PSEG Nuclear LLC
P O Box 236, Hancocks Bridge, New Jersey 08038-0236

PSEG
Nuclear LLC

OCT 1 0 2002

LRN-02-0354
LCR S02-03

United States Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555

Gentlemen:

NON-PROPRIETARY CRITICAL SOFTWARE DOCUMENT FOR CROSSTIE COMPUTER PROGRAM SALEM GENERATING STATION, UNIT NOS. 1 AND 2 FACILITY OPERATING LICENSE NOS. DPR-70 AND DPR-75 DOCKET NOS. 50-272 AND 50-311

By letter dated October 2, 2002 (LR-N02-0331), PSEG Nuclear LLC (PSEG) provided additional information in support of our request for license amendment submitted on June 28, 2002 (LR-N02-0231). Attachment 3 to our October 2, 2002 letter contained a proprietary Critical Software Document for the Crosstie computer program.

Enclosed herein as Attachment 1 is the redacted, non-proprietary version of the proprietary document submitted with our letter of October 2, 2002.

Should you have any questions regarding this transmittal, please contact Mr. William McTigue at (856) 339-1033.

Sincerely,

G. Salamon
Manager – Nuclear Safety and Licensing

Attachment

A001

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LRN-02-0354
ATTACHMENT 1

Non-Proprietary Version

Critical Software Document for CROSSTIE

HOLTEC
INTERNATIONAL

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VERIFICATION AND VALIDATION FOR COMPUTER PROGRAM CROSSTIE

for

PUBLIC SERVICE ELECTRIC AND GAS COMPANY

by

Yu Wang, Ph.D.
Holtec International

Holtec Project 20890
Holtec Report HI-931099

Safety Related
Report Category: A

NON-PROPRIETARY VERSION

HOLTEC
INTERNATIONAL

REVIEW AND CERTIFICATION LOG

DOCUMENT NAME:	Verification and Validation Documentation for Computer Program CROSSTIE
HOLTEC DOCUMENT I.D. NUMBER:	HI-931099
HOLTEC PROJECT NUMBER:	20890
CUSTOMER/CLIENT:	Public Service Electric and Gas Company

REVISION BLOCK				
ISSUE NUMBER	AUTHOR & DATE	REVIEWER & DATE	QA MANAGER & DATE	APPROVED* & DATE
ORIGINAL	12/28/93	IR 12/29/93	MS 12/29/93	12/28/93
REVISION 1				
REVISION 2				
REVISION 3				
REVISION 4				
REVISION 5				
REVISION 6				

This document conforms to the requirements of the design specification and the applicable sections of the governing codes.

Note: Signatures and printed names are required in the review block.

* Must be Project Manager or his designee.

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Appendix A: Test Data (224 pages)
Appendix B: Test Instrument Calibration (19 pages)

1.0 REQUIREMENTS

Program CROSSTIE is developed for Salem Generating Station Units 1 and 2. This report provides the necessary verification and validation for the program in compliance with the applicable Holtec QA requirements. The prime verification approach will be the experimentation. The program will be verified against the site measurements obtained during Salem 1R11 outage.

The principal objectives of this program are summarized in four points:

(i) Predict the refueling cycle when the cross-tie operation is not possible with 120°F maximum operating temperature limit.

(ii) Develop a predictive tool which enables PSE&G to adjust the system variable to extend the cross-tie operation further into the future without upgrading the system.

(iii) Provide the plant reactor engineering a user friendly code to predict spent fuel pool water temperatures and to manage the cross-tie operation with *minimum* input data requirements.

(iv) Provide the plant mechanical engineering group with the necessary software capability to *quantify system changes* which might be required in the future to deal with cross-tie operation.

This computer program will have the following features:

Holtec International
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2.0 DESIGN

To meet the requirements described in Section 1.0, the following analytical components need to be developed for the program:

a) Decay heat calculations.

b) Heat loss calculations.

c) Heat exchanger performance.

d) Numerical algorithm for the non-linear differential equations.

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HOLTEC PROPRIETARY INFORMATION

HOLTEC PROPRIETARY INFORMATION

HOLTEC PROPRIETARY INFORMATION

HOLTEC PROPRIETARY INFORMATION

2.6 Program Acceptance Criteria

Program CROSSTIE will be validated by comparing runs with experimental data. Experimental data is to be collected from both Salem spent fuel pools and Unit 2 spent fuel pool cooling system during the scheduled 1R11 outage. Calculated water temperatures from program CROSSTIE will be compared to experimental data water temperatures over a defined time period. The acceptability of the program will be determined through engineering judgement based on the percent deviation between the measurements and the calculated results.

Holtec International
Proprietary Information

3.0 IMPLEMENTATION

The program CROSSTIE is developed using FORTRAN. The Salem specific heat exchanger parameters and the spent fuel pool geometry are built into the program. The program requires the following input data files:

UNIT1.DCY:	Burnup and discharge data for the Unit 1 spent fuel inventory.
UNIT2.DCY:	Burnup and discharge data for the Unit 2 spent fuel inventory.
RFILE:	Name will be specified by the user. The file contains input parameters for a specific outage.

Note: RFILE contains data for a specific outage and the fuel inventory data inputted in files UNIT1.DCY AND UNIT2.DCY should cover all prior discharges.

A sample of the input files is attached.

The program also requires the following inputs during the execution of the program:

RFILE Name

TAVC:	Time after-reactor-shutdown to start crosstie, hrs.
TL:	Pool water temperature limit for switchover, °F
TI:	CCW coolant temperature, °F
TEND:	Ending time for integration, hrs.

CROSSTIE will generate the following output files:

RESULT.TEM:	Hard copy of input and output results.
PLOT.DAT:	Containing time coordinates, Units 1 and 2 pool temperatures for plotting.
UNIT1.HTL:	Decay heat results from Unit 1 spent fuel inventory.
UNIT2.HTL:	Decay heat results from Unit 2 spent fuel inventory.

INPUT FILE #1 & #2

BURNUP FOR THE FUEL IN THE SFP
SALEM UNIT 1 & 2

File Name: "Unit1.dcy"
"Unit2.dcy"

Cycle No.	Discharge Date	Batch No.	No. of FAS	Wt. Assy KgU	Exposure MWD/MTU	Power MW(t)

Note: Batch - Group of assemblies having same burnup. It is numbered sequantialy from 1 for each cycle.

Power - Reactor power in MW(t).

Discharge Date- Enter in the format of MM,DD,YY. Example: 09,22,93

EXAMPLE DATA FILE:

1	01,21,83	1	56	461.0	18400	3411
1	01,21,83	2	12	461.0	19700	3411
2	10,04,84	1	09	461.0	20700	3411
2	10,04,84	2	52	461.0	23900	3411
2	10,04,84	3	07	461.0	21600	3411
3	10,02,86	1	53	461.0	33400	3411
3	10,02,86	2	04	461.0	21600	3411
4	08,31,88	1	02	461.0	32200	3411
4	08,31,88	2	30	461.0	37000	3411
4	08,31,88	3	42	461.0	37400	3411
4	08,31,88	4	03	461.0	38500	3411
5	03,31,90	1	09	461.0	36000	3411
5	03,31,90	2	08	461.0	29700	3411
5	03,31,90	3	12	461.0	41500	3411
5	03,31,90	4	01	461.0	25300	3411
5	03,31,90	5	45	461.0	36500	3411
6	11,09,91	1	33	461.0	42400	3411
6	11,09,91	2	28	461.0	36400	3411
6	11,09,91	3	08	461.0	32300	3411
7	03,16,93	1	08	461.0	34800	3411
7	03,16,93	2	08	461.0	39600	3411
7	03,16,93	3	01	461.0	29300	3411
7	03,16,93	4	01	461.0	43100	3411
7	03,16,93	5	08	461.0	39900	3411
7	03,16,93	6	39	461.0	36400	3411
7	03,16,93	7	04	461.0	30400	3411

INPUT FILE #3
SALEM UNITS 1&2 CROSS-TIE EVALUATION
INPUT INSTRUCTION

LINE 1:

FIN: DESCRIPTION OF YOUR JOB

LINE 2:

MTD(3): REACTOR SHUTDOWN DATE. MTD(1)=MONTH, MTD(2)=DAY, MTD(3) = YEAR.

LINE 3:

ND: UNIT WHICH IS GOING TO BE IN OUTAGE

LINE 4:

Wt: SPENT FUEL POOL COOLING HEAT EXCHANGER COOLANT (CCW) FLOW RATE, GPM (DESIGN=3000 GPM)

Ws: SPENT FUEL POOL WATER FLOW RATE, GPM (DESIGN=2280GPM; 1R11 MEASUREMENT: UNIT1=2400 GPM, UNIT2=2000 GPM)

V: NET WATER VOLUME IN THE SPENT FUEL POOL AND THE TRANSFER POOL

LINE 5:

N1: NO OF FAS IN THE BATCH 1 OF THE DISCHARGE

N2: NO OF FAS IN THE BATCH 2 OF THE DISCHARGE

N3: NO OF FAS IN THE BATCH 3 OF THE DISCHARGE

TAO: DECAY TIME BEFORE TRANSFER FOR THE 1st DISCHARGE,HRS

TAOS: TOTAL FUEL TRANSFER TIME FOR THE DISCHARGE, HRS

LINE 6:

RP:	REACTOR RATED POWER, MW(t)
CF:	CAPACITY FACTOR OF THE LAST 4 MONTHS BEFORE THE LATEST SHUTDOWN
BP1:	AVERAGE BURNUP FOR THE ASSEMBLIES IN BATCH 1
BP2:	AVERAGE BURNUP FOR THE ASSEMBLIES IN BATCH 2
BP3:	AVERAGE BURNUP FOR THE ASSEMBLIES IN BATCH 3
UW:	ASSEMBLY AVERAGE URANIUM WEIGHT

LINE 7:

TDRY:	AMBIENT AIR TEMPERATURE (DRY BULB) IN THE FUEL HANDLING BUILDING, F
WR:	RELATIVE HUMIDITY IN THE FUEL HANDLING BUILDING, FRACTION

EXAMPLE INPUT:

```
Salem cross-tie for Unit 1 outage, 10/2/93
10,02,93
1
2100, 2040, 59000
0,0,0,240.,60.
3411.,1.0,40300.,43200.,40000.,461.0
74., 0.33
```

4.0 EXPERIMENT

An experimental program to calibrate program CROSSTIE was jointly undertaken by PSE&G and Holtec International. Data was collected at both Salem spent fuel pools and Unit 2 spent fuel pool cooling system during the scheduled 1R11 outage in the timeframe October-November, 1993. The test instruments were installed by the Research and Testing Laboratory of PSE&G. The instrument calibration data is attached in Appendix B of this report.

4.1 Test Setup

Measurements are connected to four data acquisition computers. The corresponding data collected are named "DB1", "DB2", "DB3", and "DB4", respectively. DB1 contains all the measurement channels from the Unit 1 pool; DB2 contains all the measurement channels from Unit 2 pool; DB3 contains measurement channels for the Unit 2 SFHX; and DB4 contains the measurement channels for both Unit 1 and Unit 2 spent fuel water flows. The readings on the ambient air temperature and the relative humidity of the Fuel Handling Building are done manually. The instrument locations in the spent fuel pool and the associated data acquisition channels are described below and shown in Figures 4.1 to 4.4. The instrument locations for the fuel pool cooling systems are shown in Figure 4.5a.

a. Unit 1 Spent Fuel Pool Temperature

- Suction from pool (DB1, CH 1,2)
- Discharge to pool (DB1, CH 3,4)
- Grid location CC-14, 5' above fuel rack (DB1, CH 5,6)
- Grid location CC-14, 2' below water surface (DB1, CH 7,8)
- Grid location A-35, 5' above fuel rack (DB1, CH 9,10)
- Grid location A-35, 2' below water surface (DB1, CH 11,12)
- Near existing station monitor probe (TIC-651) (DB1, CH 13)

b. Unit 2 Spent Fuel Pool Temperature

- Suction from pool (DB2, CH 1, 2)
- Discharge to pool (DB2, CH 3,4)
- Grid location D-36, 5' above fuel rack (DB2, CH 5,6)
- Grid location D-36, 2' below water surface (DB2, CH 7,8)
- Grid location DD-10, 5' above fuel rack (DB2, CH 9,10)
- Grid location DD-10, 2' below water surface (DB2, CH 11,12)
- Near existing station monitor probe (TIC-651) (DB2, CH 13)
- Air near water surface (DB2, CH 14)

c. Spent Fuel Temperature at Inlet of Unit 2 SFHX

- Used a surface style thermocouple with a range of 32-200°F near inlet to SFHX. (DB3, CH 1)

d. Spent Fuel Temperature at Outlet of Unit 2 SFHX

- Temporarily removed local temperature indicator at instrument location TI-653. Installed a thermocouple with a range of 32-200°F. (DB3, CH 7)
- Installed a surface style thermocouple with a range of 32-200°F near outlet from SFHX (DB3, CH 2)

e. Unit 1 Spent Fuel Flow

- Installed a Panametric System Flow Meter, or equivalent, on 8" line 1-SF-50 (DB4, CH 1)

f. Unit 2 Spent Fuel Flow

- Installed a Panametric System Flow Meter, or equivalent, on 8" line 2-SF-59 (DB4, CH 2)

  (Performed a zero flow calibration on the flow meter.)

g. Component Cooling <u>Inlet</u> Temperature to Unit 2 SFHX

1) 21CCHX Outlet Temperature

- Installed a thermocouple with a range of 32-200°F, at location TA9286, along with existing instrumentation (DB3, CH 5)

2) 22CCHX Outlet Temperature

- Installed a thermocouple with a range of 32-200°F, at location TAS264, along with existing instrumentation (DB3, CH 6)

3) Installed a surface style thermocouple with a range of 32-200° near inlet to SFHX (DB3, CH 3)

h. Component Cooling Outlet Temperature from Unit 2 SFHX

- Temporarily removed local temperature indicator at instrument location TI-604. Installed a thermocouple with a range of 32-200°F.

