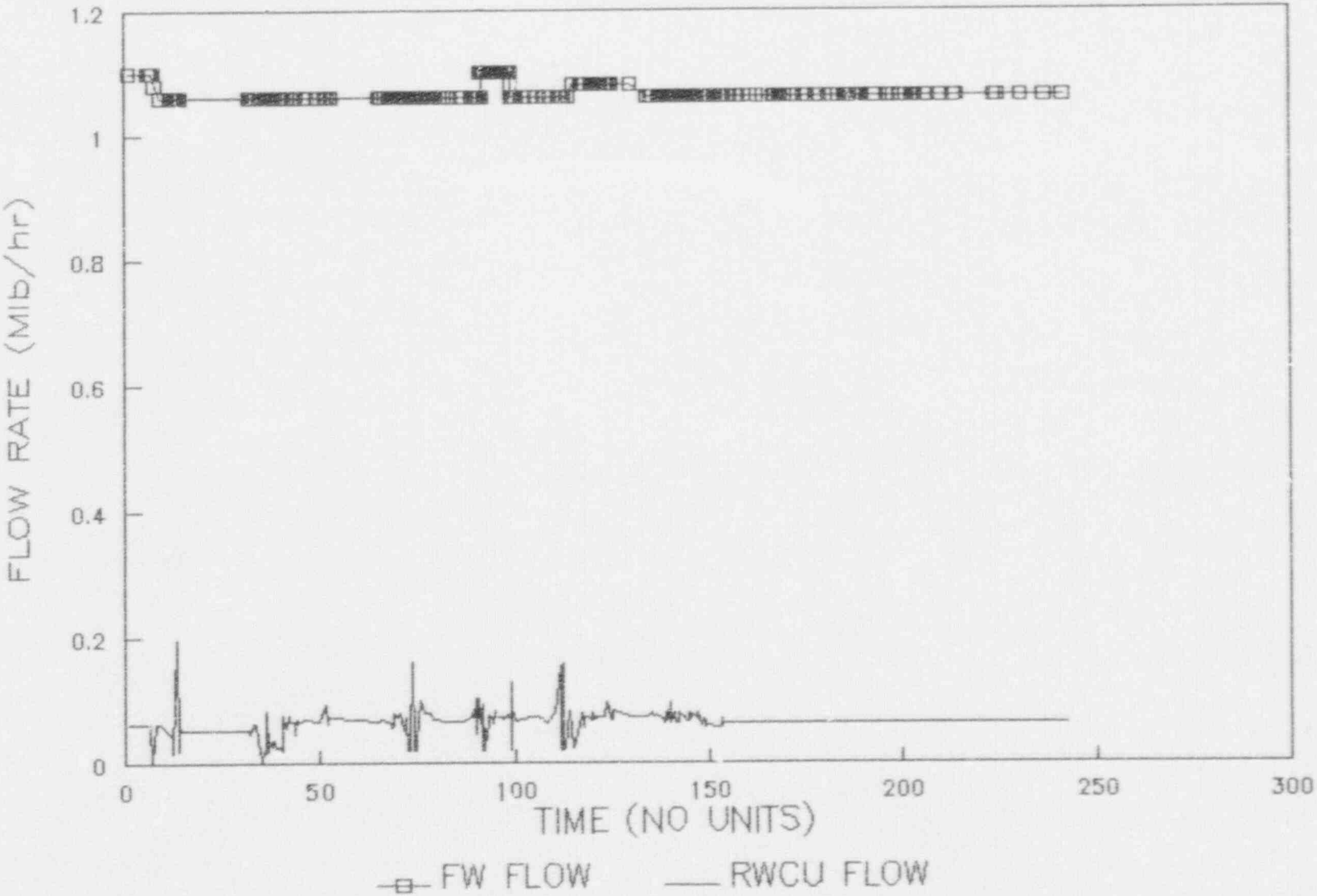
APPENDIX A

APPENDIX A

PLOTS OF DIGITIZED STRIP CHART DATA

(20 plots = 2 plots/trace for each of the 10 traces
shown in Figures 2-1 through 2-10)

APRIL 10-15, 1990 SCRAM, SHUTDOWN AND STARTUP



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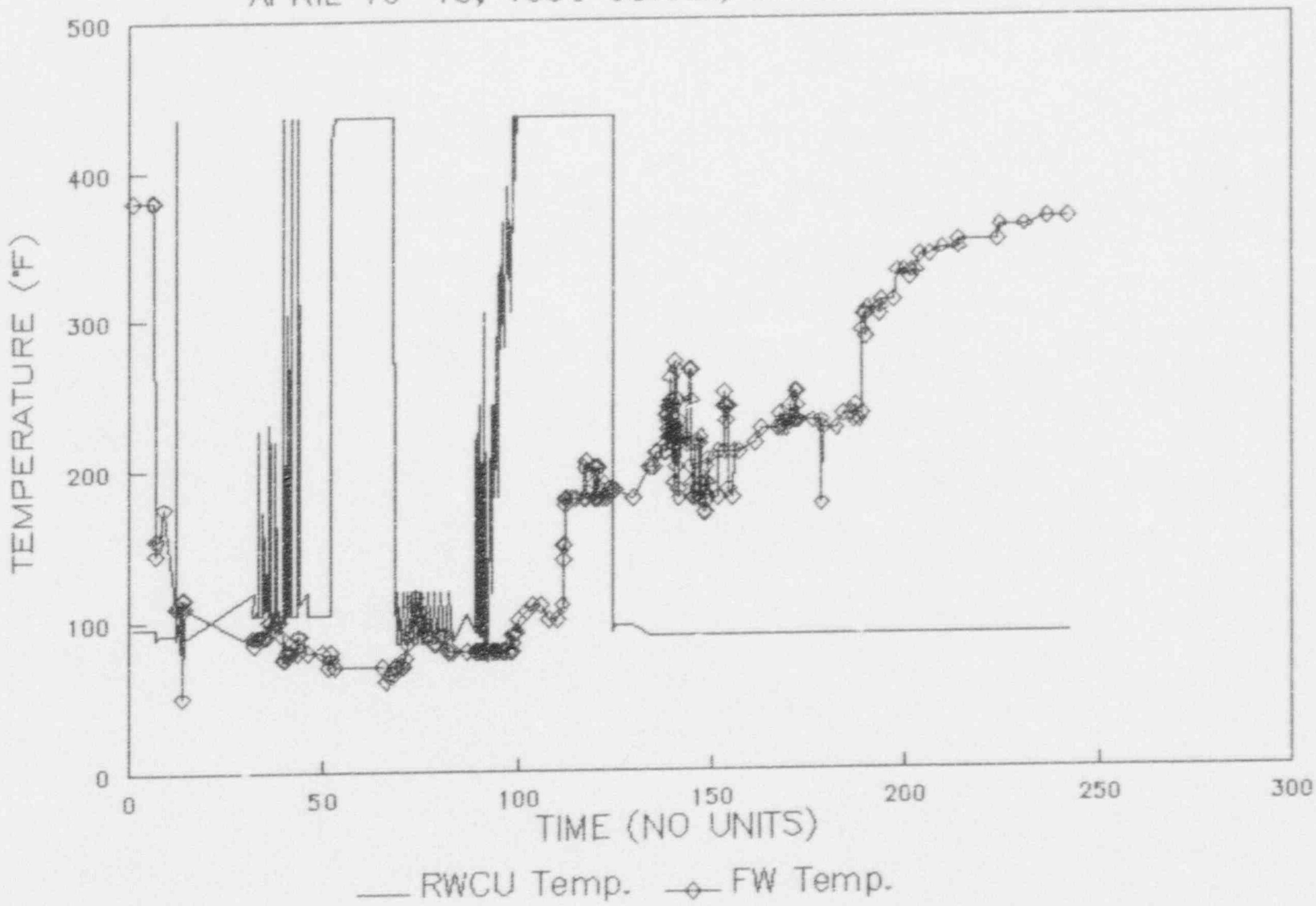
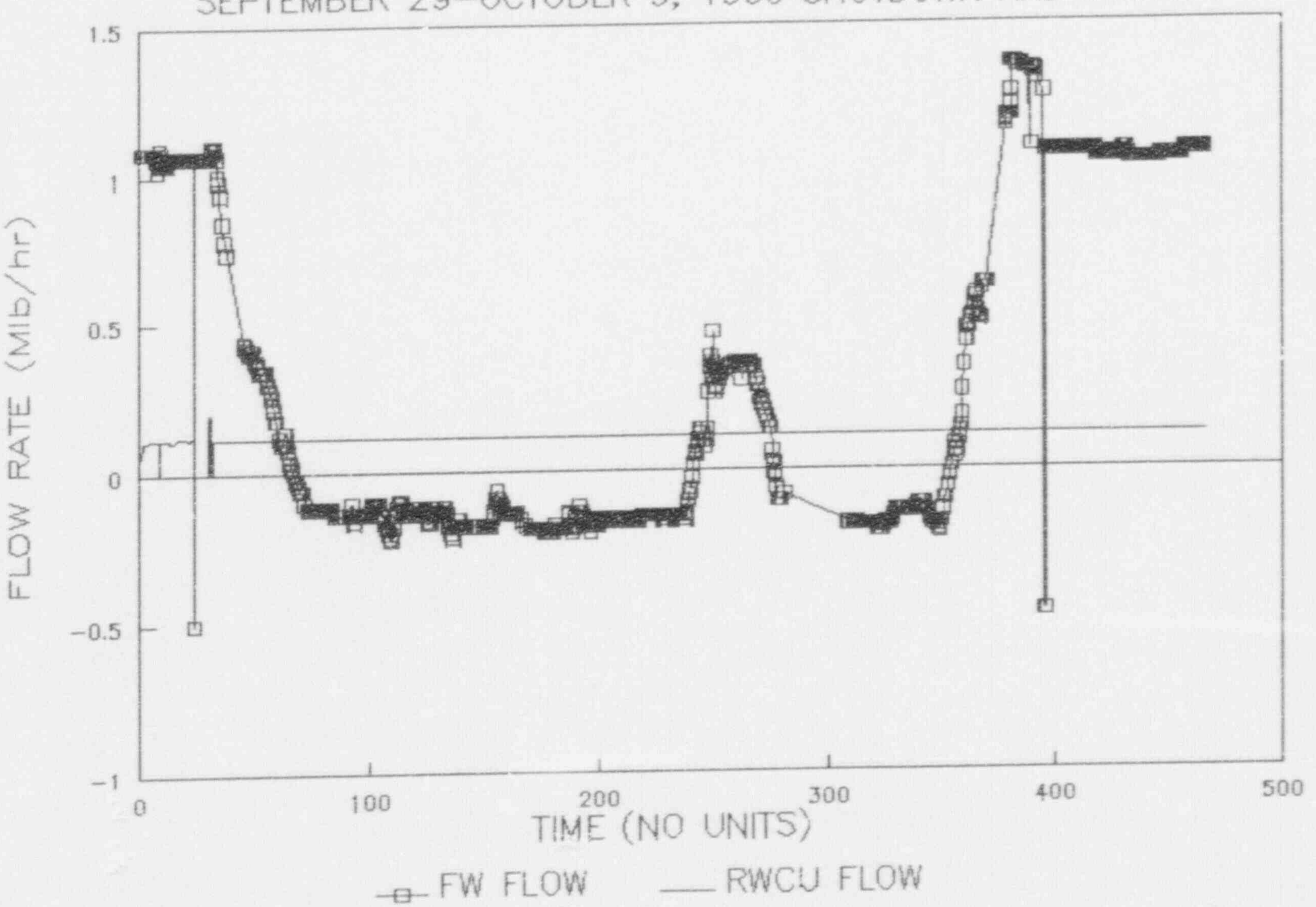
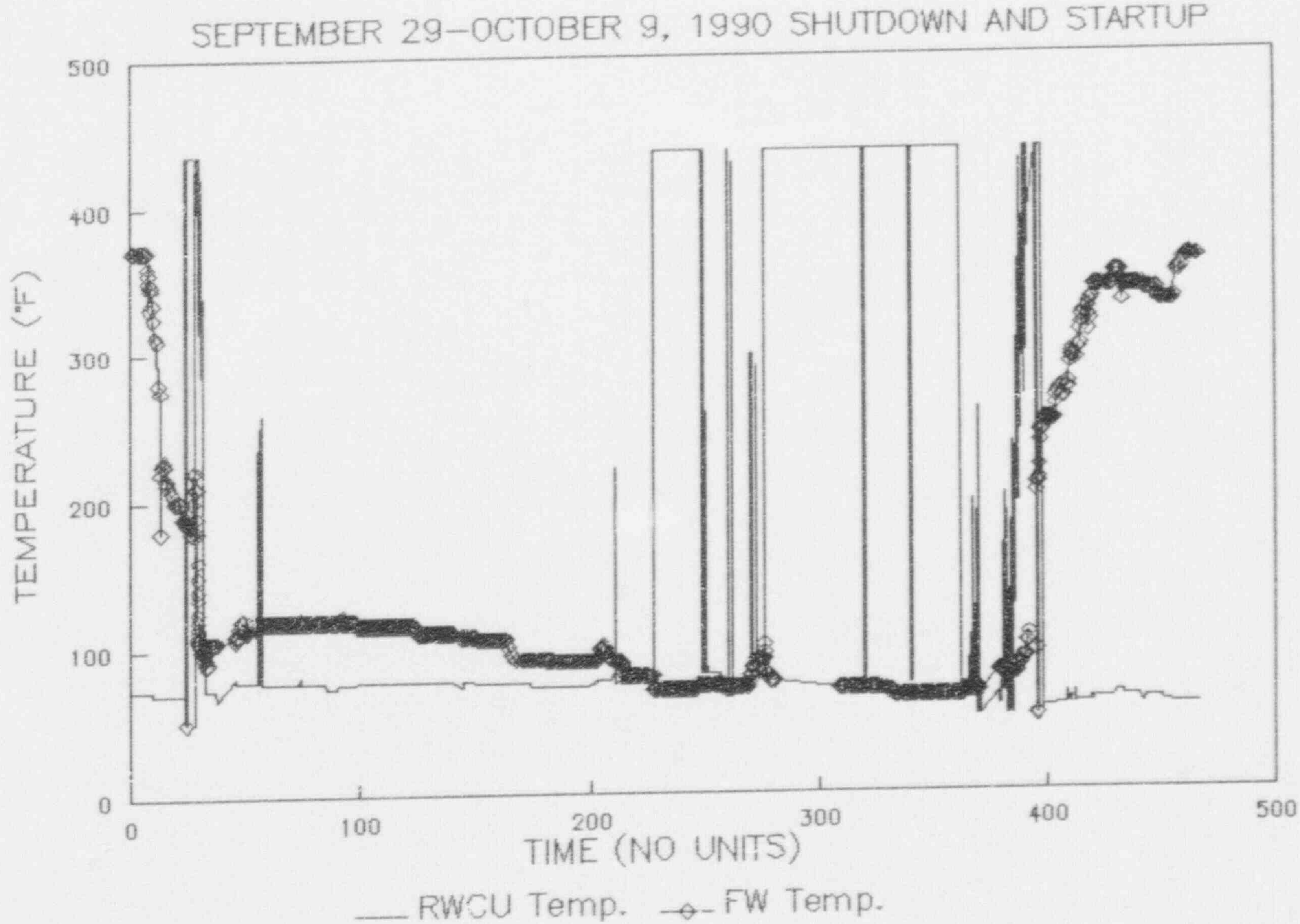
Revision 0

