CONTRACTOR REPORT

SAND82-8192
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Final Report
Sodium Solar Receiver Experiment

Rockwell International

Prepared by Sandia National Laboratories, Albuquerque, New Mexico 87185
and Livermore, California 94550 for the United States Department of Energy
under Contract DE-AC04-76DP00789.

Printed December 1983

Printed in the United States of America
Available from
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes
Printed copy: A13
Microfiche copy: A01

FINAL REPORT

SODIUM SOLAR RECEIVER EXPERIMENT

OCTOBER 1, 1982

Rockwell International

Energy Systems Group
8900 De Soto Avenue
Canoga Park, California 91304

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1.0 INTRODUCTION AND SUMMARY

The test of a company-funded, sodium-cooled receiver panel was successfully conducted during the period from October 10, 1981, through March 12, 1982. Testing was accomplished at the Sandia Central Receiver Test Facility (CRTF) in Albuquerque under a test agreement between the Energy Systems Group (ESG) and Sandia. The test panel was connected to a sodium flow loop supplied by CRTF. Figure 1 shows the ESG receiver during a test at CRTF.

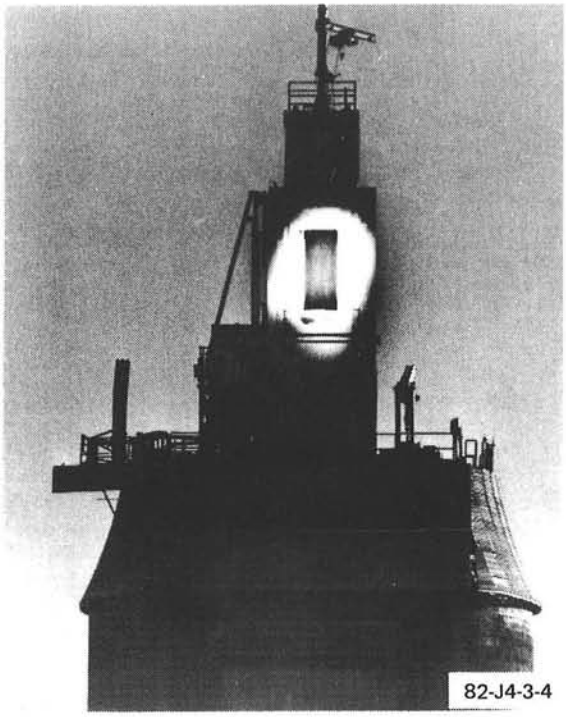

Figure 1. ESG Sodium-Cooled Solar Receiver Panel Test

The general objectives of this test were to provide:

1) A proof-of-principle test of sodium-cooled receiver panels
2) Fabrication experience
3) Practical operating experience.

The specific test goals that supported these objectives were to:

1) Demonstrate satisfactory panel operations at the design heat flux and temperature
2) Demonstrate satisfactory diurnal startup and shutdown
3) Demonstrate control during insolation changes
4) Control several panels in parallel
5) Demonstrate panel dimensional stability
6) Achieve representative lateral power distributions
7) Demonstrate acceptable panel thermal losses
8) Accommodate various simulated emergency conditions.

The solar receiver was the only sodium component for a solar central receiver system that lacked development and test experience. This test provided the development experience leading to a commercial-type receiver panel.

1.1 PANEL DESCRIPTION

The ESG solar panel (Figure 2) consists of three subpanels operating in parallel. Each subpanel comprises 21 Type 316 stainless steel tubes, each 19 mm (3/4 in.) in diameter with a 1.2-mm (0.049-in.) wall. The tubes are butt-welded to 102-mm (4-in.) manifolds. The overall width of a subpanel is 40 cm (15.75 in.) with an overall length including manifolds of about 530 cm (208.5 in.). The three subpanels are assembled on a test frame with the center manifold nestled in the tube bend region of the outer panels (Figure 3).

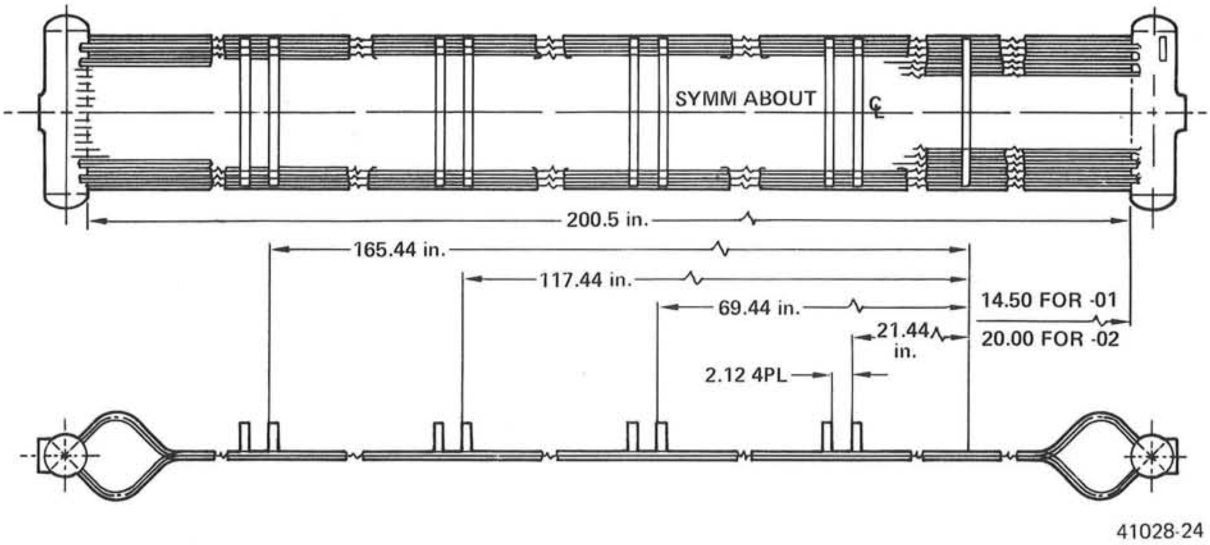

Figure 2. ESG Central Receiver Panel Design

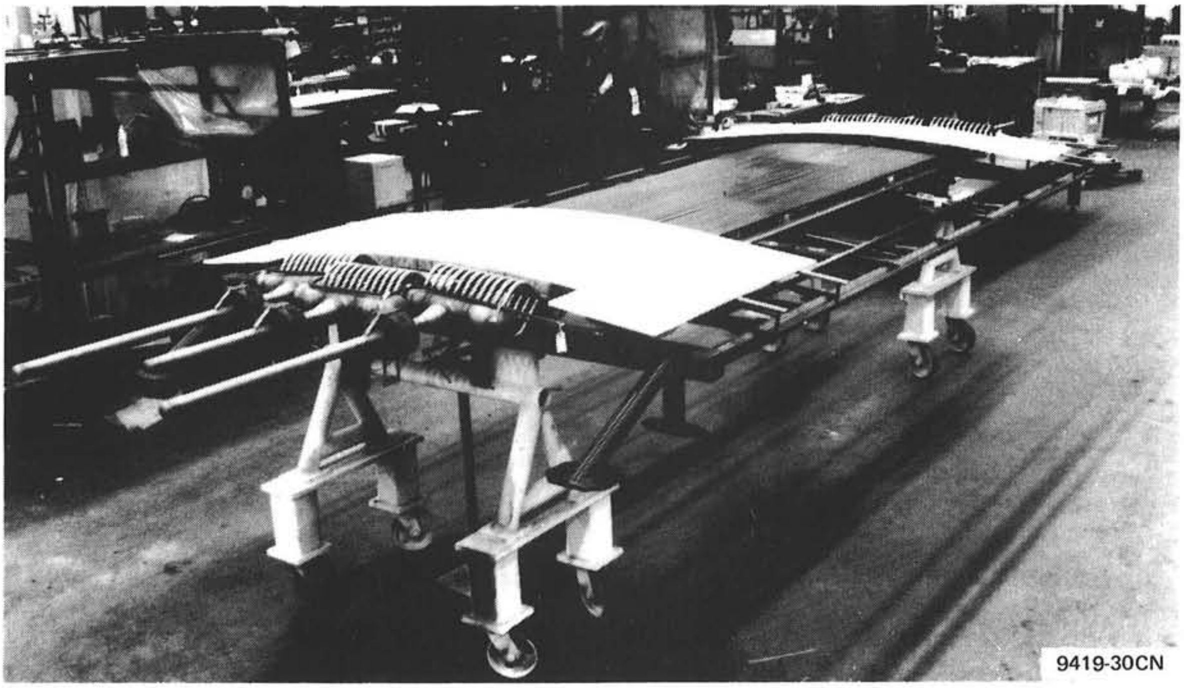

Figure 3. ESG Solar Panel as Assembled for Shipment to CRTF

This arrangement provides a continuous panel surface. The surface is curved on a radius of about 6 m to represent a segment of an external receiver for a repowering application. Figure 3 shows the completed test panel in the ESG manufacturing area.

The active aperture area of the panel exposed to solar radiant energy is 3 m high by 1.2 m wide. This area is surrounded by an insulated frame to protect the subpanel manifold ends and side areas of the loop from spillage energy. The active area of the panel is covered by Pyromark paint to enhance the absorptivity of the surface. The design absorbed-power capability of each panel is 1 MWt, for a total of 3 MWt for the test article. The operating power of 2.5 MWt was selected based on the expected heat rejection capability of the sodium loop.

Peak design absorbed heat flux for the test was 1.5 MWt/m^2. The average flux level over the panel at the operating power of 2.5 MWt was 0.69 MWt/m^2.

The instrumentation on the solar panel consists of 57 thermocouples, three displacement transducers, and three heat flux sensors. Each subpanel has an electromagnetic flowmeter to measure flow rate and a flow control valve. The flow control valve can be operated manually or automatically by the flow control system. The control system contains the controllers, switches, indicators, and logic to control subpanel flow rate.

The primary control requirement is to maintain the panel outlet sodium temperature for each subpanel at the set-point value. For the design conditions, this value is 593 ± 14°C (1100 ± 25°F) with an inlet temperature of 288°C (550°F). Since there is a direct relationship between the solar flux available to the panel and the flow required to achieve a given set of operating conditions, solar flux is used as the primary master signal in a feed-forward configuration. Panel exit sodium temperature is then processed through a controller and used as a trim to this master. The resulting summed signal is then used to modulate the sodium inlet valve position.

Extensive thermal and structural analyses were performed on the test design. The panel is designed to ASME Section VIII Division 1 and ANSI B31.1 with creep fatigue effects for the tubes evaluated according to the high-temperature Code Case ASME N-47. The design meets the specific test conditions and safety requirements imposed by CRTF on test articles for that facility. In addition, the panel tubes in the high-flux region were analyzed for commercial application with a reasonable expectation for a 30-year life.

1.2 SODIUM LOOP DESCRIPTION

The ESG test article was connected to a CRTF-installed sodium loop. A flow schematic for the sodium loop is shown in Figure 4. Sodium circulation through the test panel is provided by an electromagnetic (EM) pump at a design flow rate of 0.007 m^3/s (115 gal/min).

Liquid sodium enters the test panel at a temperature of 288^{0}C (550^{0}F) and under normal operation exits at a temperature of 593^{0}C (1100^{0}F). A flow-through surge tank is provided to accommodate changes in sodium volume in the system. Argon cover gas is provided in the surge and drain tanks. The sodium is cooled by the dump heat exchanger (DHX) from 593^{0}C (1100^{0}F) nominal temperature to 288^{0}C (550^{0}F) before circulating back to the EM pump. The heat removal capability of the DHX can be changed by varying the airflow through the unit.

At night, the sodium in the loop is drained into the drain tank, where it is maintained by the electrical heat tracing at a temperature of 204^{0}C (400^{0}F). All sodium piping in the system is heat traced, insulated, and maintained at a temperature of $\sim$204^{0}C (400^{0}F) throughout the night. The aperture area of the test panel is allowed to cool to ambient conditions.

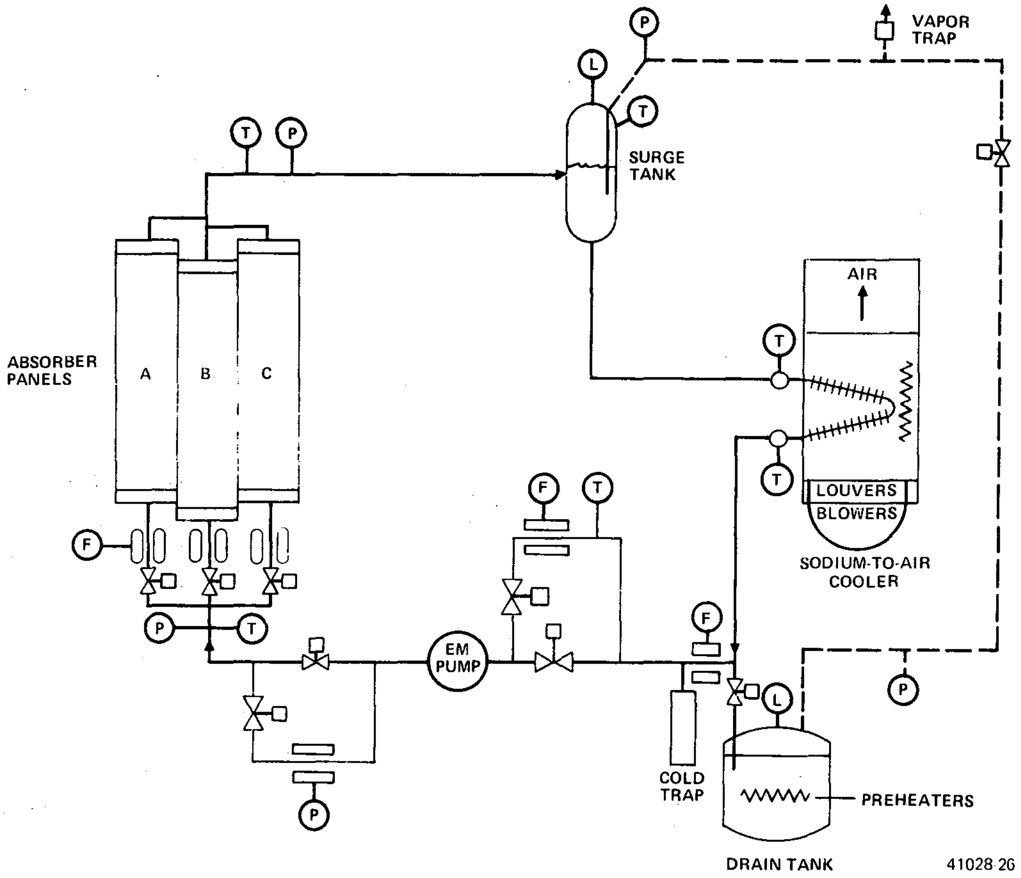

Figure 4. Flow Schematic for Sodium Loop at CRTF

1.3 TEST DESCRIPTION

The test activity for the ESG solar panel comprised the following phases:

1) Dry checkout
2) Wet checkout
3) Testing
    a) Low power
    b) Intermediate power
    c) Design power.

The checkout tests, completed during October 1981, consisted of functional checkout of the mechanical, electrical, and instrumentation items in the system. About 200 gal of liquid sodium from 55-gal drums was loaded into the loop drain tank. Testing began on 30 October 1981.

The low- and the intermediate-power tests were conducted primarily to give the sodium system operating crew experience with the manual and automatic controls and in coordinating these activities with heliostat operation. Once this operating experience had been attained, the majority of the testing was accomplished at the design power conditions. Testing ended on 12 March 1982, 4-1/2 months after it had begun and with a total of 70 h of test time. All operational and performance goals were attained. The accumulation of test time during this period was substantially reduced by the poor weather and the necessity for frequent repair of the facility-installed high-temperature insulation around the test panel.

The test panel was drained of sodium each night and at any time that there was insufficient solar energy to maintain the solar-heated panel surface at a temperature of $204^{o}C$ ($400^{o}F$). The daily schedule was as follows:

1) Pretest briefing and safety review
2) Maintenance review
3) Panel preheat (four heliostats)
4) Pressure fill of system with sodium
5) Sodium flow and power buildup
6) Test activities
7) Decreasing power and shutdown
8) Sodium drain to drain tank
9) Activation of electrical preheat.

Table 1 compares the significant goals achieved during this test program with the design goals.

TABLE 1

MAJOR TEST RESULTS

Parameter	Test	Design
Power level (MWt)	2.85	2.5
Maximum solar flux (MW/m^2)	1.53	1.5
Panel inlet temperature (^oF)	550	550
Panel outlet temperature (^oF)	1100	1100
Time, start to full power (min)	29	30
Automatic control	Stable at 1100^{o}F with -40%, +70% power changes	Stable at 1100^{o}F with -50%, +100% power changes
Daily startup and drain	Satisfactory	Planned operation

The maximum power level was expected to be limited by the capability of the air-blast heat exchanger associated with the sodium loop. Maximum-power testing was restricted even more when it was discovered that the maximum pump flow rate was limited essentially to the design flow rate of ∿115 gal/min.

Figure 5 shows the panel flux gage readings during a short-duration test. One flux gage was located in the center of each of the test panels. The flux gage on Panel A had not been adjusted properly and, when corrected, indicated values similar to those indicated by the gage on Panel C. The figure also shows the durations for the several phases of the startup activity. The total time from the initiation of panel preheat with four heliostats to design power (in this case, 175 heliostats on target) was 29 min. During this test, the facility high-temperature insulation deteriorated, and the test was terminated by removing the heliostats and draining the sodium system. Shutdown required 6 min, after which the sodium system was secured until the next test.

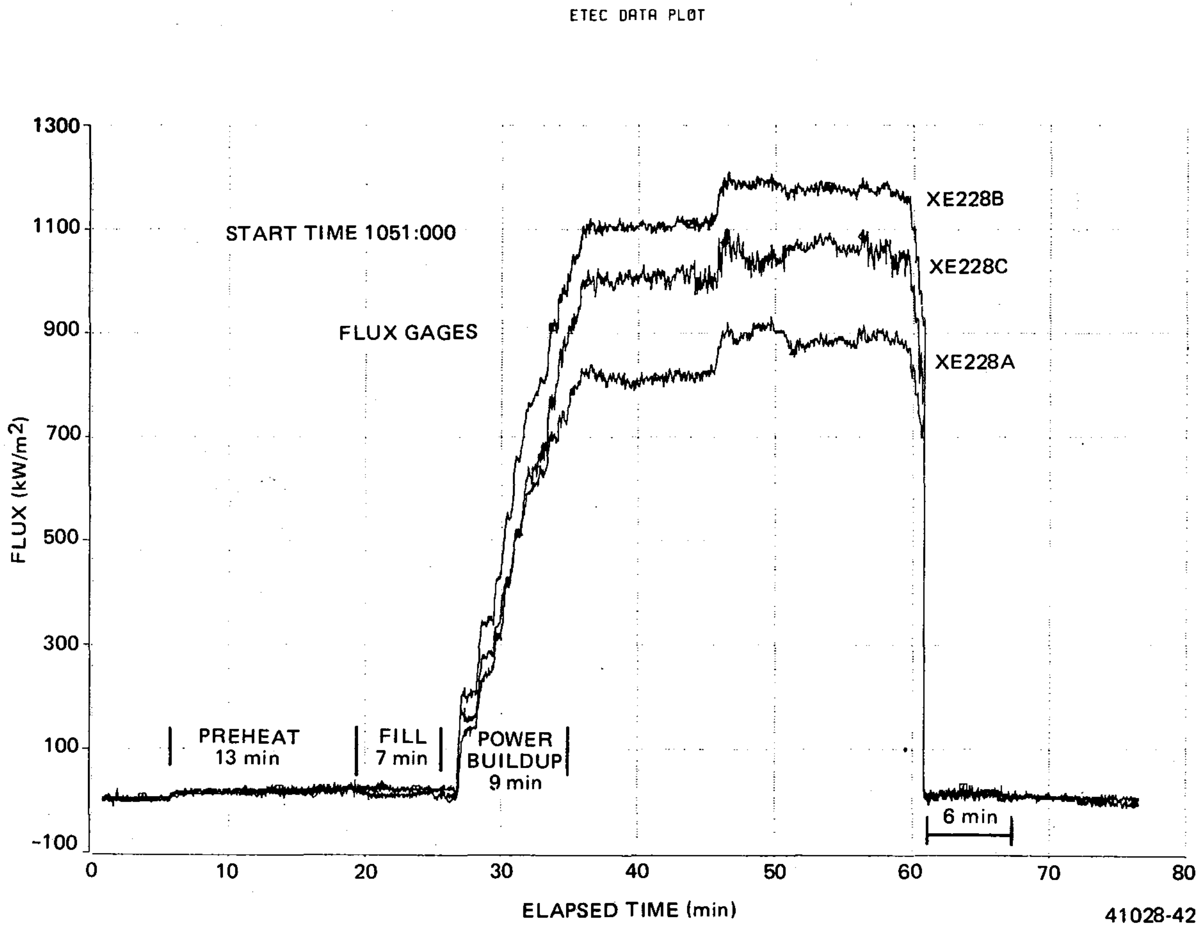

Figure 5. Test 19, Panel Flux Gage Readings

Some flow-rate interaction among the three panels was observed during the testing. This interaction was not unexpected, since the panels had been designed with a very low pressure drop in order to maximize the total loop flow rate in case of inadequate pump power (as was the case). This flow-rate interaction caused panel outlet temperature to vary about ±30°F.

Figure 6 shows the response of the panel control system to a downward power step of 40% achieved by removing a preselected group of heliostats. This step lasted 7 s. After a brief dwell time, the preselected group of heliostats was returned to the panel in 15 s to give a 70% step up in power from the reduced power level. The control system responded with valve position closely following within about 6 s the shape of the flux sensor

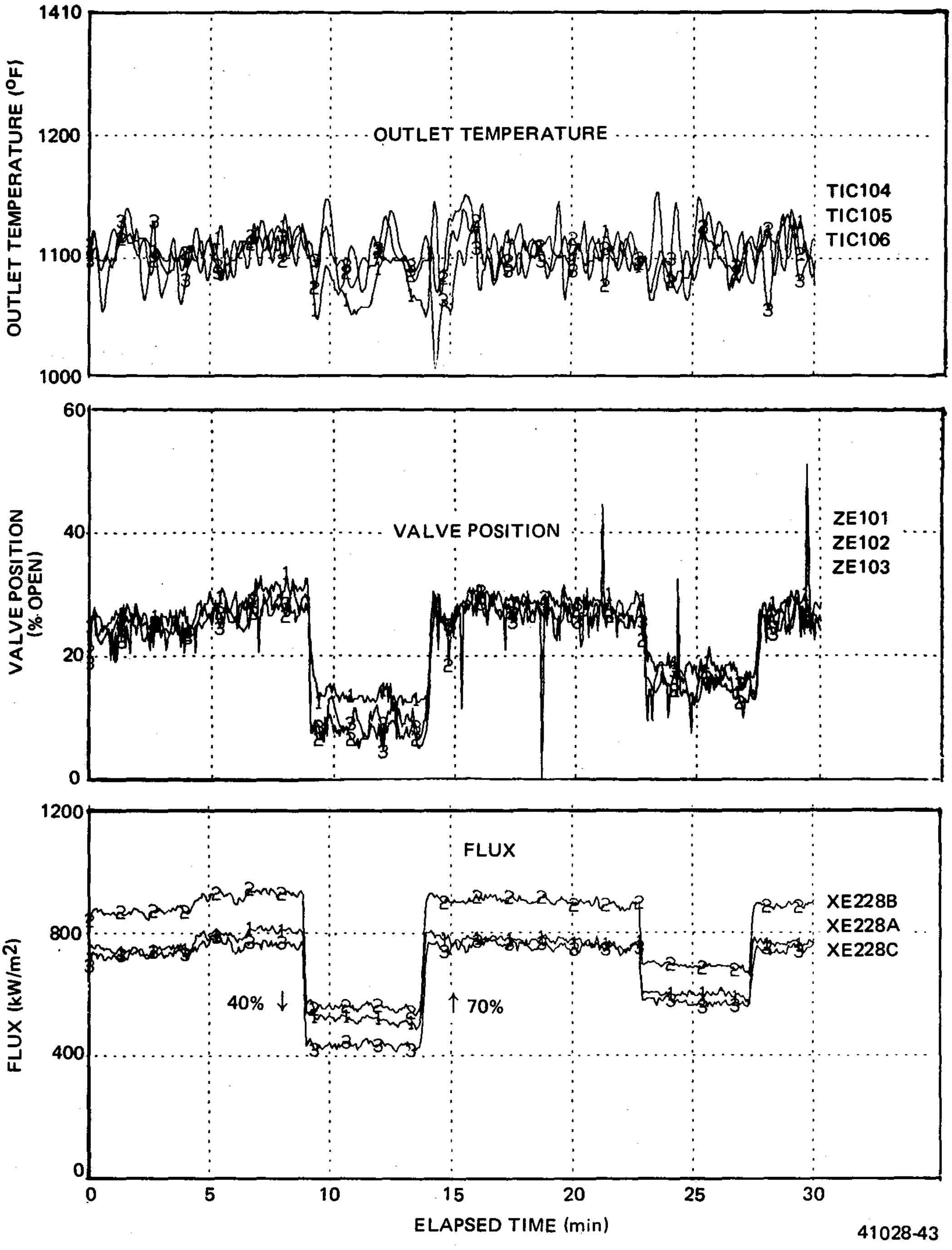

Figure 6. Test 24, Power Steps

trace, indicating the controlling action of the flux sensor feed-forward signal. The set-point temperature of $1100^{o}F$ was maintained within $\pm 50^{o}F$ for each panel and with $\pm 30^{o}F$ for the mixed mean outlet temperature given in Figure 7. An excursion outside the $\pm 50^{o}F$ band for panel C is seen following the 70% flux increase. Some of the variation in outlet temperature was due to the variation in inlet temperature caused by the relatively poor DHX control capability for these power transients. The outlet temperature trace of Figure 7 also shows the cyclical variation due to flow interaction. Also shown in this figure is a 20% power step.

Before the test, a flux distribution with a rather flat maximum across the center of the panel was requested, as in Figure 8. The data points indicated on this figure show an actual distribution attained at the several nominal power levels for the test. The desired flux shapes gave power distributions across the edge panels that were typical of distributions on a full-size commercial receiver. The actual test distribution, while showing a greater variation than desired, was well within the capability of the test panel design.

Black Pyromark paint was used on the surface of the panel to enhance absorptivity. The paint tended to flake and lose adhesion, and the central and upper parts of the panel had to be repainted three times during the test.

One of the most interesting parameters to be determined from a receiver panel test is panel efficiency. This value is also difficult to determine with accuracy, since it is the ratio of absorbed power to incident power. Both absorbed power and incident power are calculated values. The absorbed power is calculated from the measured flow rate and the temperature difference from the bottom to top of the panel. Input power is determined from the CRTF flux measuring system by integrating the flux distribution over the panel area. A CRTF computer program was used to calculate a transfer function value of 1.02 in order to relate the flux distribution measured in a plane 14 in. in front of the panel to the distribution at the panel surface. The calculated

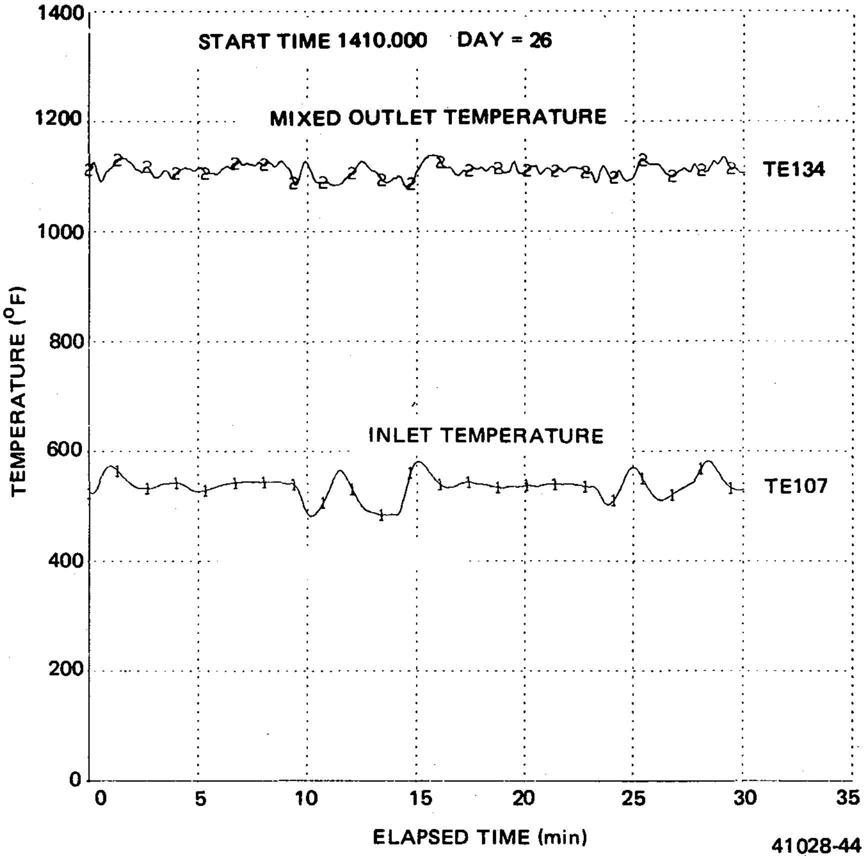

Figure 7. Test 24, Panel Inlet and Outlet Temperatures

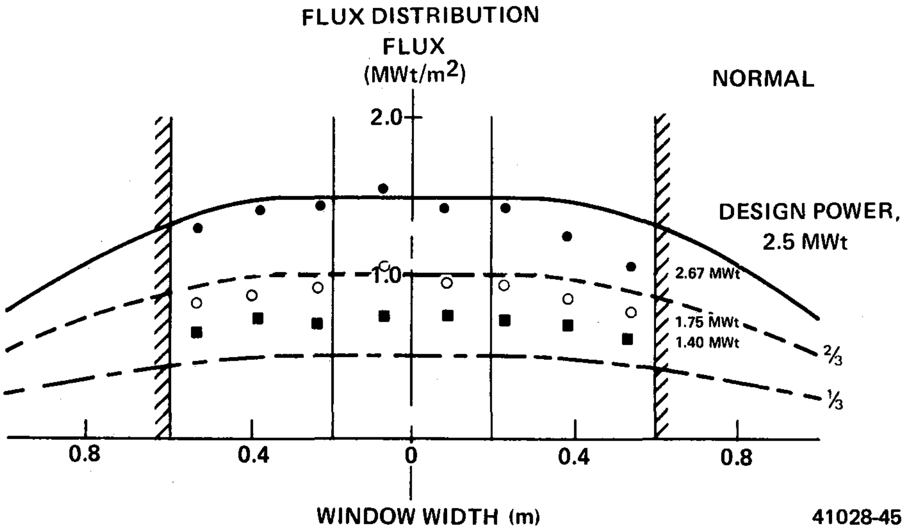

Figure 8. Heat Flux for Normal Flux Distribution (Two-Point Aim)

panel efficiency for several power levels is given in Table 2. Panel efficiencies in the range of 90 to 93% were expected. The estimated uncertainty in the calculated values is shown in Table 2.

TABLE 2

INCIDENT POWER AND ABSORBED POWER

Test	Flux Scan	Time	Number of Helio-stats	Peak Flux (MW/m^2)	Total Power From Field (MW)	Incident Power on Panel (MW)	Panel Power (MW)	Effi-ciency (%)
18	I35501	1018	110	0.71	2.10	1.33 ± 8%	1.26 ± 6%	94 ± 10%
	I35502	1217	110	0.84	2.34	1.56	1.40	90
	035503	1400	158	0.98	2.9	1.89	1.75	93
21	I01401	1200	173	1.27	3.7	2.48	2.36	95
22	I01501	1330	183	1.32	3.74	2.47	2.31	93
	I01502	1350	188	1.34	3.81	2.48	2.29	92
23	I01801	1309	213	1.53	4.39	2.89	2.67	92
24	I02601	1216	175	1.33	3.51	2.35	2.26	95
34	I06901	1145	161	1.32	3.53	2.35	2.25	96

1.4 SUMMARY

1) The panel test was successful and all significant goals and objectives were attained, although the accumulated test time was much less than expected. The low test time was due to poor weather conditions during the test period from October into March. Also contributing was the continuing problem of deterioration of the frame insulation around the panel due to the relatively high spillage flux.

2) Solar preheat and sodium fill occurred for each test. The panel headers were preheated during the entire test period, but the panel aperture surface cooled to ambient temperature between each test. The panel was drained at the end of the test day. This environment does not appear to have been deleterious for the test period.
3) The backside insulation, Cerafelt 600, was satisfactory. There is no evidence of over-temperature or damage to the backside insulation material.
4) Adequate preheat must be assured prior to fill.
5) The test panel tube material is 316 SS. The heated area of the test panel was designed for 10,000 cycles at a peak flux of 1.5 MWt/m^2. This is about one cycle daily over a 30-year period. The panel header region was designed for the test period duration. The commercial panel should be designed for several daily cycles or, say, 30,000 to 50,000 cycles for a 30-year life. The commercial design will have the headers located behind the panel. This desirable feature will accommodate more effectively any temperature gradients across the panel.

1.5 RECOMMENDATIONS

1) A detailed stress analysis must be performed to evaluate the panel design for a 30-year life and the commercial receiver operating characteristics.
2) The Pyromark paint on the panel aperature surface required frequent replacement. The manufacturer should be contacted in order to identify the probable cause of the paint problems during this test. Other surface coatings should be examined. The testing at Barstow of the water/steam receiver should be monitored to determine paint durability.

3) On early commercial receivers, thermocouples on each tube may be desirable in order to verify acceptable preheat conditions by monitoring tube temperatures during the power buildup phase.

2.0 SOLAR RECEIVER PANEL DESCRIPTION

2.1 GENERAL

The ESG solar panel consists of three subpanels operating in parallel, mounted on a test fixture. The test fixture is attached to the CRTF sodium loop structure. Figure 9 shows an artist's concept of the test fixture and sodium loop on top of the tower at the Central Receiver Test Facility (CRTF). The solar panel test requirements are identified in Appendix A. Panel design requirements are summarized in Table 3.

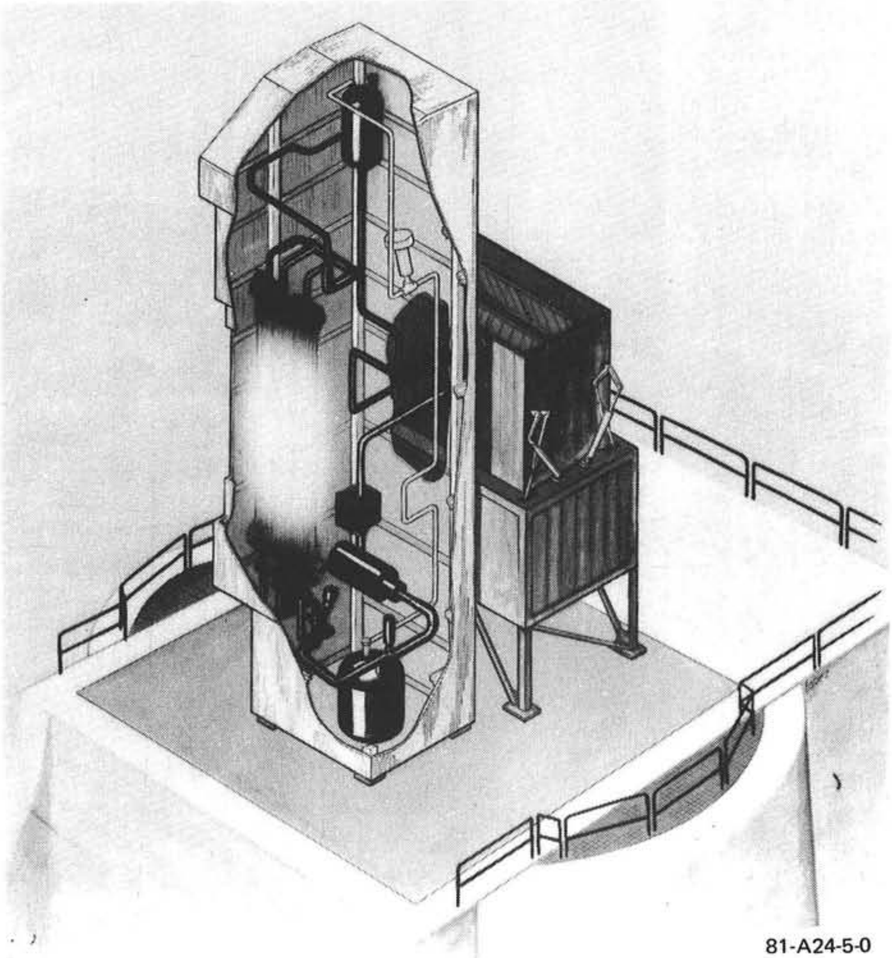

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Figure 9. ESG Sodium-Cooled
Solar Receiver Panel Test

TABLE 3

TEST PANEL REQUIREMENTS

Environmental	
Seismic (g)	0.50
Design wind,(mph)	10
Maximum operating wind (mph)	50
Maximum survival wind (mph)	100
Ambient temperature range (^{o}F)	-20 to +120
Cloud cover velocity (mph)	40
Maximum rainfall (in./h and in./yr)	3 and 30
Ice formation (in.)	5.0
Maximum hailstone size (in.)	1.0
Panel Life	
Test article life (month)	3.0
Commercial panel design life (yr)	30
Design number of startups and shutdowns	10^4
Temperature loss rate of hot but unheated and uncooled panel (^{o}F/s)	3.0
Maximum temperature transient at upper manifold weld	550^{o}F in 10 s
Maximum sodium flow rate (gal/min)	175
Maximum panel inlet pressure (psia)	40
Panel tube OD and wall (in.)	3/4 x 0.049
Panel material	316 SS
Design	Like commercial panel
Applicable codes	
Panel	ASME B&PV Sec. VIII Div. 1
Tube creep-fatigue	ASME B&PV Sec. III, modified Code Case 1592, ANSI B31.1
Temperatures (^{o}F)	
Inlet temperature	550 to 700
Minimum loop	350
Nominal mixed mean outlet	1100
Maximum tube outlet temperature difference in one panel	200
Maximum ΔT adjacent tubes in adjacent panels	200
Maximum absorbed thermal power (MWt)	3.0
Maximum throughput heat flux (MWt/m^2)	1.5

2.2 PANEL DESIGN

A sketch of the subpanel design is given in Figure 10. (See Assembly Drawing N001000399, Appendix F.) The subpanels are composed of 21 Type 316H stainless steel tubes (ASTM A213), each 3/4 in. in diameter with a 0.049-in. wall. The tubes are butt-welded to 4-in. manifolds as shown in Figure 11. The manifolds are constructed as shown by Figure 12. (See Drawing N001000429, Appendix F.) After the 4-in. manifolds are assembled from a tee, pipe sections, and end caps, two slots are cut for the two nozzle inserts. The inserts are welded into the manifold body. A consumable insert is used in assembling the tube to the nozzle in order to align the joint and to supply metal for the butt weld joint. The overall width of a subpanel is 40 cm (15.75 in.) with an overall length including manifolds of about 530 cm (208.5 in.). The three subpanels are assembled on a test frame with the center manifold nestled in the tube bend region of the outer subpanels (Figure 13). This arrangement provides a continuous panel surface. The surface is curved on a radius of about 6 m to represent a segment of an external receiver for a repowering application. Figure 13 shows the completed test panel in the ESG manufacturing area. Figure 14 shows the back side of the panel and test fixture. (See Drawings N001000397 and N001000426 in Appendix F.)

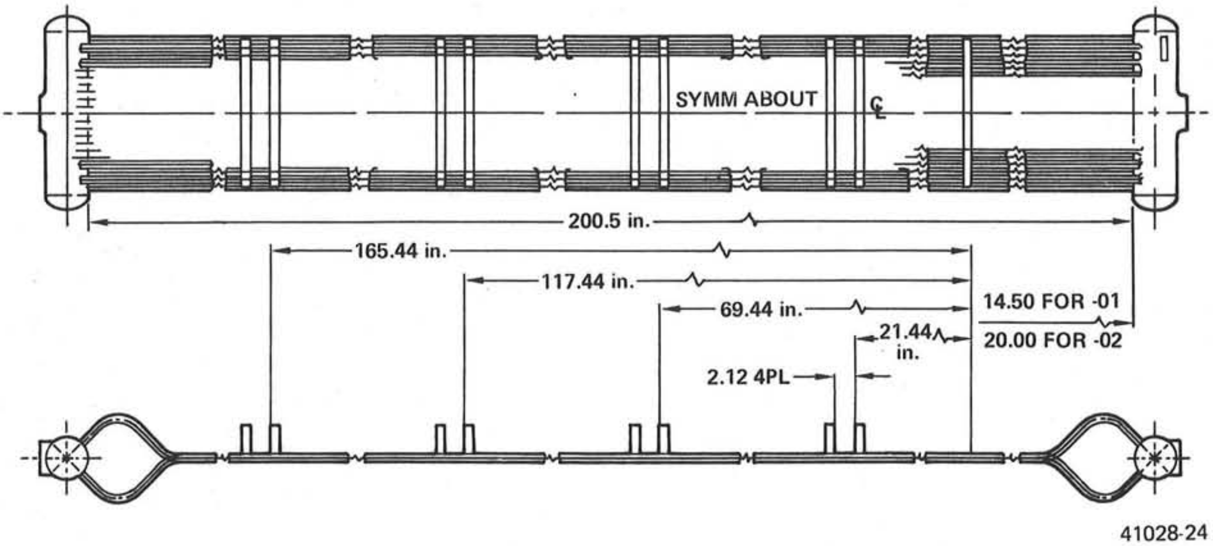

Figure 10. ESG Central Receiver Panel Design

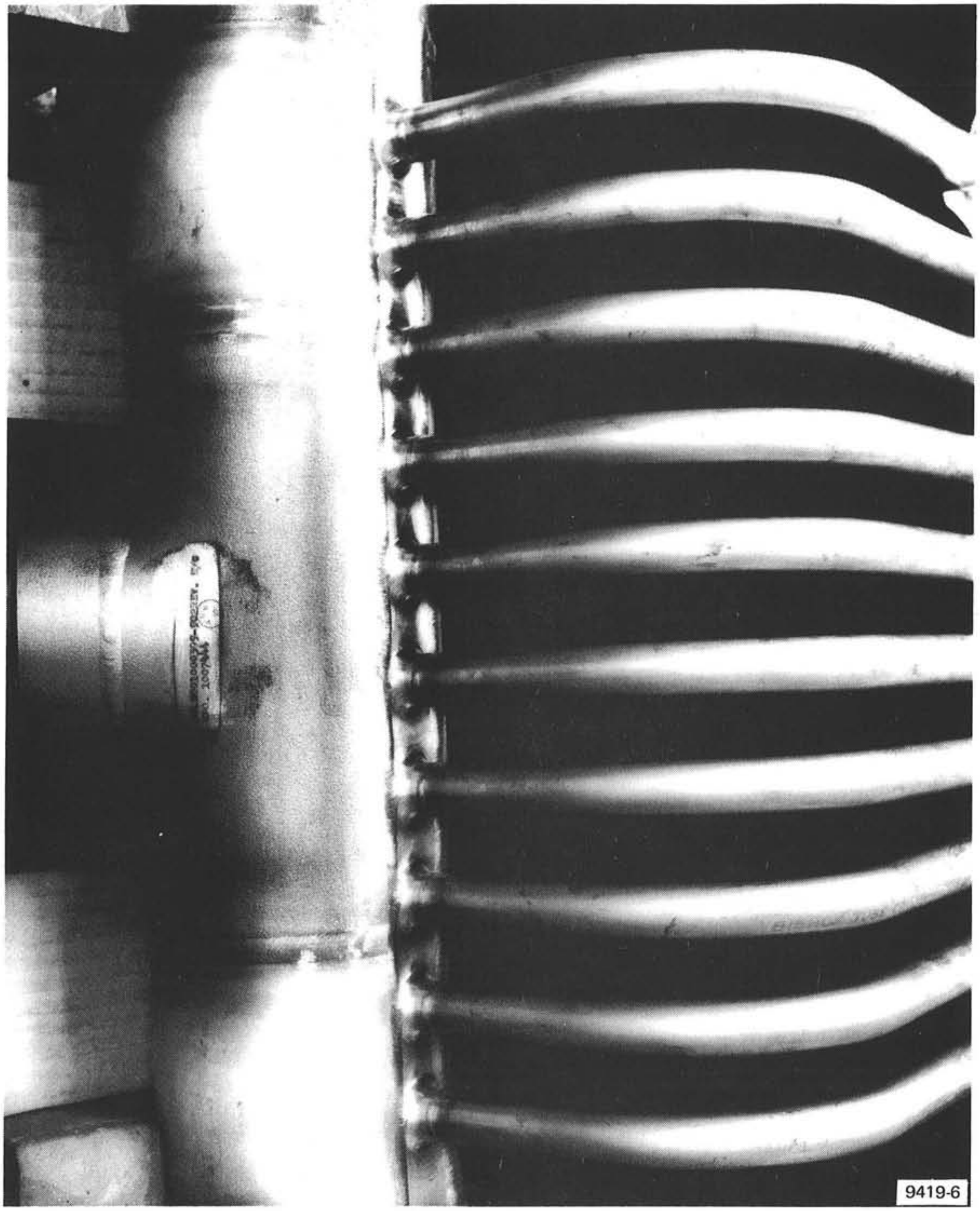

Figure 11. Tube-to-Manifold Butt-Weld Assembly

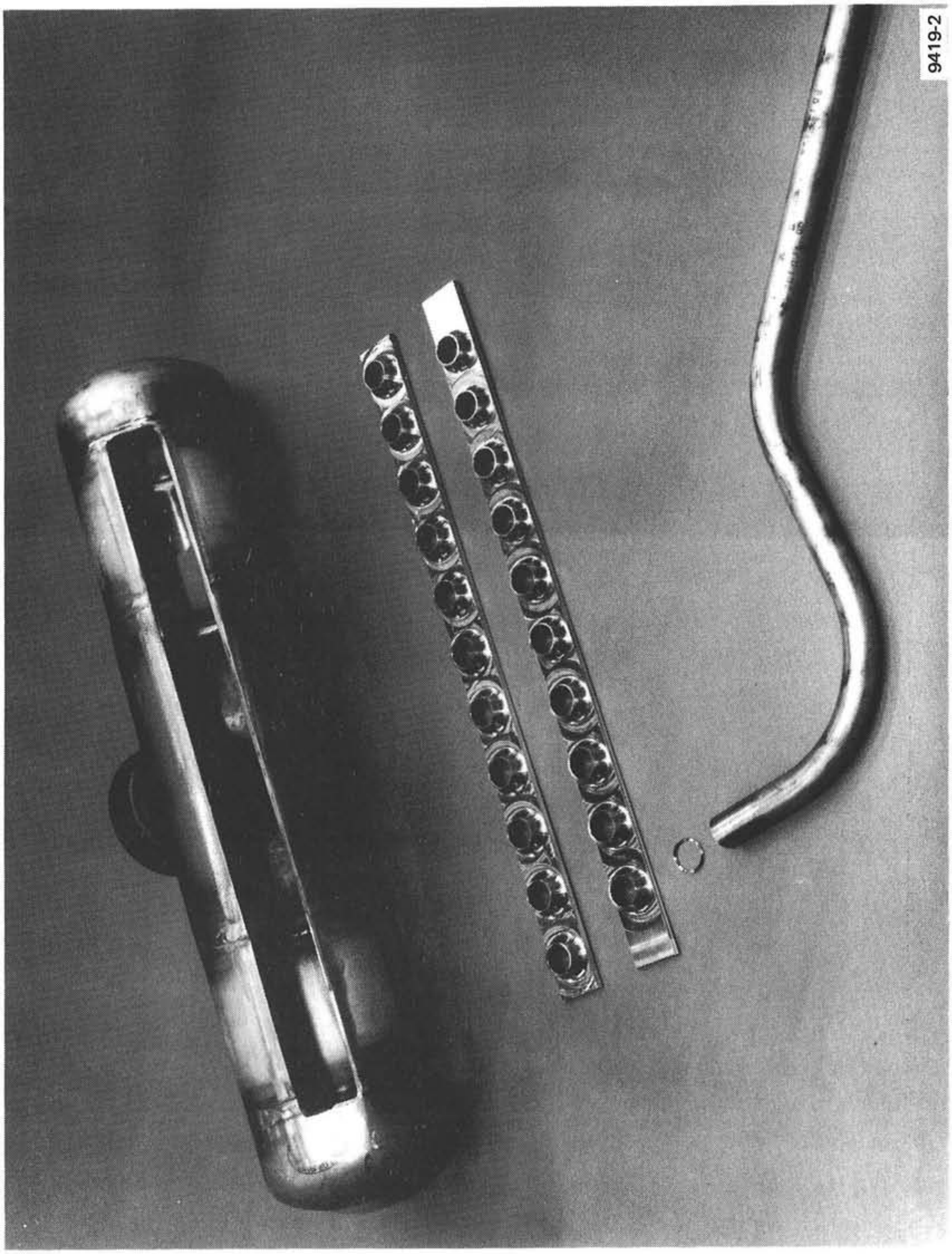

Figure 12. Manifold Construction

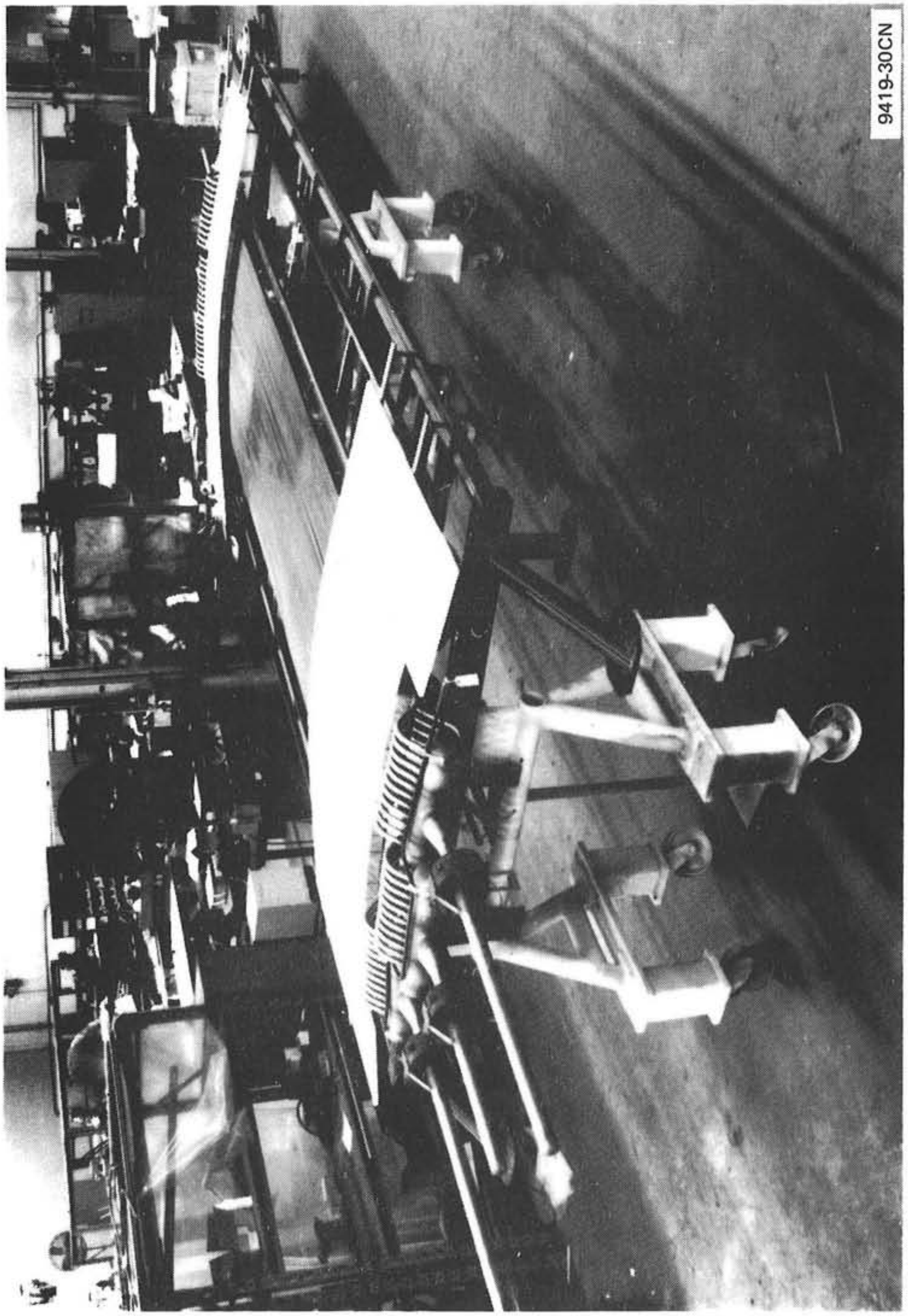

Figure 13. ESG Solar Panel as Assembled for Shipment to CRTF

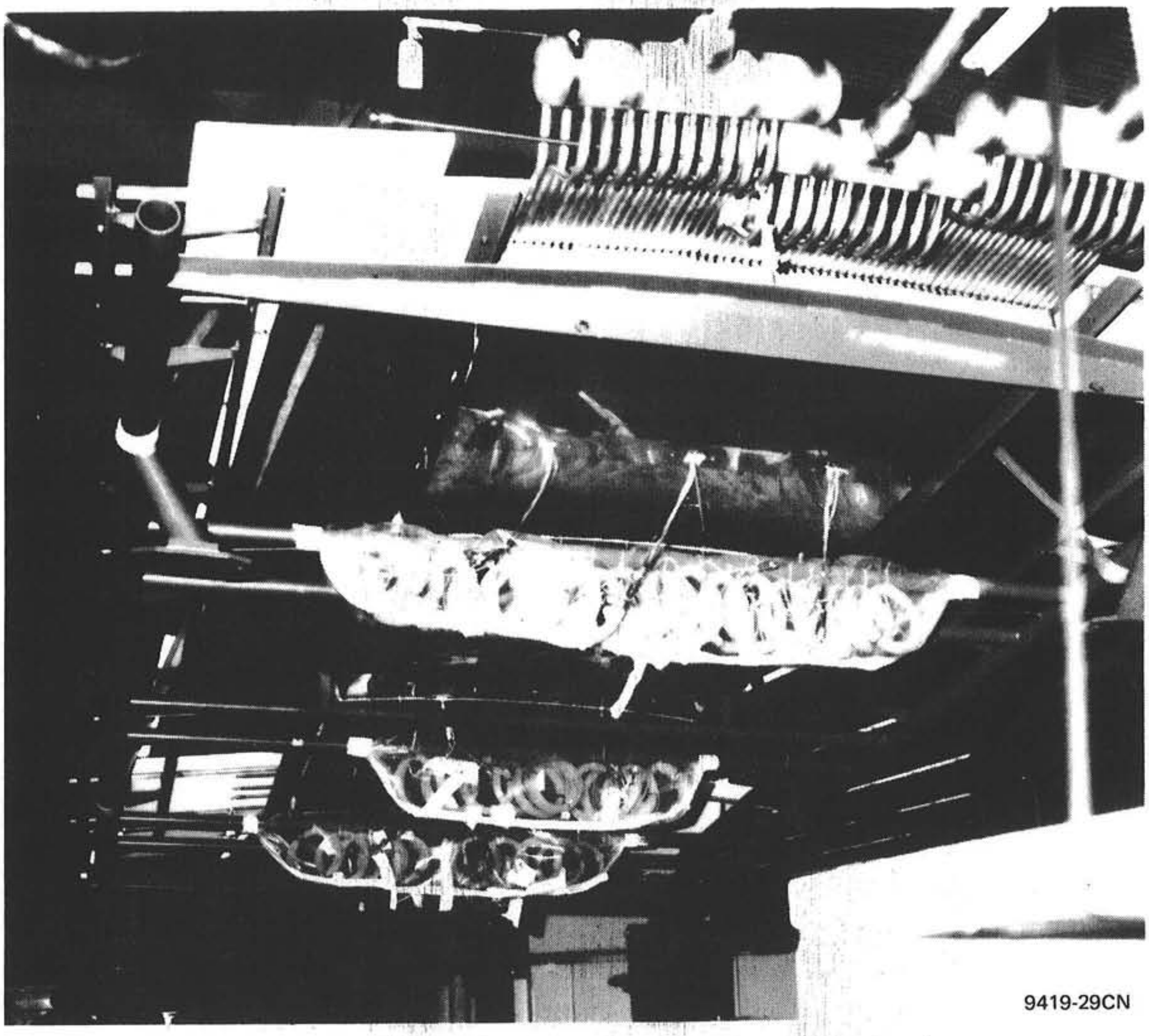

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Figure 14. Panel Assembly Structural Support

The active frontal area of the panel exposed to solar radiant energy is 3 m high by 1.2 m wide. This area is surrounded by an insulated frame to protect the subpanel manifold ends and the side areas of the loop from spillage energy. The active area of the panel is covered by Pyromark paint to enhance the absorptivity of the surface. The design absorbed-power capability of each panel is 1 MWt, for a total of 3 MWt for the test article, as described in Section 3.2. The panel subassembly (three panels) weighs about 500 lb.

2.3 SOLAR PANEL TEST FIXTURE

The test fixture serves the dual purpose of supporting the solar panel and as a structural mount for attachment to the sodium loop test structure. The fixture has a vertical height of ∿200 in. and a width of 108 in. Structural support is derived from use of a 4-in.-square box beam for the fixture's lower base, 3.0-in. by 0.250-in. wall tubing for the vertical side, and 2.0-in. by 0.250-in. wall tubing for the horizontal cross supports. Structural carbon steel is used throughout the text fixture. The cross members supporting the panels are curved to an approximate radius of 19 ft, the same as would be used in a commercial 226-MWt solar receiver application (60-MWe plant size). The fixture weighs ∿830 lb.

2.4 SOLAR PANEL-TO-TEST FIXTURE ASSEMBLY

The three subpanels are assembled on the face of the test fixture as shown in Figure 13. This assembly completes the solar panel test article (weight, 1575 lb). The hot- and cold-leg piping tree subassemblies, shown in Figures 15 and 16, are used to connect the test article to the sodium loop. The lower cold-leg piping tree contains the flow control valves for each panel.

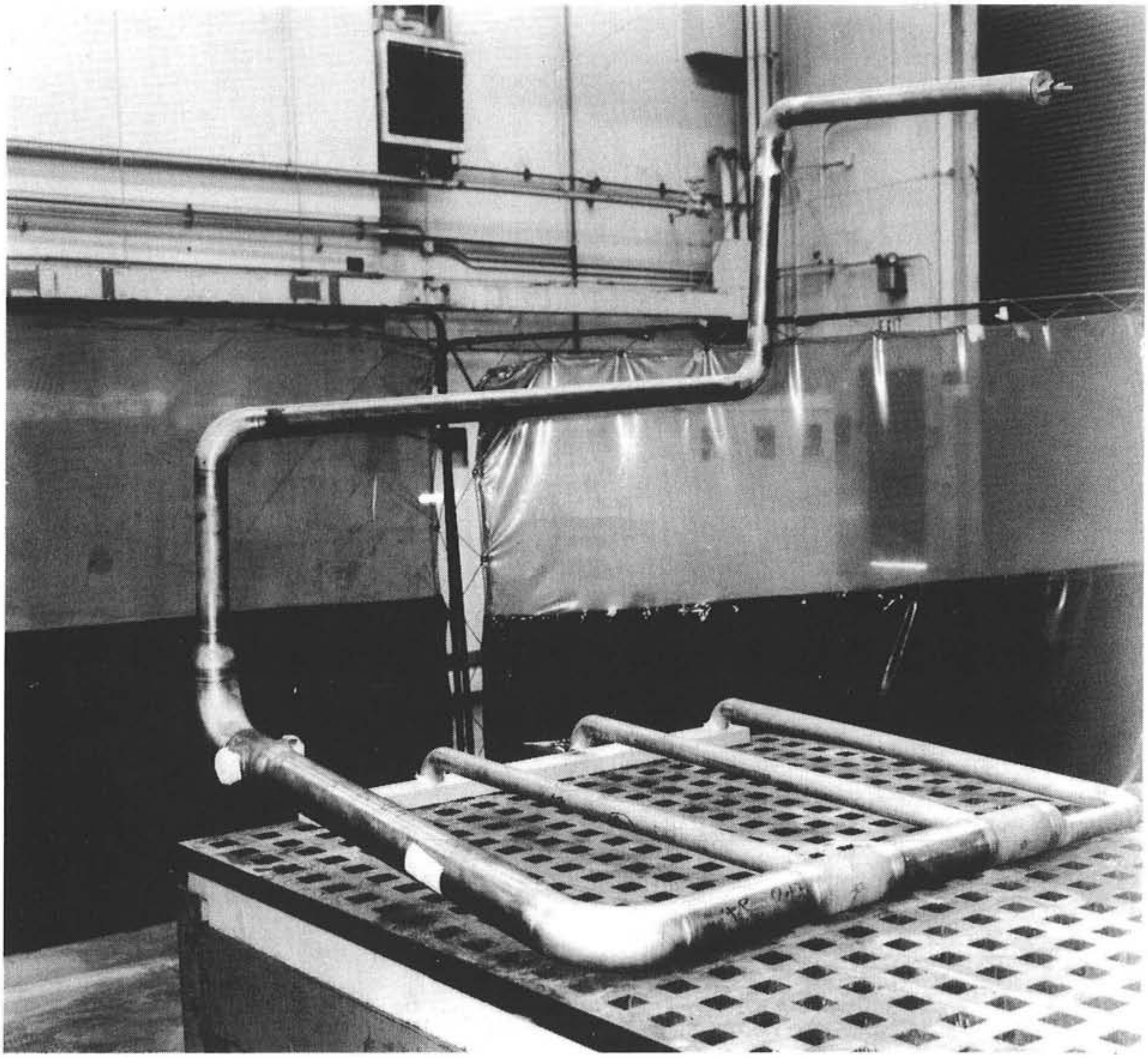


Figure 15. Hot-Leg Pipe Tree Assembly

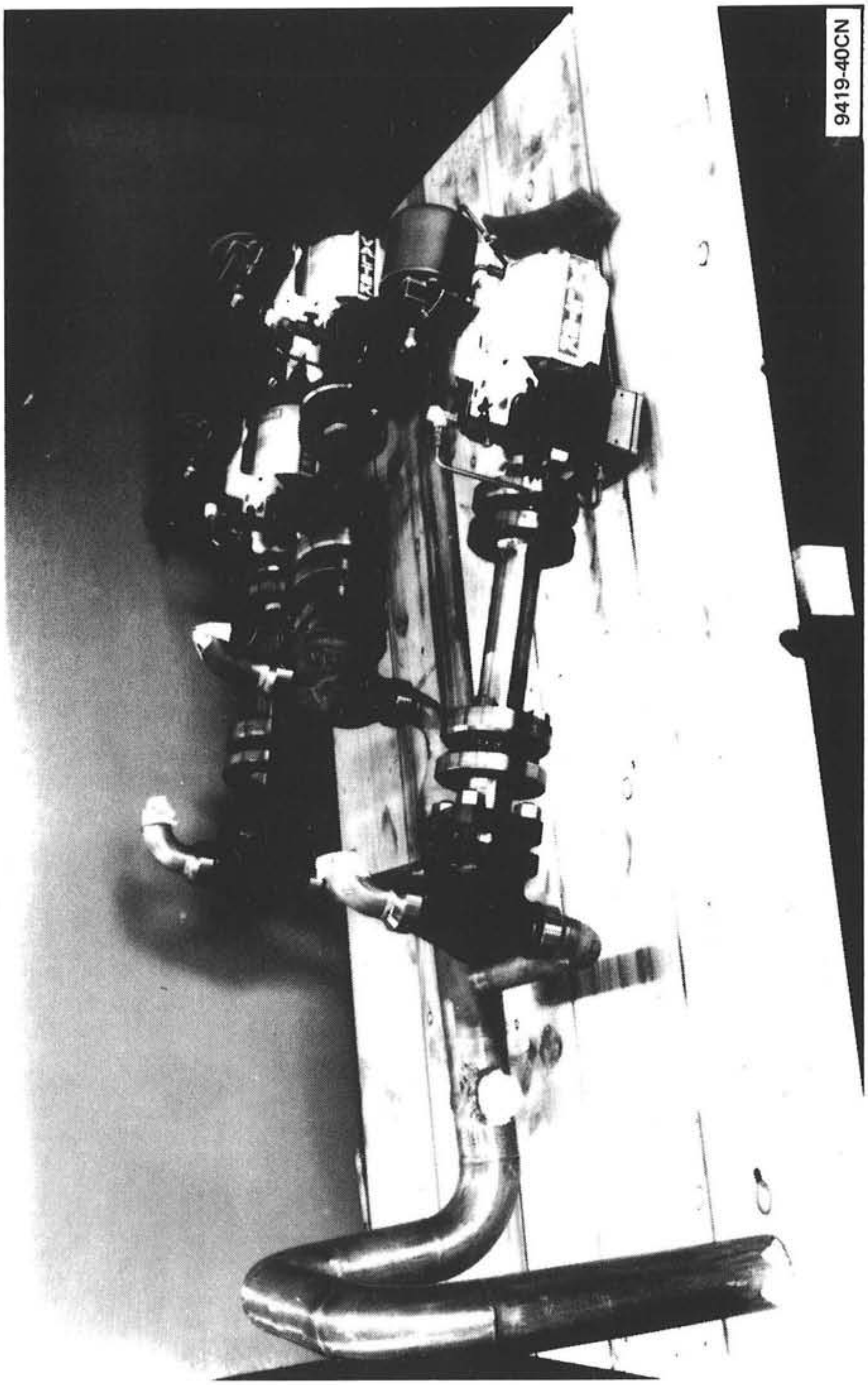


Figure 16. Cold-Leg Pipe Tree Assembly

2.5 DESIGN VERIFICATION

Extensive thermal and structural analyses were performed on the test design. The panel is designed to ASME Section VIII Division 1 and ANSI B31.1 with creep fatigue effects for the tubes evaluated according to the high-temperature Code Case ASME N-47. The design meets the specific test conditions and safety requirements imposed by CRTF on test articles for that facility. In addition, the panel tubes in the high-flux region were analyzed for commercial application with a reasonable expectation for a 30-year life.

2.5.1 Stress Analysis

A stress analysis of the solar test panel was performed. Strain-controlled stresses in the tubes under the most severe heat flux were evaluated and cyclic life was determined. Stresses in the panel and the supports due to thermal, seismic, and wind loadings were studied. Calculations indicate a tube life of 30 years. Load-controlled stresses were shown to be generally low in the tube supports. The effects of thermal striping were determined to be of negligible consequence.

A laboratory testing program was conducted to select the mechanical support-to-tube attachment weld design. The selected design uses a gas tungsten arc weld (GTAW). The calculated tensile load on each weld joint is 8.9 lb maximum. The laboratory tensile tests at a metal temperature of 900°F resulted in tensile failure loads of 436, 522, and 630 lb for three tests of this weld design. This is a factor of 50 greater than the design load. Failure was in the parent metal of the support for two tests and in the weld material for the third. In the 25 tests for various designs, failure was always in the support material or joint; in no case was there a loss of tube material.

2.5.2 Thermal Analysis

Three sets of transient thermal analyses were made for the solar test panel:

1) Solar panel tube with transient solar heat load and sodium flow: Preliminary thermal transient calculations were made to investigate the consequences of changing solar heat input and changing sodium coolant flow rate. Of particular interest is the transient resulting from loss of solar input due to rapid cloud cover.
2) Panel tube-outlet manifold joint: Calculations were made to investigate the transient temperature distribution at the tube-manifold joint as input for thermal stress analysis.
3) Steady-state, two-dimensional (radial and circumferential) temperature distributions under concentrated solar heat flux loading were determined for 3/4-in.-OD tubes with 65-, 58-, 49-, 35-, and 28-mil walls. A solar heat flux of 1.5 MW/m^2, cosine distributed, was considered, with the sodium inside the tube at 900°F. In addition, simplified stress calculations were made.

Figure 17 shows the theoretical heat flux distributions along the panel length for all collectors aimed at a single point on the panel aperture and for a multipoint aim. Table 4 shows the average thermal conditions within the sodium-cooled receiver at (0.049-in. tube wall) sodium flow rate, total power, and heat flux. Table 5 shows test conditions across the subpanels for a normal flux distribution (0.049-in. tube wall) and for low, intermediate, and 100% power levels.

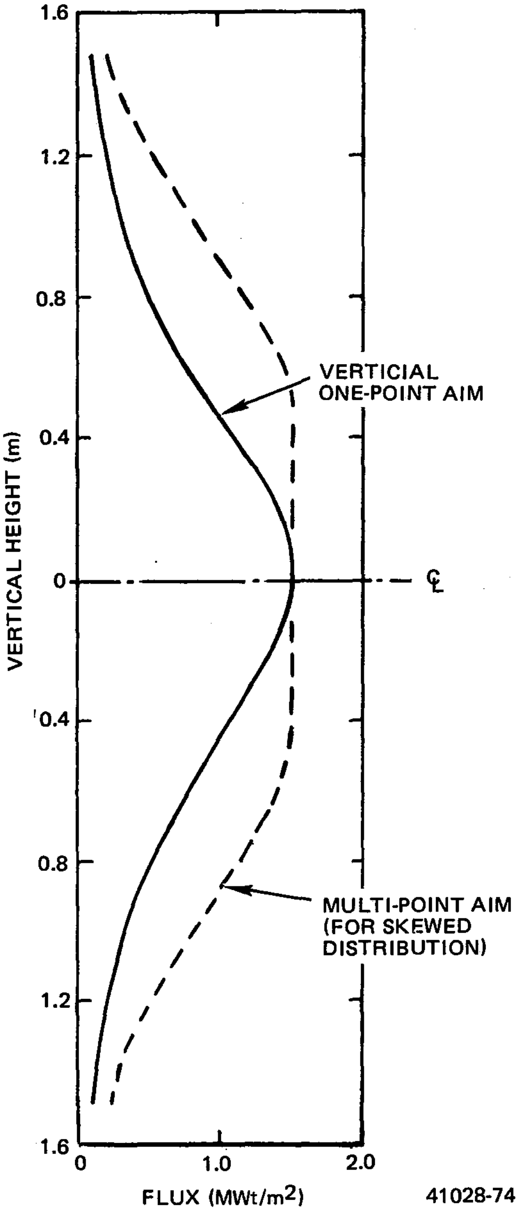


Figure 17. Vertical Flux Distribution
ESG Test Article Panel

TABLE 4

ESG SODIUM-COOLED RECEIVER THERMAL CONDITIONS (CALCULATED PARAMETERS FOR THREE COMBINED PANELS)

Flow	gal/min	50	75	100	125	150	175
	lb/s	6.11	9.16	12.21	15.26	18.32	21.37
Velocity (ft/s)		0.71	1.15	1.54	1.92	2.30	2.69
Reynolds Number		12200	18300	24500	30600	36700	42800
Peclet Number		60	90	120	150	180	210
Nusselt Number		5.65	6.15	6.57	6.97	7.25	7.60
Film Coefficient		4120	4485	4791	5083	5287	5542
		Q (MWt)					
Na ΔT	50	0.099	0.148	0.197	0.246	0.296	0.345
	150	0.296	0.443	0.591	0.739	0.887	1.035
	250	0.493	0.739	0.985	1.232	1.478	1.724
	350	0.690	1.035	1.379	1.724	2.069	2.414
	450	0.887	1.330	1.774	2.217	2.660	3.104
	550	1.084	1.626	2.168	2.710	3.251	3.793
		Film ΔT_f					
Flux (MWt/m^2)	0.50	39	35	33	31	30	29
	0.75	58	53	50	47	45	43
	1.00	77	71	66	62	60	57
	1.25	96	88	83	78	75	72
	1.50	115	106	99	94	90	86
		Tube ΔT_f					
Flux (MWt/m^2)	0.50	83	85	83	81	80	79
	0.75	133	129	127	125	124	123
	1.00	177	171	166	162	160	157
	1.25	221	213	208	203	200	197
	1.50	240	231	224	219	215	211
		Na ΔT					
Q	0.50	254	169	127	101	85	72
	1.0	507	338	254	203	169	145
	1.5	761	507	381	304	254	217
	2.0		677	507	406	338	290
	2.5			634	507	423	362

Q in MWt = $\dot{w}\,\Delta T/25373$; $\dot{w}$ (gal/min), ΔT (^{o}F)
V in ft/s = $\dot{w}/65.16$
Reynolds Number = 15935 V

TABLE 5

TEST CONDITIONS ACROSS PANELS FOR NORMAL FLUX DISTRIBUTION

	Power Level								
	Low			Intermediate			Design		
Total thermal power (MWt)	0.80			1.7			2.5		
Average heat flux (MWt/m^2)	0.23			0.46			0.70		
Peak heat flux (MWt/m^2)	0.50			1.0			1.50		
Lateral aim point separation (m)	0.40			0.40			0.40		
Inlet temperature (^{o}F)	550			550			550		
Mixed-mean outlet temperature (^{o}F)	735			920			1100		
Overall flow rates (gal/min)	115			115			115		
Panel Distribution	1	2	3	1	2	3	1	2	3
Thermal power (MWt)	0.23	0.37	0.23	0.46	0.73	0.46	0.70	1.10	0.70
Average heat flux (MWt/m^2)	0.19	0.31	0.19	0.39	0.61	0.39	0.59	0.92	0.59
Peak heat flux (MWt/m^2)	0.33	0.50	0.33	0.67	1.0	0.67	1.0	1.50	1.0
Mixed-mean outlet temperature (^{o}F)	735	735	735	920	920	920	1100	1100	1100
Hot tube temperature (^{o}F)	765	750	765	980	950	980	1200	1150	1200
Cold tube temperature (^{o}F)	700	715	700	850	885	850	1000	1050	1000
Flow rate	32	51	32	32	51	32	32	51	32
Power ratio*	1.44	1.20	1.44	1.44	1.20	1.40	1.44	1.20	1.44

*Power ratio = ratio of power bewteen two panel tubes = $\frac{\text{higher power tube}}{\text{lower power tube}}$

2.6 PANEL INSTRUMENTATION

The instrumentation on the solar panel consists of 57 thermocouples, three displacement transducers, and three flux sensors. Each subpanel has a electromagnetic flowmeter to measure flow rate and a flow control valve. The flow control valve can be operated manually or automatically by the flow control system. The control system contains the controllers, switches, indicators, and logic to control subpanel flow rate. Figure 18 shows the location of the sensors on the panel assembly. Table 6 is the instrument list. The accuracies of the sensors are given below:

Thermocouples, Type K	±4^{0}F in range 32-530^{0}F
	±0.75% in range 530-2300^{0}F
Flux sensors	±3% of full range
Displacement sensors	±1% of full range
I/P converter	±0.5%
P/E transducer	±0.25% of span

2.7 CONTROL SYSTEM DESIGN AND ANALYSIS

The primary control requirement is to maintain the panel outlet sodium temperature for each subpanel at the set-point value. For the design conditions, this value is 593 ± 14^{0}C (1100 ± 25^{0}F) with an inlet temperature of 288^{0}C (550^{0}F). Since there is a direct relationship between the solar flux available to the panel and the flow required to achieve a given set of operating conditions, solar flux is used as the primary master signal in a feed-forward configuration. Panel exit sodium temperature is then processed through a controller (TIC) and used as a trim to this master. The resulting summed signal is then used to modulate the sodium inlet valve position.

The ESG test article (solar receiver panel assembly) EI&C control panel contains the controllers, switches, indicators, and logic to control the test

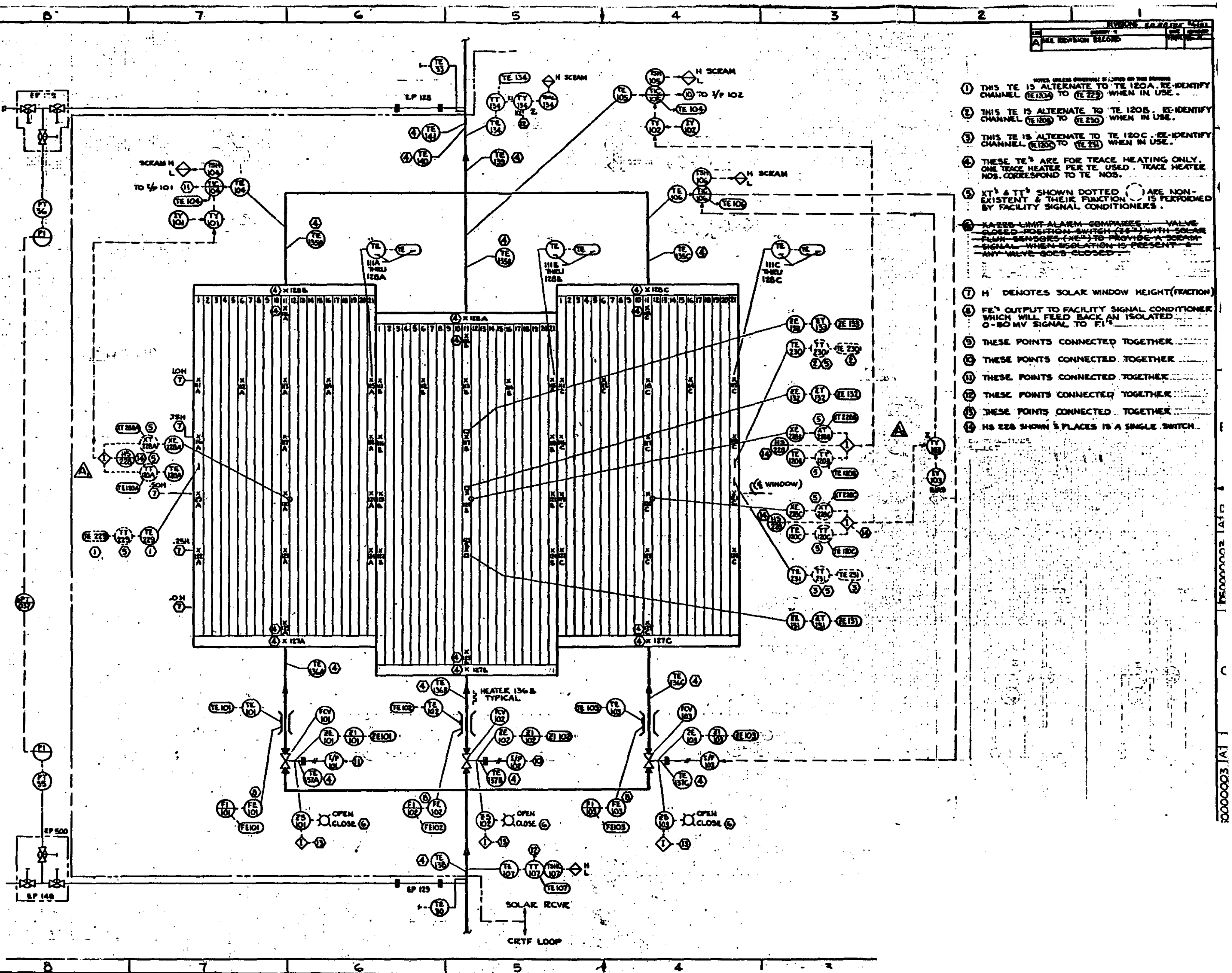


Figure 18. Solar Panel P&I

TABLE 6

INSTRUMENT LIST
(Sheet 1 of 2)

EQUIPMENT NO.	DESCRIPTION	INSTRUMENT SPECIFICATION				MANUFACTURER'S DATA		PURCHASE DATA	
		RANGE	INPUT	OUTPUT	POWER	NAME & CATALOG NO.	DWG NO.	PR	PO
FE 101	Flow Meter, Magnetic	11/2"	—	Approx. 4MV/GPM	—	ESG Sketch Vendor Fab	2	18670	N 120114 AMA
FCV 101	Flow Control Valve	1 1/2" 35 GPM	—	—	—	VALVETEK		17716	N 110129 AMN
I/P 101	I/P Converter (Integral with FCV 101)	—	4-20Ma	—	—	Robert shaw 443 I/P			
TE 101	Thermocouple (Integral with FE 101)	0-2300°F	—	K Type T/C	—				
ZE 101	Valve Position XDucer (Integral with FCV 101)	0-100%	—	4-20Ma	24VDC	Moore Products 781 P/I			
ZS 101	Valve Position Switch (Integral with FC 101)	—	—	DPDT Open/CL Switch	—				
FE 102	Flow Meter Magnetic	1 1/2"	—	Approx 4MV/GPM	—	ESG Sketch Vendor Fab		18670	N 120114 AMA
FCV 102	Flow Control Valve	1 1/2" 35GPM	—	—	—	VALTEK		17716	N 110129 AMN
I/P 102	I/P Converter (Integral with FCV 102)	—	4-20Ma	—	—	Robert shaw 443 I/P			
TE 102	Thermocouple (Integral with FE 102)	0-2300°F	—	K Type T/C	—				
ZE 102	Valve Position Xducer (Integral with FCV 102)	0-100%	—	4-20Ma	24VDC	Moore Products 781 P/I	2		
ZS 102	Valve Position Switch (Integral with FC 102)	—	—	DPDT Open/CL Switch	—				
FE 103	Flow Meter, Magnetic	1 1/2"	—	Approx 4MV/GPM	—	ESG Sketch Vendor Fab		18670	N 120114 AMA
FCV103	Flow Control Valve	1 1/2" 35GPM	—	—	—	VALTEK		17716	N 10129 AMN
I/P 103	I/P Converter (Integral with FCV 102)	—	4-20Ma	—	—	Robertshaw			
TE 103	Thermocouple (Integral with FE 103)	0-2300°F	—	K Type T/C	—				
ZE 103	Valve Position Xducer (Integral with FCV 103)	0-100%	—	—	24VDC	Moore Products 781 P/I			
ZS 103	Valve Position Switch (Integral with FC 103)	—	—	DPDT Open/CL Switch	—				
TE 104	Thermocouple (Ungrounded)	0-2300°F	—	K Type	—	Thermometrics .125 Dia, .062Tip		20411	N 179124 AMN
TE 105			—		—				

REMARKS

1. P & ID NO. 050000003

2 Vendor Data Sheets 050TI000001

PREPARED BY DATE

DEPT/GRP

APPROVED BY DATE

DEPT/GRP

REVISION DATE

RELEASING EO NO.

