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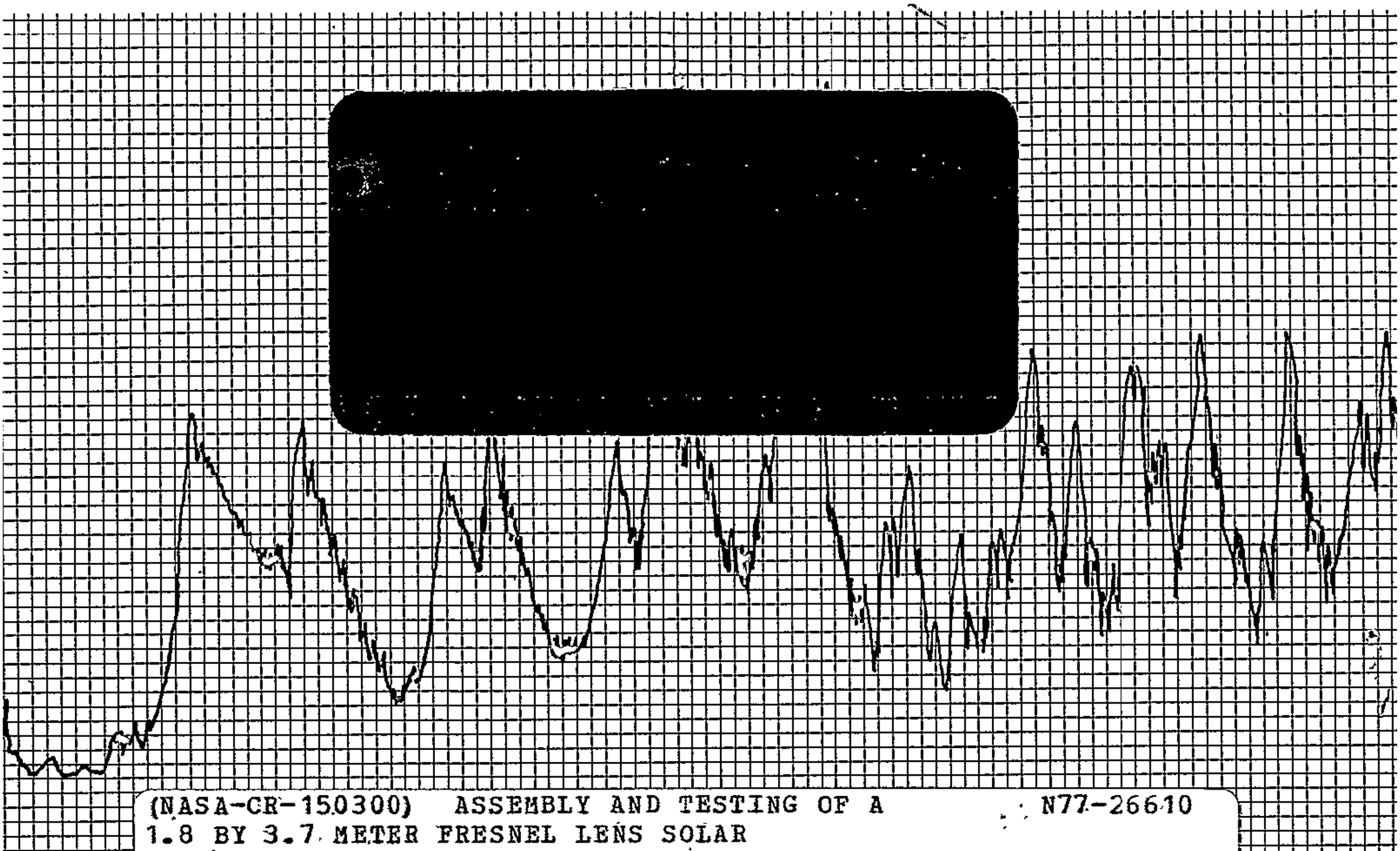

(NASA-CR-150300) ASSEMBLY AND TESTING OF A 1.8 BY 3.7 METER FRESNEL LENS SOLAR CONCENTRATOR Final Report (Wyle Labs., Inc.) 72 p HC A04/MF A01 CSCL 10A
N77-26610
Unclas
G3/44 31777

research REPORT

N77-26610

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TECHNICAL MEMORANDUM TM 77-5

ASSEMBLY AND TESTING OF A 1.8 BY 3.7 METER FRESNEL LENS SOLAR CONCENTRATOR

by

J. E. Robertson

May 1977

A FINAL REPORT

for

National Aeronautics and Space Administration
Marshall Space Flight Center

Work Performed Under Contract No. NAS8-31662

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1.0 INTRODUCTION

1.1 Background

Future energy developments will focus heavily on developing more effective and economical methods of solar energy concentration, collection, conversion and utilization. Basically, two approaches are being taken: First, integrated systems are being developed which can be utilized as self-contained power sources for the heating and cooling of individual single family, multiple family and commercial buildings. Second, limited but equally important work is being performed to develop solar power plants which provide for the conversion of heat to electricity for distribution through a network of substations similar to present fossil fuel and nuclear plants. Of these two basic approaches, the present program is related primarily to the development of a solar power plant which would supplement, and perhaps evenutally replace, conventional electric power plant facilities.

Under Contract NAS8-31662, with the Marshall Space Flight Center (MSFC), Wyle Laboratories participated in the design, fabrication, assembly and testing of a solar power collection subsystem. The overall program objectives established by MSFC, and the role of Wyle in this program, are discussed in the following subsections.

1.2 Overall Program Objectives

Activities at and sponsored by MSFC have been in progress to establish a technical data base on line-focusing acrylic Fresnel lens that can generate temperatures in the range of 200° to 370°C. Initial goals of the MSFC concentrator effort were directed toward electrical power generation in the 100 to 10,000 kWe range with the distributed collector approach (ref. 1). However, as the program progressed, it became less system oriented and centered on the development of a concentrator/collector subsystem concept that could meet the general application requirement of thermal energy delivery within the 200° to 370°C range. The specific objective and application of results for the present program were:

1. Establishment of technical data base on line-focusing Fresnel lens with application in the 200°C to 370°C range

2. Applications include: commercial heating/cooling, industrial process heat, electrical power generation

1.3 Wyle Objectives/Role

Under Contract NAS8-31662 with MSFC, Wyle Laboratories was responsible for the following elements of work leading to an operational solar power collector subsystem:

1. Assembly of major subassemblies

2. Design and installation of fluid loop, controls and instrumentation

3. Functional checkout

4. Establishment of operational procedures

5. Formulate hardware modification recommendations

6. Documentation.

The objectives of the testing of the solar power collector subsystem was the collection of experimental data for the evaluation of:

1. The optical characteristics of the lens assembly

2. The tracking system performance

3. The absorber assembly performance

4. The thermal fluid performance

5. The overall system performance as a function of:

   a. Tracking accuracy
   b. Lens focus accuracy
   c. Fluid flow conditions:
      1) Flow rate
      2) Inlet temperature

The first two items above were determined from a shake-down calibration prior to commencing system tests with the thermal fluid loop activated.

The optical characteristics of the lens assembly of interest were governed by the optical transmissibility of the lens and the focal zone definition of the lens assembly. To gain a measure of these characteristics, the isolation concentration ratio profile produced by the lens assembly was measured, by MSFC technical personnel, at the window of the collector tube reflector. This gave a direct measure of the transmission and focusing characteristics of the lens assembly.

The tracking characteristics of the collector subsystem was measured by observing the relative orientation of the lens frame to the line of site of the sun throughout a typical test period. These data defined the tracking accuracy as a function of time of day.

Following the shake-down calibration, system tests with the thermal fluid loop activated were conducted for assessing individual components as well as the integrated system performance characteristics. Following this assessment, MSFC personnel operated the subsystem to acquire experimental data which provide practical hardware design experience and supportive data for verification of MSFC analytical models and the required technology base for refining system requirements. These test results are presented in reference 1.

2.0 TEST ARTICLE DESCRIPTION

2.1 General Description

The integrated Fresnel Lens Solar Power Collection Subsystem is shown in Figures 1 and 2. Major subassemblies consisted of:

1. Fresnel Lens Assembly

2. Test Article Structural and Sun-Tracking Assembly

3. Receiver/Absorber Tube Assembly

4. Fluid Transport Loop Assembly

5. Controls and Instrumentation

The lens' active aperture was 1.83 by 3.66 m (6 x 12 ft) and consisted of an array of 32 individual square panels. The design of the apparatus provided two-axis tracking of the sun. Alignment of the lens to the sun's declination was achieved by manually adjusting the declination angle of the lens assembly. This angle remained constant for a given series of runs and only periodic adjustments were required over several weeks of testing. East-to-west tracking of the sun was achieved by a chain and sprocket drive powered by a synchronous electric motor. A slip-clutch in the tracking drive system provided for repositioning of the lens assembly normal to the sun for commencing tracking and data collection for a given day of testing.

The focused rays from the sun were concentrated along a receiver collection tube assembly located approximately 1.68 m beneath the lens. The receiver assembly consisted of a stainless steel absorber tube mounted in a reflecting trough. The collector tube was an integral part of the fluid loop such that thermal fluid circulated through the fluid loop would be heated by the run's rays as focused by the Fresnel lens and absorbed by the collector tube. The collector tube was fabricated to have a corrugated geometry and coated with an absorptive coating to enhance its thermal performance. The transport fluid was Therminol 66, a single-phase heat transfer medium produced by Monsanto Company. The fluid transport loop consisted of the fluid expansion/storage tank, pump, electric heater, absorber tube, and heat exchanger, plus associated plumbing and controls. The fluid transport loop and test article were appropriately instrumented with thermocouples, temperature sensor, sun alignment devices, flowmeter, etc for setting and maintaining test conditions and the measurement of collector performance data for a range of test conditions. Controllable test parameters consisted of fluid flow rate, receiver inlet temperature, sun tracking accuracy, and position of the receiver/absorber tube assembly relative to the lens' focal line.

The fluid transport loop was insulated with a thermal barrier to minimize heat loss and thus ensure stable test conditions. Also a polyvinyl material was used as an enclosure around the lens frame between the lens bottom surface and the collection tube assembly. The enclosure protected the groved surface of the lens from dust and other contaminants and shielded the collection tube assembly from direct atmospheric exposure, thereby minimizing contamination/degradation and thermal convection losses due to wind.