- Installed a surface style thermocouple with a range of 32-200°F near outlet from SFHX (DB3, CH 4)

i. Component Cooling Flow through SFHX

- Installed a Differential Pressure Transmitter, 4-20 mA, in parallel with FE-603, at outlet of Unit 2 SFHX (DB3, CH 9,10)

j. Service Water Temperature

- Installed a thermocouple with a range of 32-200°F, at location TT-14726 (DB3, CH 19,20)

k. Unit 1 Fuel Handling Building Temperature/Relative Humidity

- Installed three Solomat temperature/relative humidity probes, or equivalent, with a range of 32-200°F/10-90%, in the area around the Unit 1 Spent Fuel Pool (manual reading)

l. Unit 2 Fuel Handling Building Temperature/Relative Humidity

- Installed three Solomat temperature/relative humidity probes, or equivalent, with a range of 32-200°F/10-90%, in the area around the Unit 2 Spent Fuel Pool (manual reading)

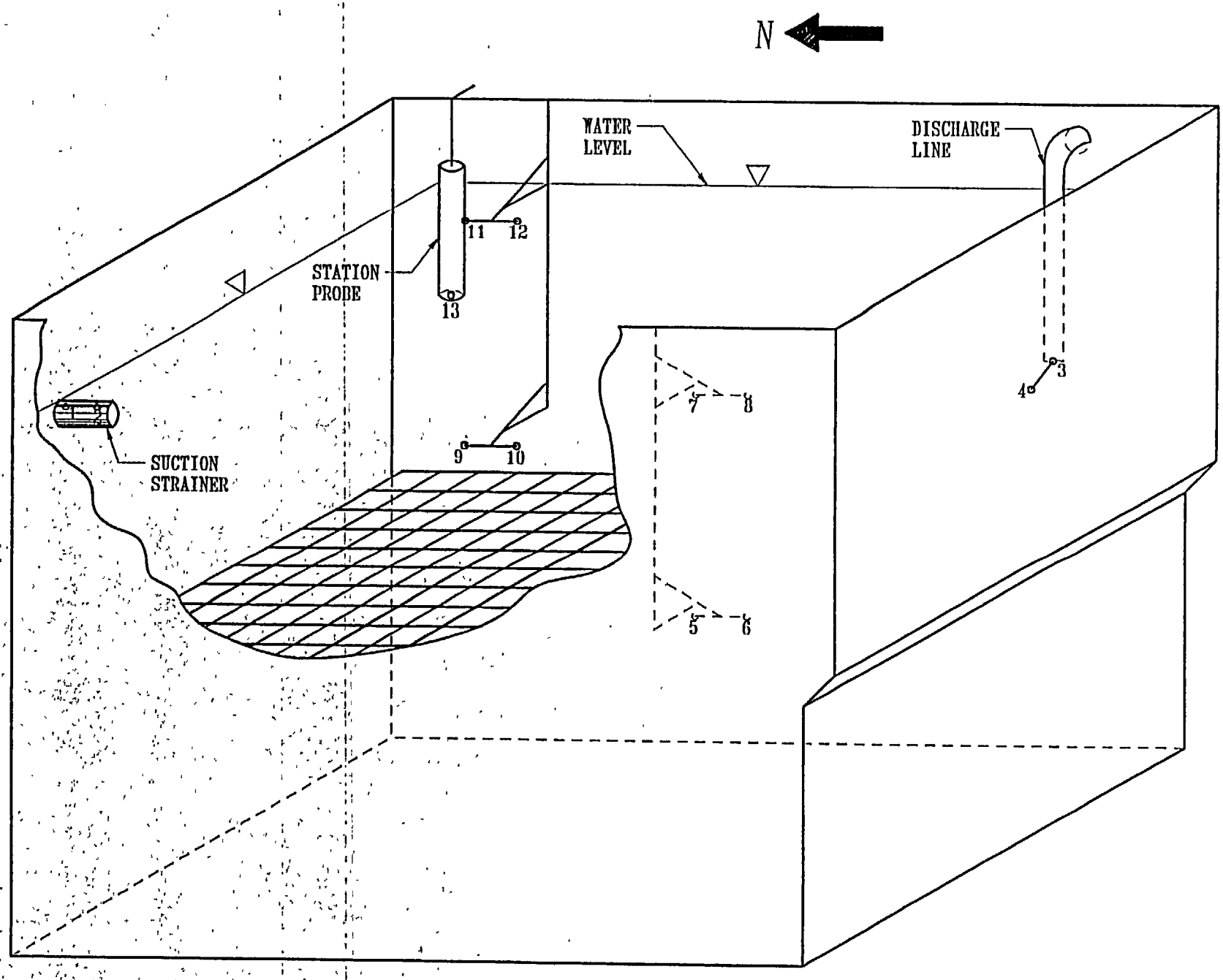

FIGURE 4-1
ISOMETRIC VIEW OF TEMPERATURE PROBE LOCATIONS SALEM UNIT 1

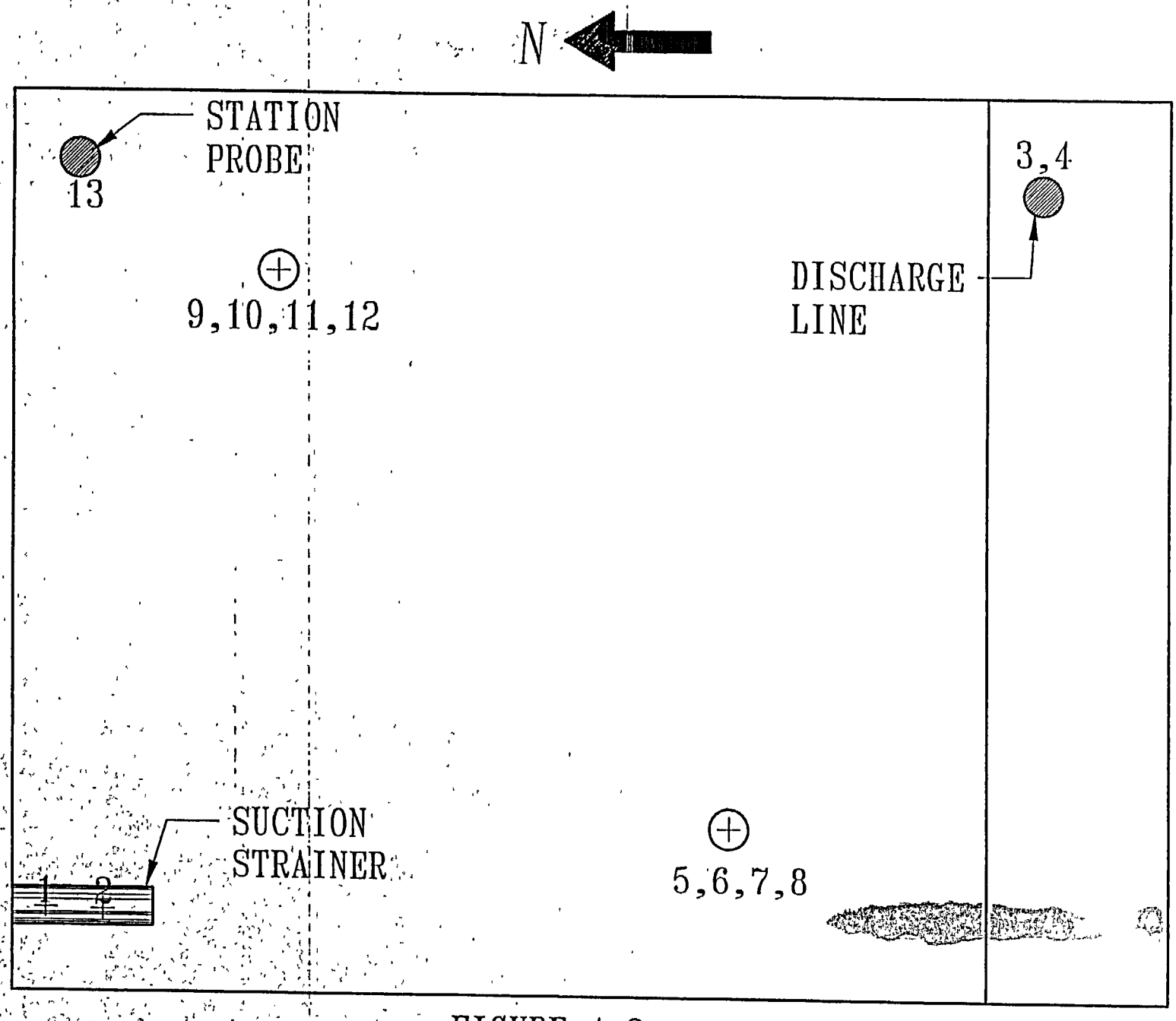

FIGURE 4.2
PLAN VIEW OF TEMPERATURE PROBE LOCATIONS SALEM UNIT 1

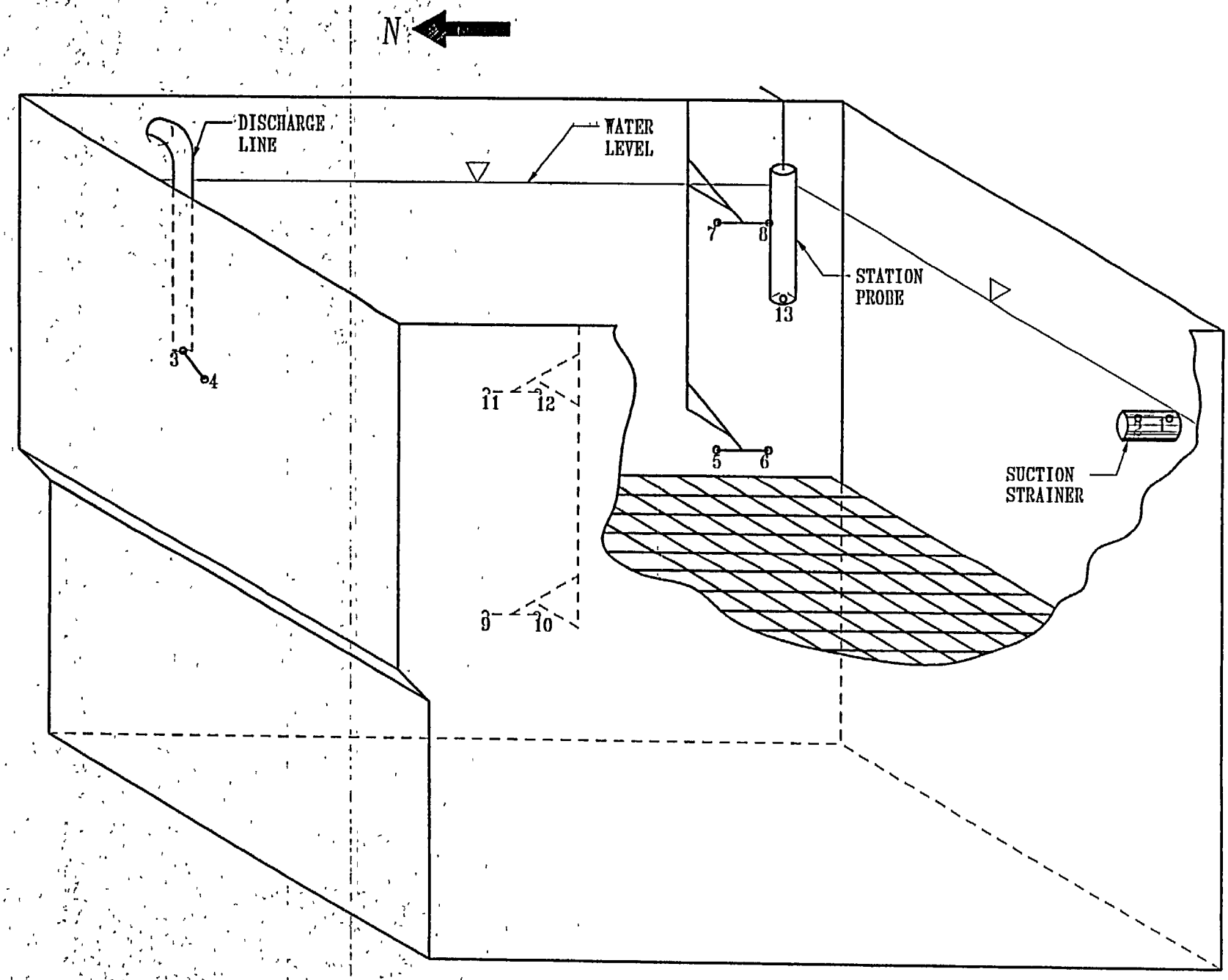

FIGURE 4.3
ISOMETRIC VIEW OF TEMPERATURE PROBE LOCATIONS SALEM UNIT 2

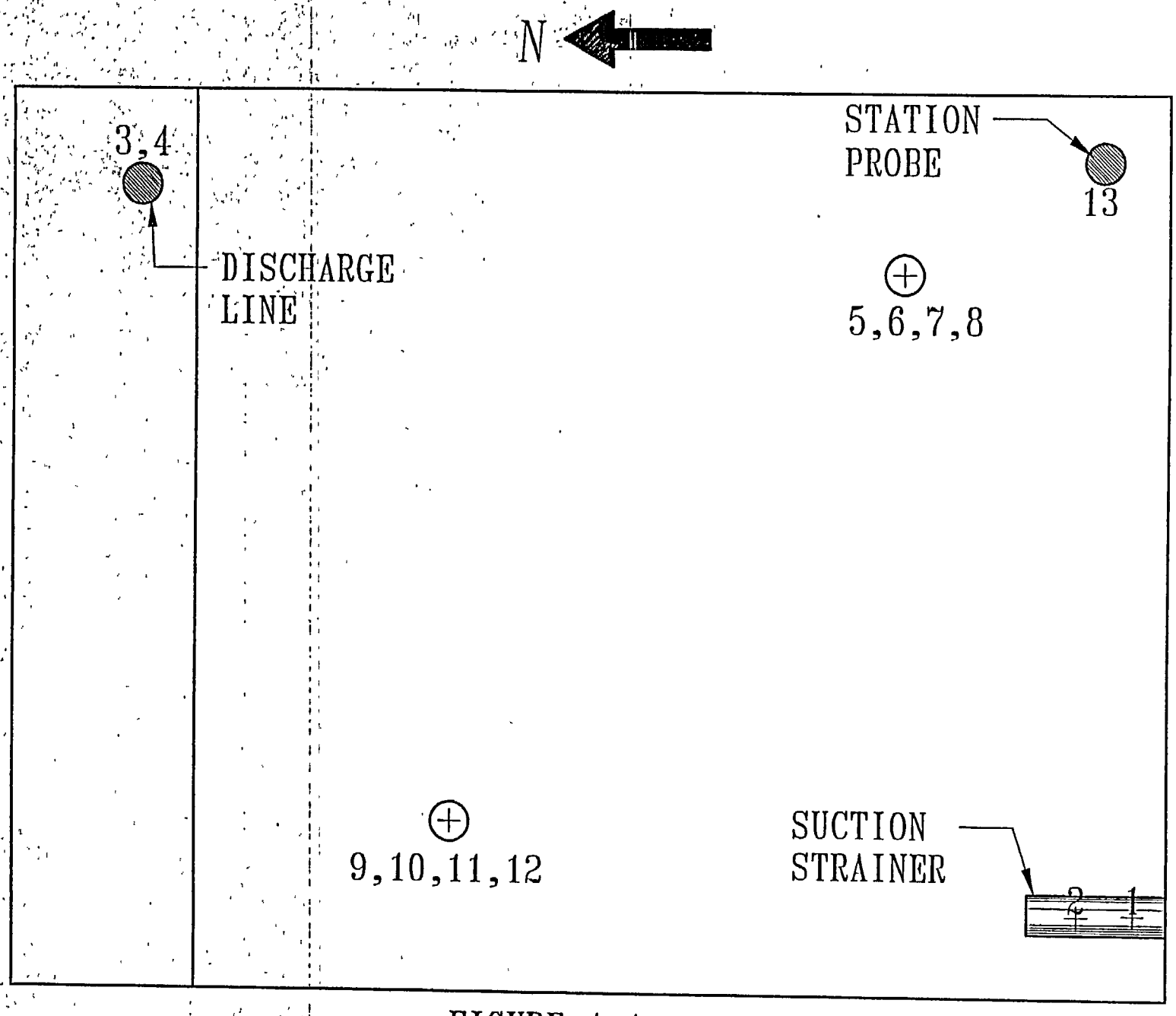

FIGURE 4.4
PLAN VIEW OF TEMPERATURE PROBE LOCATIONS SALEM UNIT 2

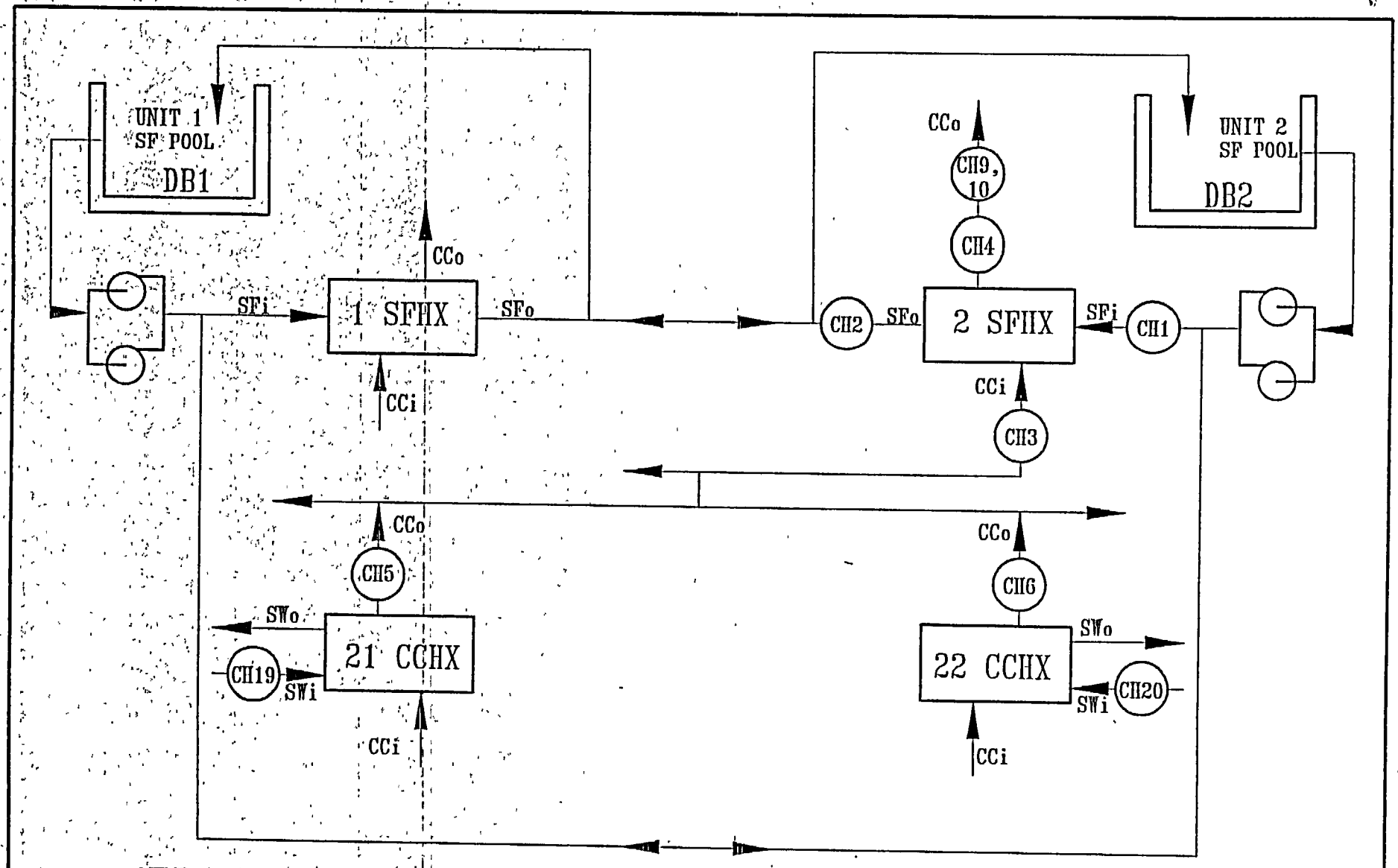

FIGURE 4.5a INSTRUMENT CHANNEL LOCATIONS FOR DB3

4.2 Test Results

The original plan for the test was to measure the pool temperatures, and other parameters, when the Unit 1 SFHX was out of service and the Unit 2 SFHX was cycled between the Unit 1 and Unit 2 pools, utilizing the cross-tie for the 1R11 outage. Heatup and cooldown data could then be obtained for both pools. However, due to a high heat load with the Unit 1 core unload, the Unit 1 pool could not be isolated from cooling. Therefore, during the cross-tie the Unit 1 SFHX was out of service, the Unit 1 pool was being cooled by Unit 2 SFHX via the cross-tie, and the Unit 2 pool was heating up. The Unit 2 pool was allowed to heat up to 140° F, at which time the Unit 1 SFHX was returned to service, and normal cooling restored to both pools.