APRIL 10–15, 1990 SCRAM, SHUTDOWN AND STARTUP

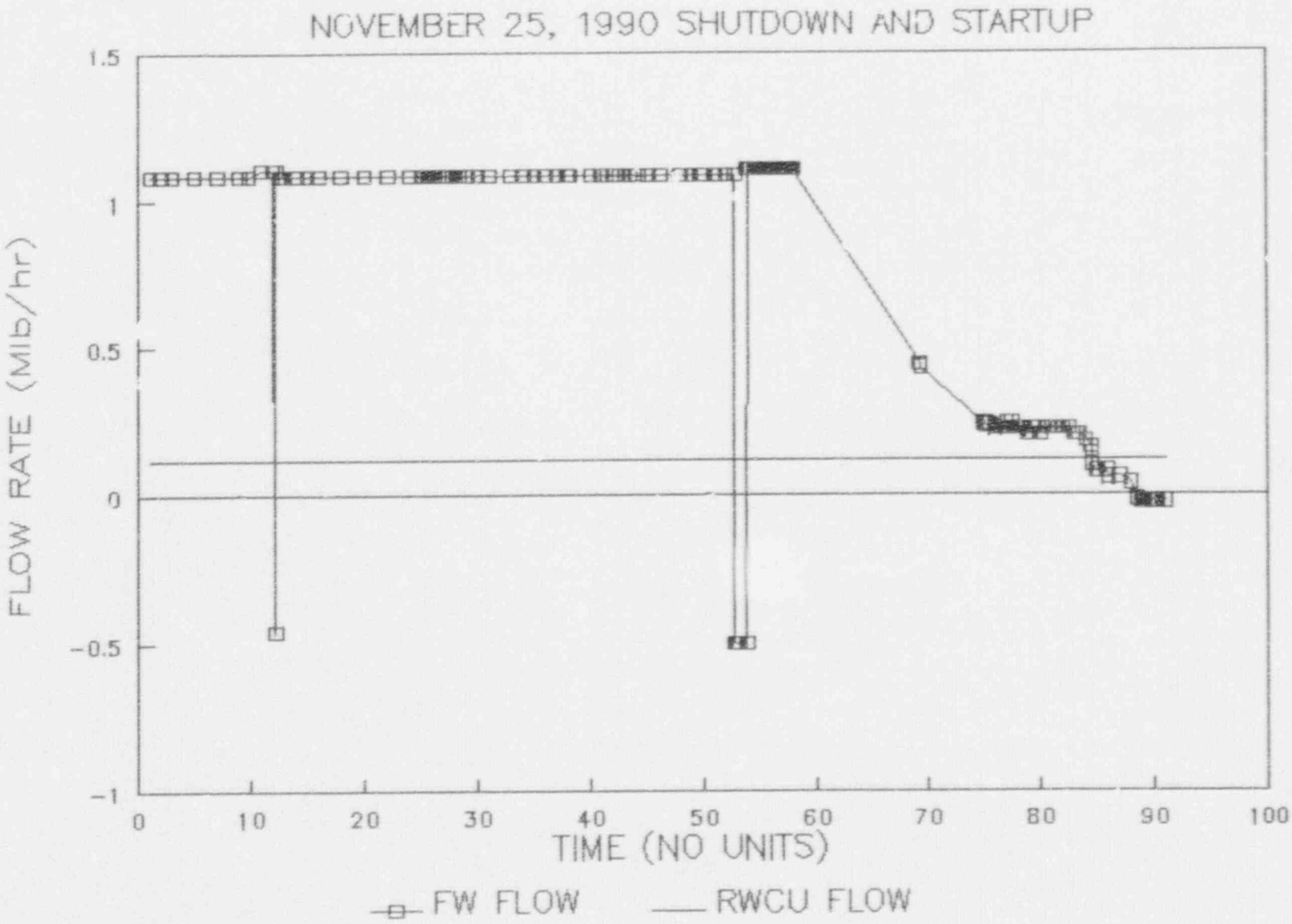


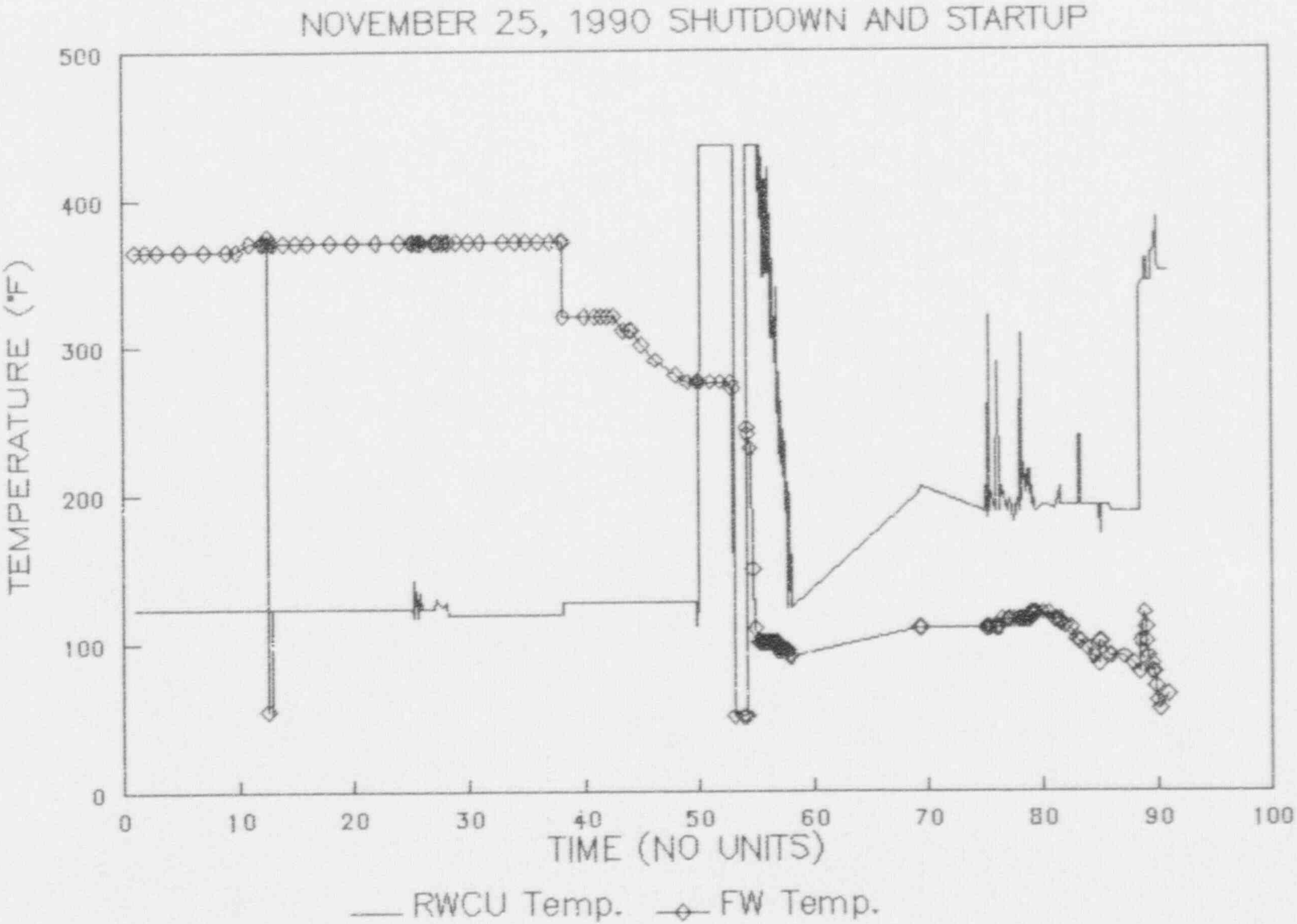
SEPTEMBER 29–OCTOBER 9, 1990 SHUTDOWN AND STARTUP

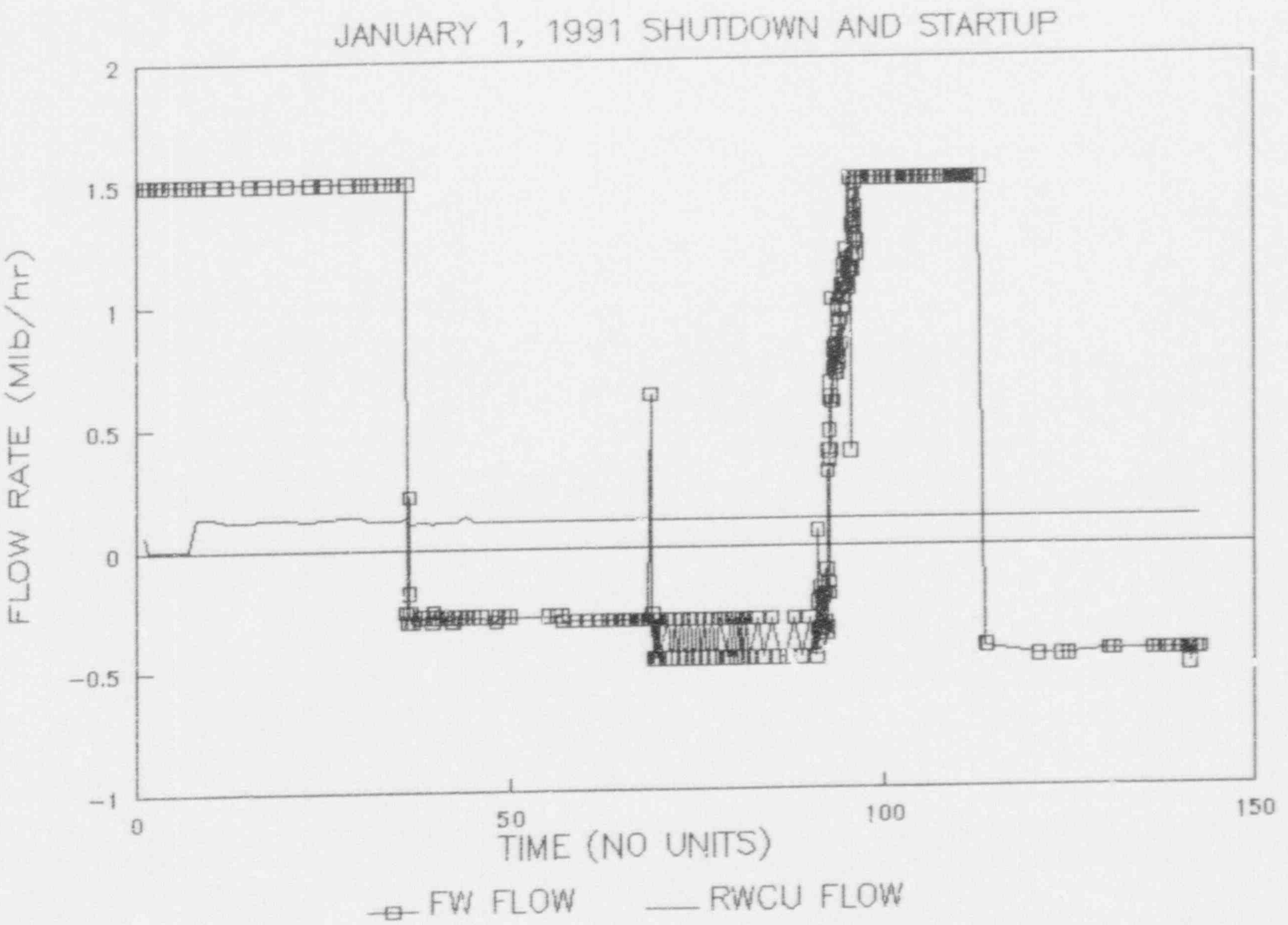