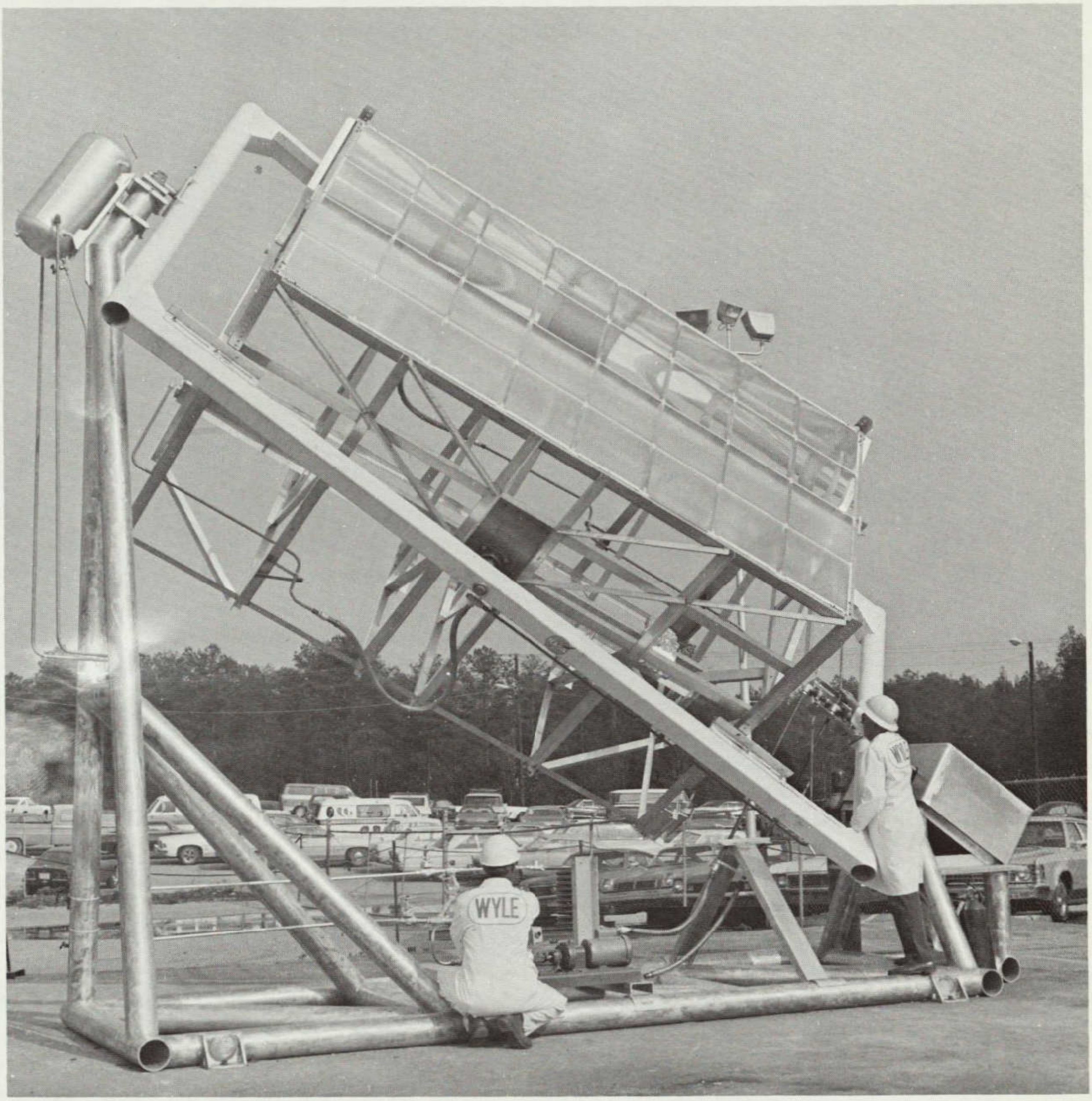


Figure 1. Photograph of Fresnel Lens Test Article

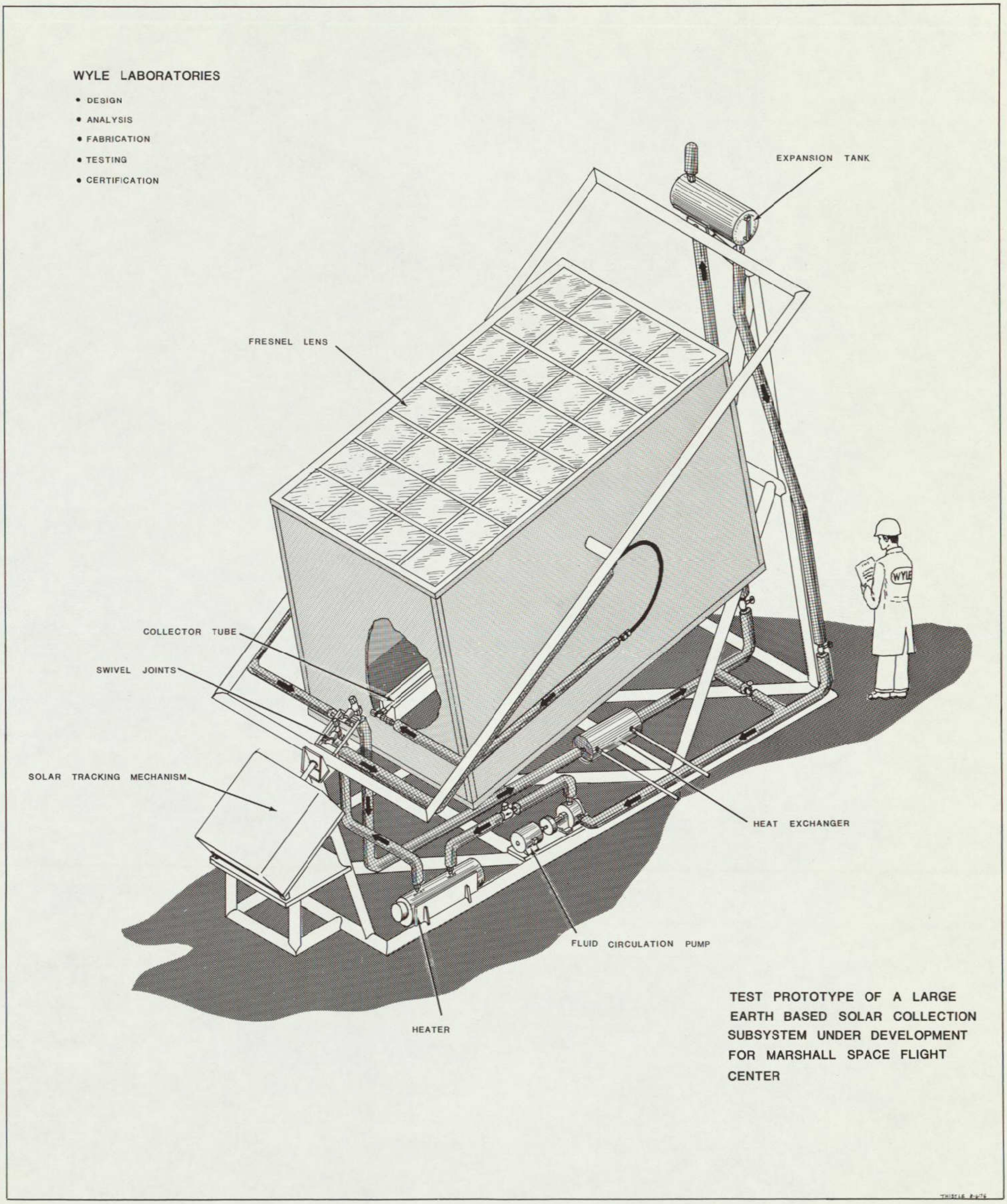


Figure 2. Schematic of Fresnel Lens Test Article

Further descriptions of the test article components and thermal transport fluid are included in the following subsections.

2.2 Component Description

2.2.1 Fresnel Lens

A comprehensive description of the Fresnel lens is presented in reference 1 and summarized herein. The lens was comprised of two basic panel configurations which are identified as inside panels (those adjoining the lens axial centerline) and outside panels. Sixteen of each panel configuration was assembled in an aluminum frame to form the 1.83 x 3.66 m Fresnel lens. Both types of panels had a 45.7 cm (18-inch) square aperture with a 0.0635 cm (1/4-inch) border for mounting purposes. The lens panel geometry and optical characteristics are further defined in Figure 3 and Table I.

2.2.2 Test Article Structural and Sun-Tracking Assembly

Photographs of the solar energy collector at various stages of assembly are shown in Figure 4. The assembly consisted of three major structural components:

1. A-frame base structure

2. Yoke for mating the lens assembly to the base structure

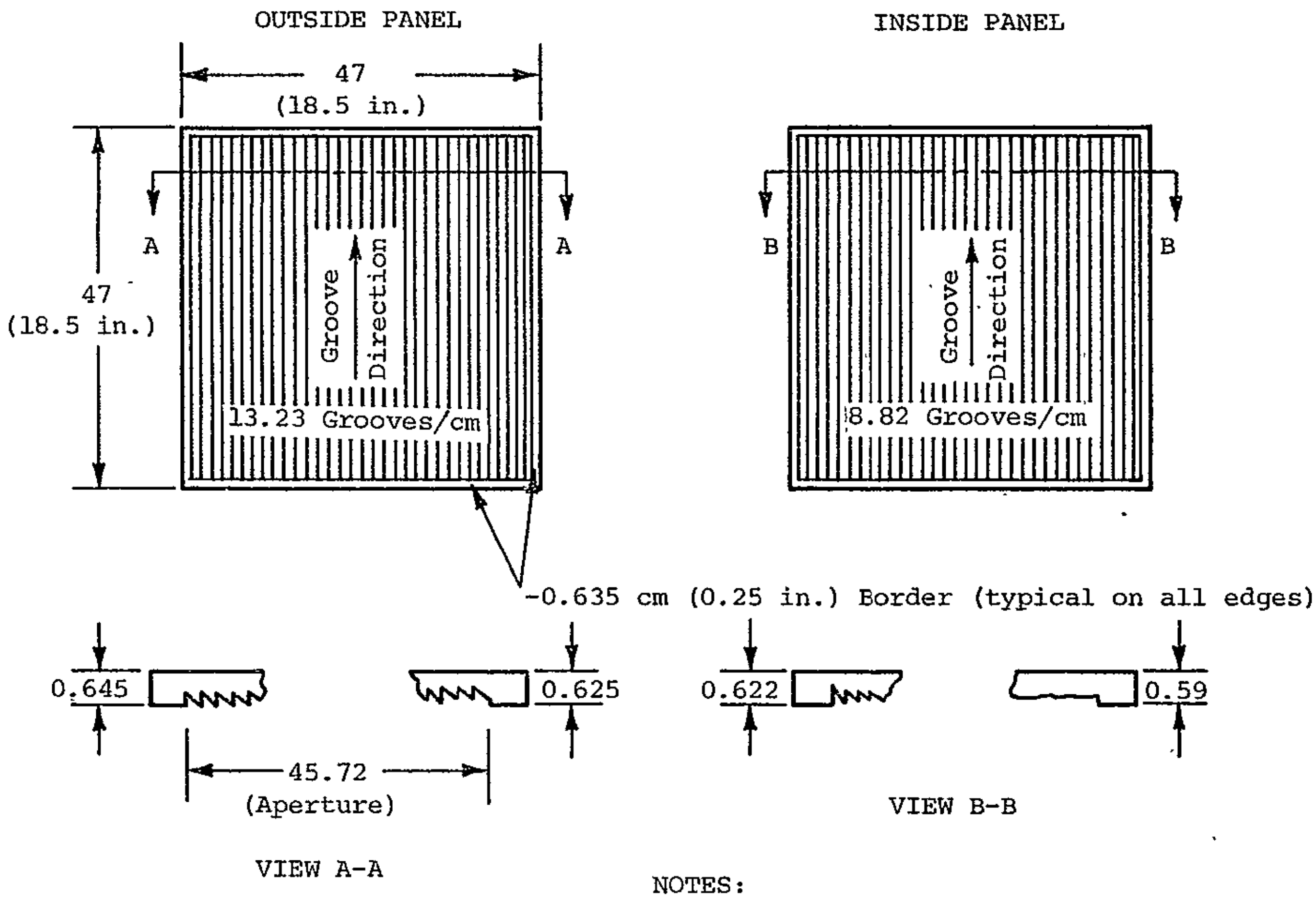
3. Lens assembly

The design of the collector structure provided an integral test system which permitted alignment with the sun. Transverse (E-W) tracking of the sun was accomplished by an electric motor drive system which coupled to the yoke frame through a Dalton clutch (see Figure 4d). Daily alignment of the lens assembly was accomplished by disengaging the clutch and manually rotating the lens assembly yoke about the north-south axis until the position of proper alignment had been located. This position was determined by five visual sight gages. A sun alignment gage was located at each of the four corners formed by the lens assembly, and a fifth gage was located on the structure just below the receiver assembly. A schematic of the sun alignment gage is presented in Figure 5.

2.2.3 Receiver/Absorber Tube Assembly

The receiver/absorber tube assembly is illustrated in Figure 6. This assembly consisted of a receiver trough and a corrugated absorber tube (Figure 6a).

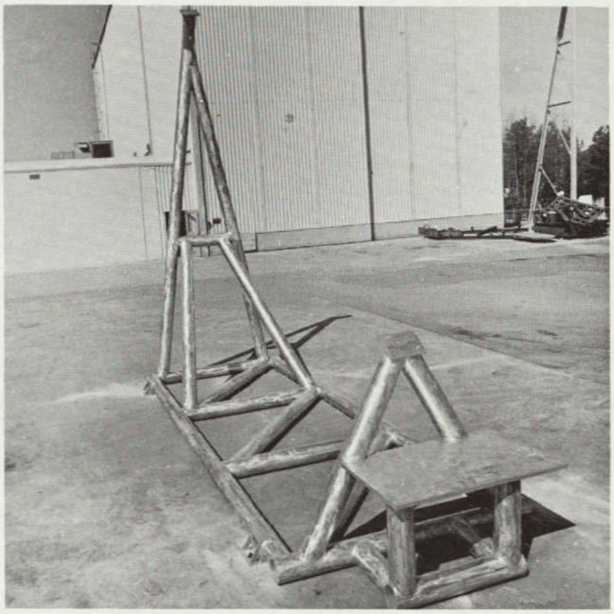
The receiver was constructed of aluminum with a reflective cavity constructed of anodized, polished aluminum (ALZAK, type 1). The reflective cavity had two functions: one was to aid in distributing the focused energy around the collection tube, thereby minimizing problems associated with circumferential temperature gradients on the tube, and, two, the reflective trough approach provided for focusing on a target width (trough opening of 6.6 cm) larger than the tube diameter (1.9 cm). Generally, the run's energy was focused on the trough aperture which minimized transverse (E-W) sun-tracking deviation effects. The trough aperture was normally covered with 0.005 cm thick Teflon FEP transparent film



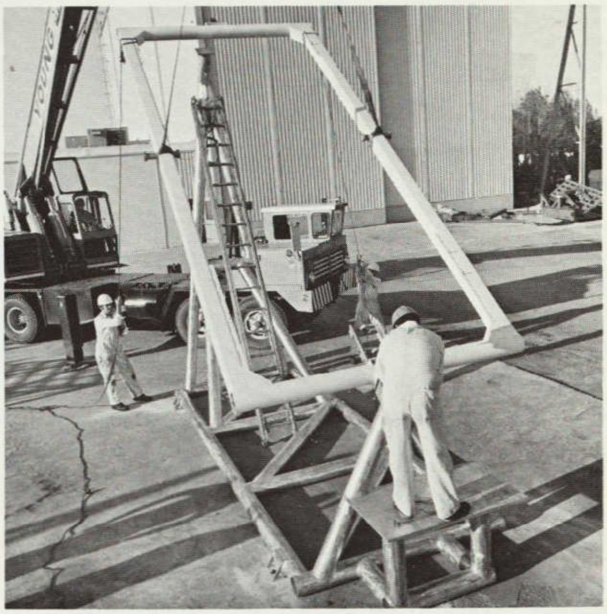
NOTES:

- Dimensions identical on inside and outside panels except for groove geometry.
- Grooves and dimensions not to scale.
- All dimensions in centimeters unless otherwise noted.