Rockwell International
Energy Systems Group

INSTRUMENT INDEX AND EQUIPMENT LIST
SOLAR PANEL

LIST NO

TABLE 6

INSTRUMENT LIST
(Sheet 2 of 2)

EQUIPMENT NO.	DESCRIPTION	INSTRUMENT SPECIFICATION				MANUFACTURER'S DATA		PURCHASE DATA	
		RANGE	INPUT	OUTPUT	POWER	NAME & CATALOG NO.	DWG NO.	PR	PO
TE 106	Thermocouple (Ungrounded)	0-2300°F	—	K Type	—	Thermometrics .125Dia, .062TIP	⟨2⟩	20411	N 179124 AMN
TE 107	↓	↓	—	↓	—	↓	↓	↓	↓
TE111 - TE128 A, B, C	(54 total) ↓	↓	—	↓	—	Thermometrics .062 Dia.	↓	↓	↓
ZE 131	Deflection Sensor (LVDT)	±1.00"	—	To ZT131	3V,2-3KC From ZT131	Schaevitz 1000HR	↓	18733	N 181093 AMN
ZT 131	Deflection Sensor Signal Conditioning Module	—	From ZE 131	±10VDC	±15VDC	Schaevitz SMS1GPM-108	↓	↓	↓
ZE 132	Deflection Sensor (LVDT)	±1.00"	—	To ZT 132	3V,2-3KC From ZT132	Schaevitz 1000HR	↓	↓	↓
ZT 132	Deflection Sensor Signal Conditioning Module	—	From ZE 132	±10VDC	±15VDC	Schaevitz SMS1GPM-108	↓	↓	↓
ZE 133	Deflection Sensor (LVDT)	±1.00"	—	To ZT 132	3V,2-3KC From ZT133	Schaevitz 1000HR	↓	↓	↓
ZT 133	Deflection Sensor Signal Conditioning Module	—	From ZE133	±10VDC	±15VDC	Schaevitz SMS1GPM-108	↓	↓	↓
TE 134	Thermocouple (Ungrounded)	0-2300°F	—	K Type	—	Thermometrics .125 Dia., .062Tip	↓	20411	N 179124 AMN
XE 228A	Solar Flux Sensor	0-3000°F	—	0-10MV	—	HYCAL ENGR C1341-D-150-36-780	⟨2⟩	20168	N 181071 AMN
XE 228B	↓	↓	—	↓	—	↓	↓	↓	↓
XE 228C	↓	↓	—	↓	—	↓	↓	↓	↓
TE 229	Thermocouple (Ungrounded)	0-2300°F	—	K Type	—	Thermometrics .030Dia Inconel	↓	17703	N 180945 AMN
TE 230	↓	↓	—	↓	—	↓	↓	↓	↓
TE 231	↓	↓	—	↓	—	↓	↓	↓	↓

REMARKS

1. P & ID NO. 050000003

⟨2⟩ Vendor Data Sheets 050TI000001

PREPARED BY DATE DEPT/GRP		Rockwell International Energy Systems Group
APPROVED BY DATE DEPT/GRP		INSTRUMENT INDEX AND EQUIPMENT LIST SOLAR PANEL
REVISION DATE		
RELEASING EO NO.		LIST NO.

article subpanel inlet flow control valves. The operator can set the controllers for local manual or automatic valve operation. Figure 19 shows the logic employed in the valve control system.

The logic diagram shows the scram signals that will be sent to the facility system as well as the facility-generated scram signals for valve control. These signals are (1) the high-temperature limit alarms on the outlet thermocouples indicating excessive outlet sodium temperature, (2) a high differential temperature between the inlet and outlet sodium temperatures, (3) the closing of any of the inlet valves when insolation is impinging on the absorber panel, and (4) the loss of two or more of the flux sensors (computer programmed).

The Figure 18 P&ID shows the instrumentation for the above. It also shows the heater thermocouples and a typical heater. The heater thermocouples are not controlled via the ESG control panel.

The controllers utilized in the ESG control panel are a microprocessor-based design. The controllers receive their temperature signal from an immersion-type thermocouple located in each outlet duct of the absorber subpanel. These thermocouples are 0.125-in.-diameter ungrounded junction type that are reduced to a 0.060-in. diameter for faster response.

The controllers also have provision for receiving a feed-forward signal input as illustrated on the Figure 19 logic diagram. This allows the controller to drive the valve to a predetermined position with respect to the flux density. The immersion-type thermocouple located in the outlet duct provides the feedback signal to the controller. The feedback signal is compared to the set point; it works as a trimmer and controls the valve to obtain a minimum temperature deviation between set point and feedback. The controller also has the bumpless transfer feature.

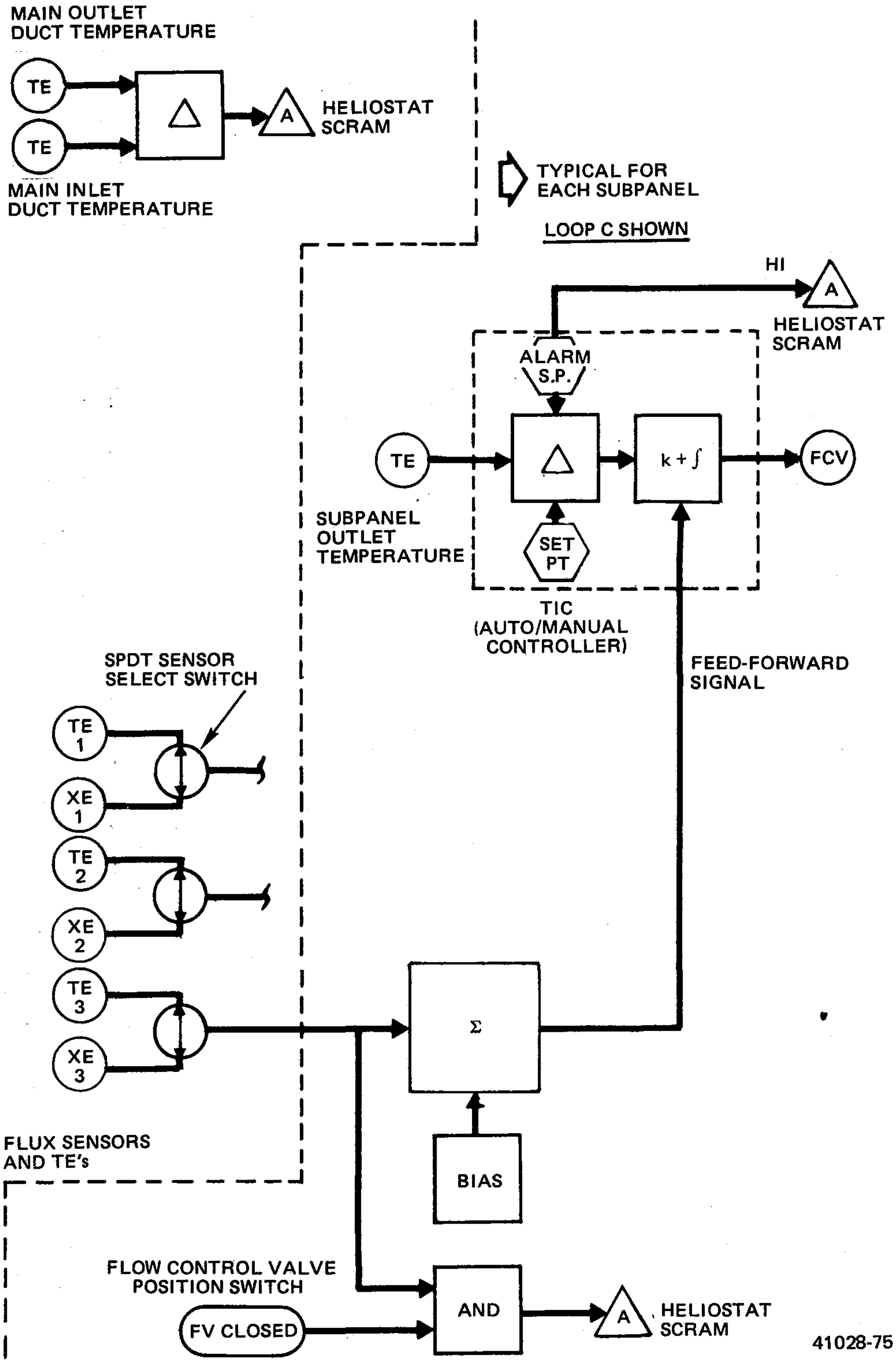


Figure 19. EI&C Control Logic

The absorber panel flux sensors are the water-cooled type. The cooling water passages employ 1/4-in. tube lines and water passages with a 0.100-in. minimum diameter within the sensor proper. The passages are large enough to assure there will be no cooling water blockage due to contaminant buildup.

Each of the absorber subpanels has fourteen 0.060-in.-diameter ungrounded junction thermocouples strapped to the back of the absorber panel tubes with spot-welded clips. There are shown on the Figure 18 P&ID. The signals are not displayed on the ESG control panel but are multiplexed data channels. One centrally located back-of-tube thermocouple in each absorber subpanel is also brazed to the tube and was tested as a substitute for the flux sensors. However, the response time was too slow, and the measurement was influenced by sodium inlet temperature variations.

Three front-of-tube thermocouples, located in the panel edge tube were provided, also as a substitute for the flux sensors but with potentially more rapid response than the back-side thermocouples. These units were also influenced by sodium inlet temperature variations as well as by flux variation, an undesirable feature. They are 0.030-in.-diameter ungrounded junction Inconel stainless steel-sheathed units that are heat-sinked to the absorber panel tubes to prevent them from experiencing excessive temperatures. These were tested to determine the feasibility of using thermocouples as indicators of solar flux changes and to assess their reliability.

A magnetic flowmeter is provided in each of the absorber subpanels to measure sodium flow rate. The signal is not used for control; it is a multiplexed data channel and is also displayed on the ESG control panel. A thermocouple is provided for each of the flowmeters to measure flowmeter permanent magnet temperature to correct the magnet temperature-related signal error.

The center absorber subpanel has three deflection sensors from which the signals are fed to the main computer for recording. These are not displayed on the ESG panel.

The valve position signal is a multiplexed signal channel and is also displayed on the ESG control panel. The Valve Open-Closed lights for these valves are also displayed on the on-line ESG control panel.

The ESG control panel was fabricated at ESG's Canoga Park facility. It is a 69-5/16-in. by 22-in. steel cabinet with annunciator, valve-position digital indicators, digital flow indicators, valve full open and closed indicator lights, temperature indicator controllers, switches, relays, and other logic instruments required to control the valves to maintain a steady temperature. The control panel layout is shown on Figures 20, 21, and 22. Two selector switches and a digital meter were added at the site to monitor the flux sensors' signals.

Analysis of the control system is presented in Appendix G.

2.8 SAFETY ANALYSIS AND QUALITY ASSURANCE

Safety analyses for the test article were conducted. The ESG test article was designed to contain the sodium coolant safely under normal and upset test conditions. This was achieved by using a simplified design approach, incorporating well-demonstrated detail design and fabrication features and proven inspecting and testing criteria. A control system capable of maintaining the test conditions within design limits was provided.

The test article was designed to the applicable requirements of the ASME Boiler and Pressure Vessel Code Section VIII Division 1 and ANSI B31.1, with large design margins. The accumulated creep and fatigue damage resulting from the elevated-temperature operating environment is evaluated using the elastic analysis methods of the B&PV elevated-temperature Code Case N-47. The construction materials and fabrication, inspection, and testing processes are within the above Code requirements. To assure reliable containment, all containment welds are of the simple-to-fabricate and inspect full-penetration butt type.

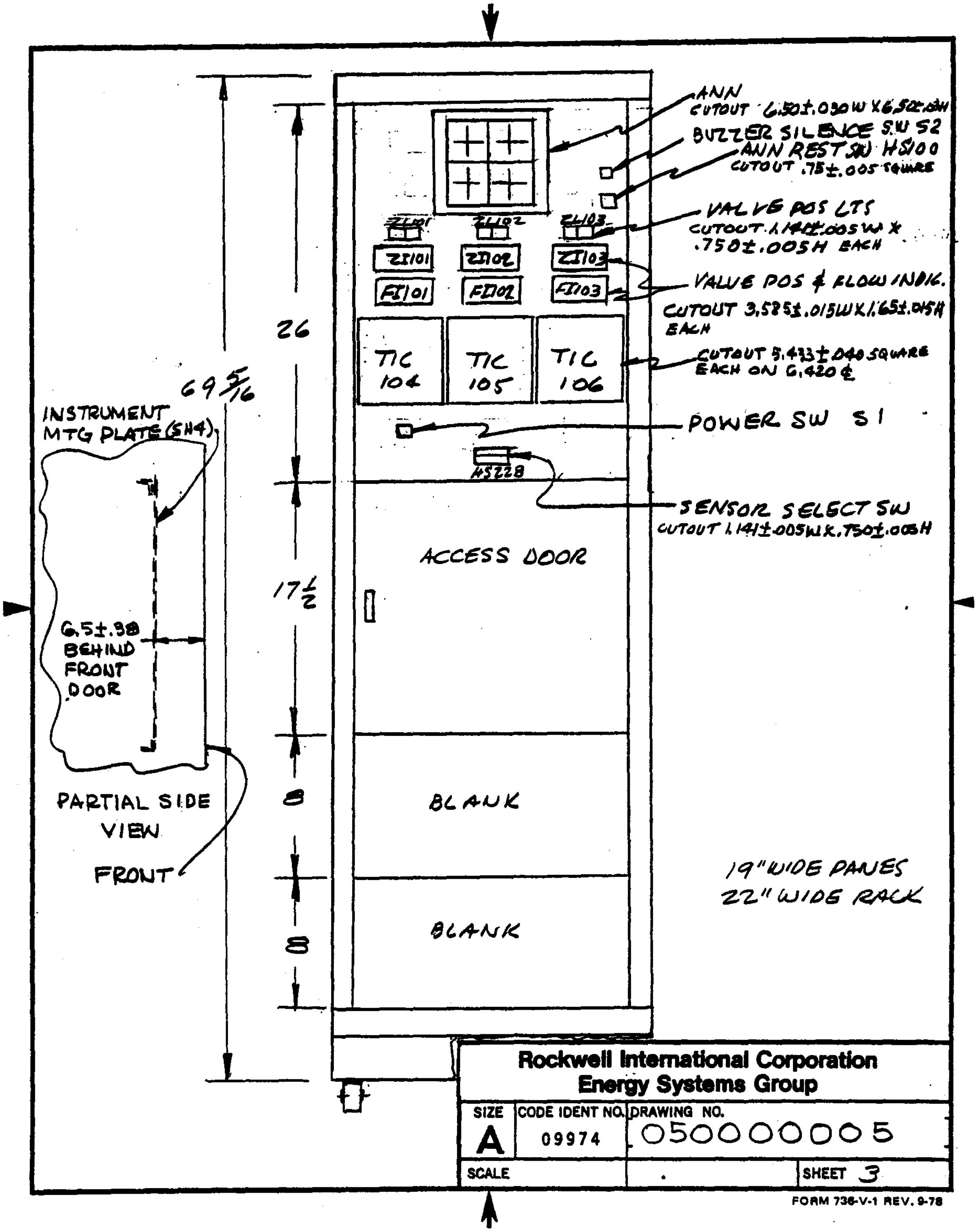


Figure 20. Control Cabinet Arrangement

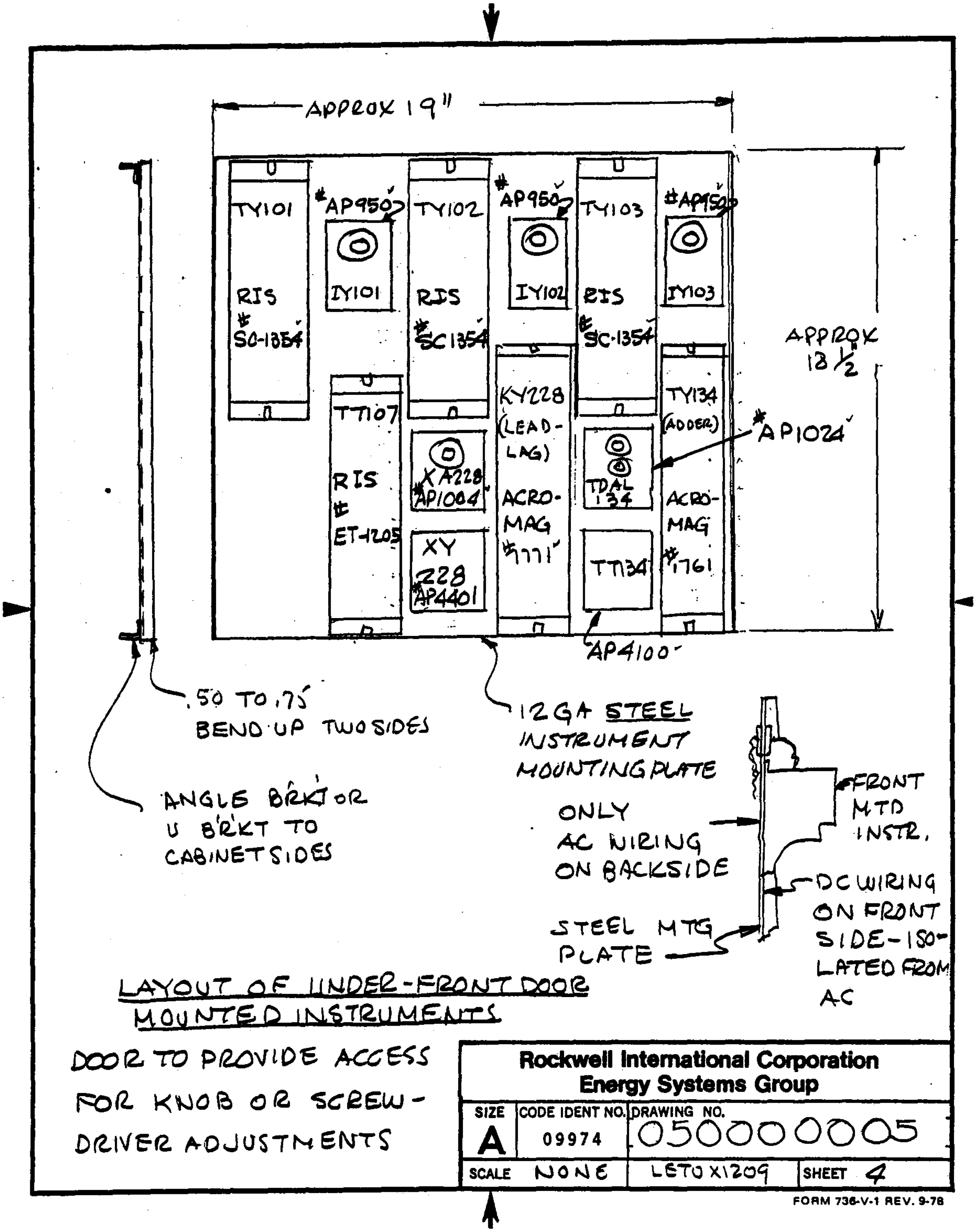


Figure 21. Control Cabinet Access Compartment Layout

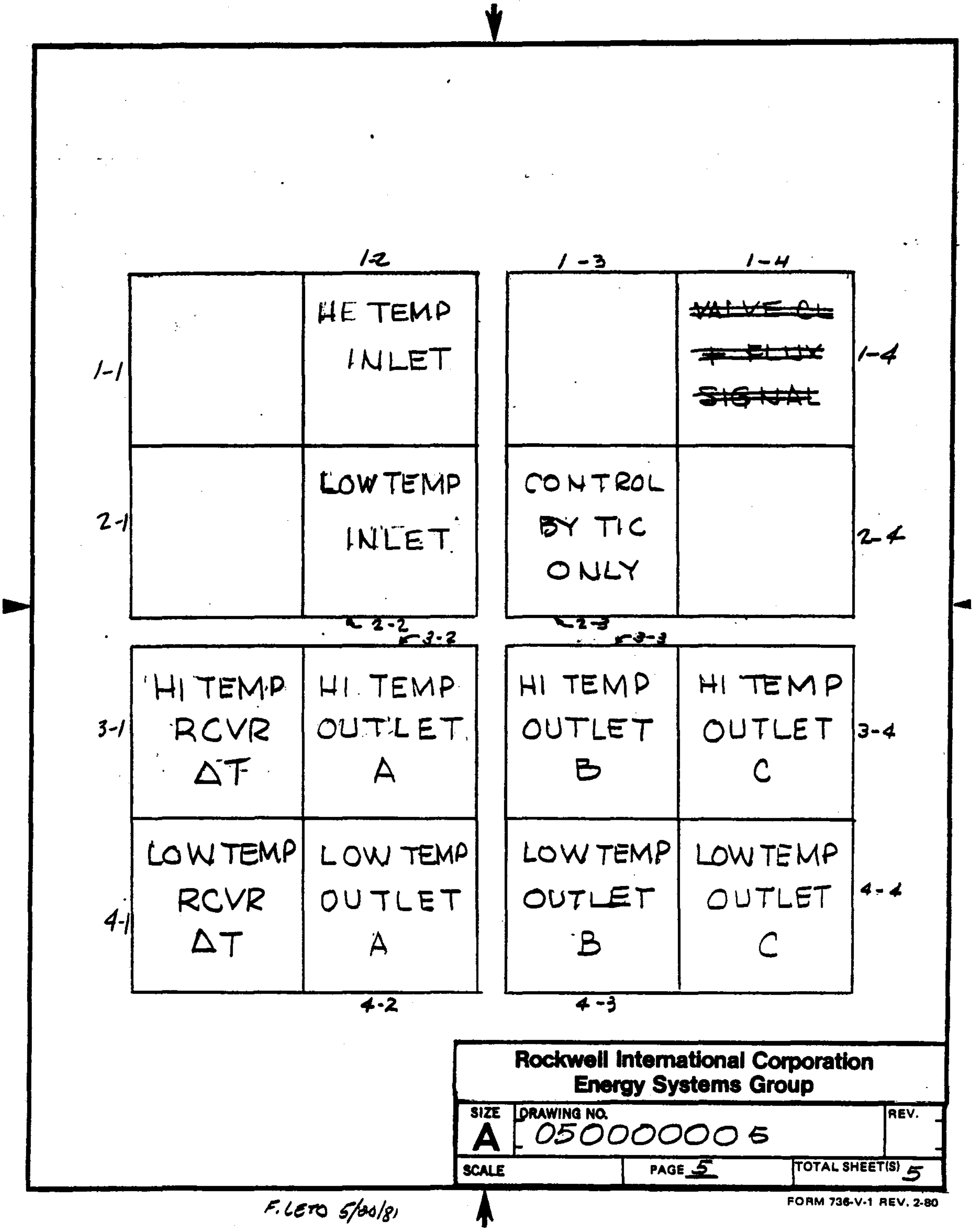


Figure 22. Annunciator Panel Layout

The control system for the test article was designed to maintain the maximum component temperatures within the design limits under the normal operational conditions, which include solar insolation variations and the performance fluctuation of the CRTF sodium test loop. Analysis verified that the failure of any control component will not result in the temperature of the containment components exceeding safe limits. Adequate instrumentation was provided to permit assessing the actual temperatures of the containment components during the tests. If necessary, the automatic control system can be overridden with manual control.

The control system was integrated with the control systems of the CRTF sodium loop and the heliostats to dump the sodium into the dump tank or defocus the heliostats under upset conditions, such as loss of solar input or loss of sodium flow through the test article. In the unlikely event of sodium leak from the test article, smoke detectors on the test loop would initiate the sodium dump into the dump tank, minimizing the effects of the sodium leak.

Quality assurance of the design and fabrication of the ESG sodium-cooled panel was verified in accordance with the QA plan. This included dye-penetrant inspection of all welds, helium leak checking, and proof pressure testing of the assembly before shipment to CRTF. Contracted inspectors were present to verify that these procedures were performed for the final integrated test assembly.

3.0 FACILITY AND TEST SYSTEM INSTALLATION DESCRIPTION

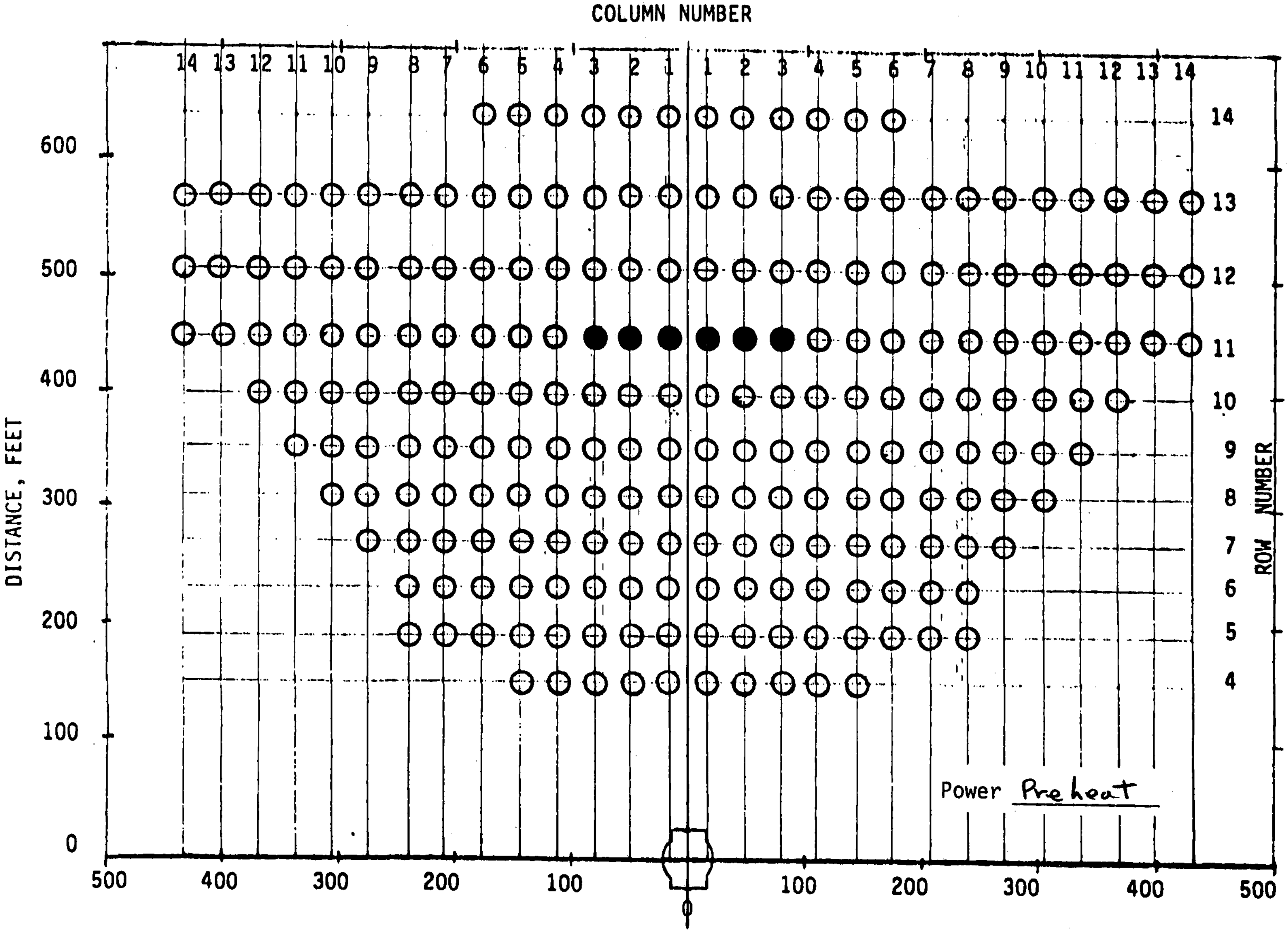
The receiver panel was tested at the Central Receiver Test Facility (CRTF) in Albuquerque, New Mexico. The facility is operated by Sandia Laboratories. The sodium test loop was also provided by Sandia Laboratories. This section describes these facilities and the data recording requirements.

3.1 CENTRAL RECEIVER TEST FACILITY

The CRTF is the primary solar test facility for component and subsystem evaluation within the Department of Energy's Solar Thermal Larger Power System (STLPS) program. The CRTF, with a thermal capability of about 5 MWt, is designed to perform a variety of functions ranging from testing collectors, receivers, thermal storage systems, instrumentation systems, direct-energy-conversion cycles, fluid coolants, and materials to training personnel to operate solar facilities. A complete description is given in Sandia Laboratories Report SAND77-1173.

3.1.1 Heliostat Array Subsystem

The CRTF energy collection system consists of 222 heliostats. The total heliostat field can concentrate more than 5 MWt of power under optimal sun, heliostat, and target conditions. The approximate heliostat arrangements for the panel test program for panel preheat, low-power, intermediate-power, 100% power, and high-power operation are shown schematically in Figures 23 through 27. For this test series, 2.5 MWt is designated as 100% power. The preheat power level shown in Figure 23 is basically a 10% level. During checkout testing, four heliostats were found to be adequate to achieve a satisfactory preheat temperature. The test procedure document (Appendix C) identifies the sequence in which the various groups of heliostats are focused on the panel aperture.



Power Preheat

Figure 23. Active Heliostat Distribution

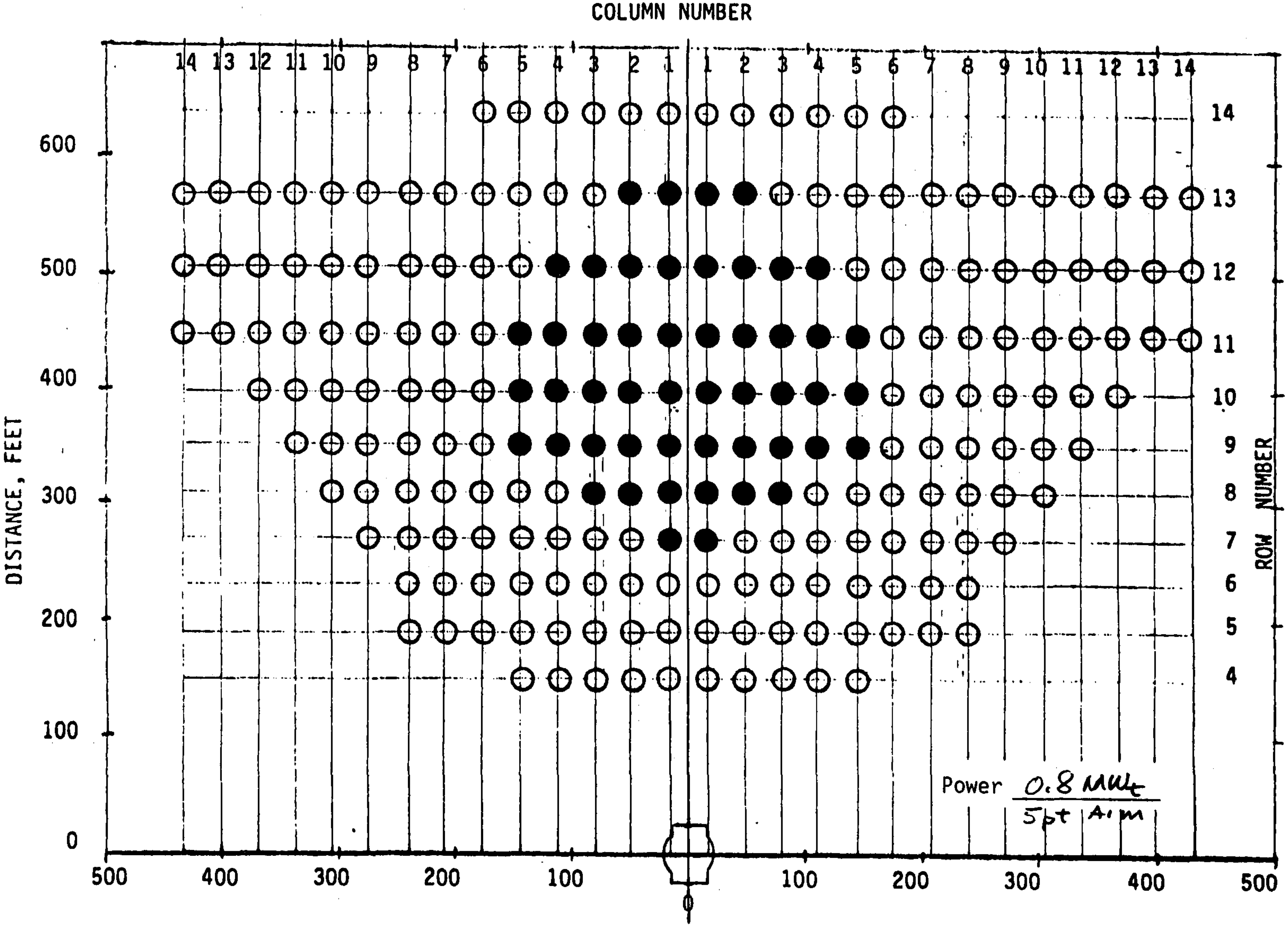


Figure 24. Active Heliostat Distribution

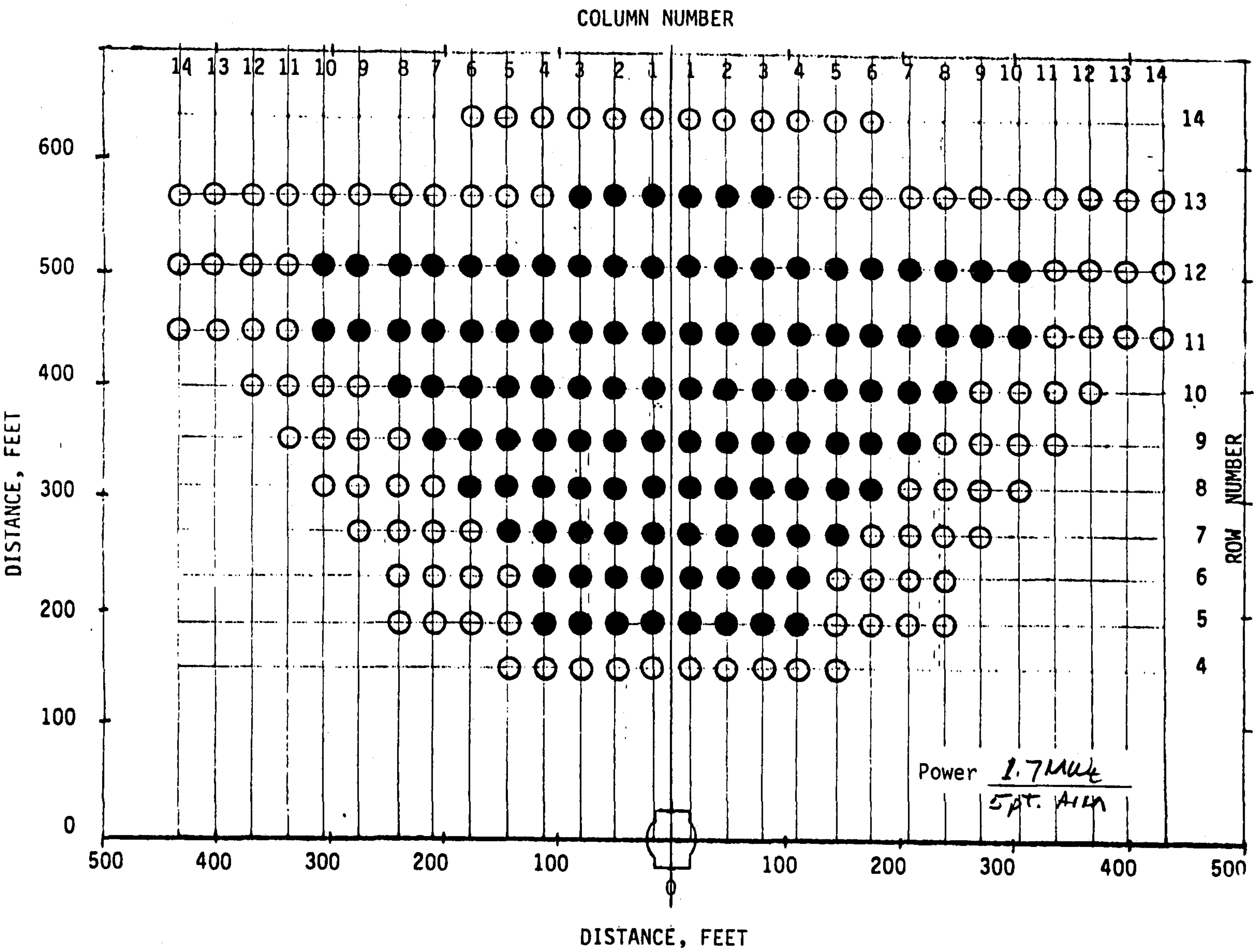


Figure 25. Active Heliostat Distribution

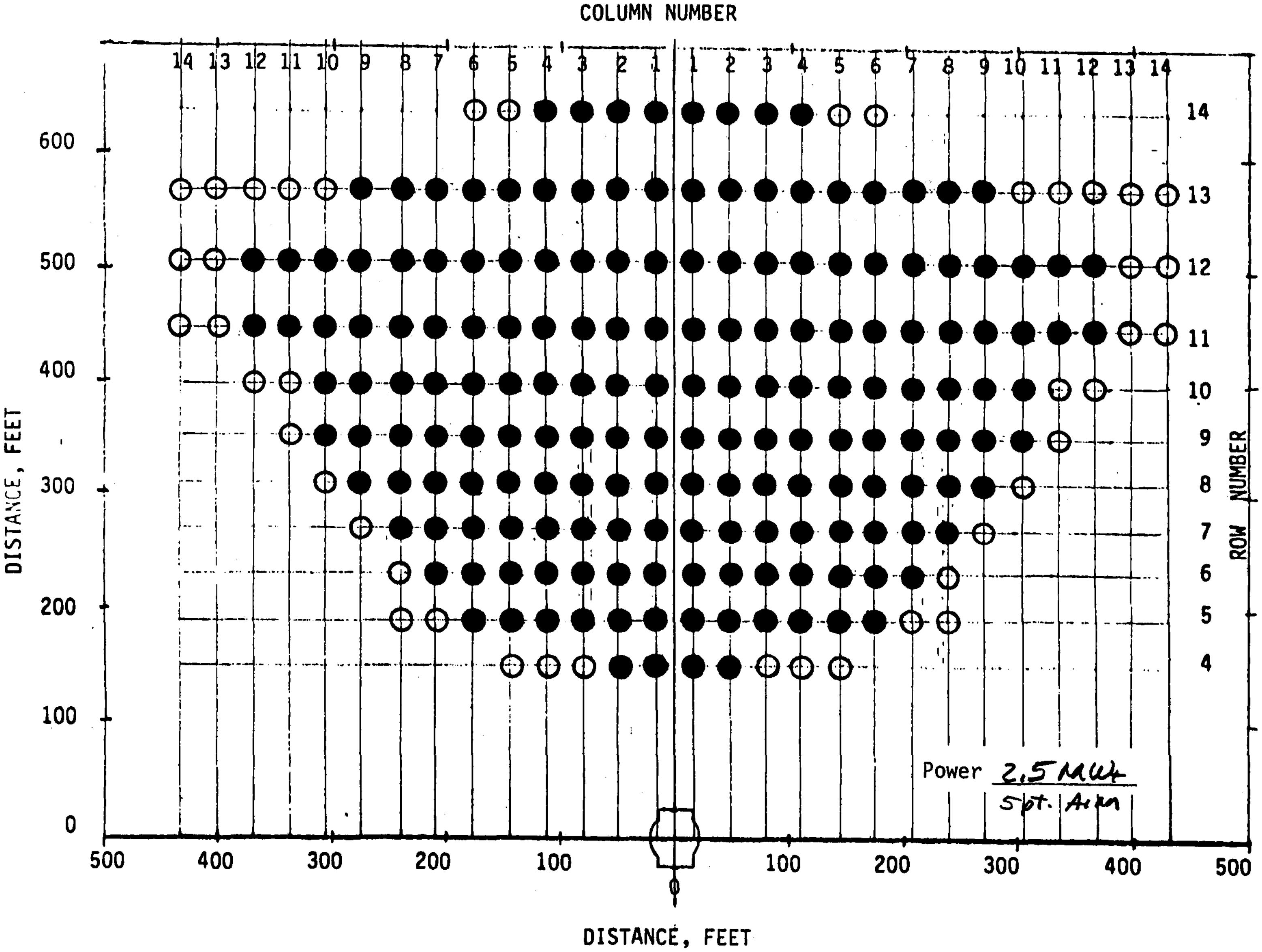


Figure 26. Active Heliostat Distribution

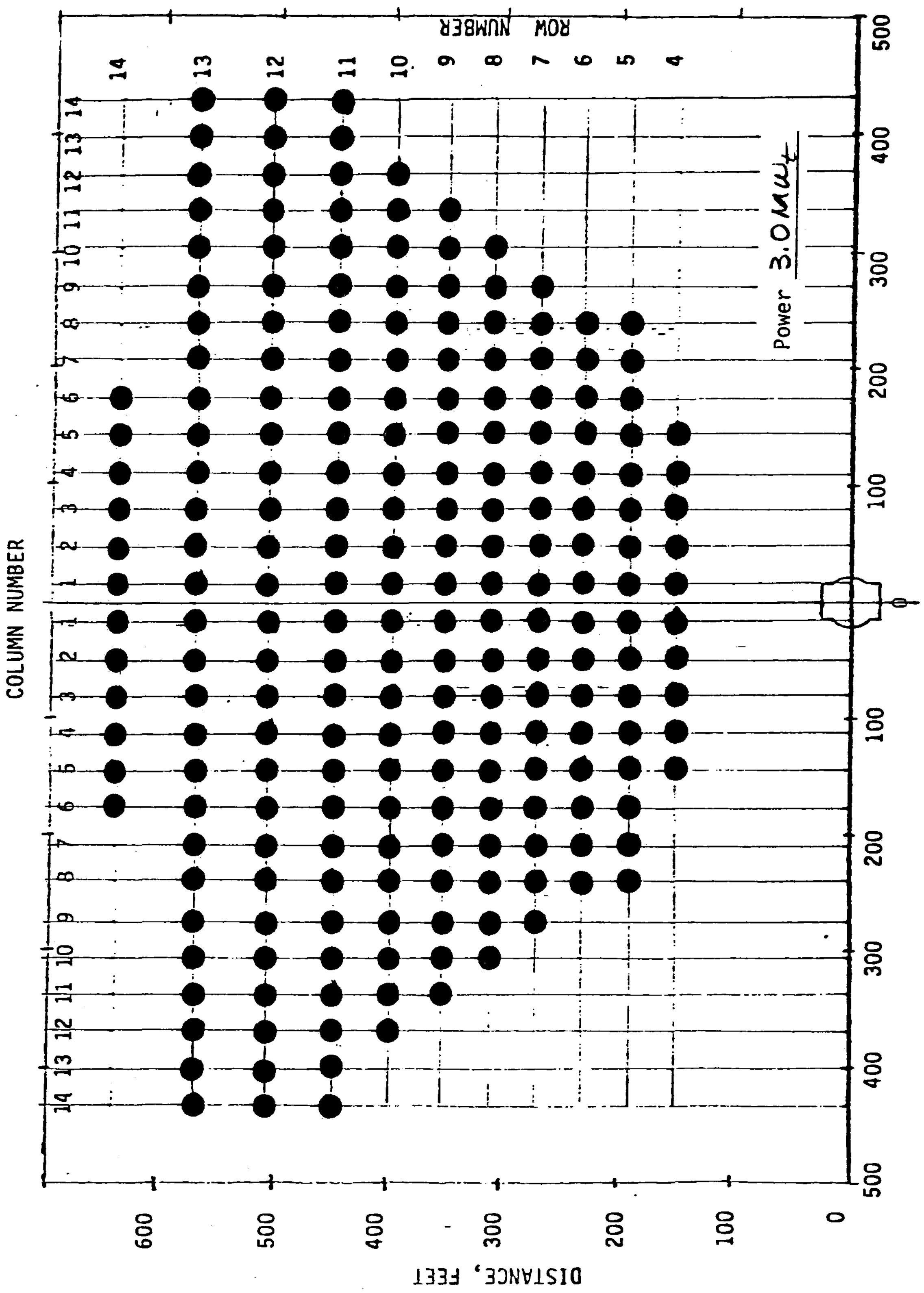


Figure 27. Active Heliostat Distribution

3.1.2 Receiver Tower

The CRTF receiver tower rises 61 m (200 ft) above ground. The ESG panel experiment was conducted at this level.

Test bays for other experiments are located on platforms at the 36.6-, 42.7-, and 48.8-m (120-, 140-, and 160-ft) levels as shown in Figure 28.

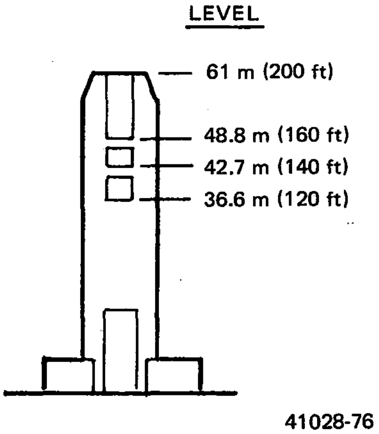


Figure 28. North Tower Elevation Showing Test Bays

For panel testing, the panel and sodium loop were assembled at ground level while mounted on the roof of an elevating module. Figure 29 shows the completed assembly within the ground-floor bay of the tower. Drawing N001000427 in Appendix F shows the solar panel assembly attached to the sodium loop enclosure. After completion of ground-level checkout tests with sodium in the system, the module was raised to the 61-m level for testing.

The elevating module, ~9.1 m (30 ft) wide by 7.6 m (25 ft) deep by 13.1 m (43 ft) high, is itself an enclosed three-story structure in which each story is a single room. The top room contains instrumentation patch panels, the middle room contains the data acquisition system, and the lowest room is a light machine shop.

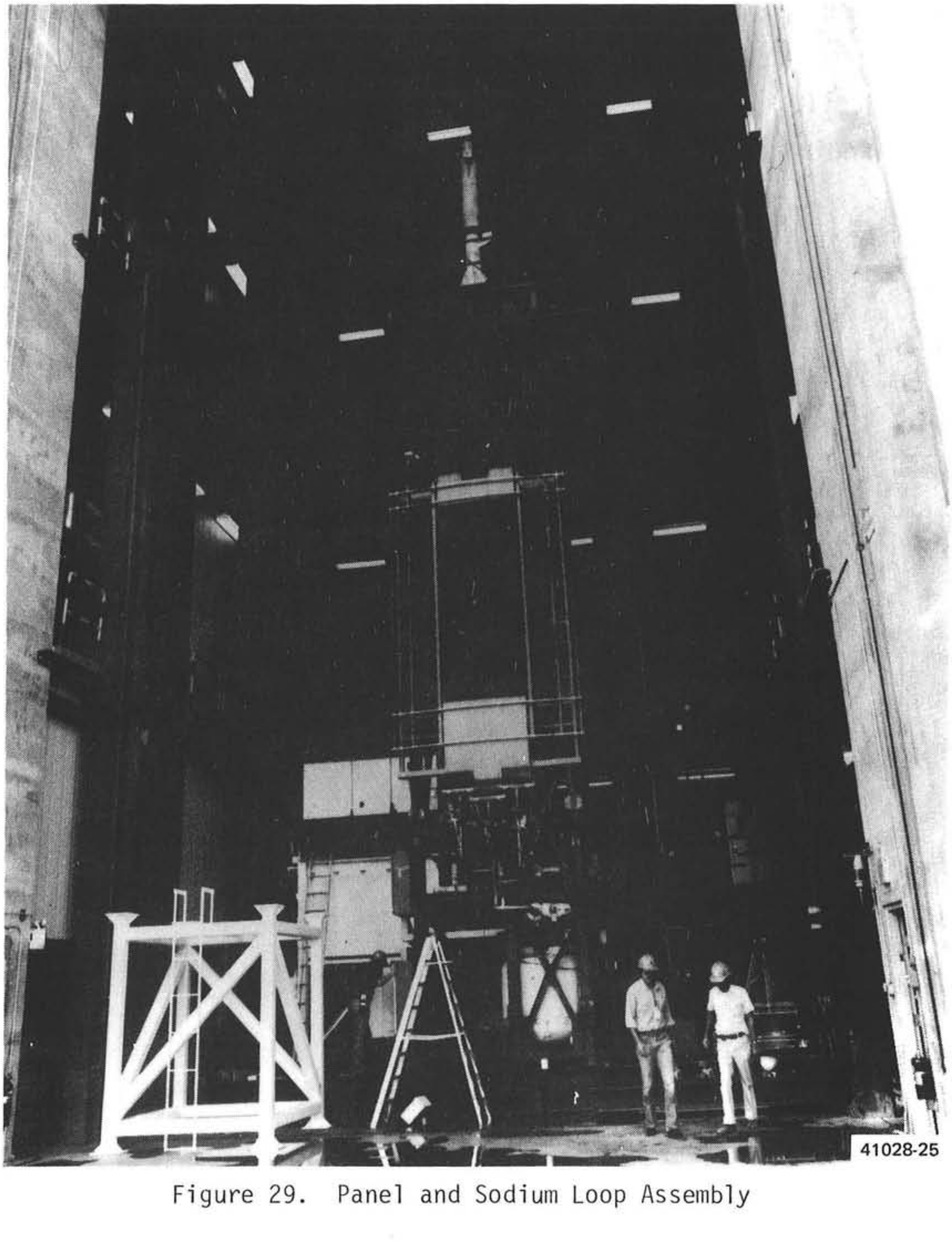


Figure 29. Panel and Sodium Loop Assembly

Figure 30 shows the test assembly in test position at the 200-ft level.

3.2 SODIUM LOOP

The ESG test article was connected to a CRTF-installed sodium loop, as shown in Figure 28. Loop assembly was started in March 1981 by CRTF personnel, with assistance from ESG.

A flow schematic for the sodium loop is shown in Figure 31. Sodium circulation through the test panel is provided by an electromagnetic (EM) pump with a rated capacity of 0.01 m^3/s (175 gal/min) at a developed heat of 200 kPa (30 psig). Nominal flow rate through the test panel is 0.007 m^3/s (115 gal/min). The pump flow control system was largely inactive for these tests, and flow control was achieved by the panel flow control valves. During the early checkout tests, pump flow rate at maximum power was found to be limited to ~115 gal/min. Whether this limitation was due to a pump performance deficiency or due to a higher than expected loop pressure drop was not determined. This flow rate limit did restrict the maximum power to which the panel could be tested.

Liquid sodium enters the test panel at a temperature of 288°C (550°F) and under normal operation exits at a temperature of 593°C (1100°F). A flow-through surge tank is provided to accommodate changes in sodium volume in the system. Argon cover gas is provided in the surge and drain tanks. The sodium is cooled by the dump heat exchanger (DHX) from 593°C nominal temperature to 288°C before circulating back to the EM pump. The heat removal capability of the DHX is changed by varying the airflow through the unit through the use of two continuously variable-speed fans. Louvers are also provided for additional control. A preheat system and doors are provided on the unit to maintain a night-time temperature of about 204°C (400°F). The

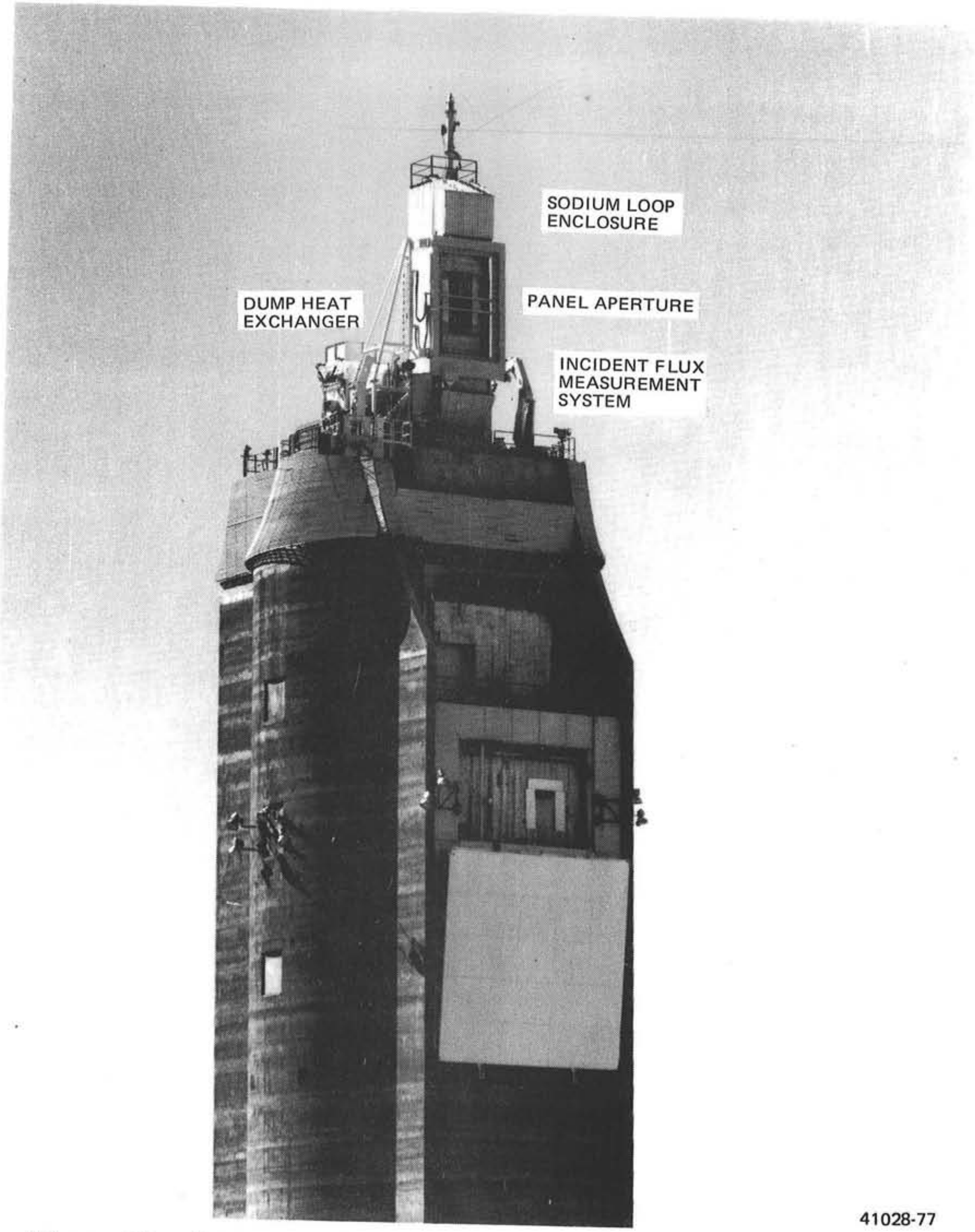


Figure 30. Test Installation at the 200-ft Level Test Position

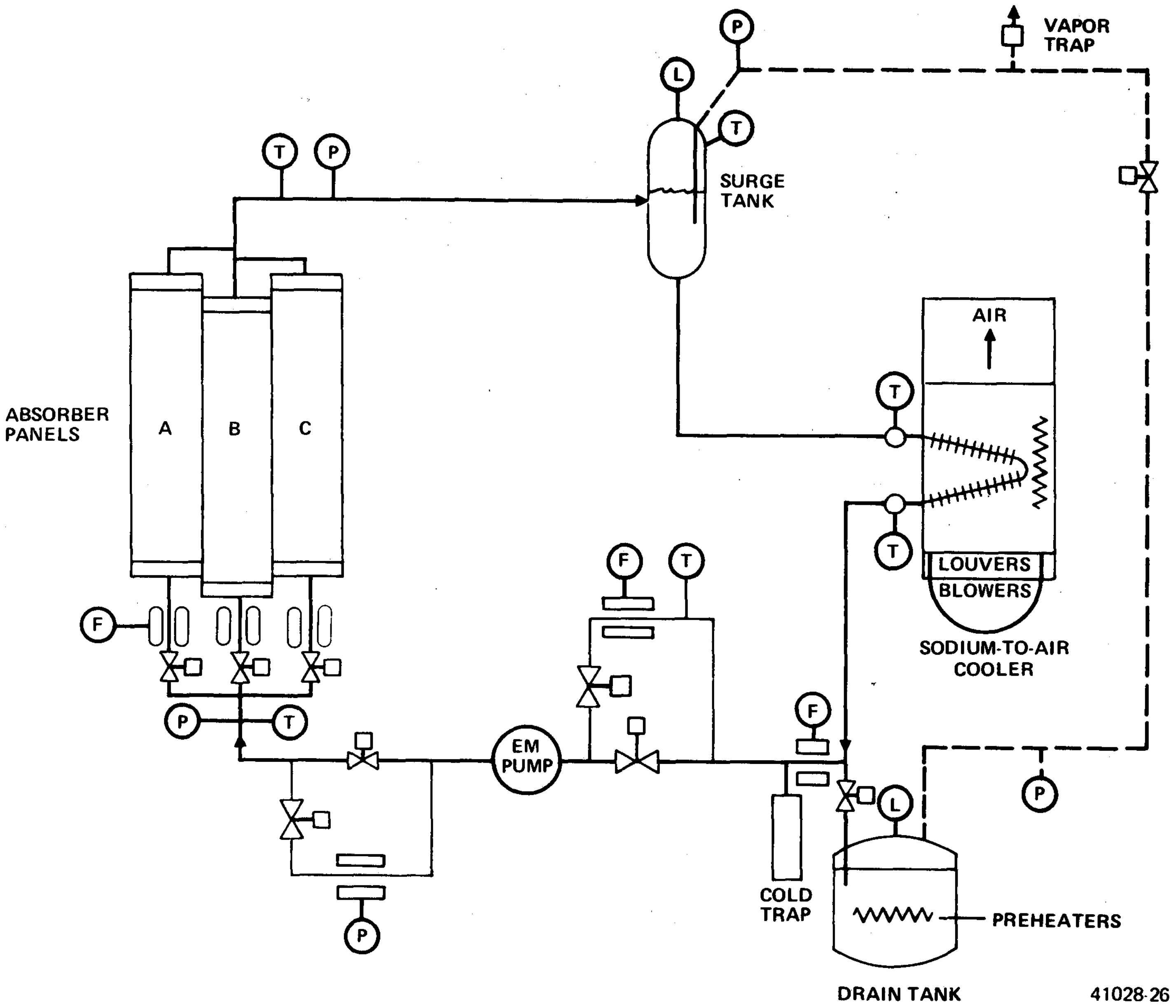


Figure 31. Flow Schematic for Sodium Loop at CRTF

DHX was rated at 2.5 MWt of heat removal capacity. An evaluation of the design parameters and the early testing indicated the actual capacity was at least 3.0 MWt and perhaps higher.

3.3 DATA ACQUISITION

3.3.1 General Requirements

Data are required from checkout and operations of the test article in the form of direct and derived measurements.

Direct Measurements

Direct measurement instrumentation consists of sensors that measure temperature, solar flux, sodium flow rate, and receiver tube displacement. The instrumentation data are summarized in Table 7. The instrumentation list is given in Table 6.

Derived Measurements

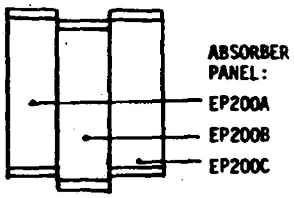
Measurements derived from the direct test measurements necessary for test article evaluation are:

1) Differential Temperatures (ΔTs)

   a) Sodium ΔTs derived from test article panel inlet and outlet manifold submerged temperature measurements
   b) Metal ΔTs derived from tube back-side and front-side surface measurements (edge tubes only).

TABLE 7

INSTRUMENTATION DATA
(Sheet 1 of 2)



Item	Quan. (Total)	CRTF Interface		CRTF Data Aquisition			Tower Control Rm.		Notes
		TE Conductor	Copper Conductor	Main Computer	Recall (Limited)	CRT	Recorder/ Data Logger	ESG Control Console	
Temperature C or F									
Common Inlet Duct TE107	1	1	-	1	1	1	1	-	Note 1: Signal from ESG Control Panel Isolate.
Common Outlet Duct TE134	1	1	-	1	1	1	1	-	Reference Note 1. TE134-TE107 high delta = SCRAM signal
PNLs A, B, C Inlet FM TE101, 102, 103	3	3	-	3	-	-	-	-	FE Flow Temperature Compensation Data Input.
PNLs A, B, C Outlet Duct TE104, 105, 106	3	3	-	3	3	3	3	3	Reference Note 1 High = SCRAM Signal. Hi/Lo Annunciated
PNLs A, B, C Solar Sensor XE228A, B, and C	3	-	3	3	-	3	-	-	Reference Note 1 and Reference Note 7.
Back of Tube MTD TEs - PNL A TE111A through 124A	14	14	-	14	1 (Note 3)	1 (Note 3)	-	-	Note 3: TE120A will alternate as substitute for XE228A.
Back of Tube MTD TEs - PNL B TE111B through 124B	14	14	-	14	6 (Note 4)	6 (Note 4)	-	-	Note 4: TE120B alternates as substitute for XE228B. TE111B through 115B to be recorded only.
Back of Tube MTD TEs - PNL C TE111C through 124C	14	14	-	14	1 (Note 5)	1 (Note 5)	-	-	Note 5: TE120C will alternate as substitute for XE228C.
Following Tube and HDR TEs to be used for preheat control	4								Note 6: Data logger; used for preheat control.
. PNL A TE125A through -128A	4	4	-				4(Note 6)		
. PNL B TE125B through -128B	4	4	-				4(Note 6)		
. PNL C TE125C through -128C	4	4	-				4(Note 6)		

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TABLE 7

INSTRUMENTATION DATA
(Sheet 2 of 2)

Item	Quan. (Total)	CRTF Interface		CRTF Data Aquisition			Tower Control Rm.		Notes
		TE Conductor	Copper Conductor	Main Computer	Recall (Limited)	CRT	Recorder/ Data Logger	ESG Control Console	
PNL A TE229	1	1	-		(See TE120A)			-	TE229 alternate to TE120A; reidentify Channel TE120A to TE229 when in use.
PNL C TE230	1	1	-		(See TE120B)			-	TE230 alternate to TE120B; reidentify Channel TE120B to TE230 when in use.
PNL C TE231	1	1	-		(See TE120C)			-	TE231 alternate to TE120C; reidentify Channel TE120C to TE231 when in use.
<u>Flow Data, GPM</u>									
PNLs A, B, C Inlet FE101, 102, 103	3	-	3	3	3	3	-	3	Reference Note 1 and TE101, 102, 103 Data (Assume Low-Flow SCRAM alarm supplied from Loop FE058)
<u>Flow Control Valves (%) PNLs A, B, C Inlet FCV 101, 102, 103</u>									
ZE101, 102, 103	3	-	3	3	-	3	-	3	Reference Note 1.
ZS101, 102, 103	3	-	3	-	-	-	-	3	Open-Close Lights Note 7: Any ZE closed with XE flux signal = SCRAM signal. Indication
<u>Deflection</u> (Inches)									
Sensors PNL B only ZE131, ZE132, ZE133	3	-	3-4 Cond. (Note 8)	3	3	-	-	-	Note 8: Three signal conditioners in loop structure - MTD WP Box.

2) Power

Panel power (P) was computed for each panel as well as the total, using measured flow rates ($\dot{w}$) and temperatures (T).

$$P = \dot{w}\int C_p\, dt = 0.34574\,(T_{out} - T_{in}) + \frac{0.079226}{2 \times 10^3}\,(T_{out}^2 - T_{in}^2) + \frac{0.034086}{3 \times 10^6}\,(T_{out}^3 - T_{in}^3) \text{ in Btu/s}$$

$$P_1 = \frac{P}{947.8} \text{ in MWt}$$

where

$\dot{w} = Q\,\frac{0.1337}{60}\,\rho$ in lb/s where $\rho = f(T_{in})$

Q = flow rate in gal/min

$C_p = 0.34574 - 0.079226 \times 10^{-3}\, T_F + 0.034086 \times 10^{-6}\, T_F^2$, sodium specific heat

$\rho = 59.566 - 7.9504 \times 10^{-3}\, T - 0.2872 \times 10^{-6}\, T^2 + 0.06035 \times 10^{-9}\, T^3$, in lb/ft^3, sodium density

3) Differential Pressures (ΔPs)

Sodium ΔPs derived from test article panel inlet and outlet pressure measurements

3.3.2 Test Data Tape

The format for test data tape supplied to ESG is given in Table 8.

TABLE 8

DATA CHANNEL LIST
(Sheet 1 of 3)

Buff No.	Mnemonics	Channel No.	Unit	Low Value	High Value
1					
2					
3					
4					
5					
6					
7					
8	TE-050	19	°F	400	1200
9	TE-051	20	°F	400	1200
10					
11	TE-070	22	°F	0	1500
12	TE-072	23	°F	0	1500
13	TE-030	24	°F	0	1500
14	TE-032	25	°F	0	1500
15	LE-042	26	in.	0	50
16	LE-061	27	in.	0	50
17	PT-045	28	psi	0	50
18	PT-062	29	psi	0	50
19	PT-077	30	psi	0	50
20	PT-078	31	psi	0	50
21	PT-035	33	psi	0	50
22	PT-036	34	psi	0	50
23	FE-038	35	gal/min	0	10
24	FE-086	46	gal/min	0	10
25	FE-058	37	gal/min	0	150
26	ZT-001	38	%	0	100
27	ZT-002	39	%	0	100
28	ZE-131	40	mil-in.	-500	500
29	ZE-132	41	mil-in.	-500	500
30	ZE-133	42	mil-in.	-500	500
31	ZE-101	49	% open	0	100
32	ZE-102	50	% open	0	100
33	ZE-103	51	% open	0	100
34	FE-101	52	gal/min	0	60
35	FE-102	53	gal/min	0	60

TABLE 8

DATA CHANNEL LIST
(Sheet 2 of 3)

Buff No.	Mnemonics	Channel No.	Unit	Low Value	High Value
36	FE-103	54	gal/min	0	60
37	TE-111A	145	°F	0	1500
38	TE-112A	146	°F	0	1500
39	TE-113A	147	°F	0	1500
40	TE-114A	148	°F	0	1500
41	TE-115A	149	°F	0	1500
42	TE-116A	150	°F	0	1500
43	TE-117A	151	°F	0	1500
44	TE-118A	152	°F	0	1500
45	TE-119A	153	°F	0	1500
46	TE-120A	154	°F	0	1500
47	TE-121A	155	°F	0	1500
48	TE-122A	156	°F	0	1500
49	TE-123A	157	°F	0	1500
50	TE-124A	158	°F	0	1500
51	TE-111B	159	°F	0	1500
52	TE-112B	160	°F	0	1500
53	TE-113B	161	°F	0	1500
54	TE-114B	162	°F	0	1500
55	TE-115B	163	°F	0	1500
56	TE-116B	164	°F	0	1500
57	TE-117B	165	°F	0	1500
58	TE-118B	166	°F	0	1500
59	TE-119B	167	°F	0	1500
60	TE-120B	168	°F	0	1500
61	TE-121B	169	°F	0	1500
62	TE-122B	170	°F	0	1500
63	TE-123B	171	°F	0	1500
64	TE-124B	172	°F	0	1500
65	TE-111C	173	°F	0	1500
66	TE-112C	174	°F	0	1500
67	TE-113C	175	°F	0	1500
68	TE-114C	176	°F	0	1500
69	TE-115C	177	°F	0	1500
70	TE-116C	178	°F	0	1500

TABLE 8

DATA CHANNEL LIST
(Sheet 3 of 3)

Buff No.	Mnemonics	Channel No.	Unit	Low Value	High Value
71	TE-117C	179	°F	0	1500
72	TE-118C	180	°F	0	1500
73	TE-119C	181	°F	0	1500
74	TE-120C	182	°F	0	1500
75	TE-121C	183	°F	0	1500
76	TE-122C	184	°F	0	1500
77	TE-123C	185	°F	0	1500
78	TE-124C	186	°F	0	1500
79	TE-229	187	°F	0	1500
80	TE-230	188	°F	0	1500
81	TE-231	189	°F	0	1500
82	TE-101	190	°F	0	1500
83	TE-102	191	°F	0	1500
84	TE-103	192	°F	0	1500
85	XE-228A	257	kW/m^2	0	6000
86	XE-228B	258	kW/m^2	0	6000
87	XE-228C	259	kW/m^2	0	6000
88	EPPLEY	260	W/cm^2	0	1200
89	TIC-104	6	°F	400	1200
90	TIC-105	7	°F	400	1200
91	TIC-106	8	°F	400	1200
92	TE-107	43	°F	0	800
93	TE-134	44	°F	0	1600
94					
95					
96					
97					
98					
99	POWER DX		kW	0	5000
100	POWER A		kW	0	5000
101	POWER B		kW	0	5000
102	POWER C		kW	0	5000
103	DELT A		°F	0	800
104	DELT B		°F	0	800
105	DELT C		°F	0	800

3.3.3 CRT Displays

The CRT displays are for the purpose of presenting current panel operating and performance data and to indicate when limiting conditions are reached. Tables 9, 10, 11, 12, and 13 present alarm/current information displays available to the ESG Panel Test Conductor. Figure 32 presents a flow schematic for a color graphic display.

0024C/lad

TABLE 9

ALARM CONTROL LU12 DISPLAY
Control Mode M/A

OUTLET TEMP	134	_ _ _ _	°F	INLET TEMP	107		_ _ _ _	°F*
	104	_ _ _ _	°F	HIGH DELT	134/107		_ _ _ _	°F
	105	_ _ _ _	°F	TTMAX			_ _ _ _	°F
	106	_ _ _ _	°F	FLUX PANEL	A		_ _ _ _	MW
				FLUX PANEL	B		_ _ _ _	MW
				FLUX PANEL	C		_ _ _ _	MW
VALVE POSIT	101	_ _ _ _	PCT	PANEL BACK	A	104	_ _ _ _	°F*
	102	_ _ _ _	PCT			111A	_ _ _ _	°F*
	103	_ _ _ _	PCT			115A	_ _ _ _	°F*
FLOW RATE	101	_ _ _ _	GPM	PANEL BACK	B	105	_ _ _ _	°F*
	102	_ _ _ _	GPM			111B	_ _ _ _	°F*
	103	_ _ _ _	GPM			112B	_ _ _ _	°F*
PRESSURE, IN	PT35		PSI			113B	_ _ _ _	°F*
OUT	PT36		PSI			114B	_ _ _ _	°F*
ΔP	PT36-PT35		PSI			115B	_ _ _ _	°F*
EM PUMP	---	- - - -	PCT	PANEL BACK	C	106	_ _ _ _	°F*
DNX FAN	---	- - - -	RPM			111C	_ _ _ _	°F*
ST PRES 0/HI		- -	PSI			115C	_ _ _ _	°F
DT PRES 0/HI		- -	PSI					
ST PRES 0/HI		- -	IN					

*Indicates low alarm 300°F, limit to flash

TABLE 10
PANEL PERFORMANCE SUMMARY

Control Mode ______
TC 033 _____ °F
FE 058 _____ gpm
Power _____ MWt

Panel A	Panel B	Panel C
TC104 ____ °F	TC105 ____ °F	TC106 ____ °F
TC111A ____ °F TC115A ____ °F	TC111B ____ °F TC113B ____ °F TC115B ____ °F	TC111C ____ °F TC115C ____ °F
TC117A ____ °F	TC117G ____ °F	TC117C ____ °F
TC120A ____ °F	TC120B ____ °F	TC120C ____ °F
TC123A ____ °F	TC123B ____ °F	TC123C ____ °F
FE101 ____ °F	FE102 ____ °F	FE103 ____ °F
XE228A ____ °F	XE228B ____ °F	XE228C ____ °F
	ZE 131 ____ in. ZE 132 ____ in. ZE 133 ____ in.	
ΔT ____ °F Power _____ MW	ΔT ____ °F Power ____ Mw	ΔT ____ °F Power ____ Mw

TABLE 11

TEST ARTICLE DATA, DISPLAY LU9

Panel A	Panel B	Panel C
(DELT) ( ) °F	(DELT) ( ) °F	(DELT) ( ) °F
	(TE134) ( ) °F	
(TE104) ( ) °F	(TE105) ( ) °F	(TE106) ( ) °F
	(ZE131) ( ) IN.	
(XF228A) ( ) MW/m^2	(XF228B) ( ) MW/m^2	(XF228C) ( ) MW/m^2
	(ZE132) ( ) IN.	
	(ZE133) ( ) IN.	
(TE123A) ( ) °F	(TE123B) ( ) °F	(TE123C) ( ) °F
(FI101) ( ) GPM	(FI102) ( ) GPM	(FI103) ( ) GPM

TABLE 12
TEMPERATURE PROFILE DISPLAY, LU10

	A (TE115A)	(TE118A)	(TE121A)	(TE124A)	
	B (TE115B)	(TE118B)	(TE121B)	(TE124B)	
	C (TE115C)	(TE118C)	(TE121C)	(TE124C)	
	A (TE114A)				
	B (TE114B)				
	C (TE114C)				
A (TE104)	(TE113A)	(TE117A)	(TE120A)	(TE123A)	(TE125A)
B (TE105)	(TE113B)	(TE117B)	(TE120B)	(TE123B)	(TE125B)
C (TE106)	(TE113C)	(TE117C)	(TE120C)	(TE123C)	(TE125C)
OUTLET	A (TE112A)				INLET
(TE33 or or 134)	B (TE112B)				(TE30 or 107)
	C (TE112C)				
	A (TE111A)	(TE116A)	(TE119A)	(TE122A)	
	B (TE111B)	(TE116B)	(TE119B)	(TE122B)	
	C (TE111C)	(TE116C)	(TE119C)	(TE122C)	

Test Article Temperature Profile (°F) (Flow ←)

Each ( ) designates XXXX

NOTES FOR ALARM DISPLAYS
TABLES 9, 10, 11, and 12

1. Displays shall be easily interpreted by the test conductor with clear lettering recognizable 3 ft from the screen.

2. Alarm (limiting) conditions shall be indicated by a flashing reversed lettering display of the specific parameter.

3. TT MAX of Table 9 is the panel backside T/C with the highest temperature.

TABLE 13

CRT DISPLAYS 1 THROUGH 8

CRT No.	Title		Parameter Versus Time
1	Power - Panels A, B, C,		Calculated
2	Deflection - Panels A, B, C		ZE131, 132, 133
3	Flux - Panels A, B, E		XE228A, B, C,
4	flow - Panels A, B, C		FE101, FE102. FE103
5	ΔT - Panels A, B, C		(TE104-TE107), (TE105-TE107) (TE106-TE107)
6	Tube Temp along Panel A	a	TE122A, TE116A, TE111A
		b	TE123A, TE117A, TE113A
		c	TE124A, TE118A, TE115A
7	Tube Temp along Panel B	a	TE122B, TE116B, TE111B
		b	TE123B, TE117B, TE113A
		c	TE124B, TE118B, TE115A
8	Tube Temp along Panel C	a	TE122C, TE116C, TE111C
		b	TE123C, TE117C, TE113C
		c	TE124C, TE118C, TE115C
	Tube Temp along Panel A	d	TE111A, TE113A, TE115A
		e	TE111B, TE113B, TE115B
		f	TE111C, TE113C, TE115C

*Maximum of 3 parameters per display.

