TID-29434(Vol.1)

ERDA 10MW$_e$ SOLAR PILOT PLANT SUBSYSTEM RESEARCH EXPERIMENTS, STEAM GENERATOR TESTS AT NORTHERN STATES POWER RIVERSIDE STATION

Volume I: Test Description and Data Submittal

April 1977

Work Performed Under Contract No. EY-76-C-03-1109

Honeywell, Inc.
Energy Resources Center
Minneapolis, Minnesota

U.S. Department of Energy

Solar Energy

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Paper Copy $7.25
Microfiche $3.00

TID-29434(Vol.1)
Distribution Category UC-62b

SOLAR PILOT PLANT

SRE STEAM GENERATOR TEST
NORTHERN STATES POWER RIVERSIDE STATION

VOLUME I

TEST DESCRIPTION AND DATA SUBMITTAL

ERDA CONTRACT E(04-3)-1109

Honeywell
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INTRODUCTION

In the spring of 1977 a 5mW SRE steam generator, a scaled-down version of the Pilot Plant steam generator, was tested at the Riverside Station of Northern States Power Company in Minneapolis. This report, in eight volumes, describes that test program and submits test data. Specifically, Volume I contains the test description including installation, instrumentation and data handling, test objectives, results commentary and data analysis. Volumes II through VIII are test data logs for Tests 17 through 23. These include all performance testing specified by the steam generator manufacturer (whereas previous testing was primarily given over to equipment checkout and proving of the test installation). The tests include steady-state, transient, trip simulation and asymmetric heat/ input modes of operation.

The testing was done in a vacant location of the turbine room at Riverside using available services: feedwater, condensate water, cooling water, instrument air, condenser cooling water discharge, low-voltage and 13.8KV power. Heating of the steam generator was done using a radiant array consisting of quartz-iodine heat lamps to simulate reflected solar radiation. Steam raised in the steam generator was exhausted to ambient through the condenser cooling water discharge of an adjacent power generating unit.

Test parameters were read out by the operator from analog displays at a central control console, and by the data acquisition system into CRT display, printer, X-Y plotter, alarm status panel, magnetic tape* and disk storage. Approximately 600 data points were sampled by the data acquisition system. Fluid conditions and metal temperatures were sampled as often as every ten seconds.

---

* The magnetic tapes for individual tests may be used for post-test data retrieval using the software and equipment described herein.

Heat balance calculations over the range of loads run indicate that about 70 percent of the input power going to the radiant array was absorbed by the steam generator, about 24 percent was absorbed by the cooling water going to the radiant array, and about 5 percent was unaccounted for.

SECTION 1
DESCRIPTION OF TEST INSTALLATION AND METHOD

TEST LAYOUT

The test installation of the SRE steam generator at the Northern States Power Riverside Station is shown in Figure 1-1. The steam generator is installed on the 4-foot station elevation; the control trailer is adjacent but on the 38-foot elevation. Four 2000 KVA transformers provide electrical power to the four zones of the water-cooled solar simulator (radiant array). Three support positions for the steam generator, corresponding to the tower corbel positions, provide access for steam and water connections to the steam generator (i.e., feedwater, blowdown, water sampling, recirculation, main steam).

The steam generator instrument cabinet and remote data acquisition cabinet are located near, and northwest of, the steam generator. These provide electrical connection interfaces between the control console, data acquisition system, and steam generator instrumentation.

The SRE steam generator arrangement is shown in Figure 1-2. The boiler, first-stage and second-stage superheater heat transfer surfaces form the inside surface of a right circular cylinder (cavity). The boiler section, which is relatively cool, covers the bottom portion of the cavity; the superheaters cover the upper portion of the cavity with the second-stage superheater uppermost in the region of lowest heat input. The two superheaters are the same size. The cavity ceiling is insulated.

Feedwater is supplied to the test installation from the No. 8 Unit at Riverside at about 2600 psi and 227°C (440°F). The generated steam, as well as blow-down and by-passed feedwater, is delivered to the spent condenser cooling

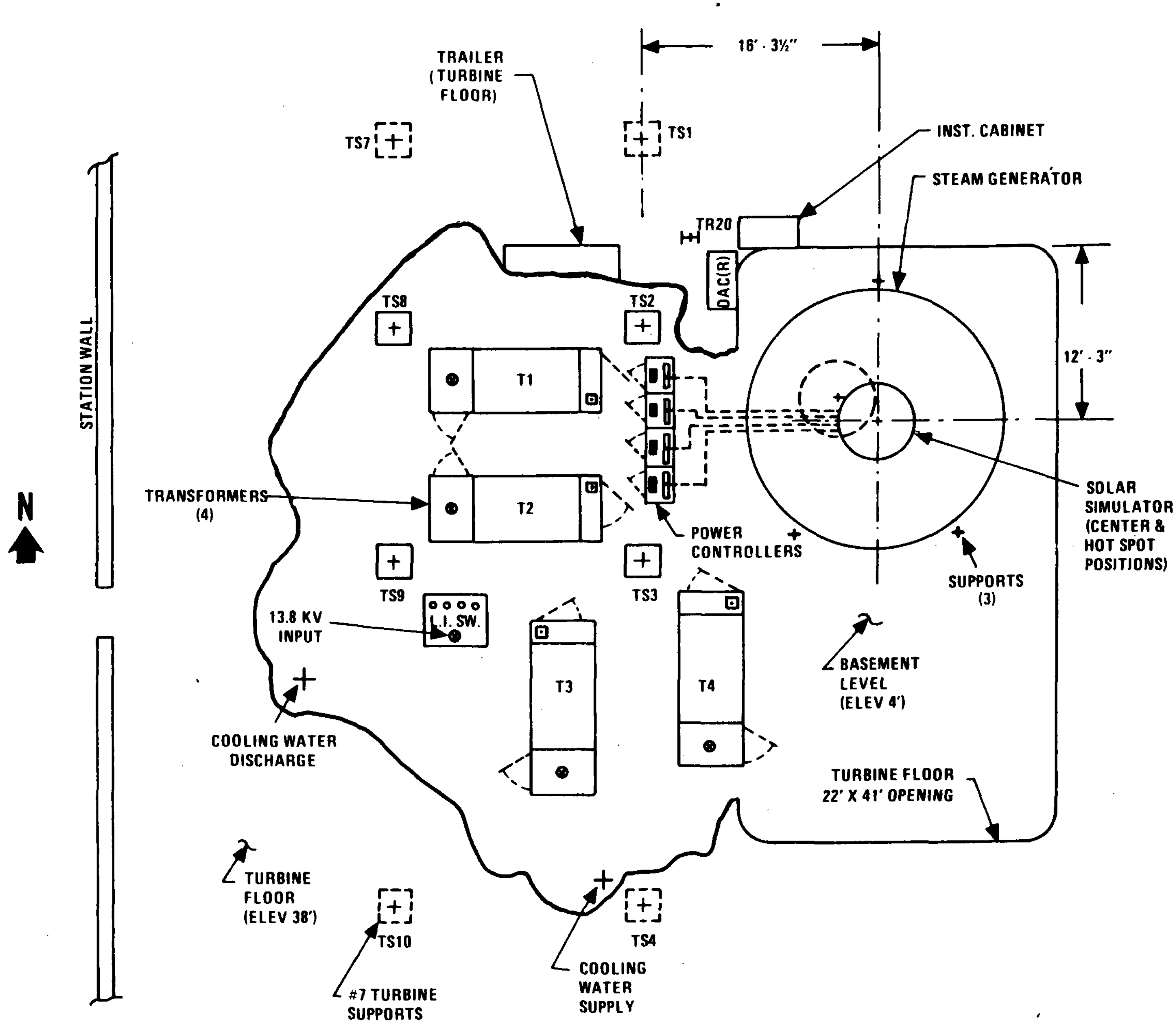

Figure 1-1. SRE Steam Generator Test Layout

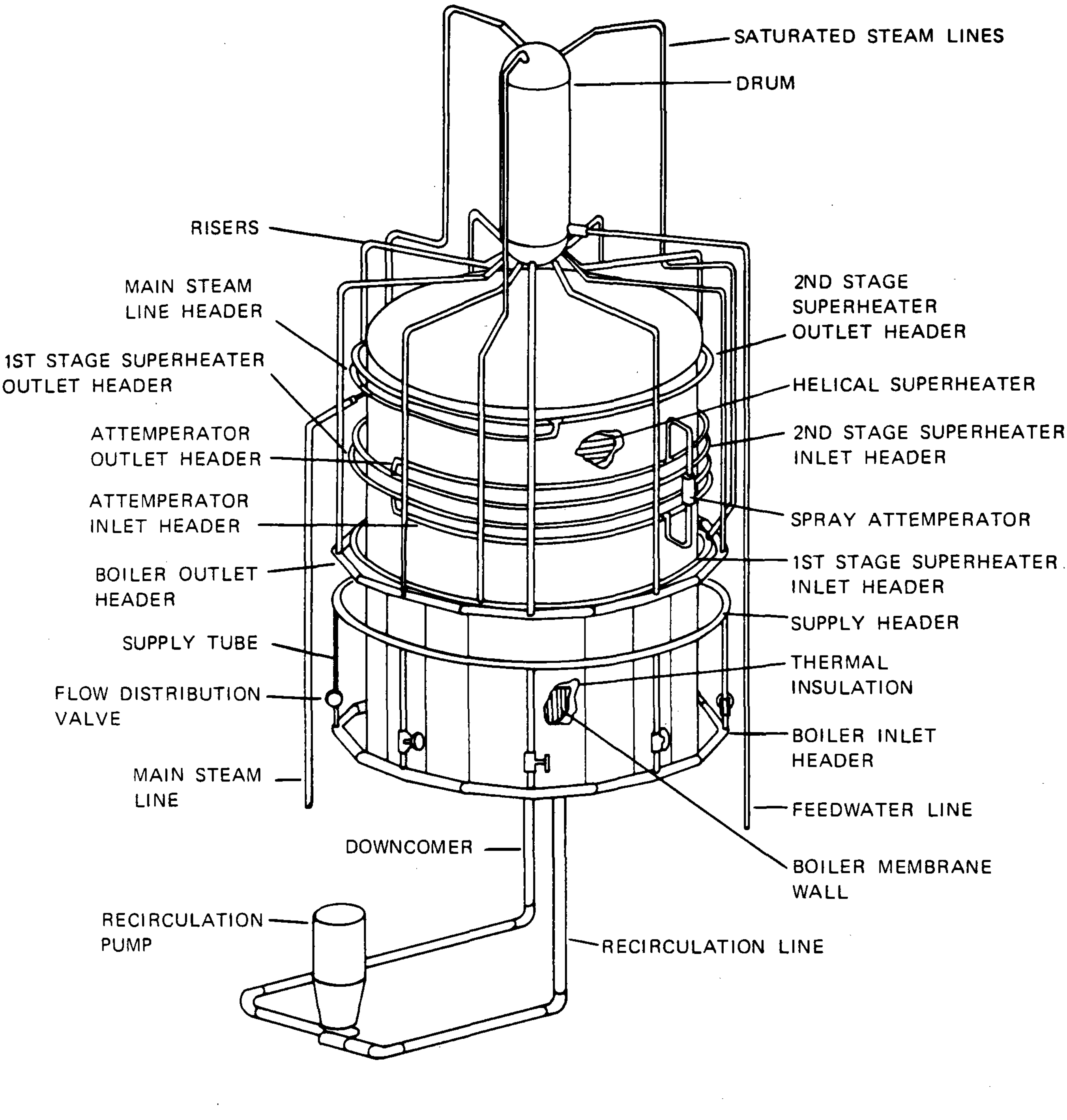

Figure 1-2. SRE Steam Generator Design Arrangement

water of the Riverside No. 6 Unit by means of a pressure-regulated header and sparge tube. Water for cooling the solar simulator comes from the Riverside service water line. Flow and temperature rise are measured before wasting to the Riverside No. 7 Unit condenser cooling water line.

Pressure-regulated feedwater at about 1900 psig is introduced to the drum of the steam generator. Water at about 315°C (600°F) circulates continuously through the drum and boiler. Water leaves the drum through the downcomer pipe and is pumped through the recirculation line to the boiler section. A valve in the recirculation line provides control of recirculation rate. The water leaving the recirculation pump is parallel-distributed to the nine panels of the boiler section where steam generation takes place.

The saturated steam-water mixture at about 328°C (622°F) then flows through the risers to the steam drum. The steam drum contains centrifugal and inertial separators for drying the steam before its passage to the superheaters. The steam leaving the first-stage superheater passes through the spray attemperator where additional feedwater is injected as required to control the temperature of the steam leaving the generator at 513°C (955°F). The exiting steam is throttled to near-atmospheric pressure after which it is discharged through the sparge tube.

INSTRUMENTATION

The field-located instruments for the SRE steam generator, excluding cooling water circuits, are listed in Table 1-1. This listing designates the various functions as to control, indication, alarm, and data acquisition. Transmitters generate 4-20 DC milli-ampere signals proportional to the magnitude of the process variable (i.e., pressure, temperature, flow, level). Temperature elements are primarily chromel-alumel thermocouples, the largest percentage of which are read out by the data acquisition system.

Table 1-1. SRE Steam Generator Field Instruments

INSTRUMENT	IDENTIFICATION NO.	QUANTITY	CONTROL	FUNCTION INDICATE	FUNCTION ALARM	DATA ACQUISITION
Pressure:						
Feedwater	PT-1	1	1			1
Drum (Transmitter)	PT-230	1			D/A	1
Drum (Gage)	PT 230	1		A		
Recir. Pump Outlet (Gage)	PT 300	1		A		
Attemerator Inlet - Steam	PT 475	1				1
Main Steam - Exit of SRE	PT 590	1		B		1
Main Steam - Control Valve	PT-2	1	1			1
Discharge Header	PT-3	1	1			
Flow:						
Feedwater	FT-1	1	1	B		1
Blowdown	FE 260	1				
	FT 260	1		C		1
Boiler Inlet (Total)	FE 310	1				
	FT 310	1		C	D/A	1
	FS 310	1			I	
Boiler Inlet (9 Circuits)	FE 350-358	9				
	FT 350-352	3		C		3
Attemperator Spray Water	FE 480	1				
	FT 480	1		B		1
Main Steam	FT-3	1	1	B		1
Level:						
Level Transmitter	LT 210	1	1	C	C	1
Level Transmitter	LT 211	1		B	D/A	1
Level Gage	GG 220	1		A		
Fluid Temperatures:						
Feedwater	TE-1	1		B		
Feedwater	TE-19	1				1
Attemperator Spray Water	TE 480	1				1
Blowdown	TE 260	1				1
Downcomer - Pump Inlet	TE 300	1			D/A	1
Downcomer - Pump Inlet	TE 301	1				1
Boiler Inlet - Pump Outlet	TE 310	1				1
Boiler Inlet - Pump Outlet	TE 311	1				1
Saturated Steam #1	TE 400	1				1
Saturated Steam #2	TE 401	1				1
Saturated Steam #3	TE 402	1				1
Steam into Attemperator	TE 475	1		B	D/A	1
Steam into Attemperator	TE 476	1				1
Attemperator Outlet	TE 500	1		B	D/A	1
Attemperator Outlet	TE 501	1				1
Main Steam - SRE Outlet	TT 590	1		C	C	1
Main Steam - SRE Outlet	TE 591	1		B	D/A	1
Metal Temperatures:						
Drum Shell	TE 210-217	8				18
Boiler - Membrane (Heat Flux	TE 330-389	60				60
1st Stage SH Inlet	TE 405-409	5			D/A	5
1st Stage SH (Heat Flux)	TE 420-440	21				21
1st Stage SH Outlet	TE 450-454	5			D/A	5
1st Stage SH Outlet Legs	TE 455-466	12				12
1st Stage SH Outlet Header	TE 470-471	2				2
2nd Stage SH Inlet	TE 505-509	5			D/A	5
2nd Stage SH (Heat Flux)	TE 520-540	21				21
2nd Stage SH Outlet	TE 550-554	5			D/A	5
2nd Stage SH Outlet Legs	TE 555-566	12				12
2nd Stage SH Outlet Header	TE 570-571	2				2
Boiler Output Support Lug	TE 600-602	3				3
1st Stage SH Outlet Support Lug	TE 603-605	3				3
2nd Stage SH Outlet Snubber Plate	TE 606-608	3				3
2nd Stage SH Outlet Tube Snubber Bracket	TE 609-611	3				3
Pump Seal Flush	TE 612	1				1

Definitions

Indicate
- A - Visual Reading, i.e., gage
- B - Chart Recorder
- C - Indicator on Controller

Alarm
- D/A - Alarm is activated by the data acquisition system
- C - Alarm is activated by the controller
- I - Alarm is an independent circuit

The control of the basic fluid circuit of the steam generator is shown schematically in Figure 1-3. There are seven control stations providing automatic-manual control and one providing manual control. Automatic-manual control is provided for feedwater pressure, drum level (two contollers), steam temperature and pressure, boiler recirculation flow, and discharge header pressure. Manual control is provided for boiler blow-down flow.

Drum level control uses three measurements: steam flow, feedwater flow, and drum level. Flow measurements are linearized by square root extractors. The linearized steam flow signal passes through the summer whose output sets the control point of the feedwater flow controller to effect equality of steam and feedwater flows. The drum level controller output signal trims the output signal of the summer to restore water level in the drum after completion of a steam load change or after blow-down.

High-pressure feedwater from the No. 8 Unit at Riverside is throttled by Valve 3 to maintain a pressure of about 1900 psig at the attemperator and drum-level control valves. A portion of the feedwater is bled off through the by-pass line to assure adequate pressure control when there is low flow through the steam drum. Some of the feedwater is routed to the attemperator for temperature control of the steam leaving the steam generator. This control is effected by Valve 485 operating in response to Temperature Transmitter 590.

Valve 1, acting in response to Pressure Transmitter 2, controls main steam pressure. Valve 1 simulates turbine throttle-pressure control.

Valve 310, acting in response to Flow Transmitter FT310, maintains a controlled recirculation flow through the boiler. Drum blow-down is effected by Valve 260 which is operated by a manual control station.

Back pressure in the discharge header is maintained at about 200 psig by Valve 15 acting in response to Pressure Transmitter 3. This control effects pressure

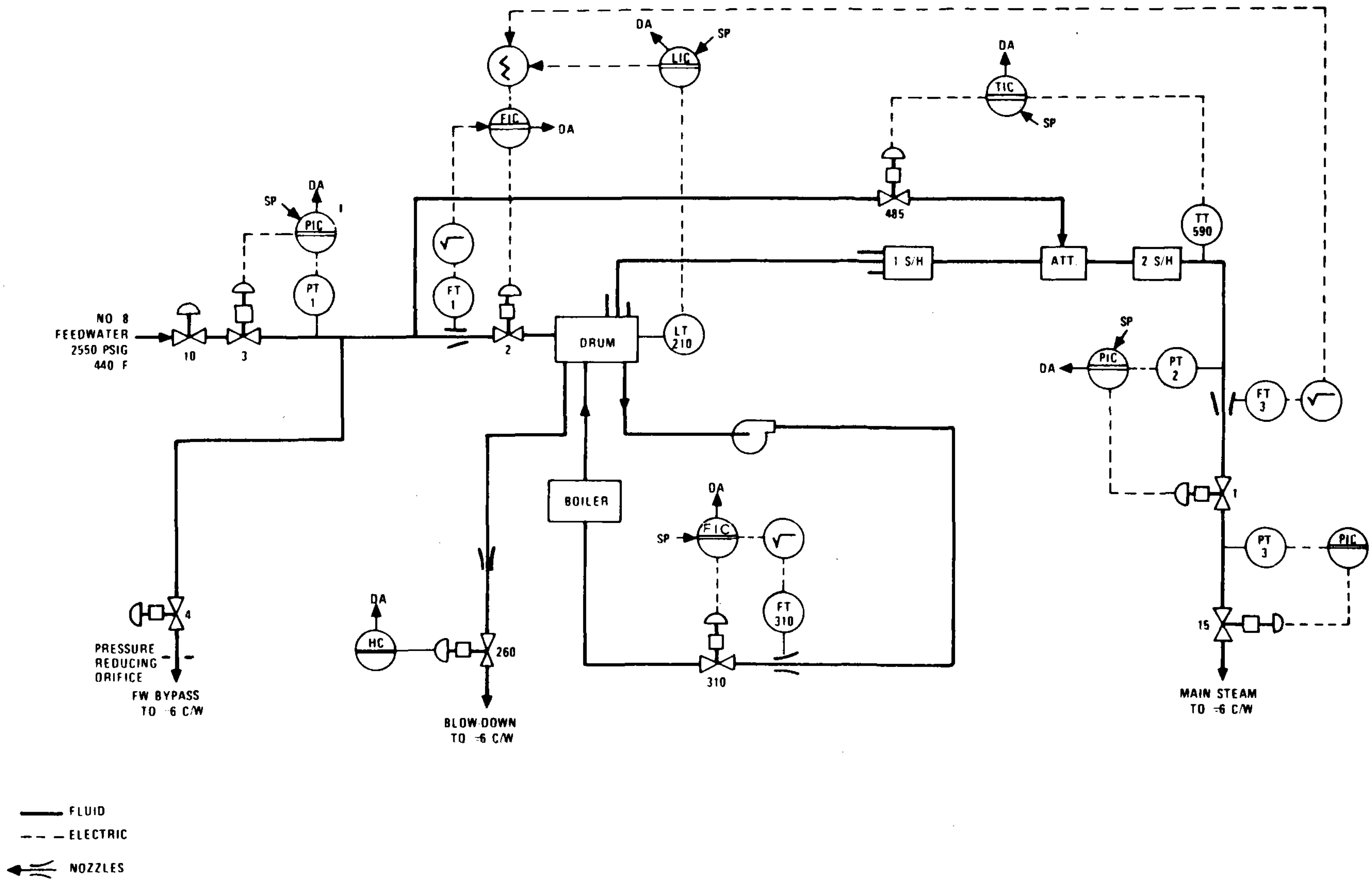

Figure 1-3. SRE Steam Generator Controllers

staging of the main steam discharge for better control of steam admission to the No. 6 condenser discharge circulating water.

Analog readout of the process variable is provided at each control station. In addition, other analog readouts are provided to the test operator as shown in the flow schematics, Figures 1-4 (steam generator basic fluid circuit) and 1-5 (cooling water circuits). Figure 1-6 shows the steam generator fluid sensors feeding directly to the data acquisition system.

The steam generator control console, or operator's station, is shown in Figure 1-7. The solar simulator control station is at the right in the picture. Note the recorders and water conductivity meter in the left-hand rack. The right-hand rack of the control console houses the controllers (top row), cooling water indicators (next to top row), the alarm panel, and the power switching panel (bottom).

Table 1-2 is a code sheet for identifying recorder traces and signal sources.

DATA ACQUISITION SYSTEM

The data acquisition operator station is pictured in Figure 1-8. The major components of this system are the Tektronix 4012-6 CRT/console (left), Versatec 1110A printer/plotter (center), Hewlett-Packard 9611A measurement and control system (right), and the Hewlett-Packard 9611R remote measurement and control station (not shown).

The 9611A consists of a 2112A controller with 64K memory and RTE III disk-based software, remote analog/digital communication system, 2.5 MW disk, paper tape reader, and nine-track NRZI magnetic tape unit.