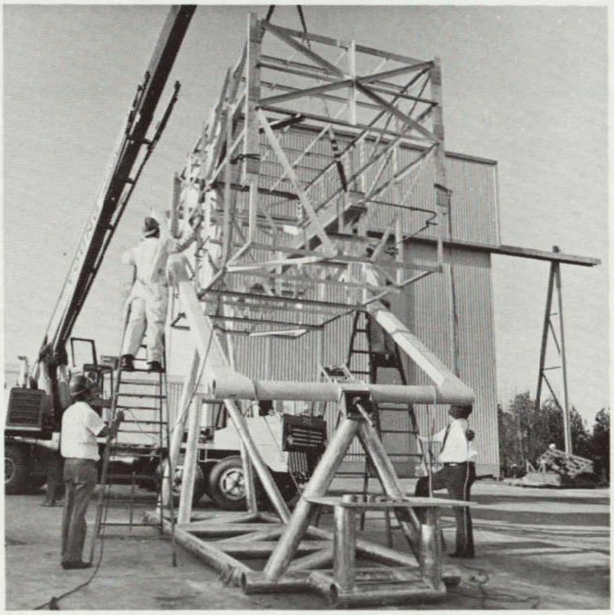
Figure 3. Lens Panel Geometry



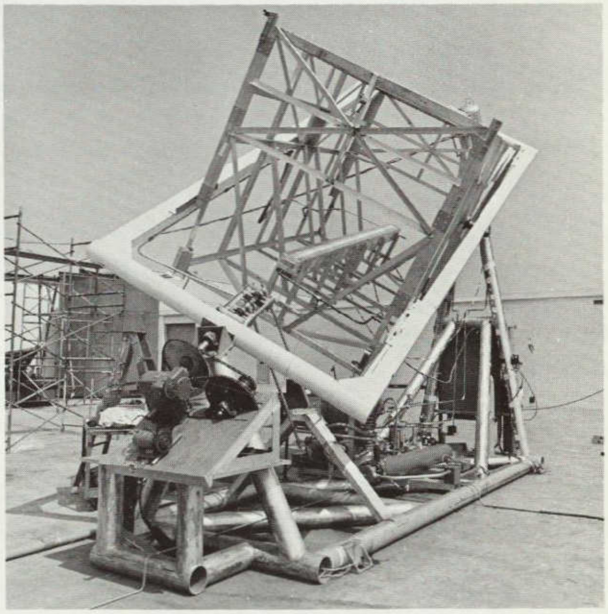
a. A-Frame Base



b. Yoke Installation



c. Lens Frame Installation



d. Assembled Test Article

Figure 4. Photographs of the Fresnel Lens Test Article at Various Stages of Assembly

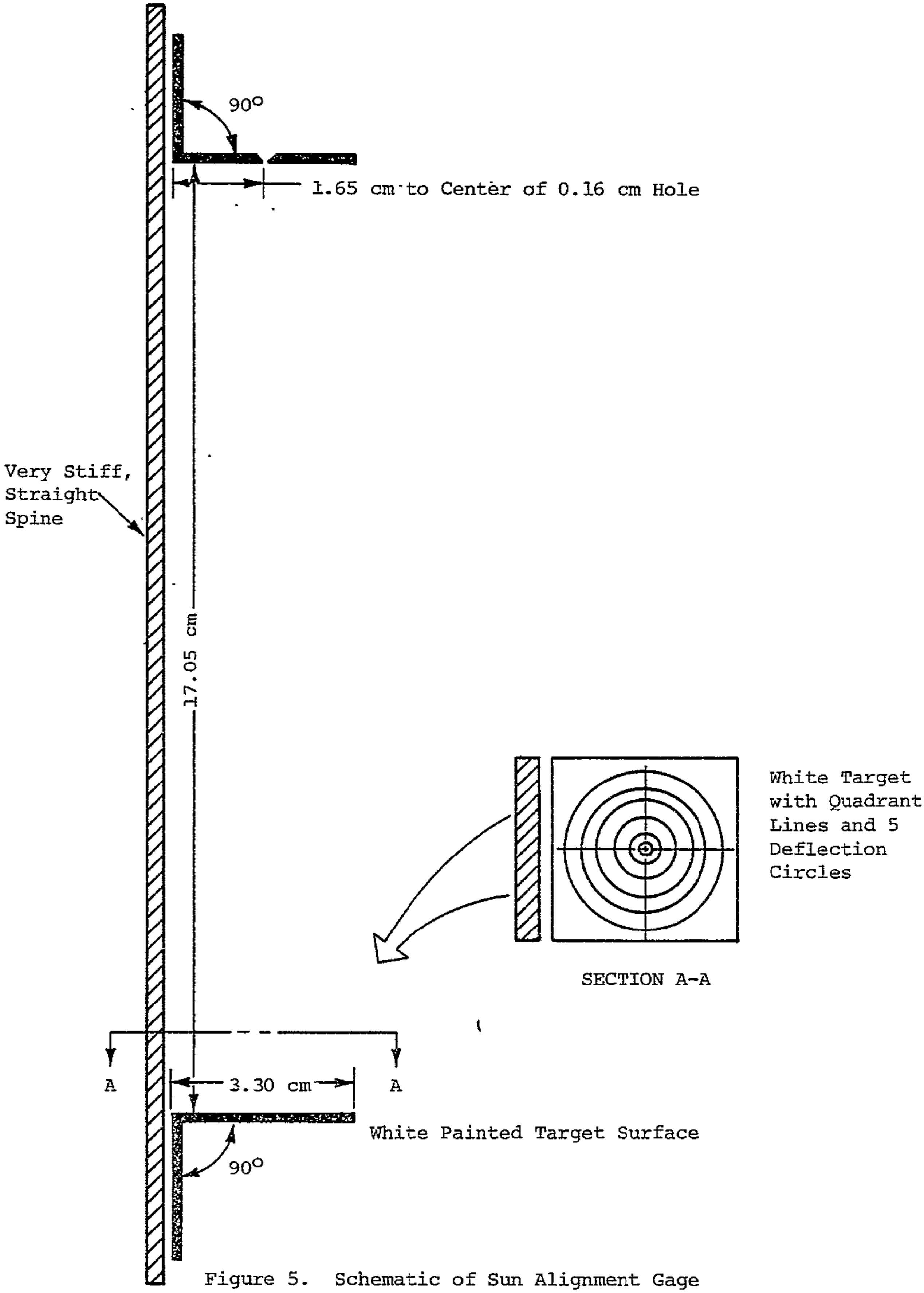
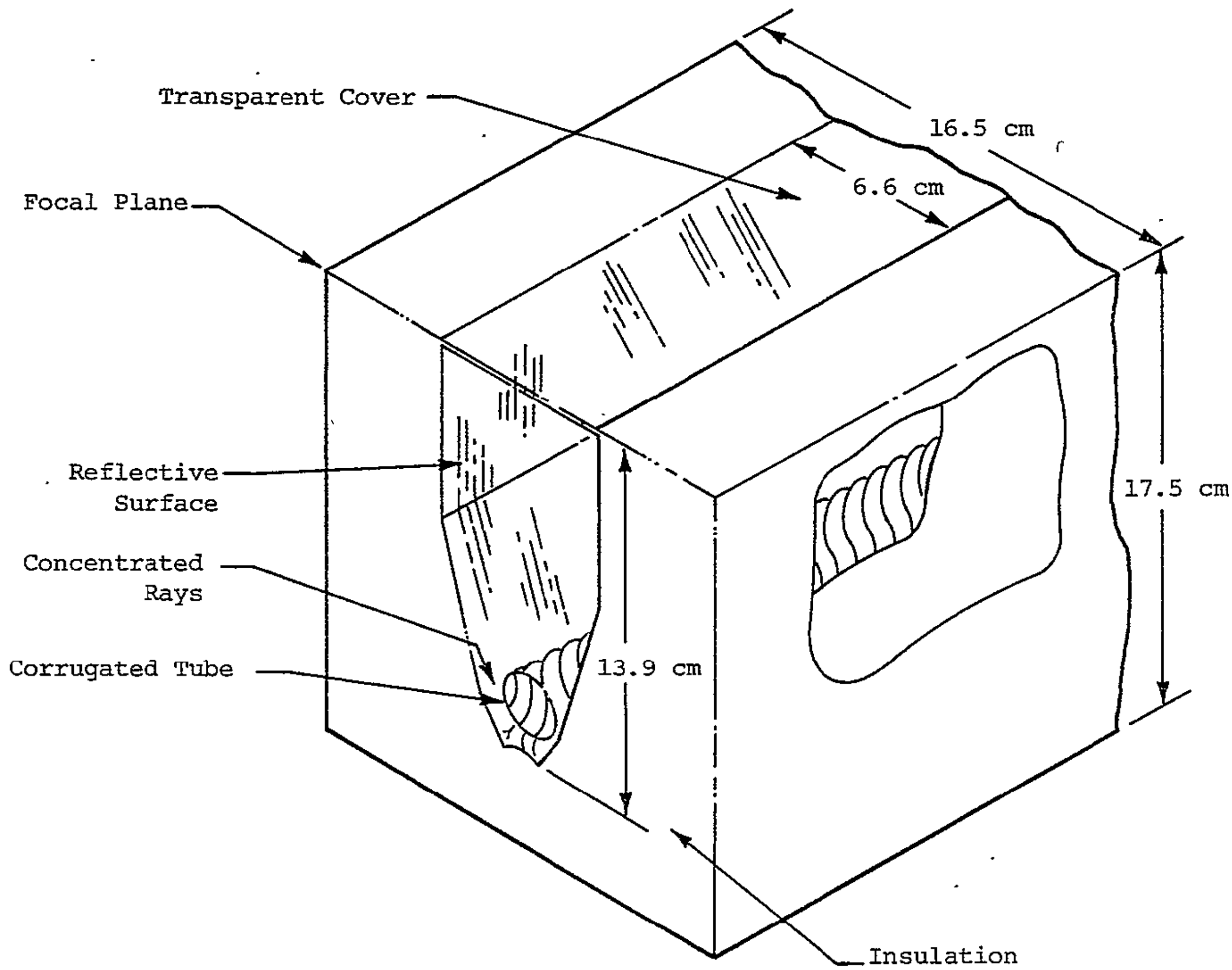
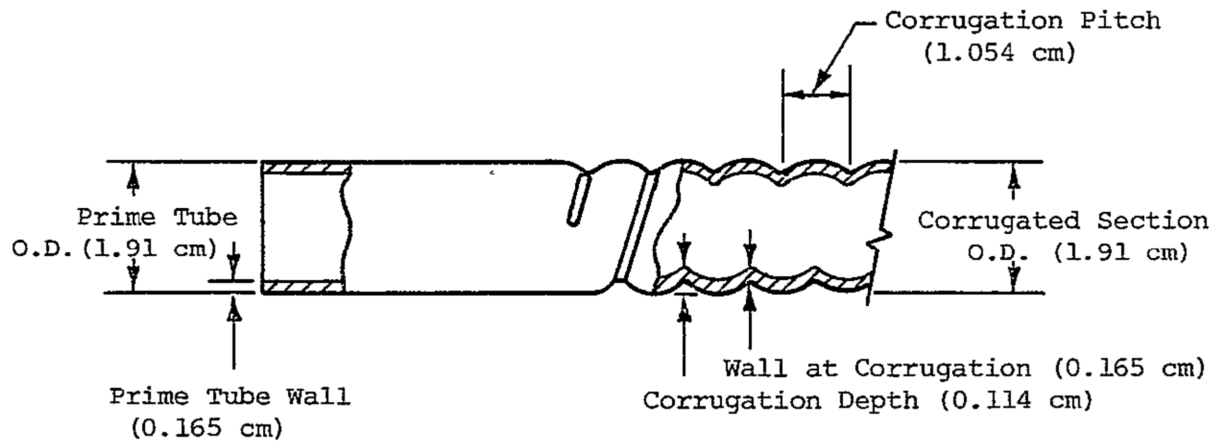


Figure 5. Schematic of Sun Alignment Gage



a. Receiver Assembly Description



CORRUGATION GEOMETRY

b. Absorber Tube Corrugation

Figure 6. Schematic of Receiver/Absorber Tube Assembly

TABLE I.

TEST LENS CHARACTERISTICS

Lens Type:	Cylindrical Fresnel, grooves down
Material:	Rohm and Haas Plexiglas V (811)
Fabrication Technique:	Compression molding
Manufacturer:	Optical Sciences Group, Inc.
Active Aperture:	182.9 cm (72 in.) wide 365.8 cm (144 in.) long
Total Aperture:	186.7 cm (73.5 in.) wide 374.6 cm (147.5 in.) long
Nominal Focal Length:	168.0 cm (66.15 in.)
Geometric f-number:	0.9 (based on total aperture)
Expected Transmission:	82 percent
Design Wavelength:	5893 Å

NOTE: Specifications provided by manufacturer.

manufactured by DuPont. The receiver assembly length of 4.1 m (13.48 ft) exceeded the lens length by 36.2 cm. This excess length allowed for solar heat collection for longitudinal sun-tracking deviations of ±5.0 degrees.