The theory was developed based on the overall average bulk temperature, and the operation was controlled based on the station monitor probe reading. Observations were made on the pool water temperature distribution during different phases of the cross-tie, namely, steady state cooling, heating up without cooling, and cooling down when resuming cooling.

A close perusal of the pool temperature data shows that (i) during the heating up the maximum temperature difference between different measurement points in spent fuel pool is less than 1°F; (ii) during the steady state cooling, the temperature differences between different locations are less than 1°F.

After resuming forced cooling, the Unit 2 pool temperature cooled down sharply from 140°F to 80°F, at about 2.5°F/hr. As a result: (i) the maximum temperature difference between the bulk water temperature and the station probe is increased to about 5°F; (ii) the temperature difference between water surface and the bottom is less than 25°F. The surface temperature is higher, since coolant has higher density and tends to "sink".

The SFP bulk temperatures were calculated individually by taking nodal averages of temperature:

$$T = \frac{\sum_{i=1}^{n} T_i}{n}$$

where:

n = number of the measurement points

T_i = temperature value at the measurement point i (i = 1,2,3...n except for the discharge location)

Average pool surface/bottom/station temperature was calculated by

$$T_s = \frac{\sum_{i=1}^{m} T_i}{m}$$

where:

m = number of local measurement points

T_i = test value at surface/bottom/station location i,i = 1,2...m

Hard copy of all raw test data and the processed bulk temperatures at surface, bottom, and station-probe locations are attached in Appendix A.

The bulk temperatures for both Units 1 and Unit 2 are plotted vs. time after reactor shutdown in Figures 4.5 through 4.12. The fuel handling building ambient air temperature and relative humidity ratio during the cross-tie are also plotted vs. time in Figures 4.13 to 4.16.

HOLTEC INTERNATIONAL

SALEM OUTAGE 1R11, UNIT 1 FUEL POOL WATER TEMPERATURE

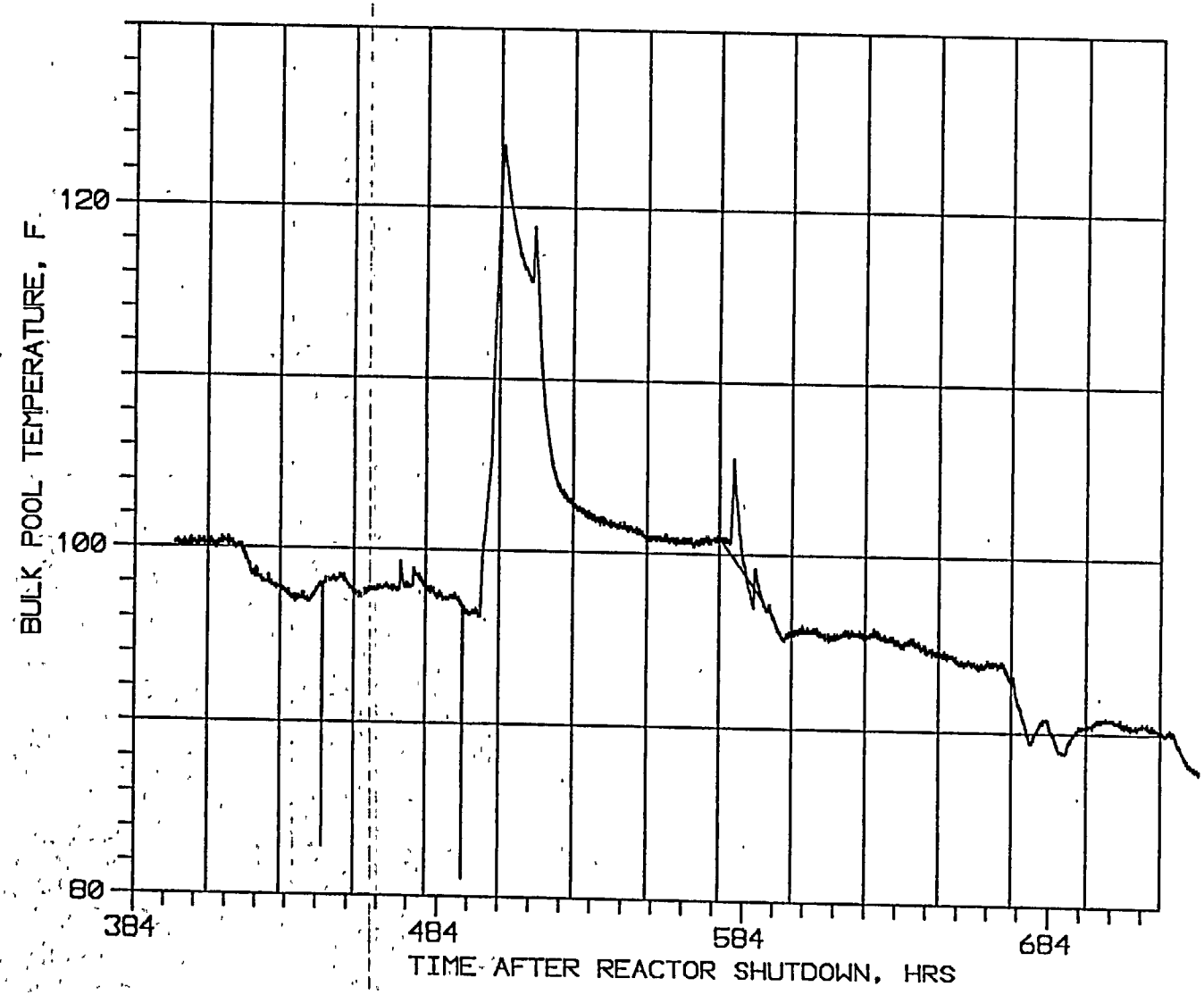

FIGURE 4.5

HOLTEC INTERNATIONAL

SALEM OUTAGE 1R11, UNIT 1 POOL BULK WATER/DISCHARGE FLOW TEMPERATURS
(During Cross-Tie Initiation)

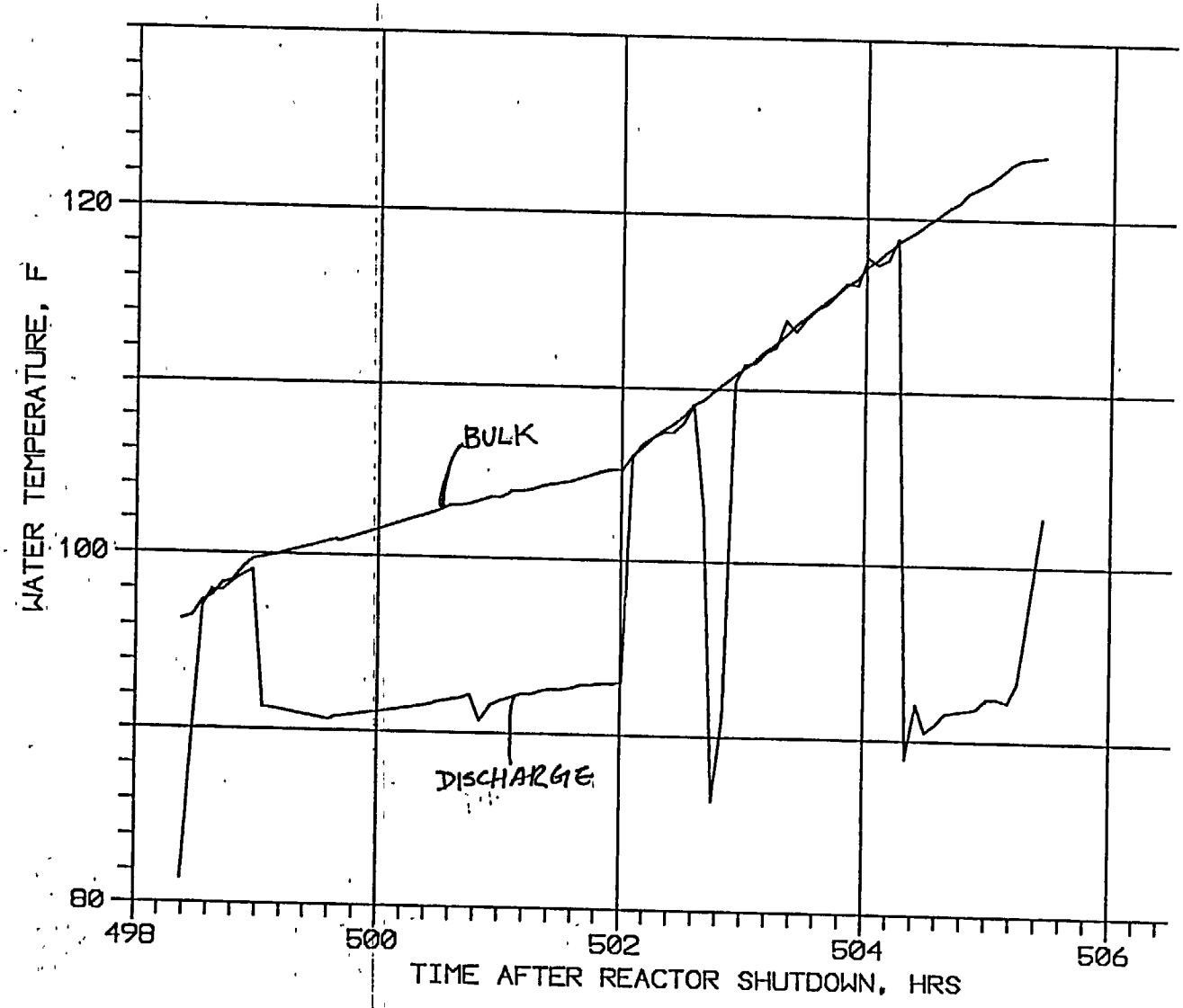

FIGURE 4.6

HOLTEC INTERNATIONAL

SALEM OUTAGE 1R11, UNIT 1 POOL WATER/UNIT 2 CCW INLET TEMPERATURES
(During Cross-tie)