The 9611R provides for system input and output interfacing with field-located instrumentation and has 19 analog input multiplexer modules each having 16

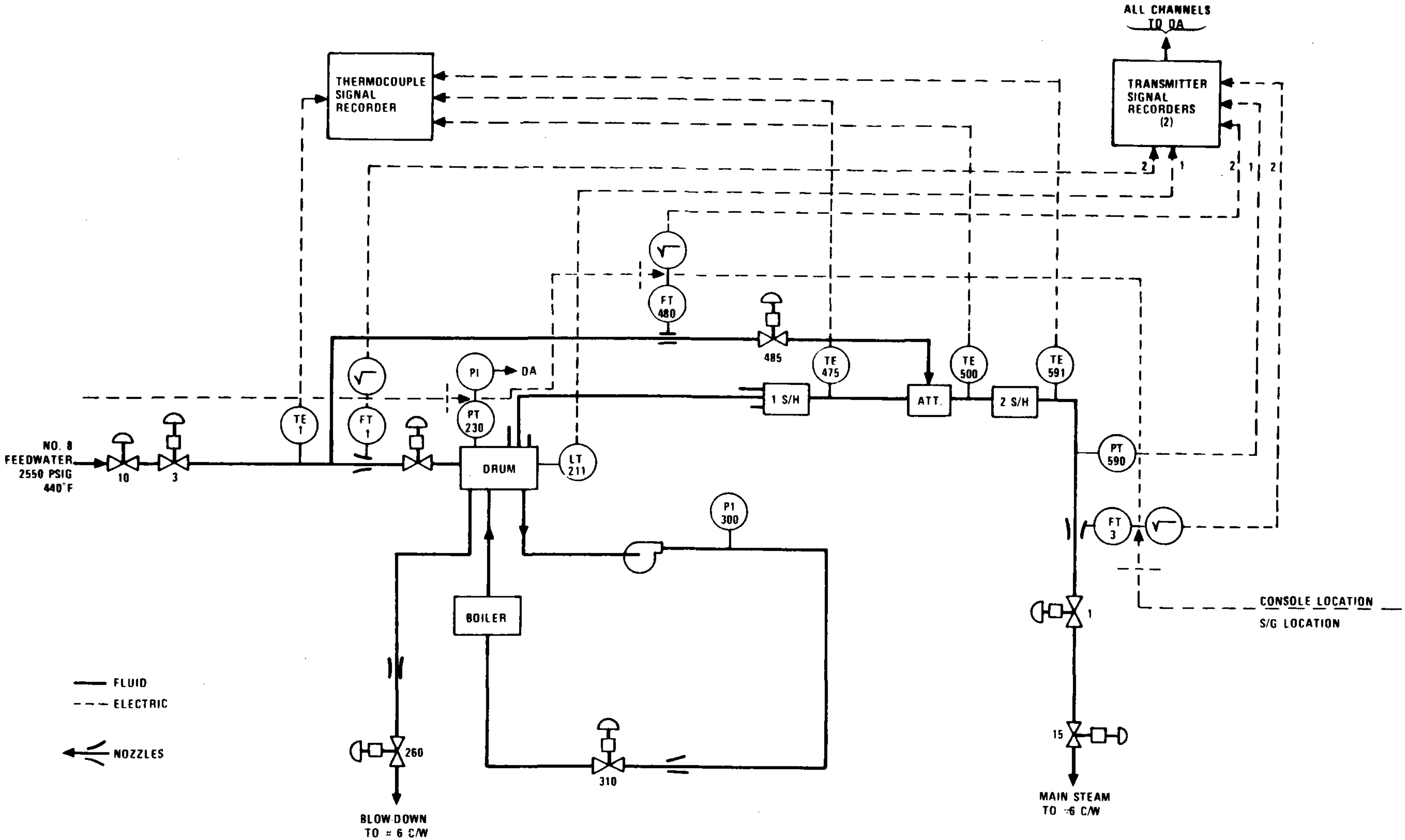

Figure 1-4. SRE Steam Generator Sensors and Readout (Except Controllers)

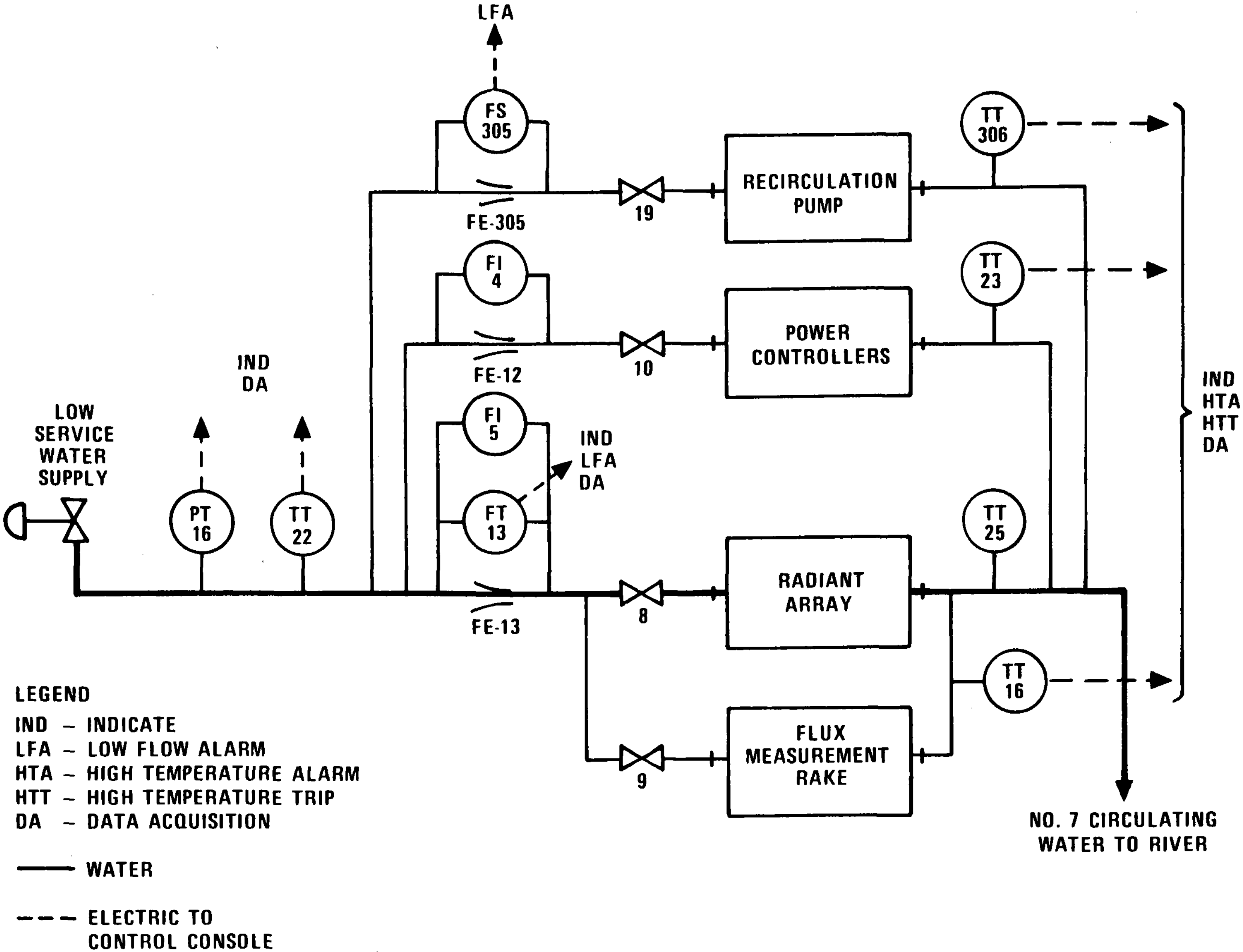

Figure 1-5. Cooling Water Sensors and Readout

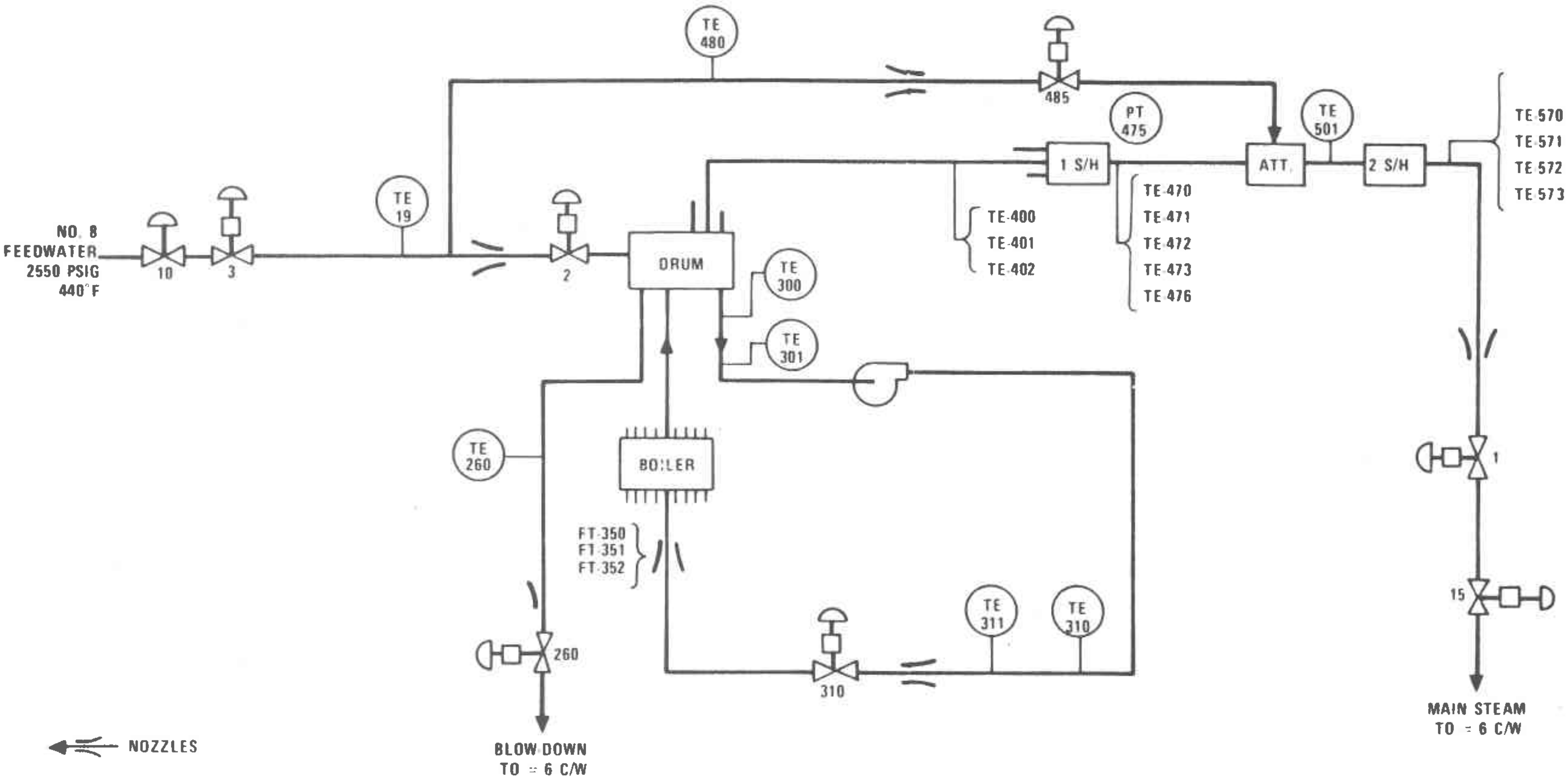

Figure 1-6. SRE Steam Generator Fluid Sensors Feeding Directly to Data Acquisition

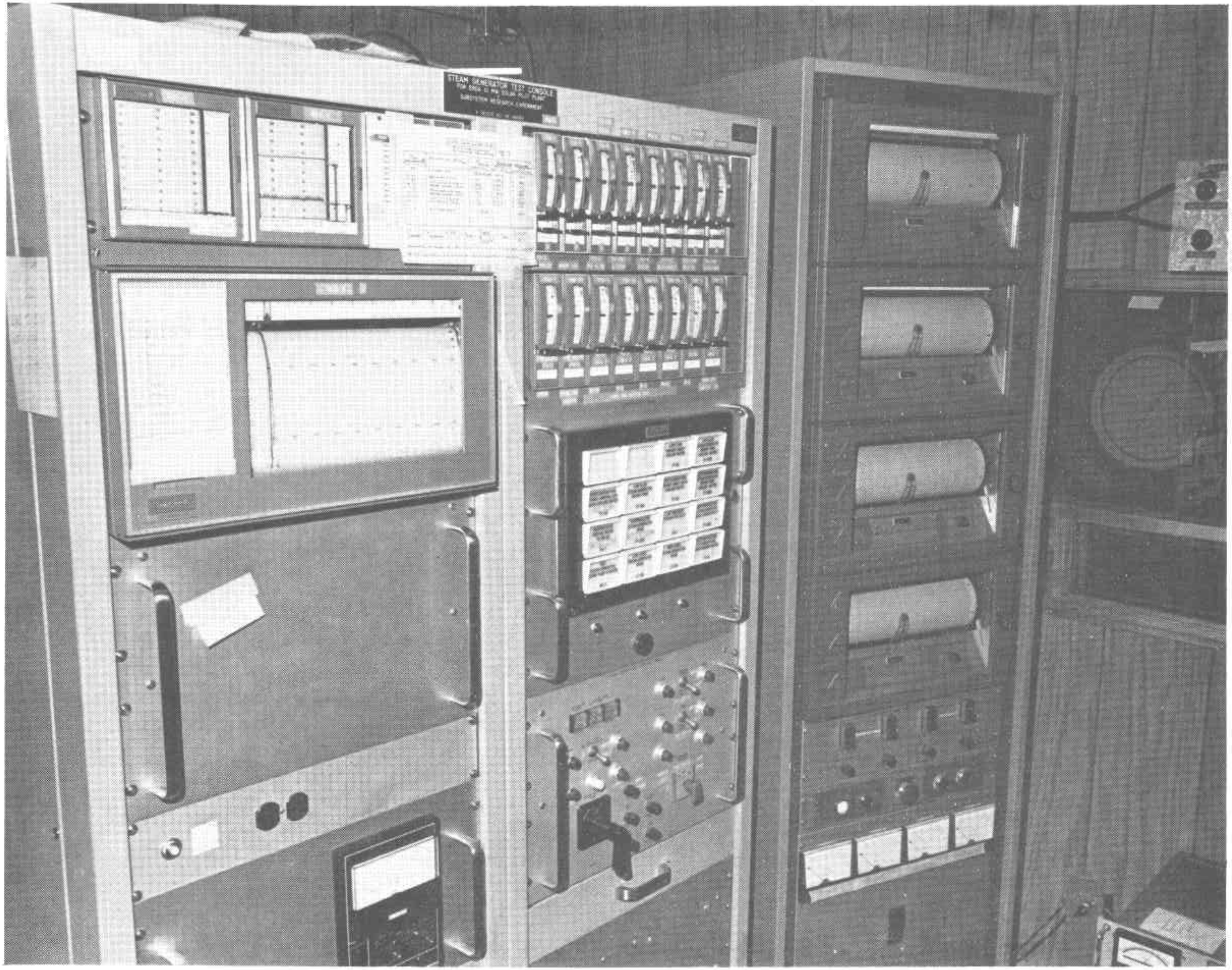

Figure 1-7. Analog Control and Solar Simulator Consoles

Table 1-2. Code Sheet for Recorders

Recorder Number	Pen or Point Number	Process Variable	Data Source	Scale Range
RCD-1	1, Red	Main Steam Flow	FT-3	0-18,000 lb/hr*
	2, Blue	Drum Inlet Feedwater Flow	FT-1	0-18,000 lb/hr**
	3, Green	Attemperator Spraywater Flow	FT-480	0-2,000 lb/hr**
RCD-4	1, Red	Drum Water Level	LT-211	0-55 Inches†
	2, Blue	Main Steam Pressure	PT-590	0-2,100 psig
	3, Green	Trend Panel PV-1: Water Conductivity	Beckman solu-meter®	0-100 micromhos/cm††
RCD-3	1	Feedwater Temperature (F)	TE-1	0-1,000°F (K)
	2	Attemperator Inlet Temperature (F)	TE-475	0-1,000°F (K)
	3	Attemperator Outlet Temperature (F)	TE-500	0-1,000°F (K)
	4	Main Steam Temperature (F)	TE-591	
	5	Lower 1st Stage Superheater (M)	TE-405	0-1,000°F (K)
	6	Upper 1st Stage Superheater (M)	TE-452	0-1,000°F (K)
	7-10	Recirculation Pump Inlet Water Temperature (F)	TE-301	0-1,000°F (K)
	11	Lower 2nd Stage Superheater (M)	TE-507	0-1,000°F (K)
	12	Upper 2nd Stage Superheater (M)	TE-550	0-1,000°F (K)

*lb/hr. at 955°F, $\rho = 2.06\ lb_m/ft^3$

**lb/hr. at 440°F, $\rho = 52.52\ lb_m/ft^3$

†Datum is centerline of lower pipe; transmitter output is for 80°F water; alarm and trips set for 620°F water.

††Specific conductance at 25°C.

(F): Fluid Temperature

(M): Metal Temperature

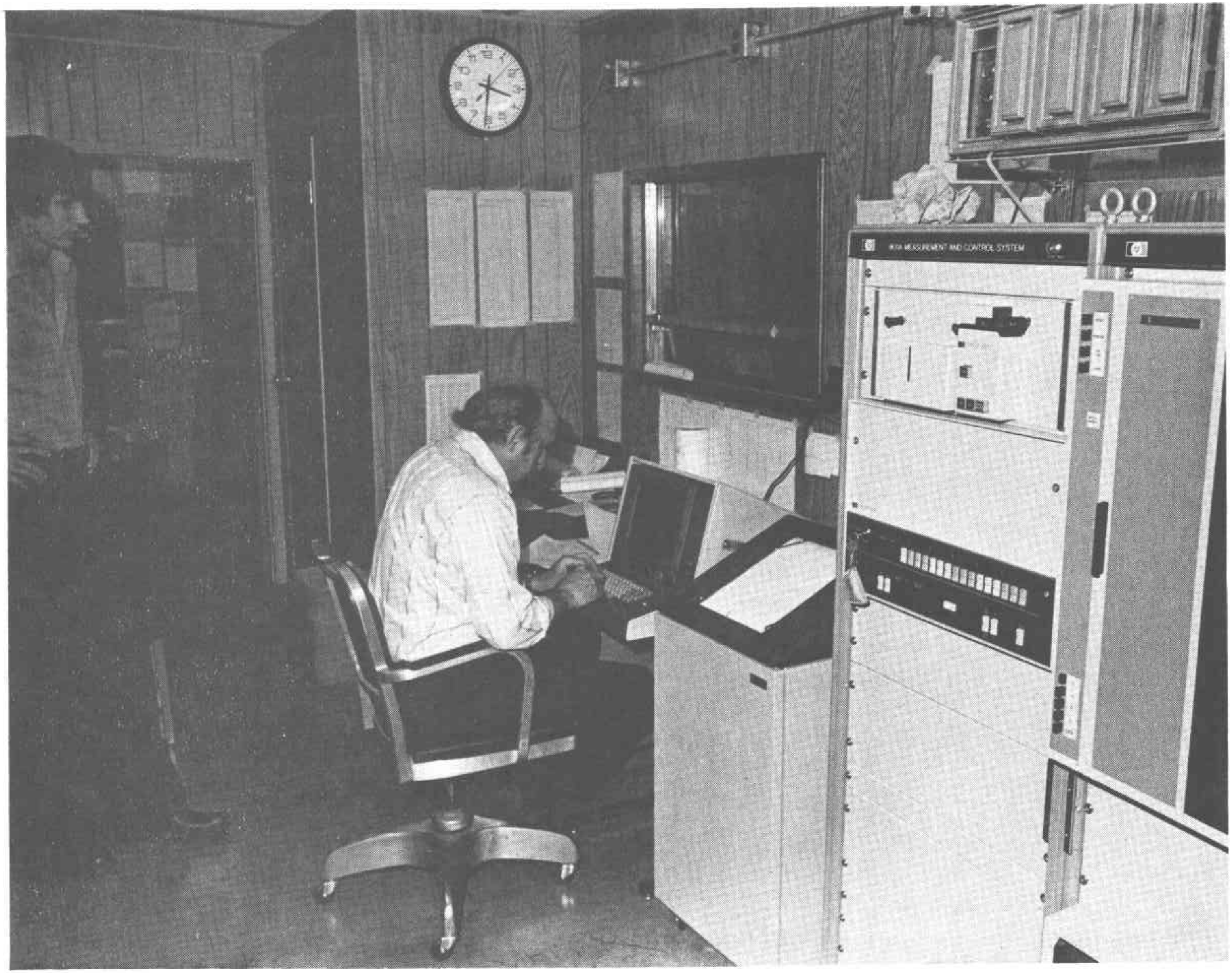

Figure 1-8. Data Acquisition Operator Station

differential inputs. Each of two digital I/O modules has 12 inputs. The digital output module is a set of 12 individual relay contacts.

Table 1-3 is the parameter identification legend for the Operator and Performance Summaries printed by the data acquisition system.

DATA ACQUISITION SYSTEM SOFTWARE DESIGN

Summary

The software design for data acquisition, reduction, monitoring, recording and display on the HP21MX computer system included 11,800+ lines of Hewlett-Packard Fortran source coding. Most of this was new coding to achieve the test program objectives. The structure and utilization of the 86 programs and subroutines are described briefly in the section below. Major program user descriptions are shown in Tables 1-4 and 1-5. The organization of the data is described in Table 1-6 for main memory real-time common and in Table 1-7 for disk files.

The program complement includes features to allow ready accessibility to tape recorded data either by using existing reduced data or by using modified data reduction methods and raw data items from tape. This extensive post-test analysis capability is entirely in Fortran coding. Transferability to other than H-P systems may be feasible if warranted.

Software Design Rationale

The data acquisition software system was designed to meet four main objectives:

- Real-time data acquisition, monitoring and recording
- Summary and report generation, automatically or by operator request

Table 1-3. Parameter Identification Legend:
Operator and Performance Summaries

LABEL	PARAMETER	UNITS	SOURCE (5)
OPERATOR SUMMARY BOILER DRUM			
P-D	Pressure, drum	psig	PT-230
T-D	Temperature, drum	°F	CALC.
L-D	Level, drum	Inches above-55" reference	LT-210
W-FW	Flow, feedwater	Lbs_m/Hour	FT-1
W-BD	Flow, blowdown	Lbs_m/Hour	FT-260
PUMP			
W-B	Flow, boiler recirculation	Lbs_m/Hour	FT-310
T-DC	Temperature, downcomer	°F	TE-300
T-SUB	Temperature, pump suction subcooling	°F	CALC.
T-PC	Temperature, pump coolant	°F	TE-306
SUPERHEATER 1			
TE-	Temperature, thermocouples	°F	TE-420-440; 406-409; 450-454; 455-466
T-S1I	Temperature, steam, superheater inlet	°F	TE-400-402
W-ATT	Flow, attemperator water	Lbs_m/Hour	FT-480
SUPERHEATER 2			
TE-	Temperature, thermocouples	°F	TE-520-540; 506-509; 550-554; 555-566
T-S2O	Temperature, steam, superheater outlet	°F	TT-590
P-S2O	Pressure, steam, superheater outlet	psig	PT-590
W-S2	Flow, superheater	Lbs_m/Hour	FT-3
POWER			
BOILER ABS	Absorbed power, boiler	Kilowatts	CALC.
S.H. #1 ABS	Absorbed power, superheater	Kilowatts	CALC.
S.H. #2 ABS	Absorbed power, superheater	Kilowatts	CALC.
TOTAL INPUT	Net power input (1)	Kilowatts	CALC.
TOTAL ABSORBED	Absorbed power, steam generator	Kilowatts	CALC.
POWER RATIO	$\frac{\text{Total Absorbed}}{\text{Total Input}}$	Dimensionless	

(1) Electrical power to Radiant Array minus cooling water heat absorbed.