The absorber tube was a corrugated tube manufactured by the Wolverine Tube Division of Universal Oil Products Company. The corrugated tube is a commercial product labeled as Wolverine Korodense Tube, type MHT. The tube was produced from stainless steel tube stock with a 1.91 cm (0.75 inch) O.D. and a 0.165 cm (0.065 inch) wall thickness. A schematic of the corrugated tube is presented in Figure 6b. The axially spaced helical grooves on the outer wall and the inwardly extending helical ridges on the inner wall gave the tube a "corrugated" appearance. Shaping was performed without thinning the wall and the corrugated section outside diameter did not exceed the outside diameter of the original or "prime" tube. The corregations created a turbulating action on the fluid flowing through the tube, thereby reducing the laminar sublayer and increasing the heat transfer between the tube wall and the internal fluid. Absorber tube performance data is presented in reference 1.

2.2.4 Fluid Transport Loop Assembly

The fluid transport loop and thermocouple instrumentation locations are illustrated in Figure 7. The thermocouple code is presented in Table II. Key elements of the fluid transport loop consisted of:

1. Expansion tank which contained a reservoir of thermal fluid

2. Fluid pump

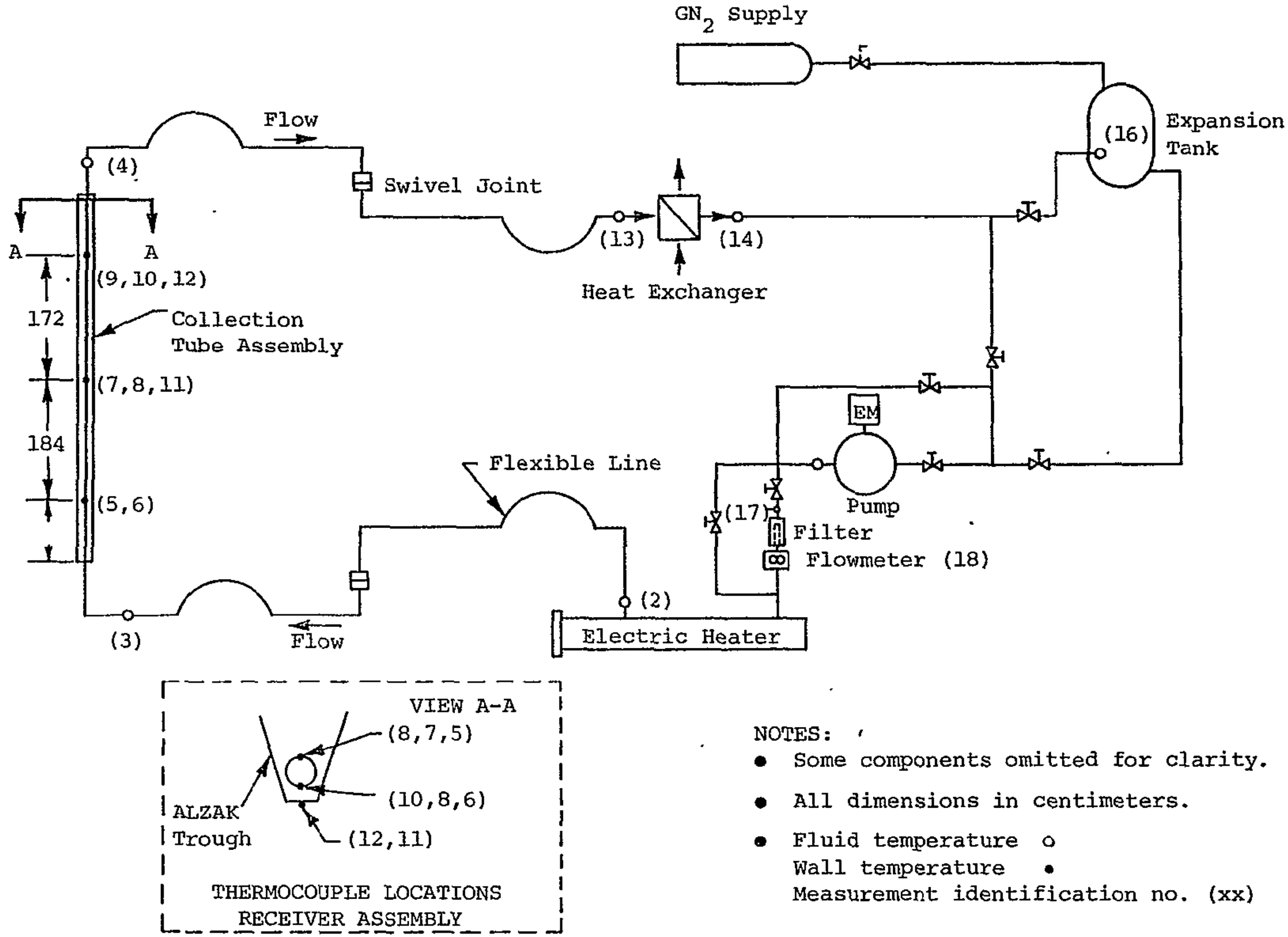


Figure 7. Test Article Fluid Flow Loop

TABLE II.

THERMOCOUPLE CODE

IDENTIFICATION NUMBER	THERMOCOUPLE NAME	MEASUREMENT LOCATION	
		WALL	FLUID
1	Ambient Air Temperature		
2	Heater Outlet		X
3	Absorber Tube Inlet		X
4	Absorber Tube Outlet		X
5	Absorber Tube Inlet Top	X	
6	Absorber Tube Inlet Bottom	X	
7	Absorber Tube Center Top	X	
8	Absorber Tube Center Bottom	X	
9	Absorber Tube Outlet Top	X	
10	Absorber Tube Outlet Bottom	X	
11	Trough Backside Center	X	
12	Trough Backside Outlet	X	
13	Heat Exchanger Inlet		X
14	Heat Exchanger Outlet		X
15	Pump Outlet		X
16	Reservoir		X
17	Flowmeter Inlet		X

3. Electric heater

4. Heat exchanger

5. Valves, piping and fixtures to interconnect the fluid loop components with the absorber tube assembly.

Auxiliary elements which were not an integral part of the fluid loop consisted of:

- A gaseous nitrogen pressurization system, and
- A thermal fluid supply and make-up system.

The fluid was pumped from the expansion tank to the heater, where it was heated to provide the desired absorber tube inlet temperature. Upon exiting the absorber tube, the fluid passed through the heat exchanger where it was cooled before entering the expansion tank. The expansion tank was pressurized with gaseous nitrogen (typically 2 atm, absolute) to provide an inert atmosphere and to prevent air leakage into the fluid loop. Also, the expansion tank was located at the highest position in the loop to minimize vapor entrapment and to provide a positive pressure on the pump inlet.

Flow loop filtration was provided by a 100 micron, metal-mesh-type strainer upstream of the pump and a 20 micron filter upstream of the flowmeter.

The fluid transport loop was designed to control two basic test parameters: absorber tube inlet fluid temperature and flow rate. The flow rate could be varied between 0.95 and 4.9 liters/minute (0.25 to 1.3 gpm) and the temperature from ambient to 316°C. A constant volumetric flow for a given fluid temperature was maintained by the positive displacement pump as verified with the flowmeter downstream of the pump. The flowmeter was a Fischer and Porter Company series 10C1512, 3/8-inch meter with a maximum capacity of 9.5 liters/minute (2.56 gpm) and a rated accuracy of ±0.24 percent of the actual flow rate. The electric heater and associated controls was a Chromalox 15 kW heater system manufactured by Edwin L. Wiegard Company. The heater system maintained selected heater outlet temperatures within ±0.2 percent. Selected absorber tube inlet temperatures were in turn maintained because the line between the heater outlet and tube inlet was insulated. The tube inlet and outlet fluid temperature measurement locations were upstream and downstream of the receiver assembly, respectively (see Figure 7). However, negligible temperature differences occurred between the tube interfaces and measurement locations because the lines were insulated.

Receiver assembly thermal characteristics were defined with additional temperature measurements. The longitudinal and circumferential temperature gradients on the absorber tube were measured using a pair of thermocouples at each of three longitudinal positions (Figure 7). At each position, two thermocouples were mounted 180 degrees apart, one on top of the tube and one on the bottom. Additionally, thermocouples were located on the backside bottom of the ALZAK reflective trough at two positions. Other instrumentation supporting the fluid transport system was that required for system monitoring, pump pressure, heat exchanger inlet/outlet temperatures, and expansion tank temperature and pressure.

2.2.5 Instrumentation and Controls

2.2.5.1 Instrumentation

Instrumentation consisted of the following:

1. Thermocouples
2. System Pressure Gauge
3. Flowmeter
4. Radiometer
5. Data Logger

Thermocouples were Chromel-Alumel which were recorded by a Fluke Summa II, series 2240A data logger. The Summa II data logger had the capability to condition thermocouple voltage inputs and provide direct temperature readout (either °C or

°F). This unit provided linearization, reference junction compensation and open-circuit detection.

The System Pressure Gage was a 6-inch, Borden tube pressure gage, 0 to 100 psig, which measured fluid loop line pressure on the discharge side of the fluid pump. This gage was employed primarily for leak testing, monitoring the system pressure while activating the system for test, and changing test conditions.

The Flowmeter was a Fisher and Porter, series 10C1512, turbine flowmeter of 3/8-inch size, with a maximum capacity of 9.5 liters/minute (2.56 gpm). This meter was a compact, totally enclosed, fluid flow rate measuring instrument that generated a varying frequency output signal proportional to flow velocity. Major components of this instrument consisted of a precision-machined, stainless steel meter housing, front support (flow conditioner), rear support, rotor assembly, and a "low drag: magnetic pick-off assembly. The flowmeter dynamic signal was conditioned through a frequency-to-voltage converter and recorded on the Fluke Summa II data logger. Complete details of the flowmeter are presented in Fischer and Porter Company Instruction Bulletin 10C1512-B, Rev. 2.

Each flowmeter is individually calibrated by the manufacturer and this data is plotted to develop the volumetric calibration factor for the meter. The calibration curve is a linear plot of the meter cycles per gallon ratio (K) on the ordinate versus frequency normalized by viscosity along the abscissa. The calibration curve for the unit employed in the present test apparatus is presented in Figure 8. The data shown on the meter calibration curve deviates from the mean value ($\overline{K}$) by no greater than ±0.5% down to the minimum flow rate in gpm that determines the limit of the linear range of the meter. The meter calibration factor ($\overline{K}$) is 46,000. The value was used to establish standardization or present values for conversion of the process variable signal to a direct reading signal in the engineering measurement unit selected for readout. Although $\overline{K}$ is normally specified in cycles per gallon, it can be converted easily to other common engineering measurement units, such as cycles/pound, cycles/cubic meter, etc, by multiplying the $\overline{K}$ by the appropriate conversion factor, as shown in Table III. The $\overline{K}$ may be used for flow rate indication applications as follows:

1. Volumetric Units:

When operating with a frequency-indicating instrument, such as a variable time base counter, the basic equation is:

$$\text{Flow rate} = \frac{f}{\overline{K}}$$

In practical units the time base setting is:

$$\text{Flow rate in gallons per minute} = \frac{60f}{\overline{K}}$$

where:

f = flowmeter output frequency in cycles/second

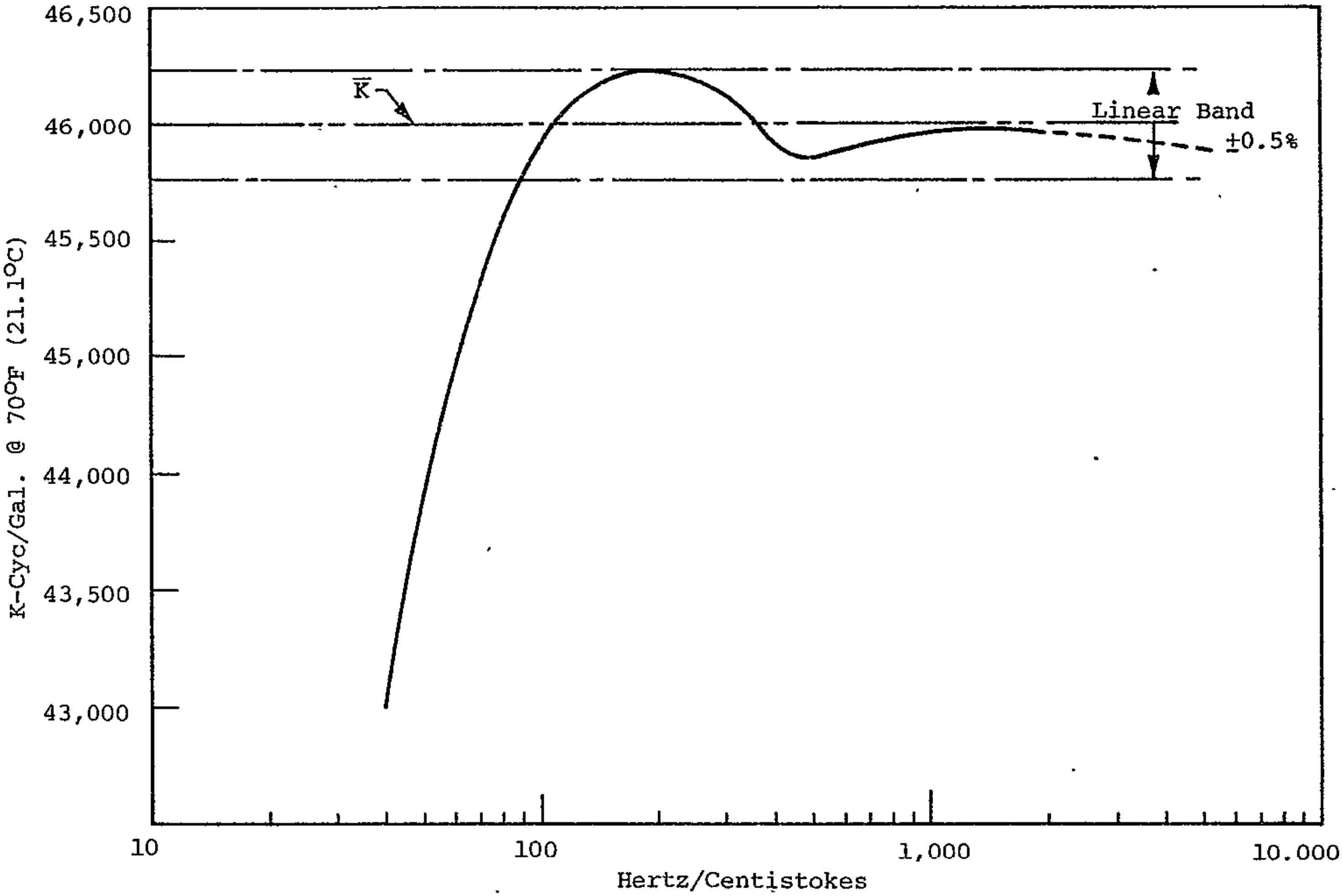


Figure 8. Flowmeter Calibration Curve

TABLE III.