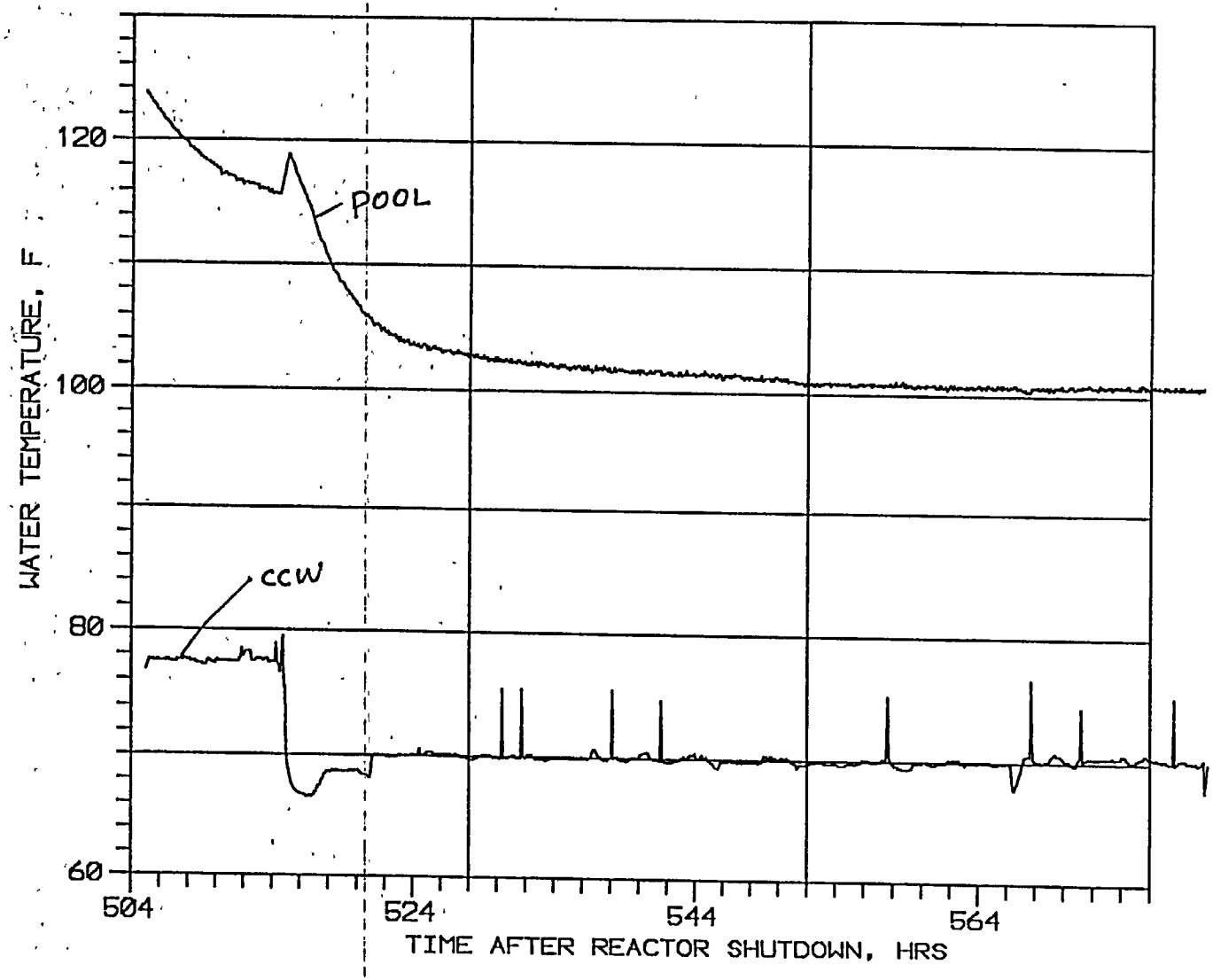

FIGURE 4.7

4-12

HOLTEC INTERNATIONAL

SALEM OUTAGE 1R11, UNIT 2 POOL BULK WATER TEMPERATURE

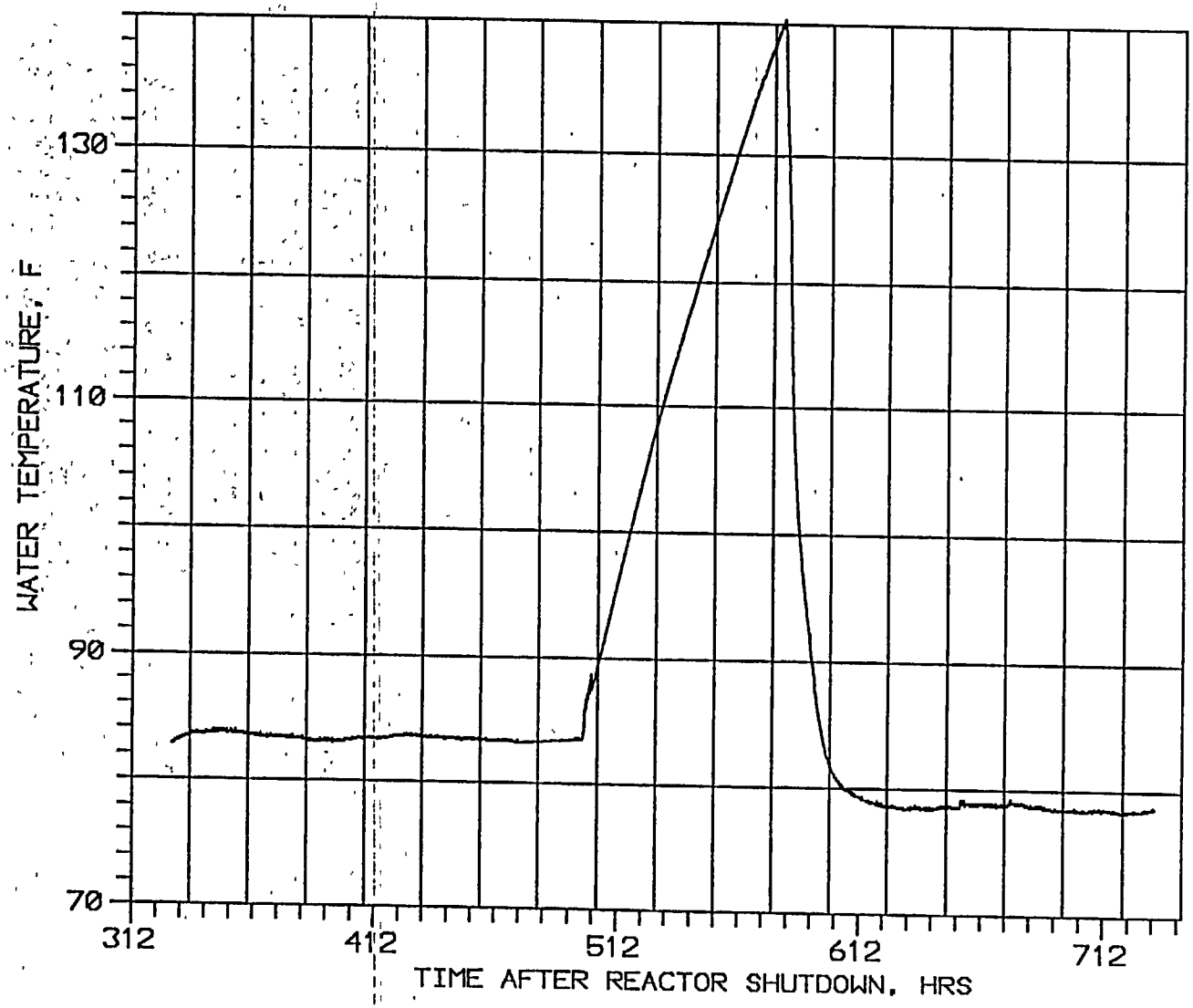

FIGURE 4.8

4-13

HOLTEC INTERNATIONAL

SALEM OUTAGE 1R11, UNIT 2 POOL BULK WATER TEMPERATURE
(During Cross-Tie Heating Up and After Cross-Tie Cooling Down)

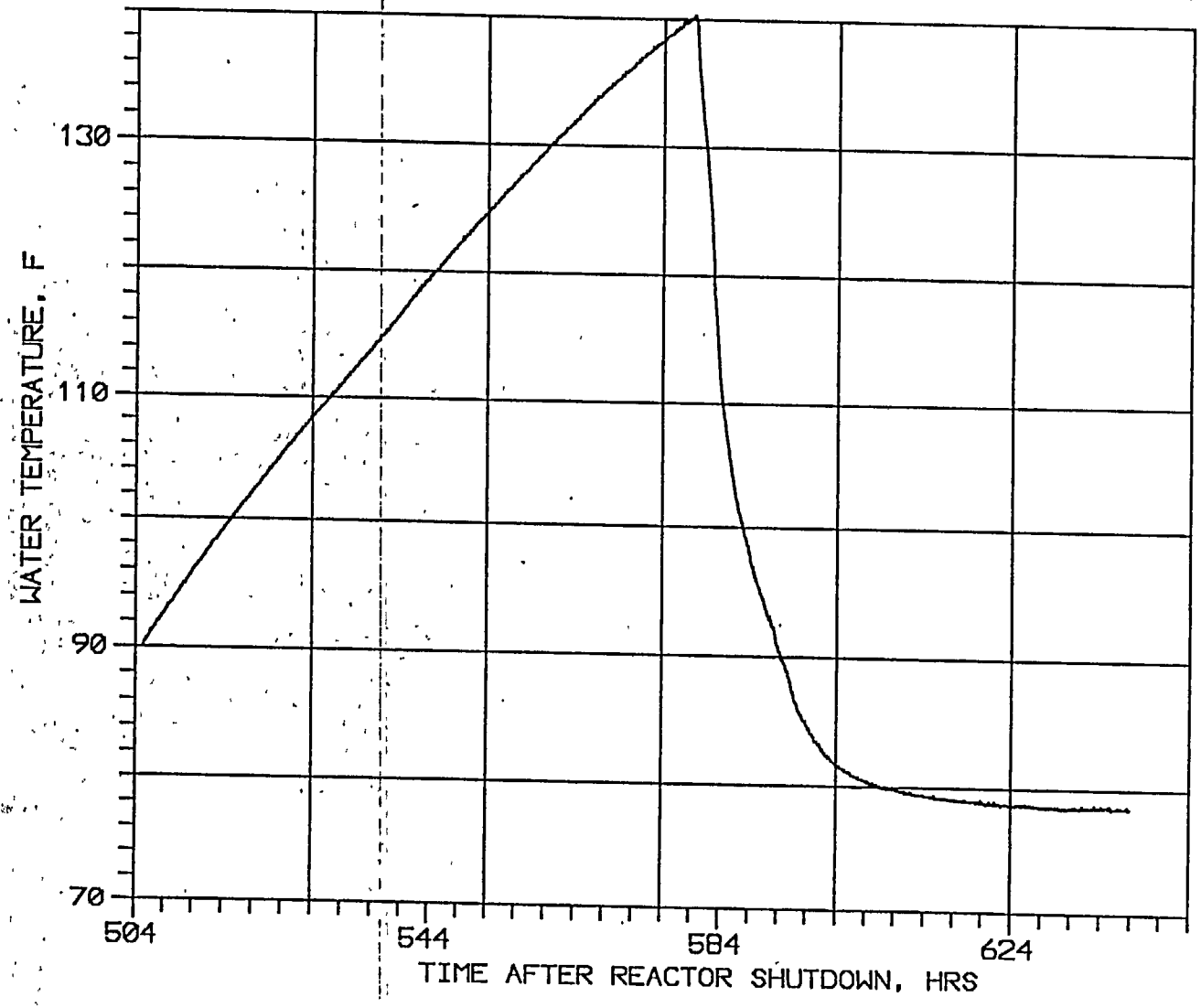

FIGURE 4.9

4-14

HOLTEC INTERNATIONAL

SALEM OUTAGE 1R11, UNIT 2 POOL BULK WATER/CCW TEMPERATURES
(Post Cross-Tie Cooling Down and Steady State)

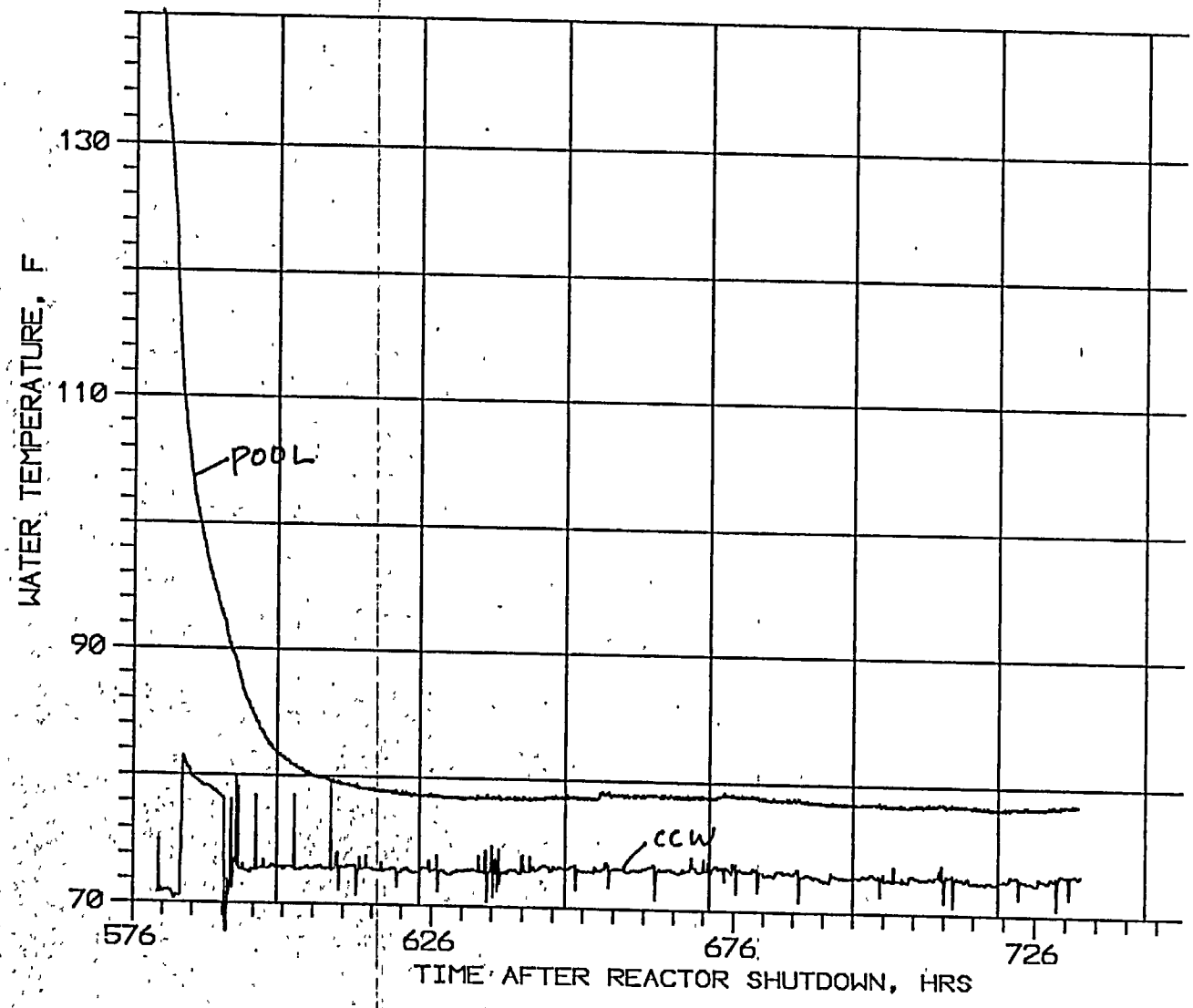

FIGURE 4.10

4-15

CASE 1

HOLTEC INTERNATIONAL

SALEM OUTAGE 1R11, UNIT 2 POOL BULK WATER/CCW TEMPERATURES
(STEADY STATE)

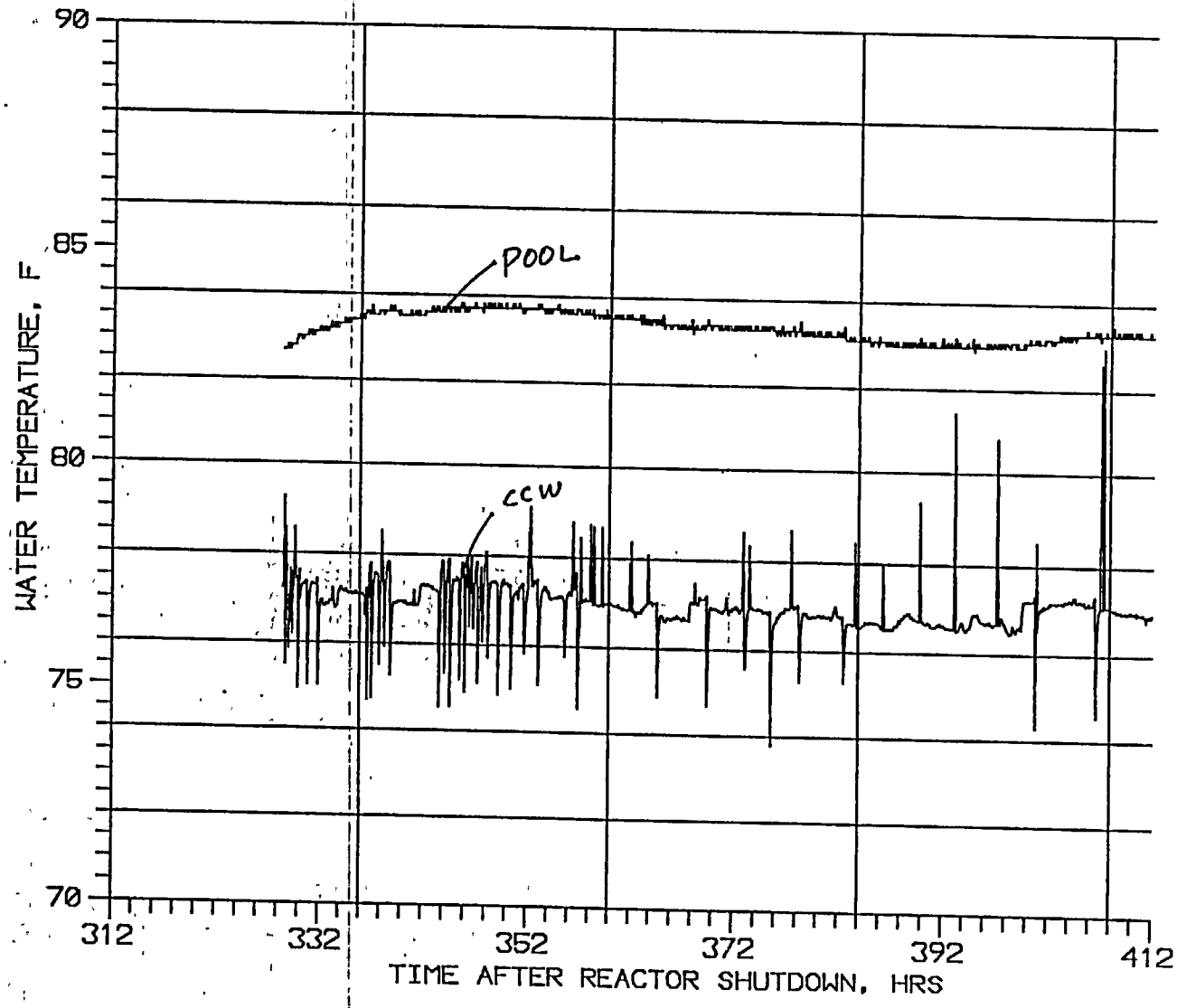

FIGURE 4.11

HOLTEC INTERNATIONAL

SALEM OUTAGE 1R11. UNIT 2 POOL BULK WATER/CCW TEMPERATURES
(STEADY STATE)