(2) Recirculation flow divided by Superheater #1 flow.

(3) Reciprocal of recirculation ratio (N-CR).

(4) Electrical power to Radiant Array minus cooling water heat absorbed.

(5) Sources are cited by transmitter or thermocouple designations as indicated in the P & ID Diagrams, or as calculated (Calc.) by the Data Acquisition System (DAC) (i.e., enthalpies, power). Transmitter and thermocouple raw outputs are modified by the DAC to provide readouts in engineering units.

Table 1-3. Parameter Identification Legend: Operator and Performance Summaries (Continued)

LABEL	PARAMETER	UNITS	SOURCE (5)
PERFORMANCE SUMMARY BOILER DRUM			
P-D	Pressure, drum	psig	PT-230
T-D	Temperature, drum	°F	CALC.
H-GD	Enthalpy, drum steam	BTU/Lb_m	CALC.
H-FD	Enthalpy, drum water	BTU/Lb_m	CALC.
N-CR	Recirculation ratio (2)	Dimensionless	CALC.
FEEDWATER			
P-FW	Pressure, feedwater	psig	PT-1
T-FW	Temperature, feedwater	°F	TE-19
W-FW	Flow, feedwater	Lb_m/Hour	FT-1
H-FW	Enthalpy, feedwater	BTU/Lb_m	CALC.
FLOW CIRCUITS			
T-DC	Temperature, downcomer	°F	TE-300
T-SUB	Temperature, pump suction subcooling	°F	CALC.
W-B	Flow, boiler recirculation	Lbs_m/Hour	FT-310
W-BC1	Flow, boiler circuit (Transmitter #1)	Lb_m/Hour	FT-350
W-BC2	Flow, boiler circuit (Transmitter #2)	Lb_m/Hour	FT-351
W-BC3	Flow, boiler circuit (Transmitter #3)	Lb_m/Hour	FT-352
X-B	Quality, boiler steam (3)	Dimensionless	CALC.
SUPERHEATERS S.H. Stage 1			
W-SI	Flow, superheater #1	Lb_m/Hour	WS2-WATT
T-S1I	Temperature, steam, superheater inlet	°F	TE-400-402
T=S10	Temperature, steam, superheater outlet	°F	TE-476
P-S10	Pressure, steam, superheater outlet	psig	PT-475
H-S10	Enthalpy, steam, superheater outlet	BTU/Lb_m	CALC.

(1) Electrical power to Radiant Array minus cooling water heat absorbed.

(2) Recirculation flow divided by Superheater #1 flow.

(3) Reciprocal of recirculation ratio (N-CR).

(4) Electrical power to Radiant Array minus cooling water heat absorbed.

(5) Sources are cited by transmitter or thermocouple designations as indicated in the P & ID Diagrams, or as calculated (Calc.) by the Data Acquisition System (DAC) (i.e., enthalpies, power). Transmitter and thermocouple raw outputs are modified by the DAC to provide readouts in engineering units.

Figure 1-3. Parameter Identification Legend: Operator and Performance Summaries (Concluded)

LABEL	PARAMETER	UNITS	SOURCE (5)
ATTEMPERATOR			
P-ATT	Pressure, attemperator water inlet	psig	PT-1
T-ATT	Temperature, attemperator water inlet	°F	TE-480
W-ATT	Flow, attemperator water	Lb_m/Hour	FT-480
H-ATT	Enthalpy, attemperator water	BTU/Lb_m	CALC.
S.H. Stage 2			
W-S2	Flow, superheater #2	Lb_m/Hour	FT-3
T-S2I	Temperature, superheater #2 inlet	°F	TE-500,501
T-S20	Temperature, steam, superheater outlet	°F	TT 590
P-S20	Pressure, steam, superheater outlet	°F	PT 590
H-S20	Enthalpy, steam, superheater outlet	BTU/Lb_m	CALC.
BOILER			
L-D	Level, drum	Inches above-55" reference	LT 210
T-BI	Temperature, boiler inlet	°F	TE-310, 311
H-BI	Enthalpy, boiler inlet	BTU/Lb_m	CALC.
R-BI	Density, boiler inlet	Lb_m/Ft^m	CALC.
R-GD	Density, drum steam	Lb_m/Ft	CALC.
R-FD	Density, drum water	Lb_m/Ft	CALC.
POWER			
Boiler ABS	Absorbed power, boiler	Kilowatts	CALC.
S.H. #1 ABS	Absorbed power, superheater	Kilowatts	CALC.
S.H. #2, ABS	Absorbed power, superheater	Kilowatts	CALC.
Total Input	Net power input (4)		CALC.
Total Absorbed	Absorbed power, steam generator	Kilowatts	CALC.
Power Ratio	Total Absorbed Total Input	Dimensionless	CALC.

(1) Electrical power to Radiant Array minus cooling water heat absorbed.

(2) Recirculation flow divided by Superheater #1 flow.

(3) Reciprocal of recirculation ratio (N-CR).

(4) Electrical power to Radiant Array minus cooling water heat absorbed.

(5) Sources are cited by transmitter or thermocouple designations as indicated in the P & ID Diagrams, or as calculated (Calc.) by the Data Acquisition System (DAC) (i.e., enthalpies, power). Transmitter and thermocouple raw outputs are modified by the DAC to provide readouts in engineering units.

Table 1-4. Real-Time Test Support Programs

OPERATOR SUMMARY RU, OPSM (,6)	Drum conditions Pump conditions Superheater metal temperatures Power summary
PERFORMANCE SUMMARY	Boiler steam conditions: drum, flow circuits, feedwater Superheater steam conditions: flows, pressures, temperatures, enthalpies Transient additions: drum conditions and densities
BASE DATA REPORT - METAL: METAL TEMPERATURES RU, METL (,6)	Drum, boiler, superheater 1, superheater 2, structural points
BASE DATA REPORT - FLUID: FLUID CONDITIONS RU, FLUD (,6)	Temperatures, levels, pressures, flows, pump jacket temperature
FIRST STAGE SUPERHEATER METAL TEMPERATURES RU, SPM1 (,6)	Metal temperatures, superheater 1: tube outlet, tube inlet, tube-to-tube, header, plus drum temperatures
SECOND STAGE SUPERHEATER METAL TEMPERATURES RU, SPM2 (,6)	Metal temperatures, superheater 2: tube outlet, tube inlet, tube-to-tube header, structure lugs
BOILER TEMPERATURE PROFILE RU, BTP (,6)	Boiler temperatures by level and column - 8 levels, 10 columns
FIRST STAGE SUPERHEATER TEMPERATURE PROFILE RU, SPR1	S.H. 1 inlet, outlet, leg temperatures, S.H. 1 temperatures by turn and column - 4 turns, 6 columns
SECOND STAGE SUPERHEATER TEMPERATURE PROFILE RU, SPR2 (,6)	S.H. 2 inlet, outlet, leg temperatures, S.H. 2 temperatures by turn and column - 4 turns, 6 columns

Table 1-4. Real-Time Test Support Programs (Continued)

COOLING WATER TEMPERATURES RU, COOL (,6)	Cooling water temperatures: inlet, array points, flux boom outlet, array/flux boom outlet, recirc. pump jack outlet, bearing jacket, power controllers outlet
WARNINGS AND ALARMS REPORT RU, WARPT (,6)	Warning and alarm parameters and current limits, with counts of occurrences
MODIFY WARNING AND ALARM LIMITS RU, MOLMT	Operator - interactive modification of current warning and alarm limit Valves - automatic report of new settings Parameters are referenced by position number in report
NEW WARNING AND ALARM LIMITS RU, NWLMT	Automatic preset/reset of all warning and alarm limits to programmed values - automatic report of revised settings
CLEAR WARNING AND ALARM COUNTS RU, WACLR	Reset counts of occurrences to zero for all warning and alarm parameters
WARNING AND ALARM CHECKING (RU, WARNA)	Checks all warning and alarm parameter conditions against current values of warning and alarm limits Provides screen display and slow beep for warnings Provides printed report and fast beep for alarms Provides printed report, fast beep and calls trip subroutine for alarm-and-trip limits exceeded This program is automatically scheduled by data acquisition program RDIN

Table 1-4. Real-Time Test Support Programs (Concluded)

READ DATA AND CONVERT TO INPUT BUFFERS (RU, RDIN)	Reads the data acquisition interface system - stores ran data and system time Reduces ran data using preset conversion factors and stores it in real time common for use by other programs Schedules WARNA for warning and alarm checking, and schedules PLOT for writing current data and disk file and mag tape
PRESET CALIBRATION PARAMETERS AND BEGIN TEST (RU, PRCAL)	Preset conversion/calibration factors for use by RDIN and conversion subroutines Offers option to rewind tape, set recording interval, begin monitor and record operations, by scheduling RDIN and ESXXX
READ, CONVERT AND STORE INCIDENT FLUX DATA (RU, ESXXX)	Interrupt-triggered program reads flux boom position and incident flux valves Converts flux data for storage, performs integrations Normally initiated by PRCAL
SEARCH DISK FILE FOR PLOT GENERATION RU, SERCH	Operator-interactive search program to select plot items from disk file One argument, up to 6 parameters may be selected by number Search mode 1: start time, stop time, time interval Search mode 2: start time, no. of points, each Nth point Automatically schedules KOUK for actual plot execution

Table 1-5. Pre-Test and Post-Test Programs: Additional Programs Available on SRE DAC Disk

KOOK (Called by EXEC)	Scheduled by search to produce Versaplot output up to six simultaneous functions.
TABLE RU, TABLE (6)	Produces up to 12-column tabular output (paginated) of operator-selected variables from disk file.
CRPLT (Called by EXEC)	Produced Tektronix (plot IØ based) graphics display of up to six simultaneous variables (not currently in use).
SUPLT RU, SUPLT	Produced Tektronix screen plot of super-heater tube temperature profiles - temperature vs. feet of tube length.
TCHEK RU, TCHEK	Provides operator-controlled monitoring of single DAC channel input.
CCHEK RU, CCHEK	Provides operator-controlled monitoring of DAC input electronics card.
RATER RU, RATER	Operator modification of on-line data scanning repetition rate.
TRPON RU, TRPON	Operator-controlled trip test routine for DAC trips.
BEEP (Called by EXEC)	Produced repetitive audible signal at operator console for warning and alarm annunciation.
CALPR RU, CALPR	Sets pressure transmitter zero correction.
CALFM RU, CALFM	Sets flowmeter differential pressure zero calibration
CALTM RU, CALTM	Sets temperature element calibration correction.
STEAM RU, STEAM	Runs test points for 'steam table' routines from B&W.
FTEST RU, FTEST	Runs test points for flowmeter computation routines for Honeywell and B&W flowmeter routines.
MAGTP RU, MAGTP	Reads raw and reduced data from magtape for post test data outputs.
IAPRT RU, IAPRT	Prints raw data table of all DAC input channels.
SCANR RU, SCANR	Automatically scans DAC input cards for test.
SCATR (Called by EXEC)	Produces scatter plot output of up to six simultaneous functions on Versaplot.
TPIN (Not Tested)	Reads raw data from magtape and re-reduces data with new coefficients for summaries and plots.

Table 1-6. Real-Time Common Memory Allocation

HEADER DATA: Integer Format - 9 words

Year Date Time Test Number Test Start Point

RAW DATA BUFFER: Integer Format - 304 words

Multiplexed data input from data acquisition interface. Data is checked for hardware-detected errors and hardware flag bits are removed on input.

FLUX DATA HEADER: Integer Format - 2 words

Current Flux Reading Time
Current Boom Position

RAW FLUX DATA BUFFER: Integer Format - 12 X 34 array

Mapped array of multiplexed flux data from data acquisition interface. Data is checked for hardware-detected error and hardware flag bits are removed on input.

PRECALIBRATION FLAG: Integer value one indicates precalibration completed.

DATA FILE INITIATION FLAG: Integer value one indicates disk data file has been created.

INCIDENT FLUX SUMMATIONS: Incident flux integer totals for boiler, superheater #1, and superheater #2.

REDUCED DATA BUFFER: Integer - 245 words

Buffer for data readings converted to engineering units.

REDUCED FLUX DATA BUFFER: Integer - 12 X 34 array

Incident flux intensity for 34 boom positions, 12 readings per position.

INTEGRATED INCIDENT FLUX BUFFERS: Three integer - 34 words

Buffers for incident flux integration on boil or, superheater #1 and superheater #2.

ZERO OFFSET COEFFICIENTS BUFFER: Real 213

Item buffer containing on-line automatic calibration correction values for analog input data.

CALIBRATION COEFFICIENTS BUFFERS: Real buffers of 3 X 2, 2 X 24, 1, and 2 data items respectively carrying predetermined calibration constants for conversion of raw data to engineering units.

POSITION REFERENCE VALUE: Integer word containing flux boom zero position reading.

Table 1-7. Disk Files Data Storage

On-Line Plot Data Files Name: DISKPT This file is initiated and written by program PLOT. It contains up to 2600 records of fifty integer words each. Each record contains time and test number, and up to 44 items of reduced test data. During test operations, the file is automatically written, by appending one new fifty-word record for each scan of the input data system. It is normally purged prior to the start of each test. The file may be rebuilt from magnetic tape data using the Magnetic Tape search routines.
Search Data Transfer File Name: PVARI This file is initiated and written by program SERCH for plotter outputs. It consists of two to seven equal-length records containing up to 128 integer data words each. Once built by SERCH, the file may be automatically accessed by KOOK or SCATR for producing line plots or scatter plots respectively, with the first record serving as argument (abscissa) data, and following records serving as function(s) (ordinate) data.
Zero References File Name: ZEROES This file is initiated and cleared by the precalibration program if not already in existence. If already existing, it is read by the precalibration program to provide operating data coefficients in real-time common. It may be updated by the pressure calibration, flowmeter calibration, or temperature calibration routines. The file contains the system record of the most recent calibration correction data for the analog sensors. It consists of four records of 64 real data items in each. At each test start, this file is read into real-time common to provide updated calibration adjustment factors for data reduction computations.
Test Warnings and Alarms Limits File Name: LIMIT This file is initiated and written by program NWLMT. It contains one record of 128 integer words. During test operations, the file is automatically read by program WARNA for current assignment of warning and alarm limit values. This file may be updated by program MDLMT during test operations.
Test Fault Counts File Name: KLIMIT This file is normally initiated and written with all zeros by program NWLMT at the beginning of each test run. It contains one record of 128 integer words corresponding to the entries in file LIMIT. Each entry in file KLIMIT contains the current count of data input and monitoring scans in which a warning or alarm limit parameter was found to be outside its limits. The file is automatically updated by program WARNA and may be cleared to zeros by program WACLR under operator control.

- On-line displays of reduced data by plots or tabulations
- Recovery and presentation of recorded test data.

Real Time Data Acquisition, Monitoring and Recording--Data flow followed a path from sensor systems accessed via multiplexed analog signals through the A/D converter, into main memory buffers, to magnetic tape storage and to limited-entry disk file storage. Two classes of sensed data were handled:

- A programmed repetition rate read nineteen analog data input cards carrying the multiplexed analog channels.
- For flux sensing, position-generated interrupts from a hardware angular position counter triggered a separate prioritized input program (ESXXX).

The main data scanning program (RDIN) read inputs and converted raw data to integer engineering units in main memory buffers. It provided system executive calls that automatically scheduled following programs; these further reduced data for disk file storage, provided magnetic tape outputs of both raw and reduced data, and automatically checked warning and alarm parameters (WARNA). The interrupt controlled program (ESXXX) that read the flux sensors at various boom positions updated the complete map of all possible flux sensor position readings for both raw and reduced data. It also updated flux summation values for use in on-line reports. The flux data maps were positioned in memory so as to simplify automatic recording on magnetic tape.

The main data reduction program RDIN performed three main functions by means of structured subroutines. Structured programming conventions were used with the H-P systems' real-time common and local common data base structures to result in a flexible and highly workable main program. The temperature, pressure, and flow data reductions were performed primarily in separate subroutines supplied by Babcock and Wilcox, and H-P, and modified for use on the steam generator experiment. Special data reduction subroutines were written to handle items outside the capability of vendor-supplied routines.

The first major function of program RDIN was to acquire data from the interface and verify its hardware-checked validity. The subroutine DATIN was called, which in turn employed H-P supplied multiplexer control routines. It was necessary to use the H-P routines on a card-by-card basis for error detection rather than as a single-stream operation. This permitted continued operation even in the event of non-critical data card failures or transmission errors. The data input and reduced data key is shown in Table 1-8.

Program RDIN's major function was to reduce acquired data in real-time common to engineering units integer data also in real-time common. The constraints of memory in the H-P system and the large programs required for display routine support dictated the choice of an integer format for reduced data. The data reduction routines themselves, however, operated in 'real' arithmetic and, in some cases, in double precision floating point. The necessary precision in the reduced data was maintained by this scheme. Warnings and alarms, summaries and reports, and on-line operator access were all simplified by maintaining current reduced data in real-time common and operated at a rate appropriate with the scanning required for monitoring the steam generator.

The third major function was to record the data in forms useful for both on-line and post-test data retrieval. On-line data displays were supported by a disk File containing up to 2600 records of current test data. Each record was written automatically with thirty-three items of reduced data which included all predefined real-time and post-test automatic plots. This file normally contained reduced data from all scans made during a test run, and supported post-test plots with a minimum of operator interaction. Longer-term data records were written on magnetic tape. Each magnetic tape data entry consisted of twenty-five records of sixty words each, and included all header and sensor data (both raw and reduced) taken directly from the real-

Table 1-8. Raw and Reduced Data Map Key

IB*	ISA**	IDENTIFIER	LABEL	IB*	ISA**	IDENTIFIER	LABEL
1	1	FBPS	J	46	70	TE338	
2	2	VPOØ	J	47	71	TE339	
3	3	TT16	TBC	48	72	TE340	
4	4	TT23	TCC	49	73	TE341	
5	5	TT306	TPC	50	74	TE342	
6	6	PT16	PCW	51	75	TE343	
7	7	PT2	PFW	52	76	TE344	
8	8	PT2	POUT	53	77	TE345	
9	9	PT3	PWW	54	78	TE346	
10	10	PT23Ø	PD	55	79	TE347	
11	11	PT590	PS20	56	80	TE348	
12	12	FT13	FAR	57	81	TE349	
13	13	FTI	WFW	58	82	TE350	
14	14	LT210	LD	59	83	TE351	
15	15	LT211	LD2	60	84	TE352	
16	16	FT3	WS2	61	85	TE353	
17	17	FT310	WB	62	86	TE354	
18	18	TT590	TS20	63	87	TE355	
19	19	FT480	WATT	64	88	TE356	
20	20	FT260	WBD	65	89	TE357	
21	21	MZ1	SZ1P	66	90	TE358	
22	22	MZ2	SZ2P	67	91	TE359	
23	23	MZ3	SZ3P	68	92	TE360	
24	24	MZ4	SZ4P	69	93	TE361	
25	49	TE210		70	94	TE362	
26	50	TE211		71	95	TE363	
27	51	TE212		72	96	TE364	
28	52	TE213		73	97	TE365	
29	53	TE214		74	98	TE366	
30	54	TE215		75	99	TE367	
31	55	TE216		76	100	TE368	
32	56	TE217		77	101	TE369	
33	57	TE260		78	102	TE370	
34	58	TE300		79	103	TE371	
35	59	TE301		80	104	TE372	
36	60	TE310		81	105	TE373	
37	61	TE311		82	106	TE374	
38	62	TE330		83	107	TE375	
39	63	TE331		84	108	TE376	
40	64	TE332		85	109	TE377	
41	65	TE333		86	110	TE378	
42	66	TE334		87	111	TE379	
43	67	TE335		88	112	TE380	
44	68	TE336		89	113	TE381	
45	69	TE337		90	114	TE382	

Table 1-8. Raw and Reduced Data Map Key (Continued)

IB*	ISA**	IDENTIFIER	LABEL	IB*	ISA**	IDENTIFIER	LABEL
91	115	TE383		136	160	TE459	
92	116	TE384		137	161	TE460	
93	117	TE385		138	162	TE461	
94	118	TE386		139	163	TE462	
95	119	TE387		140	164	TE463	
96	120	TE388		141	165	TE464	
97	121	TE389		142	166	TE465	
98	122	TE400		143	167	TE466	
99	123	TE401		144	168	TE470	
100	124	TE402		145	169	TE471	
101	125	TE405		146	171	TE476	
102	126	TE406		147	172	TE480	
103	127	TE407		148	174	TE501	
104	128	TE408		149	175	TE505	
105	129	TE409		150	176	TE506	
106	130	TE420		151	177	TE507	
107	131	TE421		152	178	TE508	
108	132	TE422		153	179	TE509	
109	133	TE423		154	180	TE520	
110	134	TE424		155	181	TE521	
111	135	TE425		156	182	TE522	
112	136	TE426		157	183	TE523	
113	137	TE427		158	184	TE524	
114	138	TE428		159	185	TE525	
115	139	TE429		160	186	TE526	
116	140	TE430		161	187	TE527	
117	141	TE431		162	188	TE528	
118	142	TE432		163	189	TE529	
119	143	TE433		164	190	TE530	
120	144	TE434		165	191	TE531	
121	145	TE435		166	192	TE532	
122	146	TE436		167	193	TE533	
123	147	TE437		168	194	TE534	
124	148	TE438		169	195	TE535	
125	149	TE439		170	196	TE536	
126	150	TE440		171	197	TE537	
127	151	TE450		172	198	TE538	
128	152	TE451		173	199	TE539	
* 129	153	TE452		174	200	TE540	
130	154	TE453		175	201	TE550	
131	155	TE454		176	202	TE551	
132	156	TE455		177	203	TE552	
133	157	TE456		178	204	TE553	
134	158	TE457		179	205	TE554	
135	159	TE458		180	206	TE555	

Table 1-8. Raw and Reduced Data Map Key (Concluded)

IB*	ISA**	IDENTIFIER	LABEL	IB*	ISA**	IDENTIFIER	LABEL
181	207	TE556		226	221	TE601	
182	208	TE557		227	222	TE602	
183	209	TE558		228	223	TE603	
184	210	TE559		229	224	TE604	
185	211	TE560		230	225	TE605	
186	212	TE561		231	226	TE606	
187	213	TE562		232	227	TE607	
188	214	TE563		233	228	TE608	
189	215	TE564		234	229	TE609	
190	216	TE565		235	230	TE610	
191	217	TE566		236	231	TE611	
192	218	TE570		237	232	TE612	
* 193	219	TE571		238	233	TE613	
194	270	TE19		239			
195	271	TE24		240			
196	272	TE26		241			
197	273	FT350		242			
198	274	FT351		243			
199	275	FT352		244			
200	276	PT475		245			
201					241	TE700	
202					242	TE701	
203					243	TE702	
204					244	TE703	
205					245	TE704	
206					246	TE705	
207					247	TE706	
208					248	TE707	
209					249	TE708	
210					250	TE709	
211					251	TE710	
212							
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* IB REFERS TO THE SOFTWARE BUFFER ASSIGNMENT

** ISA REFERS TO THE INSTRUMENT PANEL (HARDWARE) ASSIGNMENT time common buffers. Each test began with a new reel of magnetic tape, allowing simplified post-test search and retrieval routines. Most of the summaries and displays from on-line operations were usable directly for post-test data reduction.