COMMON CONVERSION FACTORS

MEASUREMENT UNIT		CONVERSION
Volumetric	Cycles/Imperial Gallon	$1.2009 \times \overline{K}$
	Cycles/Liter	$0.2642 \times \overline{K}$
	Cycles/Barrel (U. S. Standard)	$31.5 \times \overline{K}$
	Cycles/Barrel (Petroleum Products)	$42 \times \overline{K}$
	Cycles/Cubic Meter	$264.17 \times \overline{K}$
	Cycles/Cubic Feet	$7.481 \times \overline{K}$
Gravimetric	Cycles/Pound	$\frac{0.1199 \times \overline{K}}{Sx^*}$
	Cycles/Ton	$\frac{239.8 \times \overline{K}}{Sx}$
	Cycles/Kilogram	$\frac{0.2642 \times \overline{K}}{Sx}$

*Specific gravity of metered fluid (reference H_2O at 60^oF

where:

f = flowmeter output frequency in cycles/second

$\overline{K}$ = flowmeter calibration factor in cycles/gallon = 46,000

60 = seconds per minute.

2. Gravimetric Units

Conversion of frequency indications to the gravimetric system of units requires use of the metered fluid specific gravity as follows:

$$\text{Flow rate in pounds per hour} = \frac{3600f \times 8.337\ Sx}{\overline{K}}$$

where:

f = flowmeter output frequency in cycles/second

$\overline{K}$ = flowmeter calibration factor in cycles/gallon

3600 = seconds per hour

8.337 = weight of a gallon of water in pounds

Sx = specific gravity of metered fluid (reference H_2O @ 60^oF)

3. <u>Standardization</u>

In determination of the standardization value for a linear scale rate indicating instrument (where the instrument provides a standardization frequency) the following equation applies:

$$\text{Scale standardization value} = \frac{fC}{\bar{K}}$$

where:

C = conversion factor to obtain desired flow scale units

f = standardization frequency in cycles/second

Each flowmeter is typically calibrated for the expected service viscosity. A change in temperature will change the dimensions of the flowmeter, which will in turn affect the K of the meter. This dimensional change can be compensated for by multiplying K by a correction factor determined from the temperature correction curve of Figure 9. Thus, if the flowmeter is calibrated at 70°F and then used at -100°F, multiply K by 1.0042.

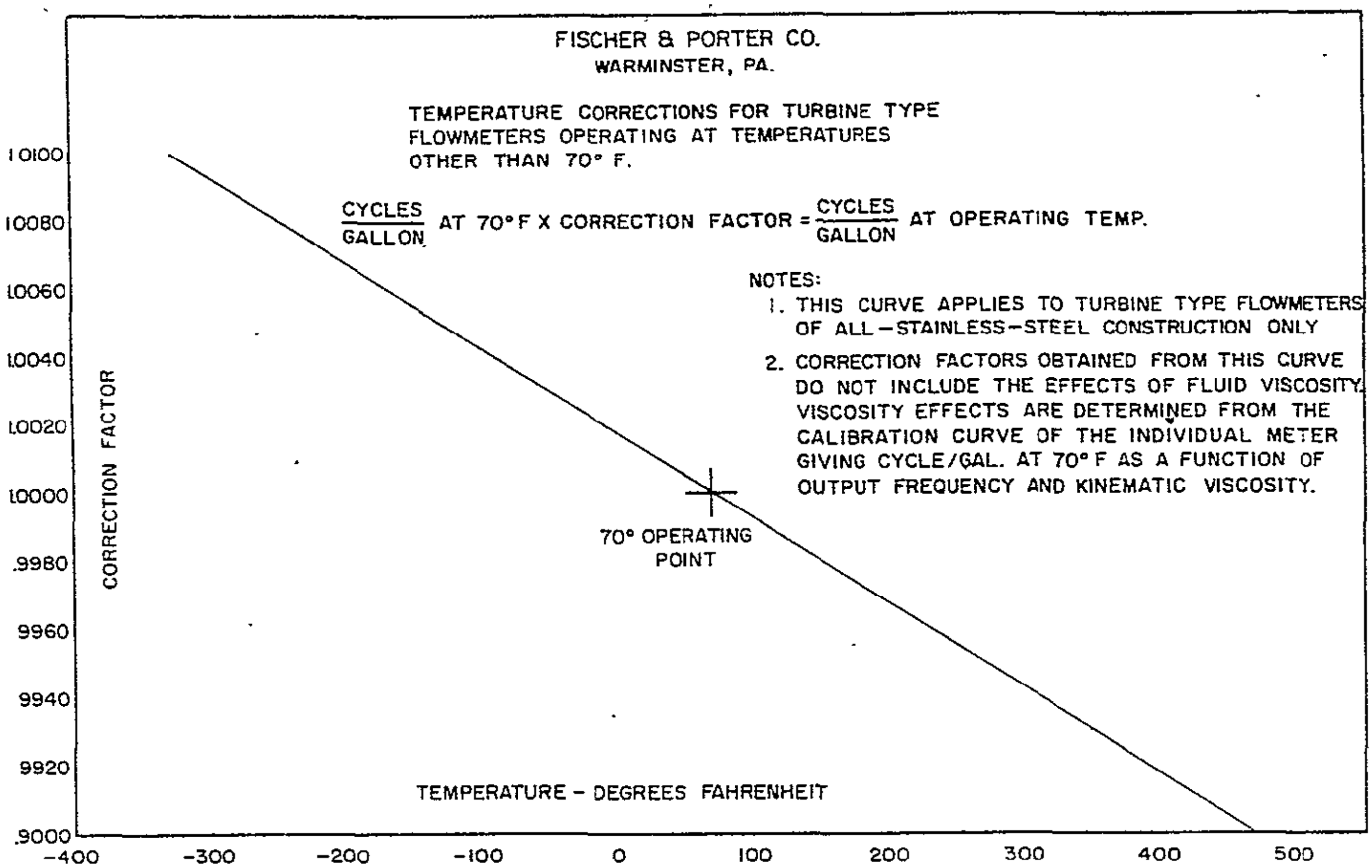


Figure 9. Temperature Correction Curve T2138

The Radiometer was an Epply normal incidence pyrheliometer, model NIP, manufactured by the Eppley Laboratory, Inc. As the name implies, this unit was designed for the measurement of solar radiation at normal incidence. In effect, it may be considered a thermoelectric version or variation of the Smithsonian Silver Disk pyrheliometer, as it incorporates in its design some of the basic features of that instrument. The sensitive element of the pyrheliometer was an E6-type, wire-wound thermopile. The present unit had a sensitivity of 8.41×10^{-2} volts/watt/meter^2. The radiometer was mounted to the lens frame assembly to measure normal incidence solar radiation which could be correlated directly with solar collector performance data.

The Data Logger was a Fluke Summa II, series 2240, manufactured by John Fluke Manufacturing Company. This instrument served as the primary means of acquiring and tabulating data. Data recorded by the data logger included:

- System temperatures (thermocouples 1 - 17)
- Flow rate (flowmeter)
- Normal incidence solar radiation (radiometer)

Data was tabulated at programmable-selected time intervals on paper print-out.

2.2.5.2 Electrical Control System

The wiring diagram of the electrical control system is shown in Figure 10. The control system was designed to provide safety interlocks to ensure against inadvertent operation of certain components which would cause an unsafe condition. Also, the control system provides for automatic warning and automatic shutdown of critical components, such as the electric heater and tracking system, when the system fluid loop temperature or pressure exceeded preset limits. Key elements of the electrical control system consisted of:

1. Heater Power Controller
2. Pump Motor Drive Control
3. Sun Tracking Motor Control
4. Hi-Lo Pressure Switch
5. Temperature Limit Switch
6. Manual Control Switches
7. Main Power Breakers
8. Remote Temperature Controller
9. Remote Main Starter
10. Alarm

For a detailed description of the operation sequence for the electrical control system, reference is made to the checkout procedure presented in the appendices.

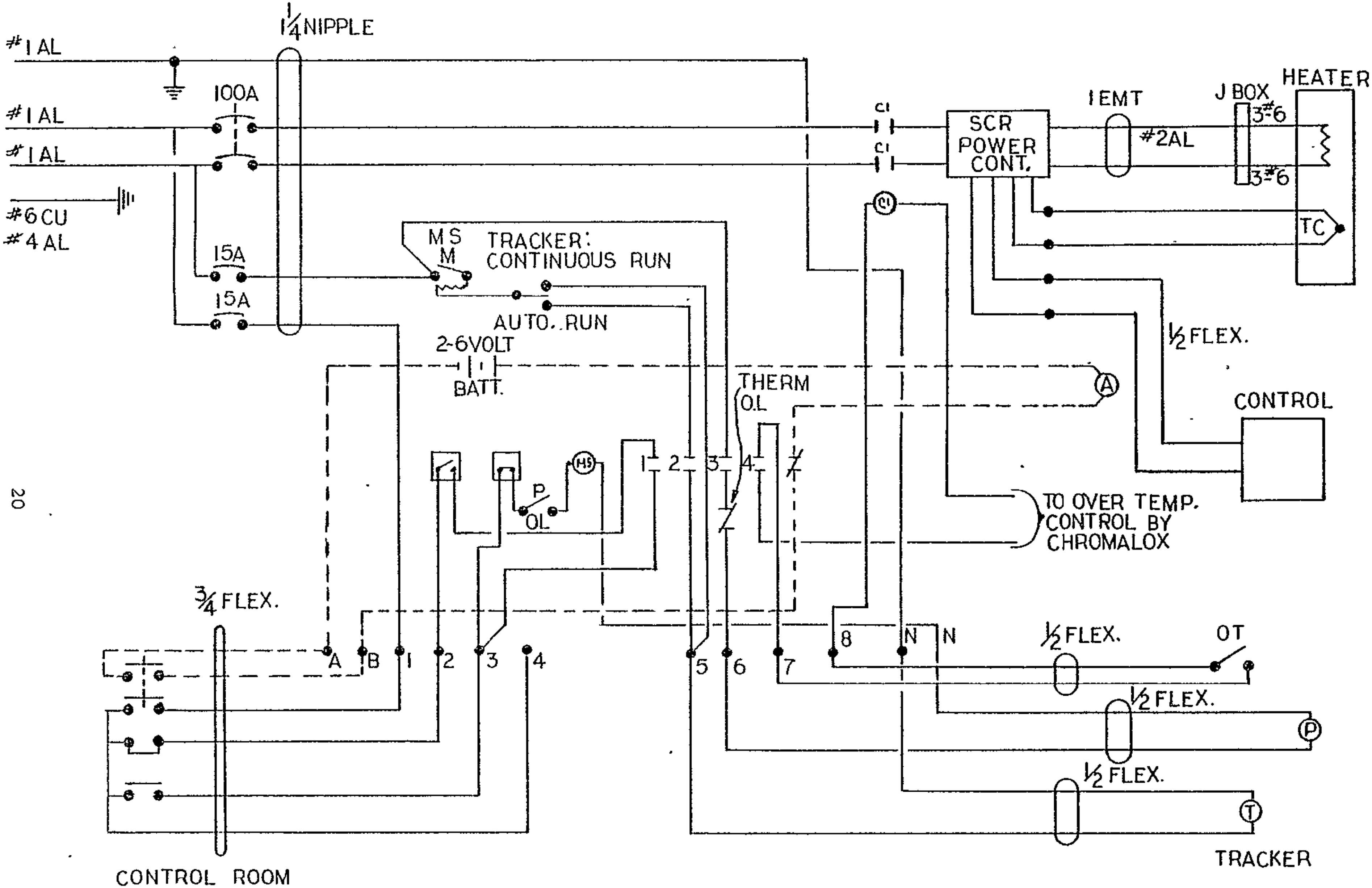


Figure 10. Wiring Diagram of Electrical Control System

2.3 Thermal Transport Fluid

The transport fluid selection was based primarily on the criterion of single phase, low pressure heat transport at operating temperatures exceeding 316°F (600°F). Additional general considerations were: fluidity at ambient temperatures, thermal stability, toxicity, materials compatibility, and commercial availability and cost. Table IV presents representative, commercially available high temperature organic heat transfer fluids and example properties. Therminol 88 and Dowtherm A have maximum bulk temperature tolerances of 427°C and 399°C, respectively. However, Therminal 88 begins to solidify below 145°C, whereas Dowtherm A solidifies at 12°C. Therminol 66 and Dowtherm G have application temperature ranges of -4° to 343°C and -11° to 343°C, respectively, and closely exhibit the overall desired characteristics. Therminol 60 and Mobiltherm 603 are representative of fluids that can be used at temperatures not exceeding 316°C. Therminol 60 and Mobiltherm 603 may be advantageous in cold climate regions where startup at low temperatures is required. Therminol 66 was selected for initial testing based on its properties and its current use by Sandia Laboratories in similar testing with parabolic mirrors. Therminol 66 property variations with temperature are listed in Table V. Dowtherm G is also considered a viable candidate and may be utilized by MSFC in tests at a later date.