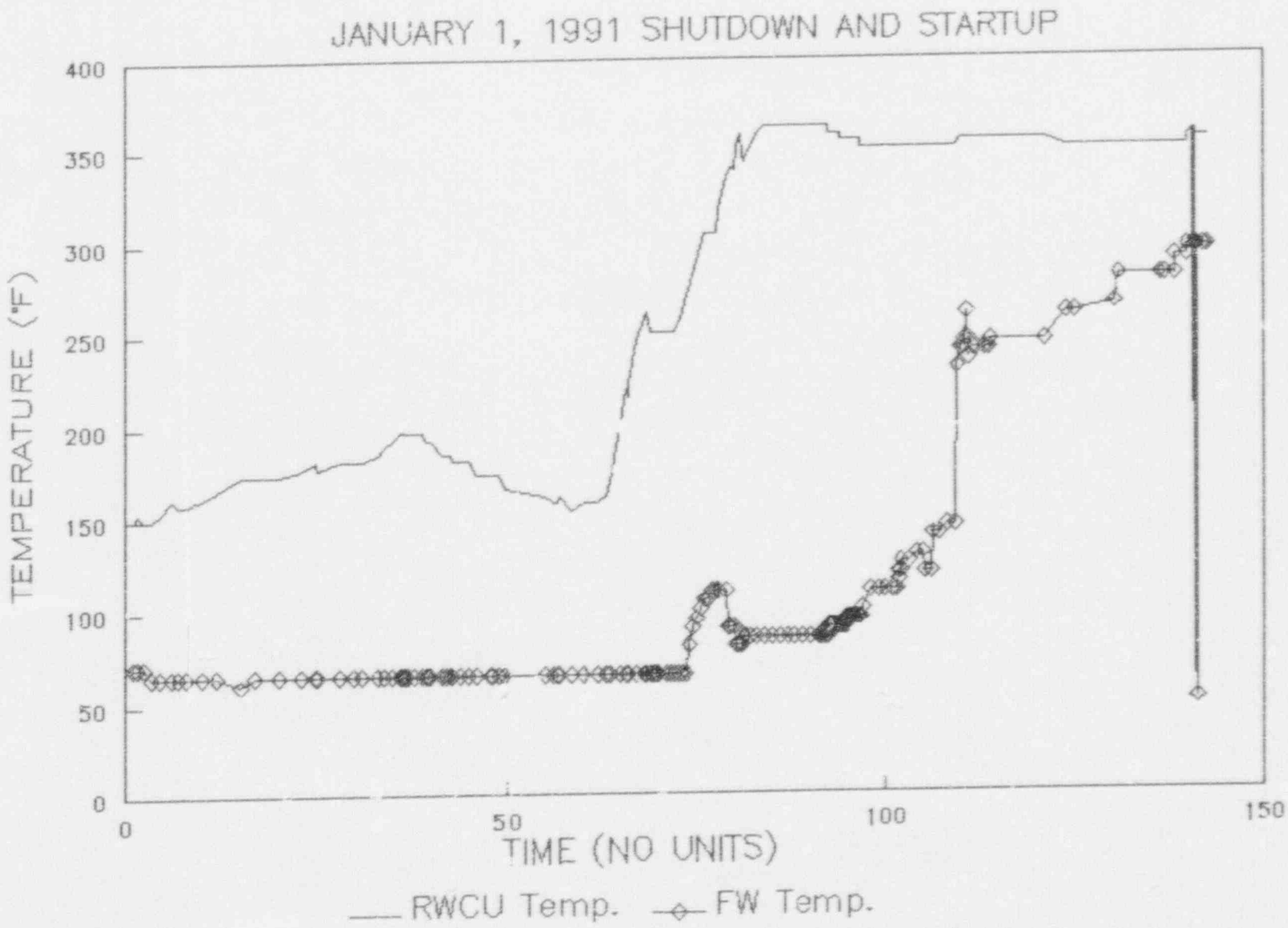
SEPTEMBER 29–OCTOBER 9, 1990 SHUTDOWN AND STARTUP
TEMPERATURE (°F)
500
400
300
200
100
0
0
100
200
300
400
500
TIME (NO UNITS)
RWCU Temp.
FW Temp.