Summary and Report Generation Automatically or by Operator Request--Generation of reports and summaries used previously-reduced data from main memory buffers wherever possible. However, certain special parameters requiring secondary calculations were programmed into the operator-initiated report programs. Three types of on-line standardized reports were provided:

- Base Data Reports
- Performance and Operating Analyses
- Special Data Selections.

Two base data reports, Fluid Conditions (FLUD) and Metal Temperatures (METL), grouped sensors by general type. These were used to review overall data acquisition systems and sensor performance rather than to evaluate the steam generator itself. Faulty sensors and channels could be identified readily using these reports, thus minimizing confusion if a questionable parameter appeared during a test.

The performance and operating analyses were organized into the Performance Summary (PFSM) and the Operator's Summary (OPSM). The Performance Summary contained the analysis by major subsystem of the SRE steam generator. It was formatted to permit ready evaluation of energy and mass balances, flow conditions, subsystem performance, solar simulator power levels and the power summary data. The Operator's Summary was designed to provide a concise display of critical operating parameters to assist in manual control of the steam generator, and included the Power Summary (same as in the Performance Summary) as well.

Special data selections were provided for tube and metal temperatures of both superheaters, for boiler tube temperatures, and for cooling water subsystem temperatures. These operator-initiated display programs were entitled Boiler Temperature Profile (BTP), First Stage Superheater Temperature Profile (SPR1), Second Stage Superheater Temperature Profile (SPR2), First Stage Superheater Metal Temperature (SPM1), Second Stage Superheater Metal Temperature (SPM2), and Cooling Water Temperature (COOL).

Incident flux conditions at the flux sensors were reported by the general flux map of the cylindrical cavity surface swept by the rotating flux boom sensor array (FARRY). This provided a set of values in units of $KWX10^{-1}/meter^2$. In addition, incident flux profiles were calculated and reported for boiler incident flux (FPB), first stage superheater incident flux (FPS1), and second stage superheater incident flux (FPS2). Each of these programs used the current state of the real-time flux readings storage buffer as the basis for computations.

Besides standardized summaries and reports, warning and alarm reports were automatically produced when certain conditions occurred. Warning and alarm parameters and their corresponding limits were maintained in a separate disk file for access by the warnings and alarms checking program (WARNA). The disk file also could be accessed by a special-purpose initialization routine which would restore it to specified values at the beginning of a test (NWLMT) and by a limit-modification routine which could alter selected parameters' warning and alarm limit values (MDLMT). This latter program was normally used during the course of a test to adjust values for failed sensors or for gradual adjustment of limits where initial values were deliberately set at a conservative level.

The occurrence of a warning condition prompted a prioritized display on the console CRT, accompanied by a slow audible 'beep' and red flashing light on the console keyboard. For an alarm condition, the report was printed on the printer/plotter; a fast audible 'beep' and red flashing light occurred.

The warning and alarm reports included the date, time, and test number; the number and identifier for each out-of-bounds parameter and its current value; and, the corresponding current alarm or warning limit value. The report stated whether the condition was a high limit or low limit (some parameters had both; e.g., drum level). A warning parameter allowed three repetitions of the warning report for each out-of-bounds excursion. An alarm parameter would be reported (in a printed report) once for each excursion.

Selected alarm values were added to cause a trip (shutoff) of the solar simulator array in addition to the printed report. Such a parameter would have four entires in the warnings and alarms parameter file assuming that it was a high limit only:

- Approaching high level - warning
- High level - alarm
- High-high level - alarm
- Trip level - alarm and trip.

The warnings and alarms checking program was required to monitor three types of data:

- Current parameter values for level checks
- Current differences between measured parameter values

- Rate-of-change of parameter values.

These latter two data types required computation of the resultant parameters in the warnings and alarms limit program (WARNA). Also, previous system time value had to be maintained with the previous set of readings for the rate-of-change parameters in a working buffer in real-time common.

On-Line Displays of Reduced Data by Plots or Tabulations--Early in the design of the software system, it was considered unrealistic to build special routines for each of the required on-line graphic displays. Limitations on active programs, in both number and size, were more restrictive than first estimated. The characteristics of the disk file manager and executive routines forced the adoption of unusually complex operating procedures, especially when preparing graphic and tabular displays.

The real-time on-line graphic display programs used proprietary software, supplied by VERSATEC and TEKTRONIX, quite extensively for actual output from data files to the output device (plotter or CRT screen). The data files proper were prepared through search routines which accessed the disk files of reduced data (containing up to 2000 records of selected reduced data parameters), and prepared output data files for transfer to the plotter output or screen output routines.

For plotting purposes, operator options allowed the preparation of up to six simultaneous functions (on the ordinate scale) against a single argument (on the abscissa scale). The plotting search routine allowed operator selection of test number and time of initial plot variable selection, and two modes of successive point selection. Mode one allowed identifying both start and stop times, with an operator-specified time interval between successive points. Mode two permitted specifying the number of points to be selected after the start time, and allowed skipping a specified number of readings between the selected points. These features of the search routine allowed flexibility in preparing graphs of operation sequences during or following a steam generator test run.

The routines were designed to be dependent on data existing in the reduced data disk file and could select up to 128 points for each variable. Any parameter in the data file could be used as either function or argument. Time parameters, usually used as the argument, were presented in seconds using the start time of the search as time zero. For each plotting search a header was printed that identified the following plot by test number, day and time, and showed the identification and correspondence of plot argument and functions, and their plotted symbols. Plot axis labels were established by operator input, allowing up to forty characters for each label.

The tabular routine allowed selection of up to twelve columns of simultaneous parameters with individual column headers supplied by operator input. Four search modes were available:

- Select for start time to stop time, at specified time interval.
- Select from start time, N number of points, skipping M points between selections.
- Select from start time, N number of points, finding points where one control parameter is between specified limits, skipping M such points found between selections.
- Select from start time, N number of points, finding points where two control parameters are both between their corresponding specified limits, skipping M such points found between selections.

The resultant tabular output included header data and page numbers for each page of the table. The plot (and tabulation) request key is shown in Table 1-9. The description of plots available is shown in Table 1-10 for directly measured parameters and in Table 1-11 for computed parameters.

Table 1-9. Plot Request Key

NUMBER	LABEL	DESCRIPTOR	WHERE USED
1-4	time		
5	year		
6	QABS	Total Absorbed Power	A-series, B-series, F-F-series, G1-1
7	QIN	Total Input Power	E1-1, G16-1, G16-2
8	WFW	Feedwater Flow	A1-4, G2-3, E2-1
9	WATT	Attemperator Flow	A1-2, E2-1, G3-1
10	WS2	Steam Flow	A1-1, E2-1, G2-1, B1b-2
11	WBD	Blowdown Flow	A1-3, E2-1
12	TE4ØØ		
13	TE4Ø1	Superheater #1 Inlet Temperature	
14	TE4Ø2		
15	QB	Boiler Absorbed Power	A6-1, F5-1, F6-1, G1-1
16	QS2	Second Stage Superheater Absorbed Power	A6-3, F5-3, F6-3, G1-4
17	WS-1	First Stage Superheater Flow	G2-1
18	PD	Drum Pressure	G4-1
19	PFW	Feedwater Pressure	G4-2
20	PS10	First Stage Superheater Outlet Pressure	A3-2, G5-1
21	PS20	Second Stage Superheater Outlet Pressure	A3-3, G5-2
22	TBI	Boiler Inlet Temperature	A5-2, G6-2
23	TDC	Downcomer Temperature	A5-1, G6-3
24	TFW	Feedwater Temperature	A2-1, G6-4

Table 1-9. Plot Request Key (Concluded)

NUMBER	LABEL	DESCRIPTOR	WHERE USED
25	TATT	Attemperator Supply Temperature	A2-2, G6-5
26	TS1)	First Stage Superheater Outlet Temperature	A2-4, G7-1
27	TS1I	First Stage Superheater Inlet Temperature	
28	TS2O	Second Stage Superheater Outlet Temperature	A2-6, G7-3
29	TS2I	Second Stage Superheater Inlet Temperature	A2-5, G7-2
30	LD	Drum Level	G-12
31	WB	Boiler Flow	A4-1, G13-1
32	TAS1	First Stage Superheater Average Metal Temp.	G15-1
33	TAS2	2nd Stage Superheater Average Metal Temp.	G15-2
51	QABS/QIN	Power Ratio	E-1
52	$\frac{(WFW + WATT)}{(WS2 + WBD)}$	Flow Ratio - Mass Balance	E-2
53	(WS2 + WBD)	Outlet Flows	E-2
54	(TD-TE400)	Drum-to-Superheater Temp. Loss	E-3.3
55	(TD-TE401)	Drum-to-Superheater Temp. Loss	E-3.3
56	(TD-TE402)	Drum-to-Superheater Temp. Loss	E-3.3
57	HS1O	Steam Enthalpy, S.H. 1 Outlet	G-8.1
58	HS2I	Steam Enthalpy, S.H. 2 Inlet	G-8.2
59	HS2O	Steam Enthalpy, S.H. 2 Outlet	G-8.3
60	H-GD	Drum - Steam Enthalpy	G-9.2
61	H-FD	Drum - Water Enthalpy	G-9.1
62	H-BI	Boiler Inlet Water Enthalpy	G-9.3
63	X-B	Boiler Outlet (Drum) Steam Quality	G-14

Table 1-10. Plot Description (Directly Measured Parameters)

PLOT	SERIES		
AI	1. Steam Flow (WS2)	vs.	Total Absorbed Power (QABS)
	2. Attemperator Flow (WATT)	vs.	QABS
	3. Blowdown Flow (WBD)	vs.	QABS
	4. Feedwater Flow (WFW)	vs.	QABS
A2	1. Feedwater Temp. (TFW)	vs.	QABS
	2. Attemperator Supply Temp. (TATT)	vs.	QABS
	4. First Stage Superheater Outlet Temperature (TS10)	vs.	QABS
	5. Second Stage Superheater Inlet Temperature (TS21)	vs.	QABS
	6. Second Stage Superheater Outlet Temperature (TS20)	vs.	QABS
A3	1. Drum Pressure (PD)	vs.	Total Absorbed Power (QABS)
	2. First Stage Superheater Outlet Pressure (PS10)	vs.	QABS
	3. Second Stage Superheater Outlet Pressure (PS20)	vs.	QABS
A4	1. Boiler Flow (W_B)	vs.	QABS
A6	1. Boiler Absorbed Power (QB)	vs.	QABS
	3. 2nd Stage Superheater Absorbed Power	vs.	QABS
G1	1. Total Absorbed Power (QABS)	vs.	Time
	2. Boiler Absorbed Power (Qb)	vs.	Time
	3. 1st Stage Superheater Absorbed Power (QS1)	vs.	Time
	4. 2nd Stage Superheater Absorbed Power (QS2)	vs.	Time

Table 1-10. Plot Description (Directly Measured Parameters (Concluded)

PLOT	SERIES		
G2	1. Main Steam Flow (WS2)	vs.	Time
	2. 1st Stage Superheater Flow (WS1)	vs.	Time
	3. Feedwater Flow (WFW)	vs.	Time
G3	1. Attemperator Flow (WATT)	vs.	Time
	2. Blowdown Flow (WBD)	vs.	Time
G4	1. Drum Pressure (PD)	vs.	Time
	2. Feed Water Pressure (PFW)	vs.	Time
G5	1. 1st Stage Outlet Pressure (PS10)	vs.	Time
	2. Steam Pressure (PS20)	vs.	Time
G6	2. Boiler Inlet Temperature (TBI)	vs.	Time.
	3. Downcomer Temperature (TDC)	vs.	Time
	4. Feedwater Temperature (TFW)	vs.	Time
	5. Attemperator Supply Temp. (TATT)	vs.	Time
G7	1. 1st Stage Superheater Outlet temp. (TS1O)	vs.	Time
	2. 2nd Stage Superheater Inlet temp. (TS2I)	vs.	Time
	3. 2nd Stage Superheater Outlet temp. (TS2O)	vs.	Time
G12	1. Drum Level (LD)	vs.	Time
G13	1. Boiler Flow (W_B)	vs.	Time
G15	1. 1st Stage Superheater Average Metal Temperature (TAS1)	vs.	Time
	2. 2nd Stage Superheater Average Metal Temperature (TAS2)	vs.	Time
G16	1. Attemperator Flow (WATT)	vs.	Total Input Power (QIN)
	2. Steam Flow (WS2)	vs.	(QIN)

Table 1-11. Plot Description (Computed Parameters)

PLOT	SERIES		
E1	Total Absorbed Power (QABS) / Total Input Power (QIN)	vs.	Total Input Power (QIN)
E2	Feedwater Flow (WFW) + Attemperator Flow (WATT) / Steam Flow (WS2) + Blowdown Flow (WBD) vs. Steam Flow (WS2) + Blowdown Flow (WBD)		
E3	1. Drum Saturation temperature (TD) - (TE400) - Superheater #1 inlet temperature	vs.	(TD) Drum Saturation Temperature
or	2. TD-TE401	vs.	TD
or	3. TD-TE402	vs.	TD
G8	1. 1st Stage Superheater Outlet Enthalpy (hS1I)	vs.	Time
	2. 2nd Stage Superheater Inlet Enthalpy (hS2I)	vs.	Time
	3. 2nd Stage Superheater Outlet Enthalpy (HS20)	vs.	Time
G9	1. Drum Saturated Water Enthalpy (hFD)	vs.	Time
	2. Drum Steam Enthalpy (hGD)	vs.	Time
	3. Boiler Inlet Enthalpy (hBI)	vs.	Time
G14	1. Boiler Outlet Quality (XB)	vs.	Time

Recovery and Presentation of Recorded Test Data--For post-test analysis, a magnetic tape search routine was provided. This program allowed operator-controlled rebuilding of the reduced data disk file from magnetic tape records. It also allowed operator-controlled additions to data normally placed in disk file records. Four search modes, similar to those established for the tabular output routine described above, were allowed.

Using the magnetic tape search routine, the operator could rebuild the disk file fairly quickly with all of the parameters desired for plot or tabular presentation. Once rebuilt, the disk file would then be used with the plotting and tabular search routines for final output to printer/plotter.

Additional routines, written but not tested, provided for re-reduction of raw data from magnetic tape using modified reduction routines. This was done to correct data in early test runs where known errors existed in certain calibration constants.

Tables 1-4 and 1-5 list the program normally used in real time test procedures and those used in pre-test checkout activities and in post-test data analysis.

CHARACTERISTICS OF STEAM GENERATOR INSTRUMENTATION

Table 1-12 presents instrumentation ranges, accuracies, and corrections for water legs, where applicable. The column titled "Analog Device" refers to the readout device as follows:

CS - Control station
IND - Indicator
RCD - Recorder

The column headed "Range of Analog Display" refers to the scale range of the "Analog Device".

Figure 1-12. Characteristics of Steam Generation Instrumentation

ANALOG DEVICE	DEVICE	DESCRIPTION	RANGE OF DEVICE	RANGE OF ANALOG DISPLAY	MFR.	MODEL NO.	DEVICE: MFR'S STATED ACCURACY	CORRECTION FOR WATER LEG ✝
CS-1	PT-1	Steam drum feedwater pressure	0-2200 psig	0-2200, linear	Honeywell	41224	<1500psi, <0.2%; >1500psi, <0.5%	-2.2psi
CS-2	LT-210	Steam drum water level	-55 to 0 inches w.c., -55 to 0 in. at 80°F	-100 to +100, linear	Rosem't	1151DP4	±0.2%span	0
CS-3	FT-1	Feedwater flow to steam drum	0-251.1 in. w.c., 0-518,000 pph at {1900 psia, 440 °F}, ρ = 52.5210 lb_m/ft^3	0-180, linear ($x10^2$)	Honeywell	41103	±0.25%span, typical	0
CS-4	TT-590	Main steam temperature	700 -1100°F, linear for 100 Ω Pt(0°C) resistor	700-1100, linear	Rosem't	442A-RGA-N8N*	~±1 °F	--
CS-5	PT-2	Main steam pressure	0-2200 psig	0-2200, linear	Honeywell	41224	<1500psi, <0.2%; >1500psi, <0.5%	-3.5psi
CS-7	PT-3	System discharge pressure	0-500 psig	0-500, linear	Honeywell	41223	<0.2%	+0.4psi
CS-8	FT-310	Recirculation pump discharge flow	0-666.8 in. w. c., 0-250,000 pph at {1775 psia, 615 °F}, ρ = 40.6339 lb_m/ft^3	0-2500, linear ($x10^2$)	Rosem't	1151DP5	± 0.2%span	0
CS-16	FT-260	Steam drum blowdown flow	0-50 in.w.c., 0-548 pph at {1775 psia, 615 °F}, ρ=40.6339lb_m/ft^3	0-540, linear	Rosem't	1151DP4	±0.2%span	0
IND-7	PT-230	Steam drum pressure	0-2200 psig	0-2200, linear	Rosem't	1151GP9	±0.25%span	-17 psi
IND-22	PT-16	Cooling water header pressure	0-120 psig	0-120, linear	Honeywell	41223**	<0.2%	-4.8psi
IND-9	TT-306	Recirculation pump discharge cooling water temperature	25 -125 °F(KTC)	25-125, KTC	L & N	479	±0.25%span	--
IND-20	TT-23	Power controllers discharge cooling water temperature	0-250 °F(KTC)	0-250, KTC	Honeywell	39101	±0.1%full scale, typical	--
IND-21	TT-25	Radiant array discharge cooling water temperature	0-250 °F(KTC)	0-250, KTC	Honeywell	39101	±0.1%full scale, typical	--
IND-25	TT-16	Flux measurement rake discharge cooling water temperature	0-250 °F(KTC)	0-250, KTC	Honeywell	39101	±0.1%full scale, typical	--
IND-1	FT-13	Cooling water flow to radiant array and flux measurement rake	0-372.5 in.w.c., 0-140,000pph at {120 psia, 80 °F}, ρ=62.2277 lb_m/ft^3	0-14, linear ($x10^4$)	Honeywell	41103	±0.25% span, typical	0
IND-2	TT-22	Cooling water header temperature	25 -125°F(KTC)	25-125, KTC	Honeywell	39101	±0.1% full scale, typical	--
RCD-1-1	FT-3	Main steam flow	0-878.9 in.w.c., 0-18,000pph at {1590 psia, 955 °F}, ρ=2.0592 lb_m/ft^3	0-100, linear (18,000f.s.)	Honeywell	41104	±0.25% span, typical	0
RCD-1-2	FT-1	See FT-1 above	See FT-1 above	0-100, linear	See FT-1, above			0
RCD-1-3	FT-480	Attemperator spray water flow	0-30 in.w.c., 0-1498pph at {1900psia, 440°F}, ρ=52.5210 lb_m/ft^3	0-100, linear (1,498f.s.)	Rosem't	1151DP4	±0.2% span	0
RCD-4-1	LT-211	Steam drum water level	-55 to 0 in.w.c., -55 to 0 in. at 80°F	0-100, linear (55f.s., T= 80°F)	Rosem't	1151DP4	±0.2% span	0
RCD-4-2	PT-590	Main steam pressure	0-2000 psig	0-100, linear (2000f.s.)	Rosem't	1151GP9	±0.25% span	-10.6psi
RCD-4-3	TREND PANEL: PV-1	Water conductivity	0-100 micromhos/cm at 25 °C	0-100, linear (100f.s.)	Beckman	SM-M( )		--
	PV-2	Not used ↓		↓				
	PV-3							
	PV-4							
	PV-5							
	PV-6							
	PV-7							
	PV-8							
	PV-9							
	PV-10							
	PV-11							
	PV-12							

Figure 1-12. Characteristics of Steam Generation Instrumentation (Continued)

ANALOG DEVICE	DEVICE	DESCRIPTION	RANGE OF DEVICE	RANGE OF ANALOG DISPLAY	MFR.	MODEL NO.	DEVICE: MFR'S STATED ACCURACY	CORRECTION FOR WATER LEG *
RCD-3-1	TE-1	Feedwater temperature		0-1000°F (KTC)				--
RCD-3-2	TE-475	Attemperator inlet temp.		0-1000°F (KTC)				--
RCD-3-3	TE-500	Attemperator outlet temp.		0-1000°F (KTC)				--
RCD-3-4	TE-591	Main steam temp.		0-1000°F (KTC)				--
RCD-3-5	TE-405	Lower 1st stage super-heater		0-1000°F (KTC)				--
RCD-3-6	TE-452	Upper 1st stage super-heater		0-1000°F (KTC)				--
RCD-3-7	TE-301	Recirc. pump inlet water temp.		0-1000°F (KTC)				--
RCD-3-8	↓	↓		0-1000°F (KTC)				--
RCD-3-9				0-1000°F (KTC)				--
RCD-3-10				0-1000°F (KTC)				--
RCD-3-11	TE-507	Lower 2nd stage super-heater		0-1000°F (KTC)				--
RCD-3-12	TE-550	Upper 2nd stage super-heater		0-1000°F (KTC)				--
--	FT-350	Boiler inlet flow	0-150 in. w. c.	--	Rosem't	1151DP5	±0. 2% span	0
--	FT-351	↓	↓	--	Rosem't	1151DP5	±0. 2% span	0
--	FT-352			--	Rosem't	1151DP5	±0. 2% span	0
--	PT-475	Attemperator inlet steam pressure	0-2000 psig	--	Rosem't	1151GP9	±0. 25% span	-10. 0psi
--	PS-1	Inlet feedwater pressure	0- psig; set at 2000; closes on decreasing pressure	--	Static O Ring	1NN-KK5-M2CJSS		-1. 3psi
--	PS-7	Cooling water strainer ΔP	0-10 psig; set at max.; closes on increasing ΔP	--	Barton	289		0
--	FS-310	Recirc. pump dis-charge flow	0- 400 in. w. c., set at 30 ; closes on decreasing flow	--	Barton	289A 199		0
--	FS-305	Recirc. pump cooling water flow	0-27 gpm, set at 22 ; closes on decreasing flow	--	Ametek, S & K	20-41500-2110		0
--	PI-230	Steam drum steam press.	0-3000 psig	--	Ashcroft	1379DS	±0. 5% span	0
--	PI-310	Recirc. pump dis-charge water pressure	0-3000 psig	--	Ashcroft	1379DS	±0. 5% span	-0. 04 psi
--	FI-5	Local indicator --see FT-13	0-350 in. w. c.	--	Barton	200		0
--	FI-4	Local indicator of cool-ing water flow to power controllers	0-100 , 50 gpm at 100 %	--	F&P	10A2227A		0
--	FI-6	Local indicator -- see FT-16	0-150 in. w. c.; didn't use, range is too small	--	Barton	200		0
--	FT-16	Feedwater bypass flow	0-150 in. w. c.; didn't use, range is too small	--	Barton	200		0
--	PI-231	Steam Drum Pressure	0-3000 psig	--	Heise	C	<3 psi	0
--	PI-591	Main Steam Pressure	0-3000 psig	--	Heise	C	< 3 psi	0

Figure 1-12. Characteristics of Steam Generator Instrumentation (Continued)

ACCURACY

~ Statements from Manuals

PT-1 PT-2 PT-3 PT-16	Under 10MPa (1500psi): Better than 0.2% Span-- Typically 0.1% Span (zero based) Over 10MPa (1500psi): Better than 0.5% Span-- Typically 0.35% Span (zero based) (See Honeywell Process Controls Division, Fort Washington, Pa. document, 811-666.)
FT-1 FT-3 FT-13	Better than ± 0.35% of span, typically ±0.25% of span (zero based). (See Honeywell document, 811-670.)
TT-23 TT-25 TT-16 TT-22	Rated accuracy with 25 Vdc nominal power supply: Typically ±0.1% of full scale, maximum error ±0.25% of full scale. ±0.2% of span (at 80°F, 55% R.H. & 25 Vd-c supply) (See Honeywell document, 811-597.)
TT-590	Sensor, as calibrated for transmitter: $\sim\pm(5.558\times10^{-4}\,T\,[°F] - 0.228)$ $700. \leq T\,[°F] \leq 1100.$ Transmitter: ±0.1% of calibrated span = ±0.4°F (1100 - 700 = 400 for span) Sensor and transmitter not physically together so add a few tenths of °F to account for wire resistance and ambient temperature effects. At 955°F these rss to less than $\lvert\pm1°F\rvert$. Rosemount's Roger Evans suggested using ±1°F would be a reasonable number for manufacturer's stated accuracy. (See Rosemount Product Data Sheet 2178, Series 78 Platinum Resistance Temperature Sensor; Schedule G-F calibration; and Instruction Manual 4134, Alphaline Temperature Transmitter, Model 4424, Types RG, RP and RD.)
LT-210 FT-310 FT-260 FT-480 LT-211 FT-350 FT-351 FT-352	±0.2% of calibrated span. Includes combined effects of linearity, hysteresis and repeatability. (See Rosemount Instruction Manual Model 1151DP Alphaline Differential... Pressure Transmitters.)
PT-230 PT-590 PT-475	±0.25% of calibrated span. Includes combined effects of linearity, hysteresis and repeatability. (See Rosemount Instruction Manual Alphaline Pressure Transmitters...Gage Models...1151GP.)
TT-306	±0.1% contingent upon specifications below [not copied here]. (Without on-site calibration ±0.25%) (See Leeds & Northrup Directions 177828 Issue 5 Centry 479 Temperature/Millivolt Transmitter.)