Details on design and operational considerations for high temperature organic heat transfer fluids are summarized in reference 2 and are available from the respective manufacturers. Therminol 66 is typical of the organic thermal fluids in that an inert gaseous "blanket" is required to minimize fluid oxidation and contamination. Also, an expansion tank is required to accommodate the fluid volumetric change that occurs with temperature fluctuations. For example, the fluid specific volume increases 34 percent with a temperature rise from 38° to 343°C. The fluid loop provisions required to accommodate Therminol 66 and to interface ith the Fresnel lens collector are described in the preceding section.

TABLE IV. HIGH TEMPERATURE ORGANIC FLUIDS AND PROPERTIES

THERMAL PARAMETERS			PROPERTIES AT 316°C (600°F)			
	THERMINOL 88	DOWTHERM A	THERMINOL 66	DOWTHERM G	THERMINOL 60	MOBILTHERM 603
Vapor Pressure, Absolute (Atmosphere)	0.342	3.09	0.46	1.23	1.0	0.225
Specific Heat (Kcal/Kg°C)	0.554	0.58	0.63	0.54	0.64	0.76
Density (Kg/m^3)	880	790	770	870	797	666
Viscosity (cp)	0.335	0.19	0.34	0.318	0.285	0.412
Thermal Conductivity (Kcal/m hr °C)	0.098	0.090	0.092	0.103	0.094	0.096
Useable Temperature Range (°C)	149 to 427	13 to 399	-4 to 343	-11 to 343	-51 to 316	-26 to 316
Pour Point (°C)	145*	12**	-28	-28	-68	-7
Flash Point (°C)	191	116	180	152	154	193
MISCELLANEOUS						
Composition	Mixed Terphenyls	Diphenyl-Diphenyl Oxide Eutectic	Hydrogenated Terphenyls	Di & Triaryl Ethers	Polyaromatic Compounds	High VI Parraffinic Oil
Toxicity	Nontoxic	Nontoxic	Nontoxic	Nontoxic	Nontoxic	Nontoxic
Corrosion	None	None	None	None	None	Copper

*Melt point
**Freeze point

TABLE V. THERMINOL 66 PROPERTY VARIATIONS WITH TEMPERATURE

TEMPERATURE		DENSITY		SPECIFIC HEAT		THERMAL CONDUCTIVITY		VISCOSITY		VAPOR PRESSURE (ABSOLUTE)	
°F	°C	LB/FT^3	KG/M^3	BTU/LB °F	KEAL/KG °C	BTU/FT HR °F	KEAL/M HR °C	LBM/HR FT	c_P	PSI	ATMAS
0	-18	64.9	1,040	0.320	0.320	0.0720	0.1072	150,000.0	6,200.0	---	---
50	10	63.6	1,020	0.350	0.350	0.0711	0.1058	617.0	255.0	---	---
100	38	62.4	1,000	0.380	0.380	0.0703	0.1046	67.8	28.0	---	---
150	66	60.9	975	0.405	0.405	0.0695	0.1034	23.6	9.75	---	---
200	93	59.3	950	0.430	0.430	0.0687	0.1022	10.1	4.20	0.0019	---
250	121	58.0	930	0.455	0.455	0.0678	0.1008	5.86	2.42	---	---
300	149	56.8	910	0.480	0.480	0.0670	0.0997	3.75	1.55	0.0039	---
350	177	55.2	885	0.505	0.505	0.0662	0.0985	2.57	1.06	---	---
400	204	53.6	860	0.530	0.530	0.0653	0.0972	1.88	0.78	0.039	0.003
450	232	52.5	840	0.555	0.555	0.0645	0.0959	1.40	0.58	0.096	0.007
500	260	50.5	810	0.580	0.580	0.0637	0.0948	1.08	0.45	1.93	0.131
550	288	49.5	793	0.605	0.605	0.0628	0.0935	0.87	0.36	3.86	0.262
600	316	48.1	770	0.630	0.630	0.0620	0.0923	0.82	0.34	6.76	0.46
650*	343*	46.8	750	0.655	0.655	0.0613	0.0912	0.65	0.26	14.70	1.0
700	371	45.6	730	0.680	0.680	0.0605	0.0900	0.49	0.20	19.33	1.32

*Maximum recommended bulk temperature. The film temperature limit is 374°C (705°F).

3.0 SYSTEM ACTIVATION PROCEDURES

3.1 Checkout Procedures

Following the assembly of the solar collector test apparatus, a sequence of three checkout procedures were followed in chronological order which led to the full activation of the test system. These procedures were prepared prior to commencing the activation sequence; however, in certain instances, refinements were made in the procedures as falacies were discovered. These procedures consisted of:

1. Component Checkout Procedure (see Appendix A)
2. Fluid Loop Purging and Loading Procedure (see Appendix B)
3. Operational Test Procedure (see Appendix C)

Detailed step-by-step procedures for each sequence are presented in the appendices as noted above. Brief summaries of these procedures are presented in the following paragraphs:

3.1.1 Component Checkout Procedure

Individual components and instrumentation were checked and/or calibrated according to prescribed instructions prior to loading the fluid loop with thermal fluid for test purposes. A component and instrumentation check list is presented in Appendix A. In addition, the procedure presents step-by-step instructions for activating and checking the pump and motor drive and the electrical control system. Checkout of the electrical control system included functional checkout of all components interlocked in the control circuit. Certain components and instrumentation, such as the electrical control circuit, heater, temperature limit switch, pump and flowmeter, required additional checkout once the fluid loop was loaded with thermal fluid. Consequently, the checkout presented in Appendix A was considered a preliminary checkout prior to thermal fluid loading with the final checkout performed during component operational tests, as described in Appendix C.

3.2.1 Fluid Loop Purging and Loading Procedure

The fluid loop was purged prior to loading the loop with thermal fluid for test purposes. The purge consisted of both a gas purge using GN_2 and a liquid purge using thermal fluid. The purging procedure consisted of four phases:

- Phase A - System Drainage and GN_2 Purge
- Phase B - Thermal Fluid Loading
- Phase C - System Bleeding
- Phase D - Repeat of Phase A, System Drainage and GN_2 Purge

The thermal fluid loding procedure, which was performed following the purging of the fluid loop, consisted of three phases:

- Phase A - System Loading
- Phase B - System Bleeding
- Phase C - Thermal Fluid Make-up

3.1.3 Component Operational Test Procedure

Following the performance of component checkout and fluid loop purging and loading, the system underwent final "pretest" operational tests for verification of component operability before commencing solar data collection. Operational tests were performed by "phasing in" the various components of the system sequentially and verifying, at each step of the "phasing in" process, the operability of each system component before proceeding to the next component. The "phasing in" sequence for the various components was as follows:

1. Electrical Heater Checkout (pump deactivated)
2. Pump Operation
3. Pump Packing Adjustment (pump activated)
4. Electrical Heater Checkout (pump activated)
5. Flowmeter Checkout (pump and heater activated)
6. Heat Exchanger Checkout (pump activated)
7. System Shutdown and System Bleed (pump activated)
8. Integrated System Operation Shakedown (pump activated)
9. System Shutdown and System Bleed (pump deactivated)

Step-by-step procedures for each of the above sequence of operation are presented in Appendix C. Following the completion of this last checkout procedure, the system was ready to commence tests for solar data collection.

3.2 System Operational Procedure

A general operational procedure has been prepared for routine operation and checkout of the solar collector test article. This operational procedure should be followed for activating the system for the purpose of commencing a period of data collection. Key elements of the procedure pertain to:

1. Thermal Fluid Makeup
2. Pump Operation
3. Pump Packing Adjustment
4. Electrical Heater Checkout
5. Flowmeter Checkout
6. Tracking System Activation
7. System Shutdown and System Bleed
8. Redlines
9. Other Precautions

Step-by-step instructions follow. See Figure 11 for nomenclature.

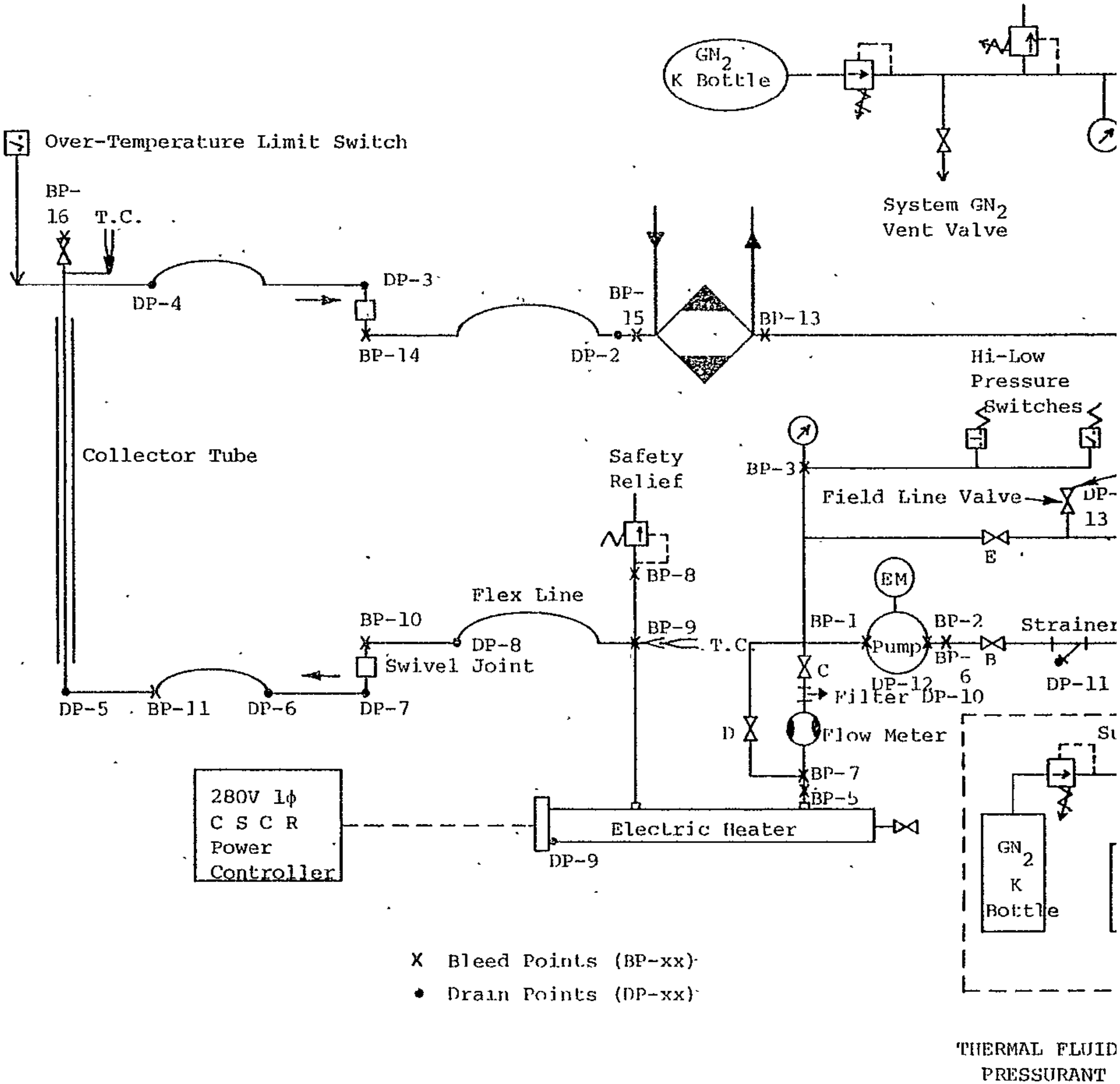


Figure 11. Test Article Fluid Flow Loop Showing Valve, Bleed Point and Drain

3.2.1 Thermal Fluid Makeup

Expansion tank replenishment should be performed when the tank fluid level drops below approximately 1/4-full level. Fluid makeup shall be accomplished by the following procedure:

Step 1. Close valves A, B, C, D and E.

Step 2. Open valves F, G, H, and I.

Step 3. Slowly open fill-line valve and observe fluid rise in storage tank. When fluid rises to approximately 3/4-full level, close fill-line valve.

Step 4. Close supply line valve.

Step 5. Open valves B, D, and E.

3.2.2 Pump Operation

Step 1. Close valves A and C.

Step 2. Open valves B, D, E, F, G, H, and I.

Step 3. Open GN_2 regulator and pressurize system to 10 psig at expansion tank and observe that fluid loop pressure is about 17 psig (pump outlet pressure gage).