NOVEMBER 25, 1990 SHUTDOWN AND STARTUP
FLOW RATE (Mlb/hr)
1.5
1
0.5
0
-0.5
-1
0
10
20
30
40
50
60
70
80
90
100
TIME (NO UNITS)
FW FLOW
RWCU FLOW

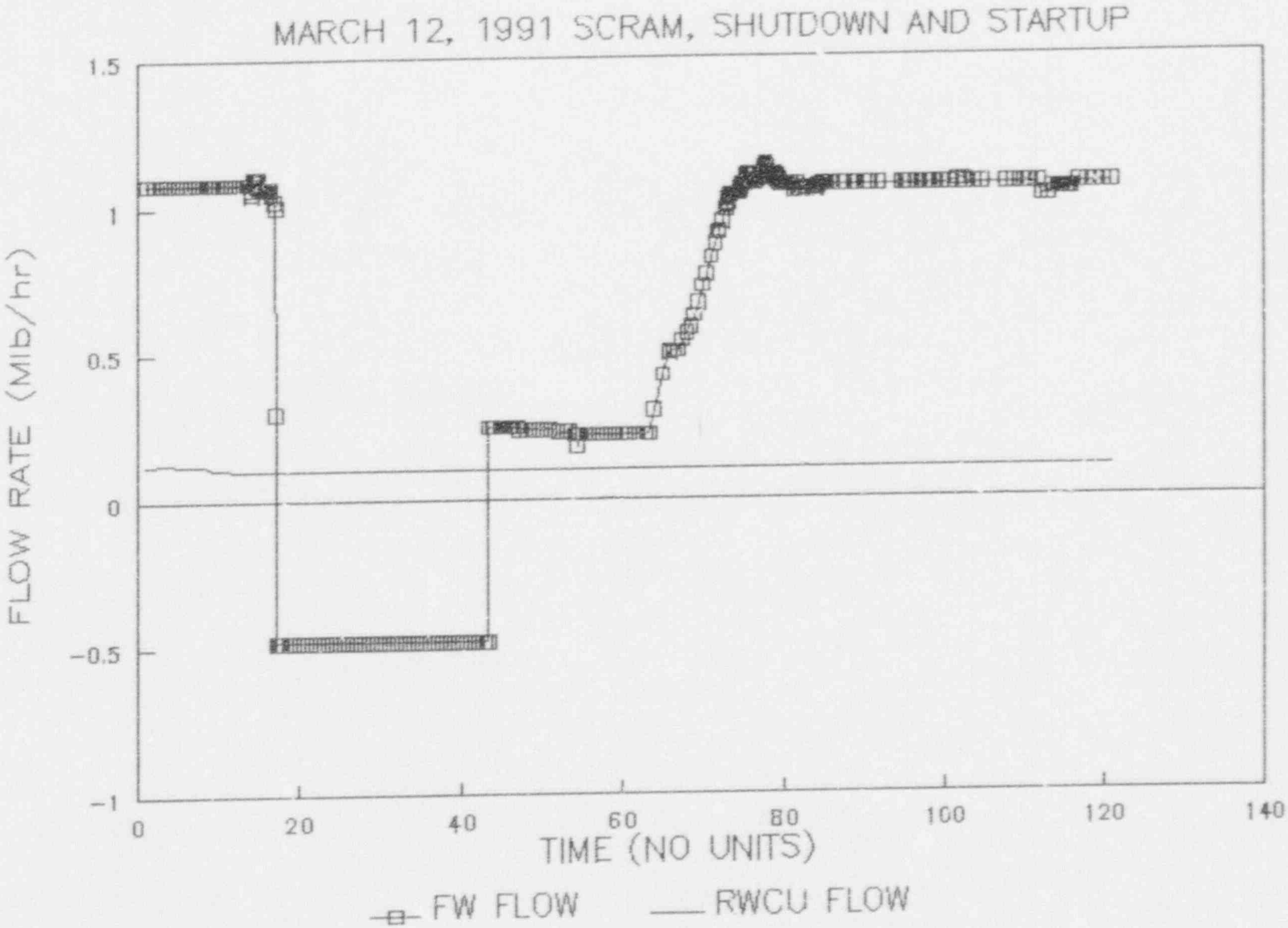

NOVEMBER 25, 1990 SHUTDOWN AND STARTUP
TEMPERATURE (°F)
0
100
200
300
400
500
TIME (NO UNITS)
0
10
20
30
40
50
60
70
80
90
100
RWCU Temp.
FW Temp.

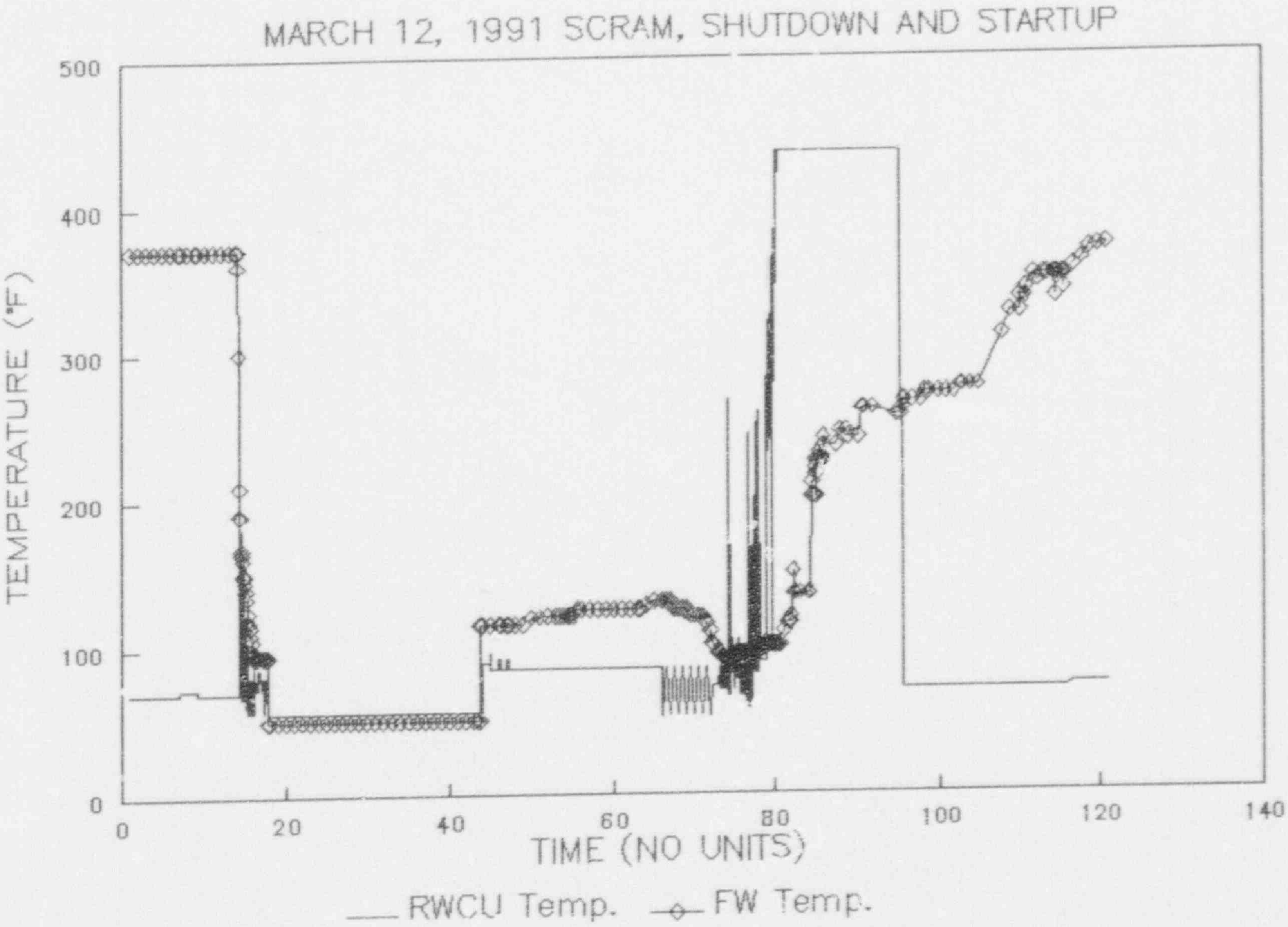


JANUARY 1, 1991 SHUTDOWN AND STARTUP
FLOW RATE (Mlb/hr)
2
1.5
1
0.5
0
-0.5
-1
0
50
100
150
TIME (NO UNITS)
FW FLOW
RWCU FLOW