Figure 1-12. Characteristics of Steam Generator Instrumentation (Concluded)

NOTES

All transmitters have 4-20 mADC outputs.
All devices were initially set with dry legs.

--	denotes not applicable
*	Series 78 platinum resistance temperature sensor was used in addition; a "calibrated" assembly.
**	CW-PT-16 failed early in service; it was replaced by TS-PT-9, reranged as indicated, but still called CW-PT-16.
†	Correction = True - Indicated; e.g., for a true reading from PT-230 subtract 17 psi (add -17 psi) to the indicated reading.

LIST OF ABBREVIATIONS AND SYMBOLS

CS	Control Station (Indicating Controller) (in the Steam Generator Control Console)
°C	Degree Celsius
°F	Degree Fahrenheit
ΔP	Pressure Drop
F & P	Fischer & Porter
FI	Flow Indicator
f.s.	Full Scale
FS	Flow Switch
FT	Flow Transmitter
gpm	Gallons per Minute
in.	Inch
IND	Indicator (in Steam Generator Control Console)
K TC	Type K Thermocouple
L & N	Leeds & Northrup
lb_m/ft^3	Pounds (mass) per Cubic Foot
LT	Level Transmitter
Ω	Ohm
PI	Pressure Indicator
pph	Pounds (mass) per Hour
PS	Pressure Switch
psia	Pounds per Square Inch, Absolute
psig	Pounds per Square Inch, Guage
Pt	Platinum
PT	Pressure Transmitter
PV	Process Variable
RCD	Recorder (in Steam Generator Control Console)
Rosem't	Rosemount
S & K	Schutte & Koerting
T	Temperature
TE	Temperature Element (Thermocouple)
TT	Temperature Transmitter
w.c.	Water Column

The column titled "Device" refers to the transducer, or transmitter, device as follows:

PT - Pressure transmitter
LT - Level transmitter
FT - Flow transmitter
TT - Temperature transmitter
PV - Process variable
TE - Temperature element
PS - Pressure switch
FS - Flow switch
PI - Pressure indicator
FI - Flow indicator

All remaining columns refer to the transducer.

Explanatory notes and abbreviations follow the table.

SOLAR SIMULATOR AND ASSOCIATED SYSTEMS

The solar simulator consists of four zones, each containing 378 6,000-watt quartz-iodine heat lamps. When positioned in the steam generator cavity, the two lower zones (1 and 2) are adjacent to the boiler section of the steam generator; the two upper zones (3 and 4) are adjacent to the superheater sections.

Power to the solar simulator is controlled by the test operator through the control console (see Figure 1-7) and the power controllers. Power to each of the four solar simulator zones is independently adjustable either manually by operator adjustment of a variable potentiometer, or automatically by the Data Trak programmers. The Data Trak uses an electro-static curve follower which follows a plotted line on an insertable chart; in this way the operator can cause zone power to be time-modulated in any desired fashion. Whether manually or automatically operated, the power controllers are responsive to a 0-5 volt DC input signal which is compared with a load-sensitive feedback signal to maintain desired power delivery to the solar simulator zone.

Power for the solar simulator comes from a Riverside Station 13.8 KV bus. Four 200-KVA transformers then provide 480-volt AC to their respective power controllers. The power controllers regulate the power fed to the solar simulator through phase angle control of silicon controlled rectifiers.

Because of chronic lamp burnt-out at higher power levels, the solar simulator was not used at its normal rating of 4.5 MW. To alleviate lamp failure, testing was conducted with every third lamp position vacant. The highest power input to the solar simulator was made during the last test run of the steam generator, and was about 5.4 MW. This input could not be sustained, however, apparently because of the rapid rate that lamp burn-out occurred.

Heat flux from the solar simulator was measured by a water-cooled flux measurement boom which traversed the circumference of the steam generator cavity clockwise and counterclockwise at about one revolution per minute. The boom contains 12 Hy-Cal Model C-1112-B flux sensors. Heat flux impinging on the cavity wall, as determined by the flux measurement boom, was read out periodically by the data acquisition system in the "Array Flux Map". From Table 1-13, the key to this flux map, it is seen that flux measurements are taken every 10 degrees in azimuth and every 15.5 inches in elevation. Two of the flux sensors measure flux impinging at the top of the cavity; flux readings at 350- and 360-degrees are not taken because of the rotational limitation in the design of the flux boom drive. The unit for flux measurement in the Array Flux Map is hundreds of watts per square meter.

Table 1-13. Array Flux Map Key

INCIDENT FLUX SENSOR	LOCATION	
IF 1	4 INCHES ABOVE TOP OF BOTTOM REFLECTOR	THERE IS 15.5 IN. OF VERTICAL SEPARATION BETWEEN ADJACENT SENSORS IF 1 THROUGH IF 10.
IF 10	6 INCHES FROM CEILING	
IF 11	40 INCHES FROM CENTER OF CEILING AT CEILING	
IF 12	20 INCHES FROM CENTER OF CEILING AT CEILING	

IF 1 THROUGH IF 4 ARE IN THE BOILER REGION
IF 5 IS ON THE LINE BETWEEN THE BOILER AND S.H. NO. 1
IF 6 THROUGH IF 7 ARE IN THE S.H. NO. 1 REGION
IF 8 THROUGH IF 10 ARE IN THE S.H. NO. 2 REGION
IF 11 THROUGH IF 12 ARE IN THE CEILING REGION

BOOM POSITION	AZIMUTH	COMMENTS
1	20°	
2	30°	
.	.	
.	.	
.	.	
8	90°	East
.	.	
.	.	
17	180°	South
.	.	
.	.	
26	270°	West
.	.	
.	.	
.	.	
34	350°	
35	360° (0°)	North - not read.
36	10°	Not read.

Each incident flux sensor measures the incident flux over azimuthal positions 1 through 34. Positions 35 and 36 cannot be read due to the design of the flux boom which switches its direction of angular motion before revolving a full 360°.

The boom positions correspond to the center positions of each of the 18 boiler panels and to their intersections.

The unit of flux for each sensor is [hundreds of watts per square meter]

SECTION 2
TEST CALENDAR

Table 2-1 is a calendar of the SRE steam generator testing at Riverside Station. Days are shown by month and by year (to correspond with the data acquisition system readouts). The 23 test runs made on the steam generator are shown as encircled numbers on the date of the test. The legend indicates significant events made later in the testing which are entered in the calendar and which affect test results. Test objectives are also shown.

Table 2-1. SRE Steam Generator Test Calendar

	1977 S	M	T	W	T	F	S
JANUARY							1
	2	3	4	5	6	7	8
	9	10	11	12	13	14	15
	16	17	18	19	20	21	22
	23	24	25	26	27	28	29
	30	31					
FEBRUARY			32 1	33 2	34 3	35 4	36 5
	37 6	38 7	39 8	40 9	41 10	42 11	43 12
	44 13	45 14	46 15	47 16	48 17	49 18	50 19
	51 20	52 21	53 22	54 23	55 24	56 25	57 26
	58 27	59 28					
MARCH			60 1	61 2	62 3	63 4	64 5
	65 6	66 7	67 8	68 9	69 10	70 (1) 11	71 12
	72 13	73 (2) 14	74 15	75 (3) 16	76 (4) 17	77 (5) 18	78 (6) 19
	79 20	80 (7) 21	81 (8) 22	82 23	83 24	84 25	85 26
	86 27	87 (9) 28	88 (10) 29	89 (11) 30	90 (12) 31		
APRIL						91 1	92 (13) 2
	93 3	94 a 4 b (14)	95 b 5	96 b 6	97 b 7 (15)	98 8	99 9
	100 10	101 (16) 11	102 c 12	103 (17) 13	104 d 14	105 (18) 15	106 16
	107 17	108 (19) 18	109 (20) 19	110 20	111 (21) 21	112 22	113 23
	114 24	115 25	116 (22) 26	117 27	118 (23) 28	119 e 29	120 30

EVENT

a - Blackened boiler surface.

b - Calibrated radiant array.

c - Corrected attemperator feedwater flow orifice taps.

d - Corrected DAC equations for blowdown and attemperator feedwater flows.

e - Laid up steam generator.

TESTS

1 - 14 De-bugging and before radiant array re-calibration

(15) - Radiant array calibration; lamp voltage limiting setting.

(16) - Duplicate boiler pre-blackening tests; radiant array calibration.

(17) - Steady state and transients

(18) - Transients

(19) - Trip; power transient; steady state; recirculation pump stability.

(20) - Trip; shrink/swell transient; attemperator tuning.

(21) - Asymmetric heating

(22) - Transients (re-run)

(23) - Steady state; maximum heat rise rate

SECTION 3
TEST OBJECTIVES AND DESCRIPTIONS

The SRE steam generator underwent 23 test runs at the Riverside Station. About 214 hours of running time were involved in testing which generally followed this course:

- Hot checkout and calibration. To achieve start-up, full-pressure operation (1575 psia) at all loads, boiler thermocouple calibration, and to verify shut-down procedure.

- Steady state performance. To bring steam generator to rated steam condition (1575 psia, 955^{o}F.), to obtain heat balance data and heat flux and temperature profiles at all loads.

- Transient tests. To determine the dynamic performance of the steam generator using step inputs of main steam valve position, solar simulator output, and attemperator feedwater.

- Trip simulation tests. To determine response to simulations of recirculation pump trip, feedwater pump trip, and heliostat trip.

- Asymmetric heat input tests. To obtain steady-state performance with the solar simulator located off the steam generator cavity center, and to determine the effect of asymmetric heating on boiler flow distribution.

The following pages are a synopsis of the testing and are copies of entries made in the Test Log by the operator on a day-to-day basis. Daily test objectives, test descriptions, and difficulties are enumerated in the Test Log entries.

SYNOPSIS OF SRE STEAM GENERATOR TESTS AT NORTHERN STATES POWER (NSP) RIVERSIDE STATION AS RECORDED IN THE OPERATOR LOG

TEST NO. 1

DATE: March 11, 1977

Test Objectives and Description

This first operational test of the system was primarily to demonstrate the capability to pressurize and heat the boiler and to generate steam at a low power level.

For this test, No. 8 Condensate (pressure 160 psig, Temp. 90°F) was the only source of feedwater supply to the steam drum. This limited maximum drum pressure to about 120 psig. Under these conditions, however, all of the boiler controls could be operated and checked. Also, operator familiarity with the controls and process parameter responses to system disturbances could be gained at very safe pressures, temperatures, and power levels.

Difficulties Encountered

The recirculation pump would not operate in a stable manner at the specified flow rate (300" on FS-310), particularly at drum levels below 50%. Pump flow rate was halved (75" on FS-310) and drum level was maintained high to alleviate this problem during Test No. 1.

TEST NO. 2

DATE: March 14, 1977

Test Objectives

1. Obtain data on rate of rise of recirculating water temperature as a function of power input with no steam flow.
2. Bring boiler to rated pressure and temperature at nominal power levels.
3. Check relief valve operation by overpressurization to insure that the 3 relief valves open at or near the setpoint pressures and otherwise perform as intended.
4. To operate the No. 8 feedwater bypass and supply system.

Description

Test 2 proceeded as planned to approximately 250 psig boiler pressure (400^{o}F recirculation water temp.) then was aborted due to lack of superheater metal temperature information.

Difficulties Encountered

During the temperature and pressure escalation from 120 psig to 500 psig (drum pressure), the data acquisition system refused to print superheater metal temperatures.

TEST NO. 3

DATE: March 16, 1977

Test Objectives

1. Bring boiler to rated pressure and temperature.
2. Check relief valve operation.
3. Operate No. 8 feedwater bypass and supply system.
4. Perform saturation temperature check on boiler metal and fluid thermocouples.

Description

Test 3 proceeded as planned and the test objectives were met.

Difficulties Encountered

480v breakers tripped for no obvious reason and could not be reset.

TEST NO. 4

DATE: March 17, 1977

Test Objectives

1. Obtain data on pumping flow rate versus drum level for stable pump operation with no feedwater injection.
2. Check operation of cooling water temperature monitoring instrumentation.

Description

Test was performed at moderate pressures, temperatures and flow rates.

Difficulties Encountered

Cooling water flow rate to the radiant array diminished as a function of time. The reflector cooler circuit throttling valves were evidently clogging with sediment.

Data acquisition system still malfunctioning intermittently.

Cooling water temperature readouts from TE-700 to 710 were very unlikely.

TEST NO. 5

DATE: March 18, 1977

Test Objectives

1. Steady state operation at higher power levels.
2. Tuning of the various automatic controls.

Description

Achieved steady state operation under automatic control at 2.7 MW gross power input. Automatic controls tuned to maintain steady operation. Analog data sufficient for a gross heat balance taken.

Difficulties Encountered

Zone 3 of the simulator tripped for no apparent reason.
Difficulty in tuning automatic control for attemperator.

TEST NO. 6

DATE: March 19, 1977

Test Objectives

1. Tuning of the automatic controls .

Description

Operation was curtailed due to Zone 3 power loss.

Difficulties Encountered

1. Zone 3 of the simulator tripped for no apparent reason.
2. CV-1 would not close completely - stuck at 25% open.

TEST NO. 7

DATE: March 21, 1977

Test Objectives

1. To continue tuning automatic controls.
2. To try same power transients to check control response.
3. To establish steady state conditions with automatic control.

Description

Operation was curtailed due to the Zone 3 trip problem.

Difficulties Encountered

Zone 3 of simulator tripped inadvertently.

TEST NO. 8

DATE: March 22, 1977

Test Objectives

1. To operate as necessary to allow the Power Controller technician to solve the Zone 3 trip problem and span the power controllers.
2. To confirm that simulator works as it should through the full power range.

Description

At 95% power on Zones 3 and 4 (Tests being performed under direction of the technician).

Smoke and debris were observed coming from the array. Unit was immediately shut down.

Difficulties Encountered

1. Many lamps were rendered inoperative.

TEST NO. 9

DATE: March 28, 1977

Test Objectives

1. Check simulator operation after repair.
2. Achieve steady state operation at several power levels to permit collection of analog data.
3. Automatic control tuning.

Description

1. Achieved steady state heat balance at moderate power.
2. Unable to achieve higher power steady state heat balance due to Zone 3 trip problem.

Difficulties Encountered

1. Zone 3 tripped.

TEST NO. 10

DATE: March 29, 1977

Test Objectives

1. To determine cause of Zone 3 trip problem.
2. Achieve steady state and take data, if possible.

Description

The Zone 3 480v transformer breaker was checked for possible thermal trip or magnetic trip malfunction. Controller installed temporary indicating lights on the three Zone 3 Silicon Controlled Rectifier (SCR) thermostats so that if another trip occurred, cause could be pinpointed.

At 1624, Zone 3 tripped off. Inspection revealed that the thermostat in the No. 1 SCR in Zone 3 (far left) had caused this. Further inspection revealed that the SCR was actually hot; i.e., this was valid circuit protection.

Difficulties Encountered

No steady state data was taken due to the trip.

TEST NO. 11

DATE: March 30, 1977

Test Objectives

1. To confirm that the Zone 3 trip problem has been solved.
2. Take steady state data at the following conditions:
   a) 1.12 Mw in to each Zones 3 and 4, none to Zones 1 and 2.
   b) 1.12 Mw in to each Zones 3 and 4, 0.2 Mw each to Zones 1 and 2.
   c) 1.35 Mw in to each Zones 3 and 4, 0.25 Mw each to Zones 1 and 2.

Description

Achieved moderate power heat balance, but failed to achieve higher power level due to Zone 3 trip problem.

Difficulties Encountered

Unable to achieve higher level due to Zone 3 trip problem.

TEST NO. 12

DATE: March 31, 1977

Test Objectives

1. To determine if the Zone 3 trip problem is caused by the Solar Simulator Controller or the 480v breaker of the zone transformer.
2. Achieve steady state operation at approximately 50% steaming rate and normal operating pressure and temperature and record data for heat balance.

Description

Operation proceeded smoothly through successful data collection at approximately 50% steaming. Shortly afterwards, the Zone 3 transformer breaker tripped, showing that the breaker was the source of the problem.

Difficulties Encountered

Zone 3 breaker tripped.
Eighteen light bulbs melted.

TEST NO. 13

DATE: April 2, 1977

Test Objectives

1. To gather heat balance data for several operating points.

Description

The test was going smoothly, but had to be delayed and finally abandoned due to Northern States Power Company (NSP) plant difficulties. With their Unit 8 out of service, they found they were unable to supply high pressure feedwater.

Difficulties Encountered

Lack of water.

TEST NO. 14

DATE: April 4, 1977

Test Objectives

1. To operate solar simulator for the purpose of checking the accuracy of the power meters, adjusting the power controllers as required, and for taking preliminary calibration data.

Description

Unit 8 was down for repairs, so only the condensate pump pressure (100 psig) was available to us. Operation of the lamps was minimized; i.e., they were only operated as required to support the power controller checkout.

Actual power readings were successfully recorded for use in heat balance calculations from Tests 9, 11, and 12. Changes were made in the Zone 1 and 2 power controller cabinets such that actual power approximately agrees with indicated power calibrations. Data was taken after these changes were made. This data is approximate, and will be used pending formal calibration of the power controller.

Difficulties Encountered

The Zone 1 transformer circuit breaker suffered a mechanical failure. The pivot pin (small) on the top of the trip module broke off.

TEST NO. 15

DATE: April 7, 1977

Test Objectives

1. To operate the solar simulator as required to respan and calibrate the power controllers.
2. To adjust the voltage limiters to exactly 420v.

Description

The Zone 1 and 2 power controllers and voltage limiters were adjusted satisfactorily.

Difficulties Encountered

The voltage feedback transformer in Zone 3 burned up for reasons that were not apparent to the field service technician.

TEST NO. 16

DATE: April 11, 1977

Test Objectives

1. To duplicate the power conditions present at data taking during Tests 11 and 12.
2. To take data at the power conditions and compare to see the effect of the black paint on the boiler.
3. To complete calibration of Zones 3 and 4.

Description

Operation proceeded normally and data was taken. The only exception is that there was a transient of unknown cause (see log).

Difficulties Encountered

Thirty-five bulbs burned out.

TEST NO. 17

DATE: April 13, 1977

Test Objectives

1. To achieve steady state operating conditions with outlet steam at 960°F, at approximately 10,000 PPH steam flow.
2. To perform the following transient tests (Refer to Appendix A):
   a) Main steam step.
   b) Radiant array step (5.1.3).
   c) Drum level shrink-and-swell.
3. To perform a power trip under automatic control.

Description

This test went nearly flawlessly.

Difficulties Encountered

1. Approximately 100 bulbs became non-functional during the test.
2. The Data Acquisition System (DAC) data recording tape quit during the drum level shrink and swell transient; thus, no digital data is available for that test.

TEST NO. 18

DATE: April 15, 1977

Test Objectives

1. To perform the following transient tests (Refer to Appendix A):
   a) Power ramp transient.
   b) Cloud obstruction transient.
   c) Attemperator step transient.
   d) 67% step power increase transient.

Description

The test went well except for difficulties encountered as described below. The Data Trac power programmers were first used today. They performed as intended.

Difficulties Encountered

1. The Data Acquisition System (DAC) caused a power trip due to a software problem.
2. The Zone 4 circuit breaker did not trip as it should have - probably has a burned out trip coil.
3. At least 154 bulbs were rendered inoperative during the test. 119 of these were in Zone 3.
4. The DAC remote cabinet quit several times during the testing.

TEST NO. 19

DATE: April 18, 1977

Test Objectives

1. To perform the following trip tests (Refer to Appendix A):
   a) Recirculation pump trip.
   b) Feedwater pump trip.
2. To operate the recirculation pump at various flow rates to demonstrate pump instability at flow rates above 100,000 PPH.
3. To obtain steady state data at several conditions.
4. To perform a 40% step power increase transient.

Description

Test was performed without difficulties.

Problems Encountered

None.

TEST NO. 20

DATE: April 19, 1977

Test Objectives

1. To perform the following trip tests (Refer to Appendix A):
   a) Heliostat trip - decay to 800^{O}F Main Steam Temperature.
   b) Heliostat trip - decay to 700^{O}F Main Steam Temperature.
   c) Heliostat trip - decay to 595^{O}F Main Steam Temperature.
2. To perform the shrink and swell transient with a 225-second delay until automatic control.
3. To tune the attemperator automatic control system.

Description

Testing proceeded without difficulties.

Low Northern States Power Company (NSP) water reserve forced test termination at 2000. At this point, attemperator tuning was not complete, but adequate; i.e., the controls would work through a power transient.

Problems Encountered

Low NSP water reserves.

TEST NO. 21

DATE: April 21, 1977

Test Objectives

1. To perform the asymmetric heating tests at three different power levels (Refer to Appendix A).

Description

Tests as described in 7.1.1 and 7.1.2 of the manufacturer's test plan were performed at three different power levels as follows:

1. 20% to all four zones.
2. 30% to all four zones.
3. 40% to all four zones.

Tests as described in 2.1.3 were performed at three different power levels as follows:

1. 40% to Zones 3 and 4.
2. 30% to Zones 3 and 4.
3. 20% to Zones 3 and 4.

Problems Encountered

1. The Data Acquisition System (DAC) had an intermittent problem. It would not read data part of the time.
2. Northern States Power Company (NSP) had low water reserves, which delayed the test.
3. The SCR cooling water circuits in the simulator Zone 1 power controller cabinet plugged with sediment, which caused a Zone 1 trip.

TEST NO. 22

DATE: April 26, 1977

Test Objectives

1. To reperform the transient tests (Refer to Appendix A):
   a) Main steam step (5.1.1).
   b) Radiant array step (5.1.3 and 5.1.7).
   c) Drum level shrink and swell (5.1.4).
   d) Radiant array ramp (5.1.5).
   e) Cloud disturbance (5.1.6).
2. To take steady state data at several power levels.