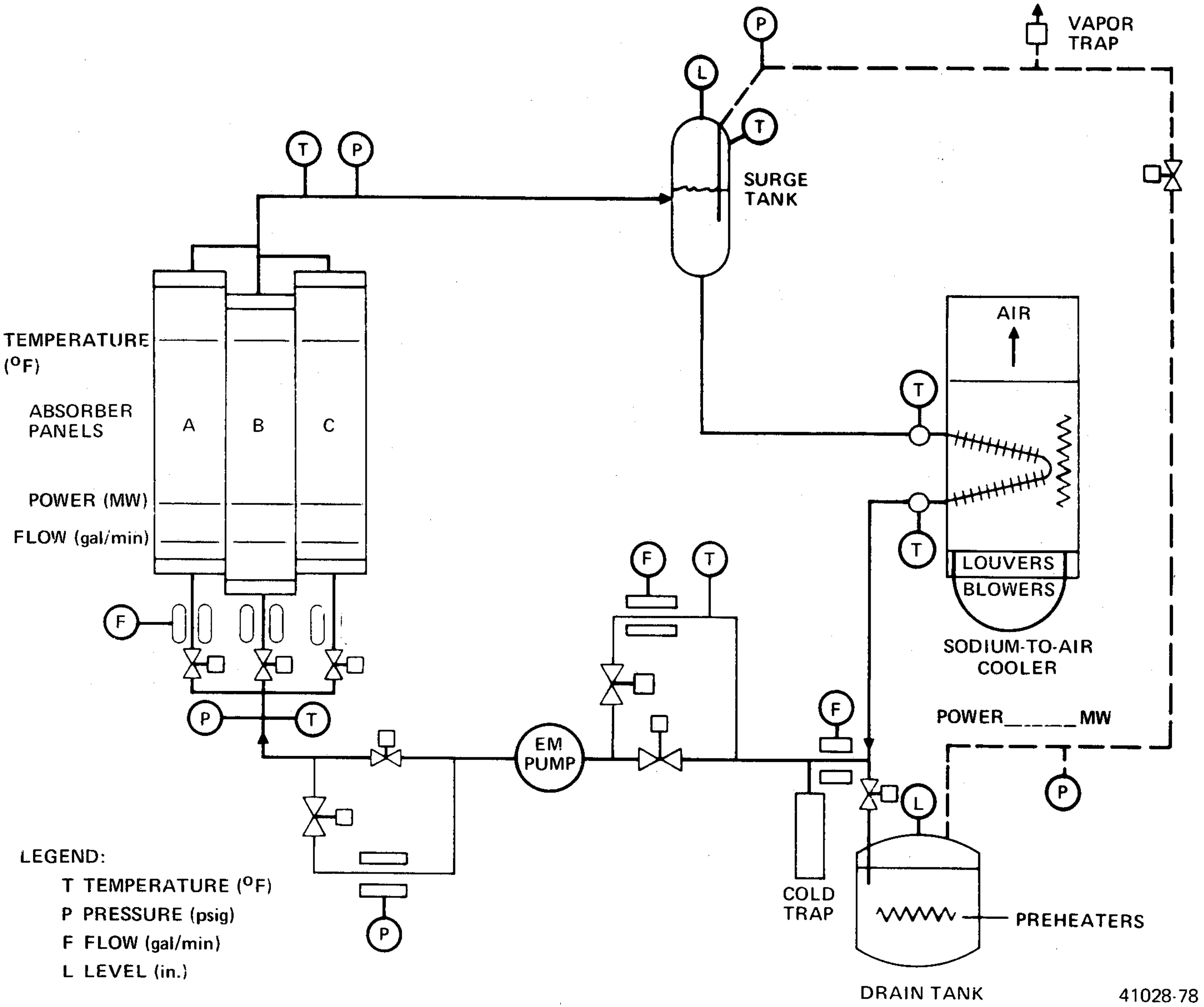


Figure 32. Flow Schematic for Color Display

4.0 TEST OPERATION

This section describes the test objectives and the operating procedures for panel testing. Appendices B and C give a detailed description of the procedures for pretest checkout, sodium loading, safety checks, emergency system checks, operating at the various power levels, obtaining the step increases and decreases in power level or sodium flow, and startup and shutdown.

4.1 TEST OBJECTIVES

The broad objective of the test program was to demonstrate satisfactory operation of a sodium-cooled receiver panel (that duplicates commercial panel construction and configuration) over a wide range of power levels, transient conditions, and emergency situations. Specific test goals that supported this objective were to:

1) Demonstrate satisfactory panel operations at design heat flux and temperature
2) Achieve a maximum number of diurnal thermal cycles
3) Demonstrate satisfactory diurnal startup and shutdown
4) Demonstrate satisfactory nocturnal thermal control
5) Demonstrate control during insolation changes
6) Control several panels in parallel
7) Demonstrate panel dimensional stability
8) Achieve representative lateral power distribution
9) Demonstrate acceptable panel thermal losses
10) Accommodate various simulated emergency conditions.

4.2 TEST PROCEDURE

The ESG test article was tested at the 200-ft (top) level of the CRTF tower. The panel and test fixture were supported by the structural frame surrounding the sodium loop. Figure 33 shows an artist's concept of the panel and loop arrangement.

The ESG panel assembly was connected to the loop assembly mounted on the CRTF tower elevating module while the module was at ground level. Prior to loading the loop with sodium, the loop piping was cleaned with TCTFE (trichloro-trifluoro-ethane). The panels were attached at this time. After drainng the TCTFE from the system and drying, the loop drain tank was loaded with sodium.

Loop checkout, including flowing sodium, was also conducted at ground level. The panel preheat was accomplished with an electric blanket covering the test area of the panels as shown in Figure 34. Following successful checkout of the loop, including flowing sodium, the elevating module was raised to the 200-ft level.

The panel was drained at the end of each day and allowed to cool to ambient conditions. Panel sections not exposed to insolation during the test were trace-heated when sodium was drained. Preheat at the start of each day was accomplished using the reflected energy from several heliostats.

The test program was designed to achieve the following types of testing:

1) Low-power
2) Isothermal
3) Intermediate-power
4) Design-power
5) High-power.

A brief description of the procedures used in each of these categories follows.

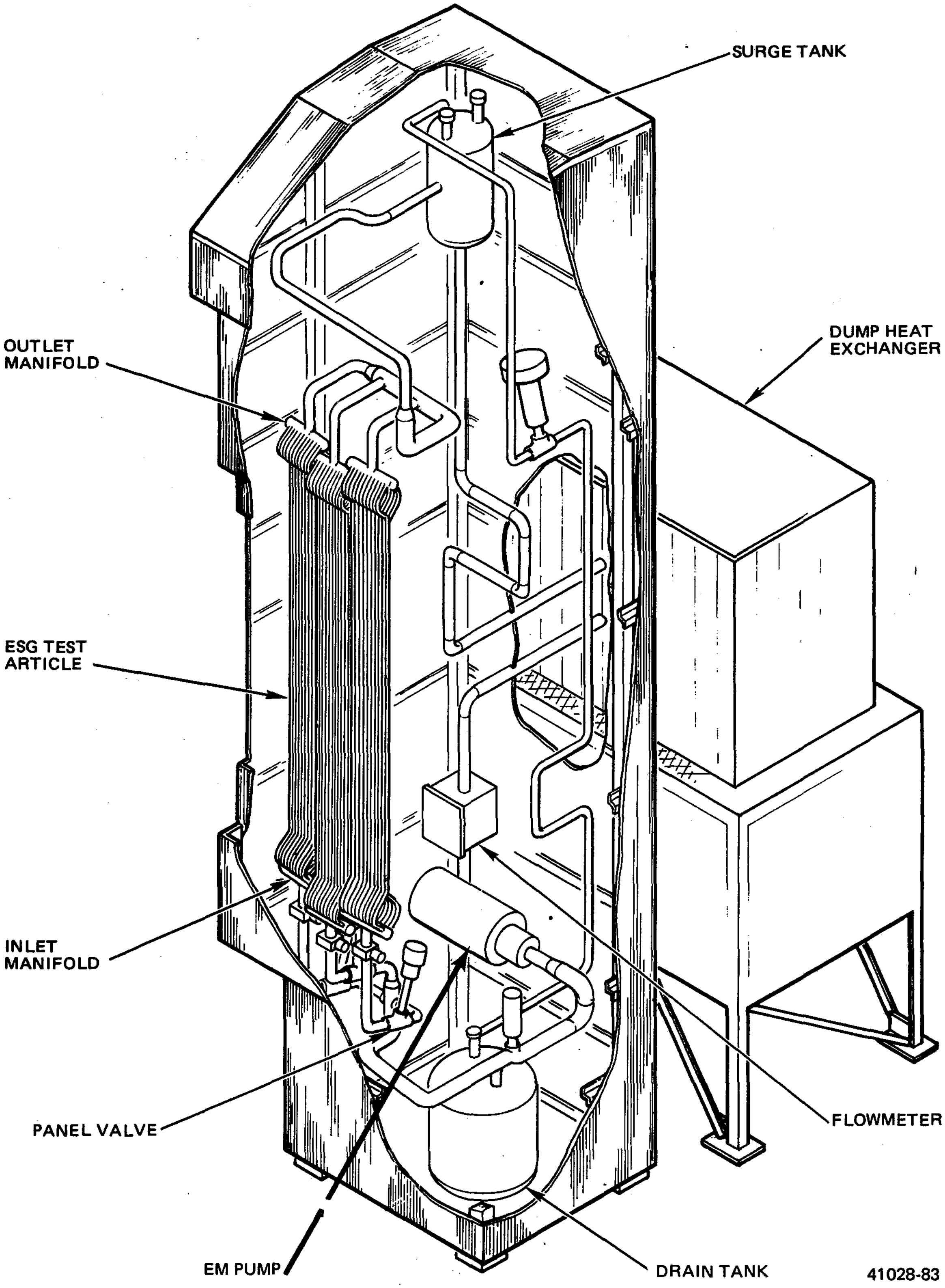


Figure 33. Artist's Concept of ESG Test Article Installed in Sodium Loop at CRTF

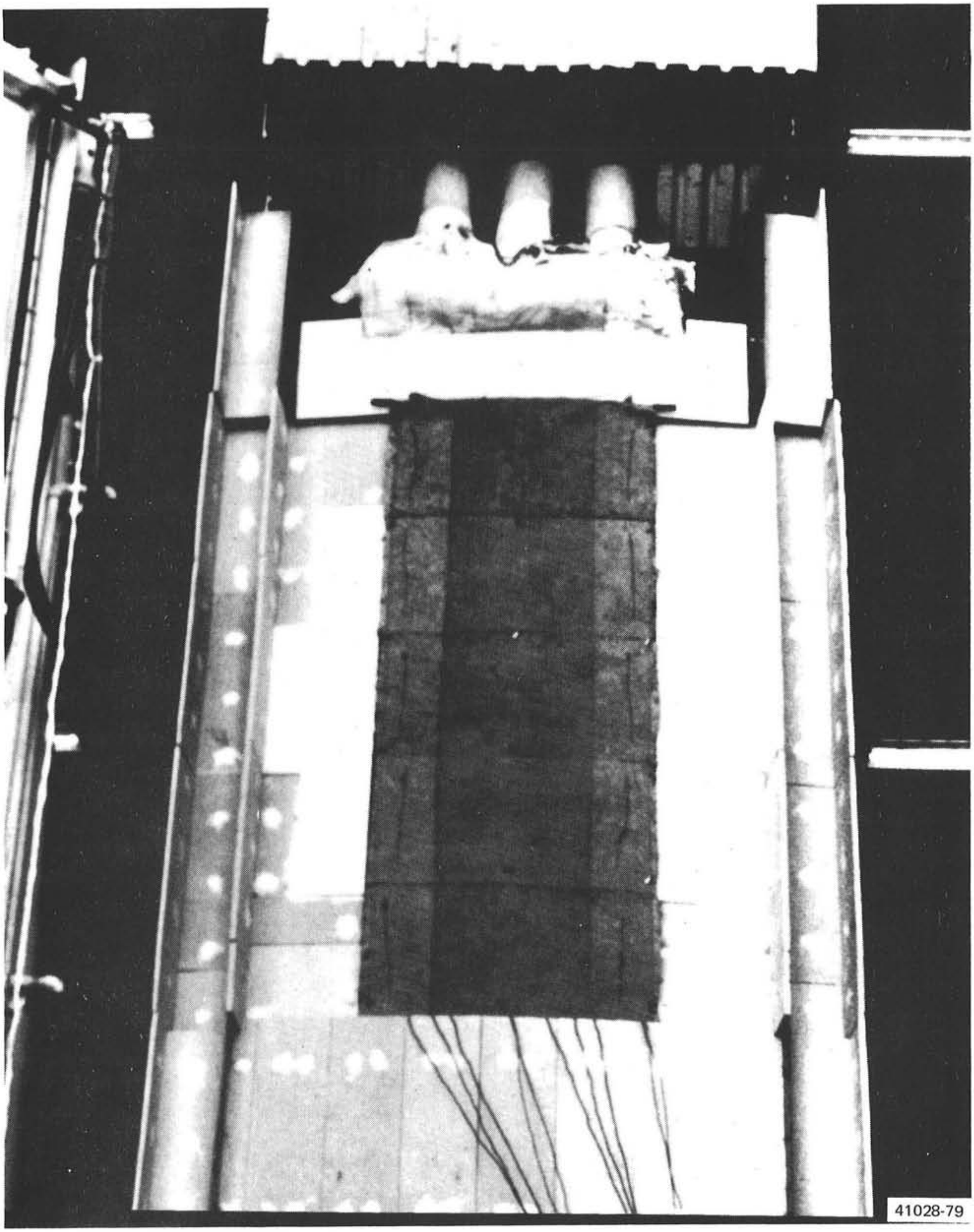


Figure 34. Panel at CRTF with Blanket

4.2.1 Low-Power Testing

The purpose of testing the sodium-cooled solar receiver (SCSR) panel at lower power (0.8 MWt) was to demonstrate the operability of the sodium loop system and determine the characteristics of the system. Methods of operation during this testing phase included both manual and automatic control. The system was routinely operated to (1) demonstrate the use of solar preheat prior to filling; (2) selectively utilize the heliostat field, building up a normal flux distribution on the panel to achieve the desired power level; and (3) perform a series of tests which verify the characteristics of the system.

To demonstrate the operability and stability of the receiver, the system was switched to and from automatic control while operating at steady state. The effectiveness of emergency shutdown and system response was determined by initiating at least one of each of the following emergency shutdowns: (1) heliostat scram, (2) loss of sodium flow scram, (3) dump valve scram, and (4) loss of DHX blower scram during each test.

4.2.2 Isothermal Testing

The purpose of performing isothermal testing of the SCSR system was to determine the conductive and convective heat losses that result when the unheated solar panels are subjected to different environments. Tests were conducted during a low wind condition and during an intermediate wind condition.

Solar preheat of the panel was used while the loop was filling with sodium and to assist heating as the loop temperature was increased to $\sim 700^{\circ}$F. Sodium flow was held constant during each test. When desired sodium flow and temperature conditions were achieved, solar heat and trace heat were terminated and then thermal decay characteristics recorded.

4.2.3 Intermediate-Power Testing

The purpose of performing intermediate power tests (1.7 MWt) on the SCSR receiver panel was to (1) demonstrate the operation of the system while developing a temperature differential of 370 and 550°F across the receiver panel; (2) determine the effects on the system of introducing either a power step (by means of increasing or decreasing the heliostat field) or a flow step (by means of increasing or decreasing sodium flow through the receiver panel). The intermediate-power test series included tests to:

1) Demonstrate stable, steady-state operation of the receiver panel with a power input of 1.7 MWt. The loop operated with a total flow of 115 gal/min through the panels, which produced a sodium temperature increase of 370°F (550 to 920°F). Both manual and automatic operation were used.
2) Demonstrate stable, steady-state operation of the receiver panel with a power input of 1.7 MWt using a total flow of 78 gal/min to develop 1100°F outlet temperatures. Both manual and automatic operation were used.
3) Provide through a series of power and flow step tests additional data on transient operating characteristics while operating at 1.7 MWt with a normal flux distribution. Several power step tests were performed by removing groups of heliostats from the target. After allowing the system to stabilize at the lower flow conditions, the same groups of heliostats were returned to the panels.

4.2.4 Design-Power Testing

The purpose of performing design power tests (2.5 MWt) on the receiver panel was to (1) demonstrate the stability of the test article operating at design power conditions, (2) determine the effects on the system resulting from a series of power steps ranging from 20 to 60%, and (3) demonstrate system response to emergency shutdown.

The tests performed in the design power test series included:

1) Stable, steady-state operation of the receiver panel and system was demonstrated at a power input of 2.5 MWt. The loop was operated at a total flow through the panels of 115 gal/min producing an overall sodium temperature increase of 550°F (550 to 1100°F). Both automatic and manual control of the receiver panel and DHX was used. During these tests, bumpless transfer of panel control sensors was demonstrated, i.e., flux sensor to thermocouple.
2) A series of power step tests was performed, allowing either natural cloud passage or preprogrammed heliostat removal and replacement to produce the power transient. The power transient tests were initiated from a steady-state power level of 2.5 MWt with system conditions as described in 1) above. The magnitude of the power steps ranged from 20 to 60%.
3) While the initial test plans included operation at steady state with a skewed flux distribution, this testing was considered unnecessary since the standard distribution gave a sufficiently large temperature gradient across the edge panels.
4) Open-loop tests were conducted from several steady-state power levels, increasing and decreasing the power in steps. Repeat tests were accomplished to establish sufficient data on the thermal characteristics of the system.
5) Additional operating experience was obtained by performing emergency shutdowns. These tests, initiated at the completion of a day's run, included (a) heliostat scram, (b) loss of sodium flow scram, and (c) dump valve scram.

4.2.5 High-Power Testing

The purpose of performing tests on the receiver panels at more than design power was to demonstrate that the panels and DHX can be safely operated at thermal power levels up to 20% greater than design. Unfortunately, because of the limitations of the EM pump, a flow rate higher than 115 gal/min could not be achieved and the first item below was not accomplished. Item 2 was conducted.

The tests to be performed in the high-power test series included:

1) Stable, steady-state operation of the receiver panel and system with the full field of heliostats on target (~3.0 MWt). The loop was to operate at a total flow of 140 gal/min, producing an overall sodium temperature increase of 550°F (550 to 1100°F).
2) An investigation of the higher temperature characteristics of the panel. During this test, the overall temperature differential across the receiver panels was increased to 600°F ΔT while maintaining a steady-state flow of 115 gal/min. A maximum power of 2.85 MWt was achieved.

5.0 TEST RESULTS

A summary of the 34 tests conducted during this program is shown in Table 14. The early tests were conducted at low power (0.8 MWt) in order to perform system and control checkout studies, to familiarize the crew with the operation characteristics of the system, and to verify the various alarm and scram conditions. After ten tests at low-power conditions, eight tests were performed at intermediate power levels (1.7 MWt). These tests tended to repeat many of the test activities conducted at the lower power level. The remainder of the testing was performed at nominal design power level conditions (2.5 MWt). However, because of the concern with the side panel insulation, power levels (and, hence, flux spillage) were reduced by about 10%.

The sodium flow system worked flawlessly throughout the tests, and no test delay or lost test time was attributed to the sodium flow system. Loss of test time was due primarily to the weather and to failure of the high-temperature insulation on the side frames. Some weather-related delays were the result of inadequate electric preheat temperature in the dump heat exchanger or, on occasion, in the header region of the test panel due to high winds and low ambient temperatures.

In general, testing was initiated whenever the weather conditions showed promise of adequate sunlight and the condition of the frame insulation was adequate.

5.1 STARTUP AND SHUTDOWN

The test startup activities consisted of preheating the test panel to a temperature of about 400°F prior to filling the loop with sodium. This was accomplished using four heliostats with a four-point aim pattern toward the corners. If the insulation was poor, additional heliostats would be used to achieve the necessary preheat. Figure 35 shows a startup sequence with a

TABLE 14

ESG SOLAR PANEL TEST — SUMMARY
(Sheet 1 of 3)

TEST	WEATHER	9 10 11 NOON 12 13 14 15 16	MAX NO. HELIO.	PURPOSE	COMMENT
1	C/WIND	1981 10/30	15	HOT CHECKOUT-FLOW METER WETTING	
2	C/HI-HAZE	11/5	22	HOT CHECKOUT-FLOW METER CALIBRATION	
3	PC	11/6	50	LOW POWER TESTING, DHX OPERATION PANEL AUTO CONTROL CHECKOUT	VALVES CLOSE TO LIMIT
4	C	11/9	22	CONTROL CHECKOUT	VALVES CLOSE TO LIMIT - MANUAL SCRAM ON PANEL A OVER TEMP.
5	C	11/2	22	CONTROL TUNE - FLOW RATE MAP	O.K. CONTROL ACTION
6	C/HI-HAZE	11/13	48	FLOW RATE MAP - CONTROL TUNE	O.K. CONTROL ACTION
7	C	11/16	48	CONTROL TUNE, PB, RS, R, LL	AUTO SCRAM COMPLETE
8	C/HI-HAZE	11/17	48	CONTROL TUNE, OPTIONAL FEED FWD	
9	C/WIND	11/18	48	CONTROL TUNE, DHX AUTO CONTROL	
10	PC	11/19	48	ISOTHERMAL COOL DOWN	STOP - CLOUDS
11	C	11/20	108	INTERMEDIATE POWER - DHX CONTROLLER TUNE, PANEL CONTROL TUNE	POOR CONTROL
12	PC	11/25	110	DHX CONTROLLER TUNE	STOP - CLOUDS MALFUNCTION PANEL A CONTROL

C - CLEAR, PC - PARTIAL CLOUDY, I.P. - INTERMEDIATE POWER, D.P. - DESIGN POWER

TABLE 14

ESG SOLAR PANEL TEST – SUMMARY
(Sheet 2 of 3)

TEST	WEATHER	9 10 11 NOON 12 13 14 15 16	MAX NO. HELIO.	PURPOSE	COMMENT
13	PC	12/5/1981		CURE PYROMARK, VIP DEMONSTRATION	
14	C	12/8		TUNE CONTROLLER-C	TC106 DISCONNECTED
15	C	12/9	110	CONTROLLER CHECKOUT, BACKSIDE TC FOR FEED-FORWARD SIGNAL	FLUX SENSORS ARE BETTER FEED FORWARD
16	C	12/17	112	I.P. CURE PYROMARK CONTROLLER TUNE	GOOD DHX CONTROL
17	C → PC	12/18	110	I.P. CONTROLLER TUNE	CONTROL GOOD
18	C	12/21	213	DESIGN POWER (D.P.) CONTROLLER TUNE	CONTROL GOOD
19	C	12/22	189	D.P. 2.6-MW STEADY STATE WITH VALVES WIDE OPEN	FRAME INSULATION FAILURE
20	C → PC	1982 1/7	112	I.P. CONTROLLER TUNE	THREE SCRAMS DUE TO LOSS OF COOLING WATER
21	C	1/14/82	175	D.P. POWER STEPS	FRAME INSULATION FAILURE
22	C	1/15	212	D.P. POWER STEPS	OVERTEMP SCRAM ON PANEL C
23	C	1/18	212	D.P. MAX FLUX, 1.53 MW/m^2	FRAME INSULATION FAILURE
24	C	1/26	201	D.P. POWER STEPS TO C/O CONTROL SYSTEM	GOOD CONTROL
25	PC	2/5	189	D.P. CONTROL SYSTEM TUNE	PANEL C CONTROLLER FAILURE
26	PC	2/9	214	D.P. POWER STEPS	STOP DUE TO CLOUD COVER

TABLE 14

ESG SOLAR PANEL TEST – SUMMARY
(Sheet 3 of 3)

TEST	WEATHER	NOON 9 10 11 12 13 14 15 16	MAX NO. HELIO.	PURPOSE	COMMENT
27	C	2/12	202	D.P. POWER STEPS	CONTROLLER STUDY
28	C	2/16	16	FLOW CALIBRATION	FRAME INSULATION FAILURE
29	PC	3/1	171	PUMP FLOWRATE CHECK	POOR INSOLATION
30	C	3/4	145	POWER STEPS-WORKSHOP	FRAME INSULATION FAILURE
31	PC	3/5	81	WORKSHOP	STOP DUE TO CLOUD COVER
32	C	3/8	215	WORKSHOP	FRAME INSULATION FAILURE
33	C	3/9	218	POWER STEPS-WORKSHOP	RTAF NOT WORKING
34	PC	3/10	217	ISOTHERMAL TEST	END OF TEST

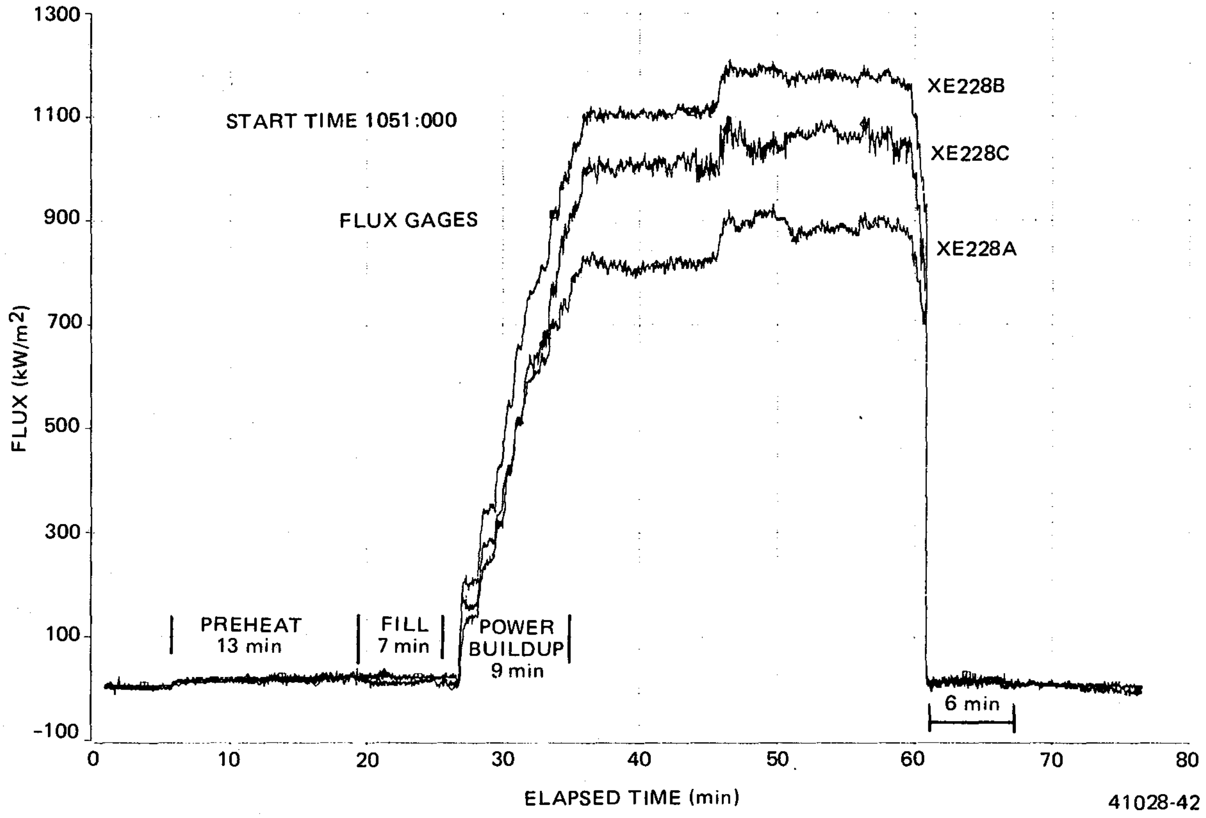


Figure 35. Test 19, Panel Flux Gage Readings

preheat phase lasting 13 min. With satisfactory preheat, the loop was filled with sodium using the sequence discussed in Section 3.0. Fill progress can be monitored by observing the temperature changes shown by pipe and panel thermocouples, which indicate the passage of the sodium level. Sodium fill is complete when the level probe in the surge tank indicates a 50% fill level. Figure 35 shows the fill time to be 7 min.

Immediately after the system is filled, power was applied to the pump and a flow rate of ~25% was established for a short period of time to establish uniform temperatures around the loop. Power was built up by moving predetermined groups of heliostats onto the panel to prearranged aim points. A five-point aim pattern was normal. Groups of heliostats were added in a continuous sequence until the desired power level was achieved. Figure 35 shows a power buildup phase of 9 min. The total startup time for the test recorded in Figure 35 was 29 min. This demonstrated a minimum startup of less than 30 min as one of the test goals. Typical startup times for clear weather were from 30 to 45 min.

Figure 35 also shows a shutdown time of 6 min from the time the heliostats were removed until the sodium loop was drained. Heliostats were removed, in general, using the scram mode. Frequently, this was done as a verification of various emergency automatic shutdown events. After the heliostats were removed, the EM pump continued to circulate sodium until the loop temperature was essentially uniform. The heat dump remained in operation at low power until the sodium temperature was reduced to about 600°F. At this point, the drain valve was opened and all sodium returned to the drain tank.

The active area of the test panel was allowed to cool to ambient air conditions. All other sodium equipment, piping, and tanks, including the panel headers and ends, were equipped with electric trace heating that maintained these items at a temperature above 400°F.

The sodium outlet temperatures for each of the panels, as well as the sodium inlet temperature during startup and shutdown for the test discussed above, are given in Figure 36. The inlet temperature (TE-107) variation is due to cold spots in the loop piping such as at the EM flowmeter locations and the dump heat exchanger tube bundle. The heat exchanger is equipped with doors that close in order to prevent air flow through the unit, but the door seals were poor and maintaining preheat temperature was difficult, on windy days.

Figure 37 presents the three panel flow rates for Test 19. A large amount of noise existed on these signals throughout most of the testing, due in part to a mismatch between the low signal conditioning and the "hi level" data system card. This condition was corrected late in the testing and improved the signal substantially. At this time, it was also noted that the EM pump generated substantial flow oscillations at power levels between 90 and 100%, without increasing total flow rate. Most testing was accomplished at full pump power, with flow modulation using the panel control. When this was observed, pump power was reduced to about 90%. Occasional bursts of noise that remain unexplained were still observed .

Panel temperature characteristics during preheat and fill for Test 24 are shown in Figures 38 through 40. This startup was not as rapid as for Test 19, described above. Following the fill sequence, the heliostats were removed for a few minutes so that an operator could turn off some preheat switches that were located in the preheat electrical panel at the base of the loop structure. (Panel preheat circuits located between the inlet and outlet temperature measurements were switched off to allow a more accurate determination of panel absorbed power.)

On each panel, the two edge tubes and the center tubes were instrumented with four backside thermocouples at 1, 3/4, 1/2, and 1/4 times the aperture

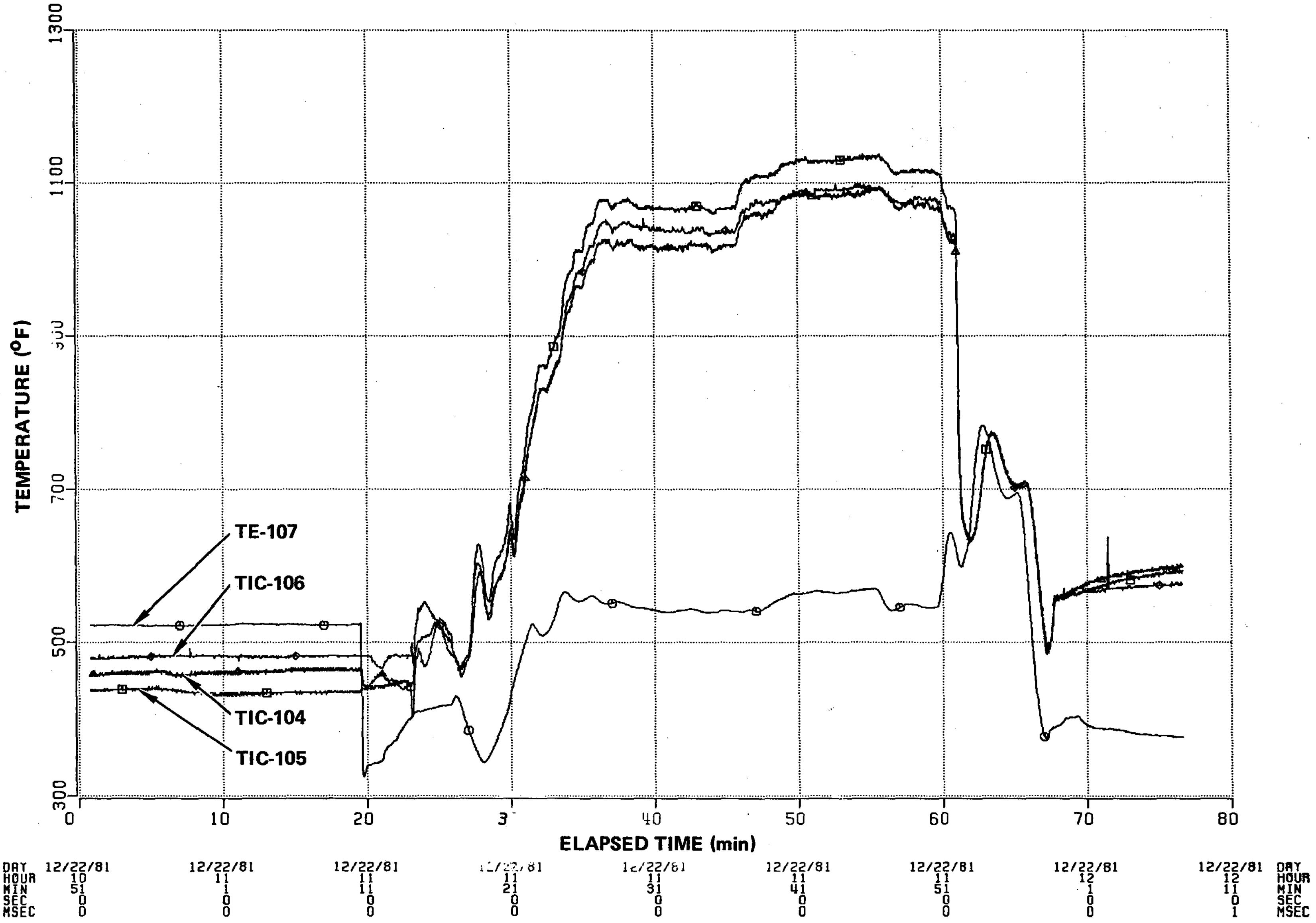


Figure 36. Sodium Inlet and Outlet Temperatures for Test 19

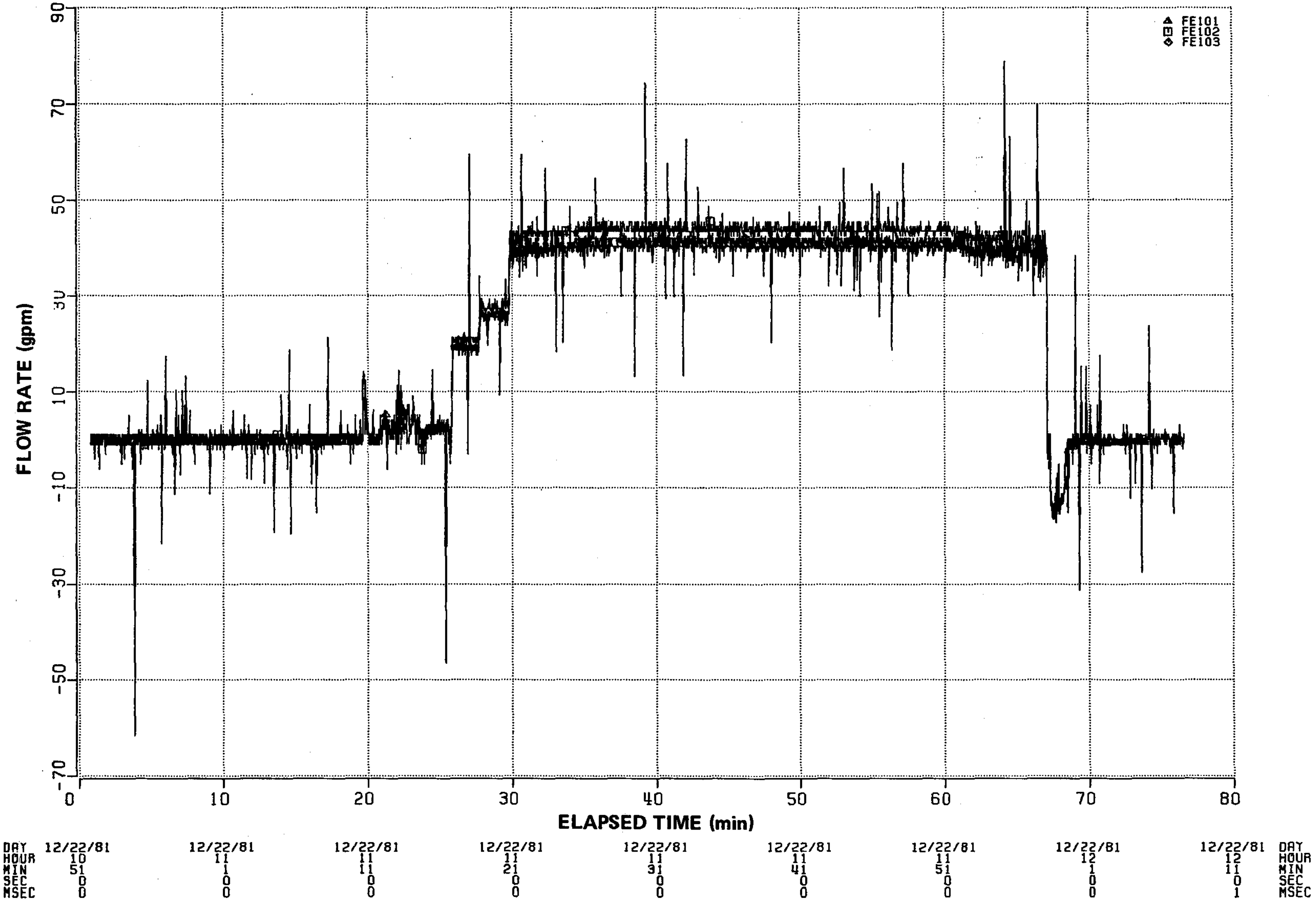


Figure 37. Sodium Flow Rate for Test 19

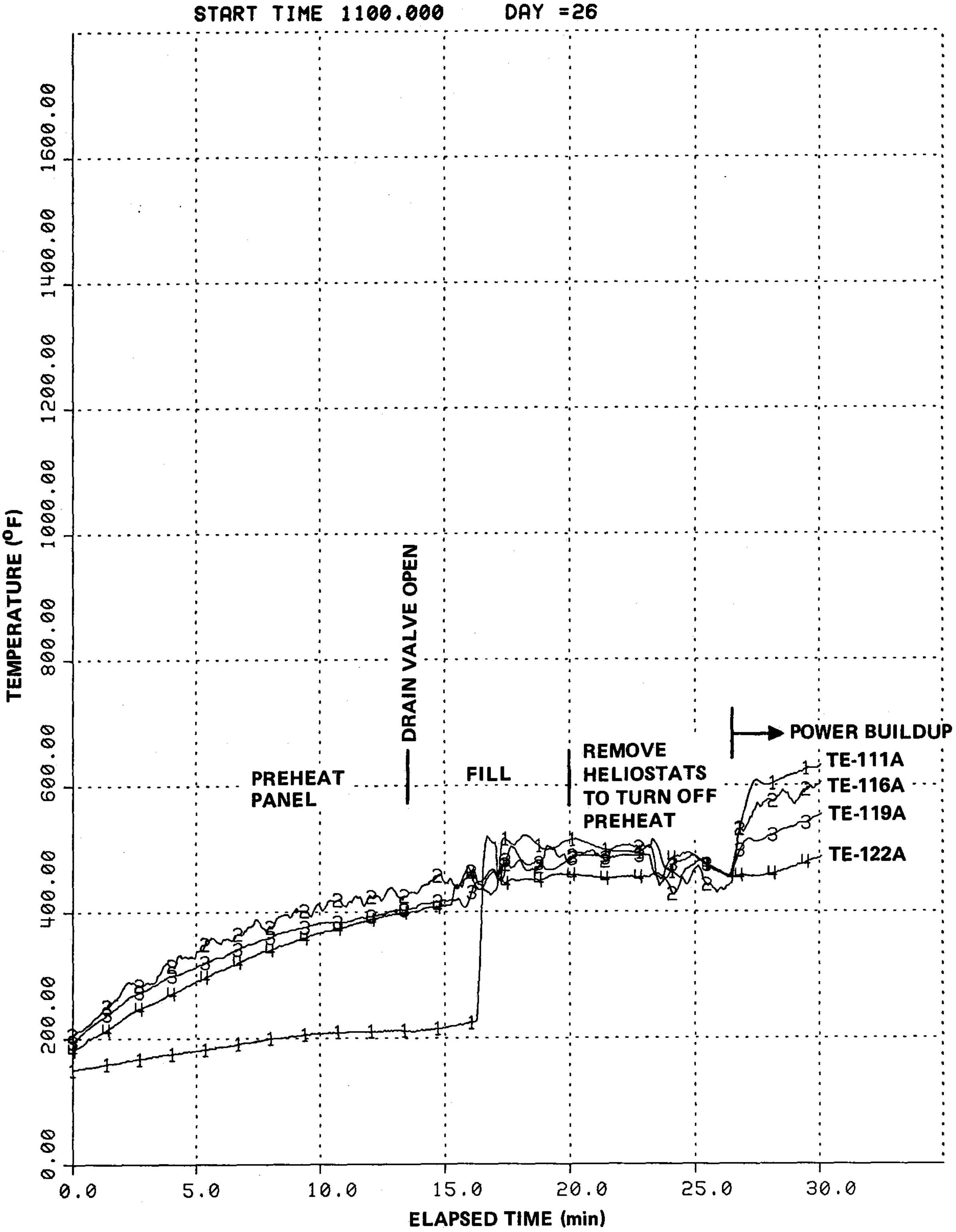


Figure 38. Preheat and Fill for Test 24

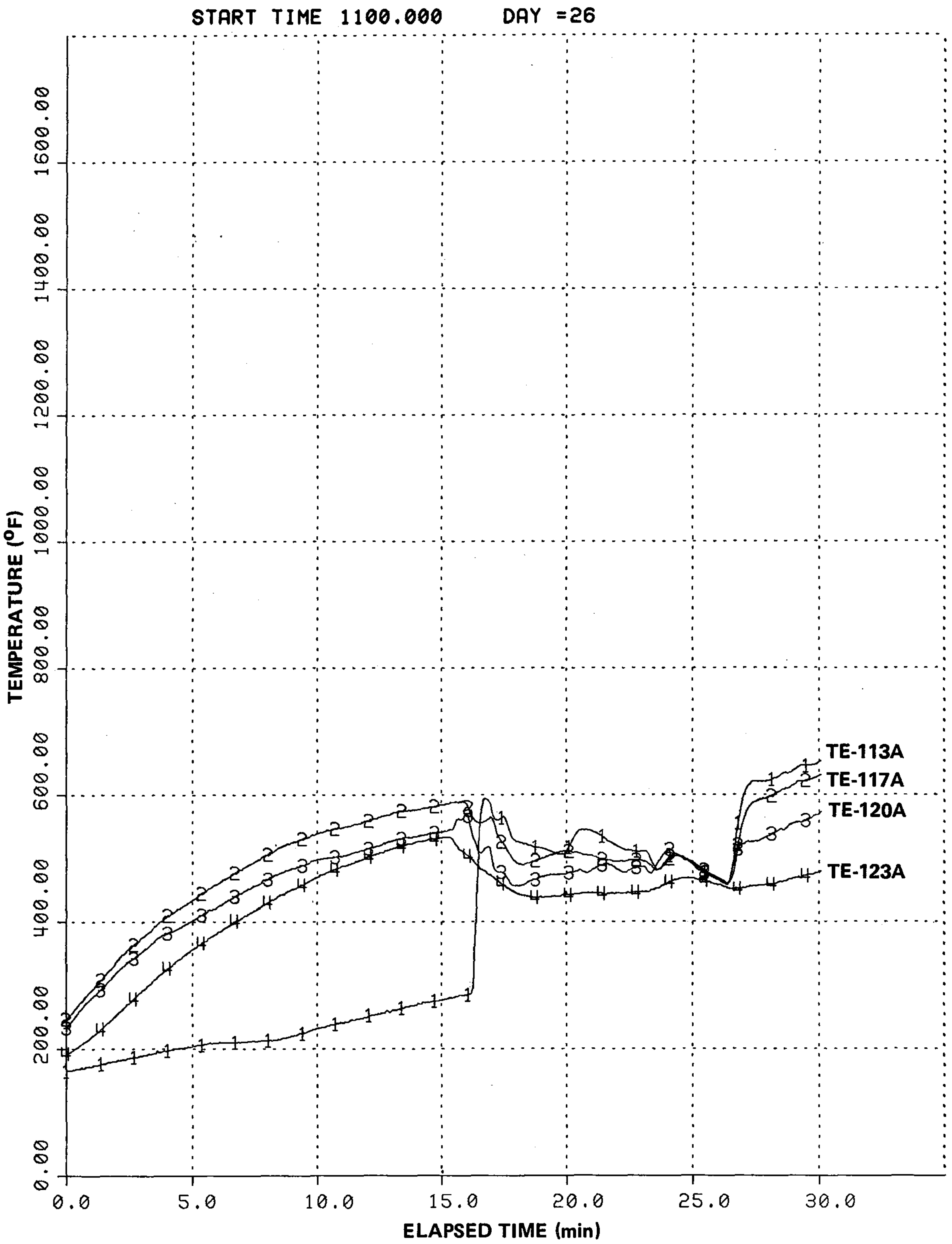


Figure 39. Panel A Temperatures during Fill for Test 24

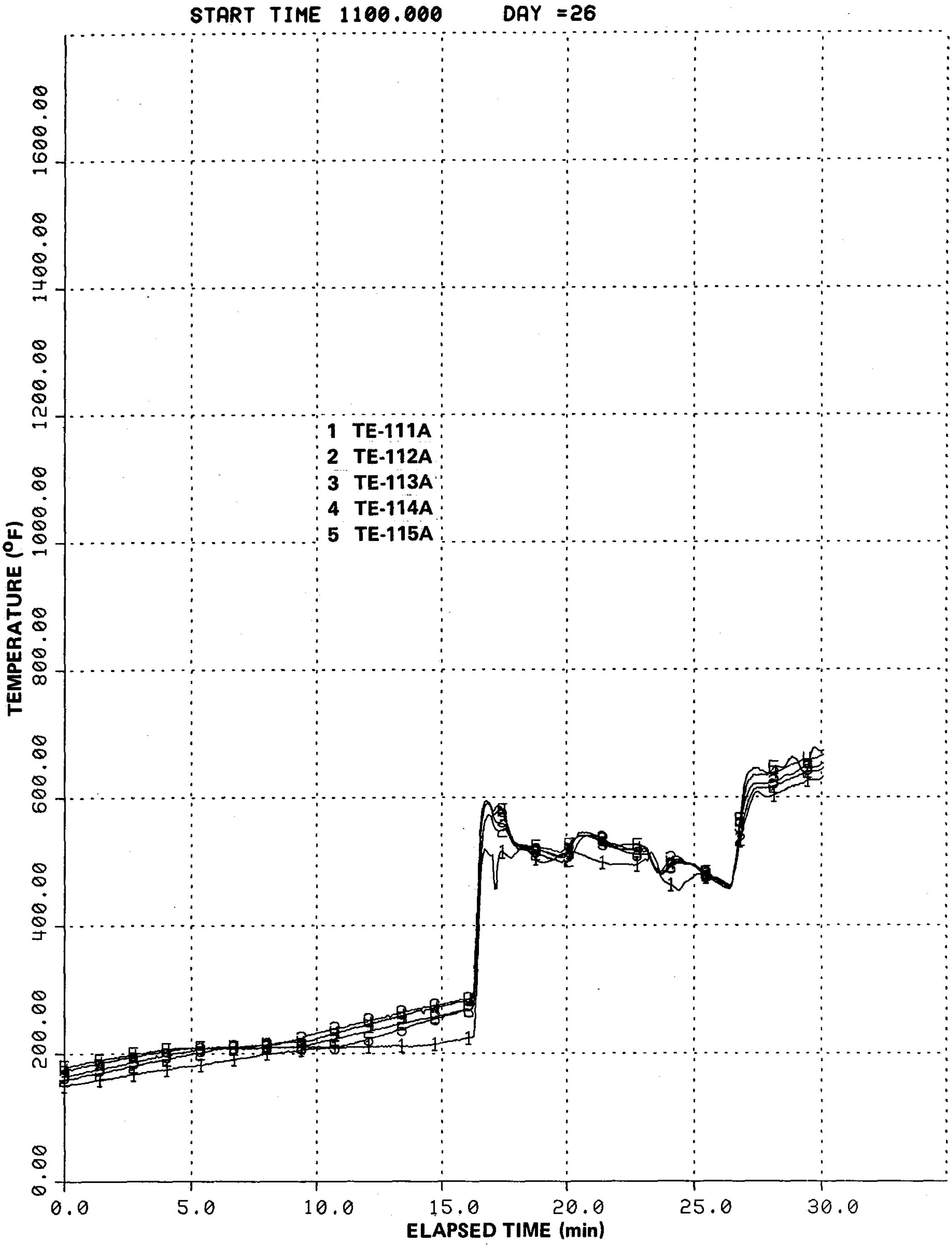


Figure 40. Top Row Temperatures for Panel A during Fill for Test 24

height. These temperatures are shown in Figures 38 and 39 for the outside edge tube and the center tube of Panel A. In general, it is noted that the outside edge tube (A-1) of Panel A has a lower preheat temperature than the center tubes, though still satisfactory. The preheat temperatures of Figure 39 are typical of the other center tubes, and Figure 37 is also typical of the outside edge tube (C-21) on Panel C. The top thermocouple on each panel was shaded by the high-temperature insulation that shielded the upper header region; consequently, preheat at this location was poor. A preheat temperature of above 200°F was considered satisfactory for fill since the temperature of the sodium filling the panel from bottom to top was adequate to heat this region without cooling enough to freeze. The upper header region was heated electrically to ~400°F, and the cool region at the top of the panel aperture was estimated to be less than 1 ft in length. The rapid increase in the tube top temperature in Figures 38 and 39 indicates the passing sodium level. Note that each of the thermocouples along the tube in Figure 39 shows the passage of the sodium with a sequential delay from bottom to top, TE-123A to TE-113A. Since the thermocouples were mechanically attached to the backside of the tubes, the variation in contact resistance tended to vary the response time.

With the four preheat heliostats, the sodium temperature is increased by about 50°F while sodium flows through the panel. When the preheat heliostats are removed (to allow topside access), the panel temperature tends to equalize since a low flow rate continued.

Figure 40 shows that the sodium fill level within the tubes of this panel (typical of all panels) is very uniform, as the temperature change response for each of these aperture top measurements is nearly identical.

During the fill and power buildup phase, Test 22 presented a special condition which appeared to be caused by the temporary blockage of the edge tube on Panel C (C-21). The over-temperature on this tube resulted in a test heliostat scram requested by the test conductor. The panel and surrounding frame insulation were inspected visually. Some insulating batting, normally between Tube C-21 and the high-temperature insulation board, was missing and was replaced. It was considered at the time that this missing insulation batting allowed high-flux insolation to have an impact on the backside thermocouples sufficient to cause the high temperature reading. The test was restarted and ran for about 3 h, until the end of the shift. Post-test examination indicated that high temperatures were reached on this tube and that the tube was moderately deformed at the top end of the panel.

Figure 41, the four temperature measurements along the backside of Tube C-21, shows that this edge tube experienced high-temperature conditions, with a peak of about 1700°F for ~2 min, at a point about 8 min after fill, during the power buildup phase. All four backside thermocouples show the high-temperature conditions. Also noted on this figure is the time that the EM pump flow was initiated. Figure 42 shows an initial flow rate of 35 gal/min through this panel, increasing later to 39 gal/min, the full capability of the pump. The solar flux on the panel at the time of this event was about 0.8 MW/m^2. The cooldown was relatively slow after the heliostats were removed from the target. The other panels show a very rapid, sharp decrease in temperature after scram as the cold sodium enters from the bottom to the top of the panel. Figure 43 shows the preheat and fill conditions for Panel C. The preheat condition shown appears to be normal and typical as described above. Fill temperature is shown to be about 450°. This is typical of the other panels. This curve also shows a low thermocouple reading, number four of the sequence, which is TE-124. This thermocouple normally reads low and apparently has pulled away somewhat from the surface of the tube. For comparison purposes, the preheat and fill condition for the inboard

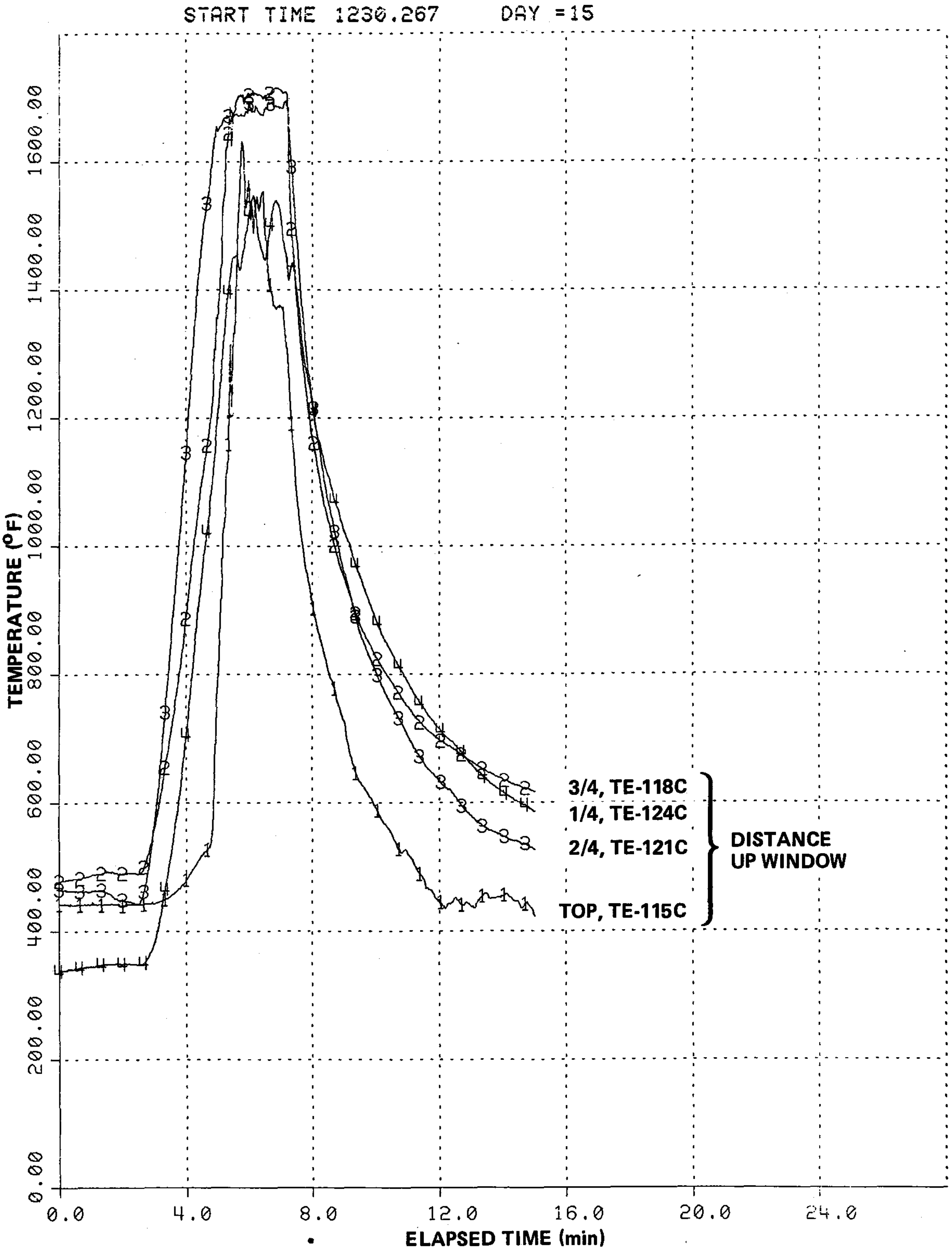


Figure 41. Tube C-21 Temperature, Test 22

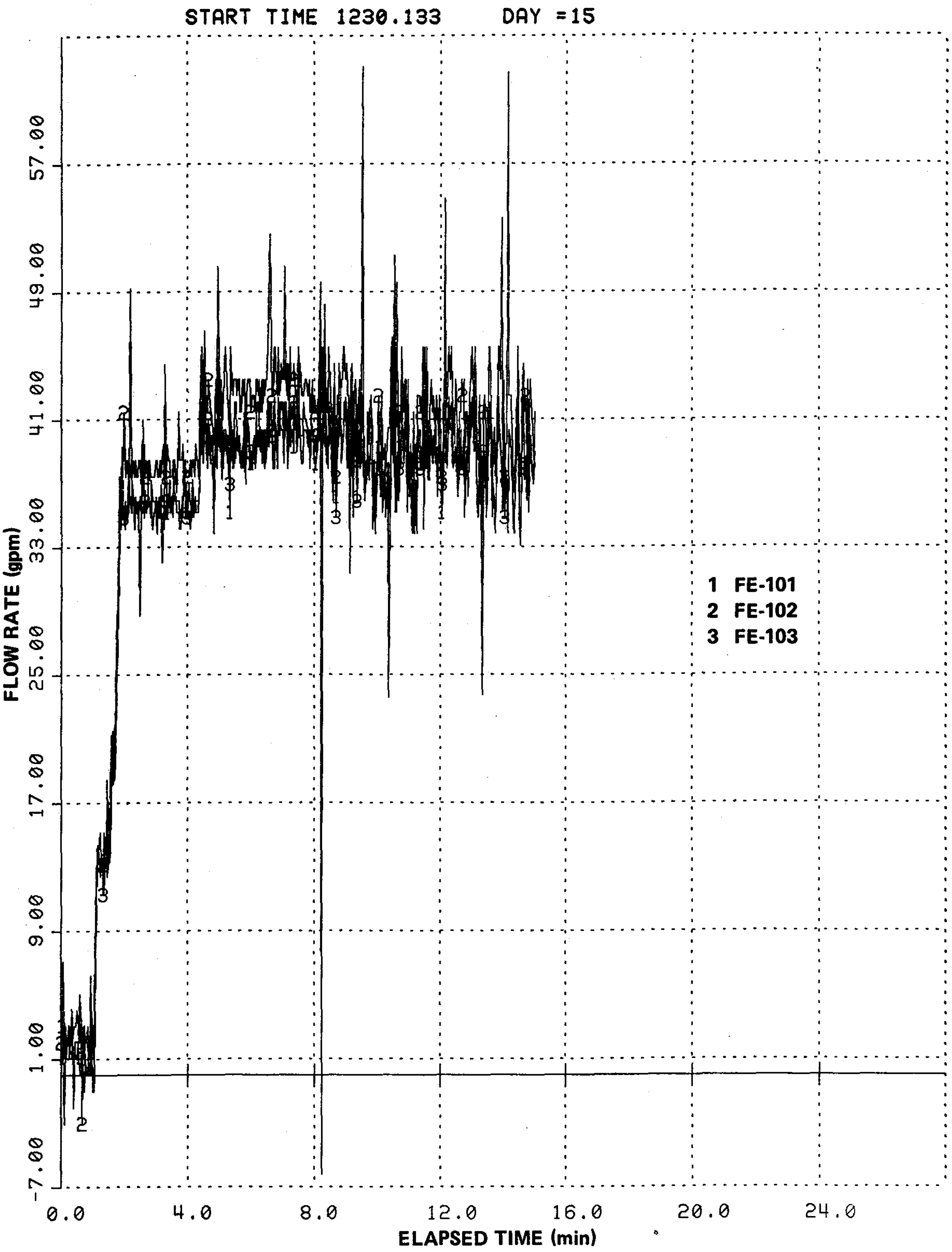


Figure 42. Sodium Flow Rate for Test 22

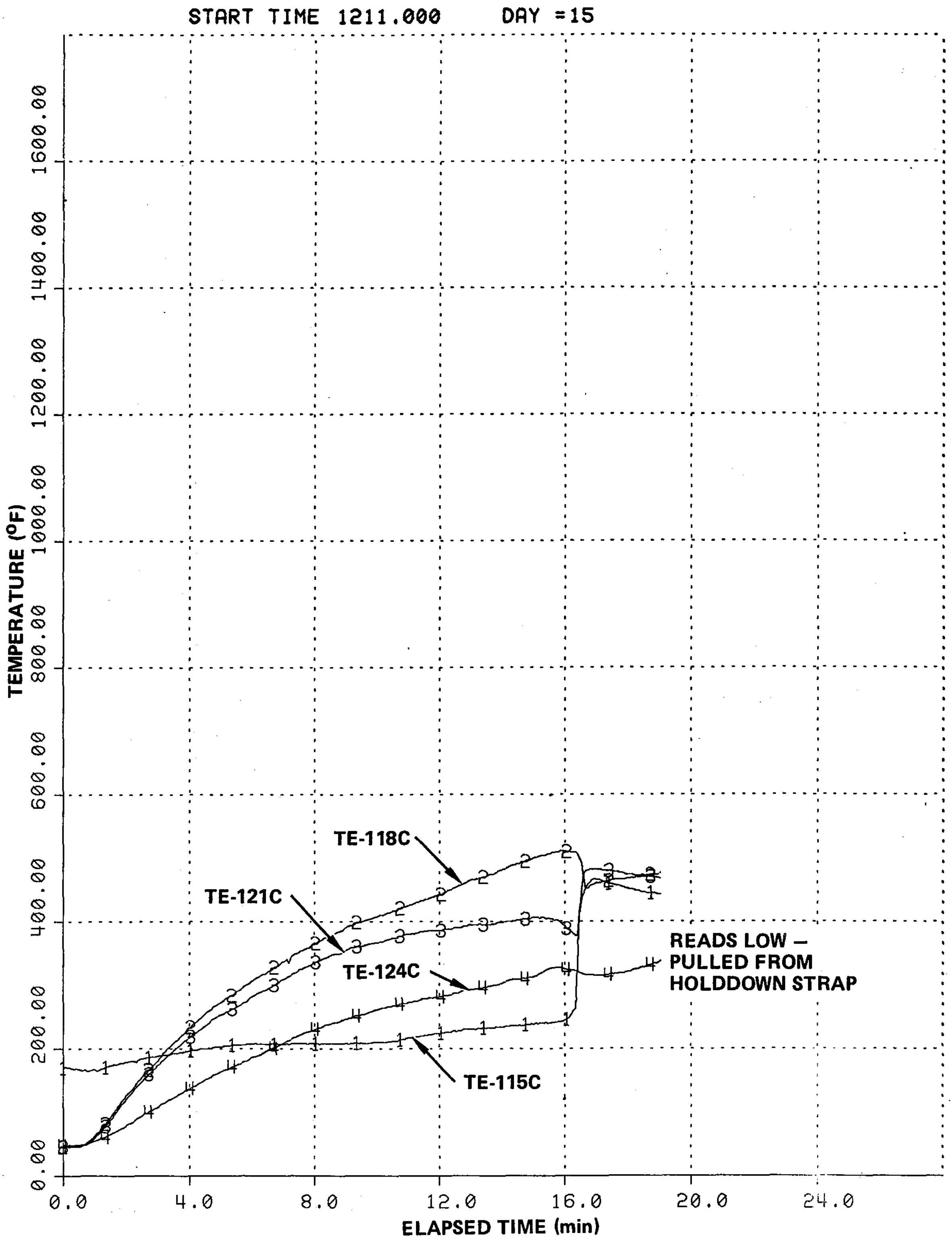


Figure 43. Outboard Edge Panel C Temperatures during Preheat and Fill, Test 22

edge of Panel C is shown in Figure 44. For the inboard edge of Panel C, fill temperature is shown to be a uniform 450^{0}, just as on the outboard edge. Figure 45 shows the backside thermocouples across the top of Panel C. CE-111C is the inboard edge of Panel C going from left to right to TE-115C, which is on the outboard edge of Panel C. Note that all these thermocouples had low preheat because of the shading from the solar radiation but that all except TE-115 show the evidences of fill at about the same time, whereas TE-115 appears to be delayed about 30 s. However, the panel did fill completely, as all thermocouples indicate temperatures above 400^{0}.

The conclusion from this data is that flow blockage occurred in Tube C-21. The reason is not clear, but it is most likely that blockage occurred in the lower panel region. In the past it had been difficult to preheat this region, particularly in strong wind conditions. During this test, the winds were not particularly strong but were from the west, which tends to expose the edge of Panel C to cooler conditions. A close visual examination of the panel indicated that the upper part of Tube C-21 is bowed outward nearly one tube diameter. The post-test examination section presents additional measurements on this tube.

The backside insulation blanket was removed from the upper header region of the panel to inspect for any damage. The tube-to-header joint appeared satisfactory and with difference compared to the adjacent tubes. A dye penetrant inspection was conducted and no anomalies were found. The mechanical support for this tube was distorted but otherwise in satisfactory condition. Testing was continued.

5.2 STEADY-STATE PERFORMANCE

Steady-state performance occurred on clear days under either manual or automatic control during periods when the power level was not being varied.

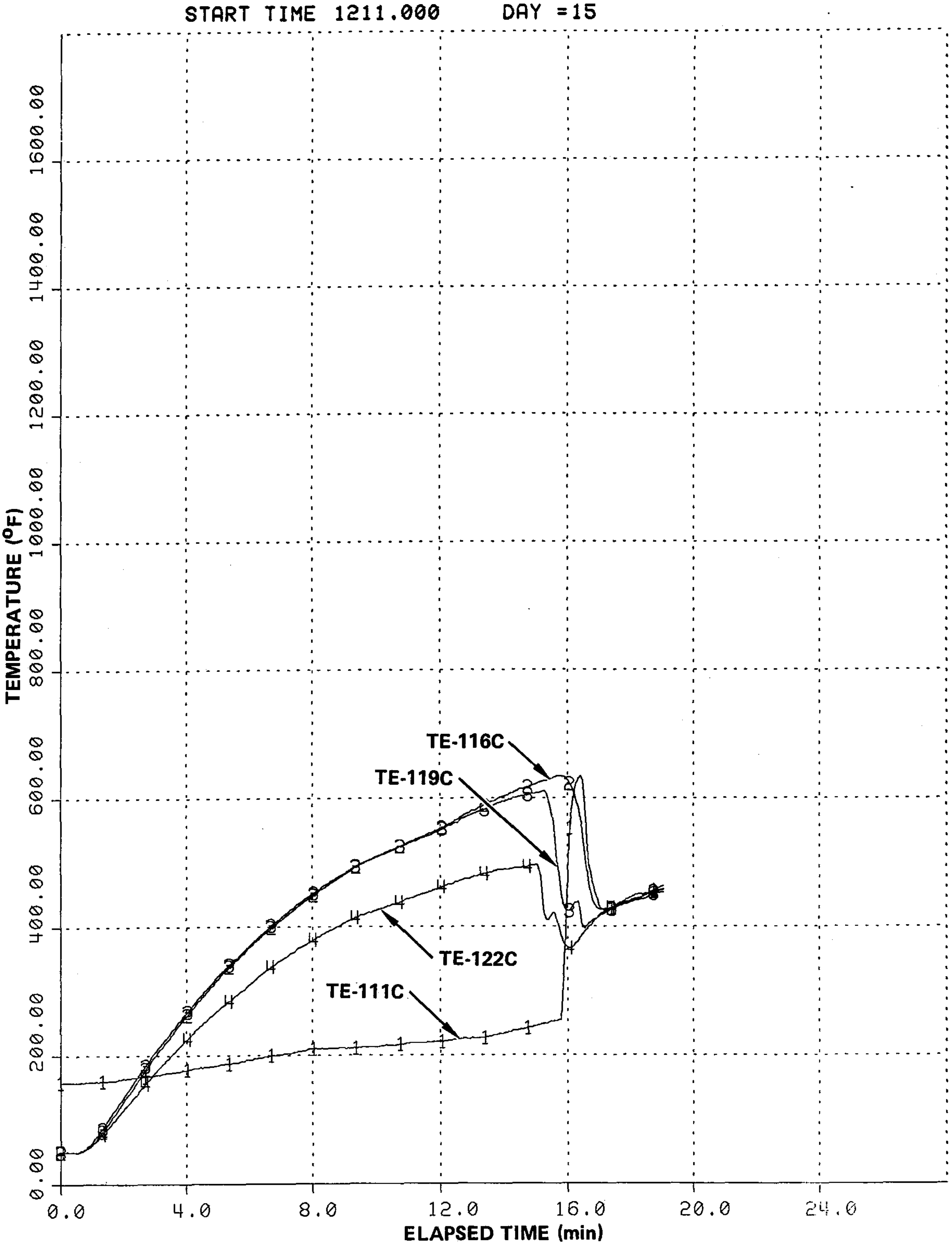


Figure 44. Inboard Edge Panel C Temperatures during Preheat and Fill, Test 22

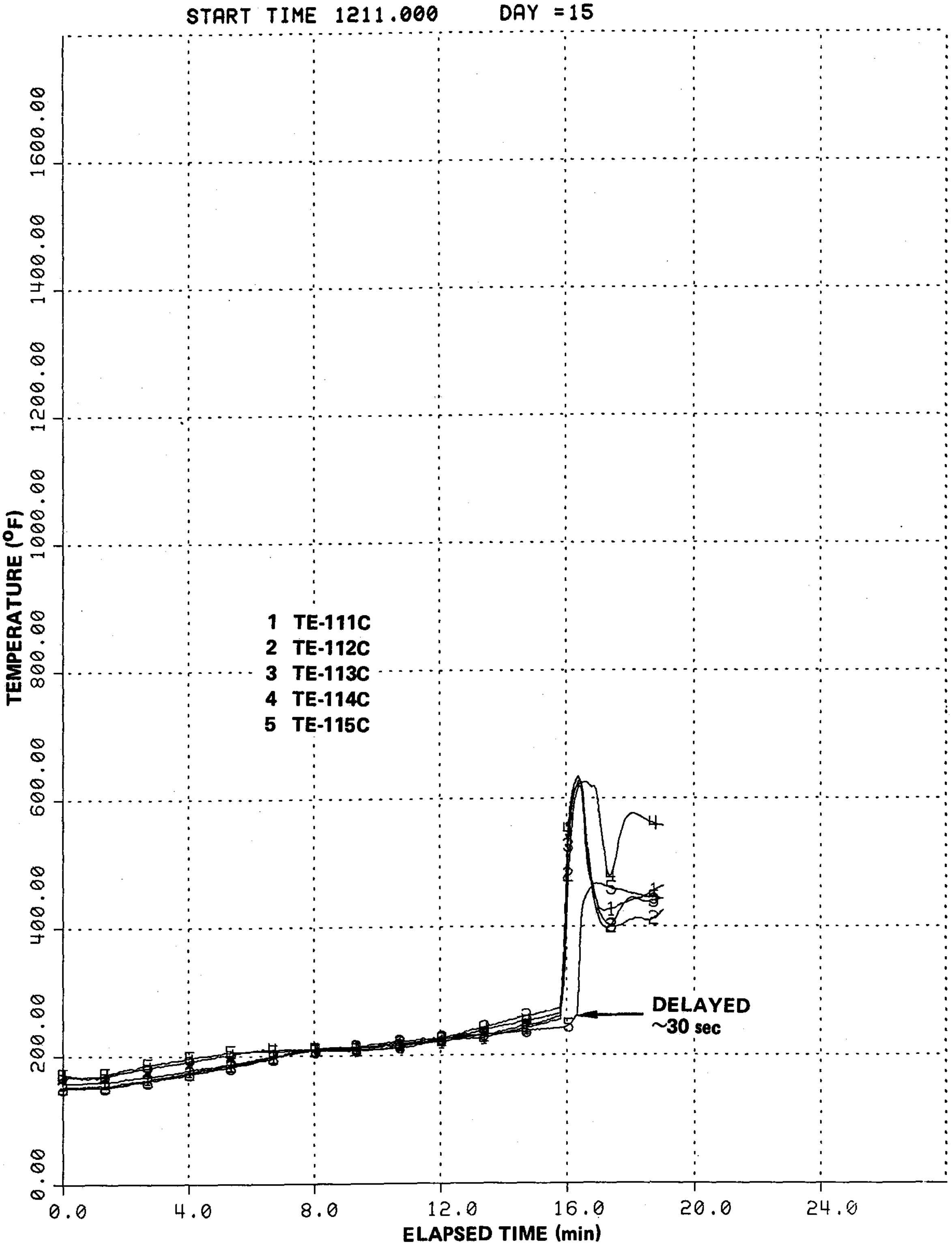


Figure 45. Top Row Temperatures for Panel C during Preheat and Fill, Test 22

Figure 46, the three-panel flux sensor measurements during the latter part of Test 23, shows that the panel incident flux was relatively steady; also superimposed on this curve is the insolation data for that period of time. Toward the end of this run, a scan with the incident flux measuring system (IFMS) was made, which shows up on the plot as deep, sharp variations in the flux reading as the scan sensor bars pass over and shadow the flux sensors. The incident flux measuring system is discussed in an earlier section. During this scan, a maximum flux of 1.53 MW/m^2 was measured. The flux distribution is discussed later in this section. Figure 47 shows the panel outlet temperatures and the variation produced during the IFMS scan, which shows a dip in temperature of about 70° in outlet temperature. During this period of time, the panels were under manual control. This was a maximum power test. Figure 48 shows the valve position during this period of time. Initially, the valves were in the wide open position, and pump power was increased to obtain maximum flow rate. The valves on Panels 1 and 3 were then partially closed in order to equalize the temperatures on all three panels as shown in Figure 47. No attempt was made to control panel outlet temperature during the IFMS scan. The sodium inlet temperature was relatively constant, as shown in Figure 49. The mixed-mean outlet temperature is also shown on this figure. The difference between these two curves gives the temperature increase across the panel. This temperature difference across the panel together with the flow rate through the panel is used to calculate the absorbed power as shown in Section 3.3.1.

The absorbed power for each of the three panels is shown in Figure 50. Also shown in this figure is the heat rejected by the dump heat exchanger. The power rejected by the dump heat exchanger is calculated in a manner similar to that for the panels. Figure 50 indicates that a peak power of 2.85 MW was achieved during this test.