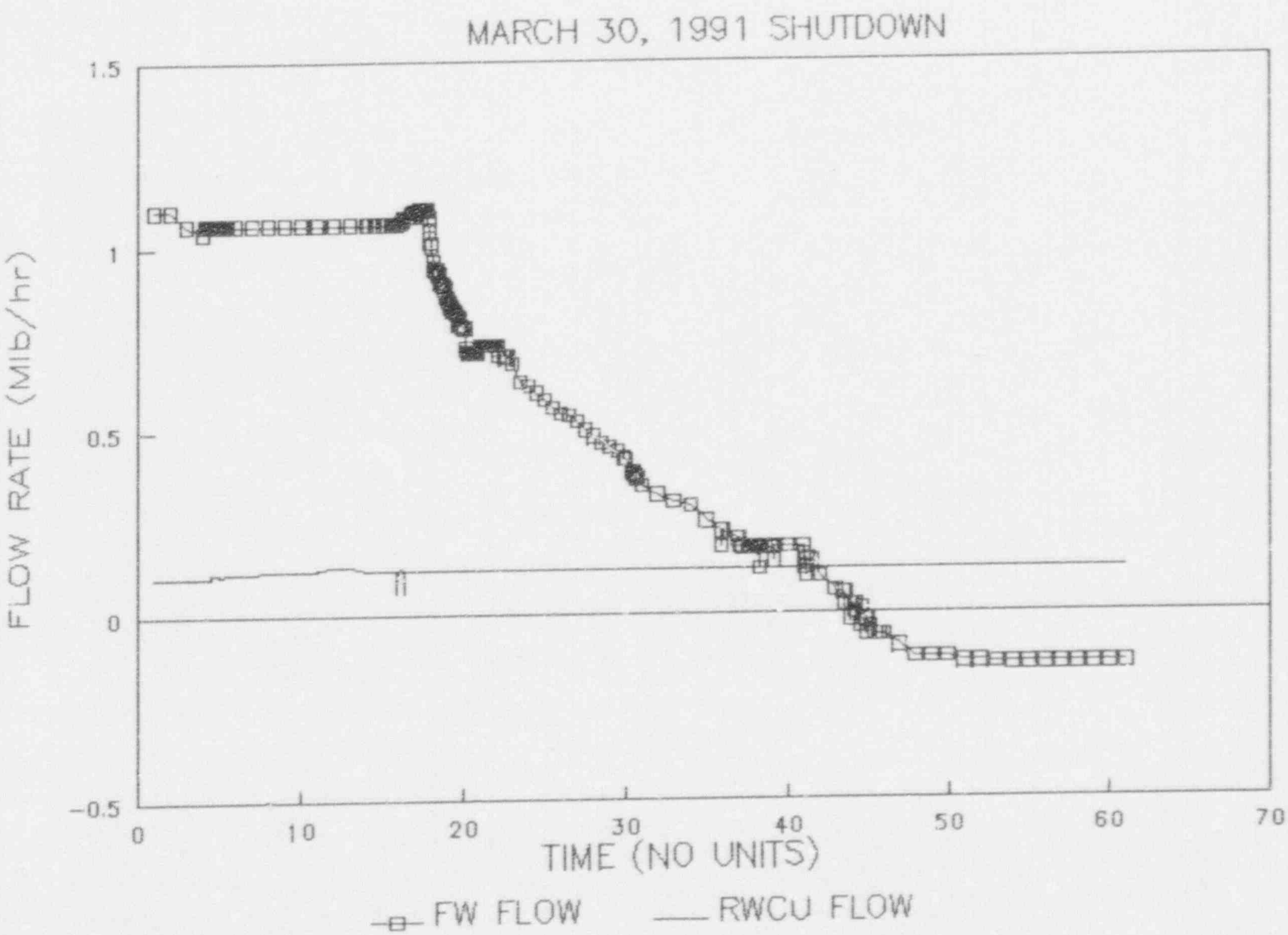


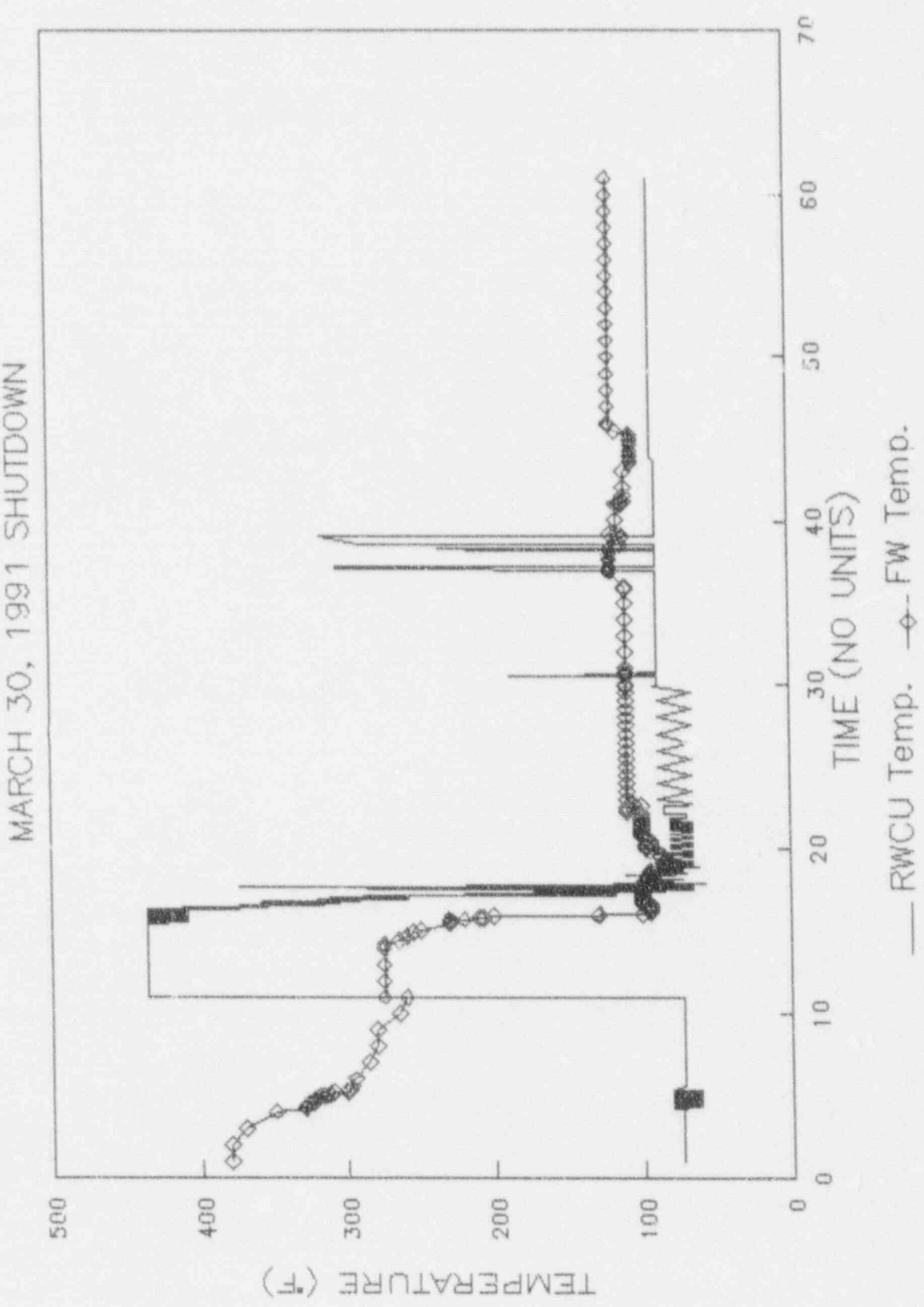
JANUARY 1, 1991 SHUTDOWN AND STARTUP
TEMPERATURE (°F)
400
350
300
250
200
150
100
50
0
0
50
100
150
TIME (NO UNITS)
RWCU Temp.
FW Temp.