Description

The test operation went very smoothly. The water supply flanged joint to the attemperator leaked at 11 pounds per hour during the testing. The automatic attemperation performed reasonably well; however, it is felt that attemperator response could be improved if adequate time (and lamps) were available.

Problems Encountered

Attemperator water leakage.

31 lamps out of service.

TEST NO. 23

DATE: April 28, 1977

Test Objectives

1. To take steady state heat balances at several points including maximum possible power.
2. To bring boiler to rated pressure at maximum rate.
3. To monitor parameters while bottled up with array down.

Description

The startup was at near maximum rate for the unit. Average rate of temperature change was 490^{O}F/hr to operating pressure.

A maximum power heat balance was performed with the power controller voltage limiters at 420v which resulted in about 3.5 Mw output.

Later, the voltage limiters were defeated and a heat balance of 3.85 Mw output was achieved, but at the expense of 350 lamps.

Problems Encountered

None.

SECTION 4
TEST DATA ANALYSIS AND COMMENTARY

INTRODUCTION

During the start-up of the steam generator and in early testing, difficulties were encountered in obtaining entirely valid test data. Since the basic responsibility for data point logging and processing was assigned to the data acquisition system (DAC), it was essential to assess its readout credibility as testing progressed. For instance, fluid and metal temperatures were checked by establishing saturated vapor conditions in the boiler, by readout consistency, and by comparison with analog readouts on the operator's control console. A major checking effort, however, involved the use of hand calculations using the analog readouts from recorder charts and the operator's log. Input power to the solar simulator was calculated manually using observed control voltage and the solar simulator calibration plots. DAC flow calculations were checked manually using the direct voltage readouts and scaling factor of the transmitters sensing differential pressures across the primary flow elements. These hand calculations were founded on steady state runs and usually involved the calculation of heat balance. (A sample calculation sheet is shown in Table 4-1). Since the solar cimulator was re-calibrated during Tests 14 and 15, most of the hand calculations were done for tests thereafter.

Using hand calculations as a base, correction factors were developed for certain DAC readouts. Errata for Tests 16 through 20 are given in Table 4-2a; Table 4-2b applies to Test 21. Tests 21-02, 22, and 23 do not require an errata sheet.

Heat balances based on hand calculated, or corrected DAC, feedwater flows are consistent from test to test, and are believed to represent true performance

Table 4-1. SRE Steam Generator Performance Calculation

SRE STEAM GENERATOR PERFORMANCE CALCULATION	SHEET 1 OF 2 SHEETS			
	A	B	C	D
1 - Run Date				
2 - Run Time				
3 - Calculation Date				
4 - Calculator				
5 - Readout FW Flow, #/Hr.				
6 - FW Press., PSIA				
7 - FW Temp., °F.				
8 - FW Enthalpy, BTU/#				
9 - FW Density, $\#/Ft.^3$				
10 - FW Density (FE-1 Spec.), $\#/Ft.^3$ (1)				
11 - FW Density Correction				
12 - Density Corrected FW Flow, #/Hr.				
13 - FW Abs. Viscosity, #/Sec. Ft. (2)				
14 - FW Reynolds # @ FE-1 (3)				
15 - Coef. Discharge (C). FE-1 (4)				
16 - Corrected FW Flow, #/Hr.				
17 - Cooling Water (Inlet) Press., PSIA				
18 - Cooling Water (Inlet) Temp., °F.				
19 - Cooling Water (Inlet) Density, $\#/Ft.^3$				
20 - Cooling Water (Inlet) Enthalpy, BTU/#				
21 - Cooling Water (Outlet) Press., PSIA				
22 - Cooling Water (Outlet) Temp., °F.				
23 - Cooling Water (Outlet) Enthalpy, BTU/#				
24 - Cooling Water Enthalpy Gain, BTU/#				
25 - Readout Cooling Water Flow, #/Hr.				
26 - Heat to Cooling Water, BTU/Hr.				
27 - Readout Blow-down Flow, #/Hr.				
28 - Blow-down Press., PSIA				
29 - Blow-down Temp., °F.				
30 - Blow-down Density, $\#/Ft.^3$				
31 - Blow-down Enthalpy, BTU/#				
32 - Heat to Blow-down, BTU/Hr.				
33 - Drum Press., PSIA				
34 - Drum Temp., °F. (T_{SAT} @ Drum Press.)				
35 - Sat. Steam Enthalpy, BTU/# (@ Drum Press.)				
36 - Boiler Enthalpy Gain, BTU/# (Lines 35-8)				
37 - Drum Flow, #/Hr. (Lines 16-27)				
38 - Heat to Boiler, BTU/Hr. (Lines 36 x 37)				
39 - #1 S/H Outlet Press., PSIA				
40 - #1 S/H Outlet Temp., °F.				

Table 4-1. SRE Steam Generator Performance Calculation (Concluded)

SRE STEAM GENERATOR PERFORMANCE CALCULATION	SHEET 2 OF 2 SHEETS			
	A	B	C	D
41 - #1 S/H Outlet Enthalpy, BTU/#				
42 - #1 S/H Outlet Enthalpy Gain, BTU/# (Lines 41-35)				
43 - Heat to #1 S/H; BTU/Hr. (Lines 37 x 42)				
44 - Att. W. Flow, #/Hr.				
45 - #2 S/H Inlet Press., PSIA				
46 - #2 S/H Inlet Temp., °F.				
47 - #2 S/H Inlet Enthalpy, BTU/#				
48 - #2 S/H Outlet Press., PSIA				
49 - #2 S/H Outlet Temp., °F.				
50 - #2 S/H Outlet Enthalpy, BTU/#				
51 - #2 S/H Enthalpy Gain, BTU/# (Lines 50-47)				
52 - #2 S/H Flow (Lines 37 + 44)				
53 - Heat to #2 S/H, BTU/Hr. (Lines 51 x 52)				
54 - Total Heat to Main Steam, BTU/Hr. (Lines 38+43+53)				
55 - Power to Zone 1, Mw				
56 - Power to Zone 2, Mw				
57 - Power to Zone 3, Mw				
58 - Power to Zone 4, Mw				
59 - Total Power to R/A, Mw				
60 - Heat to Zone 1, BTU/Hr.				
61 - Heat to Zone 2, BTU/Hr.				
62 - Heat to Zone 3, BTU/Hr.				
63 - Heat to Zone 4, BTU/Hr.				
64 - Total Heat to R/A, BTU/Hr.				
65 - Heat Fraction to Boiler (Lines(32 + 38) ÷ 64)				
66 - Heat Fraction to #1 S/H (Lines 43 ÷ 64)				
67 - Heat Fraction to #2 S/H (Lines 53 ÷ 64)				
68 - Heat Fraction to Blow-down (Lines 32 ÷ 64)				
69 - Heat Fraction to SRE S/G (Lines (32+38+43+53) ÷ 64)				
70 - Heat Fraction to Cooling Water (Lines 26 ÷ 64)				
71 - Heat Fraction Unaccounted For				
72 - % SRE S/G Heat to Boiler (Line 65 ÷ 69)				
73 - % SRE S/G Heat to #1 S/H (Line 66 ÷ 69)				
74 - % SRE S/G Heat to #2 S/H (Line 67 ÷ 69)				

(1) Ref. Flow-Dyne Nozzle specification

(2) Ref. Fluid Meters, 1971; Fig. II-I-5

(3) Ref. Fluid Meters, 1971; Eq. I-5-58

(4) Ref. Fluid Meters, 1971; Fig. II-III-19

Table 4-2a. Errata

For Test No. 16* through 20:

- FT-1: Multiply by 1.1213
  Feedwater Flow -- WFW
- FT-3: Multiply by 1.1432
  Main Steam Out -- WS2

DATA AFFECTED	ENTRY	x 1.1213	x 1.1432
Operator Summary	W-FW	X	--
	W-S2	--	X
	Boiler Abs. KW	--	X
	S.H. #1 Abs. KW	--	X
	S.H. #2 Abs. KW	--	X
	Total Absorbed KW	--	X
	Power Ratio	--	X
Performance Summary	W-FW	X	--
	W-S2	--	X
	Boiler Abs. KW	--	X
	S.H. #1 Abs. KW	--	X
	S.H. #2 Abs. KW	--	X
	Total Absorbed KW	--	X
	Power Ratio	--	X
Base Data Report-- Fluid	FT-1	X	--
	FT-3	--	X
Flow Plots	8-WFW	X	--
	10-WS2	--	X
	17-WS1	--	X
Power Level Plots	6-QABS	--	X
	15-QB	--	X
	16-QS2	--	X

X denotes to perform indicated multiplications
-- denotes not applicable

* For tests 1 through 15 the computer did not have calibration data for the radiant array power.

Table 4-2b. Errata

For Test No. 21 (not for Test No. 21-02 which doesn't need an errata sheet):*

- FT-3: Multiply by 1.1432
  Main Steam Out -- WS2

DATA AFFECTED	ENTRY	x 1.1213	x 1.1432
Operator Summary	W-S2	--	X
	Boiler Abs. KW	--	X
	S.H. #1 Abs. KW	--	X
	S.H. #2 Abs. KW	--	X
	Total Absorbed KW	--	X
	Power Ratio	--	X
Performance Summary	W-S2	--	X
	Boiler Abs. KW	--	X
	S.H. #1 Abs. KW	--	X
	S.H. #2 Abs. KW	--	X
	Total Absorbed KW	--	X
	Power Ratio	--	X
Base Data Report-- Fluid	FT-3	--	X
Flow Plots	10-WS2	--	X
	17-WS1	--	X
Power Level Plots	6-QABS	--	X
	15-QB	--	X
	16-QS2	--	X

X denotes to perform indicated multiplications
-- denotes not applicable

* Tests No. 21-02, 22, and 23 do not require an errata sheet.

of the SRE steam generator. Heat balance plots in the form of Heat Fraction vs Feedwater Flow (Load) are given for: steam generator, boiler, #1 superheater, #2 superheater, cooling water, and "unaccounted for" in Figures 4-1, 4-2, 4-3, 4-4, 4-5, and 4-6, respectively.

METHOD

Hand calculations were made for 28 test conditions which were reasonably steady (as indicated by the strip chart recordings), and at, or near, rated output pressure and temperature (1575 psig and 955^{o}F). Sufficient calculations were desired to demonstrate repeatability. Insofar as possible the hand calculations were desired to be independent of the DAC system, at least until certain DAC data were shown to be good.

Pressures and temperatures were taken from DAC tabulations (Performance Summary, Base Data Report -- Fluid, Cooling Water Temperatures), and cross-checked in many cases with analog readouts (strip chart recordings, log book entries). Feedwater flow was used as the basic indication of steam generator through-put. The hand calculations for feedwater flow were based on CKFLO, a DAC program written to make the flow transmitter voltages available directly. From these voltages and from transmitter scaling factors, manufacturer's flow nozzle specifications, and the ASME flow data (Fluid Meters, 1971), it was possible to compute feedwater flows directly.

The hand calculations were based on radiant array power inputs as derived from log book entries of power settings and the radiant array calibration data taken April 4 to 7, 1977 during Runs 13, 14, 15. (Table 4-3).

As the hand calculation work progressed, it became apparent that the DAC system did well at computing steam properties (e.g., enthalpies, saturation temperatures). However, DAC-derived flow and absorbed power readouts were suspect. Using hand calculations of flow as a basis, the Errata Sheets