Step 4a. Set tracker manual motor control switch to OFF position.

Step 4b. Set breaker 1 and breaker 2 to ON position.

Step 4c. Check that breaker 3 is in OFF position.

Step 4d. Set "main starter" toggle switch to ON position. Observe audible alarm.

Step 4e. Press "main starter" START button and observe pump operation initiation. Monitor system pressure gage and note system pressure rise. Continue to monitor system pressure gage until system pressure either (1) stabilizes below 40 psig or (2) reaches 40 psig, at which time the pump should be cut off by either pressing "main starter" STOP button or opening breaker 2. If system pressure stabilizes below 40 psig, continue with step 5. If pump cutoff is necessary due to pressure rise to 40 psig, check that valve positions are as noted in steps 1 and 2, reduce GN_2 pressure to 5 psig and repeat step 4.

Step 5. Monitor pump drive housing stuffing box for temperature increase or pump drive binding. If pump drive housing heats up, loosen packing gland nuts.

3.2.3 Pump Packing Adjustment (Pump Activated)

Step 1. While maintaining pump operation, carefully tighten the packing gland nuts to reduce any leakage. Make sure that the temperature of the stuffing box does not increase during this adjustment period. An adjustment of approximately 1/8 turn at a time is maximum.

Step 2. Allow approximately 15 to 20 minutes between adjustments. If, during this period, heating occurs such that the stuffing box is uncomfortable to the touch (140°F), back off on the adjustment nuts and allow pump to run until stuffing box cools, then start adjustment again.

Step 3. Several hours of operation may be required to achieve proper adjustment. Packing gland adjustment should be checked several times during the initial operation involving the pump.

3.2.4 Electrical Heater Checkout (Pump Activated)

Step 1. Check that pump is operating satisfactorily.

Step 2. Check that breakers 1 and 2 are in ON position and that breaker 3 is in OFF position.

Step 3. Check that heater internal SCR controller is set at 650°F.

Step 4. Check that heater remote controller is set at 200°F.

Step 5. Check that tracker manual motor control is in OFF position.

Ste0 6. Check that valves B, D, E, F, G, H, and I are open.

Step 7. Slowly close valve E and monitor fluid loop pressure gage. Close valve E until (1) fluid loop pressure reaches 30 psig or (2) valve E is fully closed.

Step 8. Set breaker 3 to ON position.

3.2.5 Flowmeter Checkout (Pump and Heater Activated)

Step 1. Check that valves B, C, F, G, H, and I are open.

Step 2. Check that valves A and C are closed.

Step 3. Set heater remote controller to 250°F.

Step 4. Stabilize flowmeter inlet temperature to 200 to 250°F. Flowmeter must not be operated below 200°F.

Step 5. Check that flowmeter electrical connections are intact and turn on flowmeter power supply.

Step 6. Slowly open valve C while monitoring flowmeter output. If no flowmeter output is detected with valve C slightly open; recheck flowmeter electrical system. If flowmeter output is detected, continue opening valve C until:

(a) Flowmeter reading indicates 2.5 gpm,
OR
(b) Valve C is full-open.

Step 7. Close valve D. Normal flowmeter reading at 200-250°F is 1100 to 1000 Hz (1.4 - 1.3 gpm).

3.2.6 Tracking System Activation

Step 1. Uncover the lens (check to ensure pump operation).

Step 2. Set tracker manual motor control switch to ON position and observe that tracker motor is operating.

Step 3. Rotate lens frame until image is centered inside the trough opening (minimum amount of spillage of the image).

Step 4. Observe accuracy of the tracking system for several minutes for image shifting, i.e. any increased image spillover. Visual alignment gages should also indicate no misalignment.

Step 5. If misalignment is indicated in step 4, perform necessary adjustments to tracking assembly motor pulley diameter and/or belt tension.

3.2.7 System Shutdown and System Bleed (Pump Deactivated)

Step 1. Open valve D.

Step 2. Close valve C to prevent flowmeter operation below 200°F.

Step 3. Set breaker 3 to OFF position.

Step 4. Set tracker manual motor control switch to OFF position.

Step 5. Rotate lens frame to horizontal position and secure.

Step 6. Cover up lens panels.

Step 7. Slightly open water valve to heat exchanger and observe steam at the outlet to the heat exchanger. When steam volume is slight and the outlet flow is steady, increase water flow rate.

Step 8. Continue water flow until heater outlet temperature is 150°F.

Step 9. Press "main starter" STOP bottom and set "main starter" toggle switch in OFF position.

Step 10. Set breakers 1 and 2 in OFF position.

Step 11. Open valves A, B, D, E, F, and G.

Step 12. Vent system to 5 psig by closing system GN_2 supply valve and GN_2 vent valve.

3.2.8 Redlines

Step 1. Upon tracking system activation, immediately observe the receiver assembly materials for overheating (smoke, discoloration, etc). If overheating occurs, immediately move lens away from the sun and deactivate tracking system.

Step 2. Therminol 66 bulk temperature limit is 650°F (monitor tube and heater outlet temperature). The Therminol 66 film temperature limit is 705°F (observe tube temperatures on top surface).

Step 3. ALZAK upper temperature limit is about 450°F (observe ALZAK temperature beneath tube at tube exit).

3.2.9 Other Precautions

Step 1. Check lens panels for any unusual contamination, misalignment, etc.

Step 2. Ascertain that Polyvinyl covers are laced/sealed such that receiver assembly is protected from wind and contamination.

Step 3. Check for any unusual Therminol 66 leakage.

4.0 TEST APPROACH

The general evaluation approach was to first establish the solar concentration or optical performance characteristics of the Fresnel lens using component bench testing and analytical modeling. The lens was then assembled in the full scale configuration and its optical performance checked to assess the impact of the assembly process. Finally, when the lens was interfaced with the receiver assembly and operated in the solar collection mode, the lens and receiver influences on the total collection efficiency could be distinguished. Testing generally was conducted between 10:00 a.m. and 2:00 p.m. CST during cloudless period to minimize variations in solar flux intensity. Significant atmospheric moisture haze which caused low, but steady, incident flux intensities was sometimes present.

4.1 Lens Performance Testing

Lens panels were experimentally evaluated by MSFC personnel at the component level using a sun-tracking heliostat. The sun-tracking heliostat provided a non-moving sun relative to the fixed Fresnel lens panels and is a gold first surface mirror, 118 cm in diameter. The sun rays were controlled to within 4 arc sec of the perpendicular by the heliostat control sensors.

The baseline flux incident on the front of a lens was continuously measured during each test using an Eppley pyroheliometer. A photodiode sensor was translated across the image plane behind the lens to measure the lens concentration characteristics. The photodiode was calibrated against the pyroheliometer before each test series to assure compatibility of incident and focused energy measurements. Evaluations included:

1. Lens baseline performance
2. Transverse alignment effects
3. Longitudinal alignment effects

A reference or baseline concentration profile at the focal plane for perfectly positioned lens panels and the lens transmittance was first established. The reference data were then used to define deviations in imaging characteristics with various sun lens orientation misalignments. Lens-sun tracking deviation data were obtained by tilting the lens at fixed angles relative to the reflected rays. After the panels were assembled to form the full scale lens/collector, the baseline concentration profile was again measured utilizing the same solar flux instrumentation used in the bench testing.

4.2 Collector Performance Testing

At the beginning of each test day, the lens surface was aligned perpendicular to the sun using the visual sight gages mounted on the tracking structural assembly. The alignment gages were periodically monitored during the subsequent testing to assure that the proper lens-sun orientation was maintained. The procedure consisted of first establishing steady conditions at the selected flow rate and inlet temperature and simultaneously monitoring the pyroheliometer to assure a constant direct solar flux input. Then, the data were recorded for periods ranging from 1 to 10 minutes. Subsequently, either the flow rate or inlet temperature was changed while maintaining the other variable as constant as possible, steady-state conditions were reestablished and another data point was acquired. The recorded inlet-to-outlet temperature difference (ΔT) and mass flow rate were used to determine the collected energy ($\dot{m}\, c_p\, \Delta T$). The incident flux on the lens or "available energy" as measured by the pyrheliometer was then divided into the collected energy to determine the collection efficiency.

Evaluations made with the assembled test article included:

1. General collector performance
2. Sun-tracking deviation effects
3. Miscellaneous effects:
   - Solar flux magnitude
   - Transport fluid flow rate
   - FEP window effects

Test variables were introduced through hardware adjustments and modifications. The receiver assembly position relative to the lens was adjusted to defocus the trough aperture. Also, tests were conducted with and without the transparent FEP cover on the trough aperture. The lens surfaces were cleaned once, before the initiation of collector testing. The lens was not cleaned thereafter although the lens was usually covered when not in use to prevent accidental focusing.

5.0 SUMMARY OF TEST RESULTS

All tests, data collection, and analyses for both the lens component tests and the collector performance tests were performed by MSFC technical personnel. Test results are presented in reference 1. To add an element of completeness to the present report, significant conclusions from reference 1 are presented herein.

5.1 Lens Performance

1. Relative to the profiles produced by an earlier 56 cm lens, the focusing properties of the present 1.8 m lens were much improved. A baseline peak concentration of 61 and a 90 percent target width of 4.5 cm were computed for the 1.8 m lens. Bench testing indicated a peak concentration of 67 with a 90 percent target width of 4.2 cm. When assembled in the full scale configuration of 1.8 by 3.6 m, the nominal peak concentration and target width were 62 and 5 cm, respectively.

2. The primary effect of small transverse (E-W) sun-tracking deviations ($<1^{\circ}$) was the lateral shifting of the concentration profile. The target width increased linearly with tracking deviation. Example measured and analytical target width increases were 70 and 80 percent, respectively, to accommodate a $\pm 0.5^{\circ}$ deviation.

3. Lens performance was relatively insensitive to sun-lens alignment in the longitudinal direction. Deviations up to 5° had no significant effects on peak concentration or profile width.

4. The measured and computed lens transmittance was 81 percent and 86 percent, respectively. Minor transmittance difficulties experienced with one of the two lens panel configurations should be correctable and enable a transmittance improvement to the 85 percent level in future lenses. Lens transmittance was not affected by sun-lens misalignment within the range tested.

5.2 Collector Performance

1. With the receiver assembly aperture placed at the focal plane, the collection efficiency ranged from 40 percent at $90^{\circ}C$ to 21 percent at $300^{\circ}C$. An efficiency of approximately 40 percent at $300^{\circ}C$ had been predicted. The reflective cavity surrounding the absorber tube apparently did not reflect the concentrated solar flux to the tube as well as expected. This conclusion was verified by testing with the receiver cavity aperture defocused -2 percent, thereby increasing the energy directly focused on the tube. An efficiency increase to 26 percent at $300^{\circ}C$ resulted.

2. Future receiver assemblies will involve placement of the absorber tube at the focal plane, thereby further increasing the energy directly concentrated on the tube. Reflective surfaces, if used, will serve in a backup rather than primary mode. Efficiency improvement to the 40 to 50 percent range at $300^{\circ}C$ is anticipated.

3. Transverse sun alignment deviations up to 0.5 degree had no measurable effect on collection efficiency. Longitudinal misalignments up to approximately five degrees have no influence on efficiency, provided sufficient receiver length is available to accommodate the profile shifting along the tube.

4. Collection efficiency was essentially independent of solar flux magnitude within the 470 to 900 W/m^2 range.

5. The transport fluid (Therminol 66) flow rate had no discernible effect on efficiency in the 70 to 300 kg/hour range.

6. The FEP window removal degrated the efficiencies only slightly at fluid temperatures above 230°C. No FEP material degradation occurred.

7. Absorber tube temperature gradients were primarily controlled by fluid flow rate and temperature. At 4.5 liters/minute the tube-to-fluid and circumferential temperature differentials were less than 20°C and 10°C, respectively. Maximum tube-to-fluid and circumferential gradients of 55°C and 22°C, respectively, occurred at a flow rate/temperature combination of 2.3 liters/minute and 120°C.

8. An evaluation of total collector performance losses indicated that optical losses comprise 71 percent of the total. The lens transmittance and receiver cavity reflectance represented 48 percent of the optical losses. Tube thermal losses were 8 percent and 29 percent of the total at 150°C and 300°C, respectively. Decreasing reliance on a reflective receiver cavity and increasing the absorber tube diameter/absorptance should enable a 20 to 30 percent reduction in total losses.

REFERENCES

1. Hastings, Leon J, Steve L. Allums and Warren S. Jensen, "An Analytical and Experimental Investigation of a 1.8 by 3.7 Meter Fresnel Lens Solar Concentrator," NASA Technical Memorandum NASA TMX-73392, April 1977.

2. Seifert, W. F., et al, "Design and Operational Consideration for High Temperature Organic Heat Transfer Systems." Process Heat Transfer Symposium of the 71st National AICHE Meeting, February 22-24, 1972.

APPENDIX A

COMPONENT CHECKOUT PROCEDURE

APPENDIX A

COMPONENT CHECKOUT PROCEDURE

Individual components and instrumentation shall be checked and/or calibrated according to prescribed step-by-step procedures prior to loading the fluid loop with thermal fluid for test purposes. The table on the following page presents components and instrumentation which require either checkout, calibration, or both.