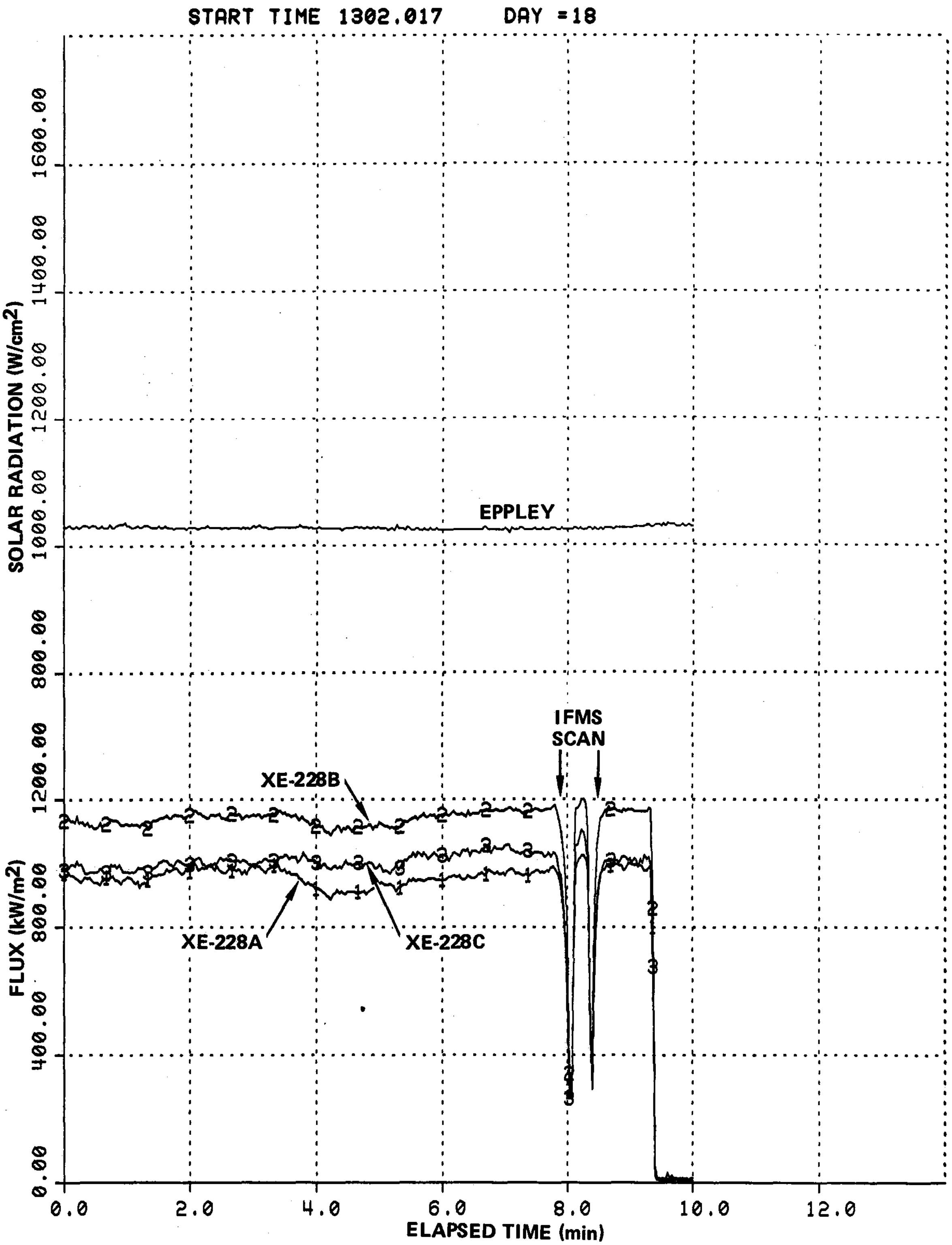


Figure 46. Incident Flux Measuring System Scan during Manual Control, Test 23

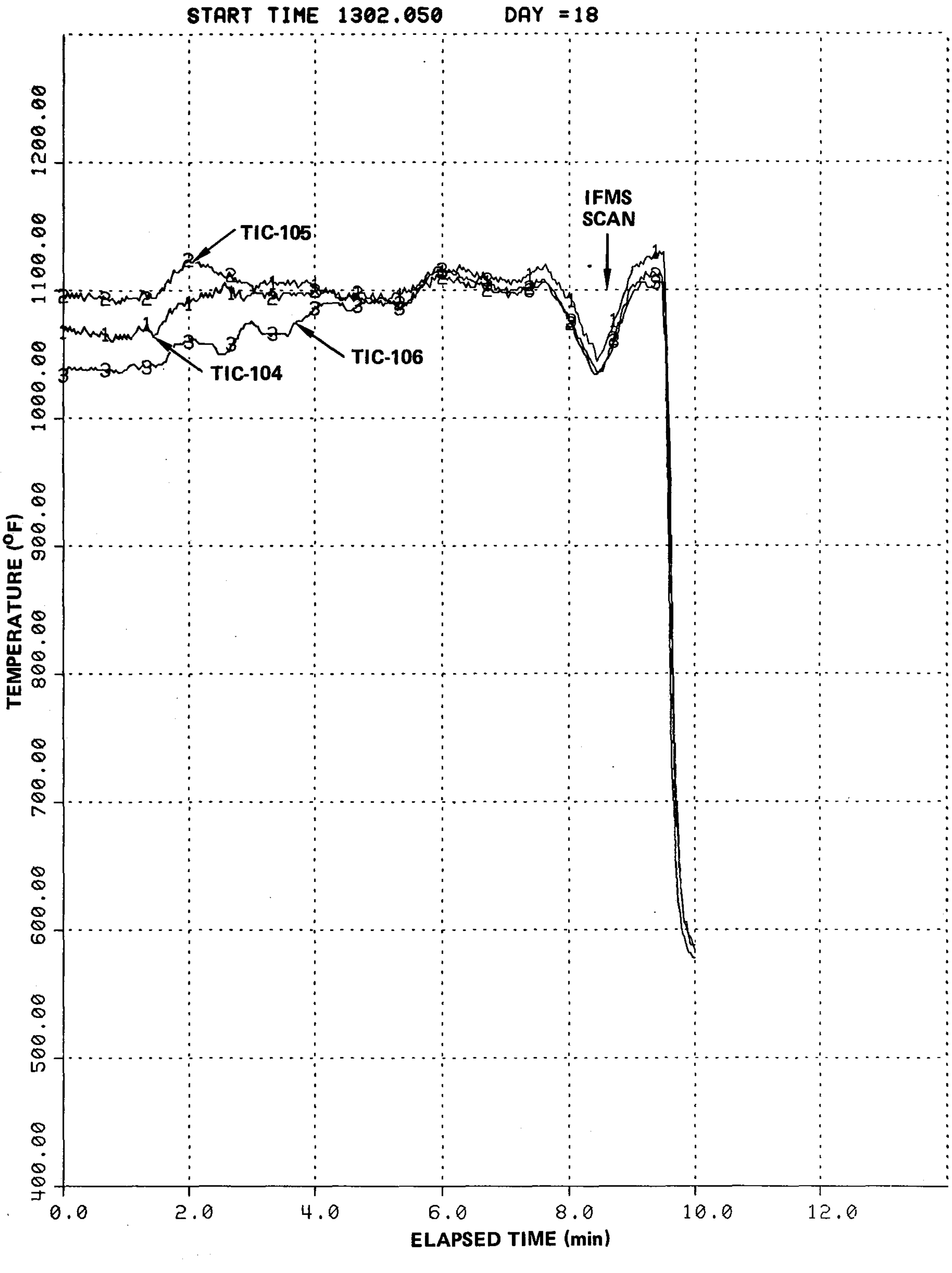


Figure 47. Panel Outlet Temperatures during IFMS Scan, Test 23

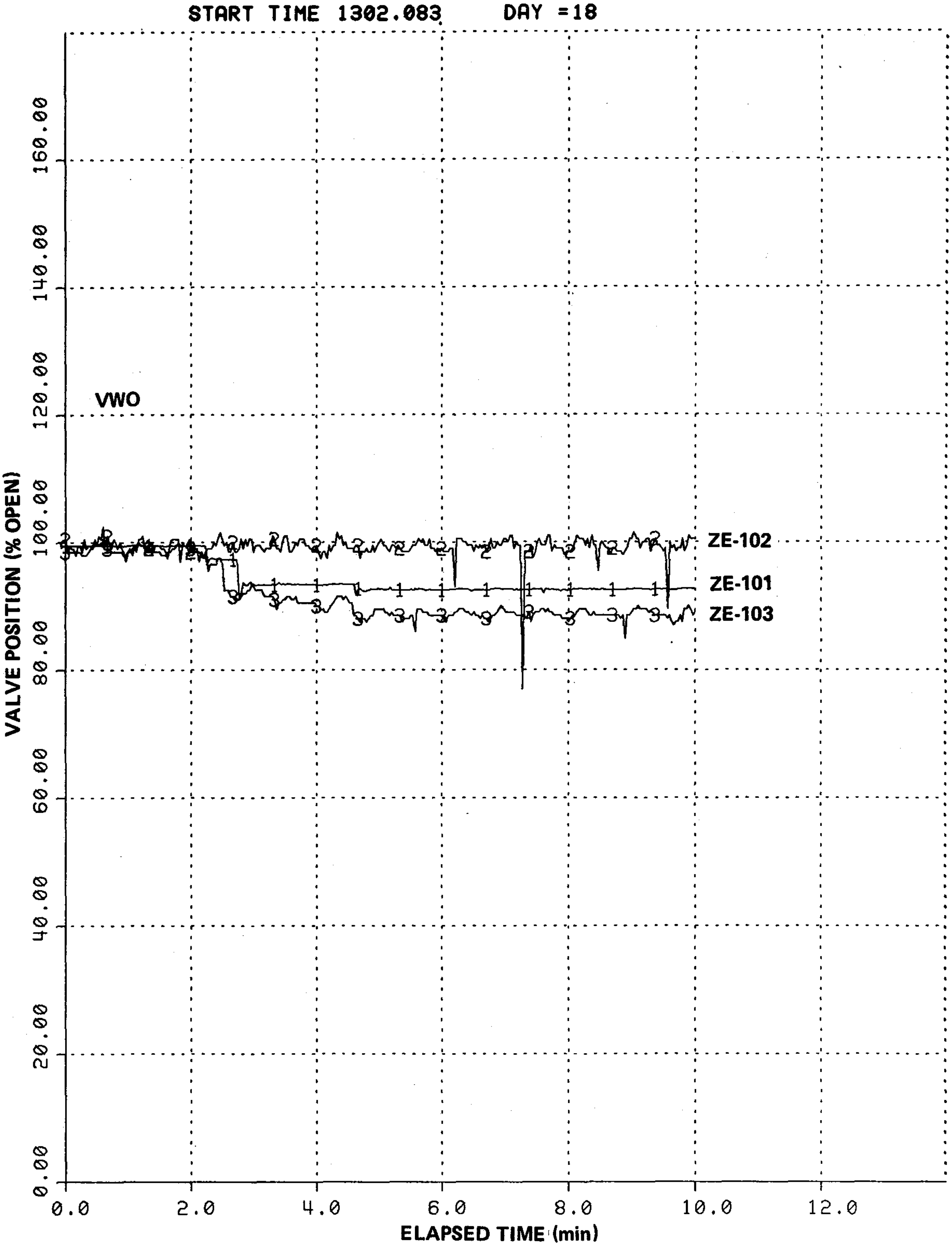


Figure 48. Valve Position during Manual Control, Test 23

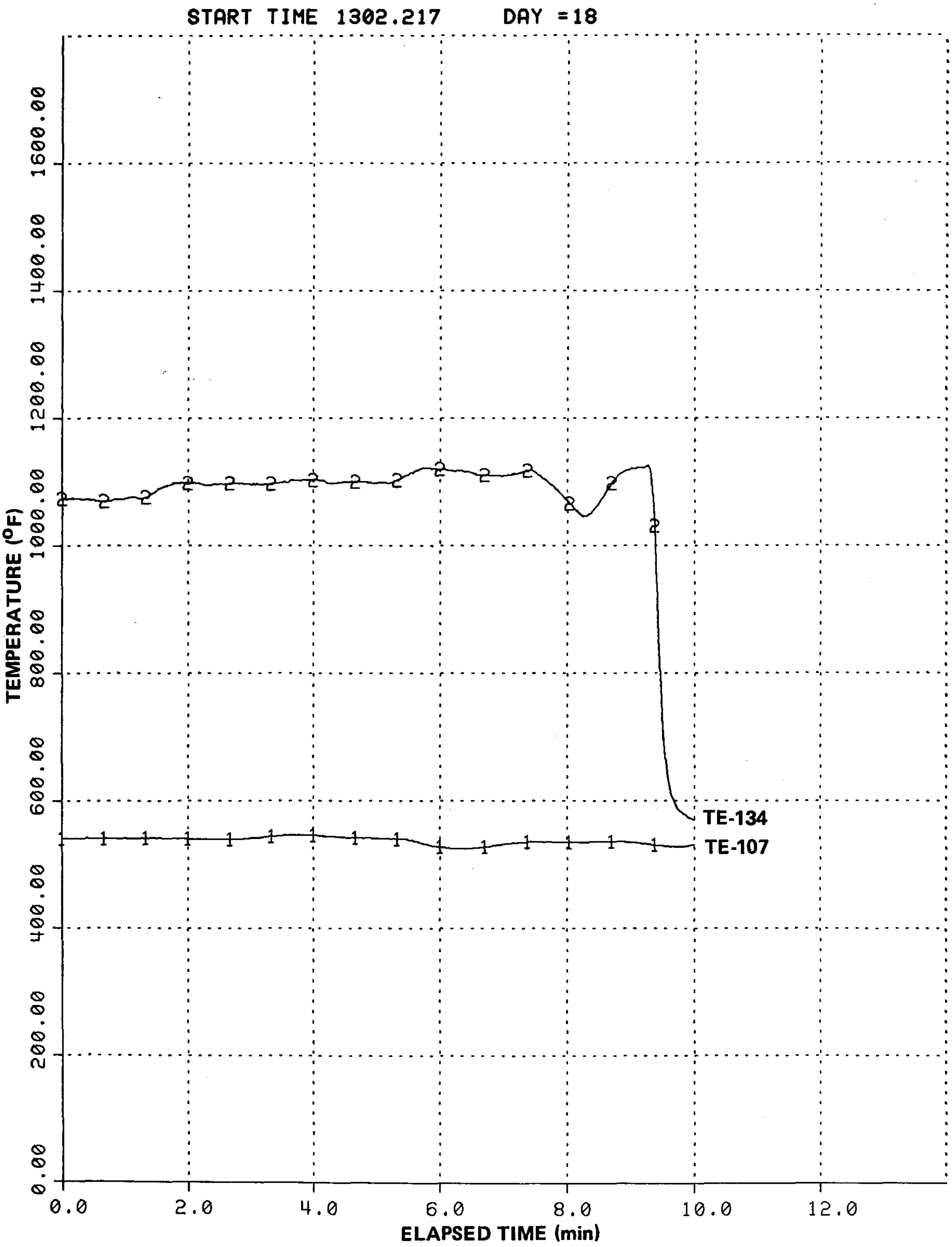


Figure 49. Inlet Temperature and Mixed Mean Outlet Temperature, Test 23

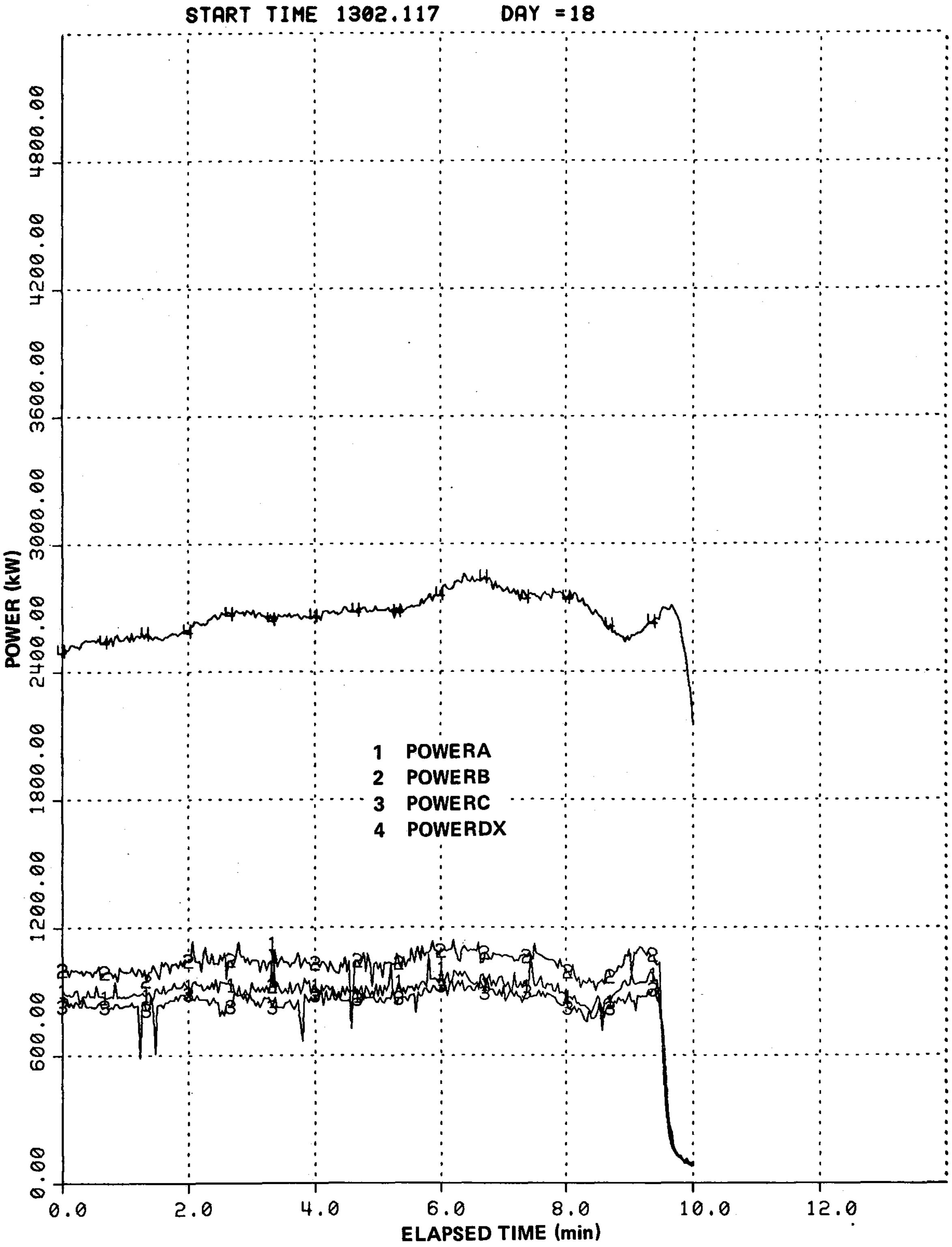


Figure 50. Panel Power and Dump Heat Exchanger Power, Test 23

The power distribution on the test panel as measured by the IFMS is shown in Table 15. The flux measuring system covers an area greater than the aperture of the panel. The panel aperture area is represented as a boxed area in Table 15. Near the center of that boxed area is a maximum flux reading of 153.4 W/cm^2, which is equivalent to 1.53 MW/m^2. This flux distribution is also pictorially represented in Figure 51. Also represented in this figure is an outline of the panel aperture area. The flux distribution across the center of the panel is shown in Figure 52, as compared to the desired flux distribution. The distribution was not as flat as desired but was acceptable. Since the flux gradients across the edge panels were larger than planned, the alternative skewed distribution that was in the original test plan was no longer required. This flux distribution data are used in Section 5.4 to compute panel efficiencies.

It was noted from the very beginning of the test that the flow rate data were rather noisy, both for the main flowmeter and for the panel flowmeters. It was suspected that part of this problem was due to the way the pump flow rate signal was handled. The pump flow rate signal was amplified with a 0- to 1-V amplifier, and this signal was supplied to a high-level card as an interface with the data acquisition system (DAS). This was later modified using a 0- to 10-V amplifier for the pump signal, which then gave a better match with the DAS interface. During Test 28, the effect of pump power and flow rate on the quality of the signal was examined. Figure 53 shows flow rate being increased in steps by changing pump power. Note that the flow rate signal for the three panel flowmeters became very noisy when 100% power was achieved and that the signal became steadier at 90% power and then tended to show noise again at 95% power. The main flowmeter signal showed that between 90% pump power and 100% pump power, no change in total flow occurred. For this reason, subsequent tests were conducted at a pump power of about 90%.

TABLE 15

MEASURED FLUX DISTRIBUTION

TEST 23

I01801 FILE FOR ESG FLUX DATA

I01801 FILE FOR ESG FLUX DATA

W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2		W/CM2	W/CM2	W/CM2	W/CM2	W/CM2
1.42	1.77	2.10	2.61	2.49	1.87	2.41	2.47		2.14	1.71	1.44	2.59	1.73
1.52	1.87	2.20	2.71	3.11	3.15	3.86	3.75		3.41	3.01	2.62	2.79	2.48
2.29	2.74	3.22	3.97	4.64	4.66	5.63	5.42		5.01	4.74	4.11	4.02	3.64
3.06	4.00	4.85	6.07	6.98	7.21	8.41	8.17		7.65	7.33	6.58	6.10	5.55
4.61	6.03	7.40	9.01	10.76	11.15	12.74	12.49		11.84	11.54	10.11	8.97	7.88
6.25	8.35	10.46	12.79	15.45	15.91	18.18	17.69	TOP	16.72	16.51	14.39	12.34	10.85
9.05	12.02	15.25	18.51	22.02	22.64	25.50	24.86		23.26	23.10	20.06	16.80	14.67
12.91	17.19	21.72	26.28	34.09	31.57	35.38	34.15		31.95	31.63	27.33	22.75	19.75
16.52	22.60	29.17	35.73	42.93	44.05	49.32	47.50		44.40	43.79	37.78	30.68	26.33
19.89	28.02	37.12	46.12	55.64	57.62	64.42	61.55		57.48	56.32	48.48	38.66	33.00
26.17	36.72	48.55	59.94	72.06	74.44	82.67	78.67		73.62	72.41	62.17	48.67	40.81
30.32	43.39	58.20	72.12	87.19	91.08	101.2	96.74		91.68	91.03	78.91	61.95	52.04
34.37	49.93	67.99	85.03	102.4	107.4	118.9	113.5		108.5	107.8	94.32	74.28	62.64
38.52	55.83	75.54	94.63	113.7	119.5	131.5	125.9		121.2	121.8	107.9	85.78	72.61
41.61	60.08	80.74	100.5	121.0	127.5	140.3	134.8		130.7	132.3	118.0	94.60	80.92
43.30	61.98	82.07	97.30	118.9	125.5	139.1	141.2		132.8	133.5	116.9	98.01	85.41
47.58	67.88	88.88	99.27	122.6	129.1	143.1	153.4		140.0	138.8	118.5	103.0	90.28
44.87	63.81	83.47	93.92	116.5	122.8	137.0	146.9		133.8	133.0	114.0	99.62	87.92
40.92	57.82	75.73	85.60	106.0	112.0	126.0	135.2		123.4	122.0	105.6	92.63	82.34
36.97	51.44	65.98	74.06	90.82	95.93	108.4	116.6		106.1	105.7	92.43	81.77	73.29
32.50	44.49	56.55	63.16	76.39	79.75	90.05	96.56		87.45	86.75	75.80	66.83	59.78
25.67	34.64	44.08	49.72	59.87	62.31	70.97	76.72		69.36	68.85	60.56	53.58	48.54
19.95	26.51	33.06	37.14	44.61	45.89	52.46	56.18		51.09	50.20	44.74	39.84	36.27
15.17	20.09	24.36	26.63	31.96	32.38	37.09	39.53		36.10	35.49	32.07	29.03	26.72
10.90	14.16	16.90	18.01	21.25	21.15	24.48	26.05		23.89	23.75	21.87	20.02	18.78
7.99	10.10	11.60	11.93	13.66	13.37	15.53	16.70		15.52	15.73	14.72	13.87	13.03
5.81	6.99	7.79	7.86	8.67	8.25	9.49	10.28	BOT	9.64	10.14	9.68	9.16	8.81
4.25	4.96	5.14	4.89	5.50	5.09	5.89	6.32		6.09	6.26	5.97	5.77	5.71
3.10	3.46	3.55	3.21	3.36	3.12	3.56	3.96		3.65	3.87	3.81	3.76	3.73
2.27	2.50	2.27	2.02	2.14	1.92	2.28	2.36		2.31	2.39	2.47	2.38	2.49
0.71	0.68	0.68	0.73	0.81	0.83	1.01	1.18		1.20	1.36	1.33	1.32	1.25

EAST

WEST

PROJECTED AREA OF
TEST PANEL

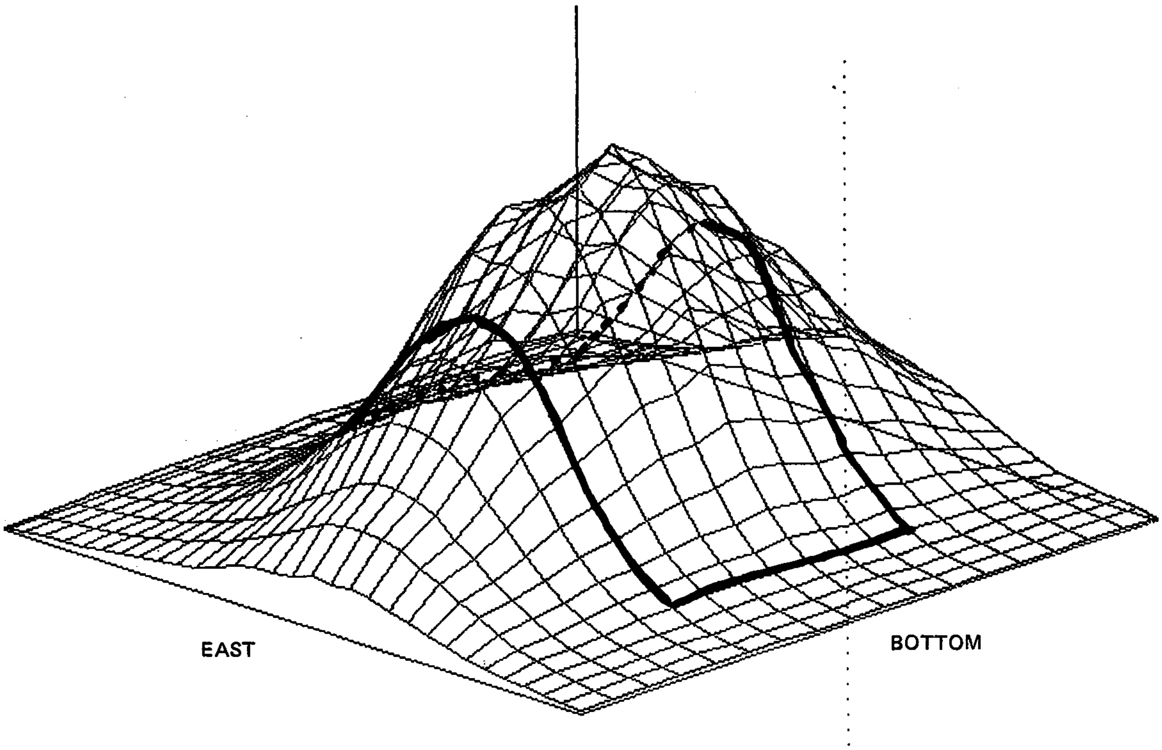


Figure 51. RTAF Measured Flux Profile

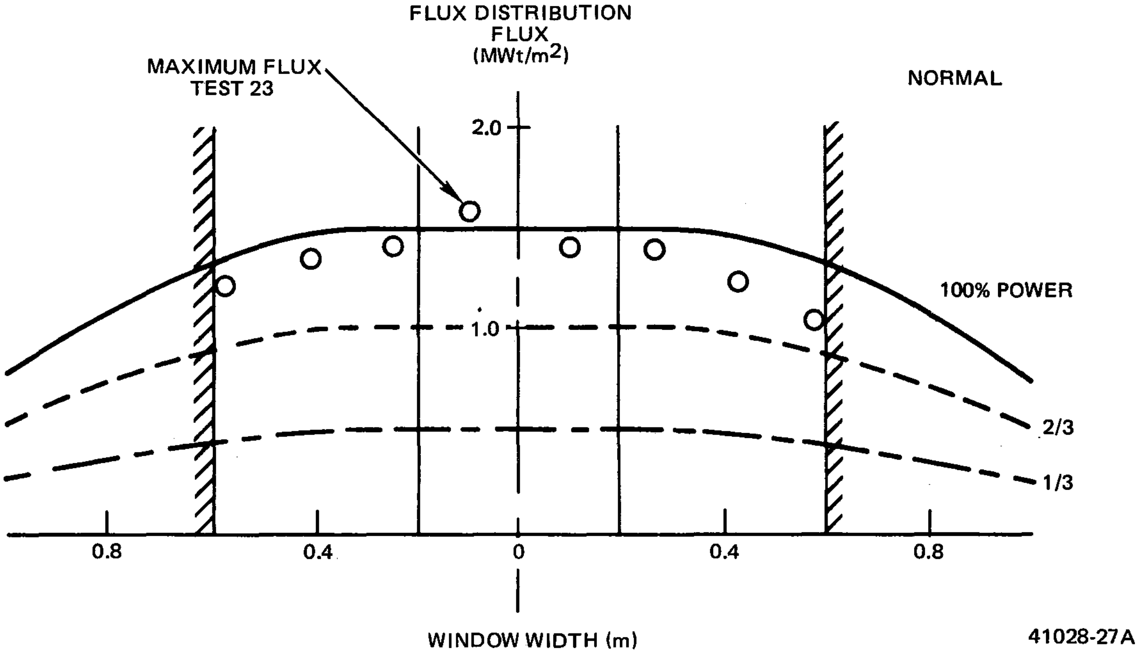


Figure 52. Heat Flux for Normal Flux Distribution
(Two-point aim)

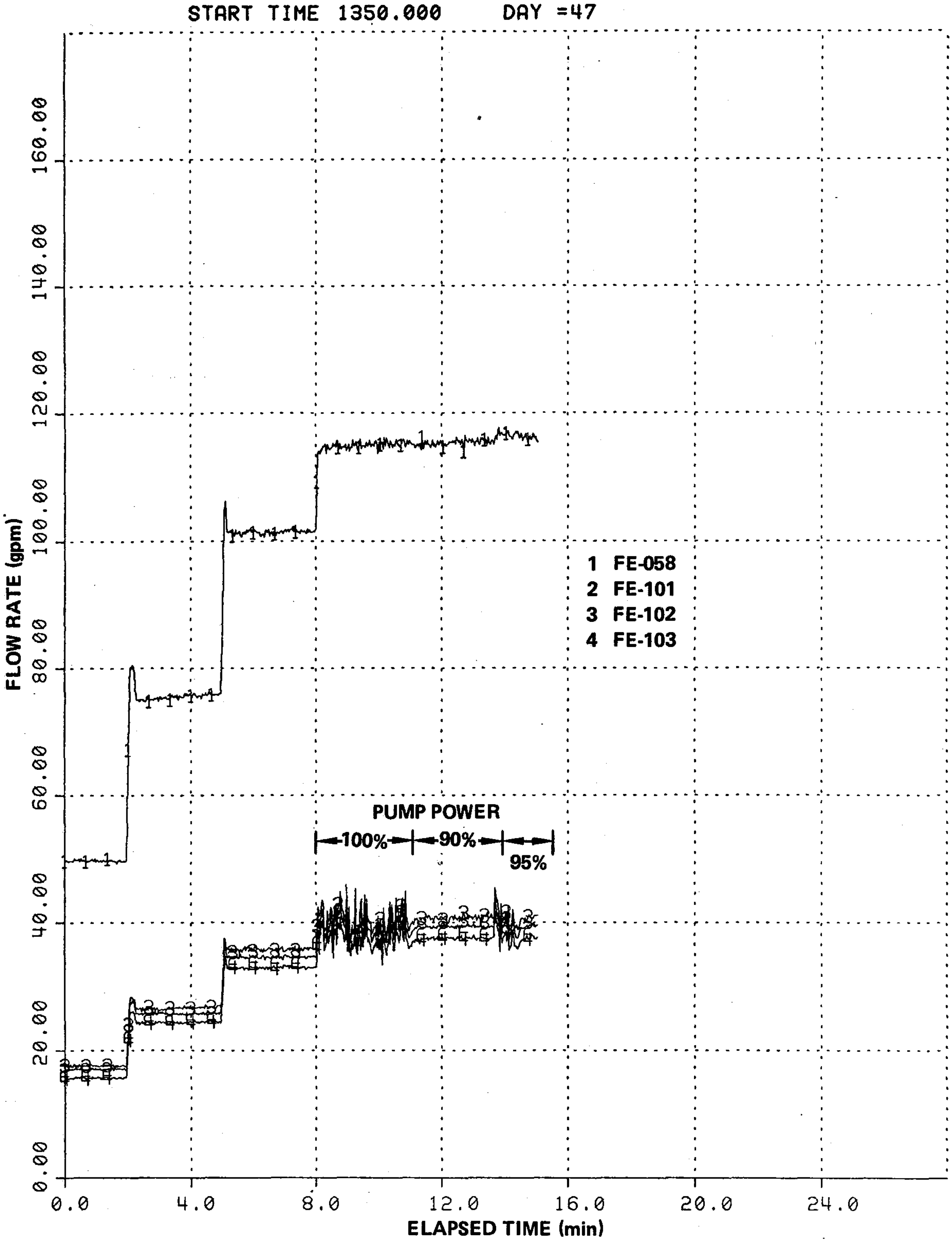


Figure 53. Pump Noise, Test 28

The three front-surface thermocouples were added to the panel for possible use as a feed-forward signal in place of the flux sensors. Measurements TE 229, on the edge tube of Panel A, and TE 230 and TE 231, on the edge tube of Panel C, are shown on Figure 54. These measurements were not used as part of the control system, since the flux sensors (once properly positioned) functioned satisfactorily throughout the test. Because the front-side measurements were not placed particularly close to a back-side measurement, a meaningful front- to back-side difference is not readily obtainable except for TE 231 and TE 124C, which are ~1 in. apart. Figure 55 shows a comparison of the front-side thermocouples and nearby backside measurements. Figure 55a shows a front-to-backside temperature difference of about 120°F at the higher power levels. A power step occurred at time 1452 on Run 22, Figure 55b. The above temperature difference is about as calculated for a temperature difference across a tube at this location.

5.3 POWER TRANSIENTS

Open-Loop Control: Open-loop control was used mainly during the power buildup phase and during the maximum power tests such as shown in Figure 48. Manual control was satisfactorily accomplished when the power input changes were relatively slow. The operator had to monitor and control three panels simultaneously with valves that responded slowly when under manual control. Manual control of the panel valves was through the setup buttons on the controllers operating at a fixed program rate that required about 60 s for full-range-of-valve travel. (With an automatic control valve, motion could be very rapid with only about 4 s required to travel full range.)

Manual control was used to stabilize the panel outlet temperatures when, under certain controller setup conditions, the panel flow interaction produced outlet temperatures that approached the trip limits. Manual control of a

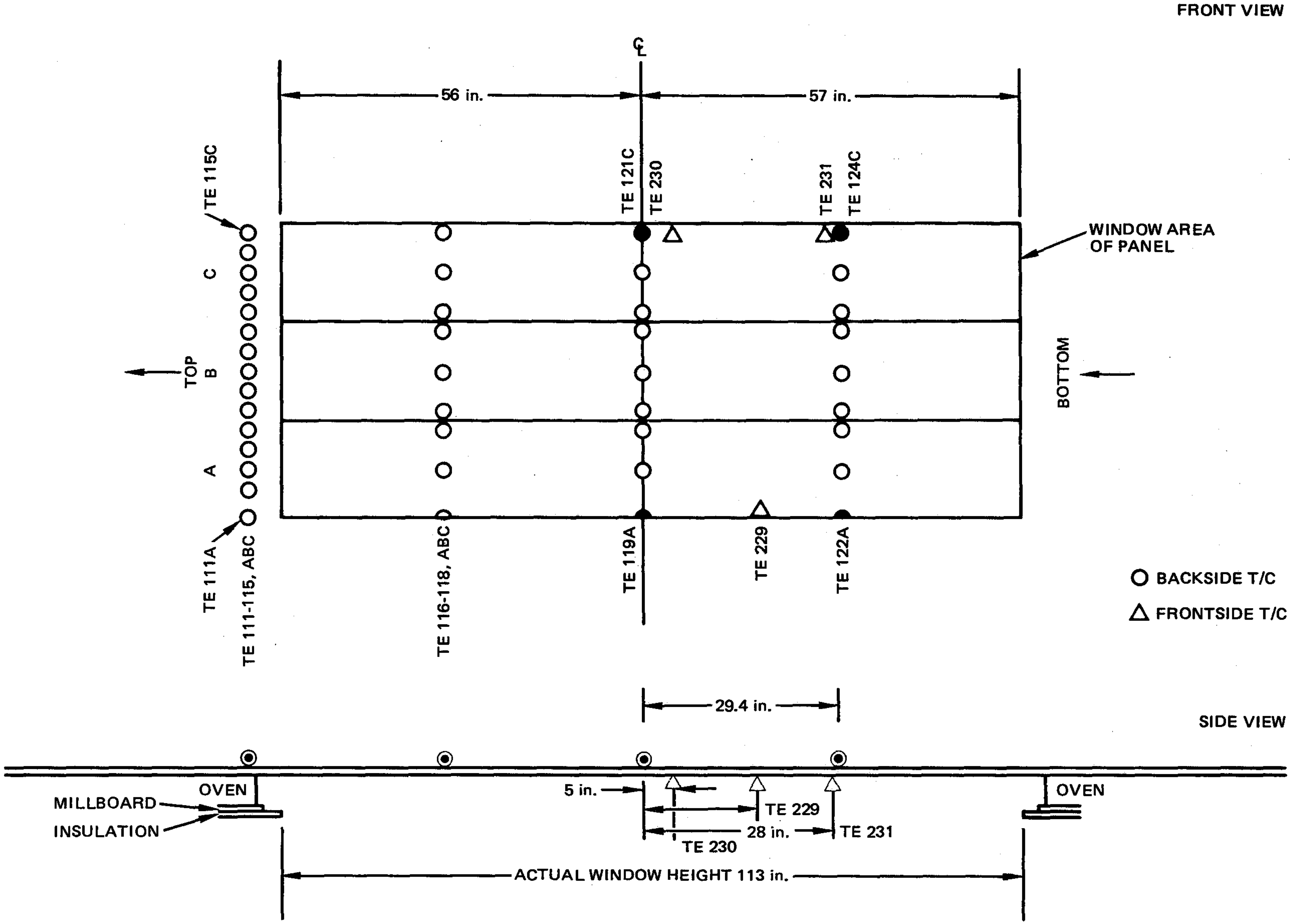
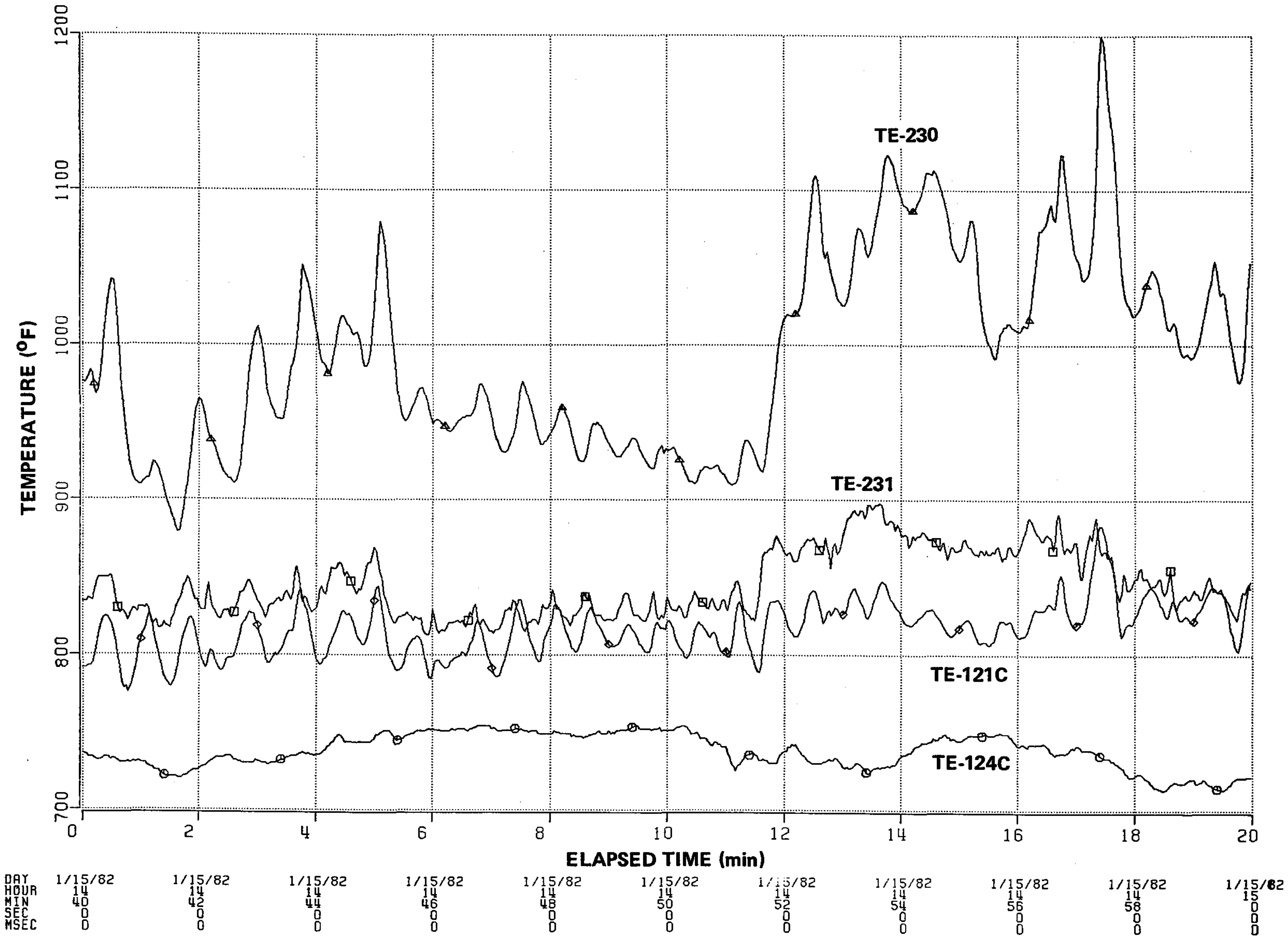
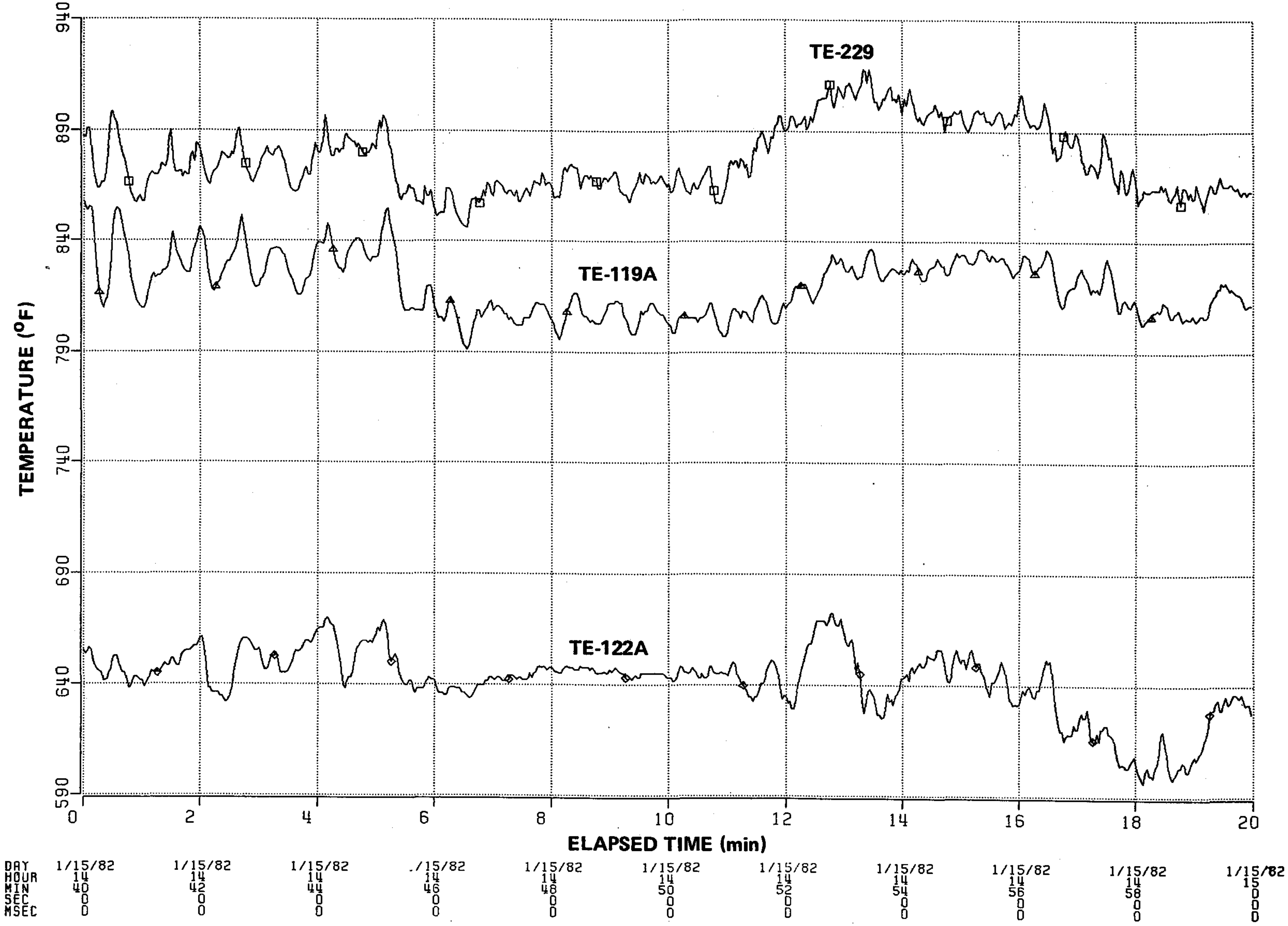


Figure 54. Thermocouple Locations



a. Panel A

Figure 55. Comparison of Front-Side and Back-Side Thermocouples (Sheet 1 of 2)



b. Panel C

Figure 55. Comparison of Front-Side and Back-Side Thermocouples
(Sheet 2 of 2)

single panel with the other two under automatic control was readily accomplished. The major goal of this testing was to obtain satisfactory operation under automatic control.

Automatic Control: Power transients either occurred naturally, due to the passage of clouds which shaded part of the collector field, or were produced by removing or adding groups of heliostats to give a change in power level. The latter method was used extensively to determine control-system response characteristics, e.g., a 20% power step downward followed by a return step (Figure 56). The insolation reading also shown on this figure indicates that the day was very clear and cloudless. The panel outlet temperature is shown in Figure 57. Control system tuning studies were still being made, but the set point temperature of 1100° was maintained to within ±45°F. This figure also shows the results of the flow-rate interaction among the three panels. The interaction is more pronounced in this figure around 20 min and following 25 min. This interaction was not unexpected, since the panels were designed with a very low pressure drop in order to maximize the total flow rate in case pump power was inadequate, as was the case. While it is not readily discernable in this plot, an expanded-scale plot would indicate that the interaction shown here is primarily between Panels 2 and 3. As explained elsewhere, a commercial panel would have a significantly higher pressure drop and this flow interaction would not occur. The power change produced by this step is shown in Figure 58. These are calculated parameters, as indicated above, using the measured flow rate and measured temperature difference across the panel or, similarly, across the dump heat exchanger. Consequently, the variations that appear in these measurements also show up in this calculated parameter. The change in power, most clearly indicated by the curve for the dump heat exchanger, was a step of about 20%. The power decrease step occurred over a period of about 1 min, while the power increase return step occurred in about 30 s. The sharpness of these steps was substantially

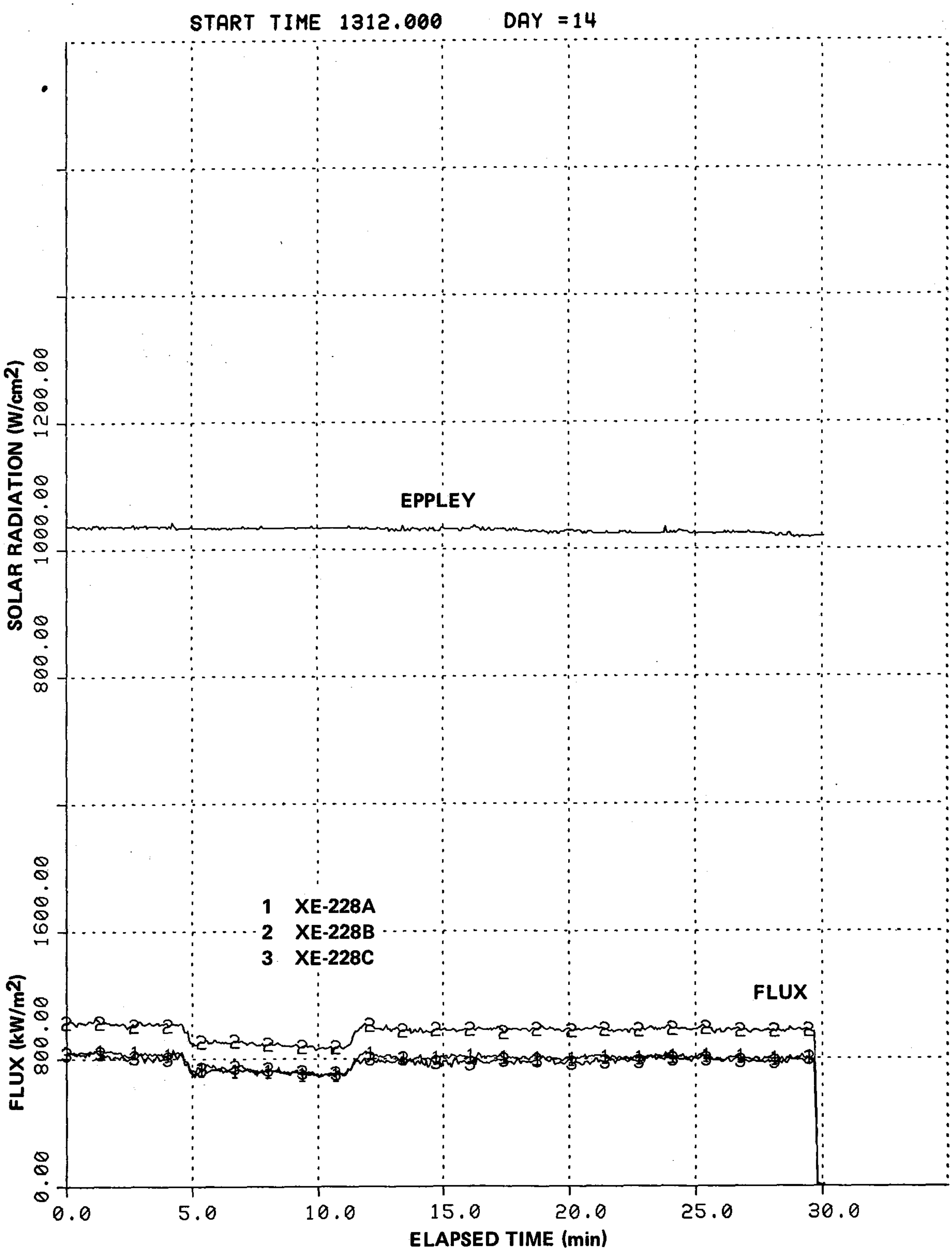


Figure 56. Typical Power Step, Test 21

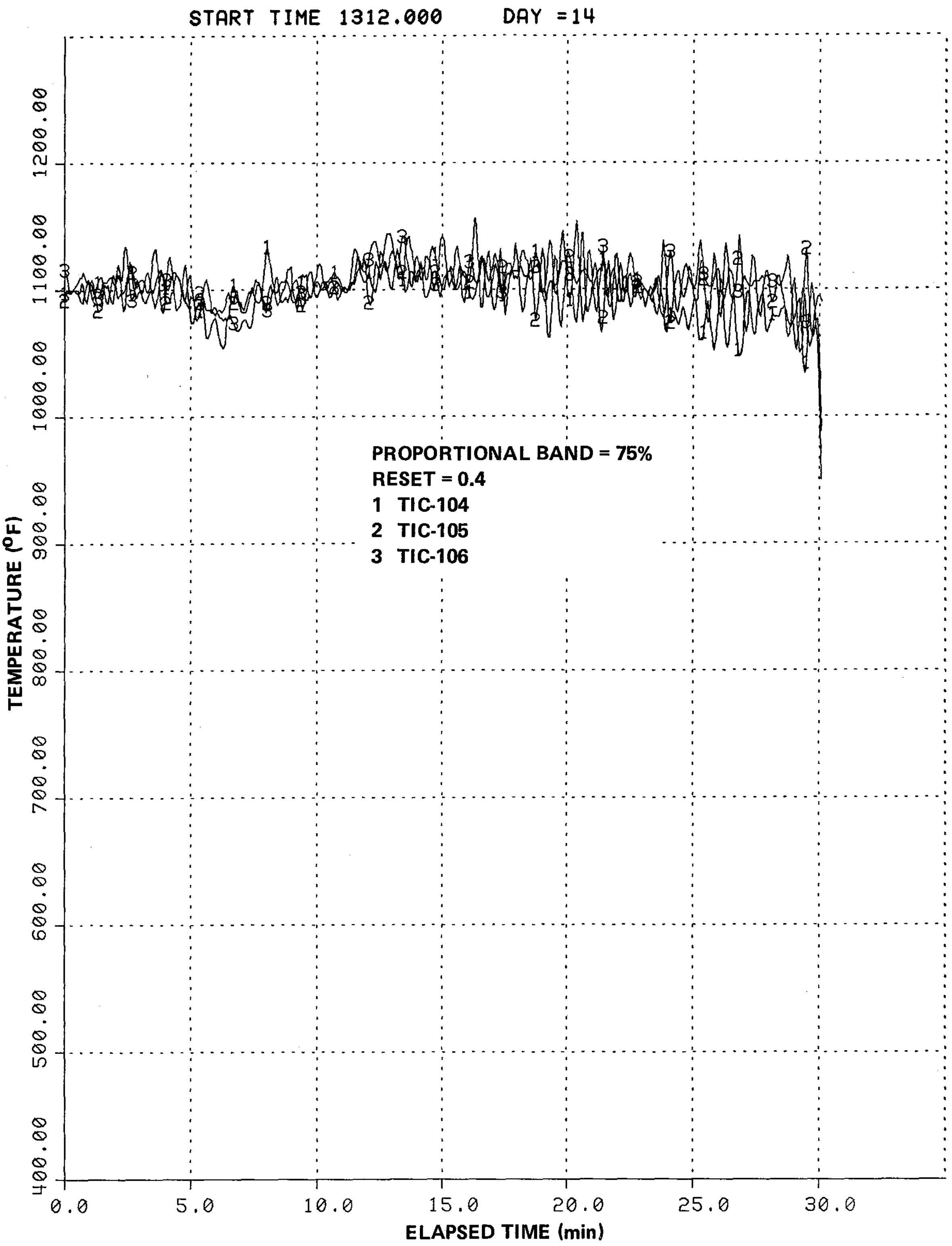


Figure 57. Panel Outlet Temperatures during Automatic Control, Test 21

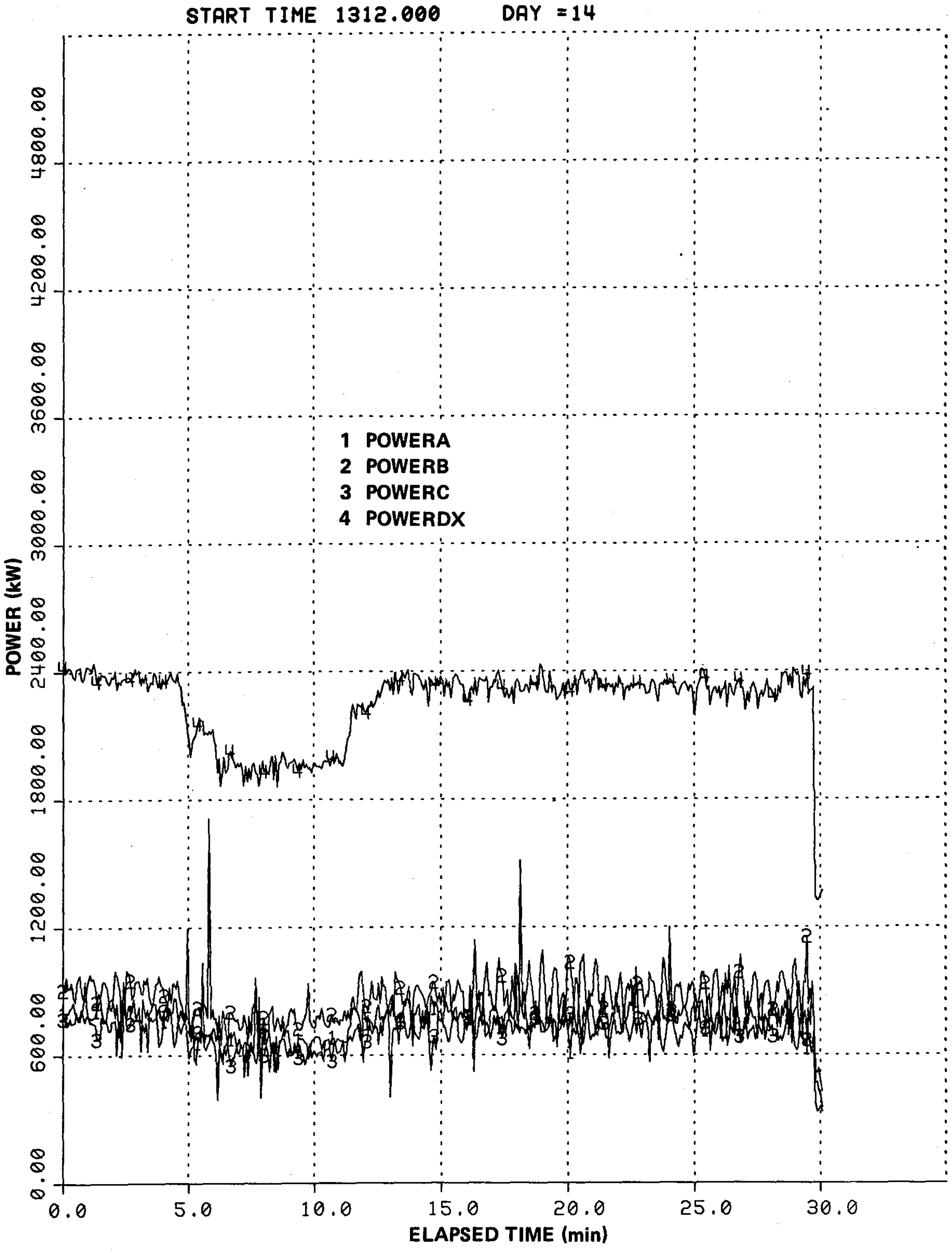


Figure 58. Panel Power and Dump Heat Exchanger Power, Test 21

increased in later tests. Figure 59 shows that the mixed-mean outlet temperature from the three panels, as indicated by Curve TE-134, was maintained to within ±25°F. The dump heat exchanger control, as indicated by outlet temperature TE-107, was also satisfactory, with relatively small inlet temperature variations of about ±25°F.

A total of eight power transients were conducted during Test 24, as shown in Figure 60. For these tests, the removal or addition of groups of heliostats was preprogrammed in such a way that relatively sharp-edged power steps would be obtained. The heliostat scram shown during the middle of this test period was due to facility problems. Control tuning studies continued during this test period. Except for very early in the test, automatic control was used throughout. Figure 61 shows panel outlet temperature and panel inlet temperature as a function of time throughout this test. Panel outlet temperature was maintained at the set point of 1100° with relatively small variations in response to the power steps that are shown in Figure 60. It was noted at this time that these sharper transients caused a greater variation in the DHX outlet temperature, as shown in Figure 61. This variation in inlet temperature to the panel was also reflected in the outlet temperature of the panel, since the control system was not equipped to sense variations in inlet temperature. An expanded section of the two previous curves that shows Power Steps 3, 4, 5, and 6 is shown in Figure 62. This composite figure shows the variation in flux, valve position, and outlet temperature. Note that for these nominal 20% steps, the set-point temperature of 1100° is held very constant. The feed forward portion of the panel control system uses the flux sensor input to change valve position. The valve position changes closely match the shape of the flux measurement changes, and the flow rate changes correspondingly as shown in Figure 63. The noise in this signal, as discussed earlier, is clearly evident. Again, the mixed-mean outlet temperature of Figure 64 is quite steady but does show the influence of the inlet temperature variation.

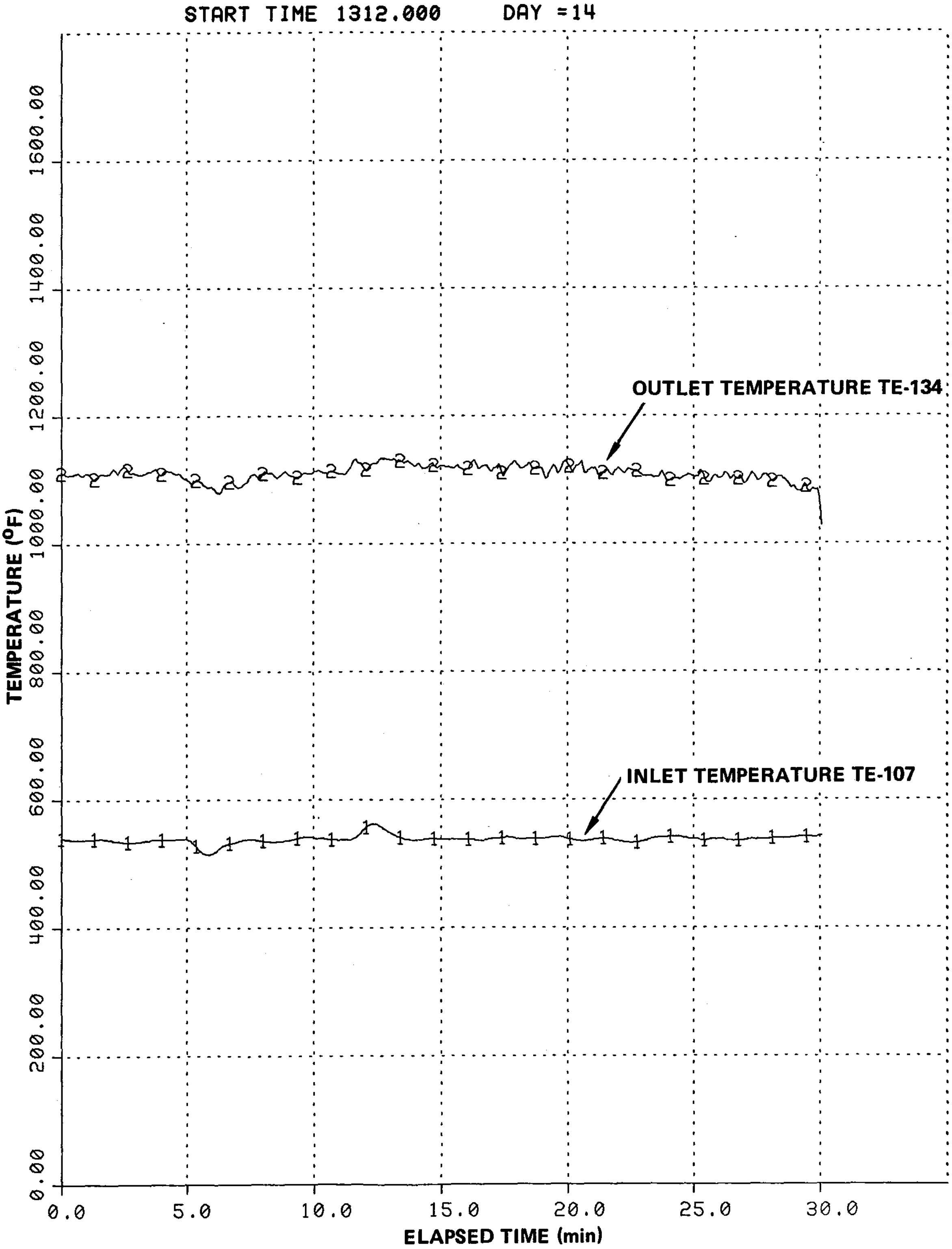


Figure 59. Panel Inlet Temperature and Mixed Mean Outlet Temperature, Test 21

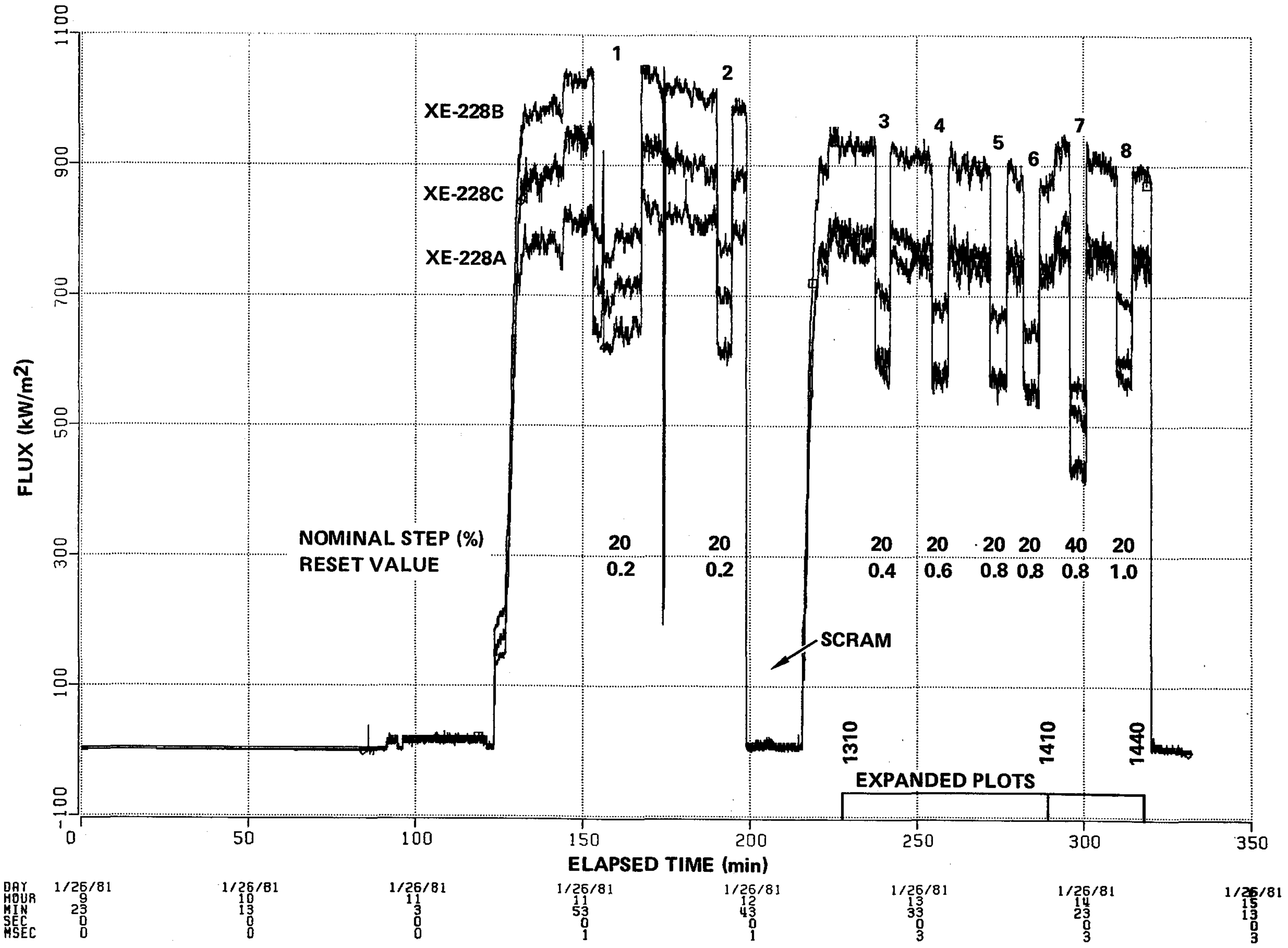


Figure 60. Power Steps with Various Reset Values, Test 24

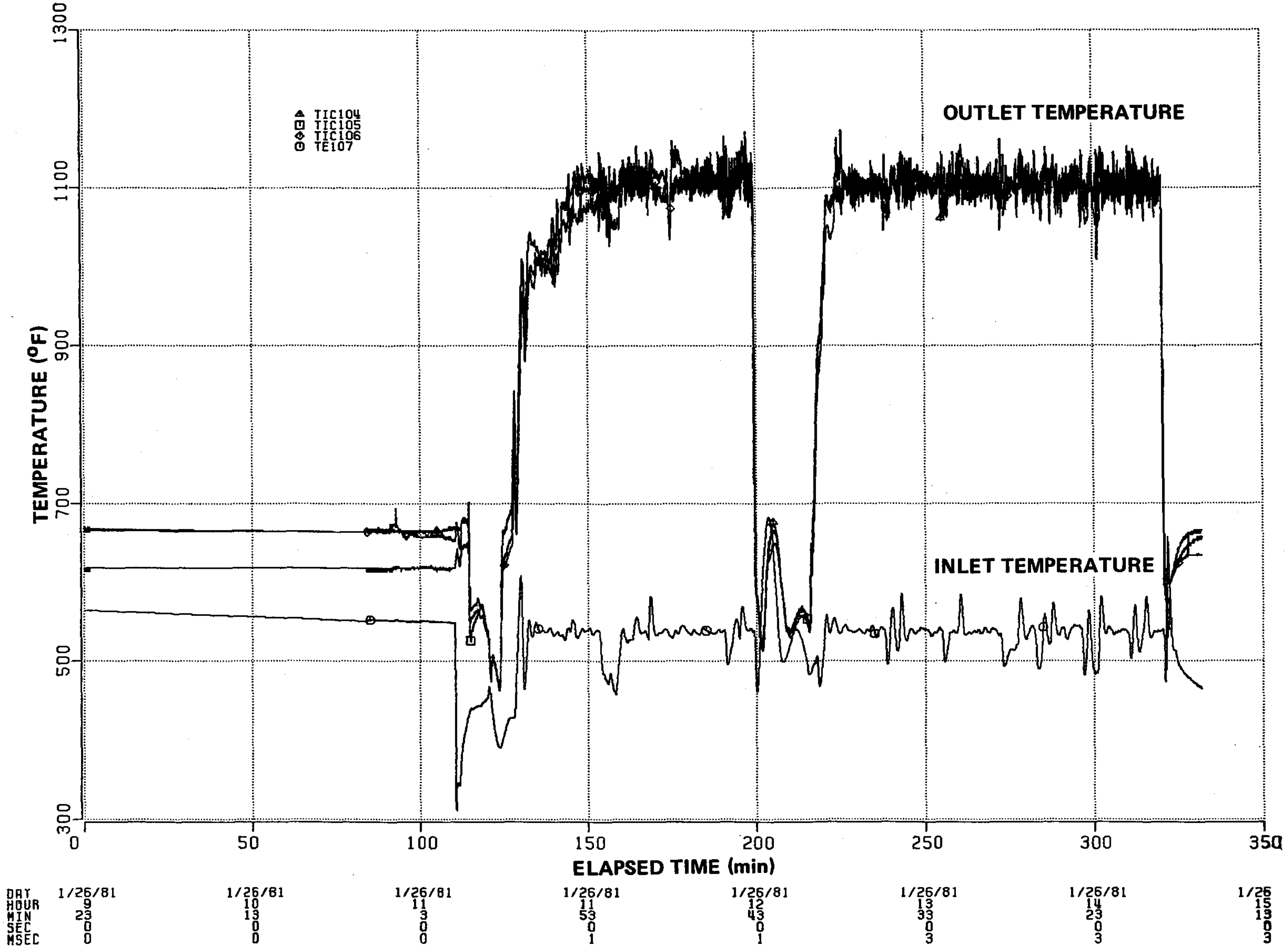


Figure 61. Inlet and Outlet Temperatures, Test 24

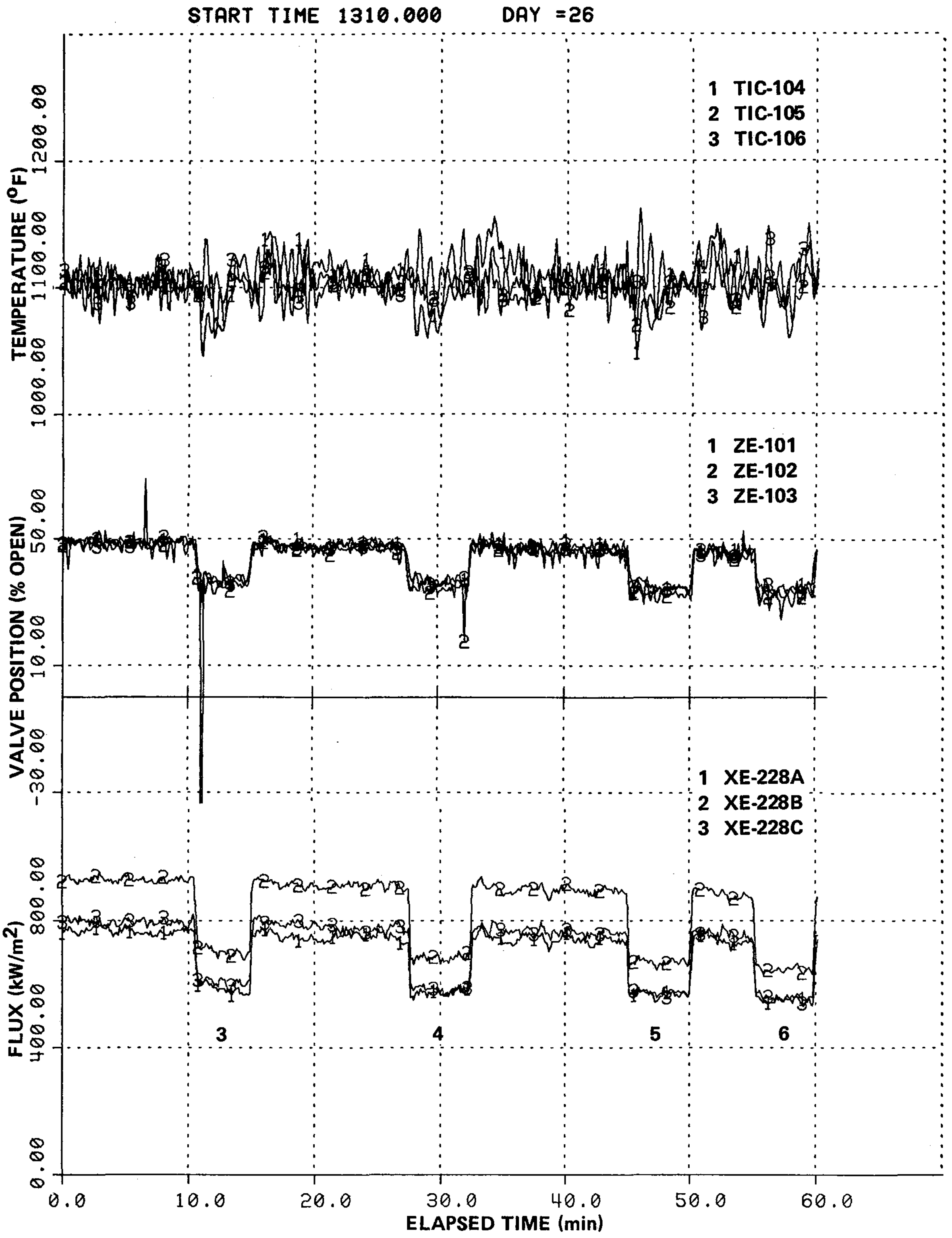


Figure 62. Power Steps 3, 4, 5, and 6, Test 24

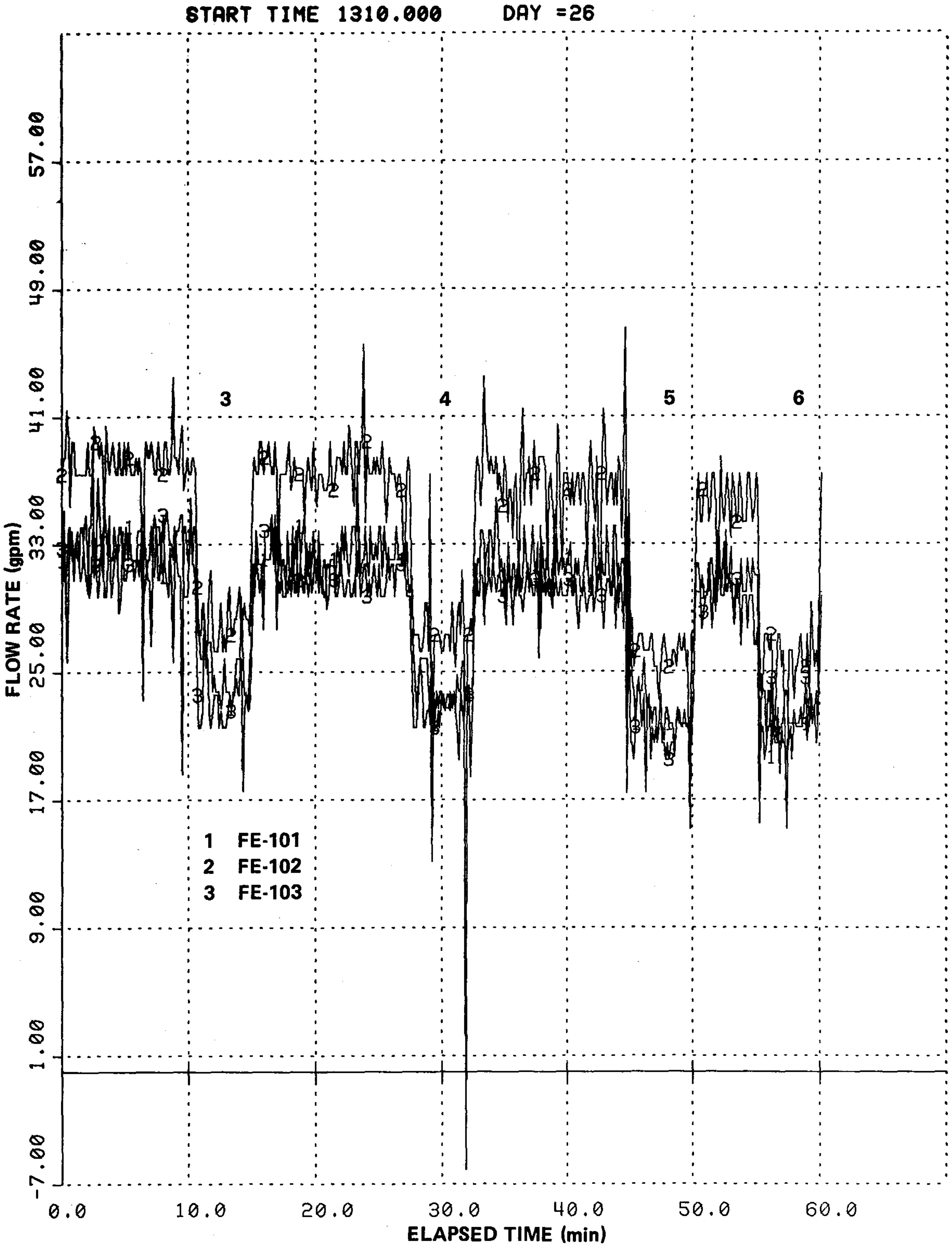


Figure 63. Flow Rate during Power Steps 3, 4, 5, and 6, Test 24

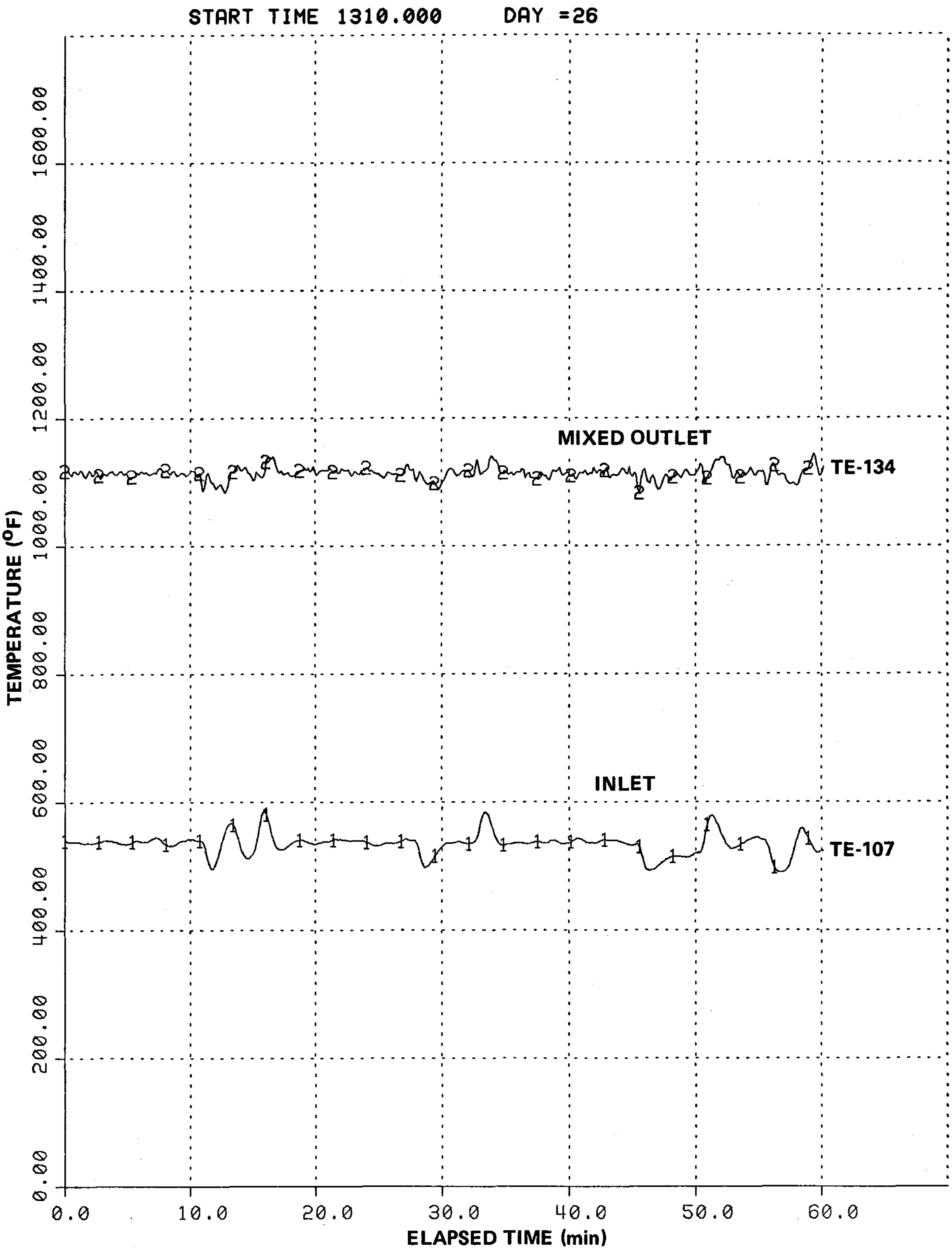


Figure 64. Panel Inlet Temperature and Mixed Mean Outlet Temperature, Test 24

A 40% change in power was tested, with the results shown in Figure 65. The down step occurred in about 7 s, and the up step occurred over a period of about 15 s. Because of a change in the reference level, the 40% downward step would be indicated as a 70% upward step. Again, valve position closely followed the step change in flux, which also changed flow rate (Figure 66). The outlet temperature variation is nominally within 30°, although this variation must be due in large part to the inlet temperature variation indicated in Figure 67.

A power buildup phase using automatic control followed by a cloud transient is shown in Figures 68 through 72. The insolation characteristics and the panel flux sensor measurements for these events are shown in Figure 68. The three panel outlet temperatures are given in Figure 69. The control valves were equipped with low-limit stops and are shown in Figure 70 to be against these stops until about the 5-min time line. For this reason, the control system could not achieve the set-point outlet temperature of 1100° until adequate power and flow rate were attained to allow the valves to move into a controllable range. The power buildup is indicated in Figure 71. Figure 72 shows panel motion during this event. These three linear motion transducers were located vertically along the centerline of the center panel. ZE-131 was the lower gauge, ZE-132 was located in the center, and ZE-133 was centered in the upper half of the panel. This motion was typical throughout the test and indicates that the center of the panel moves outwards by ~1 in. during the power buildup phase.