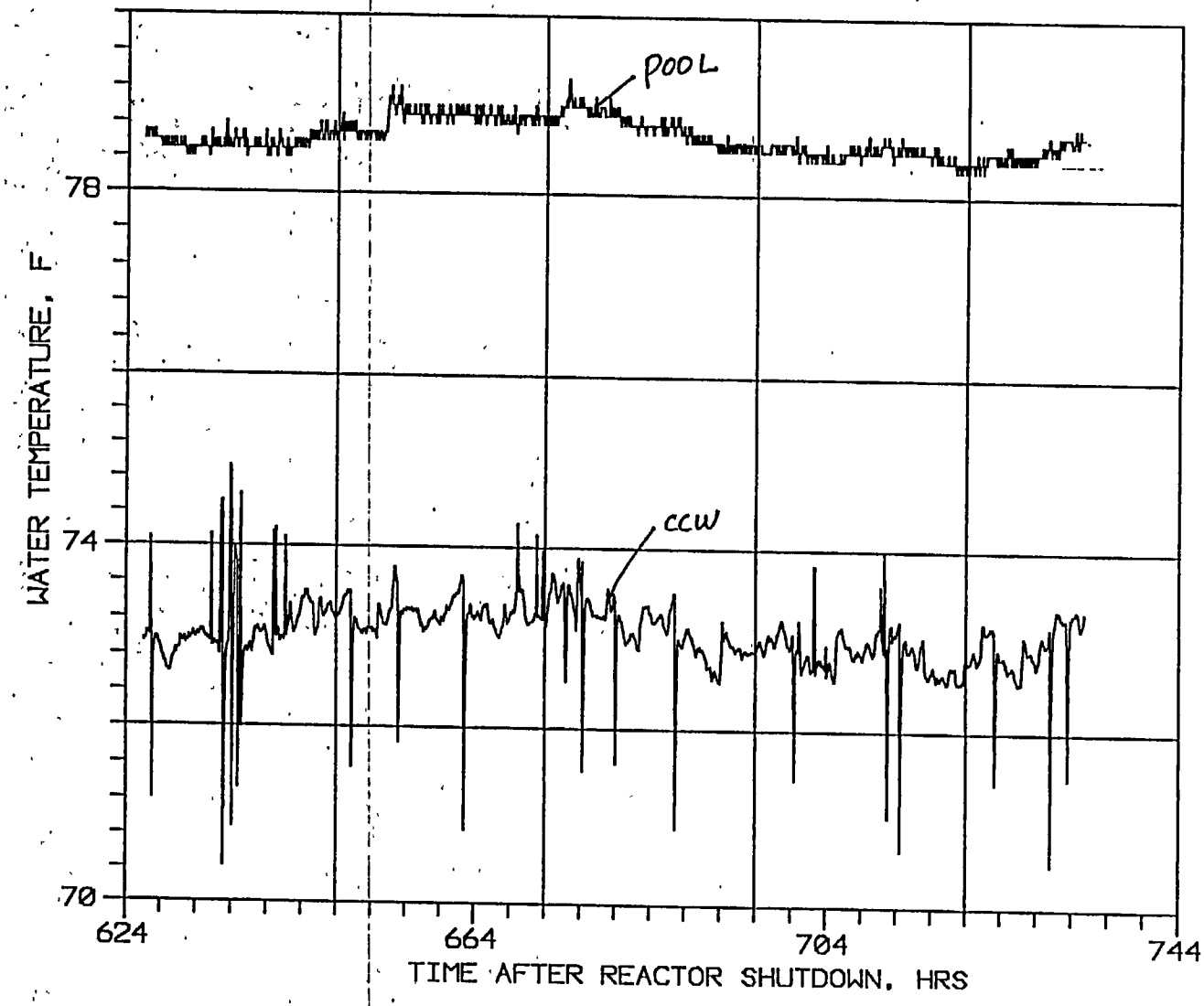

FIGURE 4.12

4-17

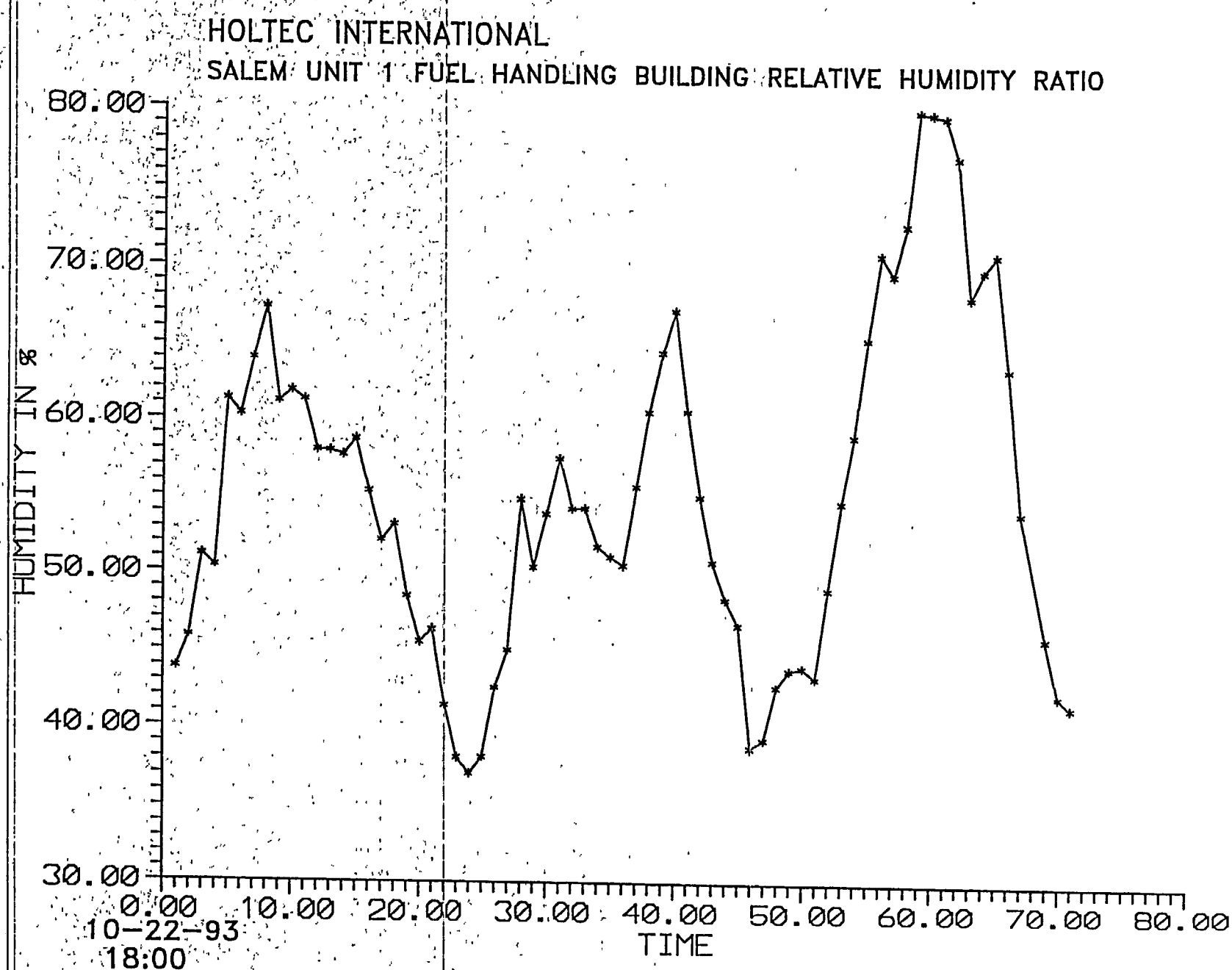
HOLTEC INTERNATIONAL
SALEM UNIT 1 FUEL HANDLING BUILDING RELATIVE HUMIDITY RATIO
HUMIDITY IN %
80.00
70.00
60.00
50.00
40.00
30.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
10-22-93
18:00
TIME

FIGURE 4.13

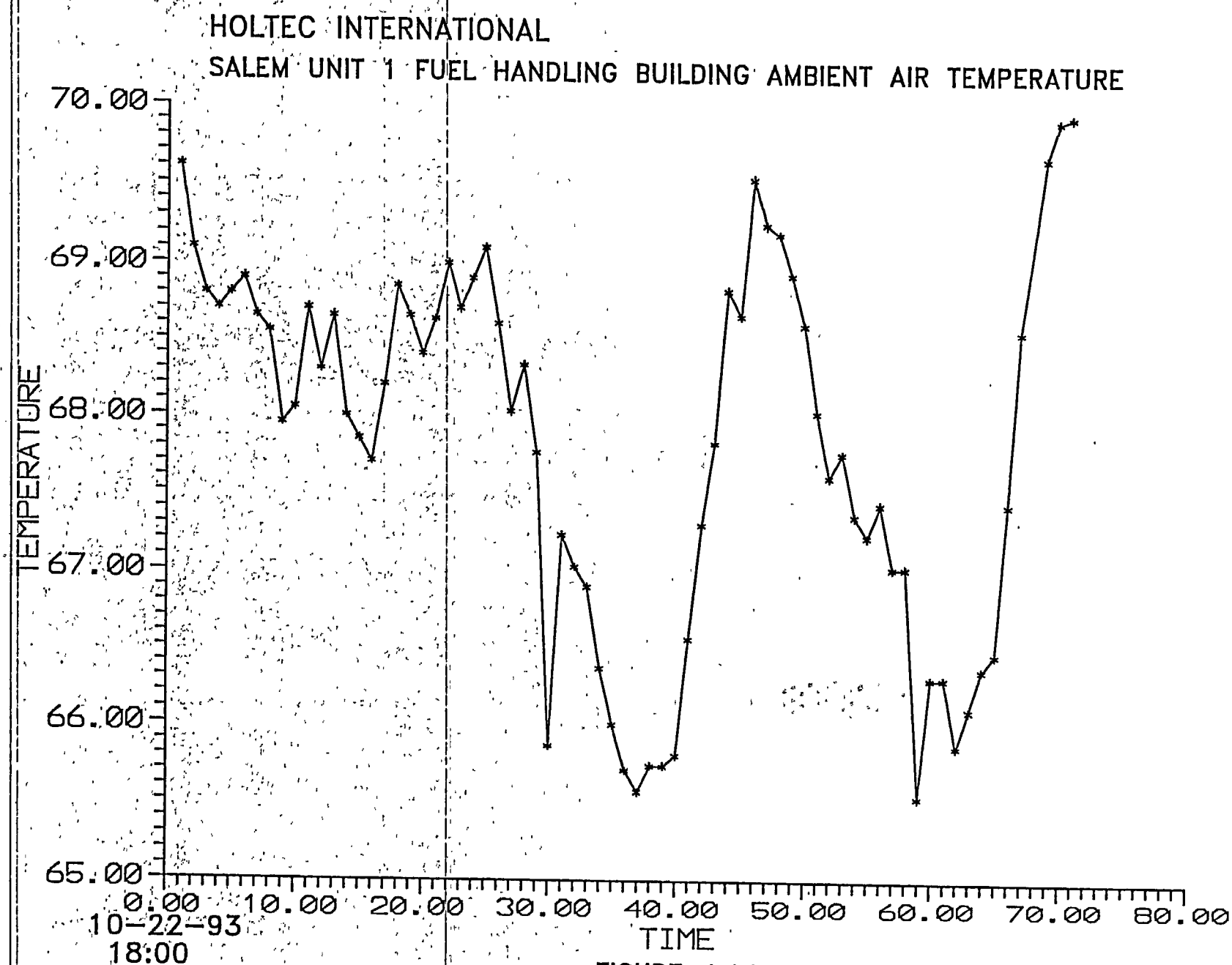
HOLTEC INTERNATIONAL
SALEM UNIT 1 FUEL HANDLING BUILDING AMBIENT AIR TEMPERATURE
TEMPERATURE
70.00
69.00
68.00
67.00
66.00
65.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
10-22-93
18:00
TIME

FIGURE 4.14

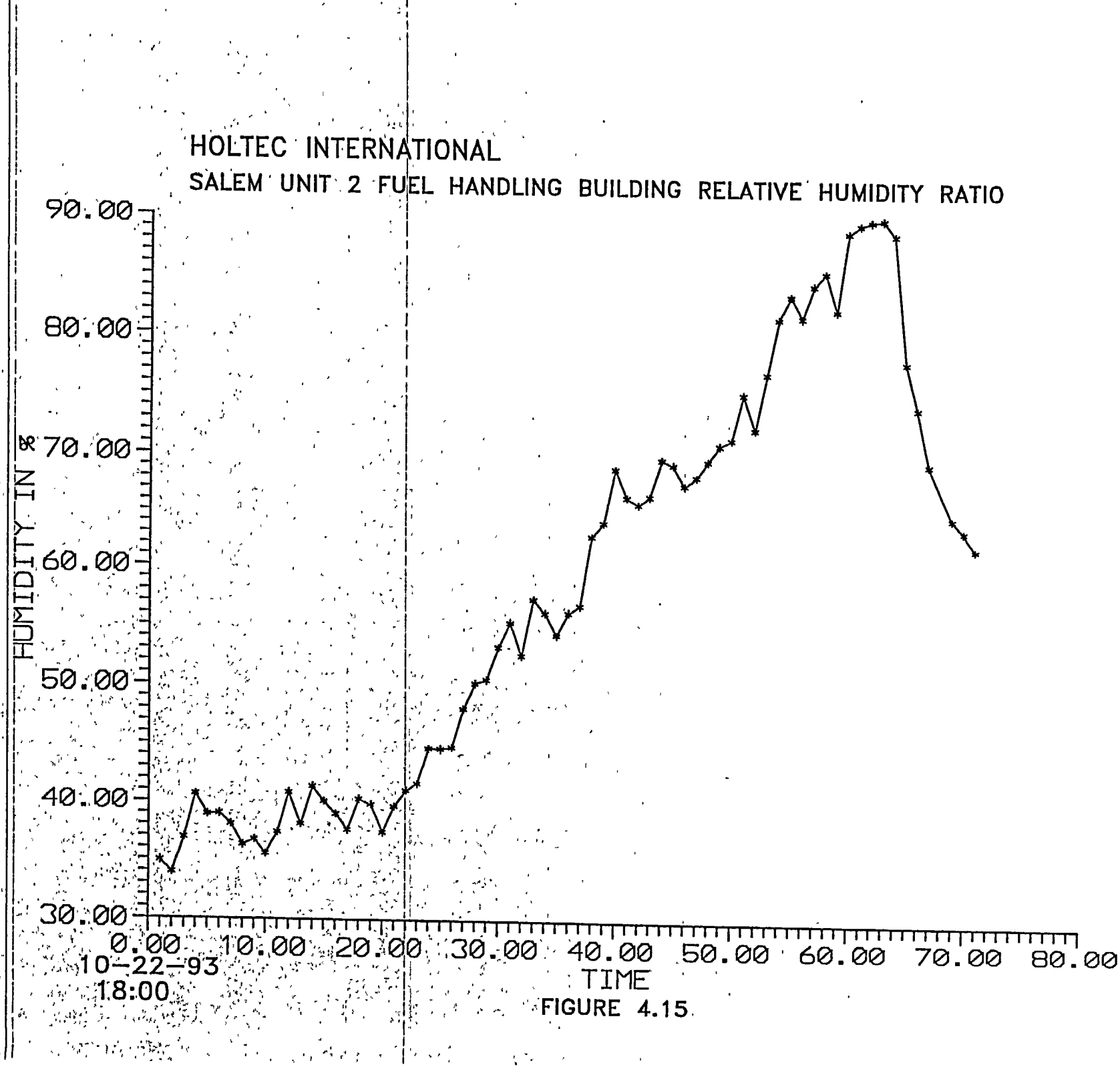
HOLTEC INTERNATIONAL
SALEM UNIT 2 FUEL HANDLING BUILDING RELATIVE HUMIDITY RATIO
HUMIDITY IN %
90.00
80.00
70.00
60.00
50.00
40.00
30.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
10-22-93
18:00
TIME