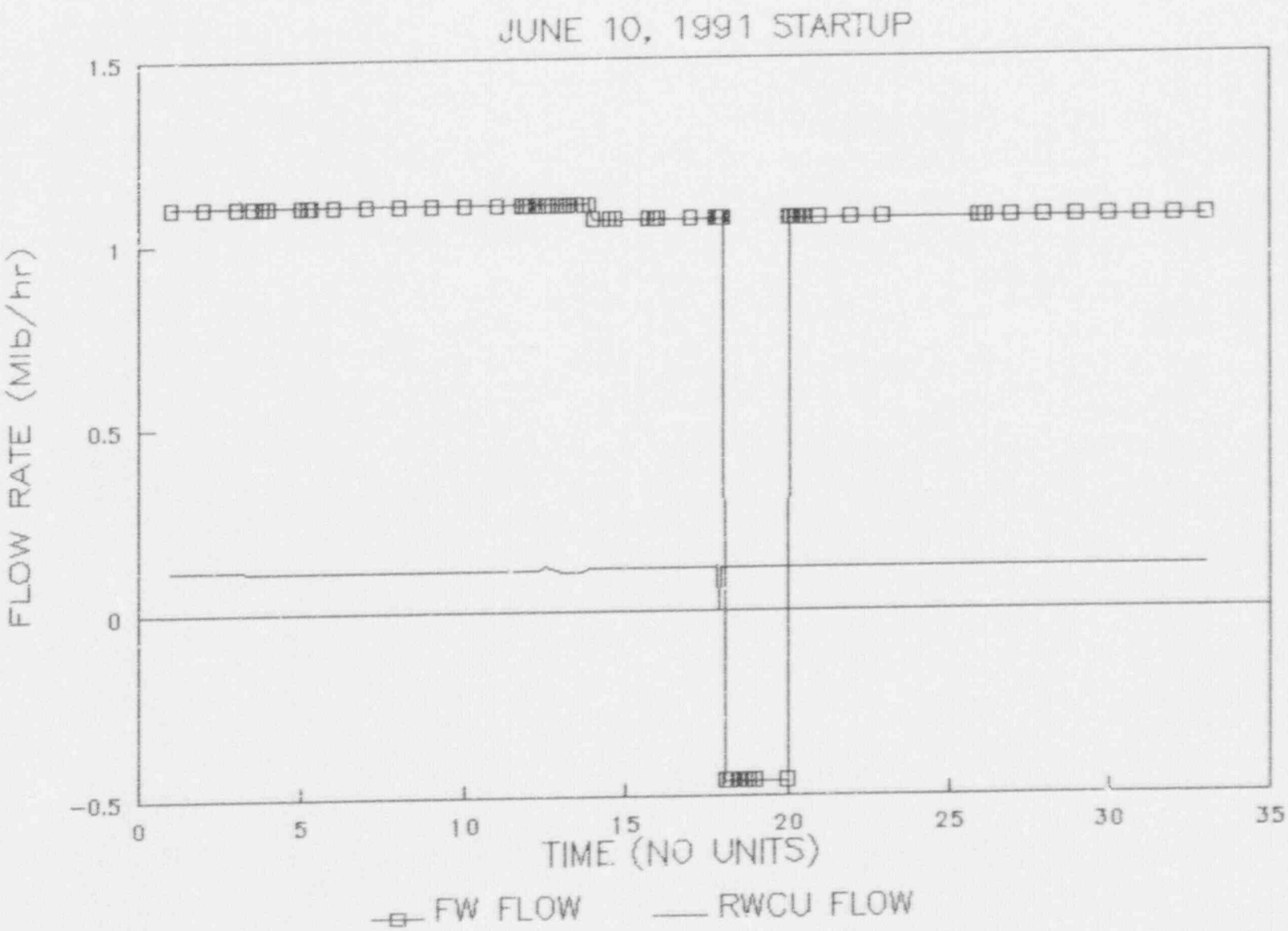

MARCH 12, 1991 SCRAM, SHUTDOWN AND STARTUP
FLOW RATE (Mlb/hr)
1.5
1
0.5
0
-0.5
-1
0
20
40
60
80
100
120
140
TIME (NO UNITS)
FW FLOW
RWCU FLOW



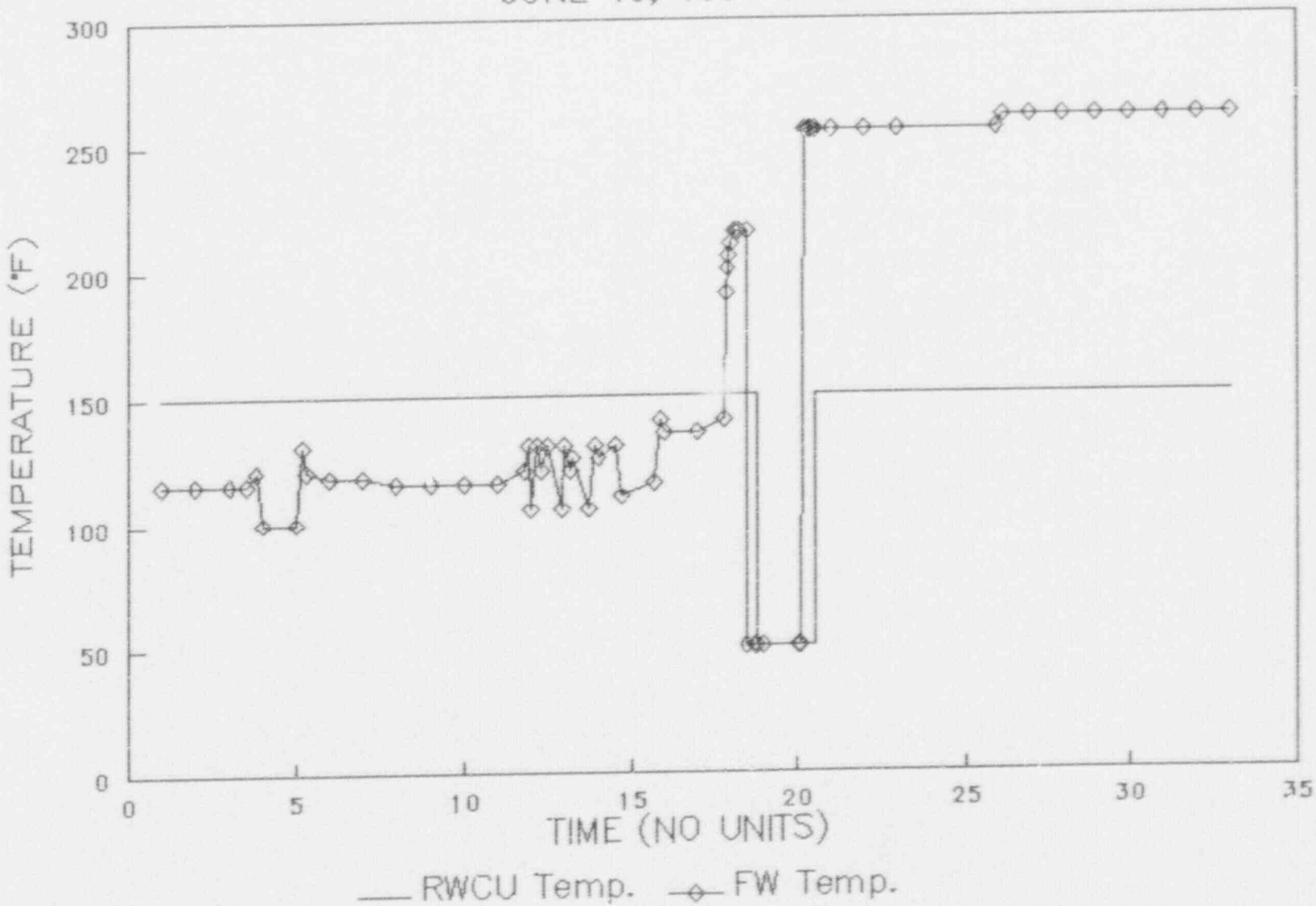
MARCH 12, 1991 SCRAM, SHUTDOWN AND STARTUP
TEMPERATURE (°F)
0
100
200
300
400
500
TIME (NO UNITS)
0
20
40
60
80
100
120
140
RWCU Temp.
FW Temp.


MARCH 30, 1991 SHUTDOWN
FLOW RATE (Mlb/hr)
1.5
1
0.5
0
-0.5
0
10
20
30
40
50
60
70
TIME (NO UNITS)
FW FLOW
RWCU FLOW

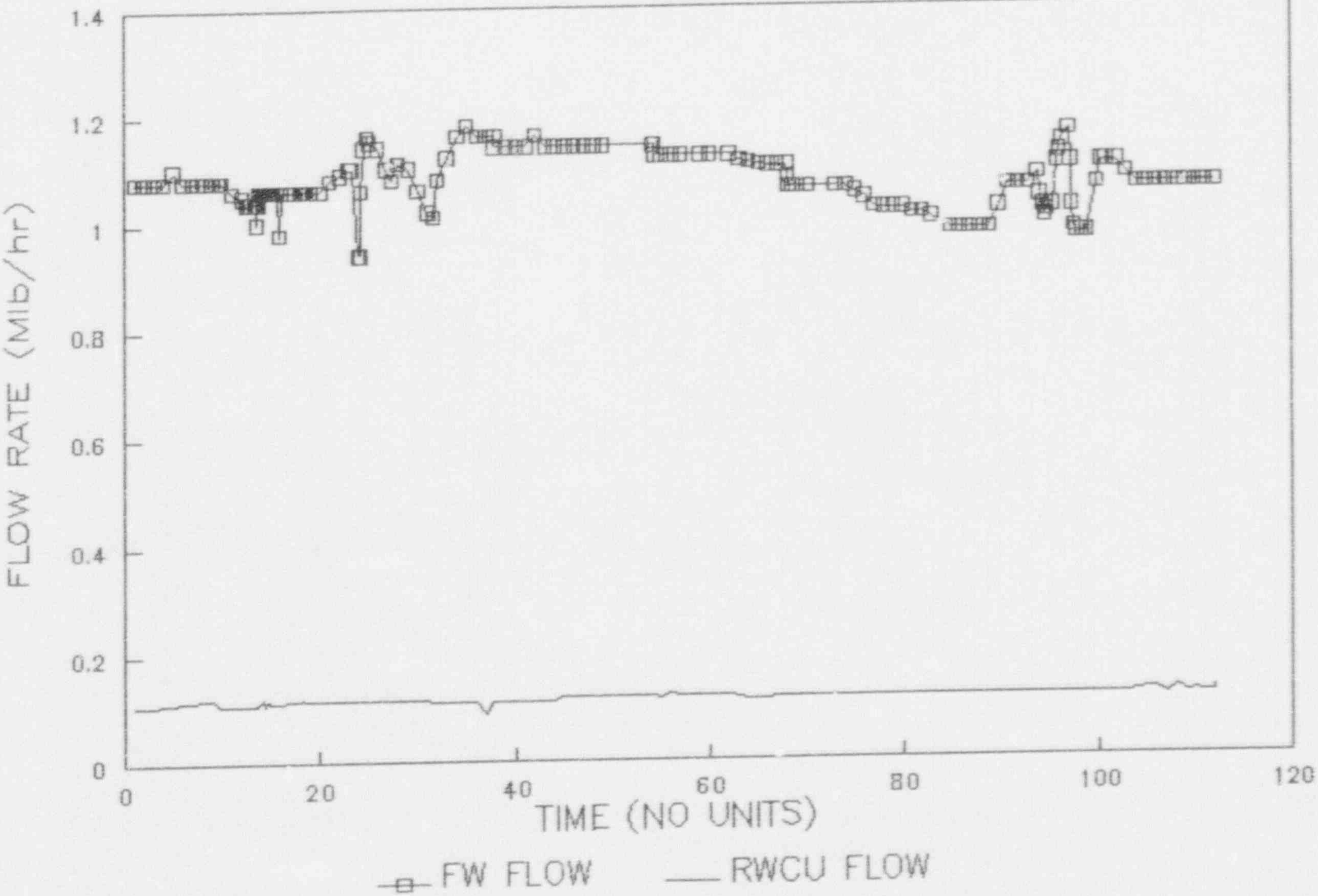

MARCH 30, 1991 SHUTDOWN
TEMPERATURE (°F)
500
400
300
200
100
0
0
10
20
30
40
50
60
70
TIME (NO UNITS)
RWCU Temp.
FW Temp.