5.4 PANEL EFFICIENCY

One of the most interesting parameters to be determined from a receiver panel test is panel efficiency. This value is also difficult to determine with accuracy, since it depends upon how well the absorbed power and incident

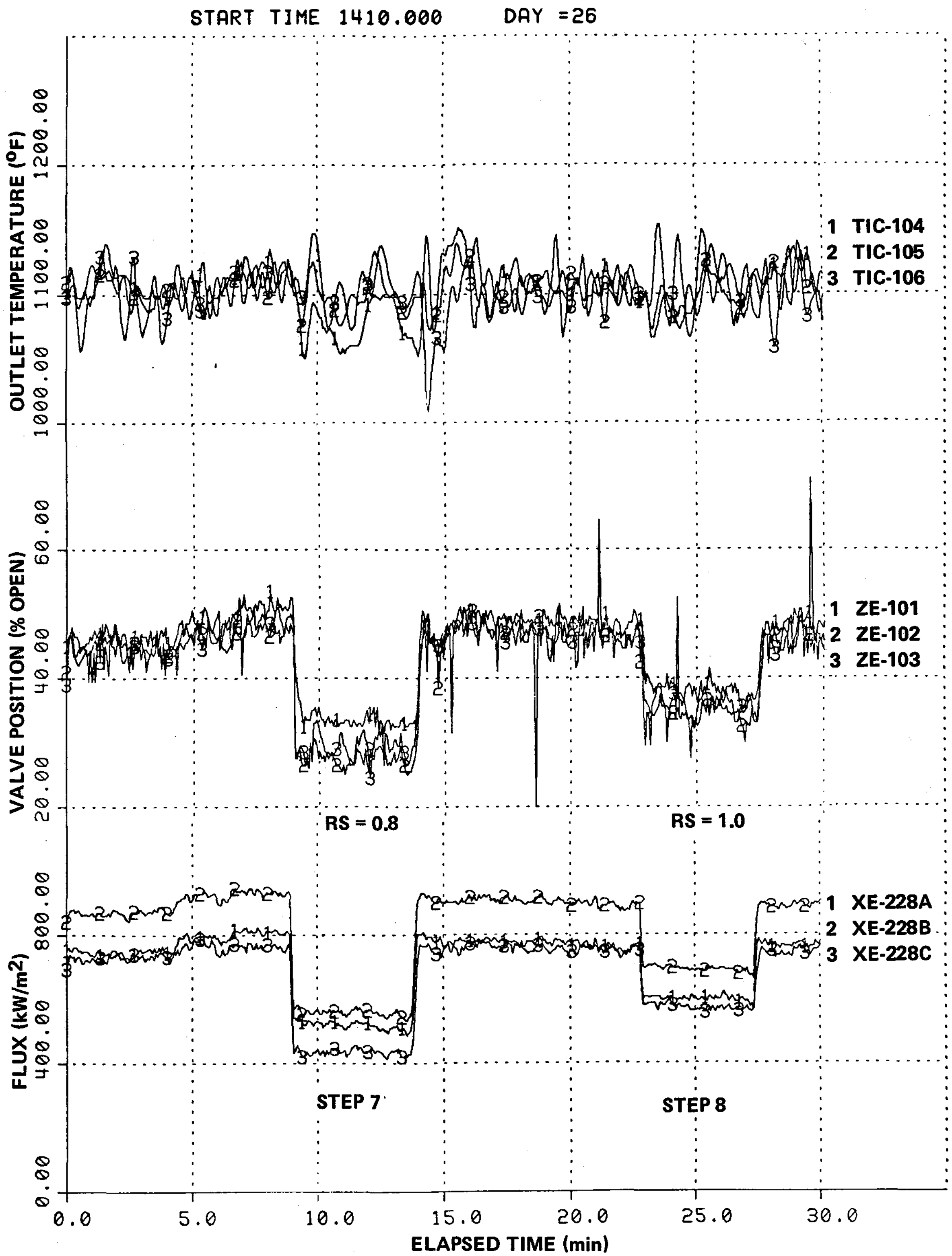


Figure 65. Power Steps 7 and 8, Test 24

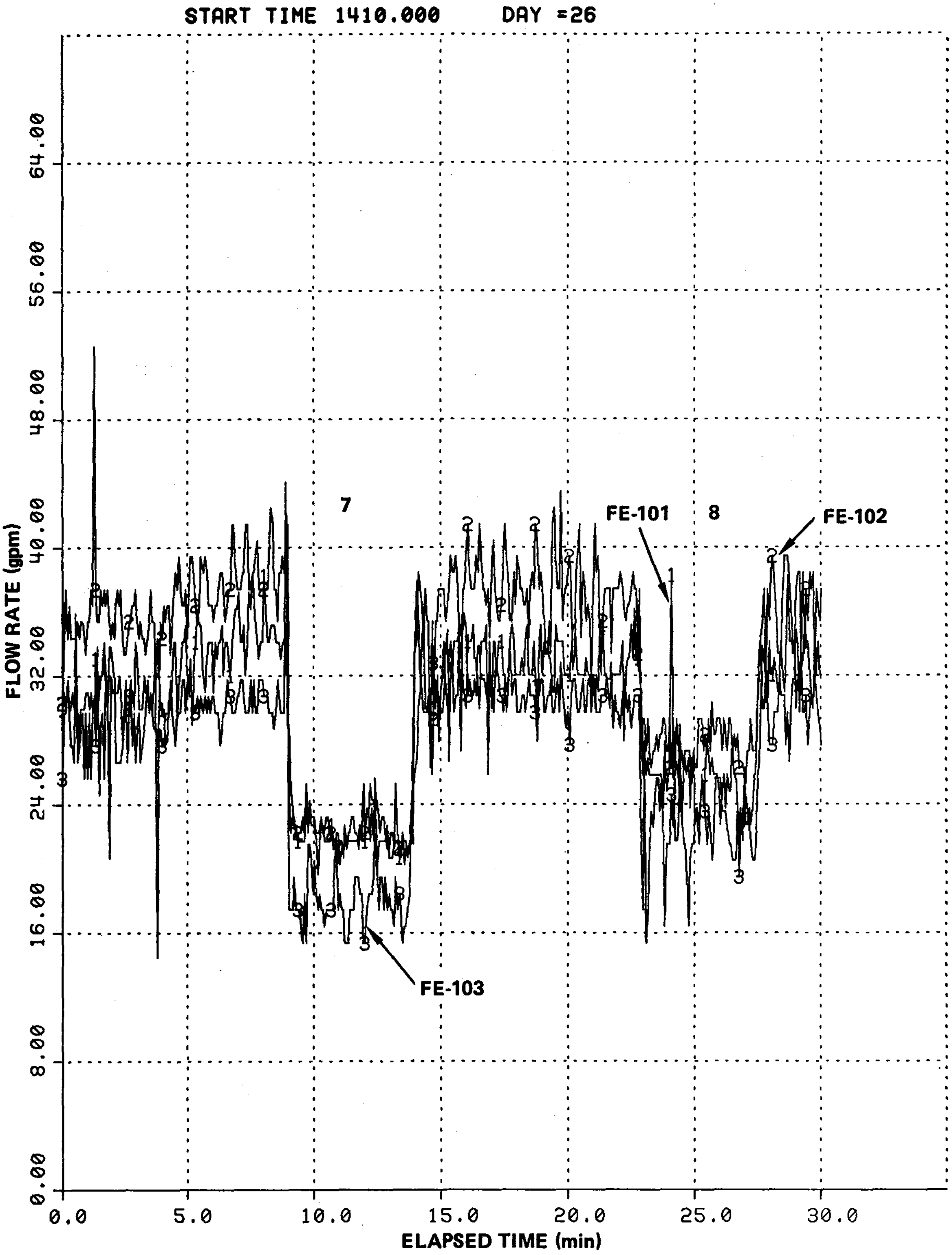


Figure 66. Flow Rate during Power Steps 7 and 8, Test 24

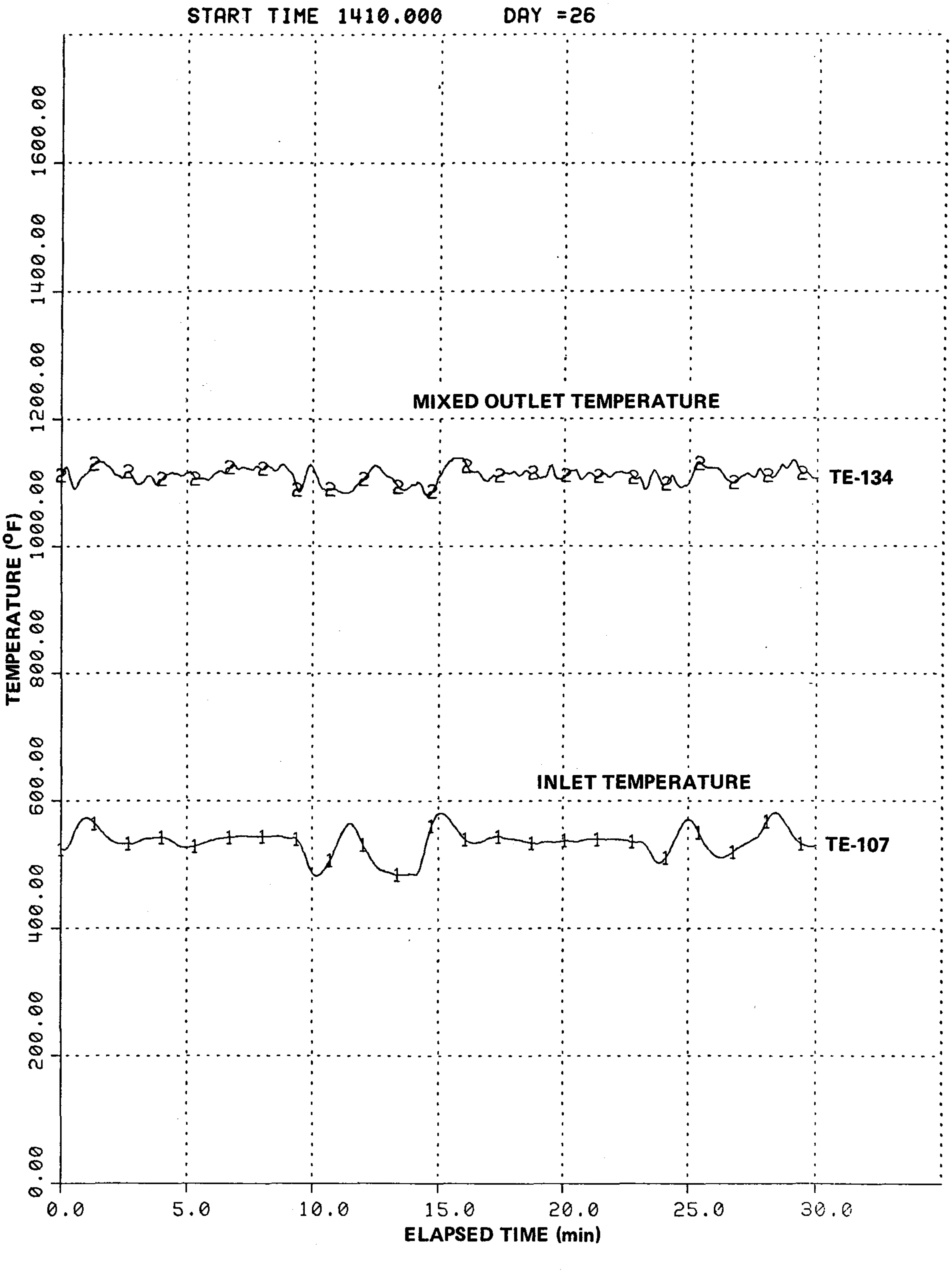


Figure 67. Panel Inlet Temperature and Mixed Mean Outlet Temperature, Test 24

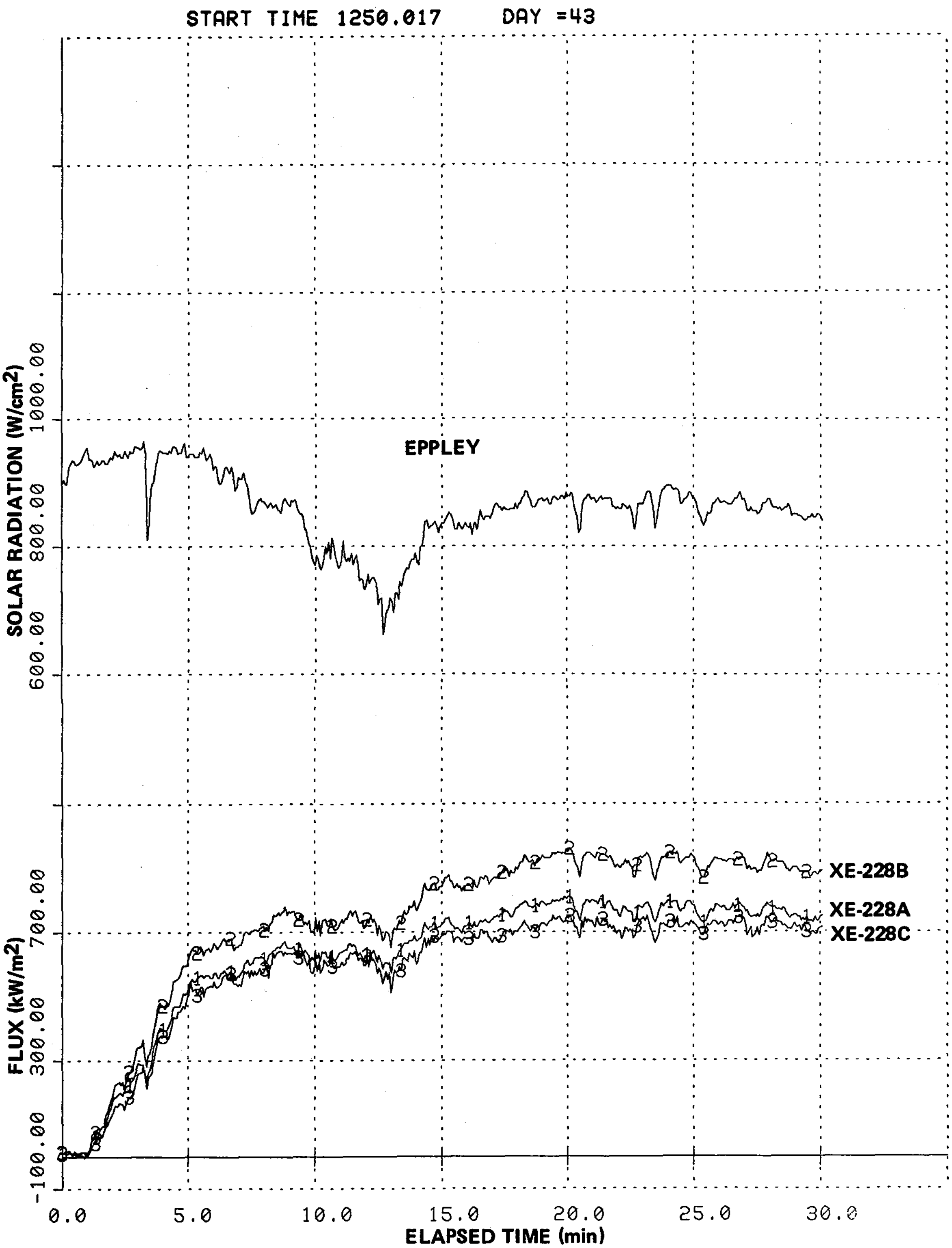


Figure 68. Power Buildup with Automatic Control Cloud Transient, Test 27

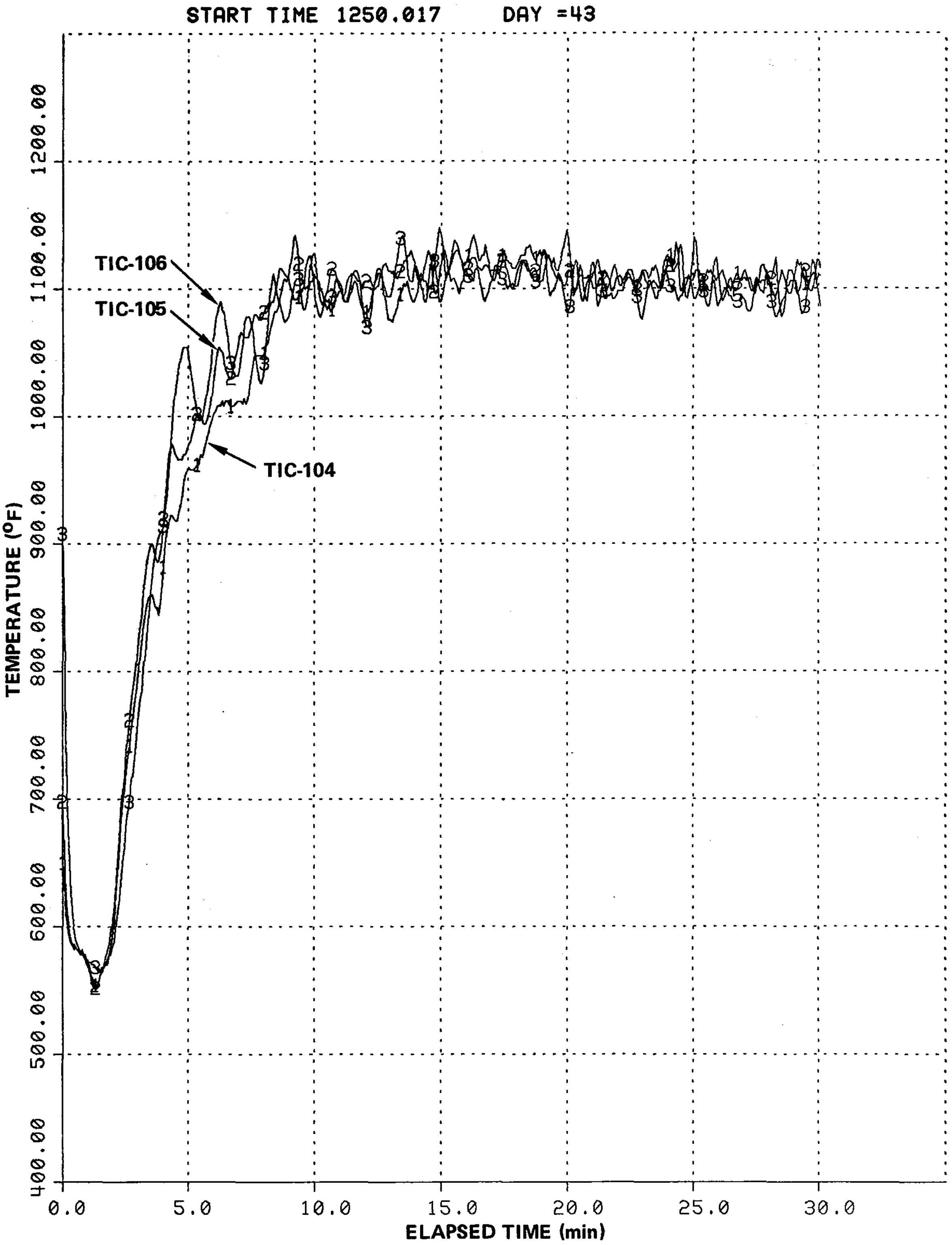


Figure 69. Panel Outlet Temperature during Power Buildup and Cloud Transient, Test 27

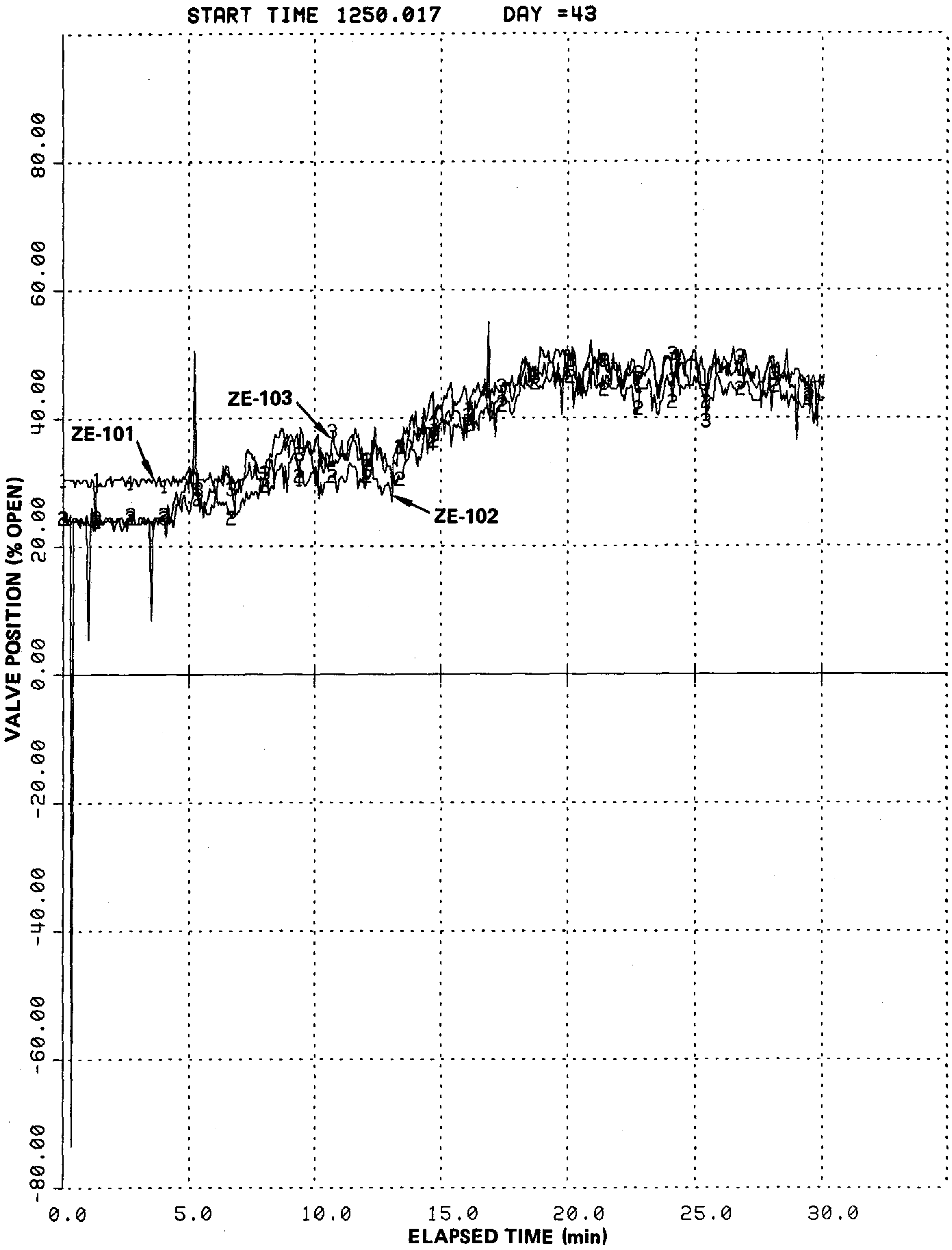


Figure 70. Valve Position during Power Buildup and Cloud Transient, Test 27

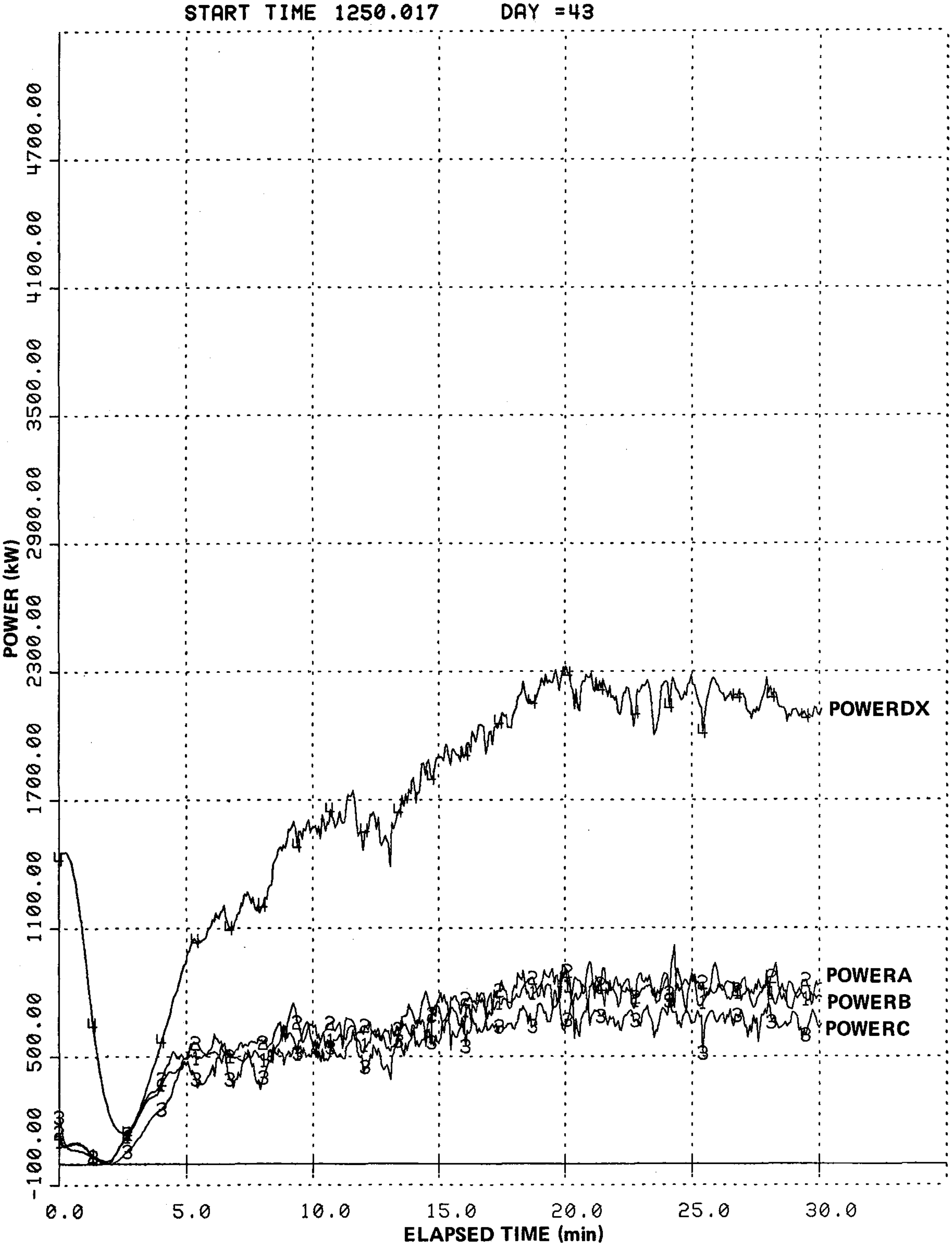


Figure 71. Panel Power and Dump Heat Exchanger Power, Test 27

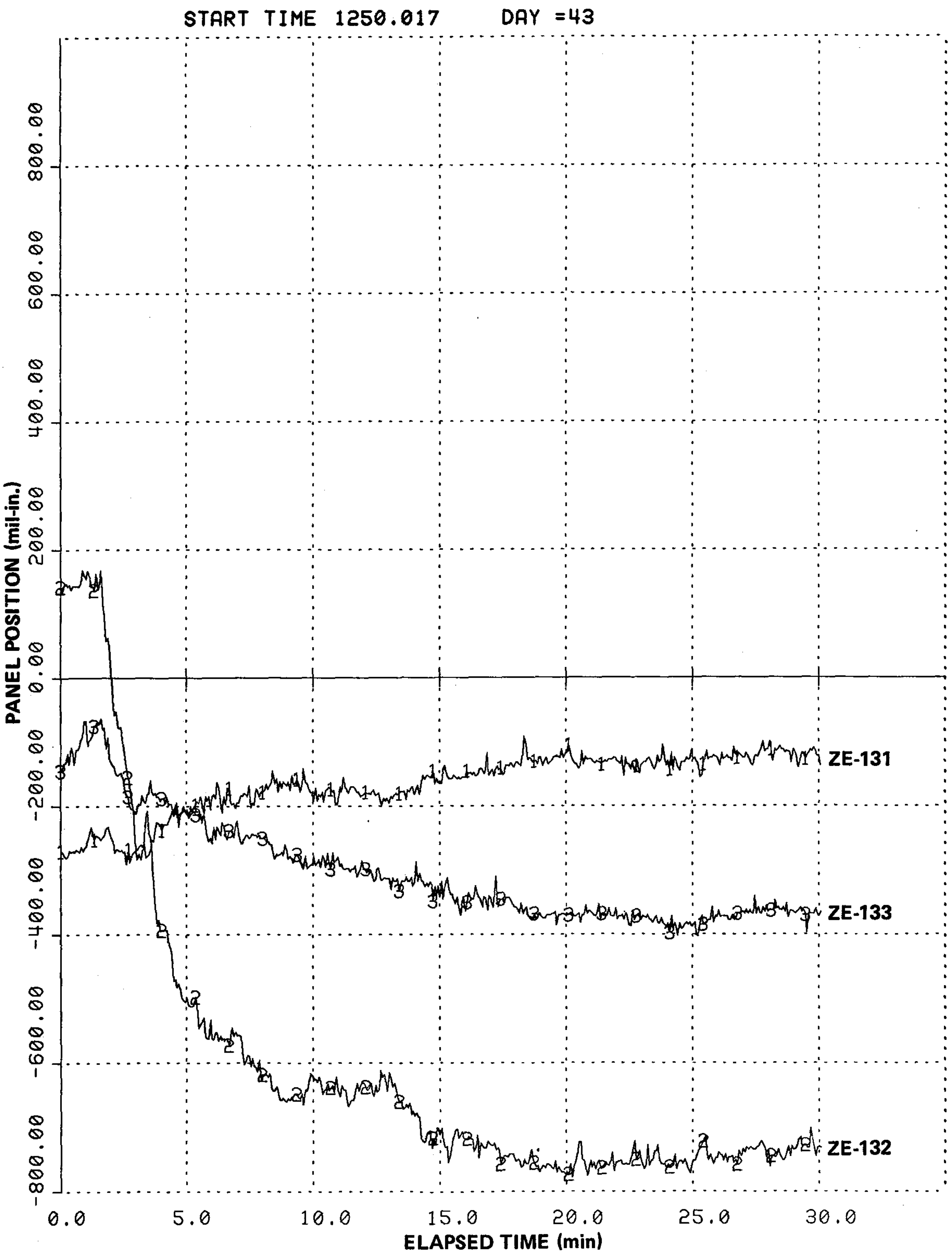


Figure 72. Panel Position during Power Buildup, Test 27

power are known. Absorbed power (MWt) is calculated from the flow rate $\dot{w}$ (lb/s), the temperature difference ΔT (^{o}F) from the inlet to the outlet of the panel, and the specific heat C_p, as given in Section 3.3.1.

Temperatures and flow rates are measured parameters. Input power is determined from the CRTF flux measuring system by integrating the flux distribution over the panel area. A CRTF computer program was used to calculate a transfer function value of 1.02 in order to relate the flux distribution measured in a plane 14 in. in front of the panel to the distribution at the panel surface. The calculated panel efficiency for several power levels is given in Table 16.

TABLE 16

INCIDENT POWER AND ABSORBED POWER

Test	Flux Scan	Time	Number of Heliostats	Peak (MW/m^2)	Total Power From Field (MW)	Incident Power on Panel (MW)	Panel Power (MW)	Efficiency (%)
18	I35501	1018	110	0.71	2.10 ± 8%	1.33 ± 8%	1.25 ± 6%	94 ± 10%
	I35502	1217	110	0.84	2.34	1.56	1.40	90
	I35503	1400	158	0.98	2.9	1.89	1.75	93
21	I02401	1200	173	1.27	3.7	2.48	2.36	95
22	I01501	1330	183	1.32	3.74	2.47	2.31	93
	I01502	1350	188	1.34	3.81	2.48	2.39	92
23	I01801	1309	213	1.53	4.39	2.89	2.657	92
24	I02601	1216	175	1.33	3.51	2.35	2.26	95
34	I06901	1145	161	1.32	3.53	2.35	2.25	96

The incident flux measuring system data for each of the scans in Table 16 are given in Appendix E.

Since early calculations of panel efficiency gave an unrealistically high value (over 100%), the measured parameters used to calculate absorbed power were examined. The accuracies of these parameters were estimated to be:

Thermocouples: ±2%
Flowmeter: ±5%
Sodium properties
    Specific heat: ±0.4%
    Density: ±0.2%

If uncertainties in these parameters are random, the error in absorbed power is about 6%. In examining the characteristics of the panel inlet temperature measurement TE-107, a bias was noted between this measurement and, for example, the lower backside panel temperatures with the heliostats removed (no heat input) as shown by Figure 73. This bias cannot be explained by the line and header preheat. A bias was also noted between TE-107 and TE-130. TE-130 is a resistance temperature device (RTD) that is part of the sodium loop but not considered to be calibrated adequately. A spare RTD was calibrated and installed prior to Test 34. The bias in TE-107 was confirmed as shown in Figure 74, which compares TE-030 and TE-107. This comparison also confirms the temperature correction factor of Figure 73. The panel power calculations and efficiencies of Table 16 have been corrected for this bias, and the uncertainty in the thermocouple measurements has been increased to ±2%. The reason for the bias in TE-107 is considered to be a result of the way in which the measurement was connected to the test panel control cabinet alarm system and to the data system.

The accuracy of the flux measuring system given above as 7% is currently being reevaluated at CRTF. As part of this effort, the flux gages are being recalibrated using the new solar furnace at CRTF. However, this effort will not be completed for several months.

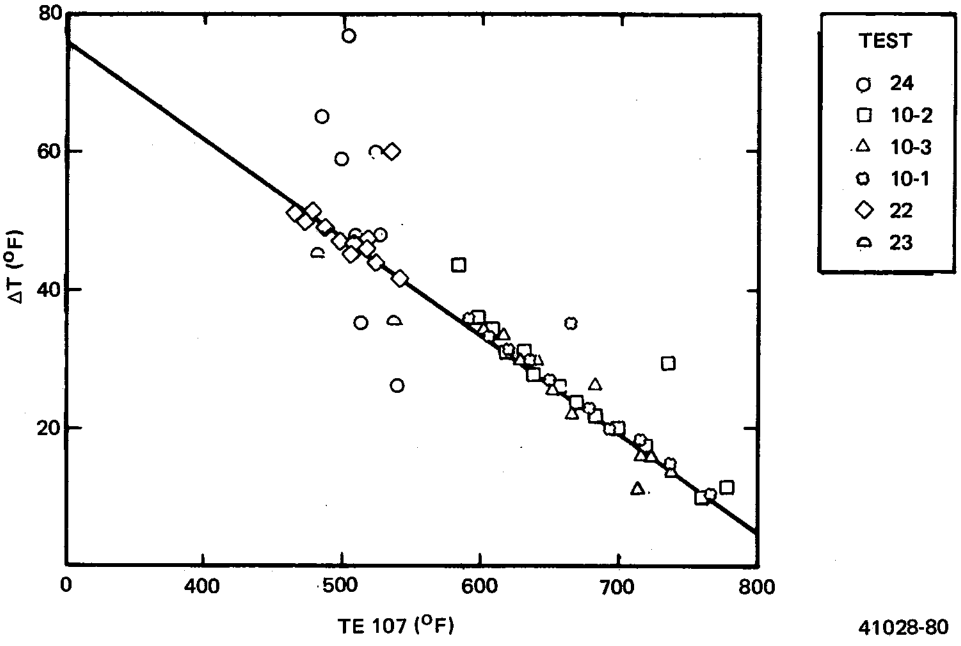


Figure 73. Correction to TE-107 (difference between average backside panel temperature and TE-107)

The combined uncertainties in the input power and the absorbed power give an estimated uncertainty in the efficiency parameter of Table 16 of 10%.

Isothermal Tests

These tests, conducted during Test 10, were for the purpose of determining the heat loss characteristics from the test panel. The tests consisted of heating the sodium loop to between 700 and 800°F using the heliostats, then removing the heliostats and observing the panel temperatures over a 15-min period. Three such periods are shown in Figure 75. During the first cooldown period of Figure 75, the trace heaters on the inlet and outlet piping for the panel were on, which would tend to distort the results. These heaters were turned off for the next two cooldown periods. A constant flow rate was maintained during the cooldown periods. Figure 76 shows a representative temperature distribution along the center tube of Panel B. The data obtained during these cooldown periods were very difficult to analyze, and a meaningful heat

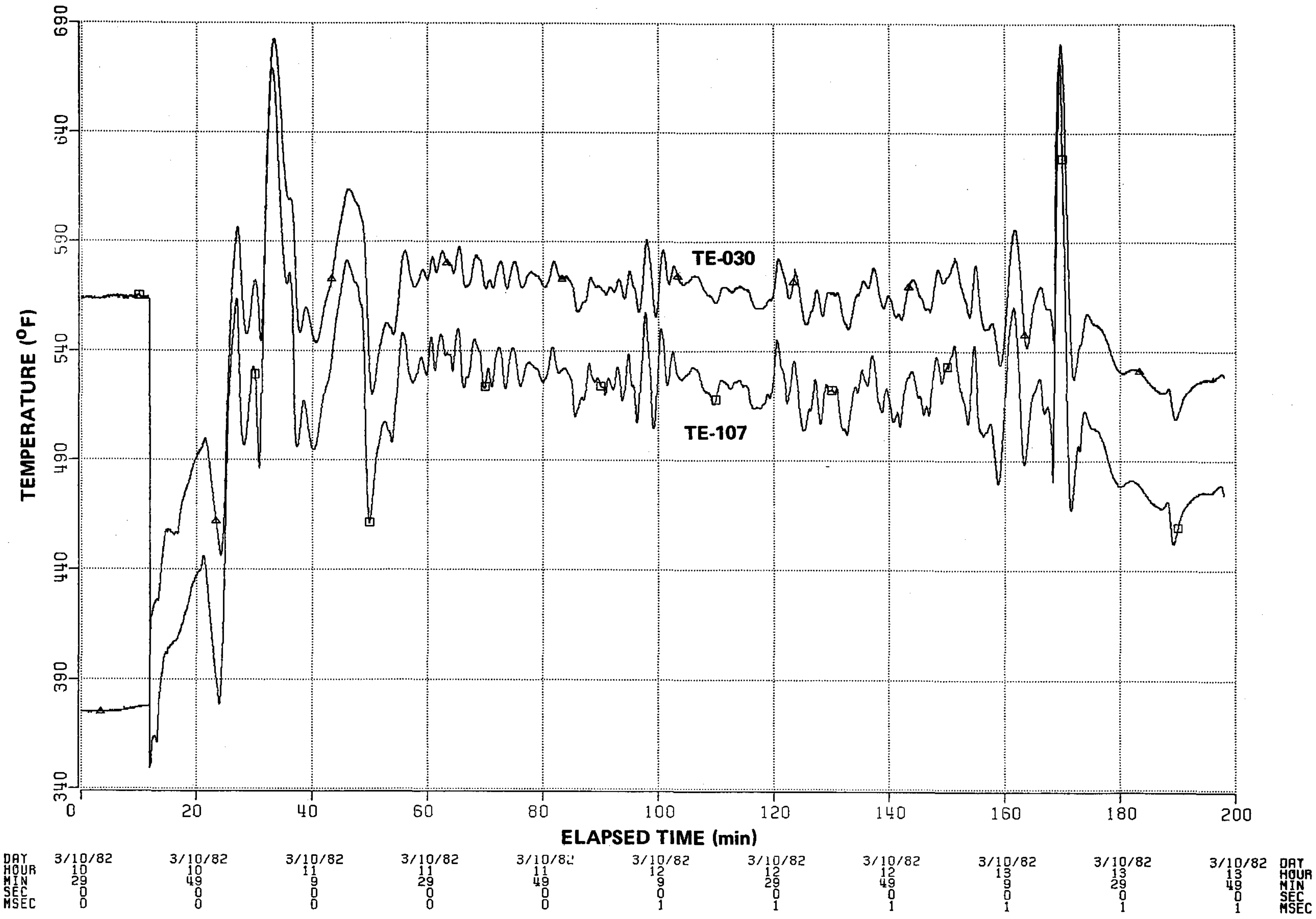


Figure 74. Comparison of Inlet Temperature Measurements, Test 34

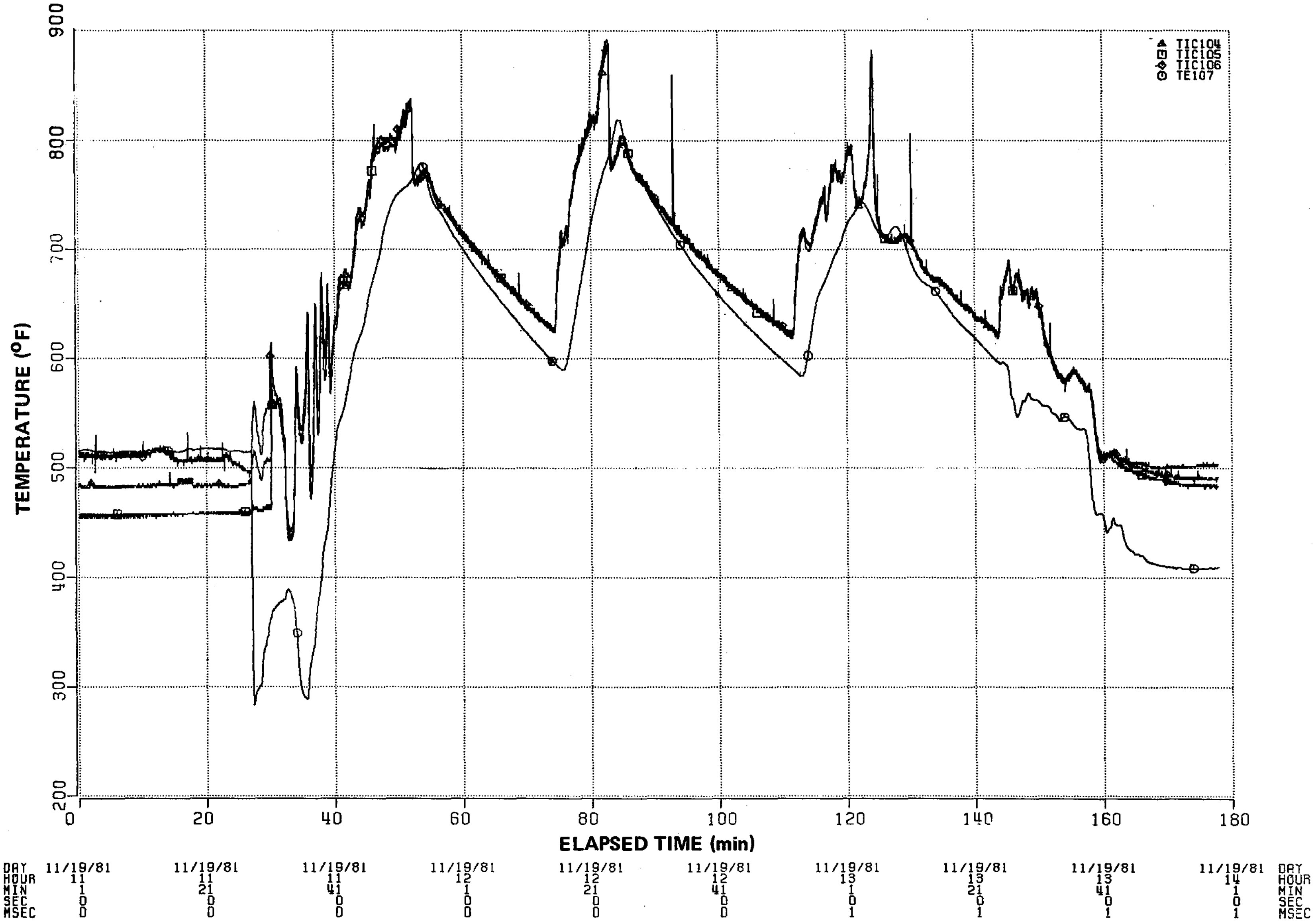


Figure 75. Panel Cooldown Periods during Test 10

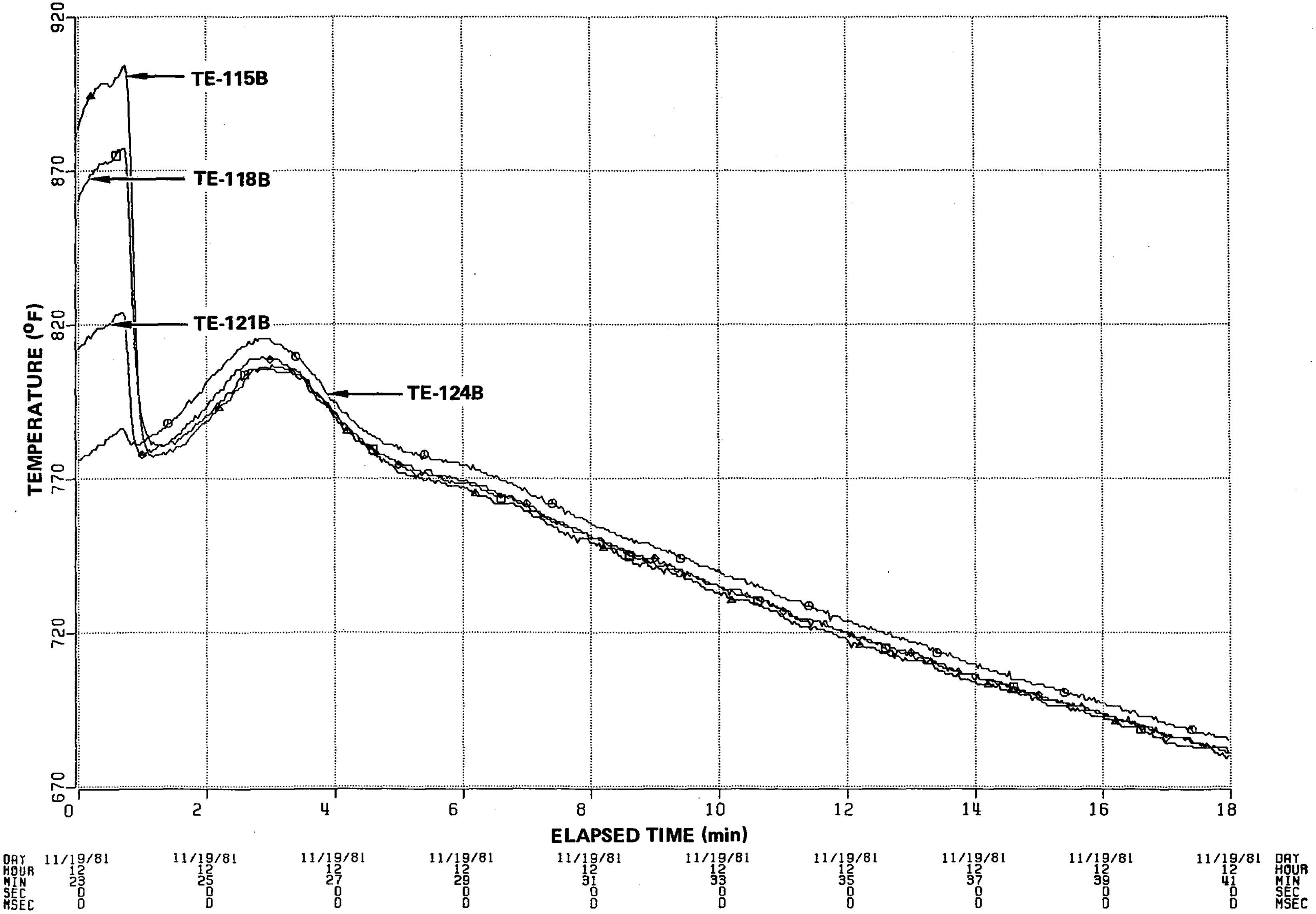


Figure 76. Cooldown Period No. 2, Test 10

loss estimate could not be made. The difficulty results from (1) the relatively small temperature differences involved, (2) the bias in the inlet temperature measurement that was identified late in the test program, (3) the variable inlet temperature, and (4) the transit time for the sodium between the various temperature measurement locations. Test 34, which was scheduled to include cooldown tests, was terminated early due to cloud cover before the test conditions could be established.

5.5 PANEL STRUCTURE

The tubes of each of the three subpanels are held in alignment by mechanical constraints located every 4 ft along the length of the panel. These mechanical constraints allow the tube to expand differentially in the longitudinal direction but restrict the motion of the tubes in the lateral direction. The locations of the mechanical constraints are indicated in Figure 77.

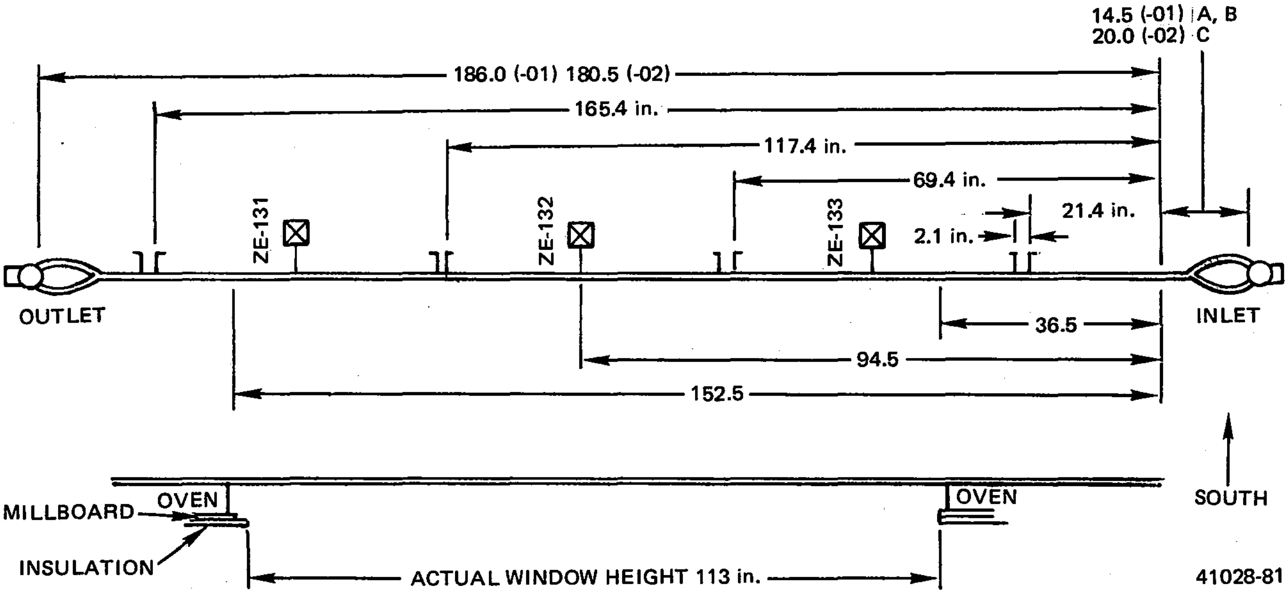


Figure 77. ESG Solar Panel Mechanical Constraints

The panel mounting on the test frame is described in Section 2.

The center panel was equipped with three linear motion transducers to indicate panel movement in the forward or backward (north or south) direction. As described in Section 2, forward panel motion was constrained by the three sets of tie rods. These rods did not particularly constrain backward movement.

Figure 78 shows the panel motion during Test 19. During power buildup, the panel center moves northward by about 3/4 in. The top of the panel tends to move backward a small distance, and the bottom transducer location shows a forward movement. The flux profile during this test is shown in Figure 79 over a greater time period than for Figure 78.

The panel movement is shown to closely follow the incident flux profile as seen by the comparison of Figures 80 and 81 for Test 24.

During the latter portions of the test, it was observed that at ambient temperatures, the panel had a permanent set in the backward direction. This position was measured after the test, as given in Figure 82. All three panels had a similar shape. Also shown in this figure is the shape of the edge tube (C-21) of Panel C. The reason for the shape of Tube C-21 is given in Section 5.1.

The panel location prior to each test at ambient temperature conditions is given in Figure 83. While these gages were not intentionally reset during the testing, some shifts may have occurred during the repainting activity or during repair of the frame insulation. For the low- and intermediate-power tests, the recorded panel deflections (north-south direction) of Figure 83 indicated very little change in panel position at ambient conditions.

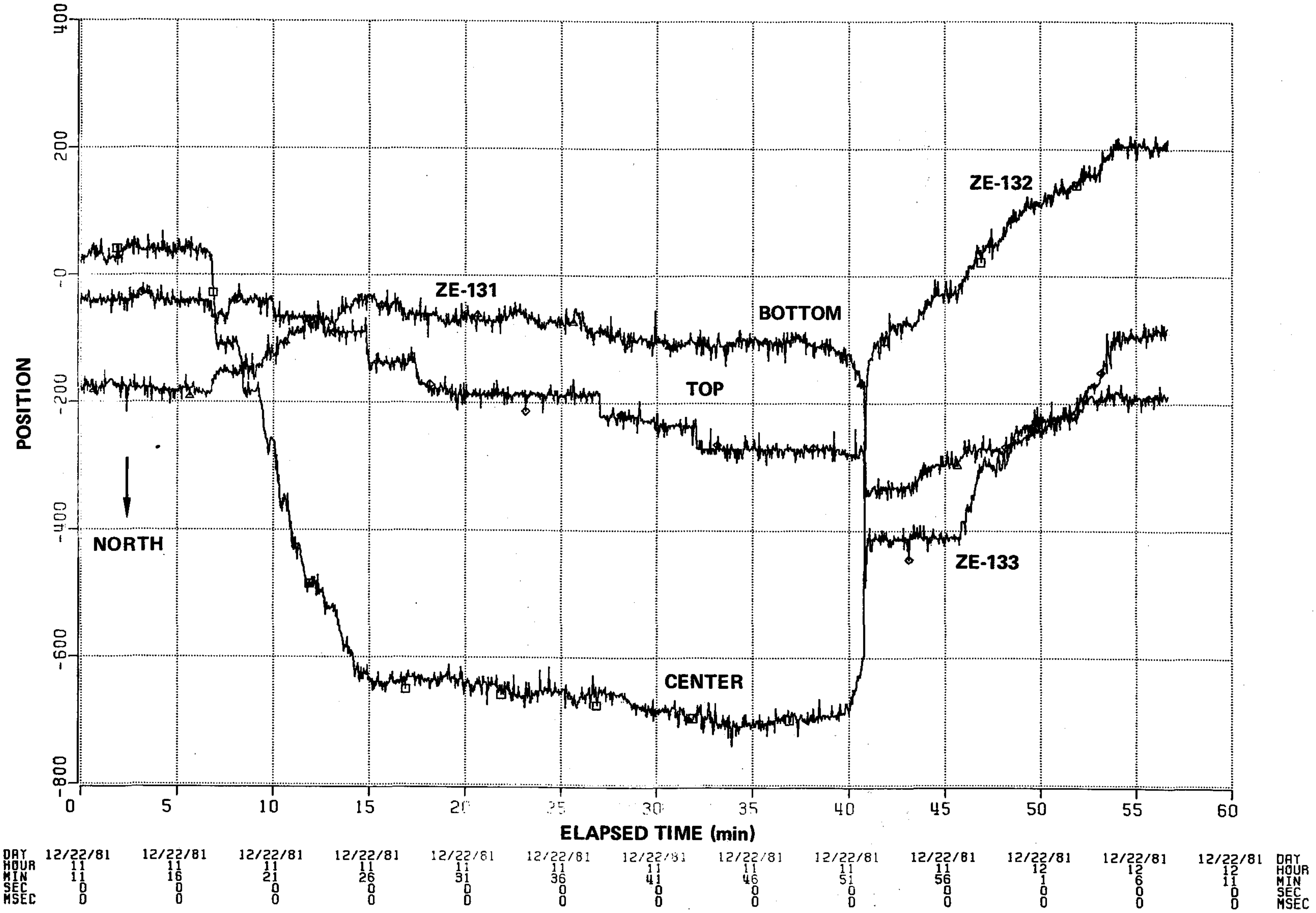


Figure 78. Panel Motion during Test 19

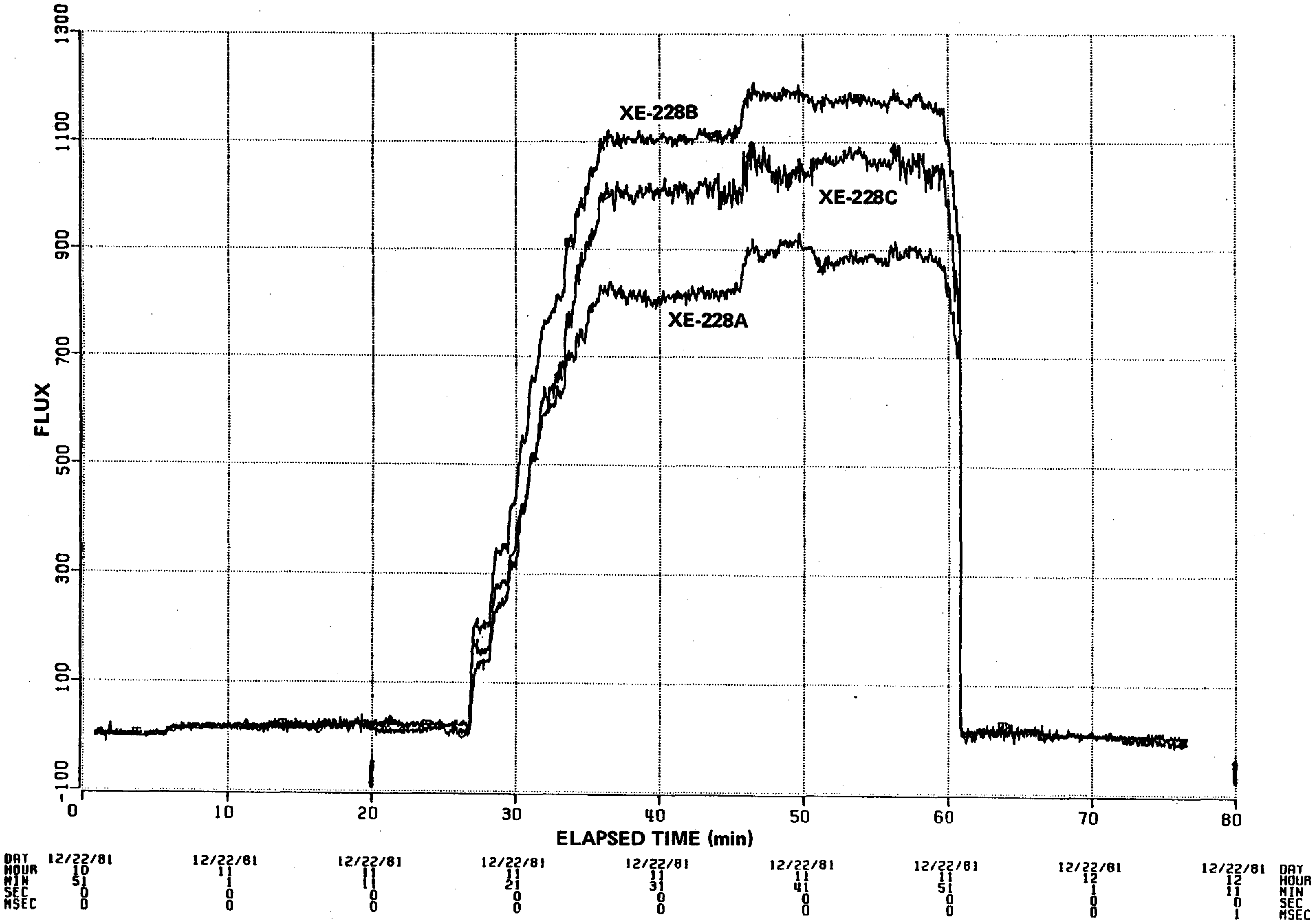


Figure 79. Flux on Panel during Test 19

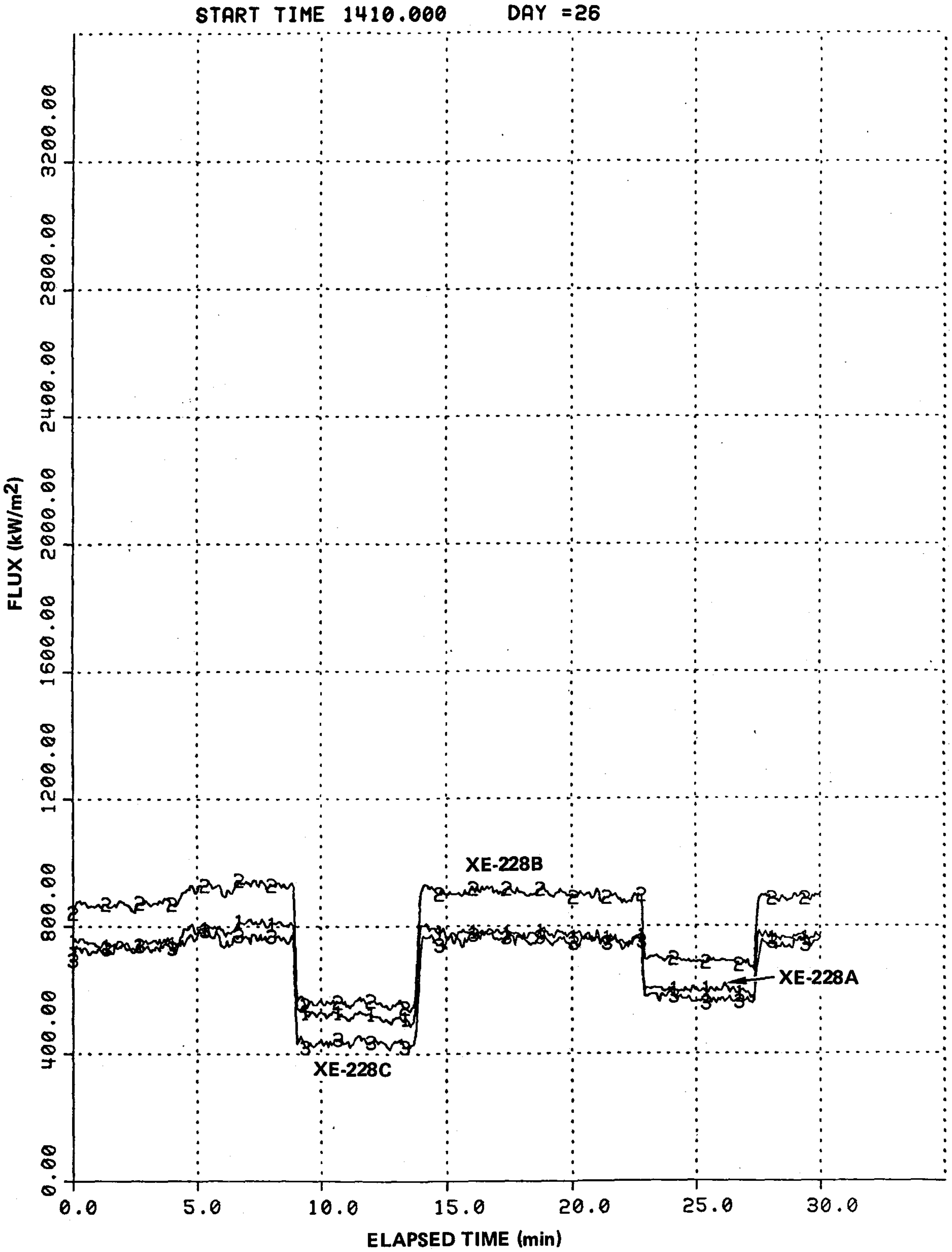


Figure 80. Panel Flux Transients during Test 24

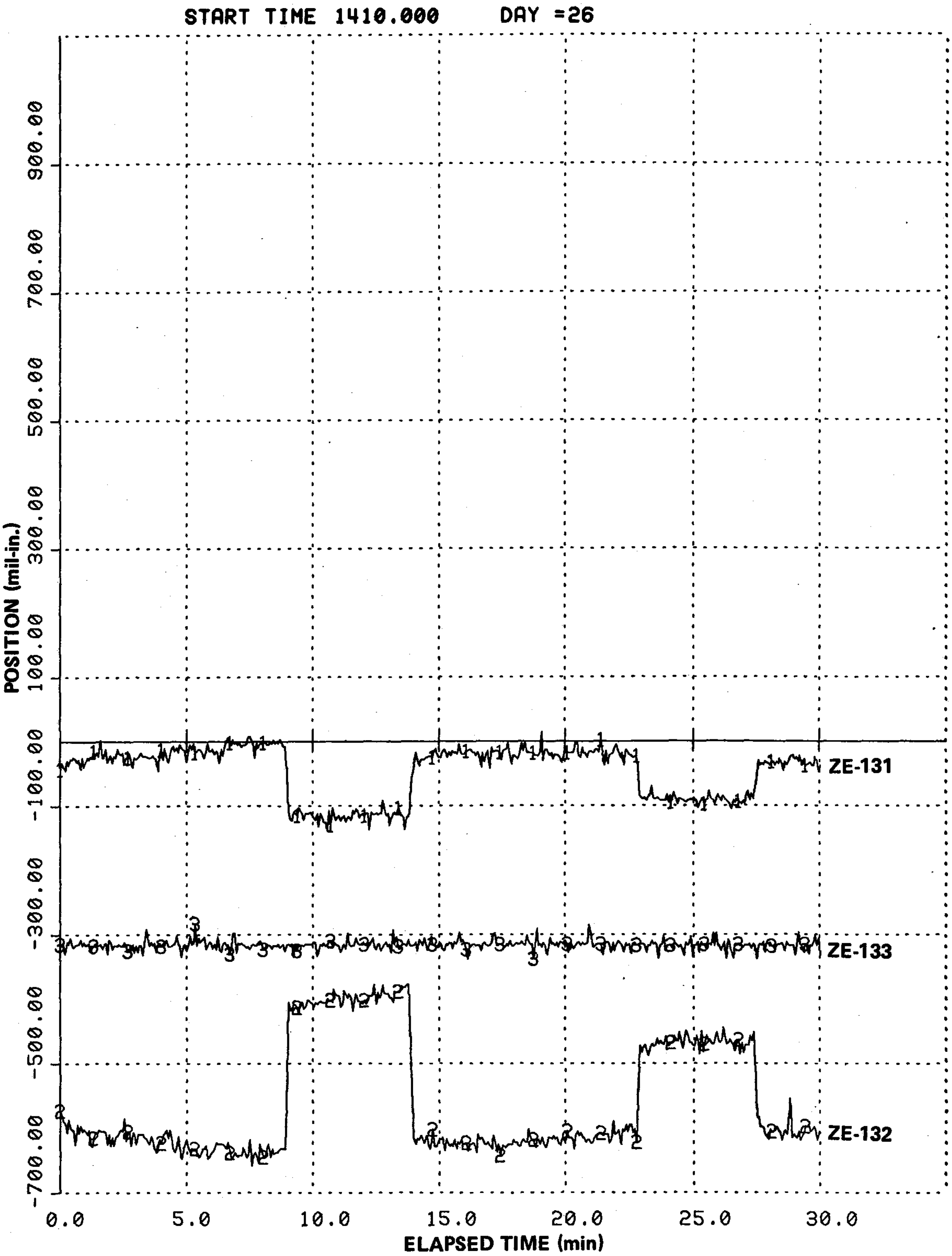


Figure 81. Panel Position during Power Steps, Test 24

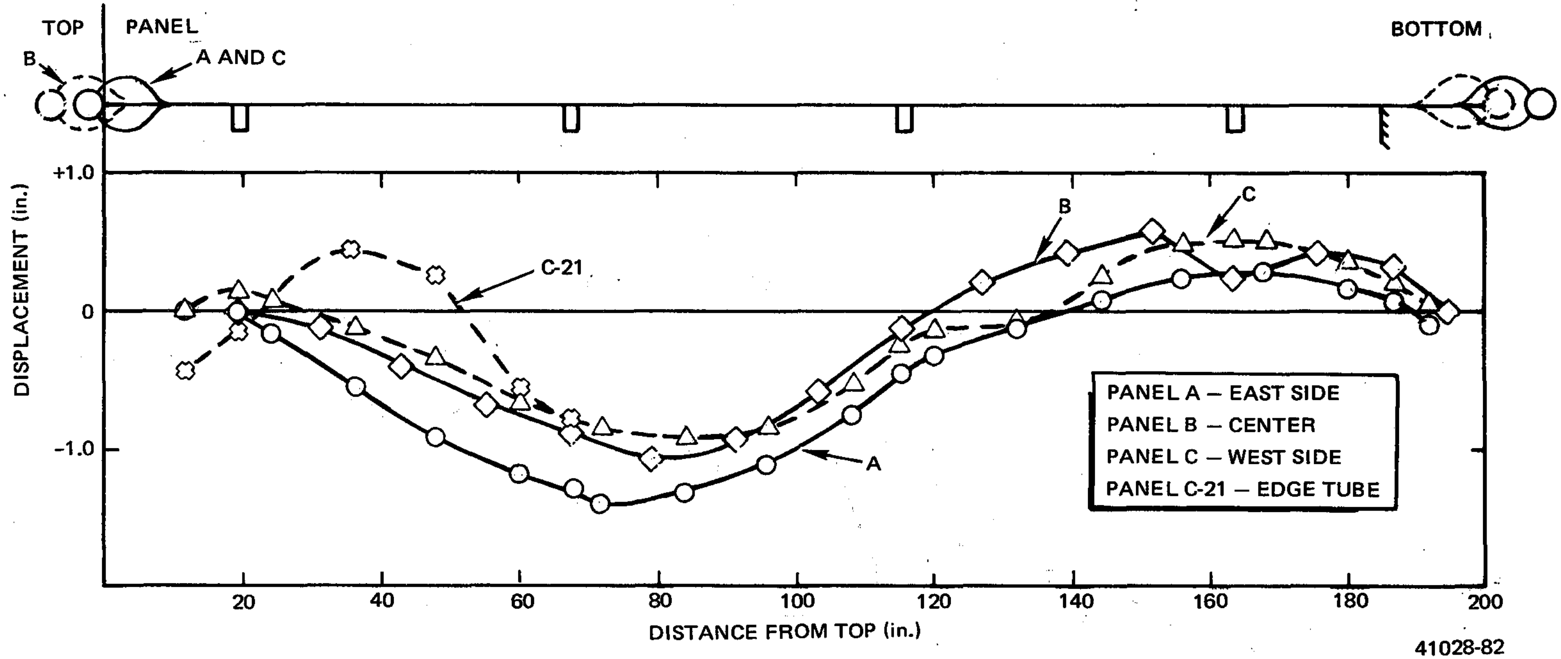


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Figure 82. Panel Placement

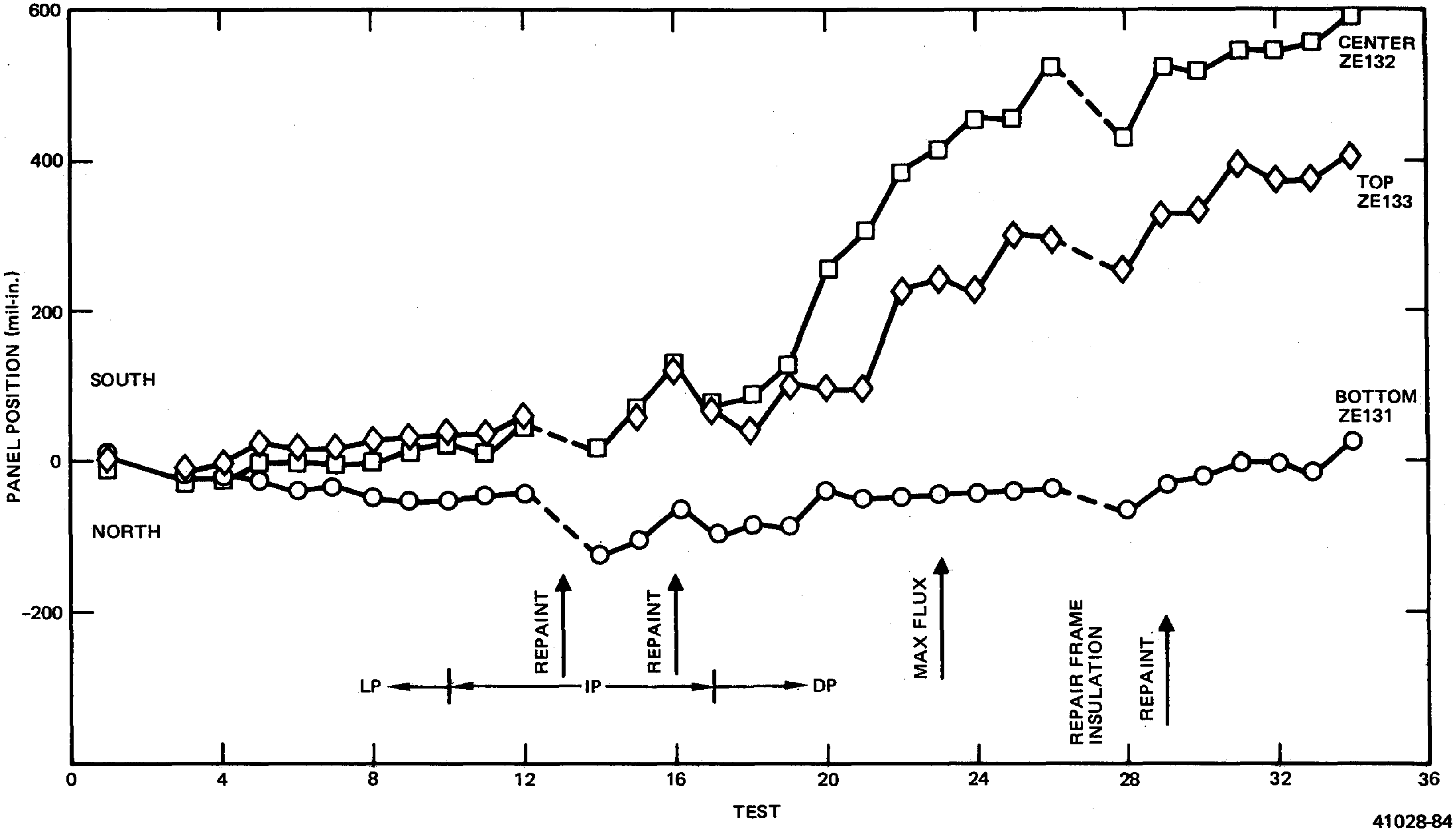

Figure 83. Panel Position at Ambient Temperature Prior to Each Test

During later portions of testing at full power, it was observed, between tests, that at ambient temperature, the panel was significantly bowed in a southerly direction in the thermal window area and slightly bowed in the northerly direction near the inlet region, as shown in Figure 83. Inspection of the panel after testing also indicated that the upper set of tie rods (both sides) between the panel and its support structure had elastically buckled.

Previous structural analysis of the panels indicated that during full-power operation, the panel tubes developed stresses beyond yield and, therefore, behaved inelastically. Figure 84 presents a diagram of the anticipated displacement behavior of the panel during heatup and cooldown cycles.

If the panel were not restrained by the tie rods, the panel would displace a specified distance and return to its original position during heatup and cooldown. This is shown by Line 1 of Figure 84. However, since the tie rods do restrain the panel and analysis indicates that the tubes act inelastically, the displacement of the panel during heatup follows Lines 2 and 3 and puts the tie rods in tension. During cooldown, the panel develops a reverse bow due to the restrained plastic strain and the unloading follows Line 4. During this unloading phase, the panel support tie-rod tension load becomes compressive. This load is sufficient to elastically bend these relatively flexible rods, which allows the panel to displace as if not restrained and results in a permenent reverse set. This condition is represented by Line 5.

Visual inspection of the tube mechanical supports after testing did not reveal any damage, except for the unusual conditions on Tube C-21. Analysis indicates that the compressive strength (buckling) of the mechanical supports is much greater than that of the tie rods; therefore, during unloading, when both the supports and tie rods are in compression, the tie rods will buckle, thus relieving the compression load on the supports.

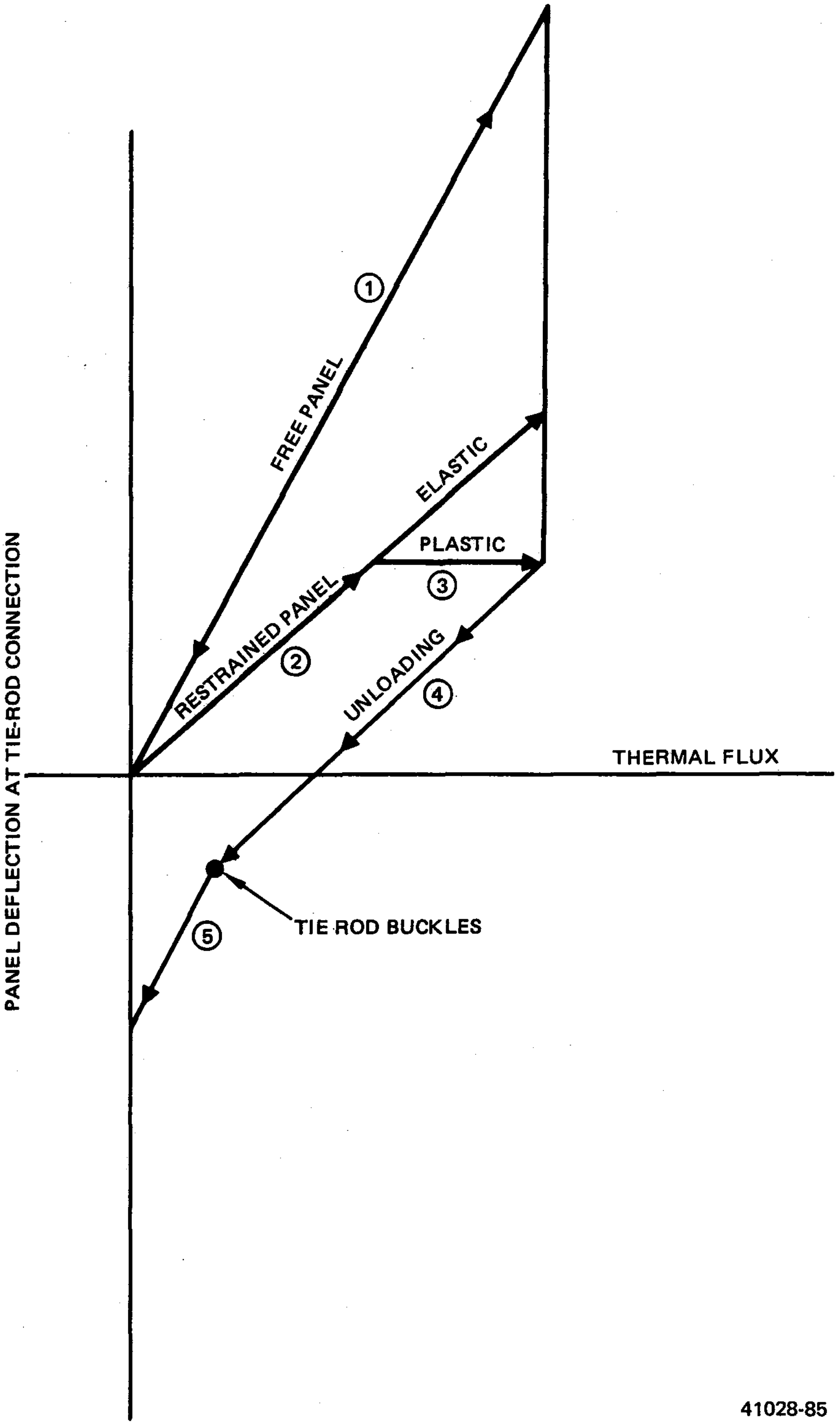

Figure 84. Panel Deflection versus Thermal Flux

The inelastic behavior of the tubes and the reversed permanent set of the panel is small relative to the size of the panels and should not affect the commercial applicability of the design or its capabilities to meet its performance criteria.

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6.0 COMMERCIAL RECEIVER DESIGN

In May 1982, Rockwell submitted a proposal to DOE for the preliminary design of a 30-MWe power plant using the sodium-cooled solar central receiver concept. The central receiver design for this plant is based upon the results obtained from the solar panel tests at CRTF and is configured as a north-facing billboard (Figure 85). The successful completion of this panel test program has enabled Rockwell to present a design concept for which all components have been thoroughly tested and component fabrication capability has been demonstrated (Figure 86). This has prompted the prediction (in the proposal) that a fixed-price construction contract with performance warranties could be offered at the conclusion of the plant design study. The specific design details of the proposed receiver concept and a comparison of these details with the solar test panel are presented in the following paragraphs.

6.1 COMMERCIAL PANEL DESIGN CHARACTERISTICS

The performance of a commercial receiver subsystem is summarized in Table 17. The receiver selected for this plant is an external flat panel configuration, which is cost effective for plants of this size using a compact sodium receiver. The receiver and its support structure are located atop a 111-m (365-ft) steel tower. The midplane of the receiver is at 125 m (410 ft) above ground elevation. The receiver assembly consists of eight panels as shown in Figure 87. Each panel consists of 102 19-mm (3/4-in.) diameter, Type 316 stainless steel tubes with a wall thickness of 1.24 mm (0.049 in.). The panel is constructed using a Rockwell proprietary system that reduces thermal stresses and extends operating life. This system was used and proven in the successful CRTF test of the prototype panel. The inlet and outlet manifolds at each end of the tubes are made of Type 316 stainless steel tubing. The inlet manifold is anchored to the supporting structure, while the outlet manifold accommodates thermal growth along with the piping. The panel detail is shown in Figure 88.