FIGURE 4.15

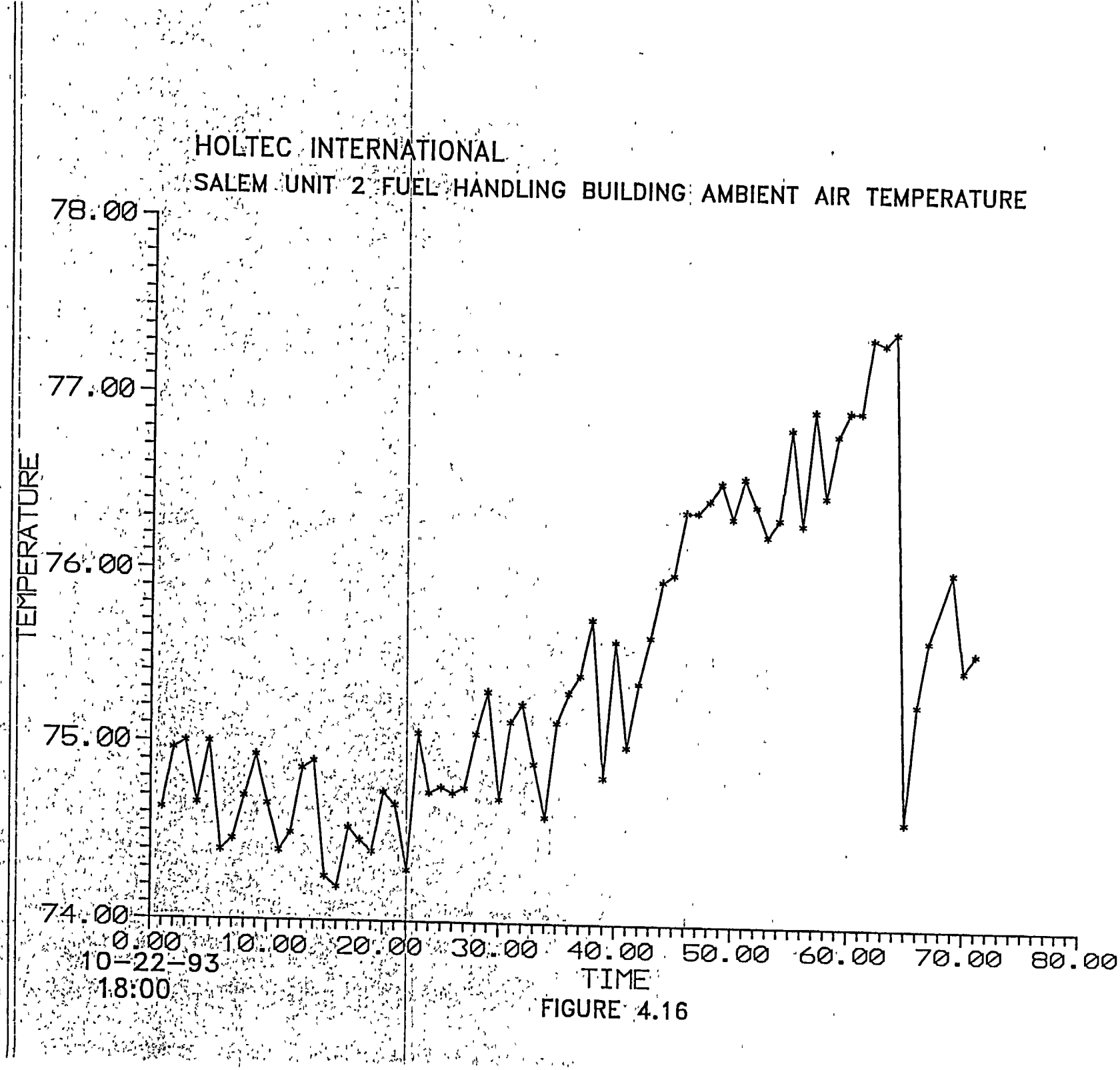
HOLTEC INTERNATIONAL
SALEM UNIT 2 FUEL HANDLING BUILDING AMBIENT AIR TEMPERATURE
TEMPERATURE
78.00
77.00
76.00
75.00
74.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
10-22-93
18:00
TIME

FIGURE 4.16

HOLTEC PROPRIETARY INFORMATION

HOLTEC PROPRIETARY INFORMATION

HOLTEC PROPRIETARY INFORMATION

HOLTEC PROPRIETARY INFORMATION

SALEM UNIT 1 SPENT FUEL POOL
SPENT FUEL INVENTORY BURNUP DATA (PROVIDED BY PSE&G)

CYCLE	DISCHARGE DATE	BATCH	#FAs	U-kg	MWD/MTU	R-POWER MW(t)
1	04,03,79	1	28	461.0	17000	3338
1	04,03,79	2	04	461.0	17500	3338
1	04,03,79	3	06	461.0	12000	3338
2	09,19,80	1	36	461.0	24100	3338
2	09,19,80	2	28	461.0	26100	3338
3	01,01,82	1	32	461.0	34100	3338
3	01,01,82	2	24	461.0	32400	3338
4	10,15,82	1	33	461.0	36200	3338
4	10,15,82	1	01	461.0	23600	3338
5	02,20,84	1	01	461.0	26800	3338
5	02,20,84	2	39	461.0	32500	3338
5	02,20,84	3	28	461.0	26700	3338
5	02,20,84	4	03	461.0	26600	3338
5	02,20,84	5	01	461.0	17200	3338
5	02,20,84	6	01	461.0	12200	3338
6	03,21,86	1	09	461.0	30300	3338
6	03,21,86	2	04	461.0	34500	3338
6	03,21,86	3	01	461.0	41900	3338
6	03,21,86	4	25	461.0	33500	3338
6	03,21,86	5	28	461.0	31100	3338
6	03,21,86	6	02	461.0	36900	3338
7	10,02,87	1	01	461.0	43600	3411
7	10,02,87	2	09	461.0	36400	3411
7	10,02,87	3	08	461.0	40500	3411
7	10,02,87	4	41	461.0	36600	3411
7	10,02,87	5	11	461.0	36900	3411
8	03,23,89	1	08	461.0	39800	3411
8	03,23,89	2	04	461.0	37900	3411
8	03,23,89	3	01	461.0	40600	3411
8	03,23,89	4	04	461.0	34900	3411
8	03,23,89	5	47	461.0	35000	3411
8	03,23,89	6	08	461.0	37800	3411
8	03,23,89	7	02	461.0	16300	3411
9	02,09,91	1	07	461.0	31500	3411
9	02,09,91	2	01	461.0	31800	3411
9	02,09,91	3	04	461.0	37000	3411
9	02,09,91	4	29	461.0	42700	3411
9	02,09,91	5	41	461.0	33500	3411
9	02,09,91	6	01	461.0	39300	3411
9	02,09,91	7	02	461.0	19500	3411

10	04,03,92	1	08	461.0	26600	3411
10	04,03,92	2	07	461.0	33200	3411
10	04,03,92	3	04	461.0	36600	3411
10	04,03,92	4	02	461.0	41100	3411
10	04,03,92	5	08	461.0	39500	3411
10	04,03,92	6	15	461.0	40100	3411
10	04,03,92	7	25	461.0	39300	3411
10	04,03,92	8	01	461.0	25700	3411
10	04,03,92	9	08	461.0	38600	3411
10	04,03,92	10	08	461.0	48100	3411
10	04,03,92	11	01	461.0	43700	3411
10	04,03,92	12	01	461.0	31500	3411
10	04,03,92	13	01	461.0	48700	3411
10	04,03,92	14	01	461.0	49400	3411
10	04,03,92	15	01	461.0	43600	3411
10	04,03,92	16	01	461.0	42200	3411
10	04,03,92	17	01	461.0	48200	3411

SALEM UNIT 2 SPENT FUEL POOL
SPENT FUEL INVENTORY BURNUP DATA (PROVIDED BY PSEG)

CYCLE	DISCHARGE DATE	BATCH	#FAs	U-kg	MWD/MTU	R-POWER MW(t)
1	01,21,83	1	56	461.0	18400	3411
1	01,21,83	2	12	461.0	19700	3411
2	10,04,84	1	09	461.0	20700	3411
2	10,04,84	2	52	461.0	23900	3411
2	10,04,84	3	07	461.0	21600	3411
3	10,02,86	1	53	461.0	33400	3411
3	10,02,86	2	04	461.0	21600	3411
4	08,31,88	1	02	461.0	32200	3411
4	08,31,88	2	30	461.0	37000	3411
4	08,31,88	3	42	461.0	37400	3411
4	08,31,88	4	03	461.0	38500	3411
5	03,31,90	1	09	461.0	36000	3411
5	03,31,90	2	08	461.0	29700	3411
5	03,31,90	3	12	461.0	41500	3411
5	03,31,90	4	01	461.0	25300	3411
5	03,31,90	5	45	461.0	36500	3411
6	11,09,91	1	33	461.0	42400	3411
6	11,09,91	2	28	461.0	36400	3411
6	11,09,91	3	08	461.0	32300	3411
7	03,16,93	1	08	461.0	34800	3411
7	03,16,93	2	08	461.0	39600	3411
7	03,16,93	3	01	461.0	29300	3411
7	03,16,93	4	01	461.0	43100	3411
7	03,16,93	5	08	461.0	39900	3411
7	03,16,93	6	39	461.0	36400	3411
7	03,16,93	7	04	461.0	46800	3411

5.2 Program Verification

Input from Measurement:

Verification Case 1 - Unit 2 Steady State Before Cross-Tie

CCW inlet temperature, °F:	77
CCW flow rate, gpm:	2100
SFP flow, gpm:	2040
Time after reactor shutdown, hr.:	336-408 (about 15-17 days after reactor shutdown)
Ambient air temperature, °F:	74
Relative humidity ratio, %:	33

Verification Case 2 - Unit 2 Steady State After Cross-Tie

CCW inlet temperature, °:	73.2
CCW flow rate, gpm:	3050
SFP flow, gpm:	2040
Time after shutdown, hr.:	624-744
Ambient air temperature, °F:	75.5
Relative humidity ratio, %:	50

Verification Case 3 - Unit 2 Pool Heating Up During 1R11 Cross-Tie

Before HX isolation:

CCW inlet temperature, °F:	77
CCW flow rate, gpm:	2100
SFP flow rate, gpm:	2040
TARS* to start exchanger isolation, hrs.:	496
Temperature limit, °F:	140.3
Ambient air temperature, °F:	75.5
Relative humidity ratio, %:	60

Verification Case 4 - Unit 2 Pool Cooling Down After 1R11 Cross-Tie

CCW inlet temperature, °F:	73
CCW flow rate, gpm:	3050
SFP flow rate, gpm:	2040
TARS to re-initiate exchanger, hrs.:	580.27
Initial temperature, °F:	140.3
Ambient temperature, °F:	75
Relative humidity ratio, %:	60

* TARS = Time After Reactor Shutdown

Verification Case 5 - Unit 1 Pool Cooled by Unit 2 Exchanger During 1R11 Outage

CCW inlet temperature, °F:	77.5
CCW flow rate, gpm:	2100
SFP flow rate, gpm:	2460
TARS to start cooling, hrs.:	505
Initial bulk water temperature, °F:	123.6
TARS to end, hrs.:	514.6
Average burnup of 61 assemblies, MWD/MTU	41,300
Average burnup of 64 assemblies, MWD/MTU	27,760
Average burnup of 68 assemblies, MWD/MTU	15,240
Capacity factor:	0.9
Ambient air temperature, °F:	68.5
Relative humidity, %:	55

Verification Case 6 - Unit 1 Pool Cooled by Unit 2 Exchanger During 1R11 Outage

CCW inlet temperature, °F:	70
CCW flow rate, gpm:	3050
SFP flow rate, gpm:	2460
TARS to start cooling, hrs.:	515.13
Initial bulk water temperature, °F:	118.9
TARS to end, hrs.:	579.7
Average burnup of 61 assemblies, MWD/MTU	41,300
Average burnup of 64 assemblies, MWD/MTU	27,760
Average burnup of 68 assemblies, MWD/MTU	15,240
Capacity factor:	0.9
Ambient air temperature, °F:	67.5
Relative humidity, %:	55

For each verification case, the calculated temperature is plotted with the measurement (see Figures 5.1 to 5.6). It is shown that the maximum mean error in all cases is less than 1.0% of the measured values, which is well within the experimental error.

Hard copy of all cases of runs are attached.