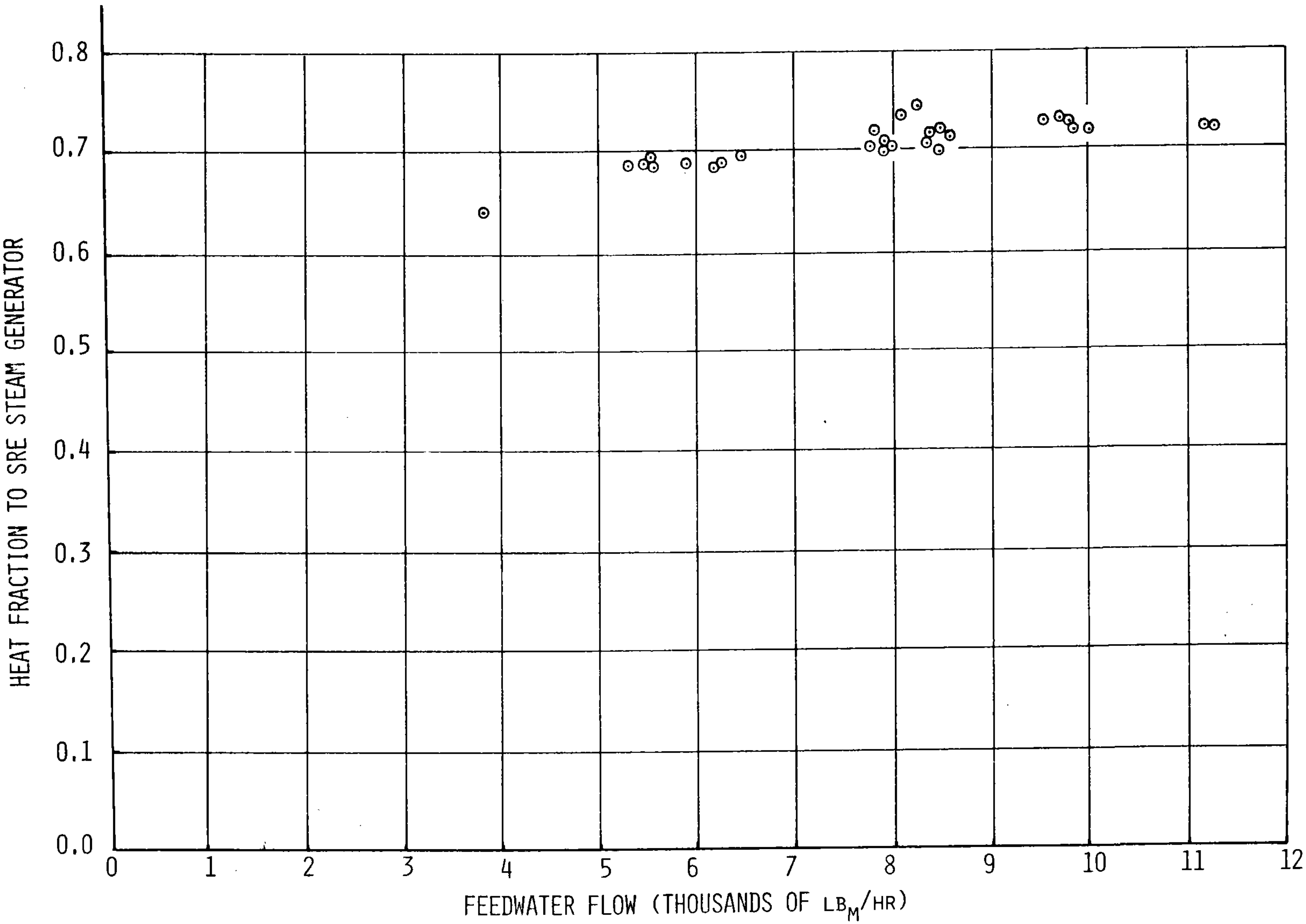

Figure 4-1. Heat Fraction to Steam Generator versus Feedwater Flow

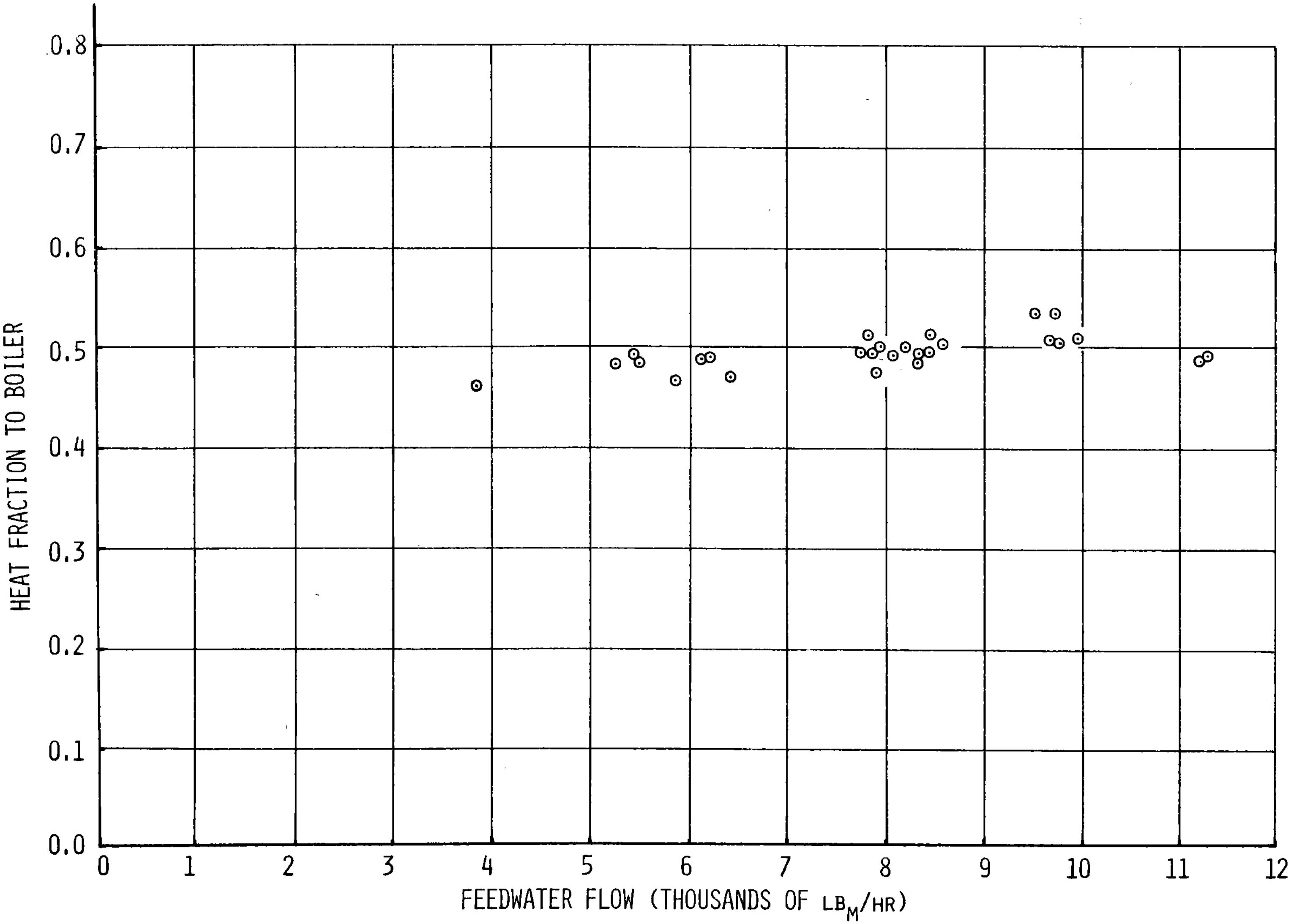

Figure 4-2. Heat Fraction to Boiler versus Feedwater Flow

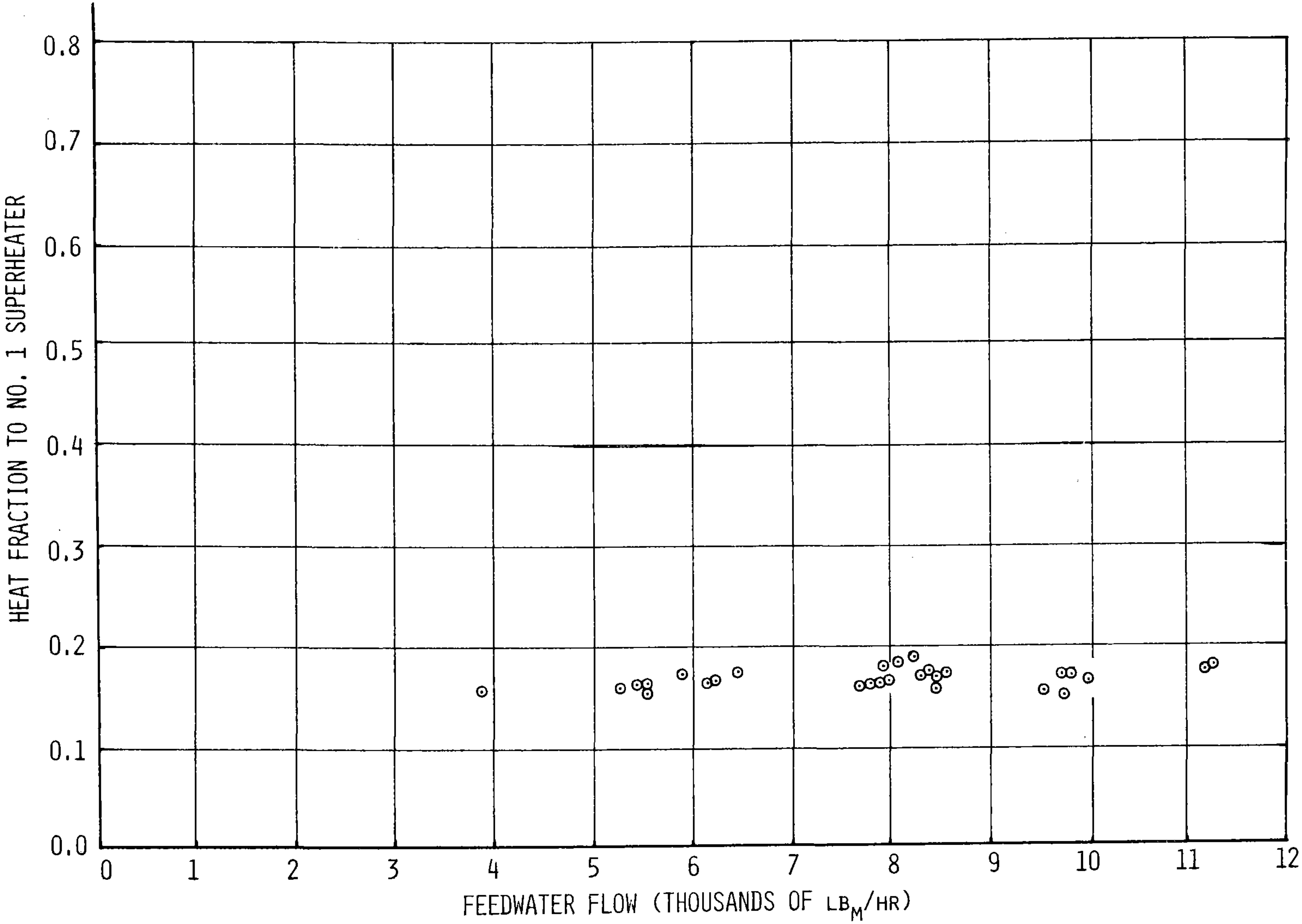

Figure 4-3. Heat Fraction to No. 1 Superheater versus Feedwater Flow

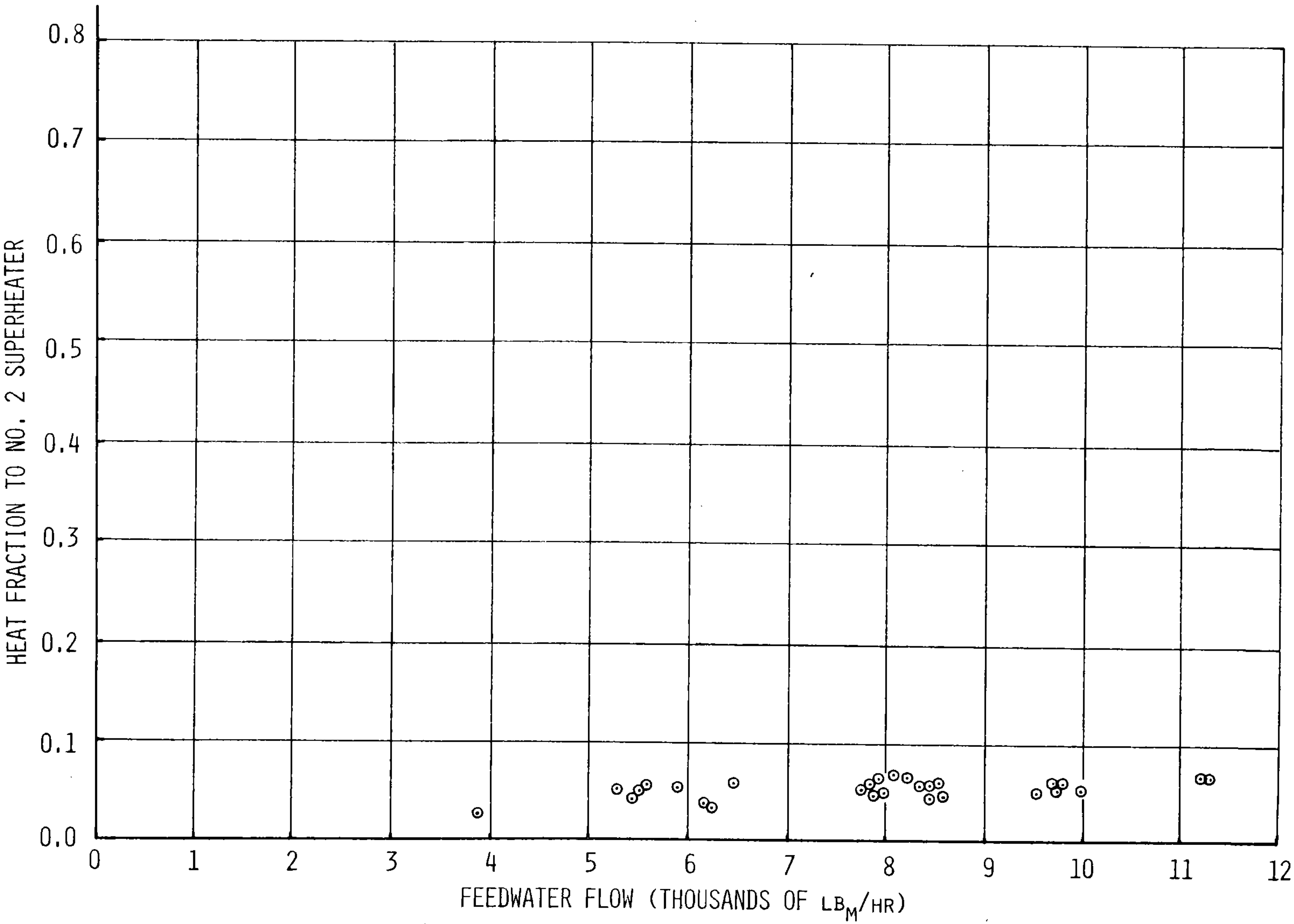

Figure 4-4. Heat Fraction to No. 2 Superheater versus Feedwater Flow

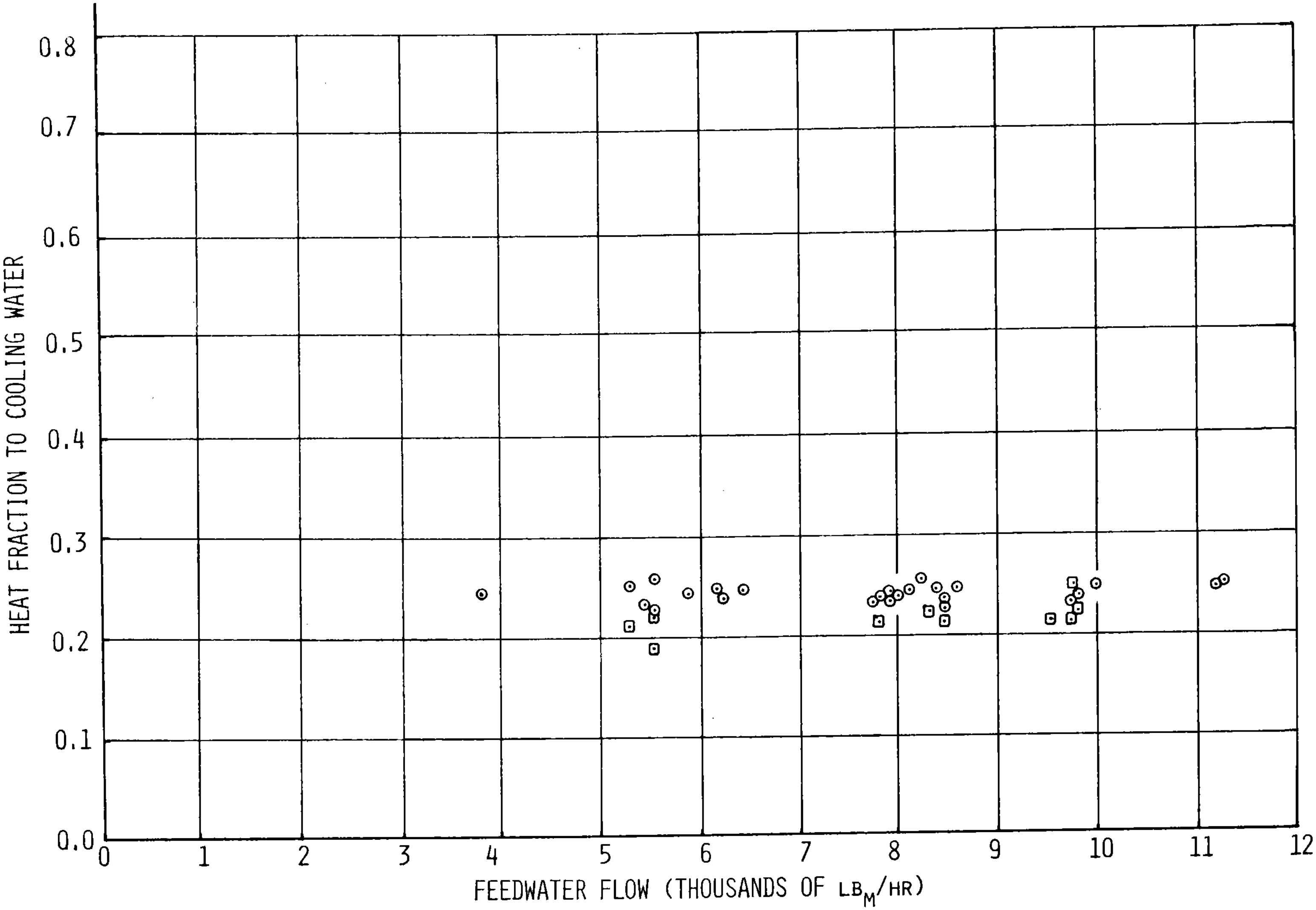

Figure 4-5. Heat Fraction to Solar Simulator Cooling Water versus Feedwater Flow

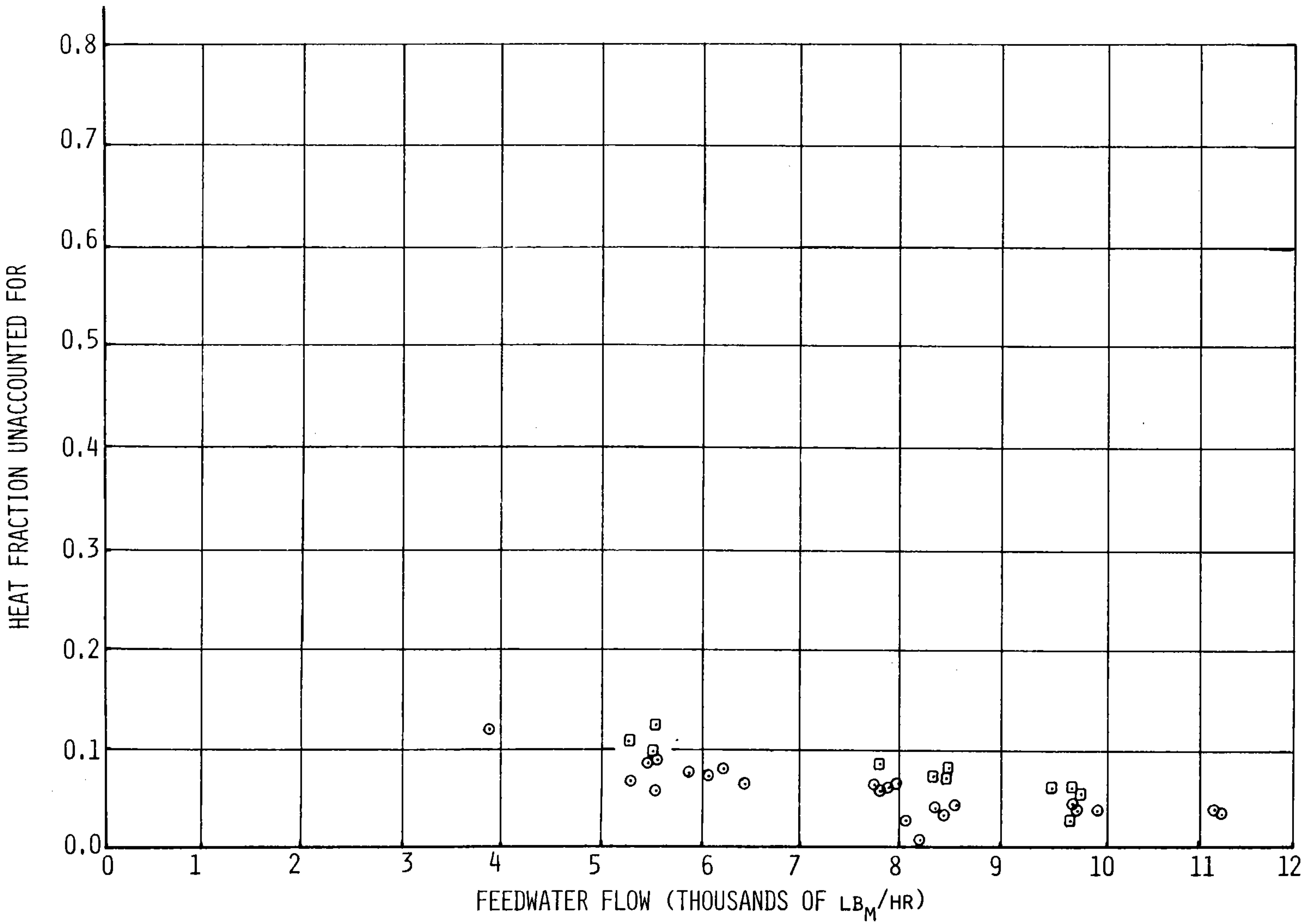

Figure 4-6. Heat Fraction Unaccounted for versus Feedwater Flow

POWER SETTING%	ZONE 1			ZONE 2			ZONE 3			ZONE 4		
	KW	LAMP VOLTS	CONTROL VOLTS	KW	LAMP VOLTS	CONTROL VOLTS	KW	LAMP VOLTS	CONTROL VOLTS	KW	LAMP VOLTS	CONTROL VOLTS
0												
10	210.5	134.5	0.44	224.4	138.7	0.47	229.5		0.45	230.4		0.45
20	420	209.3	0.89	445.5	217.3	0.97	460.8		0.90	459		0.90
30	633	270	1.34	682.5	284.3	1.47	679.5		1.35	670.5		1.35
40	849	322.7	1.79	922.5	340.3	1.97	909		1.80	900		1.79
50	1065	367.3	2.25	1155	396	2.48	1120.5		2.25	1120.5		2.24
60	1278	420	2.70	1287(2)	420.7	2.76	1350		2.71	1341		2.70
70							1575		3.16	1566		3.15
80							1809		3.60	1800		3.60
90												
100												
KW/Volt (1)	473			464.8			500.9			499		

(1) Based on averages in which 10% values were omitted for Zones 1 and 2; 10% to 20% values were omitted for Zones 3 and 4.

(2) Apparently erroneous

Figure 4-3. Solar Simulator Calibration*

*Reference: Calibration Runs of April 4 and 7, 1977.

(Tables 4-2a, 4-2b) were then derived. When errata factors are applied as indicated the DAC-derived feedwater flows agree quite well (within 1 or 2%) with hand-calculated flows; steam flow comparisons seem to be nearly as good.

There is a basic difficulty in determining steam flow and the performance of the #2 superheater due to the presence of the attemperator. Insufficient information is available on attemperator performance, in part due to the inability to run the steam generator at more than about 2/3 load because of the solar simulator power-delivery limitation. Further, attemperator flows were appreciable only in Tests No. 22 and No. 23. Neither attemperator or blow-down flow measurements were dependable prior to Test No. 18 because of transposed coefficients in the DAC program and reversed connections on the attemperator flow transmitter.

HEAT BALANCE RESULTS

"Heat Fractions" have been calculated for the various elements absorbing the power input to the solar simulator using feedwater flow as the indicator of system load. Feedwater flow values were either hand-calculated or DAC-calculated with application of errata as required. The consistency of the heat fraction data is apparent in the plots.

"Heat Fraction" values for the various elements are as follows:

- Steam Generator (Ref. Figure 4-1). The steam generator absorbs 68% to 73% of the solar simulator input power in the region of 5,000 to 11,000 lbs. per hour of feedwater flow. The increase in power absorption with load is seen in the plot.

- Boiler (Ref. Figure 4-2). The boiler section of the steam generator absorbs some 46.5% to 51% of the input power with increasing absorption at higher load indicated in the plot. These data are derived with the boiler heat absorption surface painted black (Novamet 150 with absorptivity claimed to be 0.97).

- No. 1 Superheater (Ref. Figure 4-3). The No. 1 superheater absorbs 15% to 17.5% of the input power in the region of 5,000 to 11,000 lbs. per hour of feedwater flow. The plot suggests that this absorption is unvarying with feedwater flow.

- No. 2 Superheater (Ref. Figure 4-4). The No. 2 superheater accounts for relatively small power absorption, in the order of 4.5% to 6.5%, in the feedwater flow range shown. The power absorption appears to be relatively unvarying with feedwater flow.

- Cooling Water (Ref. Figure 4-5). The power going to the solar simulator cooling water is thought to be from 22.5% to 25%, and appears to be unvaried with respect to load. The points falling below 22.5% in the plot (squares) were calculated assuming no calibration difference between the transmitters measuring input and output temperatures of the solar simulator cooling water. It is likely, however, that there was a calibration difference of two degrees Fahrenheit in the direction to decrease the temperature differential between input and output. The hand calculations represented by circles assumed a two-degree lower input cooling water temperature than readout from the transmitter.

- Unaccounted For (Ref. Figure 4-6). From 3% to 7.5% of the solar simulator input power appears to be "unaccounted for" with the loss becoming less as load increases. Values above 7.5% in the plot indicated by squares were calculated assuming no calibration difference between the transmitters measuring input and output temperatures of the solar simulator cooling water. This is believed to be unlikely (see discussion for Cooling Water heat fraction).

  In an unpublished study of SRE steam generator losses (R.L. Sampson and W.E. Anderson) heat losses to ambient at 5000 KW thermal heat absorption are predicted to be 1.6%. The study, however, does not include losses at the inner and outer annuli of the solar simulator heat shield at the lower extremity of the steam generator cavity.

USE OF ERRATUM

Table 4-4 includes a copy of the Performance Summary for Test No. 20 at 15:11 o'clock. The copy has been marked up to show how errata are to be applied to correct the data. Such corrections result in DAC data which agree

Table 4-4. Application of Errata

	Year	Day No.	Time		Test No.
PERFORMANCE SUMMARY	1977	109	15	11	20

BOILER

DRUM	
P-D	1622
T-D	607
H-GD	1157
H-FD	627
N-CR	1.2442
FEEDWATER	
P-FW	1883
T-FW	458
W-FW	7111 × 1.1213*
H-FW	439

FLOW CIRCUITS

T-DC	600
T-SUB	-7
W-B	87240
W-BC1	18120
W-BC2	9821
W-BC3	9522
X-B	15.973

SUPERHEATERS

S.H. STAGE 1	
W-S1	7012
T-S1I	608
T-S1O	851
P-S1O	1602
H-S1O	1392
ATTEMPERATOR	
P-ATT	1883
T-ATT	76
W-ATT	60
H-ATT	36

S.H. STAGE 2	
W-S2	7072 × 1.1432
T-S2I	849
T-S2O	963
P-S2O	1578
H-S2O	1464

BOILER

L-D	32
T-BI	598
H-BI	632
R-BI	39.439
R-GD	4.0665
R-FD	41.751

ARRAY - KW

ZONE 1	709
ZONE 2	713
ZONE 3	989
ZONE 4	970
TOTAL	3391

POWER

BOILER ABS. KW	1460	NET INPUT KW	2668
S.H. *1 ABS. KW	477	TOTAL ABSORBED KW	2110
S.H. *2 ABS. KW	172	POWER RATIO	.7911

(× 1.1432)

Power to cooling water = TOTAL − NET INPUT KW

Unaccounted for power loss = NET INPUT KW − (TOTAL ABSORBED KW) corrected

(BOILER ABS. KW + S.H. *1 ABS. KW + S.H. *2 ABS. KW)$_{corrected}$ = (TOTAL ABSORBED KW)$_{corrected}$

* W-FW = 7111 × 1.1213 = 7973.6

essentially with hand calculated data with the exception of absorbed power--particularly absorbed power by No. 2 superheater. The source of the problem was not determined.

Added to Table 4-4 is an explanation of how to determine the power loss to the cooling water and unaccounted for power losses such as by convection and radiation from the steam generator.

SECTION 5
TEST DATA RECORDS AND SUBMITTAL

Test data were recorded during testing of the SRE steam generator in several ways: operator log, recorder charts, data acquisition system printouts, magnetic tapes and temporary disk record. In addition to these records, analog displays which were available at the control console were logged periodically at the discretion of the test operator. Usually this logging was made to coincide with data acquistion system readouts; i.e., Operator Summary, Performance Summary, etc. Also, the data acquisition system operator could call up tabular displays in the cathode ray tube (CRT) at will.

At the conclusion of each test, the paper read-out data were assembled in the data record books -- one for each of the 23 test runs. The contents of the entry data record books are shown in Table 5-1. In addition, raw test data and data converted to engineering units were recorded on magnetic tape, usually one tape to a test. These magnetic tape data were simultaneously recorded by disk record for retrieval on a same-day basis in the form of plot and tabular print-outs prior to write-over. The data record book for Tests 17 through 23 are submitted herewith as separate documents; these tests were run after re-calibration of the solar simulator and the data acquisition readouts are considered valid when certain corrections are applied (Reference Tables 4-2a and 4-2b). The magnetic tapes containing raw data and program software, and the operator log, are on file.

Operator Log--The operator log consists of hand-written entries kept on a time base noting operator action, test conditions, and test objectives/descriptions. Copies of pages specific to a given test are filed in the data record book for that test.

Table 5-1. Test Data Record Book Contents

EXPLANATORY SHEETS
Summary of SRE Steam Generator Testing
Test Objectives/Description
Code Sheet for Recorder Charts
Parameter Identification Legend: Operator and Performance Summaries
SRE Steam Generator Thermocouple Identifications/Locations
Explanation of Array Flux Map
DAC Real Time Plot Format
Plot Lables and Descriptors
Radiant Array Calibration
Data Acquisition System Print-Out Listing
DATA SHEETS
Test Run Log Book Pages
Recorder Charts
Data Acquisition System Tabulation and Plot Printouts

Recorder Charts--Three recorders were used for continuous, visual recording of steam generator flows, pressures, drum level, water conductivity, and temperatures at the test operator's control console. Copies of these recordings are included in the data record book for the specific test. The code sheet for these recordings was given in Table 1-2.

Data Acquisition System Printouts--The data acquisition system printouts are tabulations and plots made at significant times in the testing. The data acquisition system print-out listing is given in Table 5-2. Of course, the possibility for additional data printing exists using the magnetic tapes on file and appropriate computer hardware and software.

Table 5-2. Data Acquisition System Print-Out Listing

PAGE NUMBER	TITLE
1	Operator Summary
2	Performance Summary
3	Base Data Report -- Metal Temperatures
4	Base Data Report -- Fluid
5	Cooling Water Temperature
6	First Stage Superheater Metal Temperatures
7	Second Stage Superheater Metal Temperatures
8	Boiler Temperature Profile
9	First Stage Superheater Temperature Profile
10	Second Stage Superheater Temperature Profile
11	Warnings and Alarms Report
12	Alarm Conditions
13	Array Flux Map
14	Flows, Plots
15	Pressures, Plots
16	Fluids Temperatures, Plots
17	Metal Temperatures, Plots
18	Drum Level, Plots
19	Recirculation Flow, Plots
20	Power Levels, Plots
21	Enthalpy
22	Ratios

Magnetic Tapes--Raw data and data converted to engineering units were recorded on magnetic tape. Data-taking frequencies were usually once per minute during warm-up, stand-by, and cool-down, and once per 10 or 20 seconds during the actual test period. Software tapes for data reduction are also on file, and include:

- Versatec Plotter: sources and objects (two tapes)
- Hewlett-Packard: 9611 system executive software (two tapes)
- SRE Steam Generator Test Source Files for Data Acquisition/Reduction (4-29-77)

In addition to these, transcribed "back-up" tapes of the entire system software were made periodically from the disks as the software program evolved during the testing.

APPENDIX A

MANUFACTURER'S TEST REQUIREMENTS

This appendix documents the manufacturer's test requirements which served as a guide in testing the SRE Steam Generator. These requirements include: test objectives, control requirements, heat flux requirements, and data requirements. The tests were:

1. PRE-OPERATIONAL
2. COLD CHECKOUT
3. HOT CHECKOUT AND CALIBRATION
4. STEADY-STATE PERFORMANCE
5. TRANSIENTS
6. TRIP SIMULATIONS
7. ASYMMETRIC HEAT INPUT

1. PRE-OPERATIONAL

1.1 Verify the proper operation of the steam generator auxiliary equipment.

1.1.1 Valves - open/close remote control
1.1.2 Data acquisition system hookups
1.1.3 Controllers
1.1.4 Alarm/interlock systems
1.1.5 Flux boom operation
1.1.6 Cooling water flow

1.2 Test Control Requirements: Controls must be electrically functional for checkouts.

1.3 Heat Flux Requirements: No heat input required.

1.4 Data Acquisition System Requirements:

1.4.1 CRT - Hard copy option
Base Data Report - On Demand

1.4.2 Post Test Data - None

1.4.3 Operator Log (Manual Report):
Verify analog alarms and record settings
Verify action of all valve actuators and actuator failure mode

1.4.4 Parameter List:
All pressures, temperatures, and flow differential pressures

1.4.5 Alarm/Warning:
Set alarms and verify response
Retain printed alarms
Displayed warnings - Hard copy option

2. COLD CHECKOUT

<u>2.1 Objective</u>: Hydraulic checkout of the boiler circuit.