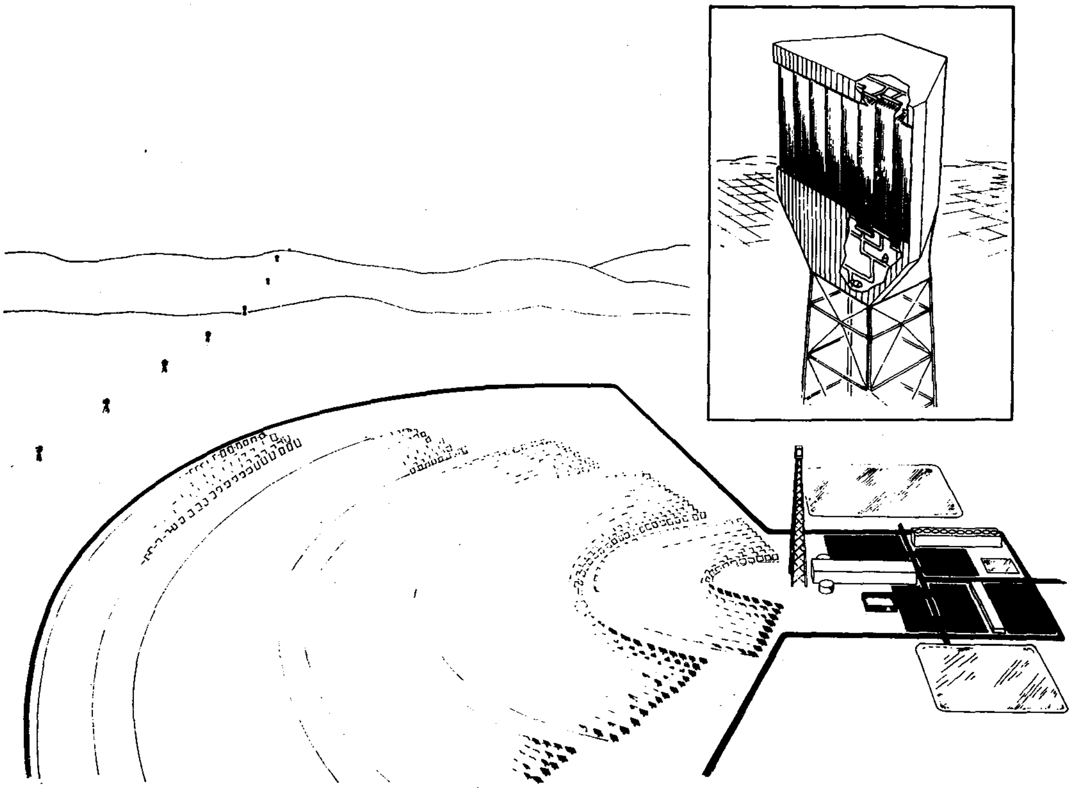

Figure 85. Commercial Solar Central Receiver Power Plant

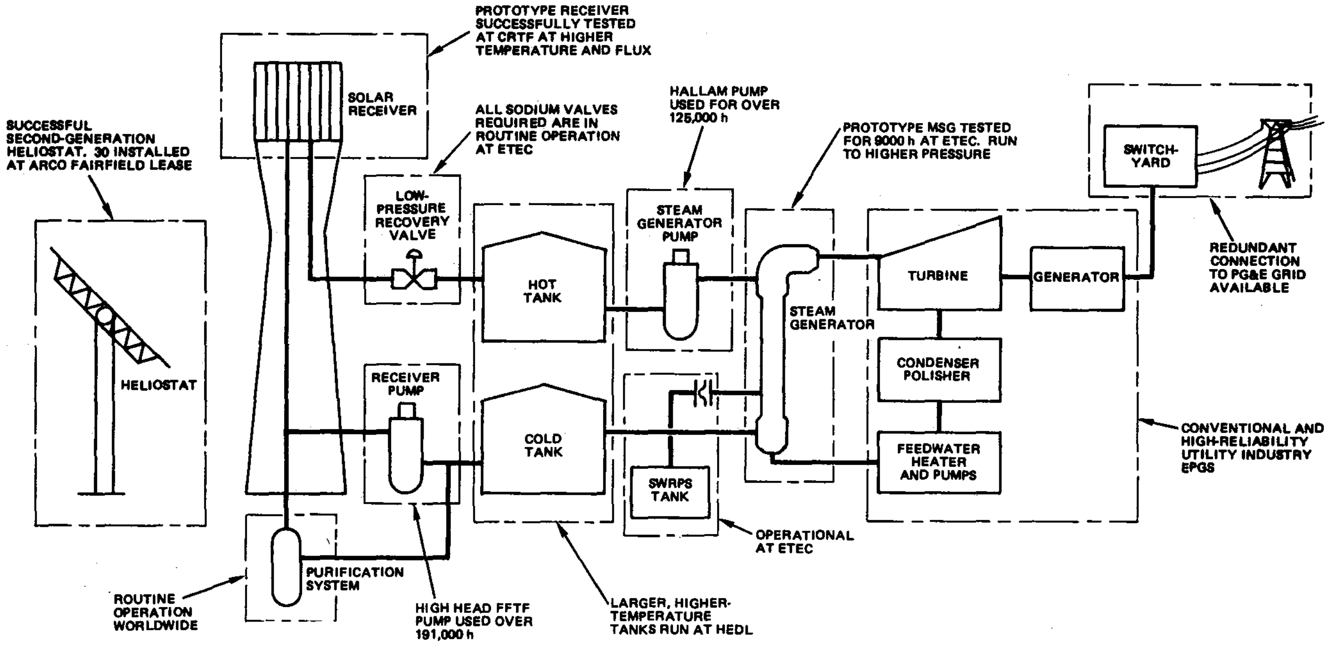

Figure 86. All Components are State of the Art

TABLE 17
RECEIVER SUBSYSTEM DESIGN SUMMARY

Key Design Parameters	
Midplane elevation	125 m (410 ft)
Receiver aperture	
Width	16 m (52 ft)
Height	12 m (40 ft)
Number of panels	8
Panel characteristics	
Width	2.0 m (6.6 ft)
Height	15.2 m (50 ft)
Number of tubes	102
Tube diameter	19.1 mm (0.75 in.)
Tube wall	1.24 mm (0.049 in.)
Material	Type 316 stainless steel
Performance	
Incident power	116 MWt
Absorbed power	107 MWt
Inlet temperature	321°C (610°F)
Outlet temperature	566°C (1050°F)
Maximum flux	1.2 MWt/m^2
Average flux	0.61 MWt/m^2
Pump flow/head	0.39 m^3/s (6200 gal/min)/167 m (550 ft)
Design Model Basis	
Test of Rockwell prototype receiver at CRTF	

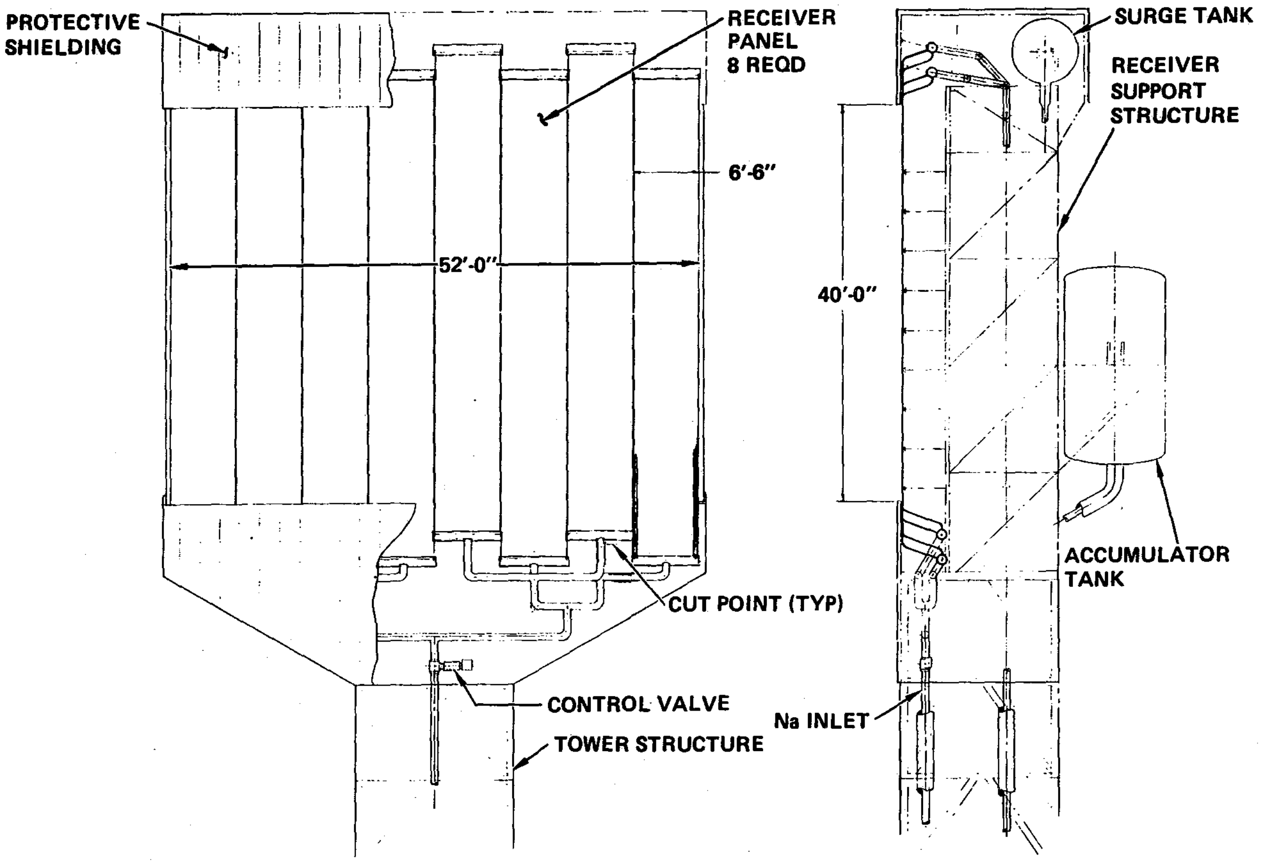

Figure 87. Commercial Solar Receiver

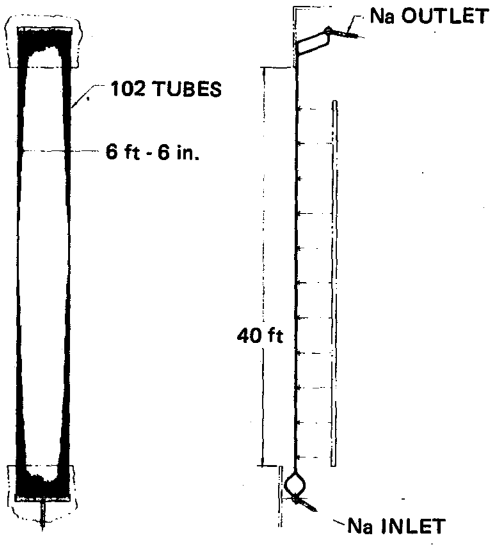

Figure 88. Receiver Panel Detail Layout

Finite element analyses have been performed to validate the design of the receiver tubes and manifolds. The major panel stresses are those thermal stresses caused by the temperature difference across the wall, especially near the crown, and the temperature difference across the whole tube. The proprietary panel construction method also allows higher tube-to-tube thermal differentials and reduces stresses. On this basis, a 30-year lifetime is achievable. Additional panel stresses due to wind, dead weight, pressure, and seismic need to be evaluated to establish the design margin. The portions of the system containing the coolant will be designed to Section VIII Division 1 of the ASME Boiler and Pressure Vessel Code, with supplemental criteria for thermal-induced stresses and life calculations. The remainder of the system (civil structures) and the steel tower will be constructed to the Uniform Building Code and governing local codes.

6.2 COMPARISON WITH TEST PANEL

The test panel is compared with the commercial 30-MWe plant panel in Table 18. The panel tests confirmed the ability of the design to allow panel and tube-to-tube thermal expansion to take place without excessive stresses developing. The peak solar flux on the prototype receiver, which causes the main stress in the tubes, was more than 25% above the commercial receiver flux, thus providing a conservative margin. The test unit was operated at an outlet temperature of 593°C (1100°F), compared to the plant unit temperature of 566°C (1050°F), providing a further design margin. During the test, the three panels were operated satisfactorily in parallel, although a small amount of panel flow rate interaction was observed, as discussed elsewhere. Since the pressure drop for the commercial panel is substantially higher than for the test panel, the likelihood of flow-rate interaction among panels is substantially reduced.

A change in the plant unit design, compared to the test panel, is to include a tube return length at the top end that increases the flexibility of the panel to accommodate across-panel temperature gradients. Since the test

TABLE 18

30-MWe CENTRAL RECEIVER PANEL SCALEUP

	CRTF Panel	30-MWe Panel
Number of panels	3	8
Maximum temperature [°C (°F)]	593 (1100)	566 (1050)
Flux density [MWt/m^2]	1.5	1.2
Aperture height [m (ft)]	3.05 (10)	12.2 (40)
Width [m (ft)]	0.40 (1.3)	2.0 (6.6)
Tube diameter [mm (in.)]	19.1 (0.75)	19.1 (0.75)
Tube wall thickness [mm (in.)]	1.24 (0.049)	1.24 (0.049)
Pressure drop [psi]	0.2	12.4
Surface paint	Pyromark	Pyromark of lithium sodium silicate
Material	SS 316	SS 316
Manifolding	Single-plane manifolding	Out-of-plane manifolding
Receiver face	Vertical	Vertical
Support structure	Truss	Truss
Passive cooling system	None	22.7-m^3 (6000-gal) accumulator tank
Flow control	Valving	Valving

panel was much shorter, this added flexibility was not necessary for the test duration. These changes are simple and amenable to straightforward analysis. The key features of the receiver design have been tested, and the scaleup to the commercial receiver is basically in length and total number of panels.

The philosophy for control of the commercial receiver consists of matching flow rate to the heat removal requirement with control valve position set by power and trimmed by outlet temperature. This control philosophy was verified for solar receiver applications by the subject testing.

APPENDIX A

SOLAR TEST PANEL REQUIREMENTS

Rockwell International
Energy Systems Group

SUPPORTING DOCUMENT

GO NO.	S/A NO.	PAGE 1 OF	TOTAL PAGES	REV LTR/CHG NO SEE SUMMARY OF CHG	NUMBER
41028	40000	19	19	New	004TI000008

PROGRAM TITLE
Solar Electric Power

DOCUMENT TITLE
Solar Test Panel Requirements

DOCUMENT TYPE
Technical Information

KEY NOUNS
Receiver test, sodium cooled, solar

ORIGINAL ISSUE DATE
June 20, 1981

REL. DATE
6-30-81

PREPARED BY/DATE	DEPT	MAIL ADDR
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IR&D PROGRAM? YES ☒ NO ☐
IF YES, ENTER TPA NO. 454

APPROVALS DATE

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T. L. Johnson 6/20/81
T. L. Johnson, Project Manager

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ABSTRACT

This document establishes the design and operating requirements for the ESG sodium-cooled test article to be tested at the Central Receiver Test Facility in Albuquerque, New Mexico. The test article shall consist of three subpanels, each with a flow control valve. The test power level shall be 2.5 MW_t.

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FORM 734-C REV. 12-79

SOLAR TEST PANEL REQUIREMENTS

June 20, 1981

APPROVED: T. L. Johnson 6/20/81
Project Manager

CONTENTS

TABLES

FIGURES

1.0 INTRODUCTION

This document establishes the design and operating requirements for the ESG sodium-cooled solar test article to be tested in the 5.0-MWt Central Receiver Test Facility (CRTF) at Albuquerque, New Mexico, in the summer of 1981.

2.0 OBJECTIVES

The overall test objectives are as follows:

1) Provide a proof-of-principle test of sodium-cooled receiver panels.
2) Gain practical fabrication and operating experience.
3) Be in a position to build a commercial panel by 1984.

Specific test goals which support the above objectives are:

- Demonstrate satisfactory panel operations at design heat flux and temperature
- Achieve a maximum number of diurnal thermal cycles
- Demonstrate satisfactory diurnal startup and shutdown
- Demonstrate satisfactory nocturnal thermal control
- Demonstrate control during insolation changes
- Control several panels in parallel
- Demonstrate panel dimensional stability
- Achieve realistic lateral power distributions and sodium flows
- Demonstrate acceptable panel thermal losses
- Accomodate various simulated emergency conditions.

3.0 TEST DESCRIPTION

The ESG test article will be tested at the 200-ft level (top) of the CRTF tower. The panel and test fixture will be supported by the structural frame surrounding the sodium loop. Figure 1 shows an artist's concept of the panel and loop arrangement.

The ESG panel assembly will be connected to the loop assembly mounted on the CRTF tower elevator module while the module is at ground level. Prior to loading the loop with sodium, the loop piping may be cleaned with alcohol. The panels may be attached at this time. After draining the alcohol from the system and drying, the loop dump tank will be loaded with sodium.

Loop checkout, including flowing sodium, will be conducted at the ground level. The panel preheat will be accomplished with an electric blanket covering the test area of the panels. Following successful checkout of the loop, including flowing sodium, the elevator module will be raised to the 200-ft level.

The panel shall be drained at the end of each day and allowed to cool to ambient conditions. Panel sections not exposed to insolation during the test may be trace-heated when sodium is drained. Preheat at the start of each day shall be accomplished using the reflected energy from several heliostats.

4.0 REQUIREMENTS

The test article consisting of three subpanels shall be designed, constructed, and operated to the requirements of this section.

4.1 APPLICABLE DOCUMENTS

The panel shall be designed to ASME B&PV Code Section VIII Division 1 and ANSI B31.1, as applicable, and shall meet requirements of the CRTF Experimental Manual, SAND 77-1173 (Rev), October 1979. Liquid penetrant examination and helium leak testing of welds per these Codes may be substituted for any radiographic examination of weld requirements.

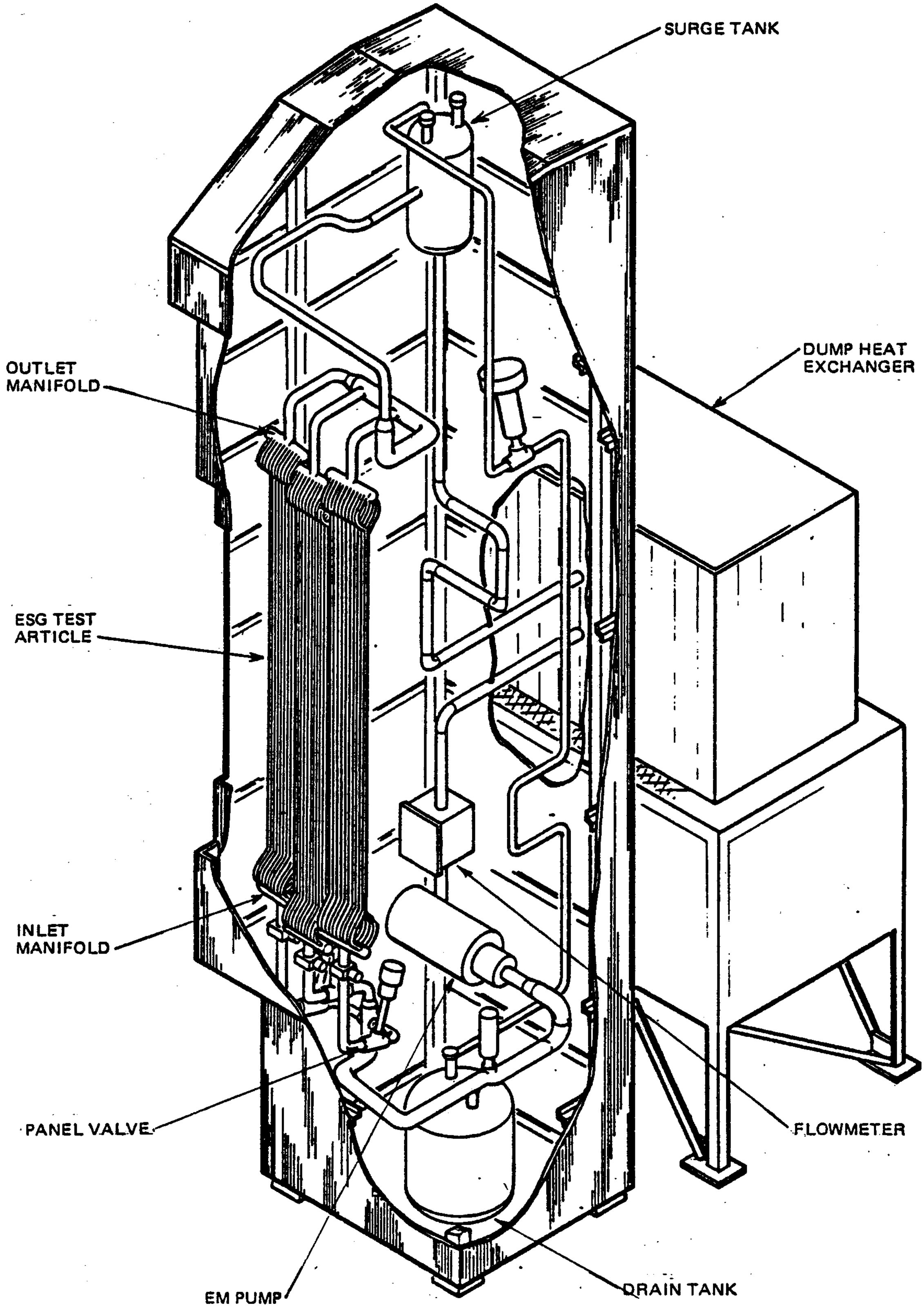


Figure 1. Artist's Concept of ESG Test Article Installed in Sodium Loop at CRTF

The stress analysis shall consider creep-fatigue effects. Other applicable documents are:

1) National Electric Code, NFPA 70-1978
2) National Electrical Manufacturers Association (NEMA) Standards

4.2 APPLICABILITY TO COMMERCIAL PANELS

The construction of the panel will be consistent with the requirements for a commercial panel with allowance made for the constraints placed on the test by the CRTF. The panel shall be designed so as to accommodate 10^4 diurnal cycles over a period of 30 years.

4.3 TEST PERIOD AND PANEL LIFE

The test period is to be 3 months, but the panel construction should be consistent with a 30-year-life commercial panel. A shorter panel projected life will be acceptable if economic justification is provided.

4.4 TEST ARTICLE SIZE AND POWER

The solar radiation heated area of the test article shall be 1.2 m wide by 3 m high.

The panel assembly shall be designed to absorb a maximum thermal power of 3.0 MWt.

Maximum expected operating power is 2.5 MWt. The power distribution ratio across a panel shall not exceed 1.4.

4.5 HEAT FLUX

The maximum throughput heat flux in the panel tubes will be 1.50 MWt/m^2.

4.6 PANEL TEMPERATURES

The nominal panel inlet temperature will be 288°C (550°F). During startup, the inlet sodium may be as low as 232°C (450°F). At no time during testing will the sodium in the loop be permitted to go below 177°C (350°F). During certain operations, the inlet temperature may be increased to 371°C (700°F).

The nominal mixed mean outlet temperature will be 593 ± 10°C (1100 ± 25°F). Hot tube outlet temperatures of 621°C (1150°F) may be encountered on a steady basis. Peak metal temperatures may be as high as 28°C (50°F) above outlet temperatures. The maximum temperature difference between inlet and outlet to a panel shall not exceed 361°C (650°F). The minimum difference shall not be less than 111°C (200°F).

4.6.1 Temperature Mixing in Manifolds

The outlet manifolds will receive sodium at temperatures that will vary laterally by up to 111°C (200°F). The manifolds are required to accommodate such temperature variations.

4.6.2 Temperature Difference in Adjacent Panels

An outlet temperature difference of up to 111°C (200°F) may exist between tubes in adjacent panels. The panel assembly design must accommodate such temperature differences.

4.7 SODIUM FLOW

The sodium flow rate in the panel will be nominally 117 gpm with a maximum of 175 gpm.

4.7.1 Fluid Purity

The panel coolant fluid will be liquid sodium with a nominal oxide concentration of 10 ppm or less by weight.

4.8 PRESSURE IN LOOP

The maximum design pressure in the panel will be 100 psia. Operating pressure will be 30 psia.

4.9 CONSTRUCTION

The solar test panel will be made of three subpanels. Each subpanel shall consist of 21 tubes for a total width of 0.4 m. The length shall be adequate for a solar heated length of 3 m. Each subpanel shall be identical in design and construction. The subpanels shall be supported by a test fixture in a manner representative of a commercial receiver. Each panel shall be supported near the bottom and allowed to expand upward. The panel absorber surface shall have a curvature representative of that for a commercial-sized receiver.

4.9.1 Panel Tubes

The panel tubes will be round, have an OD of 3/4 in., have a nominal wall thickness of 0.049 ± 0.003 in., and be constructed of 316H stainless steel.

4.9.2 Thermal Insulation and Barrier

The panel and structure will be able to resist the leakage of the maximum heat flux between tubes even with gaps as wide as one tube. The panel structure will be protected from any direct heat flux and from excessive temperatures. The subpanel headers and nearby tubing shall be shielded from the collector field energy. These areas shall be insulated and heat-traced for preheating to a nominal temperature of $550^{\circ}F \pm 100^{\circ}F$. High-temperature insulation shall abut the edge tubes of the test article without causing significant shadowing of the edge tube. Backside heat loss from a subpanel shall not exceed 0.01 MWt.

4.9.3 Structural Integrity

The panel and its structure will retain its integrity, neither warping unduly nor opening up gaps through which heat flux can penetrate.

4.10 ENVIRONMENTAL

The seismic g's will be 0.50 in the horizontal direction.

The design wind velocity will be 4.5 m/s (10 mph). The maximum operating wind velocity will be 22 m/s (50 mph).

The maximum survival wind velocity will be 44 m/s (100 mph).

4.11 TRANSIENTS

The panel will be capable of being started up and shut down once each day for the test period. At night, the panel will be drained and will reach ambient temperature.

4.11.1 Cooldown Transient

The panel shall be able to sustain ten cooldown incidents (no flow, no insolation) where the panel will lose temperature at the rate of $100^{\circ}C/min$ ($180^{\circ}F/min$).

4.11.2 Loss or Recovery of Insolation

The panel shall be able to sustain 40% loss or recovery of insolation events over a period of 10 sec at a rate of 55°F/sec.

4.12 INSTRUMENTATION

The panel shall be instrumented with thermocouples, deflection gauges, and heat flux sensors as shown on the sketch.

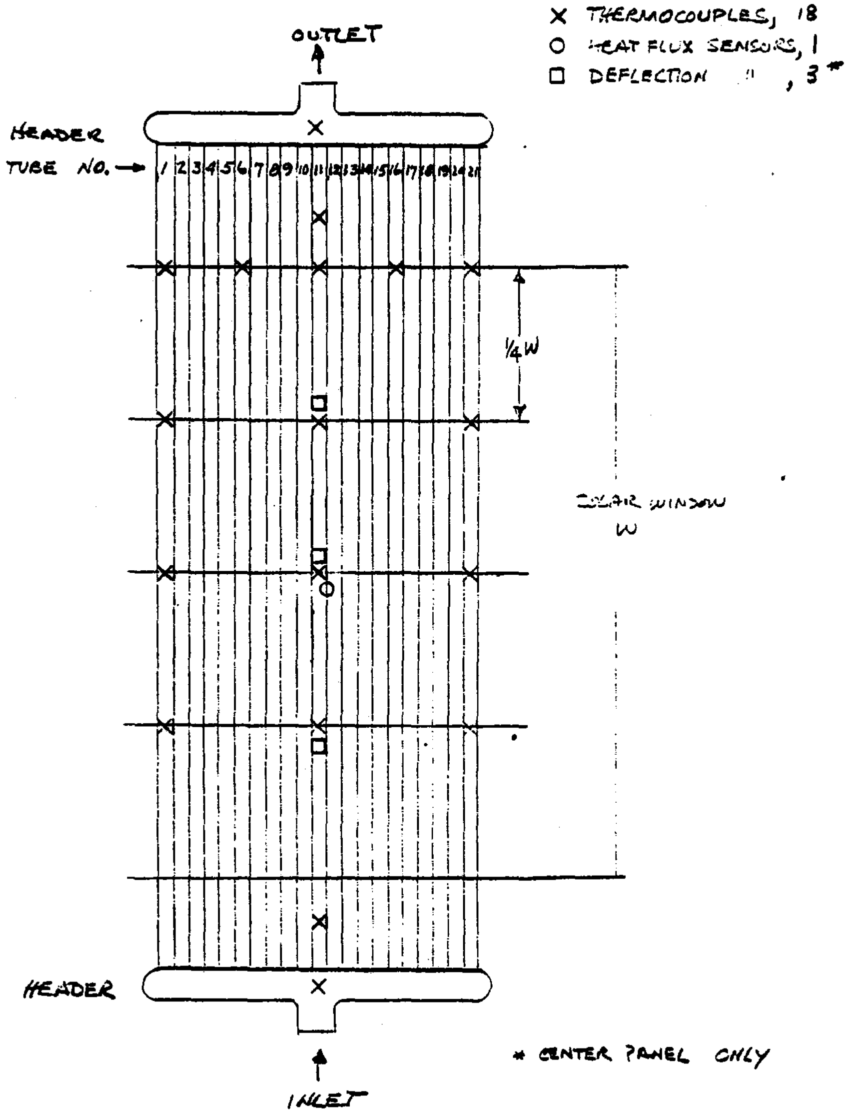
All instrumentation shall be accessible for inspection and repair with a minimum of disassembly of the panel or test fixture components. Particular attention should be given to the accessibility of the deflection sensors and flux gauges. Flux gauges may require water cooling (to be supplied by the CRTF). The cooling water may contain an anti-freeze additive. Selected thermocouples and flux gauges may be part of the panel control system. Thermocouples shall be mounted so as to minimize response time. Thermocouples used for panel control purposes shall be brazed in position. Panel instrumentation for control purposes may use any or all of the following:

1) Subpanel outlet temperature
2) Subpanel intermediate tube temperatures
3) Flux gauges
4) Subpanel inlet temperature.

4.13 PANEL CONTROL

Each panel shall be equipped with a flow control valve. The flow rate through each panel shall be controlled to maintain a constant mean outlet temperature within ±25°F. Both manual and automatic control modes are required. Automatic control shall be accomplished using process control equipment typical of that used by the utility industry. An alternative digital control system will be considered if necessary to meet test objectives. Manual override of the

INSTRUMENTATION LOCATIONS
EACH PANEL



automatic control systems is required. The control capability for automatic systems is desired to be 25-100% of the subpanel flow rate. All of the subpanels shall be capable of operating together to represent a single panel. The flow control shall also permit the maximum sodium flow (100 gpm) to go through any one of the subpanels. The insolation at such a time may range from zero to the normal amount for that subpanel (nominally 1.00 MWt).

5.0 INTERFACES

The panel will interface as follows:

1) Sodium Loop. The test article will be attached to a special three-branched manifold tree assembly at both the inlet and outlet ends. These manifold trees will connect to the sodium loop piping at locations designated by the CRTF.
2) Panel instrumentation leads will terminate in the patch panel room of the CRTF elevating module. ESG instrumentation used for panel control must be also equipped with signal conditioning equipment. All measurements including those for control shall be supplied to the CRTF control room for recording.
3) The loop control system and the panel control system shall remain separate to the extent possible. The panel control system may require information from the loop flowmeter. The dump heat control may require the panel mixed mean out temperature from the panel thermocouples.
4) All utilities will be supplied by the CRTF. ESG must designate services required.
5) CRTF will supply solar energy according to the test plan.
6) ESG must supply data recording requirements and data display requirements to the CRTF.
7) The test article shall be bolted and/or welded to the main support columns of the loop. The location shall be compatible with the real time aperature flux (RTAF) system.

APPENDIX

REFERENCE PLANT AND RECEIVER

The ESG test panel is intended to provide a data base for commercial-type solar panels. A typical receiver is the one proposed for solar repowering of West Texas Utilities (WTU) Paint Creek Unit 4. In the following tables are plant and receiver data generated in the Paint Creek conceptual design study. These data may be useful in interpreting the requirements for the solar panel test.

TABLE 1
WTU PAINT CREEK 4
SOLAR REPOWERED PLANT DATA

Maximum Solar Power (MWe)	60
Tower Height m (ft)	154 (505)
Hours of Storage	4.0
Number of Heliostats	7882
Main Steam Temperature °C (°F)	538 (1000)
Reheat Temperature °C (°F)	538 (1000)
Steam Pressure MPa (psig)	12.4 (1800)

715-B.74

Rockwell International
Energy Systems Group

DESIGN DATA SHEET

PREPARED BY	
APPROVED BY	
TITLE	WTU Solar Repowering Receiver Subsystem
WBS NO.	
NUMBER	
PAGE	
DATE	May 23, 1980

NEW REV	NO.	ITEM	DESIGN POINT		TENTATIVE	FIRM	REFERENCES AND REMARKS
			UNIT	VALUE			
		<u>Receiver Subsystem</u>					
		Nominal Thermal Power	MWt	145			
		Maximum Thermal Power	MWt	226			
		Receiver Size and Type	m x m (ft x ft)	14.0 x 15.4 (45.9 x 50.5)			External cylinder, 24 panels
		Receiver Temperature					
		- In	^{o}C (^{o}F)	288 (550)			
		- Out	^{o}C (^{o}F)	593 (1100)			
		Flow Rate - Max Receiver	Kg/hr (lb/hr)	2.08×10^6 (4.59×10^6)			
		- Nom.	Kg/hr (lb/hr)	1.33×10^6 (2.94×10^6)			
		Volume of Sodium in Subsystem	m^3 (ft^3)	204 (7230)			
		Weight of Sodium in Subsystem	kg (lbs)	174,000 (383,000)			
		Total Radiation and Convection Loss	MWt/m^2	0.027			
		<u>Receiver Assembly</u>					
		Diameter	m (ft)	14.0 (45.9)			
		Height	m (ft)	15.4 (50.5)			

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DESIGN DATA SHEET

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TITLE
WTU Solar Repowering
Receiver Subsystem

NUMBER

PAGE

WBS NO.

DATE May 23, 1980

NEW REV	NO.	ITEM	DESIGN POINT		TENTATIVE	FIRM	REFERENCES AND REMARKS
			UNIT	VALUE			
		<u>Receiver Assembly</u> - Continued					
		Receiver Midpoint Elevation	m (ft)	154 (505)			
		Receiver Maximum Elevation	m (ft)	219 (531)			
		Number of Absorber Panels		24			
		Receiver Weight, Dry					
		Total	Kg (tons)	242,000 (266)			
		Total Sodium in Receiver (Panels & Tanks)	Kg (lb)	110,000 (242,000)			
		<u>Absorber Panel</u>					
		Height	m (ft)	15.4 (45.9)			
		Width	m (ft)	1.83 (6.0)			
		Dry Weight, Pressure Parts	Kg (lb)	1,350 (3,000)			
		Number of Tubes		95			
		Tube OD	cm (in.)	1.91 (0.75)			
		Tube ID	cm (in.)	1.65 (0.65)			
		Tube Material		CRES 304H			
		Solar Surface Coating		Pyromark			
		Panel Insulation	cm (in.)	15.2 (6)			Closed-Pore Fiberglass

FORM 706-A REV.6-78

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DESIGN DATA SHEET

PREPARED BY

APPROVED BY

TITLE
WTU Solar Repowering
Receiver Subsystem

NUMBER

PAGE

WBS NO.

DATE May 23, 1980

NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TENTATIVE	FIRM	REFERENCES AND REMARKS
		<u>Absorber Panel</u> - Continued					
		Thermal Expansion	cm (in.)	12.1 (4.8)			Flexible Tube Bends
		Absorptivity, Minimum		0.95			
		Peak Heat Flux	MW/m^2 (Btu/in^2-sec.)	1.23 (0.76)			
		Outlet Temperature	°C (°F)	593 (1100)			
		Inlet Temperature	°C (°F)	288 (550)			
		Maxmimum Tube Surface Temperature	°C (°F)	649 (1200)			
		<u>Tower Assembly</u>					
		Construction					Slip formed concrete
		Concrete Height	m (ft)	141.4 (464)			
		Diameter - Base	m (ft)	17.8 (58.4)			
		- Top	m (ft)	14 (45.9)			
		Wall Thickness - Base	m (in.)	0.46 (11)			
		- Top	m (in.)	0.25 (8)			
		Mat - OD	m (ft)	33.2 (108.9)			
		- ID	m (ft)	13.7 (44.9)			
		- Thickness	m (ft)	3.0 (10)			

FORM 708-A REV.6-78

APPENDIX B

PRETEST CHECKOUT AND SODIUM LOADING PROCEDURE

OP 81-001

PRETEST CHECKOUT
AND
SODIUM LOADING PROCEDURE

AUGUST 20, 1981

CONTENTS:

APPROVALS

Ken Ball
CRTF Test Engineer

Aug 20 1981
Date

ESG Test Engineer

Aug 21, 1981
Date

John T. Holmes
CRTF Operations/Safety Engineer

8/20/81
Date

CRTF Supervisor

8/25/81
Date

A. Valve Checkout

A.1 Provide instrument air to the sodium loop at 100 ± 5 psig

A.2 Operate each of the following mannual valves through its full range, leaving each valve in the indicated position.

FILL VALVE	CLOSED
DRAIN TANK DRAIN VALVE	CLOSED
BYPASS VALVE	OPEN
PLUGGING VALVE	CLOSED
PLUGGING LOOP VENT VALVE	CLOSED

A.3 Operate sodium drain valve (LCV 003) using the drain valve control switch. Verify valve operation and limit switch indication.

A.4 Operate pressure equalization valve (PCV 004) using the pressure equalization valve switch on the control console. Verify operation and limit switch indication.

A.5 Operate panel "A" flow control valve (FCV 101) through its full operating range using Panel "A" Controller set in the manual mode. Verify valve operation, position indication at end points and midpoint, and limit switches and light at end points.

A.6 Verify that panel "A" flow control valve (FCV 101) fails in the open position when either/or both electrical and pneumatic inputs are removed.

A.7 Repeat steps A.5 and A.6 for panel "B" flow control valve (FCV 102).

A.8 Repeat steps A.5 and A.6 for panel "C" flow control valve (FCV 103).

A.9 Operate bypass flow control valve (FCV 001) through its full operating range using the bypass flow control. Verify valve operation, position indication at end points and midpoint, and limit switches at end points.

A.10 Repeat step A.9 with the plugging meter flow control valve (FCV 002).

A.11 Connect regulatable gas source to the hand valve at surge tank rupture disc vent. Adjust at gas source to 1.5 ± 0.5 psig. Open the hand valve. Verify that PSH066 activates the annunciator and open vent valve PCV066. Reset PSH066 if necessary.

A.12 Repeat step A.11 for the drain tank rupture disc vent for operations of PSH067 and PCV067. ______

B. Argon Supply System

B.1 Connect a nitrogen cylinder with regulator to the Argon supply inlet. Set the regulator to 48 psig. ______

B.2 Close pressure equalization valve (PCV 004). Close drain valve (LCV 003). ______

B.3 Using the console controls, set cover gas supply pressure to 45 psig on both surge and drain tanks. ______

B.4 Adjust the low pressure switch of PS046, surge tank cover gas Hi-lo pressure alarm switch, to activate the annunciator at approximately 1 psig. ______

B.5 Raise the pressure of the surge tank to 45 psig using the pressure set point controls on the console. ______

B.6 Adjust the high pressure contact of PS046 to activate the annunciator at approximately 45 psig. ______

B.7 Repeat step B.4 for PS063 and the drain tank pressure. ______

B.8 Raise the drain tank pressure to 45 psig. ______

B.9 Adjust PS063 high pressure contact. ______

B.10 Lower surge tank pressure to 30 psig using console controls. Read this pressure at manifold pressure inlet, outlet (PT 35, 36) and at EM pump inlet and outlet (PT 77, 78). ______

B.11 With drain tank pressure still set at 45 psig and surge tank pressure set at 30 psig, open pressure equalization valve. Observe that drain tank supply valve (PCV 006) is inoperative, that surge tank vent valve (PCV 007) vents, and drain tank pressure drops to 30 psig. ______

B.12 Reduce system pressure, remove nitrogen supply, and reconnect Argon line. ______

C. Dump Heat Exchanger Checkout

C.1 Verify that control air is connected to DHX door operator. ______

C.2 Adjust air pressure to 60 psig. ______

C.3 Operate DHX doors using heat dump door operator switch Verify door operation and limit switch lights. ______

C.4 Operate DHX louvers using heat dump louver control from full close to full open. Verify louver operations and record travel time. ______

C.5 Adjust louvers and DHX doors to full open. Switch heat dump control to LOCAL. ______

C.6 Operate DHX fan No. 1 over its full range of operating speed using the console control. ______

C.7 Repeat step C.6 for DHX fan No. 2. ______

C.8 With both fans operating, depress emergency shutdown switch on the console. Observe both fans stop and the DHX doors close. ______

D. Trace Heating Checkout

D.1 Verify data logger sensor input complete per Table I. Refer to Figures 1, 2, 3, and 4 for color grouping. Verify that DHX doors and louvers are closed. ______

D.2 Verify all trace heater control switches off. ______

D.3 For each of the following switches, activate switch, increase voltage to 40 VAC, monitor the associated thermocouples and observe a temperature rise of approximately 20°F, switch circuit off.

SWITCH	THERMOCOUPLES	DATA LOGGER CHANNEL	
S1	9A, B; 10, 11, 12	5-5,5-6,5-7,5-8,5-9	______
S2	19, 138, 136A, B, C	5-10,6-1,6-2,6-3,6-4	______
S3	13, 14, 15, 17, 18,	2-1,2-2,2-3,2-4	______
S4	20, 21	10-8,10-9	______
S5	137A, B, C	6-5,6-6,6-7	______
S6	127A, B, C	6-8,6-9,6-10	______
S7	125A, B, C	7-1,7-2,7-3	______
S8	126A, B, C	7-4,7-5,7-6	______
S9	77	4-7	______
S10	Spare	Spare	______
S11	51, 52A, B; 53, 55	1-5,1-6,1-7,1-8,1-9	______
S12	Spare	Spare	______
S13	128A, B, C; 135A, B, C, 139	7-7,7-8,7-9,7-10,8-1 8-2,8-3	______ ______
S14	140, 141, 39, 40, 41	8-4,8-5,8-6,8-7,8-8	______
S15	1, 2, 3	8-9,8-10,9-1	______
S16	4, 5, 6, 7A, B; 8A, B	9-2,9-3,9-4,9-5,9-6, 9-7,9-8	______ ______
S17	ST 1, 2, 3, 4	2-3,2-4,2-5,2-6	______
S18	ST 5, 6, 7, 8, 9, 10, 13 14	2-7,2-8,2-9,2-10,3-1, 3-2,3-3,3-4,	______ ______
S19	ST 11,12	3-5,3-6	______

SWITCH	THERMOCOUPLES	DATA LOGGER CHANNEL
S20	69, 72	4-4,4-5
S21	50	4-6
S22	65A, B; 66A, B; 68A, B; 70	3-2,3-3,3-4,3-5,3-6 3-7,3-8
S23	67A, B	3-9,3-10
S24	71	4-1
S25	25, 54	4-2,4-3
S26	61	2-7
S27	DT 1, 2	1-1,1-2
S28	DT 11, 12	2-1,2-2
S29	DT 3, 4, 5, 6	1-3,1-4,1-5,1-6
S30	DT 7, 8, 9, 10	1-7,1-8,1-9,1-10
S31	42, 43, 44, 45	9-9,9-10,10-1,10-2
S32	46, 47, 48, 49A, B	10-3,10-4,10-5,10-6,10-7
S33	28, 29, 30, 31	2-3,2-4,2-5,2-6
S34	56, 57, 60	1-1,2-1,2-2
S35	26A, B; 27A, B	2-8,2-9,2-10,3-1
S36	HX 1 THRU 18	3-7 to 3-10, 4-1 to 4-10, 5-1 to 5-4

E. Evacuate and Purge

E.1 Install blanket heater over receiver panel.

E.2 Attach vacuum pump to sodium loop. Start pump.

E.3 Activate all heater circuits at 40 VAC, monitor equilibrium temperatures in each heated circuit. Readjust each voltage to reach a uniform temperature of 400°F. Record equilibrium temperature and required voltage on each circuit.

E.4 Readjust heater circuits to attain a uniform temperature of 700°F, except for the receiver panel. Record the required voltage on each circuit.

E.5 After 24 hours of pumping, shut off vacuum pump.

E.6 Close the following valves:

Pressure equalization valve (PCV 003)
Bypass loop flow valve (FCV 001)
Plugging loop flow valve (FCV 002)
Panel flow valves (FCV 101, 102, 103)
Bypass valve
Plugging valve
Plugging loop vent valve
Fill valve
Drain tank drain valve

E.7 Open the drain valve (LCV 003)

E.8 Set drain tank cover gas to 10 psig. Set surge tank cover gas to 2 psig.

E.9 When pressure at PT077 reaches 10 psig, open plugging loop flow valve (FCV 002). Keep valve open until gas begins to vent from PCV 007, then close valve. ______

E.10 Open bypass loop flow valve (FCV 001) and panel flow control valve (FCV 101). Allow gas to vent from PCV 007 for 30 seconds, then shut off FCV 101. ______

E.11 Open panel flow control valve (FCV 102) for 30 seconds, then close and open FCV 103 for 30 seconds, then close. ______

E.12 Open pressure equalization valve (PCV 004). ______

E.13 Adjust voltages of each circuit to attain best equilibrium system temperature of approximately 400°F. ______

F. Sodium Fill

SAFETY NOTE

All personnel involved in the sodium fill shall be provided with and shall wear the following:

A. Fire resistant coveralls
B. Leather shoes
C. PVC gauntlet gloves
D. Hard hat with full face shield
E. Jones or chemical goggles

In addition, two 35 lb. NaX portable fire extinguishers will be present.

F.1 Close all sodium valves (FCV 001, FCV 002, LCV 003, and PCV 004). ______

F.2 Prepare sodium melt station by placing barrel heater in catch pan. ______

F.3 Adjust drain tank supply pressure to 1 psig and vent pressure to 1.5 psig. ______

F.4 Attach transfer lines to sodium fill valve, provide minimum purge to atmosphere. ______

F.5 Attach transfer to bottom barrel bung. Attach temporary TC to bottom of barrel. ______

F.6 Place barrel heater on barrel. ______

F.7 Attach bottled gaseous argon to top small bung. ______

F.8 Attach pressure gage and relief valve manifold to top large bung. ______

F.9 Preheat transfer line to 400°F. ______

F.10 Preheat sodium fill line to 400°F. ______

F.11 Preheat sodium barrel to 400°F. ______

F.12 Open barrel sodium transfer vlave. ______

F.13 Open sodium fill valve. ______

F.14 Transfer sodium from barrel to drain tank using 3 psig (maximum) pressure in barrel. ______

F.15 Monitor inventory in drain tank with drain tank level probe (LE61). ______

F.16 When transfer is complete, drain tank pressure will rise. ______

F.17 Close barrel sodium transfer vlave. ______

F.18 Close sodium fill valve. ______

F.19 Allow barrel and transfer line to cool to 150°F. ______

F.20 Remove transfer fittings from barrel and replace standard bungs. Replace empty barrel with full barrel. ______

F.21 Repeat steps F.4 through F.20 until approximately 205 gallons of sodium is loaded into the drain tank. ______

G. Hot System Fill Checkout

<u>SAFETY NOTE</u>

Personnel required to enter the test loop to monitor operations shall wear the following:

A. Fire resistant coveralls
B. Leather shoes
C. Hard hat with full face shield.

G.1 This checkout procedure requires use of the thermal blanket covering the test panels to heat and maintain the panel tubes in the solar window area at approximately 400°F. ______

G.2 Monitor all data logger channels to verify 400°F system temperature. ______

G.3 Establish following valve positions:

Bypass loop flow control FCV 001 open ______

Plugging loop flow control FCV 002	open
Panel flow control FCV 101	open
Panel flow control FCV 102	open
Panel flow control FCV 103	open
Pressure equalization PCV 004	closed
Bypass valve	open
Plugging valve	open

G.4 Adjust surge tank cover gas pressure to 5 psig (vent pressure to 5.5 psig).

G.5 Open drain valve LCV 003.

G.6 Adjust drain tank cover gas pressure to 20 psig to fill loop (set vent pressure to approximately 20.5 psig).

G.7 Increase the drain tank cover gas pressure until the sodium level in the surge tank activates the high sodium level alarm. Increase drain tank vent pressure setting as necessary.

<u>CAUTION</u>: Note level indication and approach high sodium level slowly to prevent overflowing sodium into vent lines.

G.8 Close the drain valve LCV 003 to complete the transfer.

G.9 Reduce drain tank cover gas pressure to 5.0 psig and vent pressure to 5.5 psig.

G.10 Close bypass valve, plugging valve, and bypass flow control valve (FCV 001). Open the pressure equilization valve. Close panel valves.

G.11 Calibrate the main flow meter (FE058) by opening the drain valve (LCV 003) and measuring the time required to drain between the high level and low level probes in the surge tank. ________

G.12 Close the drain valve to stop the drain. Close the pressure equalization valve.

G.13 Repeat steps G5 to G9 to return sodium to the surge tank.

G.14 Set surge tank pressure to 10 psig, open drain valve, and again measure flow and time surge tank level change.

G.15 Refill surge tank per steps G5 - G9.

G.16 Set surge tank pressure to 30 psig and again measure flow and time surge tank level change.

G.17 Refill surge tank to 60% level.

G.18 Open bypass loop flow valve (FCV 001) and panel control valve (FCV 101).

G.19 Start EM pump. Use manual control to increase flow in 5 gpm increments to 130 gpm. Record flow indications of the main flow meter (FE 058) and the panel flow meter (FE 101) and record the associated temperatures TC 101, TC 73. Close panel valve.

G.20 Repeat step G.19 for FE 102.

G.21 Repeat step G.19 for FE 103.

G.22 Open FCV 101, 102, 103

G.23 Adjust the I/P on FCV 101,102, 103 to obtain approximately 10 gpm minimum flow.

G.24 Depress emergency shutdown button on console. Observe EM pump stop, equalization and drain valves open. Time the return of sodium to the drain tank by observing level indication.

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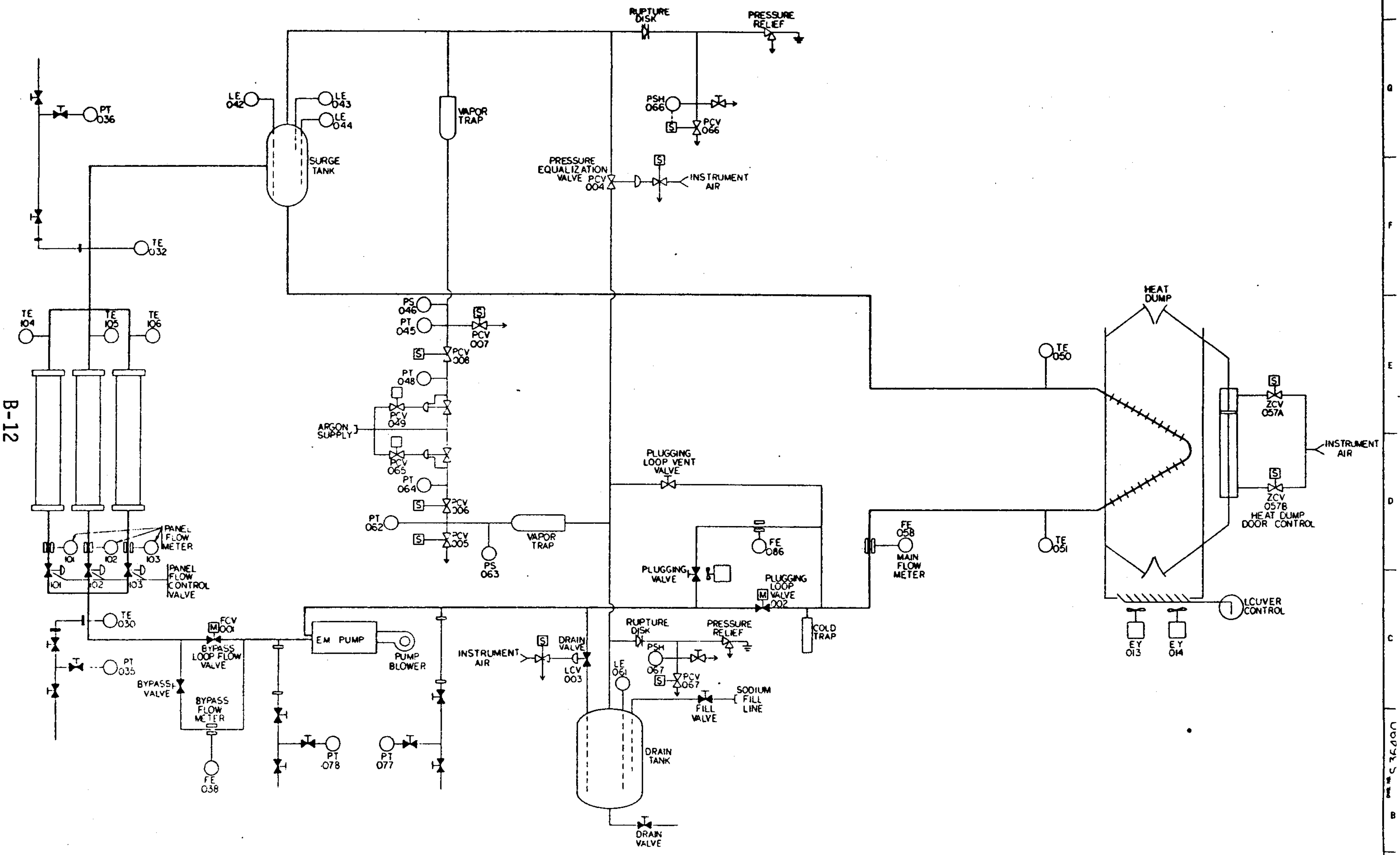

AGENCY APPROVALS	SHEET 1		TITLE
	ISSUE A		SODIUM LOOP
	PART CLASSIFICATION UNCLASSIFIED		
	DWG CLASSIFICATION LEVEL UNCLASSIFIED		SIZE E
			CODE IDENT. NO 14213
			DWG NUMBER S 36490

APPENDIX C

INTEGRATED TEST PROCEDURE FOR CRTF/ESG SODIUM-COOLED SOLAR RECEIVER TESTING

ITP 81-004

INTEGRATED TEST PROCEDURE
FOR
CRTF/ESG SODIUM COOLED SOLAR RECEIVER TESTING

AUGUST 20, 1981

APPROVALS

Ron Boal — 10-28-81

CRTF TEST ENGINEER — DATE

10/29/81

ESG TEST ENGINEER — DATE

John T. Holmes — 10/29/81

CRTF OPERATIONS/SAFETY ENGINEER — DATE

11/2/81

CRTF SUPERVISOR — DATE

CONTENTS

1. PRETEST INFORMATION

The test program for the ESG sodium cooled solar receiver panel is comprised of nine tests designed to meet the following goals:

1) demonstrate satisfactory panel operations at design heat flux and temperature
2) achieve a maximum number of diurnal thermal cycles
3) demonstrate satisfactory diurnal startup and shutdown
4) demonstrate satisfactory nocturnal thermal control
5) demonstrate control during insolation changes
6) control several panels in parallel
7) demonstrate panel dimensional stability
8) achieve representative lateral power distribution
9) demonstrate acceptable panel thermal losses
10) accommodate various simulated emergency condtions

OPERATING PERSONNEL	CREW "A"	CREW "B"
CRTF Test Conductor	Ken Bell	Larry Seamons
ESG Test Conductor	Dick Johnson	
Loop Operator	Tim George	Jim Clark
Panel Operator	Greg Poucher	
Console Operator	Bill McAtee	Tim George Debee Risvold
Field Monitor	Paul Flora	B. O. Ellis

SUPPORT PERSONNEL	PRIMARY	BACKUP
Operations/Safety	John Holmes	John Otts
Instrumentation	Milt.Stomp	
Software	Debee Risvold	

2. CRTF/ESG SAFETY CHECKLIST

Test ID ______________________________ Date __________

Test Title ____

Tower Occupants

Communications established __________

Personnel location verified __________

Safety equipment in place __________
1. PVC protective gloves
2. Fire retardent coveralls
3. Hard hats with full face shields
4. NaX (class D) fire extinguishers
5. Scott air packs at 287 level
6. Dry sodium carbonate, shovels
7. Emergency air packs at 287 level and control room

Water cleared from drip pans, drain plugs installed __________

"Test In Progress" light ON __________

Non-test personnel cleared from area or in secure location __________

Generator ON (Frequency check _____ Load check _____) __________

Field monitor in place for startup
1. Communications established __________
2. Gates closed, red lights on at tower road gates __________
3. Field clear __________

9981 Control room locked __________

Command to beam UP heliostats to far standby shall be given only after above checklist is completed by O/S Engineer __________

Heliostat and sodium systems returned to safe configurations at termination of testing __________

3. TEST DESCRIPTION

3.1 Low Power Testing

The purpose of testing the sodium-cooled solar receiver (SCSR) panel at lower power (0.8 MWt) is to demonstrate the operability of the sodium loop system and determine the characteristics of the system. Methods of operation during this testing phase include both manual and automatic control. The system is to be routinely operated, (1) to demonstrate the use of solar preheat prior to filling, (2) to selectively utilize the heliostat field, building up a normal flux distribution on the panel to achieve the desired power level, and (3) to perform a series of tests which verify the characteristics of the system.

To demonstrate the operability and stability of the receiver, the system will be switched to and from automatic control while operating at steady state. The effectiveness of emergency shutdown and system response will be determined by initiating at least one of each of the following emergency shutdowns, (1) heliostat scram, (b) loss of sodium flow scram, (c) dump valve scram, and (d) loss of DHX blower scram.

3.2 Isothermal Testing

The purpose of performing isothermal testing of the SCSR system is to determine the conductive and convective heat losses which result when subjecting the unheated solar panels to different environments. A minimum of two tests will be conducted, one during a no-wind condition and the second during an intermediate wind condition.

Solar preheat of the panel is required to fill the loop with sodium and assist heating as the loop temperature is increased to 700°F. Sodium flow is to be maintained at 115 gpm during each test. When desired sodium flow and temperature conditions are achieved, solar heat and trace heat are terminated and then thermal decay characteristics will be determined.

3.3 Intermediate Power Testing

The purpose of performing intermediate power tests (1.7 MWt) on the SCSR receiver panel is to (a) demonstrate the operation of the system while developing a temperature differential of 370 and 550°F across the receiver panel, (b) determine the effects on the system resulting from the introduction of either a power step by means of increasing or decreasing the heliostat field or a flow step by means of increasing or decreasing sodium flow through the receiver panel. The tests to be performed in the intermediate power test series include:

1) Demonstrate stable steady-state operation of the receiver panel with a power input of 1.7 MWt. The loop is to be operated with 115 gpm total flow through the panels producing a sodium temperature increase of 370°F (550 to 920°F). Both manual and automatic operation is required.

2) Demonstrate stable steady-state operation of the receiver panel with a power input of 1.7 MWt using a total flow of 78 gpm to develop 1100°F outlet temperatures. Both manual and automatic operation is required.

3) A series of power and flow step tests are to be performed to provide additional data on transient operating characteristics while operating at 1.7 MWt with a normal flux distribution. A total of two power step tests will be performed by initiating a -15 and -25% power change from steady state 1.7 MWt. After allowing the system to stabilize at the lower flow conditions, the respective positive power change is applied to the panels, returning to the original flow. The flow step tests, two each, are conducted in the same manner by increasing the flow to establish a new (lower) temperature across the receiver panel.

3.4 Design Power Testing

The purpose of performing design power tests (2.5 MWt) on the SCSR receiver panel is to (a) demonstrate the stability of the test article operating at design power conditions, (b) determine the effects on the system resulting from a series of power steps ranging from 10 to 50%, (c) determine the effect on the system resulting from redistribution of the incident flux on the receiver panel, and (e) demonstrate system response to emergency shutdown.

The tests to be performed in the design power test series include:

1) Demonstrate stable steady-state operation of the receiver panel and system at a power input of 2.5 MWt. The loop is to operate at a total flow through the panels of 115 gpm, producing an overall sodium temperature increase of 550°F (550 to 1100°F). Both automatic and manual control of the receiver panel and DHX is required. During these tests, bumpless transfer of panel control sensors is to be demonstrated, i.e., flux sensor to thermocouple.

2) A series of power step tests are to be performed, either allowing natural cloud passage to produce the power transient or preprogrammed heliostat removal and replacement to produce the power transient. The power transient tests are to be initiated from a steady-state power level of 2.5 MWt with system conditions as described in 1)

above. The magnitude of power steps is to range from 10% to 50%. During these tests, the system response to both both the negative and positive steps will be made to assure component temperature limitations are not exceeded.

3) Flow step tests will be intiated from steady-state conditions described above by either decreasing or increasing sodium flow from the nominal 115 gpm value. After equilibrium conditions are established, the system is returned to its pretest condition, during which the response of the system is determined. At least one of the intermediate flow step tests is to be repeated, where the flow ramp cycle is closely coupled.

4) The receiver will be operated at steady state with a skewed flux distribution. The loop is to operate at a total flow through the panels at 115 gpm, producing an overall sodium temperature increase of 550°F (500 to 1100°F).

5) The open loop tests are initiated from a steady-state power level of 2.0 MWt at a total flow of 115 gpm by increasing the power in 10% steps (0.2 MWt) until a total power of 2.5 MWt is achieved. A minimum of three tests are required to establish sufficient data on the thermal characteristics of the system.

6) Additional operating experience is to be obtained by performing emergency shutdowns. These tests are to be initiated at the completion of a day's run and are to include:

   a) Heliostat scram
   b) Loss of sodium flow scram
   c) Dump valve scram

3.5 High Power Testing

The purpose of performing tests on the receiver panels in excess of design power is to demonstrate that the panels and DHX can be safely operated at thermal power levels up to 20% greater than design.

The tests to be performed in the high power test series includes:

1) Demonstrate stable steady-state operation of the receiver panel and system with the full field of heliostats on target (3.0 MWt). The loop is to operate at a total flow of 140 gpm, producing an overall sodium temperature

increase of 550°F (550 to 1100°F). Both automatic and manual control of the receiver panel and DHX is required. Transient resonse is to be investigated. During these transients, the magnitude of the power step will be guided by the system recovery response i.e., feedback oscillation during power step recovery, so that test limits are not exceeded.

2) The higher temperature characteristics of the panel will be investigated. During this test the overall temperature differential across the receiver panels will be increased to 600°F ΔT while maintaining a steady state flow of 125 gpm.

TABLE I

HELIOSTAT GROUP ASSIGNMENTS

GROUP NO.	HELIOSTAT NO.	HELIOSTAT LOCATION	AIM POINT
1	100	N11W1	3
WARMUP	101	N11W2	3
	102	N11W3	3
	283	N11E1	3
	284	N11E2	3
	285	N11E3	3
LOW POWER			
2	88	N10W1	1
	89	N10W2	2
	90	N10W3	5
	91	N10W4	4
	92	N10W5	3
	103	N11W4	3
	104	N11W5	3
	114	N12W1	3
	271	N10E1	2
	272	N10E2	1
	273	N10E3	4
	274	N10E4	5
	275	N10E5	3
	286	N11E4	3
	287	N11E5	3
	297	N12E1	3
3	77	N9W1	5
	78	N9W2	4
	79	N9W3	2
	80	N9W4	1
	115	N12W2	3
	116	N12W3	3
	117	N12W4	3
	128	N13W1	3
	260	N9E1	4
	261	N9E2	5
	262	N9E3	1
	263	N9E4	2
	298	N12E2	3
	299	N12E3	3
	300	N12E4	3
	311	N13E1	3

4	58	N7W1	5
	67	N8W1	1
	68	N8W2	2
	69	N8W3	5
	81	N9W5	5
	129	N13W2	3
	241	N7E1	4
	250	N8E1	2
	251	N8E2	1
	252	N8E3	4
	264	N9E5	4
	312	N13E2	3
INTERMEDIATE POWER			
5	70	N8W4	4
	71	N8W5	1
	82	N9W6	4
	83	N9W7	2
	93	N10W6	3
	94	N10W7	3
	95	N10W8	3
	105	N11W6	3
	253	N8E4	5
	254	N8E5	2
	265	N9E6	5
	266	N9E7	1
	276	N10E6	3
	277	N10E7	3
	278	N10E8	3
	288	N11E6	3
6	59	N7W2	4
	60	N7W3	2
	61	N7W4	1
	72	N8W6	2
	106	N11W7	3
	107	N11W8	3
	108	N11W9	3
	109	N11W10	3
	242	N7E2	5
	243	N7E3	1
	244	N7E4	2
	255	N8E6	1
	289	N11E7	3
	290	N11E8	3
	291	N11E9	3
	292	N11E10	3

7	49	N6W1	1
	50	N6W2	2
	51	N6W3	5
	62	N7W5	5
	118	N12W5	3
	119	N12W6	3
	120	N12W7	3
	121	N12W8	3
	232	N6E1	2
	233	N6E2	1
	234	N6E3	4
	245	N7E5	4
	301	N12E5	3
	302	N12E6	3
	303	N12E7	3
	304	N12E8	3
8	39	N5W1	5
	40	N5W2	4
	41	N5W3	2
	42	N5W4	1
	52	N6W4	4
	122	N12W9	3
	123	N12W10	3
	130	N13W3	3
	222	N5E1	4
	223	N5E2	5
	224	N5E3	1
	225	N5E4	2
	235	N6E4	5
	305	N12E9	3
	306	N12E10	3
	313	N13E3	3

DESIGN POWER			
9	73	N8W7	5
	74	N8W8	4
	84	N9W8	1
	85	N9W9	5
	96	N10W9	3
	97	N10W10	3
	110	N11W11	3
	111	N11W12	3
	256	N8E7	4
	257	N8E8	5
	267	N9E8	2
	268	N9E9	4
	279	N10E9	3
	280	N10E10	3
	293	N11E11	3
	294	N11E12	3

10	53	N6W5	1
	54	N6W6	2
	63	N7W6	4
	64	N7W7	2
	124	N12W11	3
	125	N12W12	3
	131	N13W4	3
	132	N13W5	3
	236	N6E5	2
	237	N6E6	1
	246	N7E6	5
	247	N7E7	1
	307	N12E11	3
	308	N12E12	3
	314	N13E4	3
	315	N13E5	3
11	43	N5W5	5
	44	N5W6	4
	75	N8W9	2
	86	N9W10	4
	133	N13W6	3
	134	N13W7	3
	135	N13W8	3
	136	N13W9	3
	226	N5E5	4
	227	N5E6	5
	258	N8E9	1
	269	N9E10	5
	316	N13E6	3
	317	N13E7	3
	318	N13E8	3
	319	N13E9	3
12	28	N4W1	1
	29	N4W2	2
	55	N6W7	5
	65	N7W8	1
	142	N14W1	3
	143	N14W2	3
	144	N14W3	3
	145	N14W4	3
	211	N4E1	2
	212	N4E2	1
	238	N6E7	4
	248	N7E8	2
	325	N14E1	3
	326	N14E2	3
	327	N14E3	3
	328	N14E4	3

HIGH POWER

13	45	N5W7	2
	56	N6W8	4
	66	N7W9	5
	76	N8W10	1
	87	N9W11	3
	98	N10W11	3
	99	N10W12	3
	112	N11W13	3
	228	N5E7	1
	239	N6E8	5
	249	N7E9	4
	259	N8E10	2
	270	N9E11	3
	281	N10E11	3
	282	N10E12	3
	295	N11E13	3
14	30	N4W3	4
	46	N5W8	1
	113	N11W14	3
	126	N12W13	3
	127	N12W14	3
	137	N13W10	3
	138	N13W11	3
	213	N4E3	5
	229	N5E8	2
	296	N11E14	3
	309	N12E13	3
	310	N12E14	3
	320	N13E10	3
	321	N13E11	3
15	31	N4W4	5
	32	N4W5	1
	139	N13W12	3
	140	N13W13	3
	141	N13W14	3
	146	N14W5	3
	147	N14W6	3
	214	N4E4	4
	215	N4E5	2
	322	N13E12	3
	323	N13E13	3
	324	N13E14	3
	329	N14E5	3
	330	N14E6	3

4. STARTUP PROCEDURES

4.1 Panel Preheat

1. Activate all trace heat circuits. Monitor data logger and adjust individual heaters until all thermocouples read 400°F ± 50. ______
2. Activate/verify CRTF data acquisition system. ______
3. Verify 3 gpm cooling water flow to flux sensors. ______
4. Set warmup-run switch to warmup position. ______
5. Verify heliostat scram circuits. ______
6. Complete safety checklist. ______
7. Bring all heliostats to standby. ______
8. Adjust low delta-T scram set point on panels A, B, and C to zero. ______
9. Bring warmup group heliostats to target. ______
10. Monitor all panel temperatures to verify temperature increase to 400°F minimum. ______
11. Adjust warmup heliostats as necessary. ______

4.2 Sodium Fill Procedure

1. Verify sodium in drain tank 400°F minimum. ______
2. Verify argon gas supply at 45 psig. ______
3. Close pressure equalization valve (PCV 004). ______
4. Pressurize drain tank to 20 psig. ______
5. Open drain valve LCV 003 to initiate fill. ______
6. Monitor sodium transfer on drain tank level indicator. Vent surge tank as needed. ______
7. As sodium enters the surge tank, monitor sodium level on the surge tank level indicator. ______
8. Verify surge tank low level indicator switch clears. ______

9. Fill surge tank to 50% capacity.
10. Close drain valve when fill is complete.
11. Adjust drain tank cover gas pressure set point to 5 psig.
12. Open pressure equalization line valve (PCV 004).

4.3 Sodium Flow Procedure

1. Set EM pump control to manual.
2. Set panel control valves (FCV 101, 102, 103) to manual.
3. Turn EM pump switch on.
4. Adjust pump voltage in 10% steps to obtain 125 gpm. At each step monitor:
   a) Pump duct temperature
   b) Pump winding temperature
   c) SCSR manifold inlet/outlet pressure
   d) SCSR manifold differential pressure
   e) Pump inlet/outlet pressure
   f) Pump voltage
   g) Loop main flow
5. Turn on EM pump blower as required to maintain less than 300°F duct and winding temperature.
6. Manually adjust FCV 101, 102, and 103 (equally) to obtain a total flow of 115 gpm through panels.
7. Set warmup-run switch to run.
8. Request CRTF operator to place on target the heliostats required for operation. Select number of heliostats according to test from Table I.
9. As the panel outlet temperatures increase above 550°F, open DHX doors.
10. Deactivate trace heating except for drain tank.
11. Adjust DHX outlet temperature to 550°F. Maintain 550°F by adjusting DHX fans.
12. When the required number of heliostats are on target, adjust DHX outlet setpoint to 550°F, switch DHX control to automatic.

13. Adjust panel flow control valves (FCV 101, 102, 103) to obtain required test temperature. ____

14. When equilibrium conditions are established, slowly increase set point of Panels, A, B, and C flow controllers to obtain required test temperature. ____

15. Switch Panels A, B, and C flow controller to automatic. ____

5. TEST PROCEDURES

5.1 Low Power Operability Test

1. Initiate receiver panel preheat per procedure 4.1.
2. Initiate sodium fill per procedure 4.2.
3. Establish 115-gpm sodium flow in loop per procedure 4.3.
4. Maintain manual control of panel and DHX.
5. Initiate power increase to 0.8 MWt per procedure 4.3 maintaining normal flux distribution on panel.
6. At equilibrium conditions, 550°F inlet and 735°F outlet, initiate steady-state transfer from manual to automatic control tests for the receiver panel flow control and DHX temperature control.
7. Return receiver panel and DHX control to manual.
8. Repeat steps 6 and 7 ten times to complete operability test.

EMERGENCY SYSTEM CHECKS

9. Depress heliostat slew button on control console.
10. Return heliostats to target, reestablish equilibrium conditions.
11. Stop EM pump. Observe flow rate decline to zero. Heliostats should scram off target. If scram does not occur within 5 seconds after flow reaches zero, manually give heliostat scram.
12. Return heliostats to target, reestablish equilibrium conditions.
13. Set panel high temperature scram setpoint below 735°F.
14. Return heliostats to target, reestablish equilibrium conditions.
15. Momentarily open drain valve (LCV 003). Observe heliostat scram.
16. If sodium remains above low level alarm in surge tank, return heliostats to target, reestablish equilibrium conditions. If low sodium alarm is

activated, go directly to step 17 without returning heliostats.

17. End test by depressing emergency shutdown button on console.
18. Return loop to standby condition per procedure 6.2.

5.2 Isothermal Test

1. Initiate solar preheat on receiver per procedure 4.1, measure wind speed. Test should be done during calm conditions. 0-5 mph wind speed.
2. Initiate sodium fill per procedure 4.2.
3. Establish 115-gpm sodium flow per procedure 4.3.
4. Increase solar input to panel in small increments to approach 800°F loop temperature.
5. When uniform loop temperatures of 800°F, request heliostats be moved to far standby position.
6. Monitor flow rate and panel inlet and outlet temperatures to determine heat loss characteristics.
7. When loop temperature falls to 400°F, return heliostats to bring loop temperatures back to 800°F.
8. Readjust flow rate to 65 gpm, remove heliostats.
9. Again monitor flow rate, inlet and outlet temperatures to determine panel heat loss characteristics.
10. When lowest panel temperature reaches 400°F, initiate system shutdown per procedure 6.1.
11. Repeat this test at a time when winds are moderate (10-15 mph).

5.3 Intermediate Power Operability Test

1. Initiate receiver panel preheat per procedure 4.1.
2. Initiate sodium fill per procedure 4.2.
3. Establish 115-gpm sodium flow in loop per procedure 4.3.

4. Maintain manual control of panel and DHX.

5. Initiate power increase to 1.7 MWt per procedure 4.3 maintaining normal flux distribution.

6. Adjust sodium flow to achieve 370°F temperature differential across the receiver panel.

7. Initiate test to demonstrate system stability by transferring panel and DHX control from manual to automatic control.

    a) Adjust set point of TIC 101 approximately 5% high and switch to AUTO, verify decrease of flow in Panel A, increase in Panel A ΔT. Manually adjust flow in Panels B and C to maintain system within test limits, maintain DHX to a manual set point of 550°F. Return manual and auto set points to original setting and allow system to stabilize.

    b) Repeat Step 6.a with TIC 102 and 103, manually adjusting flow in Panels A and C and A and B to maintain system within test limits.

    c) Adjust set points of TIC 101, 102, 103 for bumpless transfer to automatic control. Set DHX TIC to automatic control. Adjust TIC 101, 102, and 103 to establish a 410°F ΔT across the receiver panel. During the transition, monitor the DHX fan speed and control to assure outlet temperature of 550°F.

8. Decrease sodium flow to approximately 80 gpm to establish a 550°F temperature differential across the receiver panel. Repeat steps 7 a, b, and c.

9. Shutdown system per procedure 6.1.

5.4 Intermediate Power, Power Step and Flow Ramp Tests

1. Startup system per startup procedures 4.1, 4.2, and 4.3.

2. Initiate power ramp tests. Set up initial system conditions:

Sodium flow (FCV 101, 102, 103 60% Open)	115 gpm
Sodium inlet	550°F
Sodium outlet	920°F
Total power input	1.7 MWt
Flux distribution	Normal
DHX control	Auto
Panel ABC control	Auto

3. Preselect required heliostats which at time of test produce 0.255 MWt power, 15% of total. ______

4. Verify pretest conditions established. Initiate command to remove heliostats to standby. ______

5. Observe (a) total flow has decreased to 96 gpm ______
   (b) total ΔT across panels remains 370°F ______
   (c) pretest and test temperature profile across panel (LU10) within test limits ______

6. When equilibrium conditions have been established, return 0.255 MWt to panel by realigning heliostats of Step 3 on target. ______

7. Observe (a) total flow increases to 115 gpm ______
   (b) total ΔT across panels remains 370°F ______
   (c) pretest and test temperature profile across panel (LU10) within test limits ______
   (d) determine magnitude of feedback oscillation on outlet temperature ______

8. Repeat steps 3 to 7 using a -25% (-0.425 MWt) power ramp. ______

   a) Test flow 85 gpm
   b) Total ΔT across panel 370°F

9. Initiate flow ramp tests. Set up initial system conditions: ______

Sodium flow (FCV 101, 103, 103 60% open)	115 gpm
Sodium inlet	550°F
Sodium outlet	920°F
Total power input	1.7 MWt
Flux distribution	Normal
DHX outlet	550°F
DHX control	Auto
Panel ABC control	Auto

10. Change flow to 96 gpm by changing EM pump voltage. ______

11. Observe (a) increased DHX fan speed to control leg temperature to 550°F ______
    (b) total ΔT across panel increases to 450°F (outlet 1000°F) ______
    (c) pretest and test temperature profile across panel within test limits ______

12. When equilibrium conditions are established, return loop flow to pretest condition. ______

13. Observe (a) total ΔT across panels decrease to 370°F _____
(b) total flow increases to 115 gpm _____
(c) DHX fan speed returns to pretest condition _____
(d) determine magnitude of feedback oscillations on outlet temperature _____

14. Repeat steps 10-13 to initiate ramp flow test at 80 gpm. _____

a) Test flow 85 gpm
b) Total ΔT across panel 550°F
c) Outlet temperature 1100°F
d) Assure increase DHX fan speed to maintain 550°F outlet temperature

15. Shutdown system per procedure 6.1. _____

5.5 Design Power Operability Test

1. Startup system per startup procedures 4.1, 4.2, 4.3 _____

2. Initiate power increase to 2.5 MWt maintaining normal flux distribution. _____

3. Initiate tests to demonstrate system stability by transferring panel and DHX control from manual to auto control. _____

a) Adjust set point of TIC 101 approximately 5% high and switch to auto, verify decrease of flow in Panel A, increase in Panel AΔT. Manually adjust flow in Panels B and C to maintain system within test limits, maintain DHX to a manual set point of 550°F. Return manual and auto set points to original setting and allow system to stabilize. _____
b) Repeat Step 3.a with TIC 102 and 103, manually adjusting flow in Panels A and C and A and B to maintain system within test limits. _____
c) Adjusting set points of TIC 101, 102, and 103 for bumpless transfer to automatic control. Set DHX TIC to automatic control. Adjust TIC 101, 102, 103 to establish a 500°F ΔT across the receiver panel. During transition, monitor the DHX fan speed and control to assure outlet temperature of 550°F across the receiver panel. During transition, monitor the DHX fan speed and control to assure outlet temperature of 550°F. _____

4. At convenient periods during this test sequence, initiate checkout of the following emergency shutdown and/or safety scrams: ______

   a) Heliostat scram
   b) Loss of sodium flow scram
   c) Dump valve scram
   d) Single-panel high outlet temperature scram from panel outlet
   e) Total high sodium temperature scram from TE134

5. Initiate sodium drain per Procedure 6.1. ______

5.6 Design Power - Power Step And Flow Ramp Tests

1. Startup system per startup procedures 4.1, 4.2, 4.3 ______

2. Initiate power increase of 2.5 MWt maintaining normal flux distribution. ______

3. Initiate power ramp tests. Set up initial conditions. ______

Sodium flow (FCV 101, 102, 103 80% open)	115 gpm
Sodium inlet	550°F
Sodium outlet	1100°F
Total power input	2.5 MWt
Flux distribution	Normal
DHX control	Auto
Panel ABC control	Auto

4. Preselect required heliostats which, at time of test, produce a 10% power change. ______

5. Verify pretest conditions established. ______

6. Initiate command to remove heliostats to standby. ______

7. Observe (a) total flow has decrease to 100 gpm ______
   (b) total ΔT across panels remains 550°F ______
   (c) pretest and test temperature profile across panel (LU10) within test limits. ______

8. When equilibrium conditions have been established, initiate return of heliostats removed to standby back to target. ______

9. Observe (a) total flow, increases to 115 gpm ______
   (b) total ΔT across panels remains 550°F ______
   (c) test and posttest temperature profile across panel (LU10) within test limits ______
   (d) determine magnitude of feedback oscillation on panel outlet temperature ______

10. Repeat steps 6-9, initiating a 20% power change. ______

11. Repeat steps 6-9, initiating a 30% power change. ______

12. Repeat steps 6-9, initiating a 40% power change. ______

13. Repeat steps 6-9, initiating a 50% power change. ______

14. Initiate flow ramp tests. Set up initial conditions per step 2. ______

15. Decrease flow by 8% (adjust to 106 gpm). ______

16. Observe (a) increased DHX fan speed to control cold leg temperature to 550°F ______
    (b) total ΔT across panels increases to 600°F (hot leg 1150°F) ______
    (c) pretest and test temperature profile across panel within test limits ______

17. When equilibrium conditions are established, return loop to pretest condition. ______

    a) Total ΔT across panels decreases to 550°F ______
    b) Total flow increases to 115 gpm ______
    c) DHX fan speed returns to pretest condition ______
    d) Determine magnitude of feedback oscillations on outlet temperature ______

18. Repeat steps 14-17 to initiate flow step test at increased flow. ______

Flow	Expected ΔT Across Panel	Expected Outlet Temp. with Inlet at 550°F
a) 127	490°F	1040°F
b) 138	460°F	1010°F
c) 144	440°F	990°F
d) 150	420°F	970°F

19. Shutdown system per procedure 6.1. ______

5.7 Design Power Operability Tests With Skewed Flux Distribution

1. Startup system per startup procedures 4.1, 4.2. 4.3 ______

2. Increase power to 2.5 MWt, maintaining normal flux distribution. ______

3. Change the heliostat aimpoints to obtain the following conditions: ______

	Panel		
	A	B	C
a) Thermal power distribution (MWt)	.9	.8	.7
b) Peak flux (W/cm^2)	1.5	1.25	1.0
c) Panel outlet temperature (°F)	1100	1100	1100
d) Flow rate (gpm)	44	38	32

4. Observe following sensors; maintain within test limits: _____

   a) Panel A, B, C flux
   b) Panel A, B, C hot tube temperature
   c) Panel A, B, C temperature distribution
   d) Panel A, B, C sodium flow
   e) Total sodium flow
   f) Panel outlet temperature
   g) DHX outlet temperature

5. Initiate power steps and flow ramps as per procedute 5.6. _____

6. Shutdown system per procedure 6.1. _____

5.8 Design Power Open Loop Test

1. Startup system as per startup procedures 4.2, 4.2, 4.3. _____

2. Increase power to 2.0 MWt maintaining normal flux distribution. _____

3. Adjust flow control to maintain 950°F panel outlet temperature. _____

4. Set panel A, B, and C flow controls to manual. _____

5. Initiate 10% power step change (to 2.2 MWt). _____

6. Monitor system response during step until equilibrium conditions are established. _____

7. Initiate another 10% power step change (to 2.4 MWt). _____

8. Monitor system response. Careful monitoring of panel temperatures is required. _____

9. Shutdown system per shutdown procedure 6.1. _____

5.9 High Power Testing

1. Startup system per startup procedures 4.1, 4.2, 4.3. _____

2. Adjust EM pump and flow control valves to establish a flow of 140 gpm.

3. Increase power to 3.0 MWt or until all available heliostats are on target.

4. Initiate auto control of both DHX and panels. Establish 1100°F panel outlet temperature.

5. Preselect required heliostats, which at time of test produce a 10% power change.

6. Initiate command to remove heliostats to standby.

7. Observe (a) total flow has decreased
   (b) total ΔT across panels remains 550°F
   (c) pretest and test temperature profile across panel (LU10) within test limits.