HOLTEC INTERNATIONAL

PROGRAM CROSSTIE VERIFICATION CASE 1
UNIT 2 POOL STEADY STATE CONDITION BEFORE 1R11 CROSS-TIE

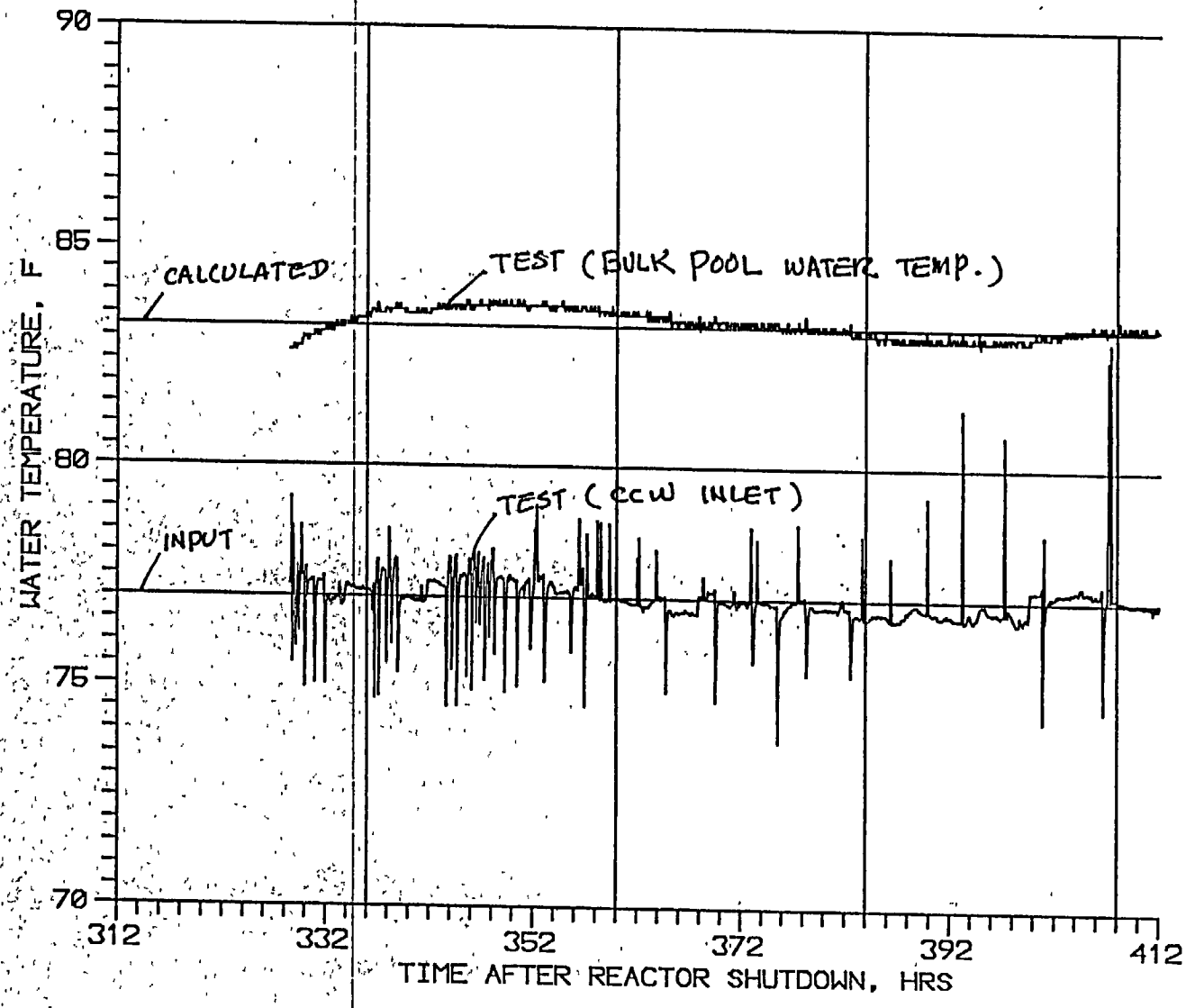

FIGURE 5.1

HOLTEC INTERNATIONAL

PROGRAM CROSSTIE VERIFICATION CASE 2
UNIT 2 POOL STEADY STATE CONDITION AFTER 1R11 CROSS-TIE

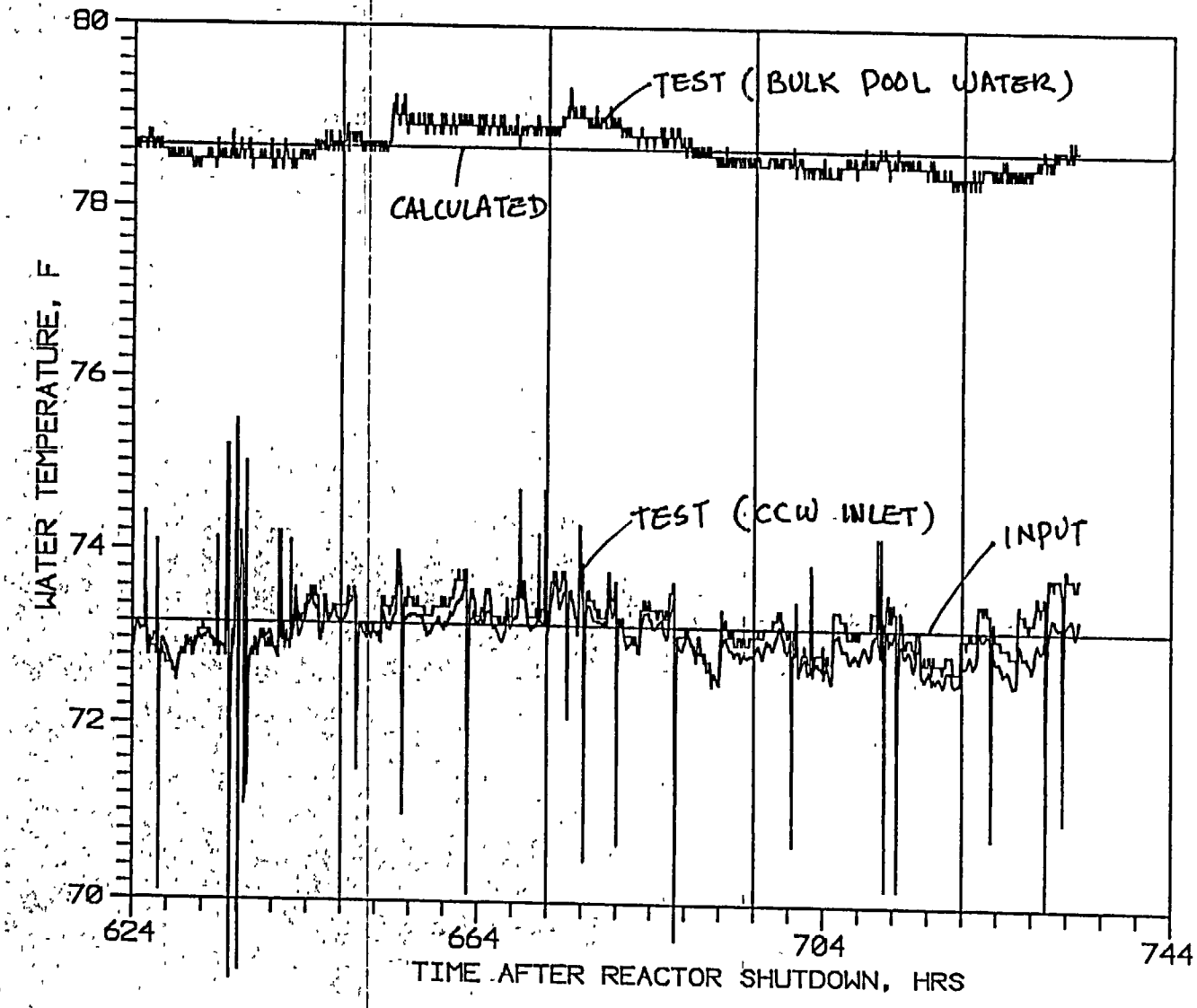

FIGURE 5.2

HOLTEC INTERNATIONAL

PROGRAM CROSSTIE VERIFICATION CASE 3
UNIT 2 POOL HEATING UP DURING 1R11 CROSS-TIE

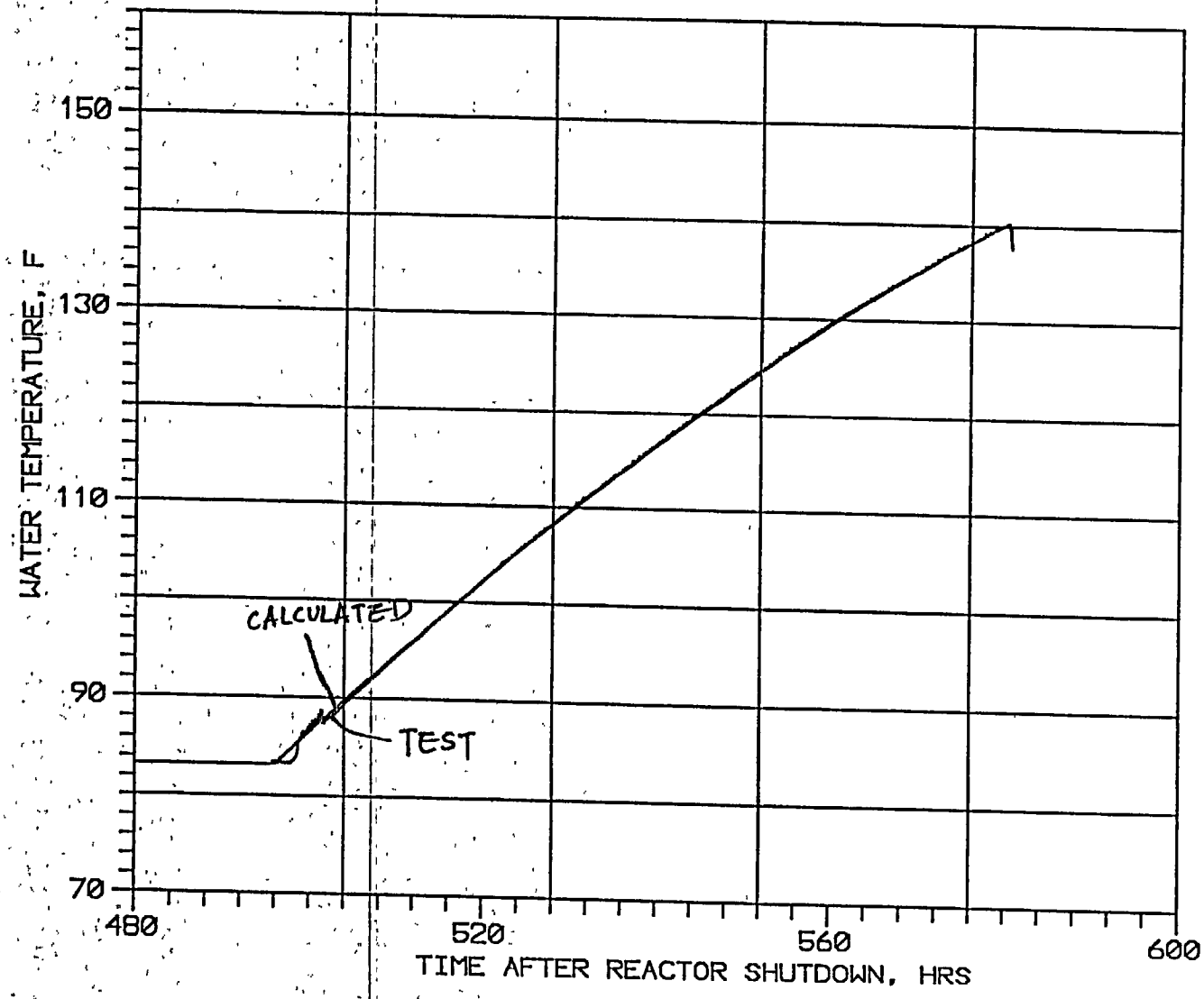

FIGURE 5.3

HOLTEC INTERNATIONAL

PROGRAM CROSSTIE VERIFICATION CASE 4
UNIT 2 POOL COOLING DOWN DURING 1R11 CROSS-TIE

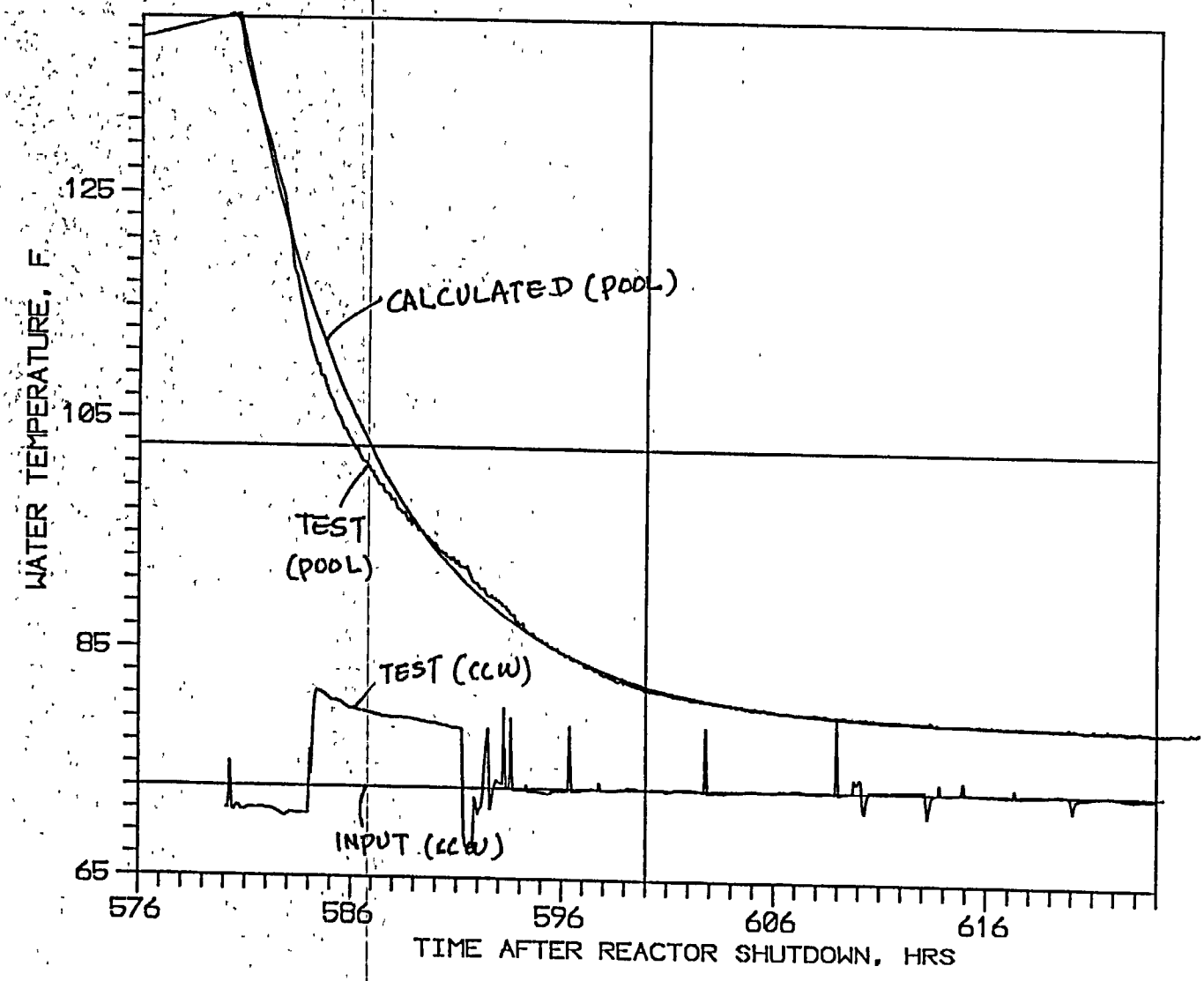

FIGURE 5.4

HOLTEC INTERNATIONAL

PROGRAM CROSSTIE VERIFICATION CASES 5 AND 6
UNIT 1 POOL TEMPERATURE DURING 1R11 CROSSTIE

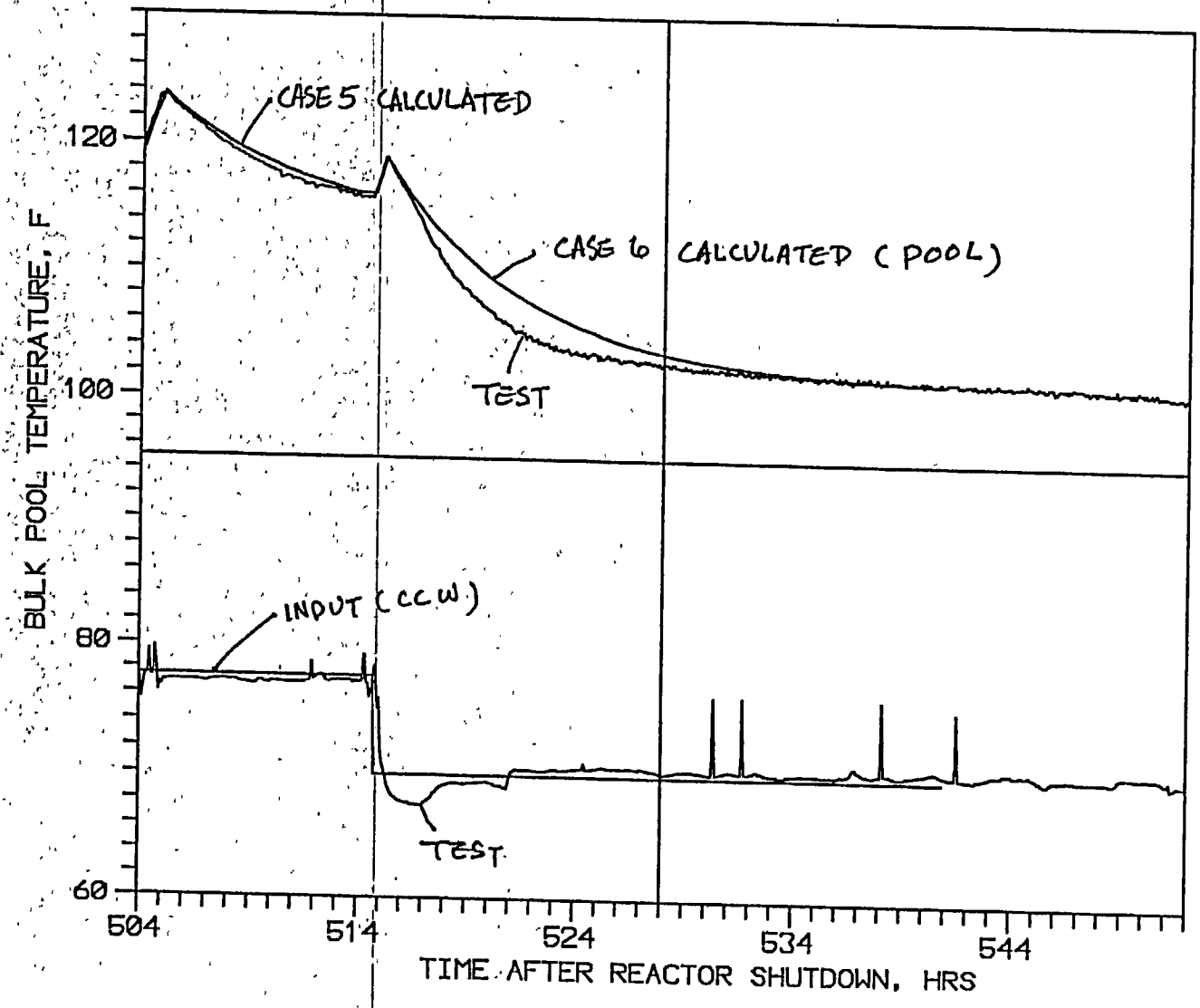

FIGURE 5.5

INPUT DATA FILES FOR ALL VERIFICATION CASES

CASE1.DAT

```
 PROGRAM CROSSTIE VERIFICATION CASE 1
10,02,93
1
2100, 2040, 60000
0,0,0,240.,60.
3411.,1.0,0.,0.,0.,461.0
74., 0.33
```