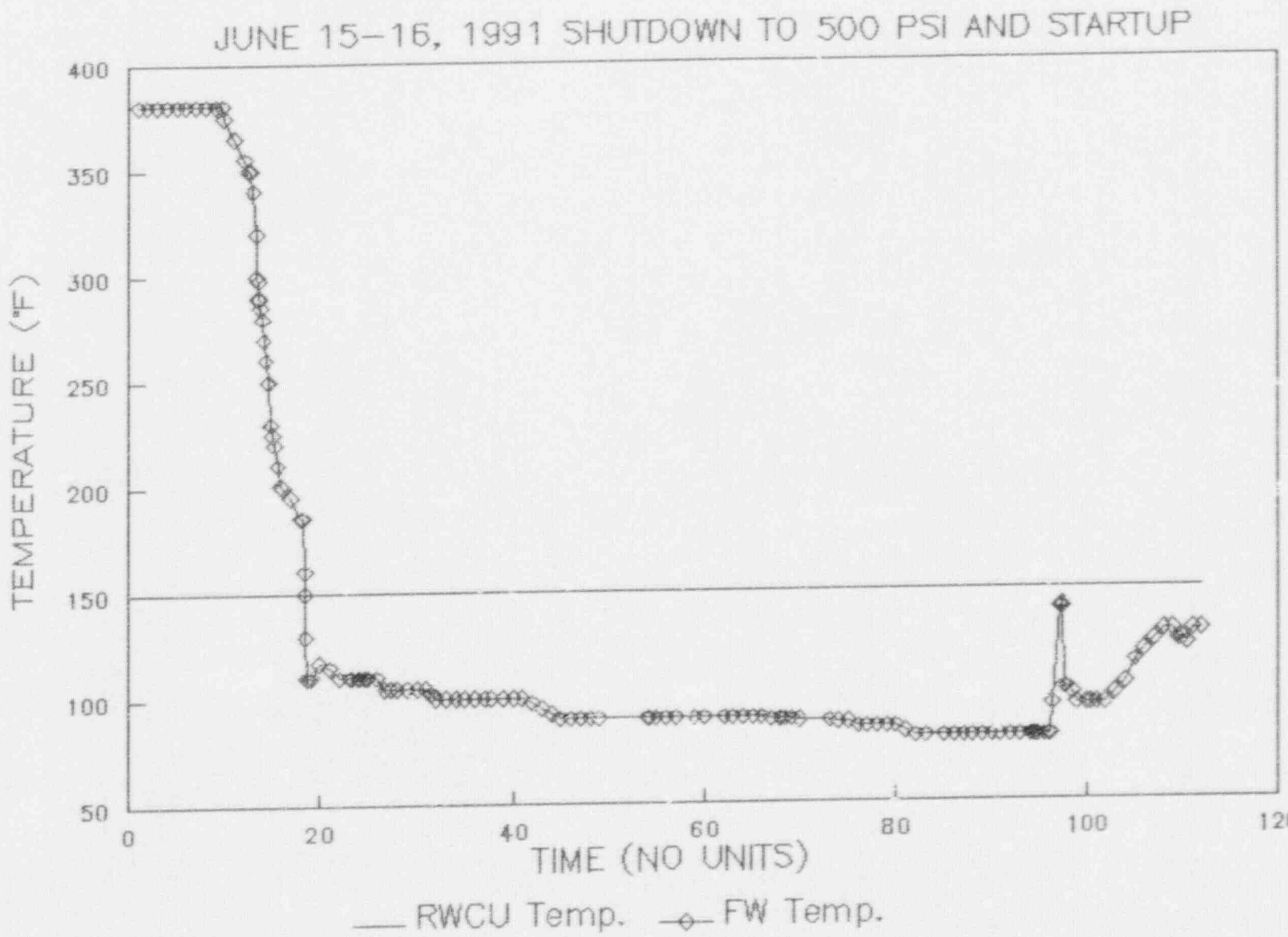

JUNE 10, 1991 STARTUP
FLOW RATE (Mlb/hr)
1.5
1
0.5
0
-0.5
0
5
10
15
20
25
30
35
TIME (NO UNITS)
FW FLOW
RWCU FLOW

JUNE 10, 1991 STARTUP

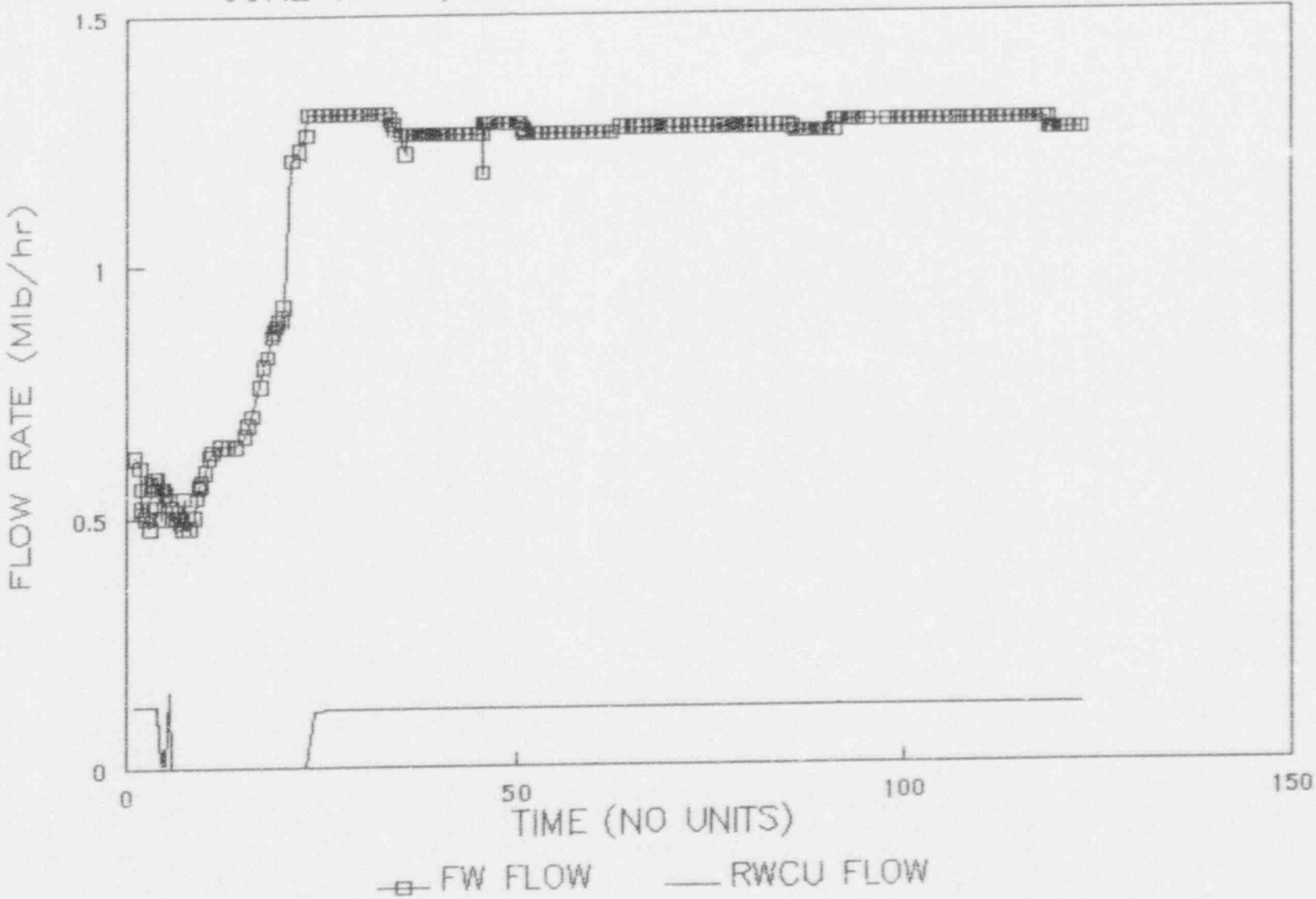


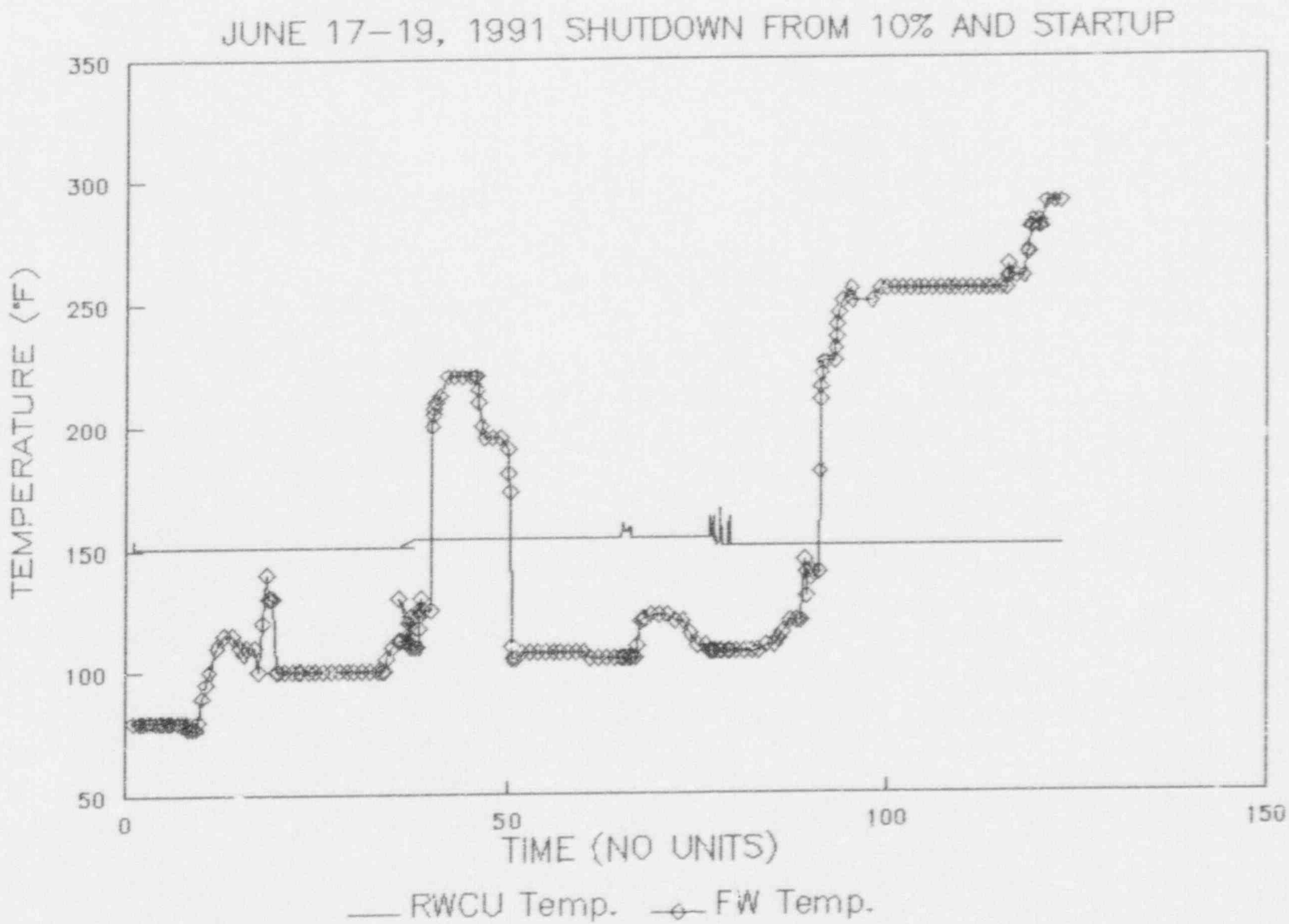
JUNE 15–16, 1991 SHUTDOWN TO 500 PSI AND STARTUP