2.1.1 Verify recirculation pump and control valve operation

2.1.2 Verify drum level transmitters (correlate to sight glass)

2.1.3 Initial chemical cleaning.

2.1.4 Check operation of boiler flow elements

2.1.5 Balance boiler flow circuits

<u>2.2 Control Requirements</u>:

- Manual control of feedwater control valve and blowdown valve for manual drum level control
- Manual operation of recirculation control valve

- Flow distribution valves:
  1. Chemical cleaning - full open
  2. Flow balancing - initial setting 4-3/4 turns open

2.3 Heat Flux Requirement: No heat input.

2.4 Data Acquisition System Requirements:

2.4.1. CRT - Hard copy option
Base Data Report - On demand

2.4.2 Post Test Date - None

2.4.3 Operator Log:
Verify drum level alarms
Drum level calibration
Pump low flow alarm
Pump current trip

2.4.4 Parameter List:
All pressures, temperatures, flows and levels

2.4.5 Alarm/Warning:
Verify alarms
Retain printed alarms
Displayed warnings - Hard copy option

3. HOT CHECKOUT AND CALIBRATION

3.1 Objective: Achieve startup, operation, calibration, and shutdown to facilitate subsequent testing.

3.1.1 Initial Startup:
Drum saturation temperature raised from ambient to a minimum of 30^{o}F above feedwater temperature. No feedwater introduced into the drum.

- Monitor drum level, drum pressure, steam pressure, steam temperature and steam flow for acceptable performance.
- Determine if boiler flow distribution is ±5 percent between circuits.
- Monitor superheater metal temperatures and outlet steam temperatures to insure these are below design temperatures.
- Monitor boiler flow for oscillations and compare to recirculation pump curve to insure no cavitation.

3.1.2 Initial Feedwater Introduction:

Drum pressure increased operating throttle pressure control. Feedwater introduced into the drum for automatic level control.

- Monitor drum level, drum pressure, steam temperature, steam pressure and steam flow for acceptable performance.
- Determine if boiler circuit flow distribution is ±5 percent between circuits.
- Monitor superheater metal and outlet steam temperatures to insure these are below design temperatures.
- Monitor boiler flow for oscillations and compare to recirculation pump curve to insure no cavitation.
- Check operation of control valves.
- Steam valve on automatic.
- Adjust automatic controls if required.

3.1.3 Boiler Thermocouple Saturation Temperature Check:

Heat input reduced to zero, steam pressure on automatic control, boiler circuit allowed to reach an equilibrium saturation temperature to facilitate thermocouple checkout.

- Monitor boiler flow for oscillations and compare to recirculation pump curve to insure no cavitation.

- Check boiler thermocouples for saturation temperature reading.
- Correct calibration constants as required.
- Check superheater thermocouples for indication of possible detachment from tubes, shorts, or open circuits.

3.1.4 Initial Steady Operation:

Unit brought to operating pressure (1575 psia), steady-state heat input distribution (70% boiler, 30% superheaters, steam temperature) and raised by 20% increments (20, 40, 60, 80, 100%) to 100% load (100% = 4.2 Mw absorbed energy). Test safety valves and adjust if required (at approximately 20% load).

At each load increment:

- Determine boiler flow distribution, no more than ±5 percent tolerance between circuits.
- Tune automatic controls.
- Maintain steady-state
- Compare drum pressure, interstage pressure, interstage temperatures, steam pressure, steam temperature, steam flow, attemperator flow, and feedwater flow to predicted values.
- Complete heat balance.
- Determine heat losses.
- Determine heat flux profile and compare integrated heat flux distribution to absorbed power

3.1.5 Initial Shutdown:

Solar simulator off, unit shutdown in sequence to protect equipment.

- Monitor drum level
- Recirculation pump maintained in operation and boiler monitored for indications of cavitation
- No feedwater or attemperator spray flow
- Steam pressure on automatic
- Nitrogen blanket when drum pressure drops to 15 psig
- Unit inspected after cooldown for temperature effects

3.2 Test Control Requirements:

3.2.1 Initial Startup:

Steam valve - Initially closed

Open 5 percent of full open port area when downcomer temperature or drum level surge indicates saturation condition. Operated manually as required to control drum level and pressure.

Feedwater valve - Closed
Attemperator valve - Closed
Blowdown valve - Closed

3.2.2 Initial Feedwater Introduction:

Steam valve - Manual 5 percent of full open port area

Automatic after operating pressure reached

Feedwater valve - Automatic drum level control
Blowdown valve - As necessary for maintaining water chemistry
Attemperator valve - Closed

3.2.3 Boiler Thermocouple Check:
Steam valve - Automatic steam pressure control
Feedwater valve - Closed
Blowdown valve - Closed
Attemperator valve - Closed

3.2.4 Initial Steady Operation:
Steam valve - Automatic steam pressure control (1875 psig)
Feedwater valve - Automatic drum level control
Blowdown valve - As required for maintaining water chemistry
Attemperator valve - Automatic steam temperature control set at 900°F initially increased to 955°F when controls are tuned.

3.2.5 Initial Shutdown:
Steam valve - Automatic steam pressure control
Feedwater valve - Closed
Blowdown valve - Closed
Attemperator valve - Closed
Recirculation pump on until water temperature is below 240°F
Nitrogen blanket when drum pressure decreased to 15 psig

3.3 Heat Flux Characteristics:

Heat flux imbalance limited by design temperatures.
Simulator centered in cavity
Circumferentially uniform flux

3.3.1 Total power input 10 percent load (100% load = 4.2 Mw absorbed power)

Absorbed power distribution: Boiler - 80%
1st Stage Superheater - 16%
2nd Stage Superheater - 4%

3.3.2 Total power input 10% load

Absorbed power distribution: Boiler - 80%
1st Stage Superheater - 16%
2nd Stage Superheater - 4%

3.3.3 No heat input

3.3.4 To bring to operating pressure:

Total power input: 10% load

Absorbed power distribution: Boiler = 80%
1st Stage Superheater - 16%
2nd Stage Superheater - 4%

Steady-state distribution change

Total power input: 10% load

Absorbed power distribution: Boiler - 70%
1st Stage Superheater - 24.3%
2nd Stage Superheater - 5.7%

Steady-state operation

Total power input: 20, 40, 60, 80, 100% load

Absorbed power distribution: Boiler - 70%
1st Stage Superheater - 24.3%
2nd Stage Superheater - 5.7%

3.3.5 No heat input

3.4 Data Requirements:

3.4.1 Initial Steam Production:

- CRT - Tabular Data - Printer Option:
  1. Operator Summary - on demand
  2. Critical Metal Temperatures - on demand
  3. Temperature Profiles - On demand, printer only
- CRT - Plots - Printer: None
- Post Test Data - Hard Copy

  Base Data Report by operator option

3.4.2 Initial Feedwater Introduction:

- CRT - Tabular Data - Printer Option:
  1. Operating Summary - on demand
  2. Critical Metal Temperatures - on demand
  3. Temperature Profiles - on demand - printer only
- CRT - Plots - Printer Option: None
- Post Test Data - Hard Copy

  Base Data Report at operator's option

3.4.3 Boiler Thermocouple Saturation Temperature Check:

- CRT - Tabular Data - Printer Option:
  1. Operator Summary - on demand
  2. Temperature Profiles - on demand - printer only
- CRT - Plots - Printer Option: None
- Post Test Data - Hard copy

  Temperature Profiles

3.4.4 Initial Steady Operation:

- CRT - Tabular Data - Printer Option:
  1. Operator Summary - on demand
  2. Critical Metal Temperatures - on demand
  3. Cross Checks - on demand
  4. Performance Summary - on demand
  5. Temperature Profiles - on demand - printer only
  6. Heat Flux Profiles - on demand - printer only
- CRT - Plots - Printer Option:

  Operator Option Plot Routine

- Post Test Data - Tabular Data - Hard Copy:
  1. Performance Summary
  2. Critical Metal Temperatures
  3. Temperature Profiles
  4. Heat Flux Profile
  5. Cross Checks
  6. Base Data Report
- Post Test Data - Plots - Hard Copy

3.4.5 Initial Shutdown:

- CRT - Tabular Data - Printer Option:
  Operator Summary - on demand
- CRT - Plots: None
- Post Test Data: None
- Operator Log (Manual Report):
  Report of visual internal (in cavity) and external inspection

3.4.6 Parameter List (Applies to test objectives 3.1.4 - 3.1.5):

Analog inputs: All pressures, temperatures, flows and levels

Calculated variables: All heat fluxes, heat inputs, heat balances and flow balances

3.4.7 Alarms/Warnings (Applies to test objectives 3.1.4 - 3.1.5):

Alarms

Printed alarms retained for records

4. STEADY-STATE PERFORMANCE

<u>4.1 Objective</u>: Verify the predicted steady-state model and evaluate absorbed heat flux measurement technique.

- Bring unit up to operating temperature (955°F) Pressure (1575 psia) and heat input distribution (boiler 70%, superheaters 30%).
- Advance to 100% load in 20% increments at each increment achieve steady state and:
  a. Obtain data to compare to predicted pressures, temperatures and flows.
  b. Obtain heat balance parameters.
  c. Obtain heat loss data.
  d. Obtain heat flux and temperature profile.

4.2 Test Control Requirements:

Steam valve - Automatic control of steam pressure
Feedwater valve - Automatic control of drum level
Attemperator valve - Automatic control of steam temperature
Blowdown vlave - As required for maintaining water chemistry; closed, if possible, for each steady-state data point

4.3 Heat Flux Characteristics:

Heat flux imbalance limited by design temperatures
Simulator centered in cavity
Circumferentially uniform flux distribution
Total power input: 20, 40, 60, 80, 100% load
Absorbed power distribution: Boiler - 70%
1st Stage Superheater - 24.3%
2nd Stage Superheater - 5.7%

4.4 Data Requirements:

4.4.1 CRT - Tabular Data - Printer Option:

1. Operator Summary - on demand
2. Temperature Profile - on demand
3. Heat Flux Profile - on demand
4. Performance Summary - on demand
5. Critical Metal Temperatures - on demand
6. Cross Checks - on demand

4.4.2 CRT - Plots - Printer Option:

Operator Option Plot Routine

4.4.3 Post Test Data - Tabular Data - Hard Copy:

1. Performance Summary
2. Critical Metal Temperatures
3. Temperature Profile
4. Heat Flux Profile
5. Cross Checks
6. Base Data Reports

4.4.4 Post Test Data - Plots - Hard Copy

4.4.5 Operator Log:

Report of internal and external inspection after cooldown

4.4.6 Parameter List:

Analog inputs: all pressures, temperatures, flows, levels
Calculated variables: all heat fluxes, heat inputs, heat balances, flow balances

4.4.7 Alarms/Warnings:

Printed alarms retained for records

5. TRANSIENTS

5.1 Objective: Determine the dynamic performance of the unit and validate the transient model

The initial condition of all transients is 100% load (4.2 Mw), on automatic control, at operating steam temperature (955°F) and pressure (1575 psia)

5.1.1 Steam Control Valve Position Step Change:
Attemperator control valve manual
Steam control valve manual, opened in near step to 5% steam flow increase
System allowed to return to steady operation (≅10 minutes)
Steam control valve returned to original position
System returned to automatic

5.1.2 Attemperator Spray Control Valve Position Step Change:
Steam control valve manual
Attemperator Spray Control Valve manual, opened in a near step to increase spray flow by 165 lbm/hour
System allowed to return to steady operation (≅10 minutes)
Attemperator spray control valve returned to original position
System returned to automatic

5.1.3 Solar Simulator Output Step Decrease:
Attemperator spray control valve, steam control valve on manual
Solar simulator output decreased in a near step by 10%
System allowed to return to steady operation (≅10 minutes)
Return solar simulator output to initial value
System allowed to return to steady operation
System returned to automatic

5.1.4 Drum Level Shrink and Swell:

Steam control valve, attemperator spray control valve, and feedwater control valve on manual

Solar simulator output decreased in a near step by 20%

Feedwater control valve on automatic after 100 seconds

System allowed to return to steady operation (≅10 minutes)

Feedwater Control Valve on Manual

Increase solar simulator to 100% power in a near step

Feedwater control valve on automatic after 100 seconds

System allowed to return to steady operation

System returned to automatic

5.1.5 Power Ramp:

Solar simulator output decreased from 100% to 57% in 300 seconds

System allowed to return to steady operation (≅10 minutes)

Solar simulator output increased from 57% to 100% in 300 seconds

System allowed to return to steady operation (≅10 minutes)

5.1.6 Simulated Cloud Disturbance:

Solar simulator output to the boiler section decreased 10% in a near step and each superheater input remaining constant

System allowed to return to steady operation

Return to full power

System allowed to return to steady operation

5.1.7 Step Decrease in Solar Simulator Output:

Solar Simulator output decreased 10% in a near step

System allowed to return to steady operation

Solar simulator output increased 100% power in a near step

System allowed to return to steady operation

5.2 Test Control Requirements:

Initial condition: All controls on automatic

For all transient tests the blowdown valve should be closed if possible, if not possible, maintain a constant position.

5.2.1 to 5.2.7 Control valves operated as indicated in Section 1 above

5.3 Heat Flux Requirements:

Heat Flux inbalance limited by design temperatures

Initial condition: Total power input: 100% load

Absorbed power distribution: Boiler - 70%
1st Stage Superheater - 24.3%
2nd Stage Superheater - 5.7%

Solar Simulator centered in cavity

5.3.1 to 5.3.7 - Solar simulator output as indicated in Section 1 above

5.4 Data Acquisition System Requirements:

5.4.1 CRT - Tabular Data - Printer Option:

1. Operator Summary - on demand
2. Critical Metal Temperatures - on demand
3. Cross Checks - on demand
4. Performance Summary and Transient Addition - on demand

5.4.2 CRT - Plots - Printer Option:
Operator Option Plot Routine

5.4.3 Post Test Data - Tabular Data - Hard Copy:
Performance Summary and Transient Additions
Base Data Report

5.4.4 Post Test Data - Plots - Hard Copy

5.4.5 Operator Log:

Report of internal and external inspection after cooldown

5.4.6 Parameter List:

Analog inputs: All pressures, temperatures, flows, levels

Calculated variables; all heat inputs, heat balances, flow balances

5.4.7 Alarms/Warnings:

Printed alarms retained for records

6. TRIP SIMULATIONS

<u>6.1 Objective</u>: Trips of critical steam generator and auxiliary equipment are simulated.

Initial status for all tests: Full load (4.2 Mw thermal absorbed power)
Operating main steam temperature (955°F) and pressure (1575 psia)
Automatic Control
Operating heat input distribution (see 6.3)

6.1.1 Simulated Heliostat Trip and Restart:

Trip solar simulator from maximum power

Steam temperature decreased to specified values for each run (see 6.3.1)

Restart solar simulator at maximum allowable rate (see 6.3.1)

6.1.2 Simulated Recirculation Pump Trip:

Decrease boiler flow to minimum value allowable for safe pump operation (in a near step)

Low boiler flor interlock trips solar simulator

Return boiler flow to normal

Restart solar simulator

6.1.3 Simulated Feedwater Pump Trip:

Close feedwater and attemperator valves (in a near step)

Trip solar simulator manually

Return drum to normal level

Return feedwater and attemperator valves to automatic

Restart solar simulator

6.2 Test Control Requirements:

Restarts referred to in 6.1.1 to 6.1.3 may be as rapid as permitted by design metal temperatures and maximum metal temperature change rates

6.2.1 Simulated Heliostat Trip and Restart:

Steam valve - Automatic

Feedwater valve - Automatic

Attemperator valve - Automatic

Blowdown valve - As required for water chemisty

6.2.2 Simulated Recirculating Pump Trip:

Steam valve - Automatic

Feedwater valve - Automatic

Attemperator valve - Automatic

Blowdown valve - As required for maintaining water chemisty

Recirculation Control valve - Initial: Normal boiler flow position
Test: Close to minimum flow for safe pump operation

Return to normal boiler flow before restarting solar simulator

6.2.3 Simulated Turbine Trip:

Steam valve - Initial: Automatic
Test: Manual: Full load position to 15% full load flow position

Return to automatic before restarting solar simulator

Feedwater valve - Automatic

Attemperator valve - Automatic

Blowdown valve - As required for maintaining water chemistry

6.2.4 Simulated Feedwater Pump Trip

Steam valve - Automatic

Feedwater and Attemperator valves - Initial: Automatic
Test: Manual: Full load position to closed

Return to automatic before restarting solar simulator

Blowdown valve - As required for maintaining water chemistry

6.3 Heat Flux Characteristics

Heat flux imbalance is limited by the design temperature limits of the pressure parts

The solar simulator is centered in the cavity for this test sequence.

Initial test condition: Full load (4.2 Mw absorbed power)

Operating heat input distribution -

Boiler - 70%

1st Stage Superheater - 24.3%

2nd Stage Superheater - 5.7%

6.3.1 Simulated Heliostat Trip and Restart

Initial test condition

Trip simulator

Restart the simulator when the outlet steam temperature (T_{S20}) decreases to the values specified by runs:

Run #1 - T_{S20} = 800°F

Run #2 - T_{S20} = 700°F

Run #3 - T_{S20} = Drum saturation temperature at full load

(The restarts in this test should be as rigid as permitted by maximum metal temperature limits and maximum metal temperature change rates.)

6.3.2 Simulated Recirculation Pump Trip

Initial test condition

Low boiler flow trips simulator

Restart after normal boiler flow is restored

6.3.3 Simulated Turbine Trip

Initial test condition

Operator trips simulator

Restart after the drum level is stabilized

6.3.4 Simulated Feedwater Pump Trip

Initial test condition

Operator trips simulator

Interlocks trip simulator

Restart after drum level is returned to normal and the feed-water and attemperator valves are returned to automatic

6.4 Data Requirements:

Section 6.1.1 - 6.1.3 identified above all have the same data requirements.

6.4.1 CRT - Tabular Data - Printer Option:

1. Operator Summary - on demand
2. Critical Metal Temperatures - on demand
3. Performance Summary and Transient Addition - on demand

6.4.2 CRT - Plots - Printer Option:

Operator Option Plot Routine

6.4.3 Post Test - Tabular Data - Hard Copy:

Performance Summary and Transient Addition

Base Data Report

6.4.4 Post Test-Plots - Hard Copy

6.4.5 Parameter List:

Analog inputs - All pressures, temperatures, flows, and levels

Calculated variables - All heat input, heat balance, and flow balance parameters

6.4.6 Alarms/Warnings

Printed alarms retained for records

7.0 ASYMMETRIC HEAT INPUT

7.1 Objective: Obtain steady-state performance data with the solar simulator offset within the cavity

Balance the boiler circuit flows to match circuit inputs. Ascertain the effect of asymmetric heating on boiler flow distribution.

7.1.1 Calibration and Performance:

Bring the unit to 20% power

Increase power by 20% increments to the maximum obtainable power without exceeding design temperature and pressure limits of the steam generator components.

At each power increment:

- Maintain the unit in steady operation
- Measure flow imbalance among boiler circuits
- Make heat balance and flow checks
- Obtain temperature and heat flux profiles

7.1.2 Flow Balancing:

Adjust flow distribution valves to match boiler circuit flows to measured heat inputs determined during 7.1.1 tests.

Bring the unit to 20% power

Increase power by 20% increments to the maximum obtainable power without exceeding design temperature and pressure limits of the steam generator components.

At each power increment:

- Maintain the unit in steady operation
- Make heat balance and flow checks
- Obtain temperature and heat flux profiles

7.1.3 Flow Distribution:

Pretest:

Experimentally dtermine the solar simulator setting required to obtain input to the boiler from the lower simulator zones and maintain the outlet steam temperature 50^{o}F above the drum saturation temperature. Complete experimental results for power inputs up to the maximum possible power input to the boiler section.

Test:

Open the flow distribution valves 100%
Bring the solar simulator to 20% of the maximum boiler input
Increase boiler input power in 20% increments to the maximum
Maintain the superheater outlet temperature 50^{o}F above the drum saturation temperature

At each power increment:

- Maintain steady operation
- Check the boiler flow distribution between circuits

7.2 Test Control Requirements:

7.2.1 Calibration and Performance:
Steam valve - automatic
Feedwater valve - automatic
Attemperator valve - automatic
Blowdown valve - as required for maintaining water chemistry

7.2.2 Flow Balancing:
Steam valve - automatic
Feedwater valve - automatic
Attemperator valve - automatic

Blowdown valve - as required for maintaining water chemistry

Flow distribution valves - adjusted to match boiler circuit flows to heat inputs

7.2.3 Flow Distribution:

Steam valve - automatic

Feedwater valve - automatic

Attemperator valve - automatic

Blowdown valve - as required for maintaining water chemistry

Flow distribution valves - 100% open

7.3 Heat Flux Characteristics:

7.3.1 Calibration and Performance:

Heat flux imbalance (between te two superheaters and boiler) limited by design temperatures

Solar simulator offset within the cavity

Absorbed power distribution: Boiler - 70%
1st Stage Superheater - 24.3%
2nd Stage Superheater - 5.7%

Initial operation at 20% power; increase power by 20% increments to the maximum possible power

7.3.2 Flow Balancing:

Heat flux imbalance limited by design temperatures

Solar simulator offset within the cavity

Absorbed power distribution: Boiler - 70%
1st Stage Superheater - 24.3%
2nd Stage Superheater - 5.7%

Initial operation at 20% power; increase power by 20% increments to the maximum possible power

7.3.3 Flow Distribution:

Solar simulator offset within the cavity

Operate the solar simulator to experimentally determine the required power inputs to the four zones required to obtain the maximum possible boiler input power and maintain the outlet steam temperature 50^{o}F above the drum saturation temperature
Operating the four zones of the simulator as identified experimentally:
Bring the unit to 20% of the maximum boiler input power
Raise the unit by 20% increments to the maximum boiler input power

7.4 Data Requirements:

7.4.1 Calibration and Performance

- CRT - Tabular Data - Printer Option:
  1. Operator Summary - on demand
  2. Critical Metal Temperatures - on demand
  3. Cross Checks - on demand
  4. Performance Summary - on demand
  5. Temperature Profiles - printer only - on demand
  6. Heat Flux Profiles - printer only - on demand

- CRT - Plots - Printer Option:
  Operator Option Plot Routine
- Post Test Data - Tabular Data - Hard Copy:
  1. Performance Summary
  2. Critical Metal Temperatures
  3. Temperature Profile
  4. Heat Flux Profiles
  5. Cross Checks
  6. Base Data Report
- Post Test Data - Plots - Hard Copy

7.4.2 Flow Balancing:

- CRT - Tabular Data - Printer Option:
  1. Operator Summary - on demand
  2. Critical Metal Temperatures - on demand
  3. Cross Checks - on demand
  4. Performance Summary - on demand
  5. Temperature Profiles - printer only - on demand
  6. Heat Flux Profiles - printer only - on demand

- CRT - Plots - Printer Option:

  Operator Option Plot Routine
- Post Test Data - Tabular Data - Hard Copy:
  1. Performance Summary
  2. Critical Metal Temperatures
  3. Temperature Profiles
  4. Heat flux profiles
  5. Cross Checks
  6. Base Data Report
- Post Test Data - Plots - Hard Copy

7.4.3 Flow Distribution:

- CRT - Tabular Data - Printer Option:
  1. Operator Summary - on demand
  2. Critical Metal Temperatures - on demand
  3. Cross Checks - on demand
  4. Performance Summary - on demand
- CRT - Plots - Printer Option:

  Operator Option Plot Routine
- Post Test Data - Tabular Data:
  1. Performance Summary
  2. Base Data Report
  3. Cross Checks
- Post Test Data - Plots - Hard Copy: None

7.4.5 Parameter List - Applicable to Sections 7.4.1 - 7.4.4 above:

Analog inputs: All pressures, temperatures, flows and levels

Calculated variables: All heat input, heat balance, and flow balance parameters

7.4.6 Alarms/Warning:

Printed alarms retained for records