CASE2.DAT

```
 PROGRAM CROSSTIE VERIFICATION CASE 2
10,02,93
1
3050, 2040, 60000
0,0,0,240.,60.
3411.,1.0,0.,0.,0.,461.0
75.5, 0.50
```

CASE3.DAT

```
 PROGRAM CROSSTIE VERIFICATION CASE 3
10,02,93
1
2100, 2040, 60000
0,0,0,240.,60.
3411.,1.0,0.,0.,0.,461.0
75.5, 0.60
```

CASE4.DAT

```
 PROGRAM CROSSTIE VERIFICATION CASE 4
10,02,93
1
3050, 2040, 60000
0,0,0,240.,60.
3411.,1.0,0.,0.,0.,461.0
75., 0.60
```

CASE5.DAT

```
PROGRAM CROSSTIE VERIFICATION CASE 5
10,02,93
1
2100, 2460, 59000
61,64,68,240.,60.
3411.,0.9,41300.,27760.,15240.,461.0
68.5, 0.55
```

CASE6.DAT

```
 PROGRAM CROSSTIE VERIFICATION CASE 6
10,02,93
1
3050, 2460, 59000
61,64,68,240.,60.
3411.,0.9,41300.,27760.,15240.,461.0
67.5, 0.55
```

OUTPUT FILES FOR ALL VERIFICATION CASES

FILE: CASE1.TEM

```
                    *****HOLTEC INTERNATIONAL*****

                 ********COMPUTER CODE CROSSTIE********

$Revision:    1.0   $

$Date:    17 Dec 1993 23:30:18   $

$Logfile:    C:/RACKHEAT/CONTROL/CROSSTIE.FOV   $

  THIS PROGRAM WAS VERIFIED BY THE TEST
  PERFORMED DURING SALEM 1R11 OUTAGE, OCTOBER 1993

 DESCRIPTION OF YOUR JOB
  PROGRAM CROSSTIE VERIFICATION CASE 1

 REACTOR SHUTDOWN DATE:
   10    2   93
 OUTAGE UNIT, TIME TO START CROSS-TIE (HR), AND TEMP    LIMIT(F)
   1       412.00       140.30
  CCW FLOW(GPM),SFP FLOW(GPM),CCW TEMP(F),& NET WATER   VOLUME (ft^3)
      2100.00      2040.00        77.00     60000.00
 N1,N2,N3,Tao(HR),TaoS(HR)
     0     0     0     240.00      60.00
 RP(MW), CF, BP1(MWD/MTU), BP2, BP3, UW(Kg)
 3411.0    1.0        .00        .00        .00 461.00
 FH BUILDING AMBIENT TEMP(F), RELATIVE HUMIDITY(%)
        74.00          .33
 THE ENDING TIME(HR)
       412.00

 Heat Exchanger Temperature effectiveness p= .4489

             UNIT 1                                  UNIT 2
         (POOL)  (HT-TO-HX)  (HT-LOSS)        (POOL)(HT-TO-HX)   (HT-LOSS)
  TIME     T1        Q1        Qls1     HX1   T2       Q2         Qls2     HX2
  (HR)     (F)    (BTU/HR)    (BTU/HR)         (F)    (BTU/HR)    (BTU/HR)
    .00    81.7   .2196E+07    .83E+05   1   83.2   .2912E+07    .96E+05    1
411.50     81.7   .2196E+07    .83E+05   1   83.2   .2912E+07    .96E+05    0
```

FILE: CASE2.TEM

*****HOLTEC INTERNATIONAL*****

********COMPUTER CODE CROSSTIE********

$Revision: 1.0 $

$Date: 17 Dec 1993 23:30:18 $

$Logfile: C:/RACKHEAT/CONTROL/CROSSTIE.FOV $

THIS PROGRAM WAS VERIFIED BY THE TEST
PERFORMED DURING SALEM 1R11 OUTAGE, OCTOBER 1993

DESCRIPTION OF YOUR JOB
PROGRAM CROSSTIE VERIFICATION CASE 2

REACTOR SHUTDOWN DATE:
10 2 93
OUTAGE UNIT, TIME TO START CROSS-TIE (HR), AND TEMP LIMIT(F)
1 744.00 140.30
CCW FLOW(GPM),SFP FLOW(GPM),CCW TEMP(F),& NET WATER VOLUME (ft^3)
3050.00 2040.00 73.20 60000.00
N1,N2,N3,Tao(HR),TaoS(HR)
0 0 0 240.00 60.00
RP(MW), CF, BP1(MWD/MTU), BP2, BP3, UW(Kg)
3411.0 1.0 .00 .00 .00 461.00
FH BUILDING AMBIENT TEMP(F), RELATIVE HUMIDITY(%)
75.50 .50
THE ENDING TIME(HR)
744.00

Heat Exchanger Temperature effectiveness p= .3473

	UNIT 1				UNIT 2			
	(POOL)	(HT-TO-HX)	(HT-LOSS)		(POOL)	(HT-TO-HX)	(HT-LOSS)	
TIME (HR)	T1 (F)	Q1 (BTU/HR)	Qls1 (BTU/HR)	HX1	T2 (F)	Q2 (BTU/HR)	Qls2 (BTU/HR)	HX2
.00	77.4	.2219E+07	.29E+05	1	78.7	.2860E+07	.39E+05	1
743.50	77.4	.2219E+07	.29E+05	1	78.7	.2860E+07	.39E+05	0

FILE: CASE3.TEM

*****HOLTEC INTERNATIONAL*****

********COMPUTER CODE CROSSTIE********

$Revision: 1.0 $

$Date: 17 Dec 1993 23:30:18 $

$Logfile: C:/RACKHEAT/CONTROL/CROSSTIE.FOV $

THIS PROGRAM WAS VERIFIED BY THE TEST
PERFORMED DURING SALEM 1R11 OUTAGE, OCTOBER 1993

DESCRIPTION OF YOUR JOB
PROGRAM CROSSTIE VERIFICATION CASE 3

REACTOR SHUTDOWN DATE:
10 2 93
OUTAGE UNIT, TIME TO START CROSS-TIE (HR), AND TEMP LIMIT(F)
1 496.00 140.30
CCW FLOW(GPM),SFP FLOW(GPM),CCW TEMP(F),& NET WATER VOLUME (ft^3)
2100.00 2040.00 77.00 60000.00
N1,N2,N3,Tao(HR),TaoS(HR)
0 0 0 240.00 60.00
RP(MW), CF, BP1(MWD/MTU), BP2, BP3, UW(Kg)
3411.0 1.0 .00 .00 .00 461.00
FH BUILDING AMBIENT TEMP(F), RELATIVE HUMIDITY(%)
75.50 .60
THE ENDING TIME(HR)
600.00

Heat Exchanger Temperature effectiveness p=.4489

	UNIT 1				UNIT 2			
TIME (HR)	(POOL) T1 (F)	(HT-TO-HX) Q1 (BTU/HR)	(HT-LOSS) Qls1 (BTU/HR)	HX1	(POOL) T2 (F)	(HT-TO-HX) Q2 (BTU/HR)	(HT-LOSS) Qls2 (BTU/HR)	HX2
.00	81.8	.2215E+07	.57E+05	1	83.2	.2911E+07	.68E+05	1
495.50	81.8	.2215E+07	.57E+05	1	83.2	.2911E+07	.68E+05	0
580.31	81.8	.2215E+07	.57E+05	0	140.3	.1720E+07	.13E+07	1

FILE: CASE4.TEM

*****HOLTEC INTERNATIONAL*****

********COMPUTER CODE CROSSTIE********

$Revision: 1.0 $

$Date: 17 Dec 1993 23:30:18 $

$Logfile: C:/RACKHEAT/CONTROL/CROSSTIE.FOV $

THIS PROGRAM WAS VERIFIED BY THE TEST
PERFORMED DURING SALEM 1R11 OUTAGE, OCTOBER 1993

DESCRIPTION OF YOUR JOB
PROGRAM CROSSTIE VERIFICATION CASE 4

REACTOR SHUTDOWN DATE:
10 2 93
OUTAGE UNIT, TIME TO START CROSS-TIE (HR), AND TEMP LIMIT(F)
1 490.30 140.30
CCW FLOW(GPM),SFP FLOW(GPM),CCW TEMP(F),& NET WATER VOLUME (ft^3)
3050.00 2040.00 73.00 60000.00
N1,N2,N3,Tao(HR),TaoS(HR)
0 0 0 240.00 60.00
RP(MW), CF, BP1(MWD/MTU), BP2, BP3, UW(Kg)
3411.0 1.0 .00 .00 .00 461.00
FH BUILDING AMBIENT TEMP(F), RELATIVE HUMIDITY(%)
75.00 .60
THE ENDING TIME(HR)
624.00

Heat Exchanger Temperature effectiveness p= .3473

	UNIT 1				UNIT 2			
	(POOL)	(HT-TO-HX)	(HT-LOSS)		(POOL)	(HT-TO-HX)	(HT-LOSS)	
TIME (HR)	T1 (F)	Q1 (BTU/HR)	Qls1 (BTU/HR)	HX1	T2 (F)	Q2 (BTU/HR)	Qls2 (BTU/HR)	HX2
.00	77.3	.2245E+07	.27E+05	1	78.6	.2945E+07	.37E+05	1
490.00	77.3	.2245E+07	.27E+05	1	78.6	.2945E+07	.37E+05	0
580.58	77.3	.2245E+07	.27E+05	0	140.3	.1716E+07	.13E+07	1

FILE: CASE5.TEM

*****HOLTEC INTERNATIONAL*****

********COMPUTER CODE CROSSTIE********

$Revision: 1.0 $

$Date: 17 Dec 1993 23:30:18 $

$Logfile: C:/RACKHEAT/CONTROL/CROSSTIE.FOV $

THIS PROGRAM WAS VERIFIED BY THE TEST
PERFORMED DURING SALEM 1R11 OUTAGE, OCTOBER 1993

DESCRIPTION OF YOUR JOB
PROGRAM CROSSTIE VERIFICATION CASE 5

REACTOR SHUTDOWN DATE:
10 2 93
OUTAGE UNIT, TIME TO START CROSS-TIE (HR), AND TEMP LIMIT(F)
1 448.50 123.50
CCW FLOW(GPM),SFP FLOW(GPM),CCW TEMP(F),& NET WATER VOLUME (ft^3)
2100.00 2460.00 77.50 59000.00
N1,N2,N3,Tao(HR),TaoS(HR)
61 64 68 240.00 60.00
RP(MW), CF, BP1(MWD/MTU), BP2, BP3, UW(Kg)
3411.0 .9 41300.00 27760.00 15240.00 461.00
FH BUILDING AMBIENT TEMP(F), RELATIVE HUMIDITY(%)
68.50 .55
THE ENDING TIME(HR)
520.00

Heat Exchanger Temperature effectiveness p= .4824

	UNIT 1				UNIT 2			
TIME (HR)	(POOL) T1 (F)	(HT-TO-HX) Q1 (BTU/HR)	(HT-LOSS) Qls1 (BTU/HR)	HX1	(POOL) T2 (F)	(HT-TO-HX) Q2 (BTU/HR)	(HT-LOSS) Qls2 (BTU/HR)	HX2
.00	81.8	.2173E+07	.10E+06	1	83.2	.2881E+07	.11E+06	1
240.00	81.8	.2173E+07	.10E+06	1	83.3	.2881E+07	.11E+06	1
240.50	81.9	.2358E+07	.10E+06	1	83.3	.2881E+07	.11E+06	1
317.46	120.4	.2148E+08	.67E+06	1	83.3	.2881E+07	.11E+06	1
317.59	120.4	.2148E+08	.67E+06	1	83.3	.2881E+07	.11E+06	1
317.72	120.4	.2148E+08	.67E+06	1	83.3	.2881E+07	.11E+06	1
448.39	115.5	.1892E+08	.56E+06	1	83.3	.2881E+07	.11E+06	0
502.95	113.8	.1808E+08	.53E+06	0	123.5	.2244E+07	.75E+06	1
504.98	123.7	.1781E+08	.76E+06	1	113.5	.2476E+07	.52E+06	0
519.91	114.4	.1781E+08	.54E+06	0	123.5	.2244E+07	.75E+06	1

FILE: CASE6.TEM

*****HOLTEC INTERNATIONAL*****

********COMPUTER CODE CROSSTIE********

$Revision: 1.0 $
$Date: 17 Dec 1993 23:30:18 $
$Logfile: C:/RACKHEAT/CONTROL/CROSSTIE.FOV $

THIS PROGRAM WAS VERIFIED BY THE TEST
PERFORMED DURING SALEM 1R11 OUTAGE, OCTOBER 1993

DESCRIPTION OF YOUR JOB
PROGRAM CROSSTIE VERIFICATION CASE 6

REACTOR SHUTDOWN DATE:
10 2 93
OUTAGE UNIT, TIME TO START CROSS-TIE (HR), AND TEMP LIMIT(F)
1 454.50 118.90
CCW FLOW(GPM),SFP FLOW(GPM),CCW TEMP(F),& NET WATER VOLUME (ft^3)
3050.00 2460.00 70.00 59000.00
N1,N2,N3,Tao(HR),TaoS(HR)
61 64 68 240.00 60.00
RP(MW), CF, BP1(MWD/MTU), BP2, BP3, UW(Kg)
3411.0 .9 41300.00 27760.00 15240.00 461.00
FH BUILDING AMBIENT TEMP(F), RELATIVE HUMIDITY(%)
67.50 .55
THE ENDING TIME(HR)
600.00

Heat Exchanger Temperature effectiveness p= .3773

	UNIT 1				UNIT 2			
	(POOL)	(HT-TO-HX)	(HT-LOSS)		(POOL)	(HT-TO-HX)	(HT-LOSS)	
TIME (HR)	T1 (F)	Q1 (BTU/HR)	Qls1 (BTU/HR)	HX1	T2 (F)	Q2 (BTU/HR)	Qls2 (BTU/HR)	HX2
.00	73.9	.2225E+07	.50E+05	1	75.2	.2935E+07	.58E+05	1
240.00	73.9	.2225E+07	.50E+05	1	75.2	.2935E+07	.58E+05	1
240.50	73.9	.2410E+07	.50E+05	1	75.2	.2935E+07	.58E+05	1
315.50	108.3	.2177E+08	.43E+06	1	75.2	.2935E+07	.58E+05	1
316.00	108.3	.2176E+08	.43E+06	1	75.2	.2935E+07	.58E+05	1
316.50	108.3	.2175E+08	.43E+06	1	75.2	.2935E+07	.58E+05	1
454.00	103.6	.1903E+08	.36E+06	1	75.2	.2935E+07	.58E+05	0
511.87	102.0	.1814E+08	.33E+06	0	118.9	.2349E+07	.64E+06	1
515.19	118.9	.1777E+08	.64E+06	1	100.5	.2683E+07	.31E+06	0
540.88	101.6	.1772E+08	.32E+06	0	118.9	.2349E+07	.64E+06	1
544.37	118.9	.1735E+08	.64E+06	1	99.8	.2693E+07	.30E+06	0
570.99	100.8	.1732E+08	.31E+06	0	118.9	.2349E+07	.64E+06	1
574.72	118.8	.1694E+08	.64E+06	1	98.9	.2705E+07	.29E+06	0