8. When equilibrium conditions have been established, initiate return of heliostats removed to standby back on target.

9. Observe (a) total flow increases to pretest value
   (b) total ΔT across panels remains 550°F
   (c) test and post-test temperature profile across panel (LU10) within test limits
   (d) determine magnitude of feedback oscillation on panel outlet temperature

   NOTE: Limit succeeding tests so feebback oscillation temperatures do not exceed test limits.

10. Repeat steps 6-9, initiating a 20% power step.

11. Repeat steps 6-9, initiating a 25% power step.

12. Shutdown system per shutdown procedure 6.1.

5.10 High Power, High Temperature Test

1. Startup system per startup procedures 4.1, 4.2, 4.3.

2. Adjust EM pump and flow control valves to establish a flow of 140 gpm.

3. Increase power to 3.0 MWt or until all available heliostats are on target.

4. Maintain auto control of both DHX and panels.

5. Establish panel outlet temperature of 1100°F and DHX outlet of 550°F. ____

6. Increase panel outlet setpoint to 1150°F. ____

7. Observe (a) total flow has decreased ____
   (b) test temperature profile across panel (LU10) within test limits ____
   (c) DHX outlet remains at 550°F ____

8. Shutdown system per shutdown procedure 6.1. ____

6. SHUTDOWN PROCEDURES

6.1 Manual Shutdown

1. Request CRTF operator to remove helisotat field to far standby, then to normal stow position. ______
2. Switch panels A, B, and C flow control to manual. ______
3. Open Panels, A, B, and C control valves to 100% open. ______
4. Switch DHX fans off. ______
5. Close DHX doors. ______
6. When loop temperatures approach 400-450°F range, switch EM pump off, EM pump blower off. ______
7. Initiate trace heating on all loop circuits. ______
8. Open pressure equalization valve. ______
9. Open drain valve. ______
10. Observe sodium level in surge tank decrease to 0. Sodium drain is complete when sodium level in drain tank reaches 100%. ______
11. Close drain valve, close pressure equalization valve. ______
12. Adjust drain tank and surge tank cover gas pressure to 5 psig. ______
13. When panel temperatures fall below 150°F, turn off flux sensor and RTAF cooling. ______

6.2 Emergency Shutdown

In the event of any abnormal condition on the system, either the tower operator or the CRTF operator can initiate a heliostat scram, which removes all the heliostats from the target and repositions them at the far standby position.

Four conditions: 1) drain valve open, 2) loop over temperature, 3) loss of sodium flow, and 4) panel over temperature will cause an automatic heliostat scram. Following the initiation of the scram, if the system is left in automatic control, the panel flow control valves will close to minimum and the DHX fan speed will decrease in an effort to maintain system set point temperatures.

At this point the system will be in the same condition as it would be after step 1 in the normal shutdown procedure, 6.1. To complete the shutdown, the remaining steps 2 through 13 of the shutdown procedure (6.1) should be followed.

If the cause of the scram is found and the test director desires, operation may resume at this point by bringing the group 1 heliostats back to target. If at any time sodium temperatures fall below 400°F, a drain down should be initiated.

Should an emergency situation arise that would require fast action by the loop operator, an emergency shutdown switch is provided on the control console. This switch immediately slews the heliostats, stops the EM pump and pump blower and closes the heat dump doors. About 10 seconds later the drain valve and the pressure equalization valve opens and the system begins to drain. This same sequence of events occurs when a loss of power is experienced.

7. SODIUM LEAK RECOVERY

A sodium leak is detected either by the loop smoke detector or by visual observation. In the event of this occurance, immediately implement the following procedures.

1) Either CRTF operator or loop operator may initiate a heliostat scram.

2) Call for continued visual observation from ground level. When CRTF operator verifies heliostats are at far standby, tower operator may observe module from tower top.

3) If sodium oxide smoke is present, loop operator will immediately drain the system via the emergency shutdown switch.

4) Loop operator will verify sodium drain completed before any entry into module is made.

5) Any entry into the loop structure following a sodium leak shall be made with the following personnel safety precautions:

   a) Full fire retardent coveralls with openings taped shut.

   b) PVC gauntlet gloves

   c) Hard hat with full face shield

   d) Chemical or Jones goggles

   e) NaX extinguishers and dry sodium carbonate available

   f) Scott air packs available

6) Determine source of sodium leak.

7) Clean fire residue.

8) Repair defect in loop.

APPENDIX D

TRACE HEATERS AND THERMOCOUPLES IDENTIFICATION

TABLE I

DATA LOGGER SENSOR SCHEDULE
(Sheet 1)

Data Logger Channel	Sensor No.	Function		HTR Circuit No.	
001	TC9	Cold leg piping-A	HTR-9A&B	S-1	Red
002	TC10	Cold leg piping-A	HTR-10	S-1	"
003	TC11	Cold leg piping-A	HTR-11	S-1	"
004	TC12	Cold leg piping-A	HTR-12	S-1	"
005	TC19	Cold leg piping-B	HTR-19	S-2	"
006	TC138	Panel inlet piping	HTR-138	S-2	"
007	TC136A	Inlet piping panel A	HTR-136A	S-2	"
008	TC136B	Inlet piping panel B	HTR-136B	S-2	"
009	TC136C	Inlet piping panel C	HTR-136C	S-2	"
010	TC13	PTI line	HTR-13	S-3	"
011	TC14	PTI line	HTR-14	S-3	"
012	TC15	PTI line	HTR-15	S-3	"
013	TC17	PTI line	HTR-17	S-3	"
014	TC18	PTI line	HTR-18	S-3	"
015	TC20	Sodium bypass line	HTR-20	S-4	"
016	TC21	Sodium bypass line	HTR-21	S-4	"
017	TC137A	Valve bonnet FCV101	HTR-137A	S-5	"
018	TC137B	Valve bonnet FC102	HTR-137B	S-5	"
019	TC137C	Valve bonnet FC103	HTR-137C	S-5	"
020	TC127A	Inlet header panel A	HTR-127	S-6	"
021	TC127B	Inlet header panel B			
022	TC127C	Inlet header panel C			
023	TC125A	Panel A lower	HTR-125-1	S-7	Green
024	TC125B	Panel B lower	HTR-125-2	S-7	"
025	TC125C	Panel C lower	HTR-125-3	S-7	"
026	TC126A	Panel A upper	HTR-126	S-8	"
027	TC126B	Panel B upper			
028	TC126C	Panel C upper			
029	TCEP125	Panel Outlet Pres Sensor	HTREP128	S-9	White
030	TCEP129	Panel Inlet Pres Sensor	HTREP129	S-10	"
031	TCEP136	Pump Outlet Pres Sensor	HTREP136	S-11	"
032	TCEP137	Pump Inlet Pres Sensor	HTREP137	S-12	"

TABLE I

DATA LOGGER SENSOR SCHEDULE
(Sheet 2)

Data Logger Channel	Sensor No.	Function		HTR Circuit No.	
033	TC128A	Outlet header panel A	HTR-128A	S-13	Amber
034	TC128B	Outlet header panel B	HTR-128B	S-13	"
035	TC128C	Outlet header panel C	HTR-128C	S-13	"
036	TC135A	Outlet piping panel A	HTR-135A	S-13	"
037	TC135B	Outlet piping panel B	HTR-135B	S-13	"
038	TC135C	Outlet piping panel C	HTR-135C	S-13	"
039	TC139	Hot leg piping	HTR-139	S-13	"
040	TC140	Hot leg piping	HTR-140	S-13	"
041	TC141	Hot leg piping	HTR-141	S-13	"
042	TC39	Hot leg piping A	HTR-39	S-14	"
043	TC40	Hot leg piping A	HTR-40	S-14	"
044	TC41	Hot leg piping A	HTR-41	S-14	"
045	TC1	Hot leg piping B	HTR-1A&B	S-15	"
046	TC2	Hot leg piping B	HTR-2A&B	S-15	"
047	TC3	Hot leg piping B	HTR-3A&B	S-15	"
048	TC4	Hot leg piping C	HTR-4A&B	S-16	"
049	TC5	Hot leg piping C	HTR-5A&B	S-16	"
050	TC6	Hot leg piping C	HTR-6A&B	S-16	"
051	TC7	Hot leg piping C	HTR-7A&B	S-16	"
052	TC8	Hot leg piping C	HTR-8A,B,C	S-16	"
053	TCST1	Surge tank top	HTR-ST1	S-17	"
054	TCST2	Surge tank top	HTR-ST2	S-17	"
055	TCST3	Surge tank top	HTR-ST3	S-17	"
056	TCST4	Surge tank top	HTR-ST4	S-17	"
057	TCST5	Surge tank sides	HTR-ST5	S-18	"
058	TCST6	Surge tank sides	HTR-ST6	S-18	"
059	TCST7	Surge tank sides	HTR-ST7	S-18	"
060	TCST8	Surge tank sides	HTR-ST8	S-18	"
061	TCST9	Surge tank sides	HTR-ST9	S-18	"
062	TCST10	Surge tank sides	HTR-ST10	S-18	"
063	TCST11	Surge tank bottom	HTR-ST11	S-19	"
064	TCST12	Surge tank bottom	HTR-ST12	S-19	"
065	TC69	Sodium fill line	HTR-69	S-20	"
066	TC72	Bonnet valve EP207	HTR-72	S-20	"

TABLE I

DATA LOGGER SENSOR SCHEDULE
(Sheet 3)

Data Logger Channel	Sensor No.	Function		HTR Circuit No.	
067	TC50	EM pump duct	HTR-50	S-21	White
068	TC65	Valve bonnet FCV001	HTR-62	S-22	"
069	TC66	Valve bonnet FCV002	HTR-63	S-22	"
070	TC68	Valve bonnet LCV003	HTR-67	S-22	"
071	TC70	Valve bonnet EP117	HTR-64	S-22	"
072	TC67	Valve bonnet PCV004	HTR-65	S-23	"
073	TC71	Valve bonnet EP116	HTR-66	S-24	"
074	TC25	Drain line	HTR-25	S-25	"
075	TC54	Drain line	HTR-54	S-25	"
076	TC61	Drain tank to VT	HTR-61	S-26	"
077	TCDT1	Drain tank top	HTR-DT1	S-27	"
078	TCDT2	Drain tank top	HTR-DT2	S-27	"
079	TCDT11	Drain tank bottom	HTR-DT11	S-28	"
080	TCDT12	Drain tank bottom	HTR-DT12	S-28	"
081	TCDT3	Drain tank sides	HTR-DT3	S-29	"
082	TCDT4	Drain tank sides	HTR-DT4	S-29	"
083	TCDT5	Drain tank sides	HTR-DT5	S-29	"
084	TCDT6	Drain tank sides	HTR-DT6	S-29	"
085	TCDT7	Drain tank sides	HTR-DT7	S-30	"
086	TCDT8	Drain tank sides	HTR-DT8	S-30	"
087	TCDT9	Drain tank sides	HTR-DT9	S-30	"
088	TCDT10	Drain tank sides	HTR-DT10	S-30	"
089	TC42	Equalizing line	HTR-42	S-31	"
090	TC43	Equalizing line	HTR-43	S-31	"
091	TC44	Equalizing line	HTR-44	S-31	"
092	TC45	Equalizing line	HTR-45	S-31	"
093	TC46	Equalizing line	HTR-46	S-32	"
094	TC47	Equalizing line	HTR-47	S-32	"
095	TC48	Equalizing line	HTR-48	S-32	"
096	TC49	Equalizing line	HTR-49	S-32	"
097	TC28	Drain tank vapor trap	HTR-28,30	S-33	"
098	TC29	Drain tank vapor trap	HTR-29,31	S-33	"
099	TC56	Surge tank vapor trap	HTR-56,58	S-34	"
100	TC57	Surge tank vapor trap	HTR-57,59	S-34	"
101	TC60	Surge tank to VT	HTR-60	S-34	"
102	TC26A	Cold trap	HTR-26A	S-35	"

TABLE I

DATA LOGGER SENSOR SCHEDULE
(Sheet 4)

Data Logger Channel	Sensor No.	Function		HTR Circuit No.	
103	TC27A	Cold trap	HTR-27A	S-35	White
104	TC26B	Cold trap	HTR-26B	S-35	"
105	TC27B	Cold trap	HTR-27B	S-35	"
106	TCDHX1	Dump Heat Exchanger			
107	TCDHX2	Dump Heat Exchanger			
108	TCDHX3	Dump Heat Exchanger			
109	TCDHX4	Dump Heat Exchanger			
110	TCDHX5	Dump Heat Exchanger			
111	TCDHX6	Dump Heat Exchanger			
112	TCDHX7	Dump Heat Exchanger			
113	TCDHX8	Dump Heat Exchanger			
114	TCDHX9	Dump Heat Exchanger	DHX Heaters		
115	TCDHX10	Dump Heat Exchanger	ON	S-36	"
116	TCDHX11	Dump Heat Exchanger			
117	TCDHX12	Dump Heat Exchanger			
118	TCDHX13	Dump Heat Exchanger			
119	TCDHX14	Dump Heat Exchanger			
120	TCDHX15	Dump Heat Exchanger			
121	TCDHX16	Dump Heat Exchanger			
122	TCDHX17	Dump Heat Exchanger			
123	TCDHX18	Dump Heat Exchanger			
124	TC73	Main Flowmeter		--	"
125					
126					
127					
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132					
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135					
136					
137					
138					

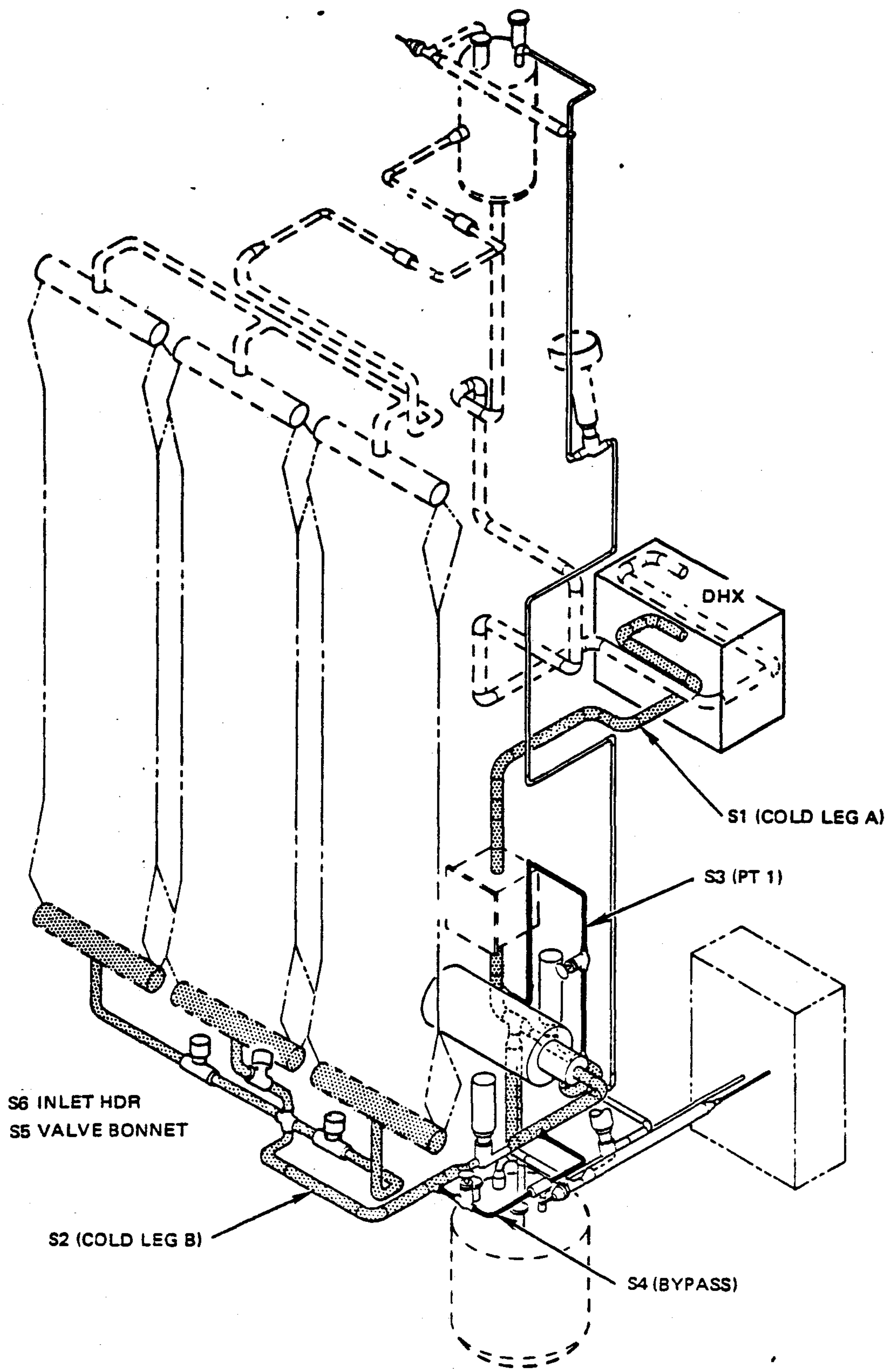

Figure 1. Red Group, S1-S6, Trace Heaters and Thermocouples

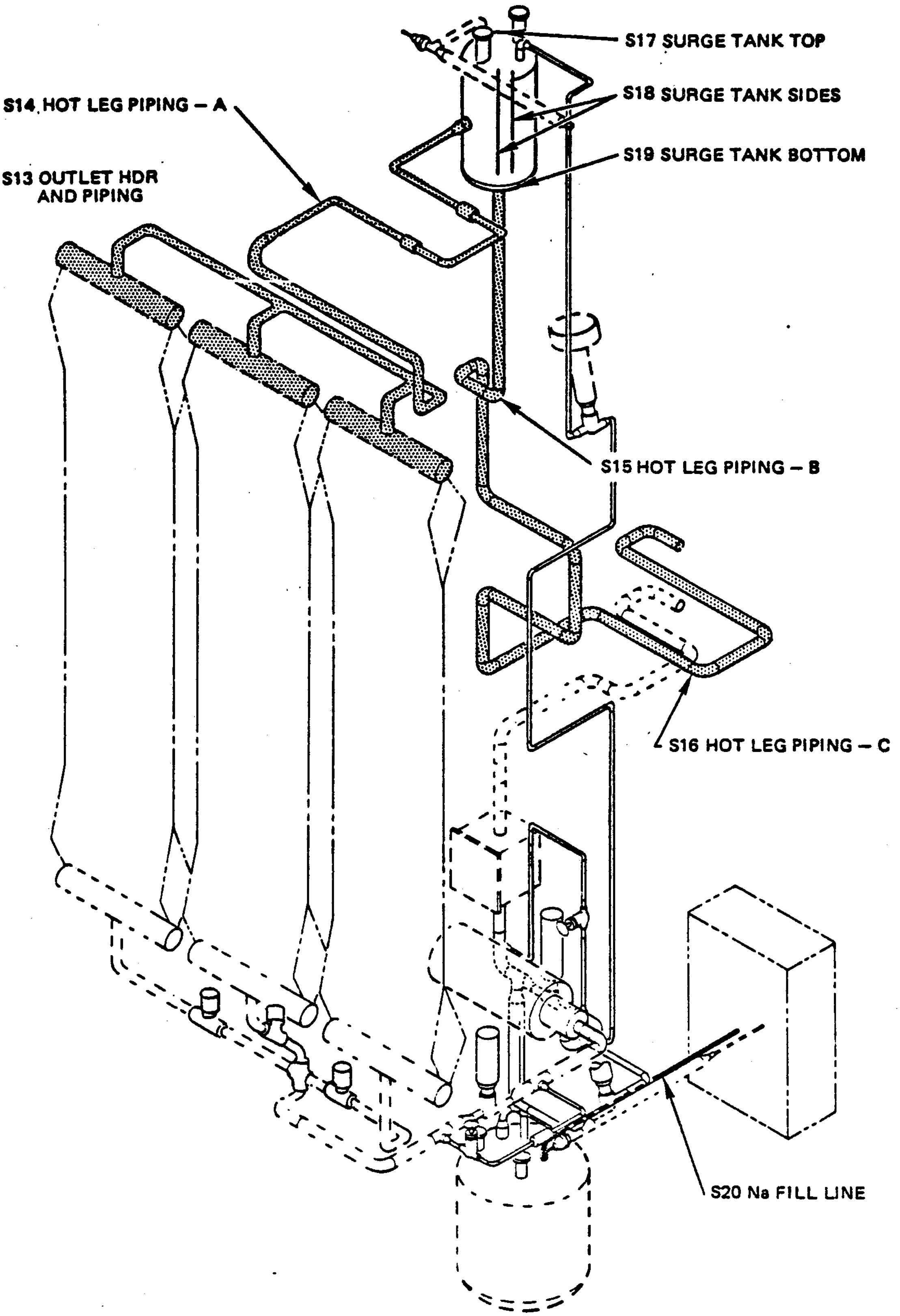

Figure 2. Amber Group, S13-S20, Trace Heaters and Thermocouples

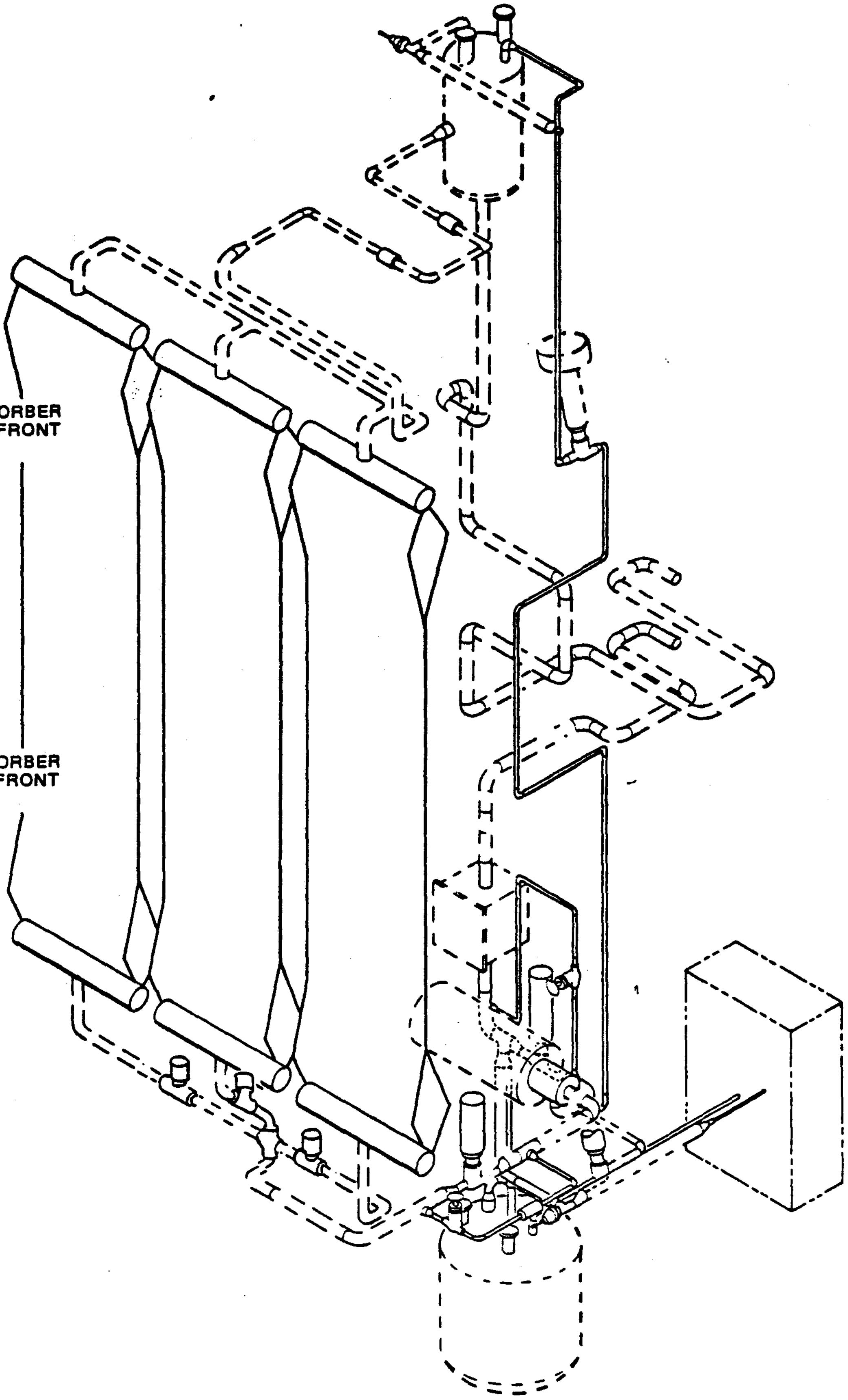

Figure 3. Green Group, S7-S8, Trace Heaters and Thermocouples

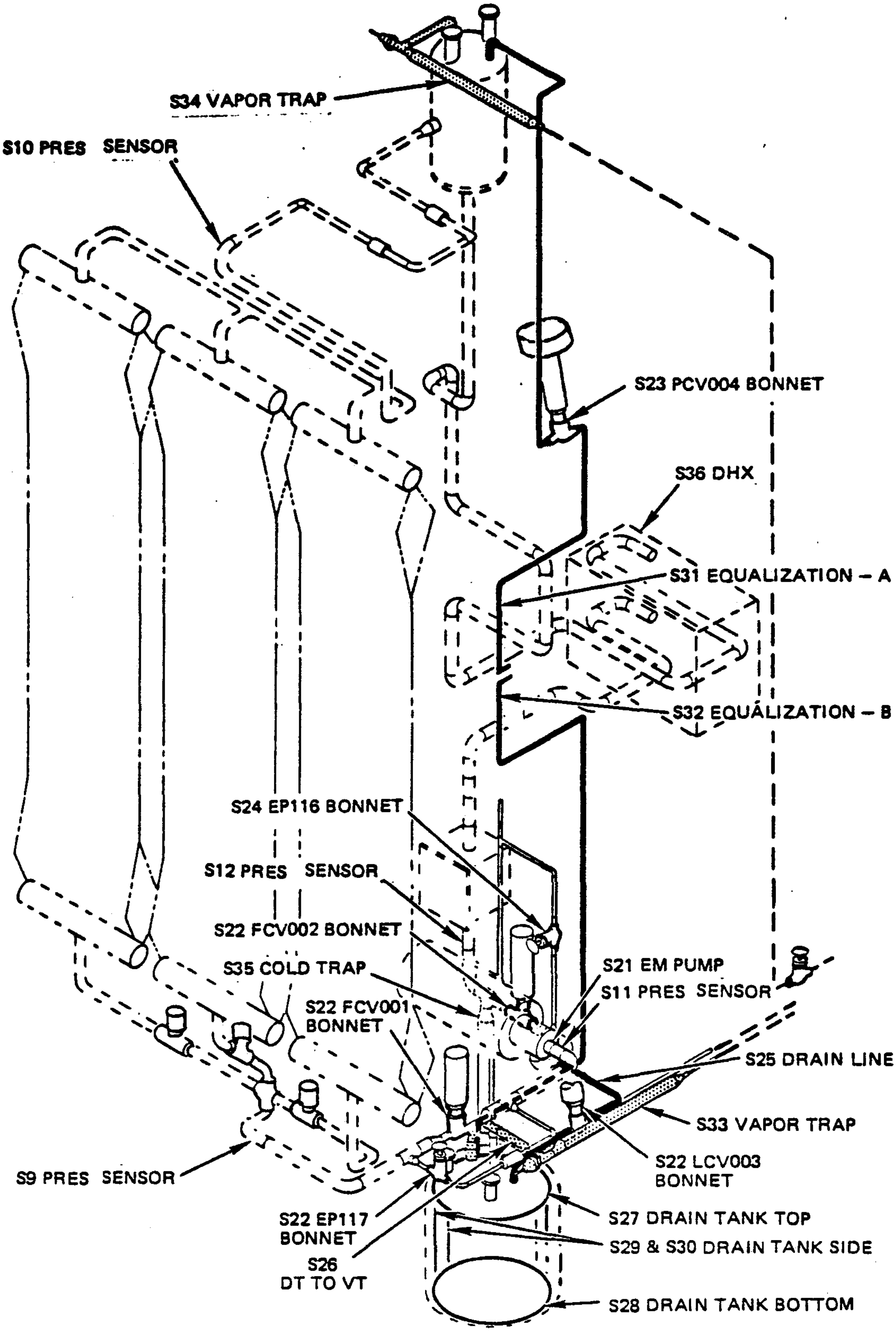

Figure 4. White Group S9, S10, S11, S21 Thru S36, Traceheaters and Thermocouples

APPENDIX E

INCIDENT FLUX MEASURING SYSTEM DATA

I35501 FILE FOR ESG FLUX DATA

	TIME											
HR:	MI:	SE:	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2
10	18	25	0.09	0.18	0.07	0.19	0.21	0.27	0.15	0.35	0.42	0.40
10	18	29	0.20	0.18	0.17	0.19	0.31	0.47	0.49	0.57	0.61	0.69
10	18	33	0.20	0.18	0.17	0.29	0.41	0.68	0.84	1.02	1.01	1.08
10	18	38	0.42	0.27	0.46	0.70	0.94	1.29	1.42	1.79	1.73	1.86
10	18	42	0.65	0.56	0.75	0.90	1.36	1.80	2.00	2.61	2.72	2.84
10	18	46	0.54	0.66	1.04	1.62	2.20	3.13	3.44	4.28	4.38	4.49
10	18	51	0.99	1.14	1.72	2.64	3.67	4.96	5.41	6.61	6.74	6.58
10	18	55	1.55	1.82	2.68	4.06	5.56	7.61	8.31	9.94	9.88	9.61
10	18	59	2.01	2.40	3.65	5.59	7.76	10.47	11.79	14.16	14.20	14.00
10	19	4	2.80	3.46	5.39	7.94	10.81	14.55	16.20	19.26	19.51	19.27
10	19	8	4.04	5.00	7.61	11.10	14.91	19.85	21.88	25.81	25.99	25.42
10	19	12	5.51	6.84	10.13	14.47	19.21	25.26	27.68	32.70	32.76	32.25
10	19	17	6.53	8.09	12.26	17.53	23.52	31.12	34.64	40.87	41.17	40.51
10	19	21	7.32	9.15	13.90	20.38	27.13	36.11	40.10	47.53	48.44	48.41
10	19	25	9.24	11.47	17.19	24.36	32.27	42.03	46.20	54.52	55.21	55.44
0	0	0	11.41	14.82	21.54	29.25	36.58	47.30	51.40	60.84	64.71	62.97
10	19	25	12.14	16.84	24.23	32.54	38.65	49.51	53.40	62.99	69.66	66.37
10	19	21	12.75	17.26	24.66	32.75	39.05	50.32	54.28	64.37	71.37	67.71
10	19	17	13.75	17.78	24.77	32.43	38.75	49.61	53.73	63.73	70.84	67.15
10	19	12	14.34	18.72	25.51	32.64	38.26	47.87	51.12	60.02	66.24	62.38
10	19	8	13.34	17.15	23.48	29.78	34.59	43.39	46.21	54.19	59.60	56.09
10	19	4	11.94	15.18	20.49	25.54	29.54	36.96	39.45	46.39	51.09	47.88
10	18	59	10.25	12.68	16.91	20.98	23.79	29.82	31.39	37.38	40.92	38.56
10	18	55	8.25	9.98	13.17	16.06	18.04	22.48	23.32	27.74	30.33	28.68
10	18	51	6.04	7.48	9.96	12.14	13.34	16.52	16.85	19.79	21.34	20.13
10	18	46	4.14	5.09	6.85	8.43	9.08	11.32	11.51	13.81	14.88	13.87
10	18	42	2.60	3.22	4.50	5.68	6.21	7.85	7.80	9.14	9.96	9.10
10	18	38	1.60	2.07	3.00	3.77	4.23	5.40	5.29	6.17	6.75	6.10
10	18	33	0.90	1.35	1.82	2.39	2.84	3.46	3.55	4.05	4.50	4.10
10	18	29	0.50	0.83	1.29	1.75	1.95	2.44	2.46	2.89	3.11	2.77
10	18	25	0.30	0.52	0.86	1.22	1.15	1.63	1.48	1.93	2.04	1.88

Test #18, Time = 1018, 110 Heliostats

I35501 FILE FOR ESG FLUX DATA

TIME										
HR:	MI:	SE:	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2
10	18	25	0.56	0.46	0.39	0.41	0.00	0.27	0.13	0.04
10	18	29	0.66	0.56	0.69	0.62	0.00	0.27	0.25	0.24
10	18	33	1.10	0.99	0.89	0.83	0.00	0.37	0.25	0.24
10	18	38	1.90	1.74	1.48	1.26	0.00	0.58	0.59	0.44
10	18	42	2.98	2.70	2.27	1.93	0.00	0.98	0.82	0.65
10	18	46	4.60	4.09	3.46	3.10	0.00	1.60	1.27	0.99
10	18	51	6.97	6.13	5.09	4.48	0.00	2.41	1.96	1.10
10	18	55	10.00	8.69	7.27	6.28	0.00	3.27	2.64	1.91
10	18	59	14.42	12.87	10.74	9.46	0.00	5.11	3.83	2.83
10	19	4	19.82	17.79	15.00	13.38	0.00	7.45	5.65	3.95
10	19	8	26.41	23.89	20.15	18.26	0.00	10.21	7.70	5.38
10	19	12	33.54	30.63	25.90	23.24	0.00	13.27	9.98	7.01
10	19	17	42.14	38.08	32.04	28.65	0.00	15.82	11.81	8.24
10	19	21	50.88	46.64	39.54	35.64	0.00	20.51	15.80	10.99
10	19	25	58.55	53.81	45.38	41.54	0.00	24.28	18.65	12.93
0	0	0	65.70	59.56	52.21	47.79	20.51	28.57	22.36	15.31
10	19	25	68.17	61.28	54.97	50.25	38.73	29.89	23.35	15.86
10	19	21	69.76	62.52	56.56	51.62	40.45	31.17	24.68	16.76
10	19	17	68.74	61.49	55.28	49.88	38.93	30.32	24.07	16.36
10	19	12	63.84	57.06	51.26	46.53	36.30	28.39	22.74	15.57
10	19	8	57.27	50.92	46.17	41.82	32.67	25.50	20.29	13.94
10	19	4	48.83	43.71	39.53	35.62	28.12	21.97	17.54	11.87
10	18	59	39.26	35.16	31.90	28.80	22.61	17.76	13.97	9.49
10	18	55	29.22	26.61	24.16	21.73	16.95	13.26	10.60	7.31
10	18	51	20.33	18.58	16.74	14.91	11.80	9.20	7.65	5.33
10	18	46	14.13	12.87	11.65	10.65	8.37	6.52	5.40	3.85
10	18	42	9.23	8.34	7.48	6.80	5.44	4.38	3.67	2.86
10	18	38	6.04	5.45	4.83	4.45	3.52	2.88	2.55	1.97
10	18	33	3.99	3.50	3.03	2.83	2.41	2.13	1.93	1.47
10	18	29	2.73	2.36	2.07	1.97	1.60	1.49	1.42	1.07
10	18	25	1.93	1.85	1.65	1.59	1.30	1.17	1.01	0.68

Test #18, Time = 1018, 110 Heliostats (cont)

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                        I35502  FILE FOR ESG FLUX DATA
     TIME
HR:  MI:  SE:    W/CM2      W/CM2      W/CM2      W/CM2      W/CM2      W/CM2      W/CM2      W/CM2      W/CM2      W/CM2

12   17   16      0.22       0.36       0.42       0.52       0.55       0.71       0.56       0.55       0.55       0.57
12   17   20      0.56       0.46       0.61       0.72       0.97       1.12       1.03       1.10       1.05       1.06
12   17   25      0.45       0.55       0.71       0.92       1.18       1.42       1.38       1.66       1.67       1.55
12   17   29      0.79       0.84       1.10       1.43       1.81       2.24       2.30       2.59       2.56       2.43
12   17   33      1.24       1.42       1.68       2.15       2.76       3.57       3.63       4.26       4.13       3.89
12   17   38      1.69       1.91       2.64       3.58       4.44       5.71       5.71       6.81       6.78       6.27
12   17   42      2.37       2.87       4.10       5.62       7.06       8.87       9.08      10.36      10.32       9.69
12   17   46      3.61       4.22       6.13       8.17      10.21      12.64      13.02      15.02      14.93      14.37
12   17   51      5.08       6.15       8.93      12.04      15.36      18.97      19.87      22.46      21.90      20.81
12   17   55      6.78       8.08      12.02      16.33      20.82      26.15      27.52      31.34      30.64      29.11
12   18    0      8.92      10.78      15.80      21.73      27.26      34.10      35.87      40.62      39.54      37.76
12   18    4     11.18      13.58      19.86      26.97      33.98      42.16      44.18      49.72      48.38      46.64
12   18    8     12.99      15.90      23.14      31.67      39.97      49.91      52.65      59.38      57.71      55.71
12   18   13     14.57      18.12      26.37      36.46      46.27      57.36      60.19      67.82      66.25      64.40
12   18   17     15.36      19.18      28.12      39.21      49.84      61.95      65.52      73.81      72.38      71.04
 0    0    0     15.66      20.68      30.19      40.95      49.97      62.54      66.13      75.07      77.30      73.82
12   18   17     15.84      22.24      32.53      43.47      51.11      64.18      67.86      77.44      83.88      77.95
12   18   13     15.74      21.93      31.89      42.19      49.47      62.25      65.68      75.11      81.10      75.29
12   18    8     15.43      20.78      29.22      38.06      44.91      56.64      60.12      69.17      75.11      69.85
12   18    4     13.74      18.50      25.90      33.29      39.16      49.64      53.08      61.33      66.34      61.74
12   18    0     11.63      15.58      21.73      27.99      32.82      41.48      44.58      52.04      56.49      52.69
12   17   55      9.54      12.57      17.51      22.37      26.38      32.91      35.64      41.76      45.73      42.70
12   17   51      7.74       9.66      13.34      17.24      20.03      25.36      27.24      32.22      35.08      32.71
12   17   46      6.04       7.26       9.59      11.94      14.44      17.92      19.51      23.21      25.82      24.49
12   17   42      4.63       5.39       6.92       8.44      10.08      12.67      13.79      16.70      18.44      17.57
12   17   38      3.34       3.83       4.88       5.90       6.71       8.39       9.00      11.08      12.30      11.79
12   17   33      2.29       2.69       3.39       4.10       4.63       5.64       5.95       7.27       8.02       7.80
12   17   29      1.60       1.86       2.32       2.72       3.15       3.49       3.66       4.40       4.92       4.58
12   17   25      1.10       1.34       1.57       1.77       1.96       2.27       2.35       2.81       3.10       2.91
12   17   20      0.60       0.82       0.93       1.02       1.26       1.35       1.37       1.65       1.81       1.58
12   17   16      0.29       0.40       0.60       0.71       0.67       0.74       0.71       0.91       0.96       0.92
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Test #18, Time = 1217, 110 Heliostats

I35502 FILE FOR ESG FLUX DATA

	TIME									
HR:	MI:	SE:	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2
12	17	16	0.64	0.32	0.49	0.45	0.00	0.20	0.22	0.20
12	17	20	0.97	0.64	0.59	0.45	0.00	0.20	0.22	0.30
12	17	25	1.51	1.17	0.89	0.77	0.00	0.30	0.45	0.61
12	17	29	2.31	1.92	1.48	1.19	0.00	0.61	0.68	0.50
12	17	33	3.82	2.99	2.37	1.87	0.00	1.02	1.02	0.85
12	17	38	6.19	5.13	4.16	3.25	0.00	1.73	1.59	1.36
12	17	42	9.65	8.13	6.58	5.37	0.00	2.54	2.16	1.77
12	17	46	14.62	12.73	10.14	8.44	0.00	4.01	3.00	2.18
12	17	51	20.77	17.97	14.01	11.62	0.00	5.44	3.92	2.99
12	17	55	29.09	25.03	19.56	16.08	0.00	7.69	5.63	4.01
12	18	0	37.95	33.06	26.20	21.91	0.00	10.54	7.45	5.03
12	18	4	47.30	41.68	33.43	28.37	0.00	13.91	9.73	6.16
12	18	8	56.70	50.14	40.43	34.52	0.00	17.07	11.90	7.69
12	18	13	65.77	58.37	47.07	40.52	0.00	20.64	14.52	9.11
12	18	17	72.79	65.44	52.82	45.92	0.00	24.11	17.37	11.15
0	0	0	75.02	66.36	55.79	48.98	18.78	26.62	19.56	12.45
12	18	17	78.42	67.95	59.25	51.88	38.23	28.13	20.80	13.06
12	18	13	75.79	65.69	57.45	50.64	37.73	28.02	20.80	13.06
12	18	8	70.44	61.05	53.63	47.41	35.61	26.73	19.99	12.77
12	18	4	62.23	54.36	48.01	42.82	32.58	24.70	18.76	12.47
12	18	0	53.15	46.78	41.59	37.12	28.34	21.60	16.62	11.08
12	17	55	43.35	38.64	34.70	30.92	23.73	18.24	14.07	9.40
12	17	51	33.55	29.99	26.96	23.85	18.28	13.96	10.81	7.32
12	17	46	25.57	23.19	20.60	18.02	13.63	10.21	8.05	5.64
12	17	42	18.22	16.35	14.56	12.89	9.79	7.43	6.12	4.35
12	17	38	12.18	11.20	9.90	8.80	6.56	4.97	3.97	2.97
12	17	33	8.19	7.49	6.67	5.95	4.34	3.15	2.65	2.07
12	17	29	5.00	4.71	4.23	3.72	2.82	2.30	2.04	1.58
12	17	25	3.06	2.76	2.33	2.23	1.71	1.65	1.42	1.18
12	17	20	1.69	1.52	1.37	1.36	1.11	1.01	1.01	0.89
12	17	16	0.90	0.80	0.84	0.86	0.70	0.69	0.61	0.59

Test #18, Time = 1217, 110 Heliostats (cont)

135503 FILE FOR ESC FLUX DATA

135503 FILE FOR ESC FLUX DATA

HR:	TIME MI:	SE:	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2
13	59	59	0.56	0.69	1.06	1.32	1.38	1.32	1.17	1.18	1.01	1.04	0.75	0.64	0.98	0.56	0.00	0.40	0.22	0.60
14	0	3	1.24	1.17	1.45	1.63	1.80	1.33	1.75	2.00	1.73	1.62	1.33	1.17	1.08	0.86	0.00	0.50	0.56	0.63
14	0	8	1.58	1.46	1.83	2.14	2.54	2.75	2.67	3.00	3.01	2.50	2.31	1.92	1.87	1.50	0.00	0.81	0.79	0.77
14	0	12	1.92	1.94	2.51	3.06	3.69	4.28	4.23	4.56	4.29	3.97	3.71	3.20	2.86	2.89	0.00	1.82	1.13	0.97
14	0	16	2.93	3.01	4.06	4.99	6.00	6.78	6.78	7.44	6.94	6.25	5.98	5.24	4.29	3.66	0.00	1.93	1.48	1.28
14	0	21	3.95	4.16	5.70	7.24	8.73	10.19	10.26	11.83	10.47	9.67	9.22	7.81	6.27	5.26	0.60	2.85	2.39	1.89
14	0	25	5.42	6.00	8.21	10.50	12.72	14.89	14.79	16.82	15.48	14.16	13.75	11.44	9.24	7.90	0.00	4.22	3.46	2.61
14	0	29	7.23	8.02	11.12	14.79	17.76	21.11	21.40	23.65	22.65	20.89	20.34	17.22	13.70	11.51	0.00	6.05	4.71	3.52
14	0	34	10.05	11.30	15.85	20.70	25.22	29.82	30.56	33.75	32.18	30.07	29.41	25.14	19.94	16.91	0.00	8.71	6.54	4.44
14	0	38	12.76	14.78	20.79	27.27	33.24	39.92	40.88	45.25	43.43	40.66	39.95	34.56	27.18	22.95	0.00	11.97	8.93	5.97
14	0	43	16.49	19.22	26.63	34.72	42.06	50.22	51.05	56.24	53.54	50.52	49.89	43.07	34.02	28.57	0.00	14.83	10.98	7.20
14	0	47	19.88	22.88	31.46	40.63	48.99	58.38	59.51	65.45	62.68	59.40	59.40	52.17	41.51	35.67	0.00	19.21	14.40	9.54
14	0	51	22.59	26.20	36.10	46.55	55.60	66.54	67.75	74.78	71.55	68.68	69.01	61.69	49.83	48.05	0.00	23.50	17.60	11.99
14	0	56	24.40	28.42	39.29	51.14	61.80	73.87	75.29	82.81	79.51	76.72	77.91	69.93	56.77	49.84	0.00	27.68	21.13	14.54
14	1	0	24.18	28.52	39.78	52.86	63.79	76.84	79.58	88.47	85.89	84.04	86.11	78.32	64.20	57.15	0.00	32.57	24.89	15.66
0	0	0	23.55	29.25	40.53	52.58	61.83	75.81	79.05	88.69	90.89	86.57	87.97	78.10	66.41	59.26	22.64	34.77	27.17	17.29
14	1	0	23.54	31.47	43.97	56.15	63.69	77.97	81.30	91.60	98.05	91.54	92.11	80.03	70.80	62.74	47.43	36.61	28.60	18.55
14	0	56	23.18	30.82	41.83	53.38	60.32	74.71	78.14	88.17	95.09	87.07	88.35	76.32	67.30	59.09	45.82	35.65	28.29	18.55
14	0	51	21.28	26.93	36.38	46.18	53.08	65.63	69.85	79.90	86.40	80.21	81.05	70.24	62.22	55.84	43.19	34.04	27.07	18.45
14	0	47	18.54	23.40	31.24	39.77	45.39	56.35	60.04	69.62	75.59	70.45	71.25	62.31	55.75	50.89	39.25	31.26	25.09	16.86
14	0	43	14.74	18.40	24.61	30.86	35.78	44.56	47.77	56.05	62.11	57.79	59.16	52.63	47.80	43.82	34.71	28.05	22.64	15.38
14	0	38	11.04	14.97	19.90	24.61	28.15	35.28	37.52	44.43	48.99	46.18	47.24	42.68	38.83	35.51	28.04	22.49	18.46	12.67
14	0	34	8.74	11.02	14.72	18.25	21.21	26.50	28.69	34.04	37.76	35.42	36.52	33.00	30.14	27.70	22.12	18.06	14.99	10.39
14	0	29	6.04	7.38	9.90	12.48	14.24	18.14	19.65	24.29	27.06	25.65	26.72	24.65	22.72	21.00	17.18	14.10	11.83	8.51
14	0	25	3.93	4.78	6.37	8.03	9.68	12.29	13.61	16.40	18.28	17.89	18.12	16.89	15.62	14.80	12.23	10.25	8.67	6.33
14	0	21	2.40	3.01	3.80	4.96	6.21	8.21	9.03	11.09	12.46	11.84	12.31	11.43	10.64	10.16	8.49	7.04	6.12	4.65
14	0	16	1.70	2.07	2.73	3.68	4.33	5.76	6.26	7.60	8.29	7.73	8.09	7.41	6.99	6.57	5.56	4.57	4.18	3.46
14	0	12	0.89	1.24	1.66	2.41	2.94	3.82	4.02	4.85	5.29	4.96	5.24	4.04	4.45	4.09	3.84	2.86	2.75	2.37
14	0	8	0.50	0.72	1.24	1.67	2.05	2.70	2.82	3.37	3.47	3.29	3.42	3.19	2.96	2.72	2.13	1.90	1.83	1.48
14	0	3	0.39	0.52	0.70	0.98	1.25	1.58	1.73	1.88	2.08	1.85	1.93	1.85	1.69	1.78	1.42	1.36	1.22	1.08
13	59	59	0.29	0.41	0.38	0.50	0.76	0.86	0.97	1.14	1.23	1.07	1.14	1.02	0.95	0.99	0.91	0.83	0.81	0.79

Test #18, Time = 1400, 158 Heliostats

I01401 FILE FOR ESG FLUX DATA

	TIME											
HR:	MI:	SE:	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2
12	19	17	0.80	0.92	1.38	1.55	1.71	1.46	1.26	1.63	1.38	1.57
12	19	22	1.25	1.02	1.28	1.65	2.02	2.18	2.23	2.63	2.46	2.25
12	19	27	1.36	1.21	1.67	2.06	2.65	3.20	3.16	3.62	3.54	3.23
12	19	33	2.04	1.89	2.63	3.28	4.02	4.73	4.79	5.73	5.41	4.92
12	19	38	2.72	2.66	3.60	4.71	5.80	6.87	7.22	8.51	8.16	7.75
12	19	43	3.85	4.01	5.54	7.16	8.95	10.54	10.93	12.50	12.08	11.27
12	19	49	4.98	5.36	7.76	10.42	13.05	15.74	16.15	18.61	18.07	17.03
12	19	54	6.67	7.39	10.76	14.81	18.65	23.13	24.16	27.49	26.62	24.93
12	20	0	8.82	10.28	15.11	20.66	26.53	32.82	34.48	39.03	37.67	35.28
12	20	5	11.08	13.37	19.60	27.19	35.03	43.73	46.38	52.42	50.83	48.12
12	20	10	12.89	15.63	23.66	33.51	43.96	55.73	59.72	68.40	66.74	63.64
12	20	16	16.39	20.26	30.43	42.79	55.57	69.60	73.99	83.77	81.41	78.03
12	20	21	18.70	23.44	35.07	49.12	64.08	80.41	85.87	97.09	94.57	91.69
12	20	26	20.39	25.76	38.84	54.59	71.22	89.02	95.85	108.1	105.9	103.6
12	20	32	21.41	27.40	41.45	58.46	76.36	95.75	103.3	116.9	114.5	112.5
0	0	0	22.31	30.17	44.83	61.73	76.09	96.09	103.5	117.8	121.5	115.8
12	20	32	22.74	32.40	48.49	65.96	77.14	98.94	106.1	121.4	131.9	121.9
12	20	26	22.84	32.40	47.63	64.26	74.87	95.37	102.4	117.2	127.2	117.5
12	20	21	22.34	30.84	44.85	59.70	69.41	87.72	94.36	108.7	117.9	108.7
12	20	16	19.64	27.04	39.29	52.22	61.19	77.68	83.63	97.26	105.8	97.71
12	20	10	17.14	23.50	33.83	44.70	52.27	65.85	70.11	82.17	89.47	82.57
12	20	5	15.04	20.07	27.84	36.43	42.10	52.69	55.62	65.95	71.71	66.47
12	20	0	12.44	16.32	22.49	29.01	33.68	41.51	43.34	51.15	54.91	51.31
12	19	54	9.94	12.79	17.31	21.59	24.46	30.19	31.03	37.16	39.76	37.32
12	19	49	8.04	9.98	13.35	16.35	18.12	21.82	21.87	25.82	27.34	25.67
12	19	43	6.04	7.38	9.60	11.47	12.63	15.15	14.85	17.61	18.57	17.52
12	19	38	4.44	5.40	7.04	8.40	9.16	10.87	10.38	11.99	12.43	11.42
12	19	33	3.24	3.74	4.79	5.54	6.49	7.30	7.33	8.18	8.58	7.75
12	19	27	2.30	2.59	3.18	3.84	4.40	4.85	4.82	5.42	5.69	5.20
12	19	22	1.60	1.66	2.11	2.57	2.82	3.42	3.19	3.83	3.98	3.76
12	19	17	0.80	0.72	1.04	1.30	1.33	1.99	1.77	2.24	2.37	2.43

Test #21, Time = 1200, 173 Heliostats

I01401 FILE FOR ESG FLUX DATA

	TIME									
HR:	MI:	SE:	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2
12	19	17	1.27	0.88	1.15	0.87	0.00	0.66	0.50	0.33
12	19	22	1.92	1.53	1.55	1.45	0.00	0.76	0.84	0.88
12	19	27	3.00	2.49	2.54	2.19	0.00	1.27	1.29	1.29
12	19	33	4.73	3.99	3.73	3.25	0.00	1.98	1.86	1.80
12	19	38	7.43	6.34	5.46	4.95	0.00	2.90	2.59	2.31
12	19	43	10.99	9.23	7.83	7.07	0.00	4.06	3.62	3.13
12	19	49	16.93	14.15	12.00	10.46	0.00	5.90	4.99	3.64
12	19	54	24.49	20.57	16.95	14.49	0.00	7.84	6.36	4.76
12	20	0	34.32	29.02	23.49	19.89	0.00	10.18	7.84	5.57
12	20	5	47.13	40.00	32.11	27.21	0.00	13.86	10.23	7.21
12	20	10	63.22	54.23	43.27	36.75	0.00	18.45	13.31	8.74
12	20	16	77.73	67.07	53.38	45.18	0.00	22.63	16.16	10.67
12	20	21	92.31	81.03	64.97	55.46	0.00	27.93	19.92	13.22
12	20	26	105.1	93.55	75.62	65.00	0.00	32.83	23.46	15.16
12	20	32	114.4	102.2	82.65	71.47	0.00	36.70	25.96	15.06
0	0	0	117.1	103.2	86.99	75.79	28.74	40.04	28.79	15.71
12	20	32	122.2	105.4	91.52	79.60	58.03	42.09	30.65	17.85
12	20	26	118.1	102.4	89.61	78.36	57.63	42.09	30.75	16.77
12	20	21	108.6	94.08	82.19	72.16	53.38	39.31	29.12	17.06
12	20	16	97.41	84.66	73.56	64.47	48.03	35.35	26.26	14.79
12	20	10	82.20	72.40	63.60	56.09	42.17	31.60	23.98	13.06
12	20	5	66.35	59.12	52.04	46.05	35.00	26.57	20.61	10.59
12	20	0	50.78	45.67	40.21	35.63	27.53	21.18	16.73	7.91
12	19	54	36.76	33.51	29.61	26.83	21.41	17.12	13.98	6.53
12	19	49	25.47	23.31	20.60	18.89	15.55	12.73	10.82	5.04
12	19	43	17.45	16.06	14.35	13.26	11.00	9.30	8.06	4.85
12	19	38	11.41	10.60	9.43	8.68	7.27	6.31	5.72	3.66
12	19	33	7.76	7.31	6.67	6.07	5.15	4.49	4.09	3.16
12	19	27	5.25	4.94	4.55	4.21	3.53	3.10	2.86	2.17
12	19	22	3.77	3.70	3.39	3.10	2.52	2.24	1.84	1.38
12	19	17	2.51	2.47	2.33	2.23	1.81	1.71	1.43	1.08

Test #21, Time = 1200, 173 Heliostats (cont)

101501 FILE FOR ESG FLUX DATA

TIME HR:	MI:	SE:	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2
13	30	30	0.76	0.99	1.34	1.63	2.10	1.83	1.13	1.63	1.51	1.34
13	30	35	1.55	1.47	1.82	2.04	2.41	2.65	2.52	2.85	2.59	2.32
13	30	41	1.89	1.76	2.21	2.44	3.04	3.46	3.34	3.85	3.77	3.29
13	30	46	2.57	2.44	3.18	3.57	4.30	5.20	5.19	5.84	5.63	5.05
13	30	51	3.59	3.50	4.53	5.40	6.51	7.64	7.51	8.51	8.28	7.30
13	30	57	4.83	4.75	6.27	7.54	9.23	11.01	11.22	12.73	12.41	11.30
13	31	2	6.19	6.59	8.79	10.81	13.22	15.80	16.10	18.28	17.81	16.67
13	31	7	8.67	9.58	12.94	16.25	19.67	23.80	24.33	27.45	26.61	24.73
13	31	13	11.84	13.24	18.01	23.09	28.07	33.70	34.84	38.99	37.21	34.39
13	31	18	14.21	16.27	23.04	30.23	37.52	45.53	47.49	53.09	50.61	46.78
13	31	23	17.37	20.91	29.81	39.41	48.76	59.26	61.80	68.67	65.44	61.37
13	31	29	20.92	25.44	36.48	48.69	60.58	73.64	77.11	85.72	81.89	76.94
13	31	34	24.20	29.88	43.25	57.93	72.23	87.14	90.64	100.2	95.94	90.31
13	31	39	26.01	32.58	47.70	64.36	80.32	96.83	101.0	111.7	106.8	101.4
13	31	45	28.49	35.67	52.01	70.17	87.04	105.2	110.2	121.2	116.1	110.8
0	0	0	28.69	37.84	54.66	72.52	85.64	104.3	109.0	120.6	121.8	113.2
13	31	45	29.25	40.93	59.02	77.75	87.01	107.8	112.3	124.4	~~132.2~~	119.5
13	31	39	28.36	39.47	56.66	74.14	83.25	102.4	106.7	118.7	126.3	114.2
13	31	34	26.96	36.87	51.85	66.89	75.62	93.15	97.91	110.0	117.7	106.4
13	31	29	24.20	32.82	45.64	58.52	65.91	81.36	84.87	96.15	102.9	93.51
13	31	23	20.60	28.14	39.05	50.04	56.35	68.71	72.01	81.99	87.97	79.75
13	31	18	17.40	23.35	32.20	40.50	45.95	55.62	57.58	65.62	70.42	63.72
13	31	13	13.40	17.84	24.28	30.58	34.39	41.74	43.19	49.72	53.47	48.74
13	31	7	10.20	13.41	17.76	21.88	23.99	29.03	29.72	34.39	37.15	33.91
13	31	2	8.00	10.29	13.26	15.95	17.25	20.87	21.22	24.43	26.23	23.80
13	30	57	5.80	7.59	9.48	11.03	12.15	14.04	14.13	15.95	17.24	15.48
13	30	51	4.20	5.30	6.59	7.32	7.70	8.90	8.75	10.08	10.78	9.89
13	30	46	2.90	3.53	4.34	4.78	4.82	5.43	5.15	5.94	6.29	5.89
13	30	41	2.10	2.39	2.84	3.08	2.94	3.29	3.08	3.50	3.72	3.67
13	30	35	1.50	1.66	1.77	1.81	1.85	1.86	1.88	2.02	2.33	2.23
13	30	30	0.90	0.83	0.81	0.64	0.66	0.64	0.57	0.75	0.83	0.78

Test #22, Time = 1330, 183 Heliostats

101501 FILE FOR ESG FLUX DATA

	TIME									
HR:	MI:	SE:	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2
13	30	30	1.16	0.98	1.19	0.63	0.00	0.48	0.30	0.13
13	30	35	2.03	1.94	1.89	1.80	0.00	1.30	1.44	1.45
13	30	41	3.21	2.80	2.68	2.33	0.00	1.50	1.67	1.35
13	30	46	4.83	4.30	3.87	3.60	0.00	2.12	2.01	1.86
13	30	51	7.10	6.01	5.26	4.66	0.00	2.93	2.92	2.37
13	30	57	10.99	9.33	7.93	6.88	0.00	4.16	3.61	2.78
13	31	2	16.39	14.03	11.60	9.96	0.00	5.48	4.41	3.19
13	31	7	24.01	20.35	16.46	13.99	0.00	7.32	5.66	4.00
13	31	13	33.19	27.79	22.01	18.44	0.00	9.26	6.80	4.72
13	31	18	45.40	38.28	29.99	25.07	0.00	12.01	8.74	5.94
13	31	23	59.91	50.41	39.51	32.92	0.00	15.68	11.25	7.37
13	31	29	75.03	63.47	49.22	40.55	0.00	19.15	13.75	9.10
13	31	34	88.60	75.88	58.57	48.39	0.00	23.23	16.72	11.04
13	31	39	101.1	88.25	69.28	58.72	0.00	29.41	21.39	14.00
13	31	45	110.6	97.34	77.36	65.72	0.00	33.49	24.01	14.51
0	0	0	112.5	97.76	81.00	70.17	26.87	37.58	27.68	16.14
13	31	45	116.8	99.13	85.05	73.34	53.20	38.88	28.84	17.46
13	31	39	112.7	96.15	82.72	72.55	53.61	39.95	30.06	17.56
13	31	34	104.9	90.52	78.16	68.33	50.68	37.92	28.74	17.46
13	31	29	92.56	80.43	69.89	61.64	46.54	35.24	27.21	16.17
13	31	23	79.00	68.79	60.35	53.45	40.68	31.07	24.25	14.49
13	31	18	63.22	55.67	49.29	43.90	33.97	26.25	20.99	12.31
13	31	13	48.40	43.10	38.37	34.53	27.20	21.33	17.58	9.99
13	31	7	33.74	30.37	27.17	24.73	19.93	16.04	13.30	7.62
13	31	2	23.59	21.41	19.22	17.79	14.58	12.09	10.34	5.64
13	30	57	15.73	14.51	13.39	12.33	10.18	8.55	7.58	4.45
13	30	51	10.21	9.63	8.94	8.44	7.15	5.99	5.44	3.76
13	30	46	6.11	5.92	5.55	5.34	4.52	3.85	3.50	2.47
13	30	41	3.83	3.65	3.60	3.36	2.90	2.46	2.28	1.68
13	30	35	2.34	2.31	2.22	2.12	1.89	1.60	1.46	1.08
13	30	30	0.98	0.97	1.06	1.00	1.09	0.96	0.95	0.79

Test #22, Time = 1330, 183 Heliostats (cont)

101502 FILE FOR ESG FLUX DATA

	TIME											
HR:	MI:	SE:	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2
13	49	47	0.45	0.57	0.87	1.22	1.36	1.25	0.53	0.74	0.86	0.71
13	49	52	1.35	1.25	1.45	1.63	1.89	2.07	1.92	2.07	1.94	1.68
13	49	58	1.69	1.44	1.74	1.83	2.20	2.47	2.38	2.51	2.33	2.07
13	50	3	1.92	1.93	2.32	2.75	3.25	3.70	3.54	3.96	3.81	3.34
13	50	8	2.71	2.70	3.38	3.97	4.72	5.53	5.40	6.18	5.87	5.49
13	50	14	3.61	3.76	4.73	5.81	7.03	8.19	8.18	9.17	9.01	8.22
13	50	19	4.40	4.72	6.28	7.75	9.34	11.35	11.43	12.95	12.84	11.83
13	50	24	6.32	6.85	9.08	11.42	13.96	17.00	17.58	19.94	19.62	18.18
13	50	30	7.68	8.78	11.99	15.60	19.25	23.73	24.66	28.00	27.43	25.46
13	50	35	11.18	13.12	18.12	23.50	28.81	34.95	36.09	40.21	38.63	35.51
13	50	40	13.33	15.63	21.89	29.21	36.58	45.35	47.93	53.86	51.82	48.20
13	50	46	18.75	22.52	31.65	41.65	51.38	62.76	65.72	73.22	70.19	65.51
13	50	51	21.85	27.15	39.00	52.02	64.47	78.26	81.73	90.83	87.24	82.26
13	50	56	26.37	32.75	46.64	61.71	75.91	91.87	95.95	105.9	100.9	95.83
13	51	2	28.40	35.45	50.67	67.83	83.89	101.1	105.4	116.2	111.4	106.3
0	0	0	29.85	38.77	55.14	72.89	86.20	105.1	109.7	122.0	124.1	115.5
13	51	2	29.56	41.62	60.12	79.03	87.96	108.3	113.1	125.9	~~133.8~~	121.2
13	50	56	30.36	41.30	58.73	76.70	86.37	106.6	111.4	124.7	133.5	121.3
13	50	51	27.36	37.62	53.48	69.70	78.44	97.50	102.7	116.0	125.3	114.9
13	50	46	25.65	35.13	49.74	63.83	72.30	88.87	93.77	105.8	114.5	104.2
13	50	40	22.50	30.45	42.57	54.71	62.65	77.44	82.32	94.31	102.4	94.17
13	50	35	19.20	25.77	35.77	45.91	52.44	64.55	67.67	76.82	82.94	75.52
13	50	30	15.70	20.98	28.70	36.63	41.44	50.58	52.30	59.61	64.28	58.83
13	50	24	11.90	15.99	21.86	27.09	31.27	37.87	39.16	44.77	48.23	43.84
13	50	19	9.30	12.18	16.40	20.30	22.95	27.87	28.48	32.73	34.79	31.79
13	50	14	6.00	7.92	10.47	12.84	14.42	17.47	18.01	20.64	22.38	20.57
13	50	8	4.00	5.22	6.94	8.60	9.63	11.61	11.87	13.86	15.00	13.69
13	50	3	3.10	3.86	5.01	5.95	6.56	7.43	7.40	8.41	8.96	8.43
13	49	58	1.60	2.10	2.66	3.30	3.78	4.57	4.67	5.44	5.86	5.55
13	49	52	1.60	1.89	2.23	2.45	2.49	2.64	2.49	2.79	2.86	2.77
13	49	47	0.50	0.74	1.05	1.08	1.01	1.21	1.18	1.42	1.58	1.55

Test #22, Time = 1350, 188 Heliostats

I01502 FILE FOR ESG FLUX DATA

	TIME									
HR:	MI:	SE:	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2
13	49	47	0.73	0.64	0.55	0.31	0.00	0.51	0.26	0.12
13	49	52	1.81	1.60	1.44	1.37	0.00	0.81	0.71	0.42
13	49	58	2.13	1.92	1.64	1.69	0.00	1.02	0.94	0.93
13	50	3	3.43	3.10	2.73	2.54	0.00	1.73	1.63	1.14
13	50	8	5.59	5.02	4.32	4.02	0.00	2.54	2.20	1.75
13	50	14	8.40	7.38	6.30	5.72	0.00	3.46	2.77	1.85
13	50	19	11.96	10.37	8.78	7.73	0.00	4.59	3.68	2.67
13	50	24	18.12	15.30	12.44	10.91	0.00	5.91	4.59	3.08
13	50	30	25.09	21.40	17.10	14.84	0.00	7.85	5.84	4.10
13	50	35	34.60	28.84	22.75	19.08	0.00	9.69	7.10	4.50
13	50	40	47.02	39.86	31.33	26.56	0.00	13.56	9.95	6.65
13	50	46	64.34	54.14	42.03	35.36	0.00	17.34	12.57	8.28
13	50	51	81.25	69.87	54.56	46.06	0.00	22.84	16.33	10.62
13	50	56	95.08	82.34	63.97	53.95	0.00	27.09	19.52	12.87
13	51	2	106.3	93.36	73.98	62.96	0.00	32.29	23.40	14.40
0	0	0	115.1	99.95	83.37	72.27	29.03	38.67	28.55	17.11
13	51	2	118.8	101.4	87.44	75.44	54.96	40.46	30.23	18.52
13	50	56	119.8	102.5	88.93	77.79	57.28	42.60	31.86	19.11
13	50	51	114.9	99.95	87.66	77.92	58.49	44.16	33.70	20.99
13	50	46	103.8	91.03	80.28	71.42	53.65	40.68	31.25	19.21
13	50	40	95.05	84.33	75.09	67.45	51.42	39.39	30.53	18.81
13	50	35	75.44	66.72	59.29	53.81	41.93	33.19	26.96	16.24
13	50	30	58.64	52.15	46.95	42.90	33.91	26.98	22.17	12.97
13	50	24	43.70	39.49	35.40	32.41	25.83	20.88	17.74	10.16
13	50	19	31.78	28.92	26.11	24.10	19.47	16.02	13.66	7.69
13	50	14	20.61	18.82	17.32	15.92	12.84	10.67	9.38	5.51
13	50	8	13.95	12.81	11.80	10.83	8.80	7.36	6.52	4.42
13	50	3	8.82	8.38	7.78	7.31	6.18	5.32	4.99	3.53
13	49	58	5.85	5.50	5.13	5.08	4.16	3.61	3.16	2.14
13	49	52	2.89	2.92	2.86	2.72	2.34	2.11	1.93	1.35
13	49	47	1.75	1.79	1.80	1.73	1.53	1.47	1.42	1.05

Test #22, Time = 1350, 188 Heliostats (cont)

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                    I01801  FILE FOR ESG FLUX DATA
     TIME
HR:  MI:  SE:    W/CM2    W/CM2    W/CM2    W/CM2    W/CM2    W/CM2    W/CM2    W/CM2    W/CM2    W/CM2

13    9    1      1.17     1.42     1.77     2.10     2.61     2.49     1.87     2.41     2.47     2.14
13    9    7      1.85     1.52     1.87     2.20     2.71     3.11     3.15     3.86     3.75     3.41
13    9   12      2.41     2.29     2.74     3.22     3.97     4.64     4.66     5.63     5.42     5.01
13    9   17      3.20     3.06     4.00     4.85     6.07     6.98     7.21     8.41     8.17     7.65
13    9   23      4.56     4.61     6.03     7.40     9.01    10.76    11.15    12.74    12.49    11.84
13    9   28      5.92     6.25     8.35    10.46    12.79    15.45    15.91    18.18    17.69    16.72
13    9   33      8.52     9.05    12.02    15.25    18.51    22.02    22.64    25.50    24.86    23.26
13    9   39     11.68    12.91    17.19    21.72    26.28    31.09    31.57    35.38    34.15    31.95
13    9   44     14.84    16.52    22.60    29.17    35.73    42.93    44.05    49.32    47.50    44.40
13    9   49     17.33    19.89    28.02    37.12    46.12    55.64    57.62    64.42    61.55    57.48
13    9   55     22.35    26.17    36.72    48.55    59.94    72.06    74.44    82.67    78.67    73.62
13   10    0     25.51    30.32    43.39    58.20    72.12    87.19    91.08    101.2    96.74    91.68
13   10    5     28.00    34.37    49.93    67.99    85.03    102.4    107.4    118.9    113.5    108.5
13   10   11     31.16    38.52    55.83    75.54    94.63    113.7    119.5    131.5    125.9    121.2
13   10   16     33.53    41.61    60.08    80.74    100.5    121.0    127.5    140.3    134.8    130.7
 0    0    0     33.08    43.30    61.98    82.07    97.30    118.9    125.5    139.1    141.2    132.8
13   10   16     34.23    47.58    67.88    88.83    99.27    122.6    129.1    143.1    153.4    140.0
13   10   11     32.44    44.87    63.81    83.47    93.92    116.5    122.8    137.0    146.9    133.8
13   10    5     29.83    40.92    57.82    75.73    85.60    106.0    112.0    126.0    135.2    123.4
13   10    0     27.23    36.97    51.44    65.98    74.06    90.82    95.93    108.4    116.6    106.1
13    9   55     24.13    32.50    44.49    56.55    63.16    76.39    79.75    90.05    96.56    87.45
13    9   49     19.13    25.67    34.64    44.08    49.72    59.87    62.31    70.97    76.72    69.36
13    9   44     14.93    19.95    26.51    33.06    37.14    44.61    45.89    52.46    56.18    51.09
13    9   39     11.63    15.17    20.09    24.36    26.63    31.96    32.38    37.09    39.53    36.10
13    9   33      8.54    10.90    14.16    16.90    18.01    21.25    21.15    24.48    26.05    23.89
13    9   28      6.34     7.99    10.10    11.60    11.93    13.66    13.37    15.53    16.70    15.52
13    9   23      4.74     5.81     6.99     7.79     7.86     8.67     8.25     9.49    10.28     9.64
13    9   17      3.54     4.25     4.96     5.14     4.89     5.50     5.09     5.89     6.32     6.09
13    9   12      2.70     3.10     3.46     3.55     3.21     3.36     3.12     3.56     3.96     3.65
13    9    7      2.09     2.27     2.50     2.27     2.02     2.14     1.92     2.28     2.36     2.31
13    9    1      0.70     0.71     0.68     0.68     0.73     0.81     0.83     1.01     1.18     1.20
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Test #23, Time = 1309, 213 Heliostats

I01801 FILE FOR ESG FLUX DATA

TIME HR:	MI:	SE:	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2
13	9	1	1.71	1.44	2.59	1.73	0.00	1.12	0.68	0.43
13	9	7	3.01	2.62	2.79	2.48	0.00	1.63	1.70	1.49
13	9	12	4.74	4.11	4.02	3.64	0.00	2.24	2.27	2.11
13	9	17	7.33	6.58	6.10	5.55	0.00	3.30	3.00	2.62
13	9	23	11.54	10.11	8.97	7.88	0.00	4.52	3.92	3.23
13	9	28	16.51	14.39	12.34	10.85	0.00	6.16	5.06	4.04
13	9	33	23.10	20.06	16.80	14.67	0.00	8.09	6.42	4.66
13	9	39	31.63	27.33	22.75	19.75	0.00	10.64	8.25	5.98
13	9	44	43.79	37.78	30.68	26.33	0.00	13.70	10.30	7.10
13	9	49	56.32	48.48	38.66	33.00	0.00	16.97	12.47	8.33
13	9	55	72.41	62.17	48.67	40.81	0.00	20.13	14.63	9.45
13	10	0	91.03	78.91	61.95	52.04	0.00	25.54	18.39	11.69
13	10	5	107.8	94.32	74.28	62.64	0.00	31.15	22.27	14.65
13	10	11	121.8	107.9	85.78	72.61	0.00	36.25	26.03	17.00
13	10	16	132.3	118.0	94.60	80.92	0.00	41.20	29.79	17.20
0	0	0	133.5	116.9	98.01	85.41	32.25	45.81	33.92	18.24
13	10	16	138.8	118.5	103.0	90.28	65.85	48.62	35.84	20.26
13	10	11	133.0	114.0	99.62	87.92	64.84	48.72	36.55	19.47
13	10	5	122.0	105.6	92.63	82.34	61.71	46.80	35.74	20.36
13	10	0	105.7	92.43	81.77	73.29	55.81	42.94	33.39	18.87
13	9	55	86.75	75.80	66.83	59.78	46.21	35.88	28.39	16.10
13	9	49	68.85	60.56	53.58	48.54	38.23	30.32	24.68	14.08
13	9	44	50.20	44.74	39.84	36.27	29.24	24.01	20.19	11.21
13	9	39	35.49	32.07	29.03	26.72	22.11	18.61	16.21	9.33
13	9	33	23.75	21.87	20.02	18.78	15.55	13.48	11.93	6.66
13	9	28	15.73	14.72	13.87	13.03	10.90	9.63	8.77	5.27
13	9	23	10.14	9.68	9.16	8.81	7.57	6.74	6.32	4.08
13	9	17	6.26	5.97	5.77	5.71	4.94	4.49	4.28	3.19
13	9	12	3.87	3.81	3.76	3.73	3.43	3.10	3.06	2.30
13	9	7	2.39	2.47	2.38	2.49	2.22	2.24	2.04	1.61
13	9	1	1.36	1.33	1.32	1.25	1.11	1.17	1.01	0.82

Test #23, Time = 1309, 213 Heliostats (cont)

I02601 FILE FOR ESG FLUX DATA

HR:	TIME MI:	SE:	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2
12	16	10	0.41	0.18	0.33	0.49	0.49	0.64	0.80	0.74	0.74	0.72
12	16	15	0.75	0.66	0.62	0.70	0.49	0.74	1.03	1.07	1.03	1.21
12	16	21	1.09	0.95	1.01	0.60	1.54	2.88	3.28	2.51	1.52	1.30
12	16	26	1.20	1.24	1.69	2.23	2.80	3.70	4.09	4.85	4.86	4.76
12	16	31	1.66	1.82	2.56	3.45	4.27	5.33	5.71	6.73	6.63	6.22
12	16	37	2.56	2.78	3.91	5.29	6.58	8.08	8.61	9.73	9.48	9.05
12	16	42	3.58	4.04	5.75	7.94	9.94	12.47	13.02	14.84	14.68	14.03
12	16	47	4.59	5.58	8.07	11.31	14.56	18.43	19.63	22.49	22.14	21.06
12	16	53	6.52	7.90	11.84	16.65	21.32	26.89	28.80	32.82	32.06	30.43
12	16	58	7.76	10.02	15.26	21.85	28.57	36.48	39.35	45.21	44.79	42.88
12	17	3	10.24	13.59	21.07	30.12	39.49	50.11	53.58	61.19	60.01	57.23
12	17	9	11.94	16.14	25.22	36.85	48.83	62.14	67.26	76.55	75.27	72.30
12	17	14	14.31	19.42	30.45	43.99	58.55	74.89	81.11	92.54	91.28	88.60
12	17	19	16.69	22.99	35.86	51.60	68.11	86.46	93.76	106.1	104.4	101.5
12	17	25	18.43	25.50	39.92	57.31	75.35	94.72	102.5	115.6	113.6	110.9
0	0	0	19.91	28.33	43.43	60.40	75.51	95.40	103.2	117.2	122.0	115.6
12	17	25	20.95	31.57	48.57	66.68	78.94	99.85	107.4	121.9	133.2	122.4
12	17	19	20.84	30.63	46.33	62.86	74.68	94.96	102.5	117.2	128.8	118.5
12	17	14	20.05	28.87	42.69	57.14	67.24	85.12	92.18	106.4	117.3	107.9
12	17	9	18.55	26.20	37.87	50.19	58.62	73.60	79.10	91.66	101.6	93.72
12	17	3	17.05	23.50	33.06	43.08	50.04	61.77	65.25	75.62	83.50	76.74
12	16	58	14.94	19.86	26.96	33.86	38.84	47.53	49.82	57.70	64.45	60.09
12	16	53	12.05	15.49	20.54	25.17	28.63	34.57	36.19	42.27	47.16	43.93
12	16	47	9.14	11.54	15.15	18.17	20.61	24.27	25.29	29.44	32.93	30.61
12	16	42	6.64	8.21	10.55	12.73	14.23	16.48	16.97	19.80	22.34	21.06
12	16	37	4.25	5.20	6.69	8.06	8.58	10.36	10.54	12.65	14.48	14.03
12	16	31	2.91	3.43	4.23	4.99	5.41	6.38	6.50	7.78	9.13	8.81
12	16	26	1.90	2.07	2.63	3.08	3.23	3.83	3.78	4.60	5.49	5.48
12	16	21	1.21	1.35	1.45	1.60	2.04	2.30	2.47	2.90	3.57	3.48
12	16	15	0.90	0.93	1.02	1.07	1.24	1.59	1.49	1.84	2.18	2.15
12	16	10	0.30	0.41	0.38	0.54	0.45	0.77	0.62	0.89	1.00	1.04