JUNE 15-16, 1991 SHUTDOWN TO 500 PSI AND STARTUP
TEMPERATURE (°F)
400
350
300
250
200
150
100
50
0
20
40
60
80
100
120
TIME (NO UNITS)
RWCU Temp.
FW Temp.

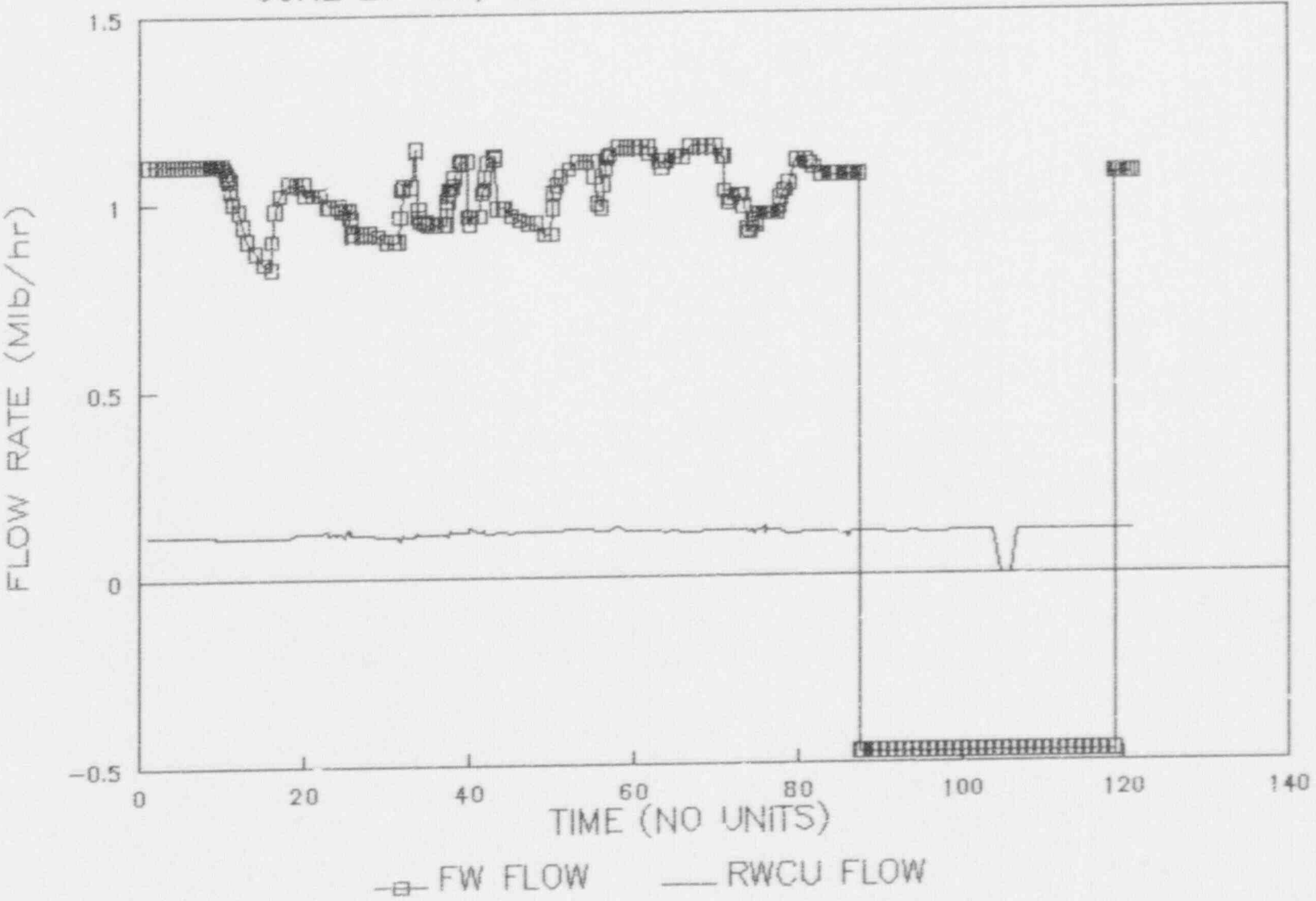
JUNE 17–19, 1991 SHUTDOWN FROM 10% AND STARTUP

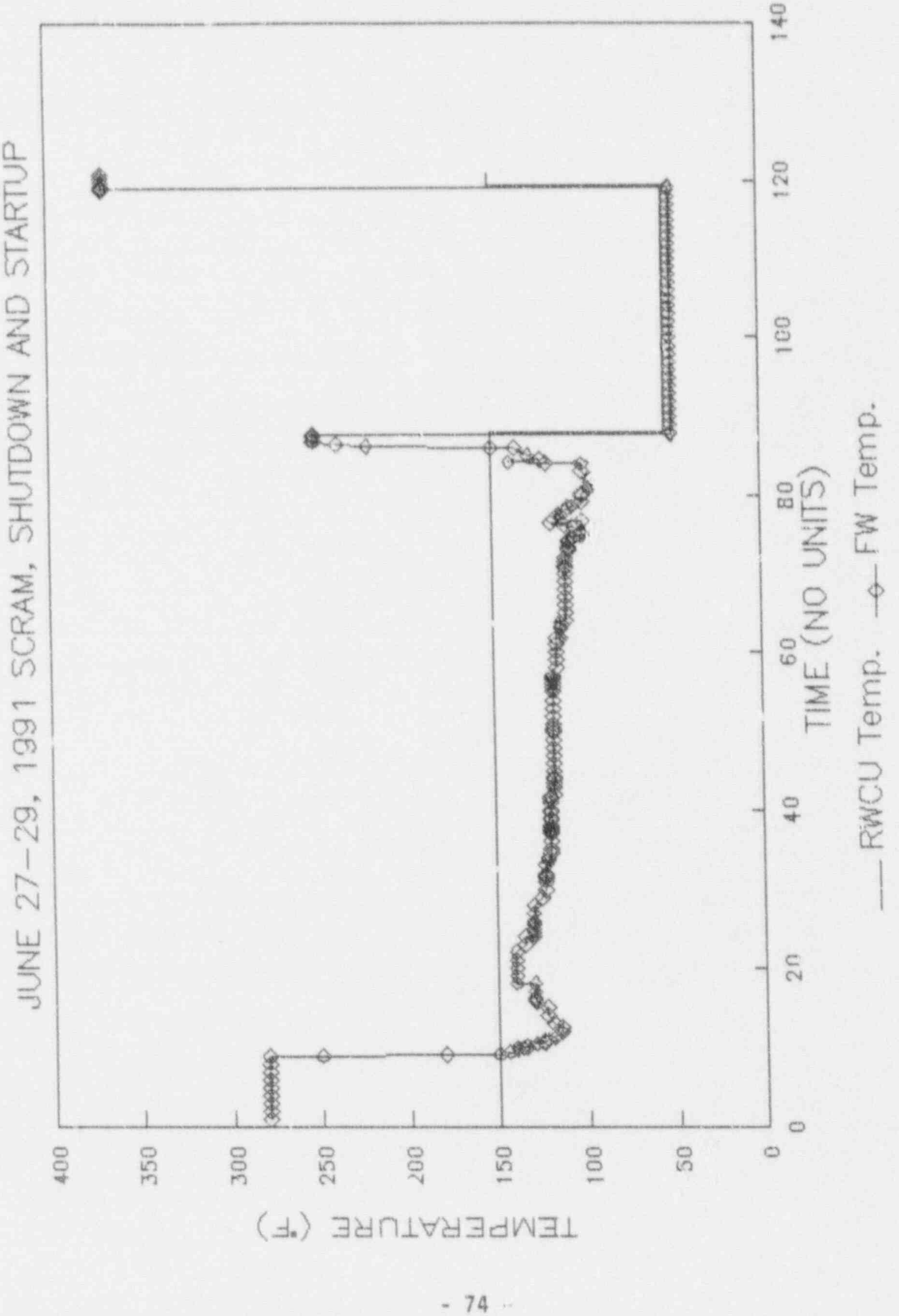




JUNE 17–19, 1991 SHUTDOWN FROM 10% AND STARTUP
TEMPERATURE (°F)
350
300
250
200
150
100
50
0
50
100
150
TIME (NO UNITS)
RWCU Temp.
FW Temp.

JUNE 27-29, 1991 SCRAM, SHUTDOWN AND STARTUP




JUNE 27-29, 1991 SCRAM, SHUTDOWN AND STARTUP
TEMPERATURE (°F)
400
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
TIME (NO UNITS)
RWCU Temp.
FW Temp.

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