Test #24, Time = 1216, 175 Heliostats

I02601 FILE FOR ESG FLUX DATA

	TIME									
HR:	MI:	SE:	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2
12	16	10	0.80	0.95	1.04	0.99	0.00	0.44	0.25	0.00
12	16	15	1.24	1.38	1.33	1.20	0.00	0.65	0.47	0.18
12	16	21	1.56	1.70	1.63	1.52	0.00	1.57	1.04	0.69
12	16	26	4.91	4.48	3.85	3.43	0.00	2.18	1.73	1.30
12	16	31	6.42	5.66	4.84	4.17	0.00	2.48	2.00	1.51
12	16	37	9.23	8.01	6.53	5.76	0.00	3.34	2.80	2.12
12	16	42	14.09	11.97	9.80	8.62	0.00	5.07	4.28	3.34
12	16	47	21.32	18.39	14.85	12.97	0.00	7.42	5.99	4.36
12	16	53	30.61	26.63	21.29	18.38	0.00	9.97	7.70	5.28
12	16	58	43.31	37.93	30.61	26.11	0.00	13.85	10.32	6.91
12	17	3	57.46	50.23	39.68	33.85	0.00	17.52	12.72	8.14
12	17	9	73.34	65.00	52.17	44.83	0.00	23.43	16.94	10.99
12	17	14	90.01	79.81	63.96	54.58	0.00	28.13	20.36	13.85
12	17	19	102.9	92.11	73.81	63.49	0.00	32.92	23.55	15.79
12	17	25	112.6	101.2	81.54	70.06	0.00	36.49	26.17	15.18
0	0	0	116.2	102.8	86.72	75.51	29.15	40.61	29.72	16.45
12	17	25	121.2	104.2	90.73	79.26	57.63	42.39	31.45	18.84
12	17	19	117.8	102.0	89.67	78.88	58.13	43.24	32.17	18.15
12	17	14	108.0	94.57	83.52	74.05	55.40	41.64	31.35	19.14
12	17	9	94.05	82.89	73.83	66.24	50.25	38.22	29.21	17.76
12	17	3	76.95	68.37	60.80	54.63	41.77	32.01	24.88	14.88
12	16	58	60.76	54.77	48.82	44.34	33.99	26.23	20.40	12.17
12	16	53	44.73	40.80	36.78	33.30	26.05	20.52	16.52	9.80
12	16	47	31.50	29.37	26.81	24.37	19.49	15.60	12.95	8.01
12	16	42	22.16	20.62	18.76	17.06	13.43	10.78	8.97	5.44
12	16	37	15.04	14.60	13.35	12.17	9.69	7.89	6.63	4.15
12	16	31	9.57	9.24	8.64	8.08	6.66	5.64	4.89	3.26
12	16	26	6.04	5.95	5.57	5.10	4.34	3.72	3.36	2.47
12	16	21	3.87	3.79	3.56	3.37	2.92	2.65	2.24	1.78
12	16	15	2.28	2.34	2.28	2.13	1.81	1.69	1.42	1.18
12	16	10	1.13	1.21	1.22	1.26	1.11	1.15	1.01	0.79

Test #24, Time = 1216, 175 Heliostats (cont)

I06901 FILE FOR ESC FLUX DATA

TIME HR:	MI:	SE:	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2
11	45	32	0.19	0.29	0.31	0.44	0.58	0.58	0.37	0.34	0.55	0.42
11	45	38	0.00	0.00	0.00	0.04	0.48	0.68	0.71	1.23	1.24	1.40
11	45	43	0.53	0.58	0.70	0.85	1.21	1.29	1.87	2.67	2.72	1.99
11	45	49	0.75	0.78	1.09	1.36	2.37	2.92	2.92	3.11	2.72	2.28
11	45	54	1.09	1.26	1.57	2.18	3.10	3.64	3.73	4.00	3.70	3.25
11	46	0	1.66	1.84	2.63	3.50	4.57	5.57	5.82	6.33	5.76	5.30
11	46	5	2.56	3.00	4.18	5.75	7.51	8.94	9.41	10.11	9.39	8.62
11	46	11	3.80	4.44	6.31	8.60	11.19	13.63	14.29	15.55	14.60	13.31
11	46	16	5.39	6.47	9.40	13.09	17.11	21.02	22.17	23.98	22.61	20.73
11	46	22	7.87	9.56	14.05	19.46	25.30	30.91	32.80	35.70	33.81	31.03
11	46	27	10.92	13.32	19.31	26.70	34.23	42.44	45.21	49.25	46.87	43.62
11	46	33	14.20	17.61	25.69	35.47	45.36	55.76	59.41	64.61	62.03	58.30
11	46	38	17.97	22.33	32.36	44.14	56.23	69.73	74.84	81.48	78.19	74.21
11	46	44	21.82	26.39	37.87	51.65	65.79	81.67	88.02	96.09	92.23	88.13
11	46	49	25.09	30.83	44.16	59.91	75.97	93.23	100.5	108.8	104.2	99.68
0	0	0	27.47	35.16	50.73	67.37	81.31	100.0	107.6	117.9	120.5	112.1
11	46	49	29.15	38.85	57.06	74.63	84.71	104.0	110.3	123.1	131.4	118.5
11	46	44	28.85	38.23	55.67	72.72	83.62	103.2	110.4	122.8	132.5	120.2
11	46	38	27.95	36.87	54.49	70.60	80.74	99.29	106.0	119.2	128.1	115.6
11	46	33	26.65	35.00	51.49	66.74	75.69	92.36	98.12	109.8	117.6	105.2
11	46	27	22.49	29.39	43.04	55.51	63.50	77.81	82.14	92.96	100.2	90.18
11	46	22	19.69	25.54	37.09	47.24	53.75	64.86	67.81	76.32	81.71	73.31
11	46	16	16.19	20.86	30.03	37.95	43.34	51.96	53.75	60.58	64.33	57.73
11	46	11	12.19	15.66	22.33	27.99	31.98	38.44	39.63	44.68	47.64	42.63
11	46	5	9.19	11.64	16.44	20.25	22.87	27.22	27.86	31.58	33.45	29.80
11	46	0	6.69	8.32	11.48	13.79	15.43	18.34	18.92	21.88	23.18	20.76
11	45	54	4.49	5.61	7.52	9.08	10.14	12.18	12.44	14.52	15.69	14.04
11	45	49	2.99	3.53	4.95	5.79	6.58	7.80	7.86	9.07	9.76	9.00
11	45	43	1.79	2.07	2.81	3.25	4.00	4.43	4.81	5.36	6.13	5.56
11	45	38	1.09	1.24	1.85	2.19	2.31	2.80	2.74	3.24	3.45	3.34
11	45	32	0.69	0.72	1.10	1.13	1.52	1.58	1.65	1.86	2.17	2.00

Test #34, Time = 1145, 161 Heliostats

I06901 FILE FOR ESG FLUX DATA

TIME HR:	MI:	SE:	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2	W/CM2
11	45	32	0.72	0.64	0.51	0.34	0.00	0.10	0.09	0.14
11	45	38	1.15	0.85	0.61	0.45	0.00	0.30	0.09	0.14
11	45	43	1.47	1.17	1.01	0.87	0.00	0.40	0.31	0.14
11	45	49	2.01	1.60	1.30	1.40	0.00	0.61	0.43	0.24
11	45	54	3.20	2.67	2.10	1.93	0.00	1.02	0.77	0.75
11	46	0	5.04	4.17	3.09	2.68	0.00	1.42	1.11	0.85
11	46	5	8.06	6.63	5.07	4.27	0.00	2.14	1.80	1.36
11	46	11	12.71	10.48	8.14	6.70	0.00	3.36	2.71	2.18
11	46	16	19.73	16.26	12.50	10.31	0.00	5.20	4.08	3.10
11	46	22	29.51	24.35	18.55	14.97	0.00	7.34	5.56	4.01
11	46	27	42.15	35.58	27.23	22.07	0.00	10.50	7.50	4.83
11	46	33	56.66	48.00	36.54	29.88	0.00	14.17	10.00	6.77
11	46	38	72.97	62.48	48.04	39.20	0.00	18.25	12.74	8.50
11	46	44	87.62	76.46	59.38	49.06	0.00	23.05	15.93	10.34
11	46	49	99.39	86.94	67.40	56.21	0.00	27.29	18.78	10.64
0	0	0	111.3	95.30	77.74	65.71	25.41	33.04	23.31	13.38
11	46	49	116.3	97.41	82.72	69.19	47.47	34.38	24.72	15.08
11	46	44	118.6	99.47	84.73	71.91	49.99	36.63	26.35	15.78
11	46	38	114.4	96.18	82.29	70.30	48.88	36.10	26.35	16.27
11	46	33	103.3	86.84	74.45	63.61	45.24	34.28	25.43	15.58
11	46	27	89.30	76.13	65.97	57.16	41.30	31.82	24.01	14.79
11	46	22	73.00	63.11	55.12	47.73	34.90	27.00	20.40	12.21
11	46	16	57.45	49.52	43.14	37.86	28.23	22.29	17.23	10.43
11	46	11	42.45	36.58	32.11	28.56	21.77	17.48	13.87	8.81
11	46	5	29.45	25.87	[illegible]	20.38	15.61	12.84	10.40	6.53
11	46	0	[illegible]	18.04	15.92	14.18	11.00	8.98	7.44	4.85
11	45	54	14.29	12.89	11.59	10.34	8.28	6.84	5.71	3.86
11	45	49	9.34	8.52	7.56	6.94	5.35	4.38	3.67	2.57
11	45	43	5.92	5.64	5.02	4.58	3.53	2.99	2.55	1.88
11	45	38	3.53	3.48	3.18	3.10	2.42	2.24	1.83	1.38
11	45	32	2.28	2.24	2.22	2.23	1.81	1.60	1.32	0.89

Test #34, Time = 1145, 161 Heliostats (cont)

APPENDIX F

ASSEMBLY DRAWINGS

APPENDIX F

ASSEMBLY DRAWINGS

N001000399	Panel Assembly - Solar Receiver Test
N001000397 (two sheets)	Test Fixture, Solar Panel
N001000425	Fitting, Manifold - Solar Panel
N001000426	Solar Panel to Test Fixture, and Insulation Assembly
N01000426	Heater Installation Details
N001000427	Solar Panel Test Fixture to Sodium Loop Assembly

APPENDIX G

CONTROLS AND INSTRUMENTATION DESIGN FOR 2.5-MW SODIUM-COOLED RECEIVER PANEL

Rockwell International
Energy Systems Group

SUPPORTING DOCUMENT

GO NO.	S/A NO.	PAGE 1 OF	TOTAL PAGES	REV LTR/CHG NO SEE SUMMARY OF CHG	NUMBER
09419	12000	28	28	0	050TI000005

PROGRAM TITLE
Sodium Cooled Solar Receiver Panel

DOCUMENT TITLE
Controls and Instrumentation Design for 2.5 MW Sodium Cooled Receiver Panel

DOCUMENT TYPE
Technical Information

KEY NOUNS
Controls, Instrumentation, Sodium Cooled Receiver Panel

ORIGINAL ISSUE DATE

REL. DATE

APPROVALS

DATE
6-26-81

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IR&D PROGRAM? YES ☐ NO ☐
IF YES, ENTER TPA NO.

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ABSTRACT

The document describes the controls and instrumentation system designed for the 2.5 MW sodium cooled receiver panel to be tested at the Sandia CRTR in Albuquerque, N.M. Included herein is a description of the control system, the method of operation and the supporting analysis performed to confirm the design.

The system design predicts control of the sodium temperature at the panel exit manifold of 1100 ± 25°F with a nominal panel inlet temperature of 550°F.

RESERVED FOR PROPRIETARY/LEGAL NOTICES

CONTENTS

FIGURES

1.0 INTRODUCTION

This report documents the controls and instrumentation design of a 2.5 MW Sodium Cooled Solar Receiver Panel. Included are the specific controls and instrumentation used for the control of the sodium temperature through the panel and the supporting analysis that was performed to substantiate this part of the receiver design.

Analytical confirmation of the design will be required when the model of the receiver is integrated with the overall sodium loop. This analysis will be performed by the technical personnel of Sandia National Laboratories located at the Central Receiving Test Facility in Albuquerque, N.M.

Sufficient versatility has been designed into the control system to allow changes to be made, if required, after the ESG supplied receiver panel and controls are installed and operated at the CRTF.

2. SODIUM RECEIVER PANEL CONTROLS AND INSTRUMENTATION

The ESG test article (solar receiver panel assembly) EI&C control panel contains the controllers, switches, indicators and logic to control the test article subpanel inlet flow control valves. The operator can set the controllers for local manual or automatic valve operation. The valves can be manually or computer controlled from the main control room when the controllers are set in the remote mode. Figure 2.11 shows the logic employed in the valve control system.

The logic diagram shows the scram signals which will be sent to the facility system as well as the facility-generated scram signals for valve control. These signals are (1) the high temperature limit alarms on the outlet thermocouples indicating excessive outlet sodium temperature, (2) high differential temperature between the inlet and outlet sodium temperatures, (3) the condition of any of the inlet valves going closed when insolation is impinging on the absorber panel, (4) the loss of two or more of the flux sensors (computer programmed) and the loss of the flux signal (due to conditioning instrument failure as detected by the signal voltage dropping below the zero insolation level).

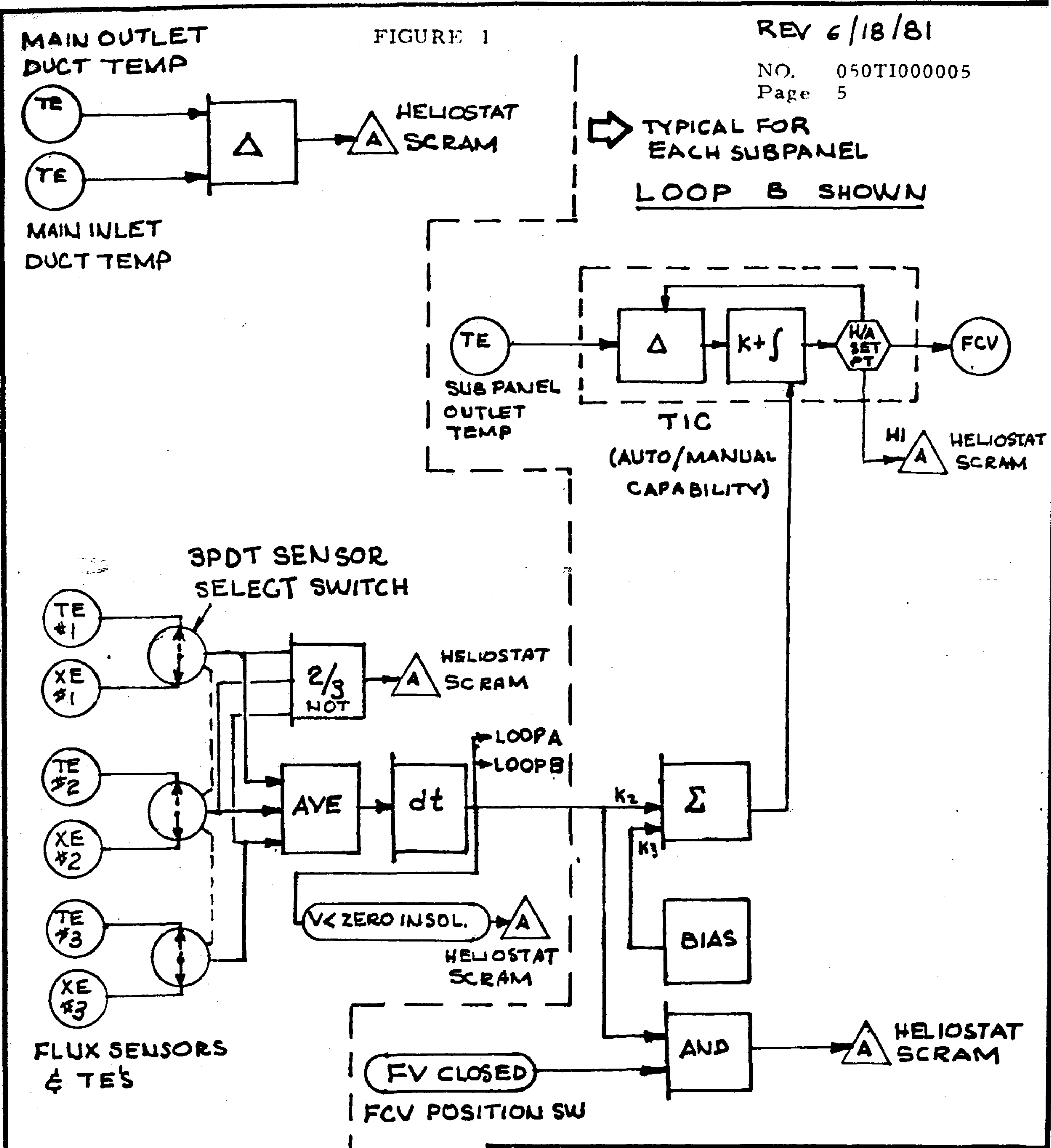
The Figure 2.10 P&ID shows the instrumentation for the above. It also shows the heater thermocouples and a typical heater. The heater thermocouples are not controlled via the ESG control panel.

The controllers utilized in the ESG control panel are a microprocessor-based design. They can be switched from local control to remote control. A second set of set points can be utilized at the remote (main computer room) control point. The controllers receive their temperature signal from immersion type thermocouple located in each outlet duct of the abosrber sub-panel. These thermocouples are 0.125 diameter ungrounded junction type which are reduced to 0.060 inch diameter for faster response.

FIGURE 1

REV 6/18/81

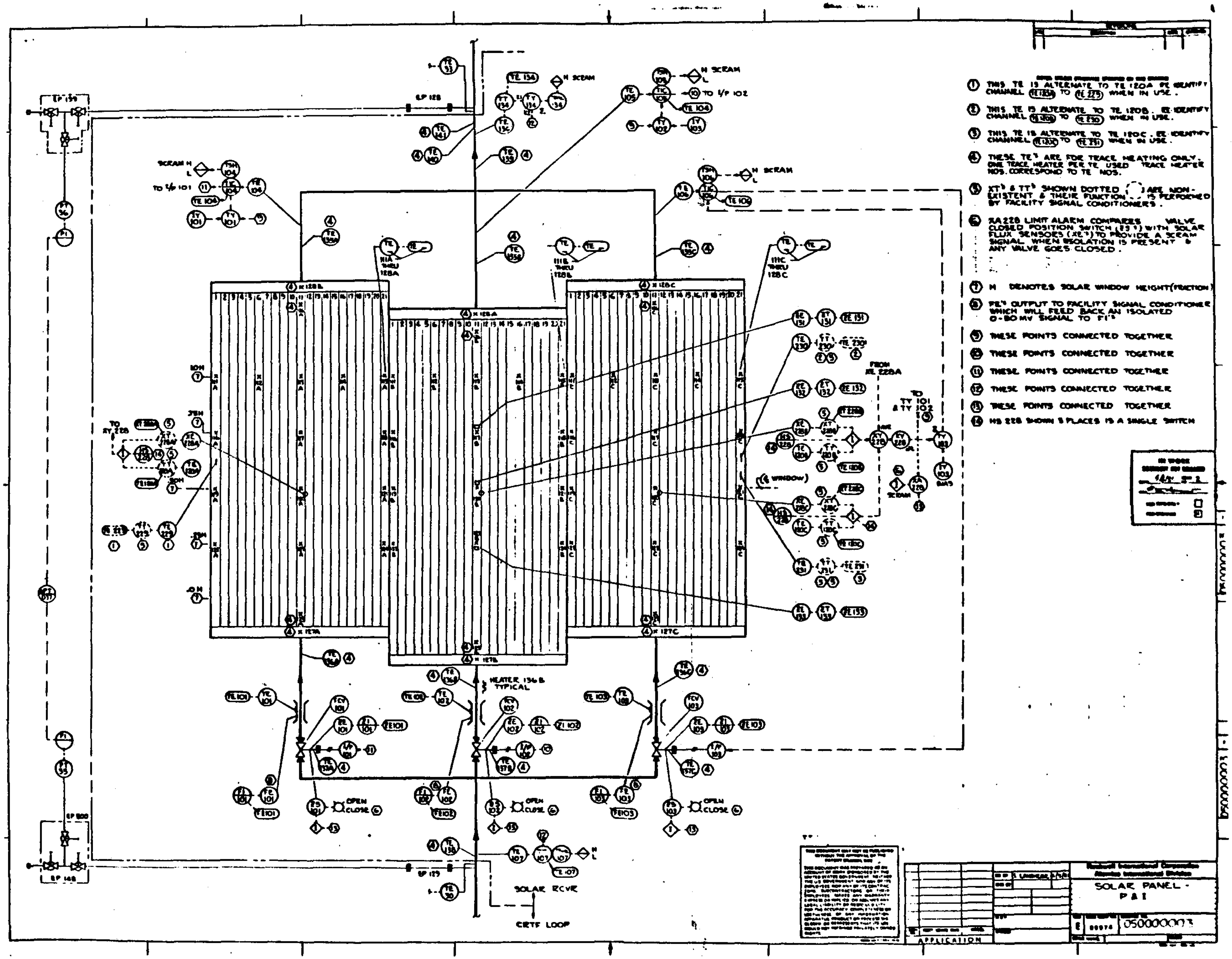
NO. 050TI000005
Page 5



Rockwell International Corporation
Energy Systems Group

SIZE	CODE IDENT NO.	DRAWING NO.	
A	09974	EI&C CONTROL LOGIC	
SCALE		LETO	SHEET

FORM 736-V-1 REV. 9-78



① THIS TE IS ALTERNATE TO TE 120A. RE IDENTIFY CHANNEL (TE 120A) TO (TE 229) WHEN IN USE.

② THIS TE IS ALTERNATE TO TE 120B. RE IDENTIFY CHANNEL (TE 120B) TO (TE 230) WHEN IN USE.

③ THIS TE IS ALTERNATE TO TE 120C. RE IDENTIFY CHANNEL (TE 120C) TO (TE 231) WHEN IN USE.

④ THESE TE'S ARE FOR TRACE HEATING ONLY. ONE TRACE HEATER PER TE USED. TRACE HEATER NOS. CORRESPOND TO TE NOS.

⑤ XT'S & TT'S SHOWN DOTTED ( ) ARE NON-EXISTENT & THEIR FUNCTION IS PERFORMED BY FACILITY SIGNAL CONDITIONERS.

⑥ XA 228 LIMIT ALARM COMPARES VALVE CLOSED POSITION SWITCH (ZS'S) WITH SOLAR FLUX SENSORS (XE'S) TO PROVIDE A SCRAM SIGNAL WHEN ISOLATION IS PRESENT & ANY VALVE GOES CLOSED.

⑦ H DENOTES SOLAR WINDOW HEIGHT (FRACTION)

⑧ FE'S OUTPUT TO FACILITY SIGNAL CONDITIONER WHICH WILL FEED BACK AN ISOLATED 0-50 MV SIGNAL TO FI'S

⑨ THESE POINTS CONNECTED TOGETHER

⑩ THESE POINTS CONNECTED TOGETHER

⑪ THESE POINTS CONNECTED TOGETHER

⑫ THESE POINTS CONNECTED TOGETHER

⑬ THESE POINTS CONNECTED TOGETHER

⑭ HS 228 SHOWN 3 PLACES IS A SINGLE SWITCH

FIGURE 2

The controllers also have provision for receiving a feed-foreward signal input as illustrated on the Figure 2.11 logic diagram. This allows the controller to be used as a manual valve controller when set in the Manual mode and to be switched back to Automatic mode without having to separately adjust for the feed foreward signal. It provides for bumpless transfer.

The absorber panel flux sensors are the water-cooled type. The cooling water passages employ 1/4-in. tube lines and 0.100 diameter minimum water passages within the sensor proper. The passages are large enough to assure there will be no cooling water blockage due to contaminant buildup.

Each of the receiver subpanels has 14 0.060-in.-diameter underground junction thermocouples strapped to the back of the absorber panel tubes with spot-welded clips. These are shown on the Figure 2.10 P&ID. The signals are not displayed on the ESG control panel but are multiplexed data channels. One centrally located back-of-tube thermocouple in each absorber subpanel is also brazed to the tube and will possibly be tested as a substitute for the flux sensors. Present indications, however, are that the time response will be too slow.

Three front-of-tube thermocouples, which would have sufficiently fast response, are to also be tested. These are 0.030 in. diameter ungrounded junction Inconel stainless steel-sheathed units which are heat-sinked to the receiver panel tubes to prevent their experiencing excessive temperatures. These will be tested to determine the feasibility of using thermocouples as indicators of solar flux changes and to assess their reliability.

A magnetic flowmeter is provided in each of the absorber subpanels to measure sodium flow rate. The signal is not used for control but is a multiplexed data channel and is also displayed on the ESG control panel. A thermocouple is provided for each of the flow meters to measure flowmeter permanent magnet temperature to correct the magnet temperature-related signal error.

The center absorber subpanel has three deflection sensors from which the signals are fed to the main computer for recording. These are not displayed on the ESG panel.

The valve position signal is a multiplexed signal channel and is also displayed on the ESG control panel. The valve Open-Closed lights for these valves are also displayed on line ESG control panel.

3.0 SODIUM RECEIVER PANEL CONTROL ANALYSIS

A. ANALYSIS OBJECTIVES

In support of the 2.5 MW sodium solar panel tests to be conducted at Sandia Laboratories, an analysis was conducted of the panel temperature control system.

B. SCOPE

This analysis considered only the panel temperature control loop. This entailed modeling the panel and its related variables (heat transfer, etc.) as well as the sodium loop hydraulics and associated control system.

4.0 DISCUSSION

A. PROCESS SYSTEM DESCRIPTION

The test panel consists of three panels, each consisting of 21, 3/4-in. tubes, operating in parallel. Flow is admitted to the three panels through an inlet manifold assembly and the flow to each of the three panels can be monitored and modulated by P-M flowmeters and bellows seal throttle valves. The panel "solar window" consists of a heat transfer section 118 in. in length. The exit manifold contains an immersed control thermocouple located 72 in. above the "window".

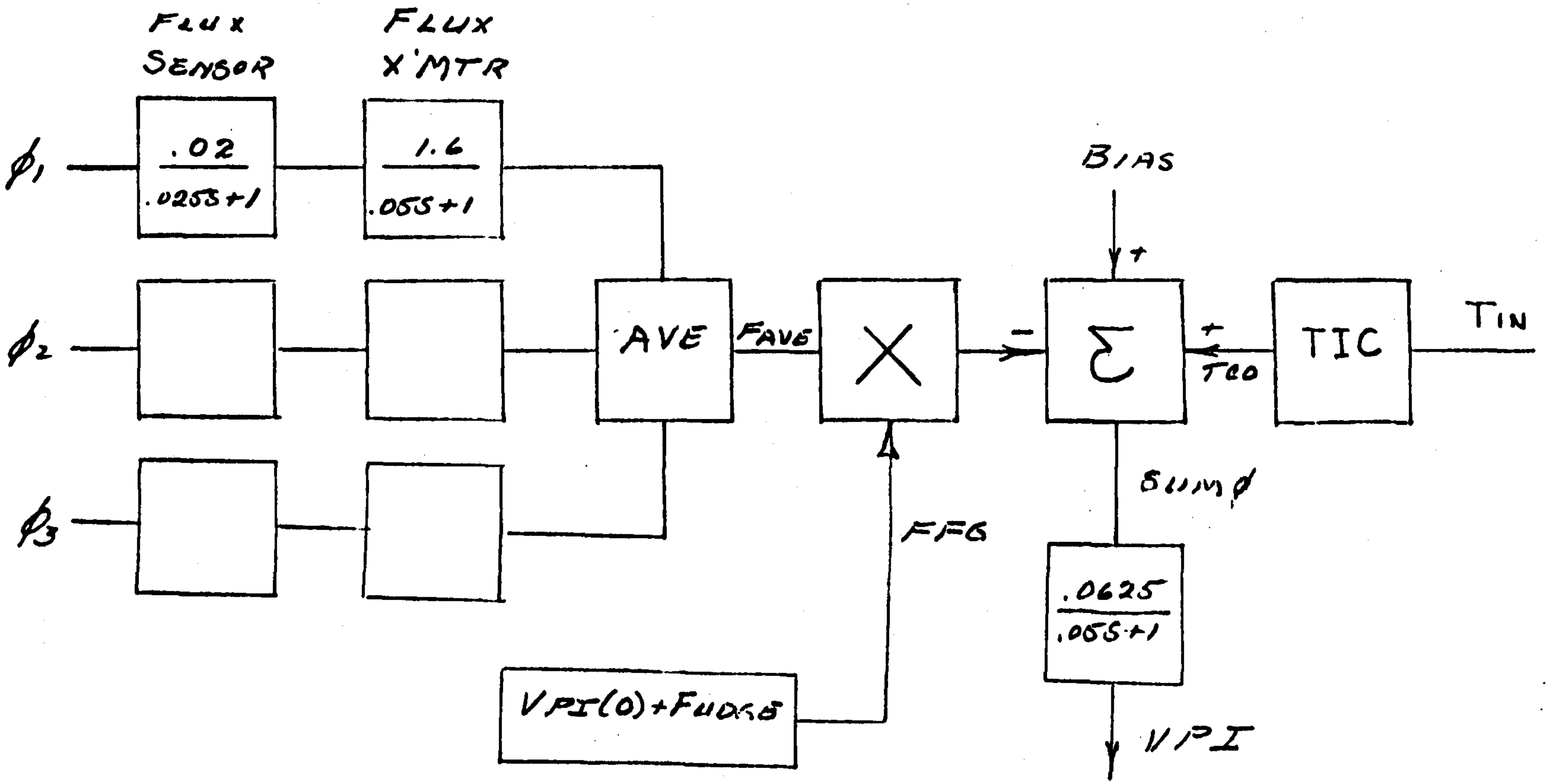
The hydraulic loop (in a closed loop configuration) is powered by an E-M pump which provides flow through the elevated panel and expansion tank, back to grade through an air blast heat exchanger (cooler) and back to the pump.

B. PANEL CONTROL SYSTEM OPERATION

The primary control requirement is that the panel exit sodium temperature be held constant (1100 ± 25°F). As there is a direct relationship between the solar flux available to the panel and the required flow to achieve a given set of operating conditions, solar flux is used as the primary master signal in a feed foreward configuration. Panel exit sodium temperature is then processed through a controller (TIC) and used as a trim to this master. The resulting summed signal is then used to modulate the sodium inlet valve. A diagram of the system is shown in Figure 3.

C. CONTROL SYSTEM REQUIREMENTS

1) Control panel(s) outlet sodium temperature to 1100 ± 25°F at full load
2) Nominal panel inlet temperature: +550°F
   Maximum panel inlet temperature: +700°F



BIAS = 8 + 16 (FUDGE)

SUMϕ = TCO + BIAS − FFG(FAVE)

FIG. 3

3)	Maximum ΔT (inlet to outlet)	+650°F
4)	Minimum ΔT	+200°F
5)	Regulating Range (flow)	+25 to 100%
6)	Maximum ΔT rate	+550°F in 10 sec
7)	Temperature Trip	1200°F

D. SIMULATION MODEL AND ASSUMPTIONS

The panel thermal model essentially consists of four thermal nodes in each panel and an output manifold mixing node (shown in Figure 4). The equations are derived in Appendix L of ESG report 79-2, Vol II, Book 2 "Conceptual Design of Advanced Central Receiver Power Systems". The control system was simulated using the information contained in Figure 1 and standard control algorithms. The hydraulic loop was modeled using calculated friction and inertia losses for the panel and steady state friction losses only for the rest of the loop. Variable transport delays were used to characterize the flow through the panel. The expansion tank, DHX, thermal action of the sodium piping or the pump dynamics were not simulated in this model.

The following assumptions were made:

1) Spatially constant flux distribution. The effects of varying panel flux distributions were not considered.
2) Constant inlet temperature: +550°F
3) Simplified E-M pump model. Only the H-Q curve was modeled.
4) No dump heat exchanger
5) Only panel fluid inertia was modeled
6) Complete loop static friction loss was simulated.

A program listing is provided in Appendix A in this report.

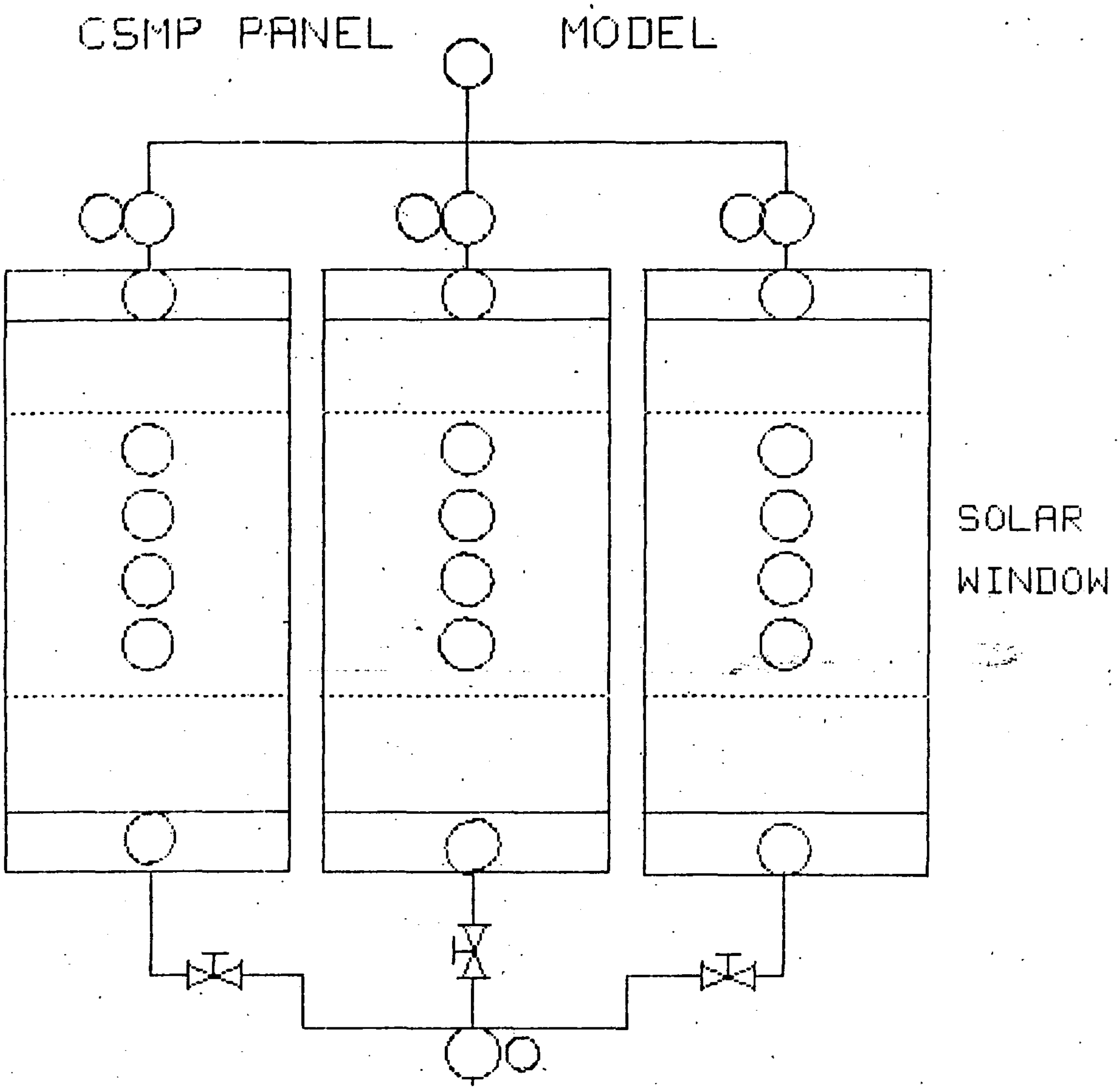


FIGURE 4

E. RESULTS

1. Stability at High and Low Flux

Initial runs were made to evaluate the need for a flux feed forward signal. Flux changes of 10% per second (cloud transient) produced excursions of several hundred degrees so the feed forward system was implemented. Set point and load changes were used to establish acceptable TIC gains; the limiting condition being the low flux, low flow, long transport delay-relationship.

2. Feed Forward Characterization

The feed forward loop was characterized by plotting the steady-state relationship between input flux and sodium valve position. This resulted in a linear curve fit that did not go through zero. Hence the "fudge" term in Figure 3. Additionally, provisions for lead-lag compensation were included.

It should be noted that this characterization of the feed-forward loop only applies to a given system resistance drop and pump pressure (voltage). Significant changes in either will require the generation of a new feed-forward gain. This requirement can be eliminated if individual flow control loops are provided for each subpanel. This would probably be desirable on a commercial plant but were thought not to be required to demonstrate controllability in this test series.

3. Solar Flux Ramps

On the advice of Sandia, these were characterized as linear ramps (up and down) of 10% per second. Figures 5 and 6 show typical results for ramps to 40% flux (where the control remains active) and to 0% (where the valve goes to 25% open limit). In the former it can be seen that the ±25^{O}F control range has not been exceeded. In Figure 6, however, the outlet temperature will decay to inlet temperature with decay to inlet temperature if the cloud transient is long enough. It is likely, at this point, that prescribed course of action will be to defocus

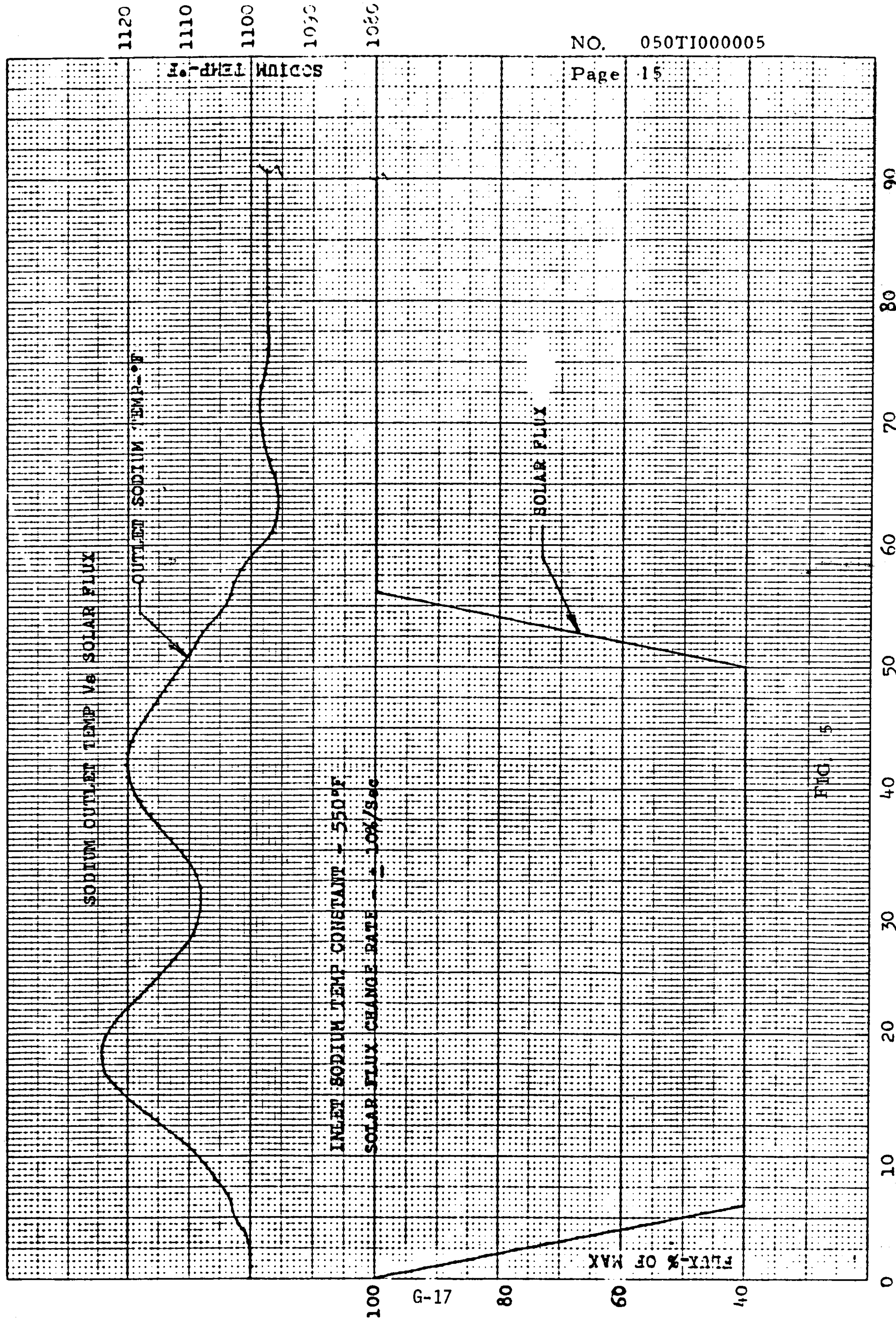

SODIUM OUTLET TEMP VS SOLAR FLUX
SODIUM TEMP-°F
1120
1110
1100
1090
1080
OUTLET SODIUM TEMP-°F
SOLAR FLUX
INLET SODIUM TEMP CONSTANT - 550°F
SOLAR FLUX CHANGE RATE - ± 10%/Sec
FLUX-% OF MAX
100
80
60
40
0
10
20
30
40
50
60
70
80
90

FIG. 5

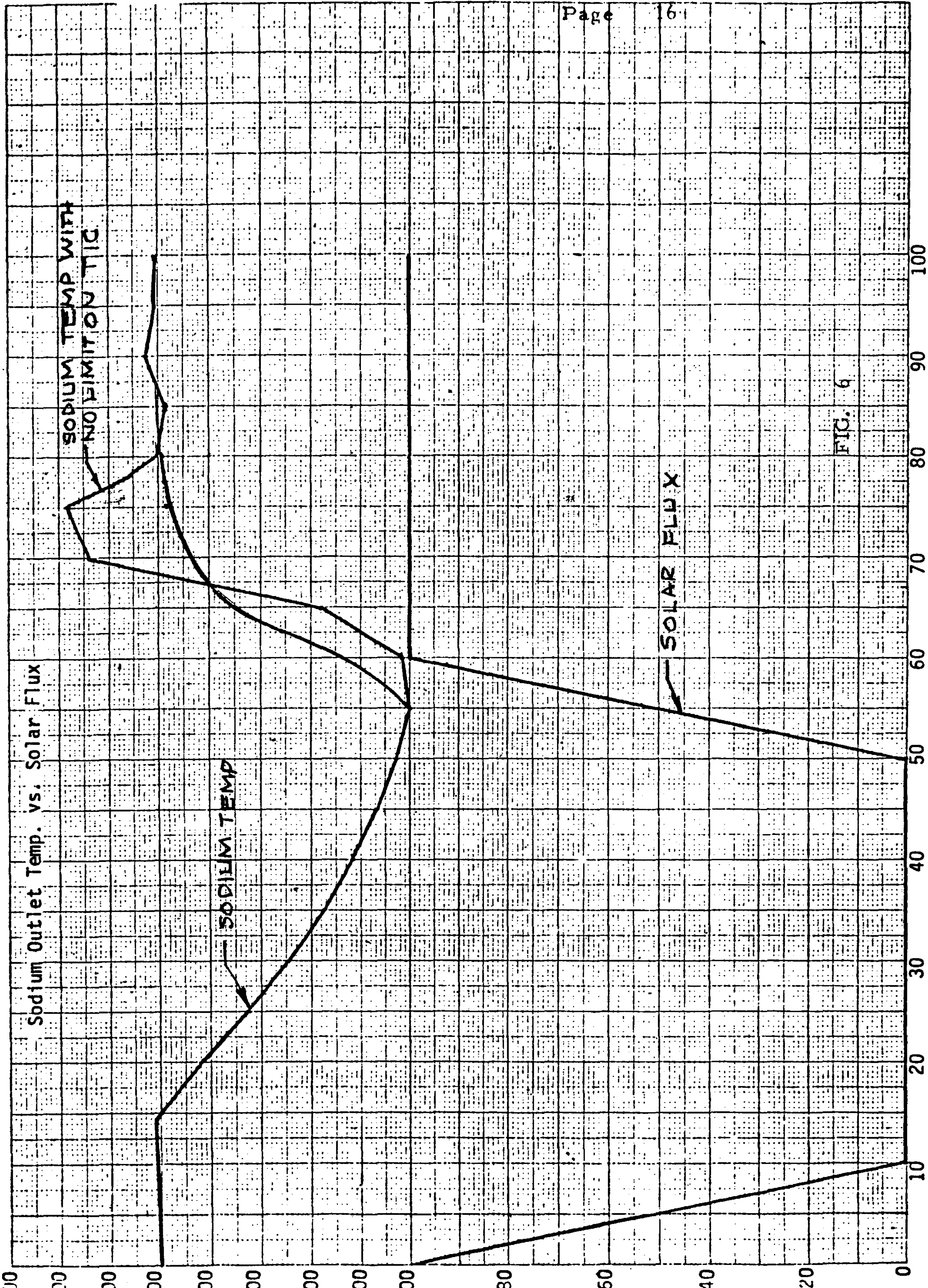

Sodium Outlet Temp. vs. Solar Flux
SODIUM TEMP WITH NO LIMIT ON T/C
SODIUM TEMP
SOLAR FLUX
TIME (sec.)
0
10
20
30
40
50
60
70
80
90
100
00
20
00
00
00
00
00
00
00
80
60
40
20
0

FIG. 6

the mirrors until flux is against established and slowly refocus with the control on manual. An alternate approach would be to incorporate a TIC closed valve position stop which would result in the undamped response shown in Figure 6.

4. Loss of Flow and Heliostat Scram

This transient was simulated by stepping the pump discharge pressure to zero (no pump dynamics) followed by a defocusing of the mirrors 2 sec later. The defocusing was assumed to have a time constant of 0.5 sec (see Figure 7).

The result of this transient was a rapid drop in sodium flow which accounts for the initial rise in the wall temperature to 1243°F. However the rapid defocusing results in the turnaround at 4 sec. The sodium flow is essentially stagnant 2 sec into the transient and the sodium outlet temperature remains constant.

5. Loss of One Flux Sensor

This transient simulated the loss of one of the three feed-foreward loop flux sensors. A peak wall temperature of 1235°F resulted and was considered to be within acceptable limits. See Figure 8. Loss of two sensors results in wall temperatures of 1440°F and is not acceptable.

6. Inlet Temperature Ramps

This transient was simulated by imposing a -2°F per second inlet sodium ramp followed by a (+) per second ramp, each for 15 sec. This resulted in only a -8°F excursion in outlet sodium temperature. See Figure 9.

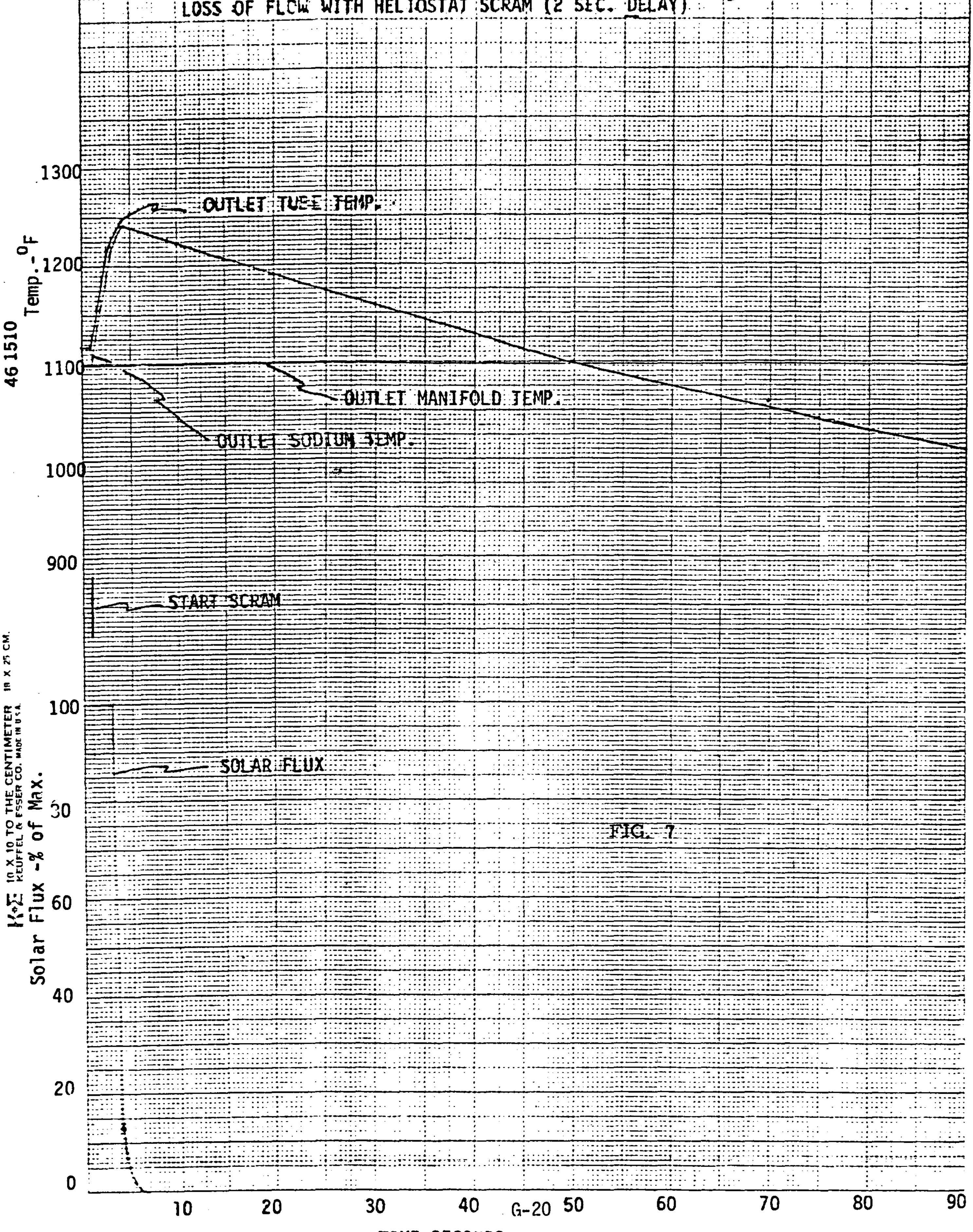

LOSS OF FLOW WITH HELIOSTAT SCRAM (2 SEC. DELAY)
Temp.-°F
1300
1200
1100
1000
900
OUTLET TUBE TEMP.
OUTLET MANIFOLD TEMP.
OUTLET SODIUM TEMP.
START SCRAM
Solar Flux -% of Max.
100
80
60
40
20
0
SOLAR FLUX
10
20
30
40
50
60
70
80
90
46 1510
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM. KEUFFEL & ESSER CO. MADE IN U.S.A.

FIG. 7

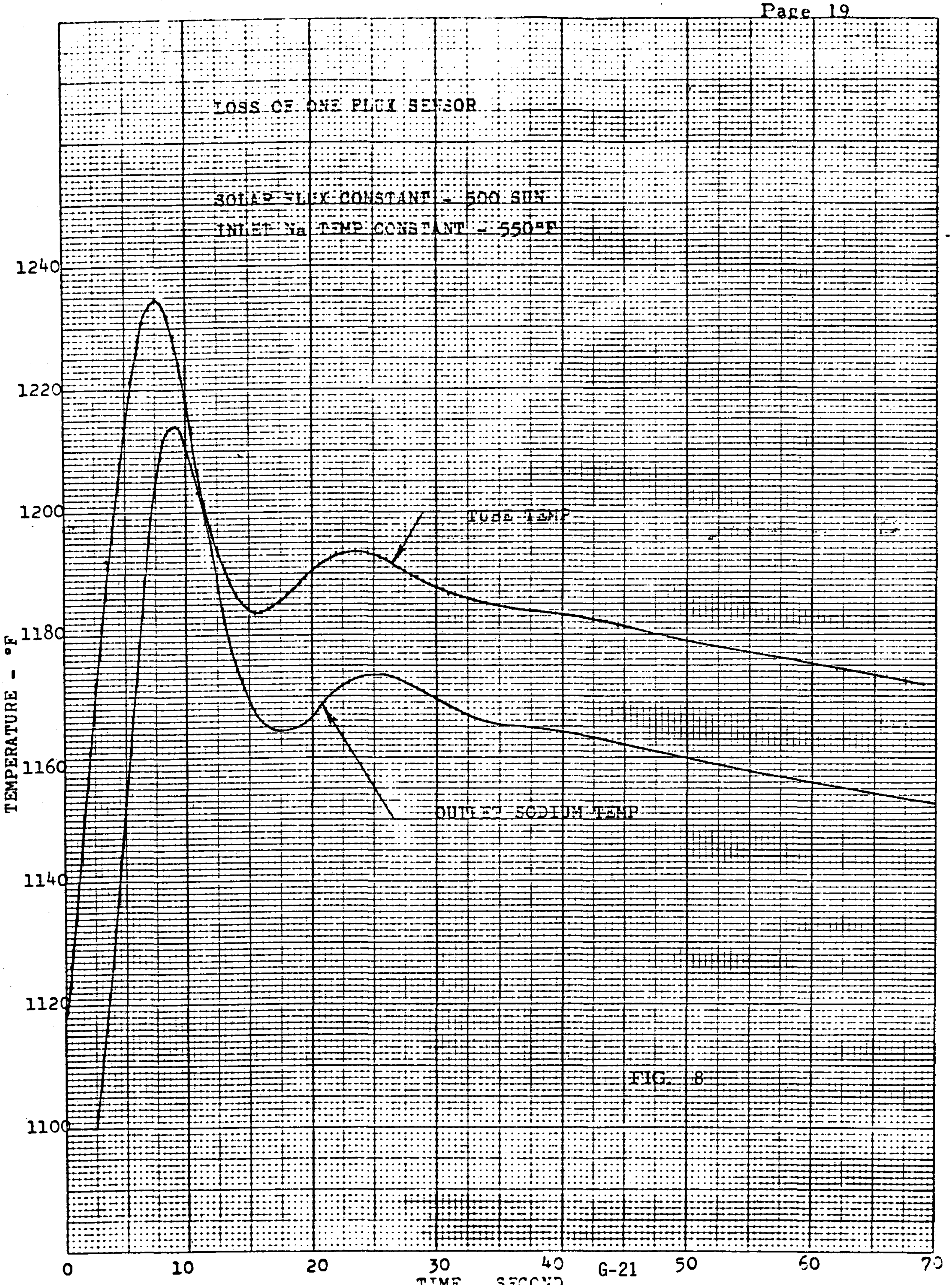
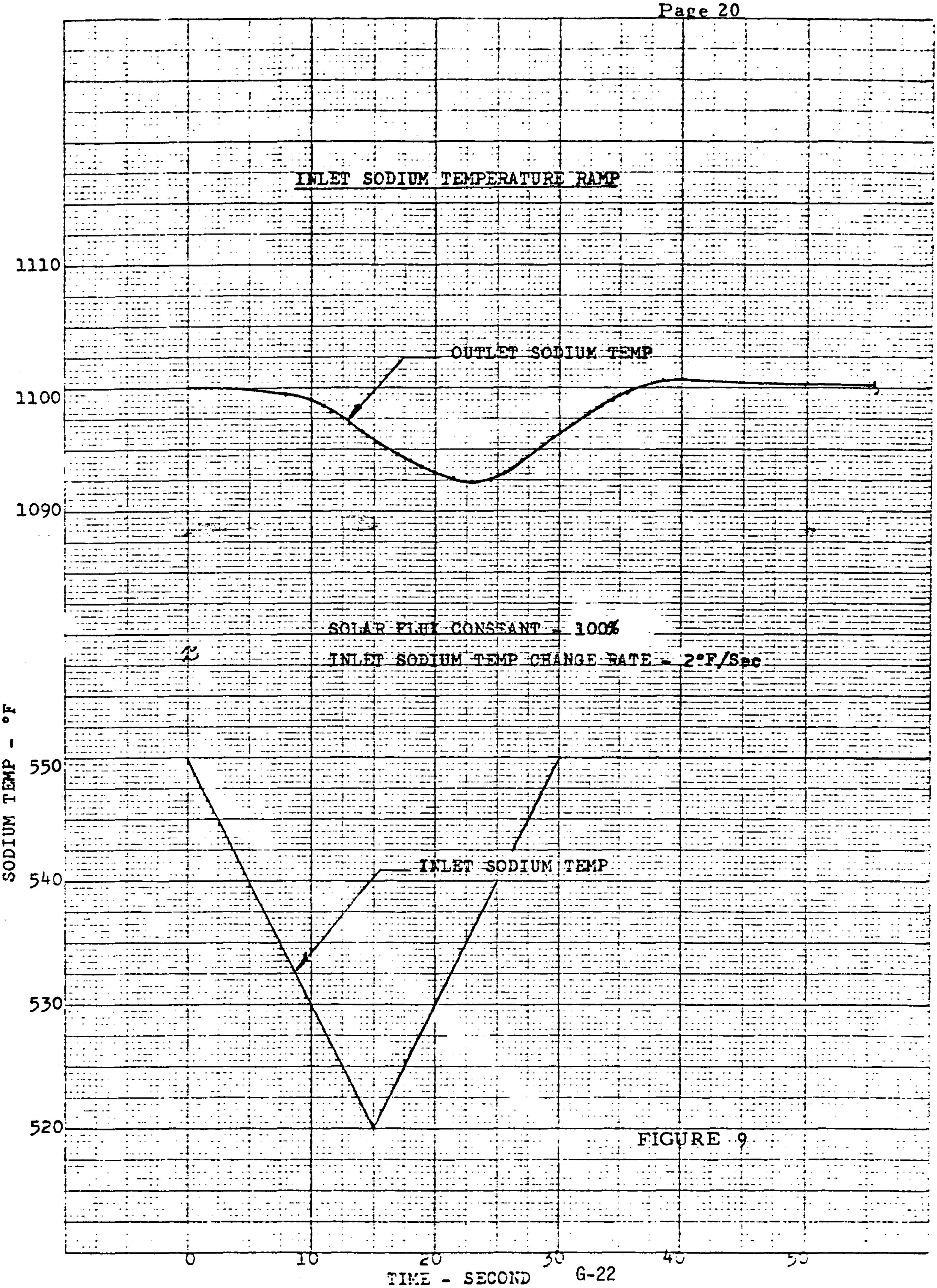

LOSS OF ONE FLUX SENSOR
SOLAR FLUX CONSTANT - 500 SUN
INLET Na TEMP CONSTANT - 550°F
TUBE TEMP
OUTLET SODIUM TEMP
TEMPERATURE - °F
1240
1220
1200
1180
1160
1140
1120
1100
0
10
20
30
40
50
60
70
TIME - SECOND

FIG. 8



INLET SODIUM TEMPERATURE RAMP

SOLAR FLUX CONSTANT - 100%

INLET SODIUM TEMP CHANGE RATE - 2°F/Sec

FIGURE 9

APPENDIX A

SODIUM RECEIVER PANEL PROGRAM LISTING

```
0004 IS ON CR00020 USING 00070 BLKS; R=0180

,L
   PROGRAM CSMPD(3,99),SOLAR PANEL CONTROL SYSTEM SIMULATION.
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
                                                                     C
   THIS PROGRAM SIMULATES THE SOLAR PANEL CONTROL SYSTEM.            C
                                                                     C
   INTEGRATION METHODS AVAILABLE:                                    C
      METHOD=1 -- EULER INTEGRATION                                  C
      METHOD=2 -- TRAPIZOIDAL INTEGRATION                            C
      METHOD=3 -- ADAMS-MOULTON INTEGRATION                          C
                                                                     C
   FUNCTIONS AVAILABLE:                                              C
                    INTGL(INITIAL VALUE,DERIVATIVE)                  C
                    REALP(INITIAL VALUE,TIME CONSTANT,INPUT)         C
                    STEP(TIME OF OCCURANCE)                          C
                    INSW(COIL VARIABLE,INPUT 1,INPUT 2)              C
                    LIMIT(LOWER,UPPER,INPUT)                         C
                    AFGEN(FUNCTION,INPUT,# OF POINTS)                C
                    NAND(INPUT 1,INPUT 2)-REAL NOT AND               C
                    FIOR(INPUT 1,INPUT 2)-REAL INCLUSIVE OR          C
                    DERIV(INITIAL VALUE,VARIABLE)                    C
                    DELAY(# OF INCREMENTS,DELAY TIME,VARIABLE)       C
                    RUNAV(# OF INCREMENTS,AVG TIME,VARIABLE)         C
                    PSHLD(SAMPLE PERIOD,VARIABLE)                    C
                    PLOT1(V1,V2,V3,V4,V5)                            C
                                                                     C
   THE LIMITS ON THE FUNCTION UTILIZATIONS ARE:                      C
   1)INTGL + REALP = 100 PER SIMULATION                              C
   2)STEP,LIMIT, AND AFGEN = NO LIMIT PER SIMULATION                 C
   3)INSW = 25 PER SIMULATION                                        C
   4)NAND = 25 PER SIMULATION                                        C
   5)FIOR = 25 PER SIMULATION                                        C
   6)DERIV = 20 PER SIMULATION                                       C
   7)DELAY + RUNAV = 10 PER SIMULATION                               C
                     3 <= # OF INCREMENTS <= 100                     C
   8)PSHLD =10 PER SIMULATION                                        C
   9)PLOT = 1001 POINTS PER PLOT                                     C
            5 PLOTS PER GRAPH                                        C
            10 GRAPHS PER SIMULATION                                 C
                                                                     C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
**********************************************************************
                                                                     *
   CSMP COMMON.                                                      *
                                                                     *
   COMMON /CSMP0/ TIME,DELT,FINTIM,PRDEL,ACC,METHOD,CSMPR(800)       *
   REAL INSW,LIMIT,NAND,INTGL                                        *
   DOUBLE PRECISION NAME0(5),NAME1(5),NAME2(5),NAME3(5),NAME4(5)     *
   DOUBLE PRECISION NAME5(5),NAME6(5),NAME7(5),NAME8(5),NAME9(5)     *
   DOUBLE PRECISION TITLE(20)
**********************************************************************
----------------------------------------------------------------------
   USER VARIABLES.

   REAL LBSGPM,DTMAN(3),DTAO(3),TCI(3),TOUT(3),SUMO(3),PSUMO(3),CV(3)
   REAL XCV(26),HANR(3,4),TUP(3,4),TNRO(3),TIN(3),ETAO(3)
   REAL KFH(3),PLOGA(3),TNR(3,4),QI(3,4),QA(3,4),CP(3,4)
   REAL TRW(3,4),KFHC(3),IR(3),RHO(3,4),VPI(3),WNR(3),DTRW(3,4)
```

```
      REAL DTNR(3,4),DWNR(3),WNRA(3),FH(3),DPCV(3),QIT(3),QAT(3)
      REAL TC(3),IES(3),ES(3),QD(3,4),QAI(3),TMAN(3),TCD(3),TCO(3)
      REAL FFG(3),QDO(3,4),TAUD1(3),FUDGE(3),BIAS(3),FFTEMP(3)
      REAL VALVE0(3)
C-----------------------------------------------------------------------
C     USER DATA FUNCTIONS.
C
C     DATA -- DATA POINTS FOR FUNCTION GENERATION,
      DATA XCV/-1.,30.,0.0,30.,0.1,28.9,0.2,24.8,0.3,14.9,0.4,8.6,
     1  0.5,5.7,0.6,4.4,0.7,2.4,0.8,1.6,0.9,1.0,1.0,0.1,2.0,0.1/
C     DATA SUN0/125.0/,WNRR/1.1200/
C     DATA TNR/3*695.17,3*836.47,3*971.92,3*1100.00/
C     DATA SUN0/200.0/,WNRR/1.8685/
C     DATA TNR/3*693.00,3*834.00,3*970.00,3*1100.00/
C     DATA SUN0/300.0/,WNRR/2.8663/
C     DATA TNR/3*688.50,3*827.50,3*965.00,3*1100.00/
C     DATA SUN0/400.0/,WNRR/3.8398/
C     DATA TNR/3*687.88,3*826.13,3*963.69,3*1100.0/
      DATA SUN0/500.0/,WNRR/4.8623/
      DATA TNR/3*687.53,3*825.70,3*963.55,3*1100.00/
      DATA TMAN/3*1100.00/
      DATA TC/3*1100.00/
      DATA WNR/3*1.0000/
      DATA VALVE0/.62575,.62394,.62575/
      DATA FUDGE/3*-0.05500/
      DEN(T)=59.566-(7.9504E-3+(2.872E-7-6.035E-11*T)*T)*T
C     NAMES OF VARIABLES TO BE PLOTTED.
      DATA NAME0/6HSUN-1 ,6HT WALL,6HT NA  ,6HFLOW  ,6HVALVE /
      DATA NAME1/6HSUN-2 ,6HT WALL,6HT NA  ,6HFLOW  ,6HVALVE /
      DATA NAME2/6H      ,6H      ,6H      ,6H      ,6H      /
      DATA NAME3/6H      ,6H      ,6H      ,6H      ,6H      /
      DATA NAME4/6H      ,6H      ,6H      ,6H      ,6H      /
      DATA NAME5/6H      ,6H      ,6H      ,6H      ,6H      /
      DATA NAME6/6H      ,6H      ,6H      ,6H      ,6H      /
      DATA NAME7/6H      ,6H      ,6H      ,6H      ,6H      /
      DATA NAME8/6H      ,6H      ,6H      ,6H      ,6H      /
      DATA NAME9/6H      ,6H      ,6H      ,6H      ,6H      /
      DATA TITLE/6H      ,6H      ,6H      ,6H      ,6H      ,
     *            6H      ,6H      ,6H      ,6H      ,6H      ,
     *            6H      ,6H      ,6H      ,6H      ,6H      ,
     *            6H      ,6H      ,6H      ,6H      ,6H      /
C-----------------------------------------------------------------------
C     USER CONSTANTS.
C
      TIME=0.0
      FINTIM=100.0
      DELT=0.010
      PRDEL=0.5
      ACC=0.0001
      METHOD=2
C     PUT IN THE REST OF YOUR CONSTANTS HERE
      TAU500=4.8623*1.5
      TI=550.0
      HFA=5.56E-4
      TA=60.0
      ASRA=1.4598E-12
      TG=(TA+460.0)**4
      TS=TG
      ALPHA=0.95
      WCPTW=2.51
```

```
      DTUBE=0.05208
      CBTUS=948.06
      ALCBTU=ALPHA*CBTUS
      VOL=0.1198
      VOLIH=2.304
      VOLOH=1.334
      AFLO=0.0478
      ENRI=9.84
      ERIT=17.23
      RNL=2.46
      ENRO=34.13
      ENR4=27.07
      SINFT=144.0
      LBSGPM=7.1928
      ELRST=37.8
      TASP=1100.0
      TNRV=TI
      TNRM=TI
      TNRI=TI
      AREEF=0.9
      KFH=1.4/4.84**2
      KFH(2)=1.1/4.84**2
      KFH(3)=1.4/4.84**2
      HART=8.453
      PLOGA=0.145
      PLOGA(2)=0.18
      PLOGA(3)=0.145
      TAUTC=0.28
      CPM=0.3
      RHOI=DEN(TI)
      SPG=RHOI/62.4
      PSOH=30.5
      QTMAX=300.0
      QTMAX2=1.0/(QTMAX*QTMAX)
      FLOK=24.0/(175.0*175.0)
      QT=3.0*WNRR*448.8/RHOI
      QT2=QT*QT
      PORI=PSOH*(1.0-QT2*QTMAX2)-FLOK*QT2
      DO 300 I=1,3
      IR(I)=PLOGA(I)*WNRR
      QTI=WNRR*LBSGPM/SPG
      DPCV(I)=PORI-KFH(I)*WNRR*WNRR
      CV(I)=QTI*SQRT(SPG/DPCV(I))
      J=11
100   IF(XCV(J+1).LT.CV(I)) GO TO 200
      J=J-2
      IF(J.GT.1) GO TO 100
200   VPI(I)=XCV(J-2)+(CV(I)-XCV(J-1))*(XCV(J)-XCV(J-2))/(XCV(J+1)-
     1   XCV(J-1))
      DO 300 J=1,4
      QDO(I,J)=2.5/12.0/AREEF*SUNO/500.0
      QI(I,J)=QDO(I,J)*CBTUS*AREEF
      QAI(I)=QAI(I)+QI(I,J)*ALPHA
300   CONTINUE
      DAF=DTUBE/AFLO
      AD=HART/DTUBE
      DO 400 I=1,3
      DO 400 J=1,4
      CALL SODEQ(DAF,AD,WNRR,TNR(I,J),CP(I,J),HANR(I,J))
      TRW(I,J)=TNR(I,J)+QI(I,J)/HANR(I,J)
```

```
      QCR=HFA*AR*(TRW(I,J)-TA)
      TRW4=(TRW(I,J)+460.0)**4
      QR=ASRA*(TRW4-TG)
      QA(I,J)=QI(I,J)*ALPHA-QR-QCR
      QAI(I)=QAI(I)+QA(I,J)
400   CONTINUE
      SNAR=DEN(TNRV)
      SPG=SNAR/62.4
      SNAR44=448.8/SNAR
      TPK=2.0
      TIK=0.01
      TDK=0.0
      TLL=0.0
      TUL=12.0
      DO 410 I=1,3
      BIAS(I)=8.0+16.0*FUDGE(I)
410   FFG(I)=VALVEO(I)+FUDGE(I)
      P1=1000.0
      P2=P1/10.0
      CONTG=1.0
      TILL=TLL+0.01
      TIUL=TUL-0.01
      TCIO=8.0
C-----------------------------------------------------------------------
C***********************************************************************
C                                                                      *
C     CSMP PROGRAM COMMANDS.                                           *
C                                                                      *
9901  ICSMP1=-1                                                        *
9902  CALL CSMP1(ICSMP1,ICSMP2)                                        *
9903  CONTINUE                                                         *
C***********************************************************************
C-----------------------------------------------------------------------
C     DYNAMIC SECTION OF USER PROGRAM.
C
      RAMP=(STEP(0.0)-STEP(10.0)-STEP(50.0)+STEP(60.0))/10.0
      SUN=SUN0*LIMIT(0.0,1.0,1.0-INTGL(0.0,RAMP))
C     SUN=SUN0*(1.0-0.1*STEP(10.0))
C     CLOUD=STEP(1.0)-STEP(51.0)
C     SUN=SUN0*(1.0-REALP(0.0,10.0,CLOUD))
C     PSOH=30.5*(1.0-STEP(1.0))
C     SUN=SUN0*(1.0-REALP(0.0,0.50,STEP(3.0)))
C     SUN=SUN0
C     TTTTT=DELAY(20,2.00,TIN(2))
C     IF(SCRAM.GT.0.5) SCRAM=INSW(TTTTT-1225.0,1.0,0.0)
C     SUN=SUN0*SCRAM
      RSUN=SUN/SUN0
      Q1=0.02*REALP(SUN,0.025,SUN)
      FAVE=1.6*REALP(Q1,0.05,Q1)
      DO 500 I=1,2
      DO 500 J=1,4
      RHO(I,J)=DEN(TNR(I,J))
      TRW4=(TRW(I,J)+460.0)**4
      QL=HFA*(TRW(I,J)-TA)+ASRA*(TRW4-TG)
      QD(I,J)=QD0(I,J)*RSUN
      QA(I,J)=QD(I,J)*ALCBTU-QL
500   CONTINUE
C     DTNRV=-2.0*(1.0-2.0*STEP(15.0)+STEP(30.0))
C     TNRV=INTGL(TNRV,DTNRV)
C     TAUD0=TAU500/(WNRA+0.001)
```

```
C     TNRM=DELAY(20,TAUD0,TNRV)
      QT=(2.0*WNR+WNR(2))*WNRR*SNAR44
      QT2=QT*QT
      PFLO=PSOH*(1.0-QT2*QTMAX2)-FLOK*QT2
      DTNRI=WNR(1)*WNRR*(TNRM-TNRI)/VOL/RHO(1,1)/CP(1,1)
4     TNRI=INTGL(TNRI,DTNRI)
      DO 800 I=1,2
      WNRA(I)=WNR(I)*WNRR
      TUP(I,1)=TNRI
      DO 700 J=1,4
      IF(J.LT.2) GO TO 600
      TUP(I,J)=TNR(I,J-1)
600   DTNR(I,J)=WNRA(I)*CP(I,J)*(TUP(I,J)-TNR(I,J))+HANR(I,J)*
     1  (TRW(I,J)-TNR(I,J))
5     TNR(I,J)=INTGL(TNR(I,J),DTNR(I,J))
      CALL SODEQ(DAF,AD,WNRA(I),TNR(I,J),CP(I,J),HANR(I,J))
      DTRW(I,J)=(QA(I,J)-HANR(I,J)*(TRW(I,J)-TNR(I,J)))/WCPTW
6     TRW(I,J)=INTGL(TRW(I,J),DTRW(I,J))
700   CONTINUE
C     TEMP FEED FOWARD COMPUTATION
C     FFTEMP(I)=(TRW(I,2)+TRW(I,3))/2.0
C     FAVE1=(2.0*FFTEMP(1)+FFTEMP(2))/3.0*0.016
C     F1=REALP(FAVE1,P2,FAVE1)
C     F2=P1*DERIV(0.0,F1)
C     FAVE=F1+F2
      TAUD1(I)=TAU500/(WNRA(I)+0.001)
      TNRO(I)=DELAY(20,TAUD1(I),TNR(I,4))
      DTMAN(I)=WNRA(I)*(TNRO(I)-TMAN(I))/VOL/RHO(I,4)/CP(I,4)
13    TMAN(I)=INTGL(TMAN(I),DTMAN(I))
14    TC(I)=REALP(TMAN(I),TAUTC,TMAN(I))
      TIN(I)=PSHLD(0.5,TC(I))
      ETAO(I)=(TASP-TIN(I))/75.0
      DTAO(I)=TIK*ETAO(I)*FIOR(ETAO(I),TCO(I)-TILL)*FIOR(-ETAO(I),
     1  TIUL-TCO(I))*TPK
15    TCI(I)=INTGL(TCI0,DTAO(I))
      TCD(I)=DERIV(0.0,ETAO(I))
      TCO(I)=TPK*(ETAO(I)+TDK*TCD(I))+TCI(I)
      TOUT(I)=LIMIT(TLL,TUL,TCO(I))
      SUMO(I)=-FFG(I)*FAVE+CONTG*(TOUT(I)+BIAS(I))
      PSUMO(I)=LIMIT(0.00,0.75,SUMO(I)/16.0)
16    VPI(I)=REALP(VPI(I),0.05,PSUMO(I))
      CV(I)=AFGEN(XCV,VPI(I),13)
      XQT=WNRA(I)*SNAR44
      DPCV(I)=XQT*ABS(XQT)*SPG/(CV(I)*CV(I))
      DWNR(I)=(PFLO-KFH(I)*WNRA(I)*WNRA(I)-DPCV(I))/IR(I)
17    WNR(I)=INTGL(WNR(I),DWNR(I))
800   CONTINUE
C-----------------------------------------------------------------------
C***********************************************************************
C                                                                      *
C     CSMP PROGRAM COMMANDS.                                           *
C                                                                      *
9904  ICSMP1=0                                                         *
9905  CALL CSMP1(ICSMP1,ICSMP2)                                        *
9906  IF(ICSMP2) 9903,9907,9911                                        *
9907  CONTINUE                                                         *
C***********************************************************************
C-----------------------------------------------------------------------
C     WRITE DATA FOR THIS TIME PERIOD.
C
```

```
D      IF(TIME.GE.FINTIM) GO TO 1000
       IF(ISSW(14).LT.0) GO TO 1002
D1000 WRITE(6,1001) TIME,TNRO,TNR,DTMAN,TMAN,TC,TIN,ETAO,DTAO,TCI,TCD,
D     1 TCO,TOUT,SUMO,PSUMO,VPI,CV,DPCV,DWNR,WNR,IR,TRW,TAUD1,HANR,WNRA,
D     2 SUN,QT,PFLO
D1001 FORMAT(" VARIABLE              VALUE"/" TIME    =",G20.5/
D     *        " TNRO    =",G20.5,"         =",G20.5,"         =",G20.5/
D     *        " TNR(1) =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " TNR(2) =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " TNR(3) =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " TNR(4) =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " DTMAN  =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " TMAN   =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " TC     =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " TIN    =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " ETAO   =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " DTAO   =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " TCI    =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " TCD    =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " TCO    =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " TOUT   =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " SUMO   =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " PSUMO  =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " VPI    =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " CV     =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " DPCV   =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " DWNR   =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " WNR    =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " IR     =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " TRW(1) =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " TRW(2) =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " TRW(3) =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " TRW(4) =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " TAUD1  =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " HANR(1)=",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " HANR(2)=",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " HANR(3)=",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " HANR(4)=",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " WNRA   =",G20.5,"          =",G20.5,"         =",G20.5/
D     *        " SUN    =",G20.5," QT       =",G20.5," PFLO    =",G20.5)
1002  CONTINUE
C----------------------------------------------------------------------
C      USER PLOTS OF VARIABLES.
C
       CALL PLOT1(TNR(1,4),TRW(1,4),TMAN(1),WNRA(1),VPI(1))
       CALL PLOT1(TNR(2,4),TRW(2,4),TMAN(2),WNRA(2),VPI(2))
C----------------------------------------------------------------------
C**********************************************************************
C                                                                     *
C      CSMP PROGRAM COMMANDS.                                         *
C                                                                     *
9908  ICSMP1=1                                                        *
9909  CALL CSMP1(ICSMP1,ICSMP2)                                       *
9910  IF(ICSMP2) 9903,9907,9911                                       *
9911  CONTINUE                                                        *
C----------------------------------------------------------------------
C      USER PLOTS OF VARIABLES.
C
       END
C
```

```
C
C
C
      SUBROUTINE SODEQ(DAF,AD,WDOT,T,CP,HA)
      TKNA=(54.306-(0.01878-2.0914E-6*T)*T)/3600.0
      CP=0.34574-(7.9226E-5-3.4086E-8*T)*T
      HA=(5.0+0.025*(WDOT*DAF*CP/TKNA)**0.8)*TKNA*AD
      RETURN
      END
      END$
```

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