Certain components and instrumentation, such as the electrical control system, heater, temperature limit switch, pump and flowmeter, will require additional checkout once the fluid loop is loaded with thermal fluid. Consequently, the checkout presented in this appendix is to be considered a preliminary checkout necessary prior to thermal fluid loading, with a final checkout to be performed during component operational tests as described in Appendix C.

1.0 LENS ASSEMBLY

Checkout and calibration of the lens assembly shall be performed by NASA-MSFC personnel with assistance from Wyle personnel. Initial declination alignment shall be established by placing an inclinometer on the lens frame and adjusting the lens frame to the sun's declination angle for the time of year. Tracking alignment will be established by locating a narrow-angle light detection diode at the center of the lens' focal zone concentration. This latter procedure will be established and performed by NASA-MSFC technical personnel. Once declination and tracking alignment have been established, tracking accuracy achieved by the tracking motor and drive system shall be established by tracking the sun over a 6- to 7-hour period. Once tracking error has been minimized through adjustments to the track motor and drive, the lens assembly will be adjusted to correspond to the mean error for midday, and each of the four tracking monitors adjusted to indicate alignment with the sun. The four tracking monitors, one located at each of the four corners of the lens frame, will serve to align the lens with the sun to initiate each rest phase. Also, the Epply radiometer will be aligned in the same manner as performed for the tracking monitors.

2.0 PUMP AND MOTOR DRIVE

The fluid loop pump, gear reducer, and motor drive should be checked according to manufacturer specifications. Before initiating pump operation, the test conductor should become thoroughly familiar with the start-up procedures for the pump system. Key instructions, taken from the manufacturer's start-up procedures, follow:

Before pushing the START button, check the following:

1. Check piping to be sure there is no strain on the pump casing.
2. Check all mounting bolts to ensure that the system is aligned and tight.
3. Check that pump pressure relief valve points toward inlet side of pump.

COMPONENTS

Item	Checkout	Calibration	Remarks
Lens Assembly:			
a. Fresnel Lens	√	√	Declination alignment and concentration ratio profile.
b. Tracking Monitors	√		Alignment with lens.
c. Tracking Motor and Drive	√	√	Tracking accuracy.
Pump and Motor Drive	√		Functional tests.
Electrical Control System:			
a. Heater Power Controller	√		Functional tests and set-point checkout.
b. Pump Motor Drive	√		
c. Hi-Lo Pressure Switch	√	√	
d. Temperature Limit Switch	√	√	
e. Manual Switches	√		
f. Remote Temperature Controller	√		
g. Alarm	√		
GN_2 Pressure Relief Valve	√	√	Set-point checkout.
Thermal Fluid Supply	√		Functional tests.
Walkie-Talkie Communication	√		Functional tests.

INSTRUMENTATION

Item	Checkout	Calibration	Remarks
System Pressure Gauge		√	Check calibration
Thermocouples	√		Signal output verification.
Flowmeter	√	√	Electrical checkout and calibration.
Ratiometer	√		Alignment and signal output.
Data Logger	√		Functional tests.

4. Lubricate any grease fittings on the pump using a good, general purpose, number 2 ball bearing grease.

5. Check that gear reducer has been properly lubricated according to manufacturer's specifications.

6. Check graphite packing in pump for proper installation and adjustment according to manufacturer's specifications.

7. Remove drive coupling guard and rotate the drive shaft by hand to be sure pump turns freely. Replace drive coupling guard.

8. Following electrical control system checkout (see following section), jog motor to be sure pump is turning in the right direction. For present pump arrangement, pump rotation should be counterclockwise when looking from the motor to the pump with the suction side on top and the discharge side on the right.

9. Following the loading of thermal fluid in the fluid loop, the pump is ready for operation.

3.0 ELECTRICAL CONTROL SYSTEM

The electrical control system schematic is shown in Figure A-1. The control system is designed to provide safety interlocks to ensure against inadvertent operation of certain control components which would cause an unsafe condition. Also, the control system provides for automatic warning and automatic shutdown of critical components, such as the electric heater and tracking system, when the system fluid loop temperature or pressure exceeds predetermined limits. The following checkout procedure shall be performed prior to commencing operational tests employing the electrical control system:

It will be noted that the following checkout does not include the electrical heater components since their checkout will require the fluid loop to be loaded with thermal fluid. NOTE: Breaker 3 in the main power cabinet is to remain OFF during all steps of the following procedure.

Step 1. Check all electrical wiring to ensure that all wiring corresponds to prescribed layout schematics.

" 2. Set breakers 1, 2 and 3 in main power cabinet to OFF position.

" 3. Set heater remote controller to 100°F.

" 4. Set heater internal SCR controller to 500°F.

" 5. Set hi-low pressure switches to 40 psig and 10 psig, respectively.

" 6. Set tracker control switch in AUTOMATIC position.

" 7. Set tracker manual motor control in OFF position.

" 8. Set "main starter" toggle switch to OFF position.

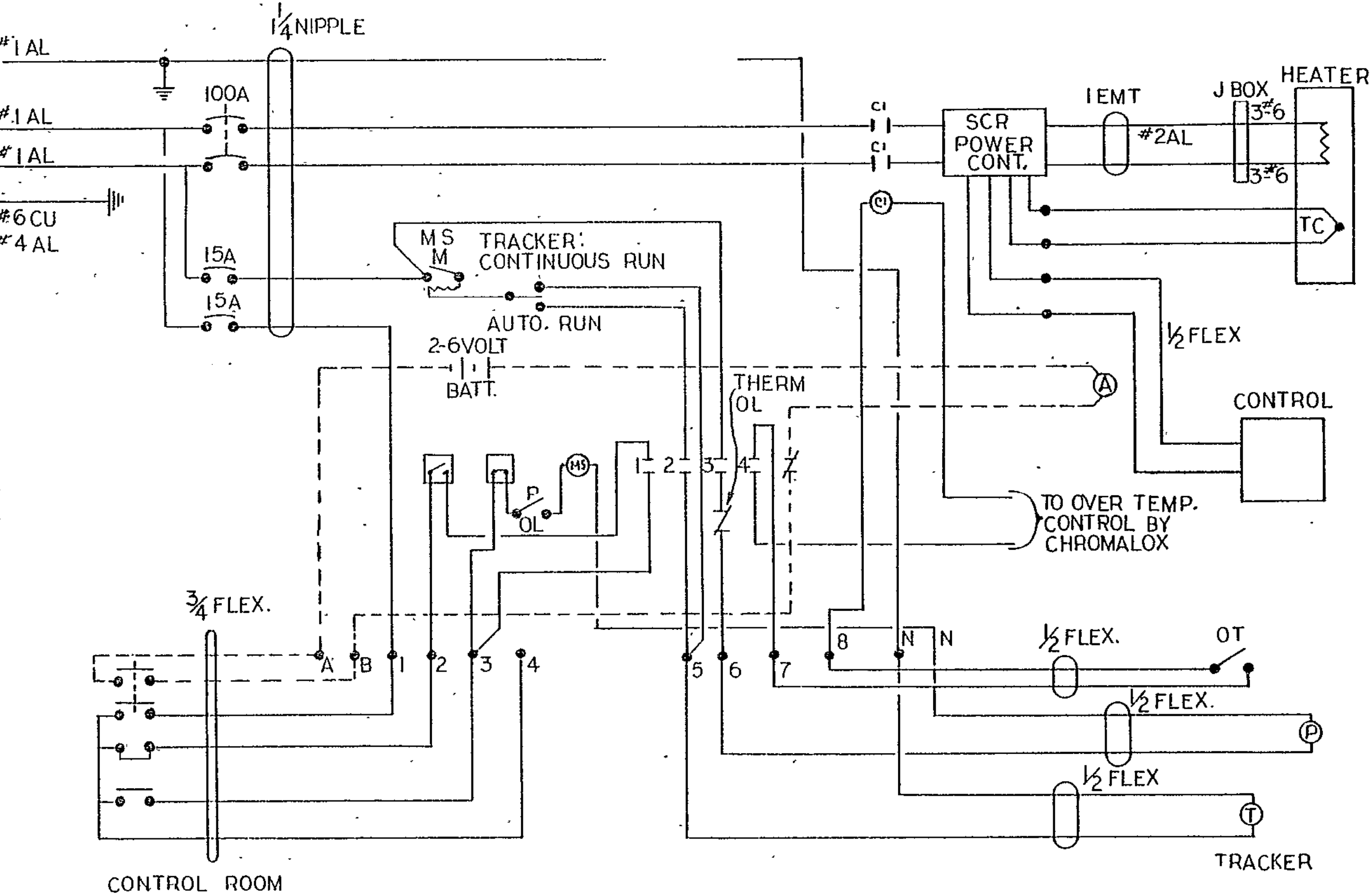


Figure A-1. Wiring Diagram for Electrical Control System

Step 9. Check voltage on dry-cell battery pack.

" 10. Check that fluid loop is pressurized to approximately 5 psig.

" 11. Press "main starter" START button and monitor pump tracker system and audible alarm components to ensure that they do not operate.

" 12. Flip "main starter" toggle switch to ON position and observe audible alarm. Turn "main starter" toggle switch OFF.

" 13. Set breaker 1 to ON position.

" 14. Set "main starter" toggle switch to ON position and observe audible alarm.

" 15. Jog START button, then jog STOP button on "main starter" and observe that audible alarm operates intermittently. Monitor pump and tracker system and note that they do not operate.

" 16. Set breaker 2 to ON position.

" 17. Set tracker control switch in MANUAL position.

" 18. Set tracker manual motor control to ON position and observe that tracker system operates.

" 19. Set tracker control switch in AUTOMATIC position and observe that tracker system ceases to operate.

" 20. Set tracker control switch in MANUAL position and observe that tracker system operates.

" 21. Set tracker motor control in OFF position and observe that tracker system ceases to operate.

" 22. Set "main starter" toggle switch to ON position. Observe audible alarm.

" 23. Jog "main starter" START button, then jog STOP button and observe that the pump does not operate. Observe that alarm sounds continuously during the START-STOP jogging operation.

" 24. Set "main starter" toggle switch to OFF position and observe that audible alarm stops.

" 25. Open valves A, B, D, E, F and G.

" 26. Check that valve C and fill-line valve are closed.

" 27. Open system GN_2 regulator and system GN_2 valve and pressurize fluid loop to 17 psig.

" 28. Set "main starter" toggle switch to ON position and observe audible alarm.

Step 29. Jog "main starter" START button, then jog STOP button and observe corresponding intermittent operation of pump and audible alarm.

" 30. Set tracker control switch in AUTOMATIC position.

" 31. Set tracker motor control in ON position.

" 32. Jog "main starter" START button, then jog STOP button and observe corresponding intermittent operation of pump, tracker system, and audible alarm.

" 33. Set "main starter" toggle switch to OFF position.

" 34. Set hi-pressure switch to 20 psig.

" 35. Set GN_2 pressure relief valve to 30 psig.

" 36. Increase system GN_2 regulator to 27 psig and pressurize fluid loop to 27 psig.

" 37. Set "main starter" toggle switch to ON position.

" 38. Jog "main starter" START button, then jog STOP button and observe that pump and tracker system do not operate and that audible alarm sounds continuously.

" 39. Set "main starter" toggle switch to OFF position.

" 40. Reset hi-pressure switch to 40 psig.

" 41. Depressurize fluid loop to 5 psig by closing system GN_2 regulator and opening GN_2 vent valve.

" 42. Close GN_2 vent valve and pressurize fluid loop to 10 psig.

" 43. Set breakers 1 and 2 to OFF position.

The remaining electrical control system checkout tests will be performed during component operational tests which follows loading of the system with thermal fluid. Components to be checked with thermal fluid in the fluid loop are:

1. Breaker 3 in the main power box which provides power to the SCR power controller.
2. Set-point SCR controller in the large power console on the test apparatus.
3. Remote set-point controller in the control room.
4. System over-temperature limit switch.

The checkout procedure for the above items are presented in Appendix C.

APPENDIX B

FLUID LOOP PURGING AND LOADING PROCEDURE

APPENDIX B

FLUID LOOP PURGING AND LOADING PROCEDURE

1.0 FLUID LOOP PURGING PROCEDURE

The thermal fluid loop should be purged prior to loading the fluid loop with thermal fluid for test purposes. The purging procedure will consist of the following sequential phases:

Phase A — System Drainage and GN_2 Purge

Phase B — Thermal Fluid Loading

Phase C — System Bleeding

Phase D — Repeat Phase A - System Drainage and GN_2 Purge

See Figure B-1 for nomenclature.

1.1 Phase A — System Drainage and GN_2 Purge

Basic System Drainage and GN_2 Purge (See Figure)

The step-by-step procedure for performing a basic drainage and GN_2 purge of the fluid loop follows:

Step 1. Check that both fill-line valve and supply-line valve are closed.

" 2. Disconnect supply line from fill line if not presently disconnected.

" 3. Check that tank drain valve is closed.

" 4. Open system GN_2 regulator and pressurize system to 10 psig.

" 5. Check that fluid loop is at near ambient temperature.

" 6. Provide drain plans for capturing drained fluid at fill-line valve and expansion tank drain valve.

" 7. Close valve C.

" 8. Open valves A, B, D, E, F and G.

" 9. Open fill-line valve and drain system.

" 10. Slowly open valve C and drain flowmeter line, then close valve C.

" 11. Close fill-line valve.

" 12. Close valves A, B and F.

" 13. Open fill-line valve and purge system through valves D, E and G.

" 14. Close fill-line valve.

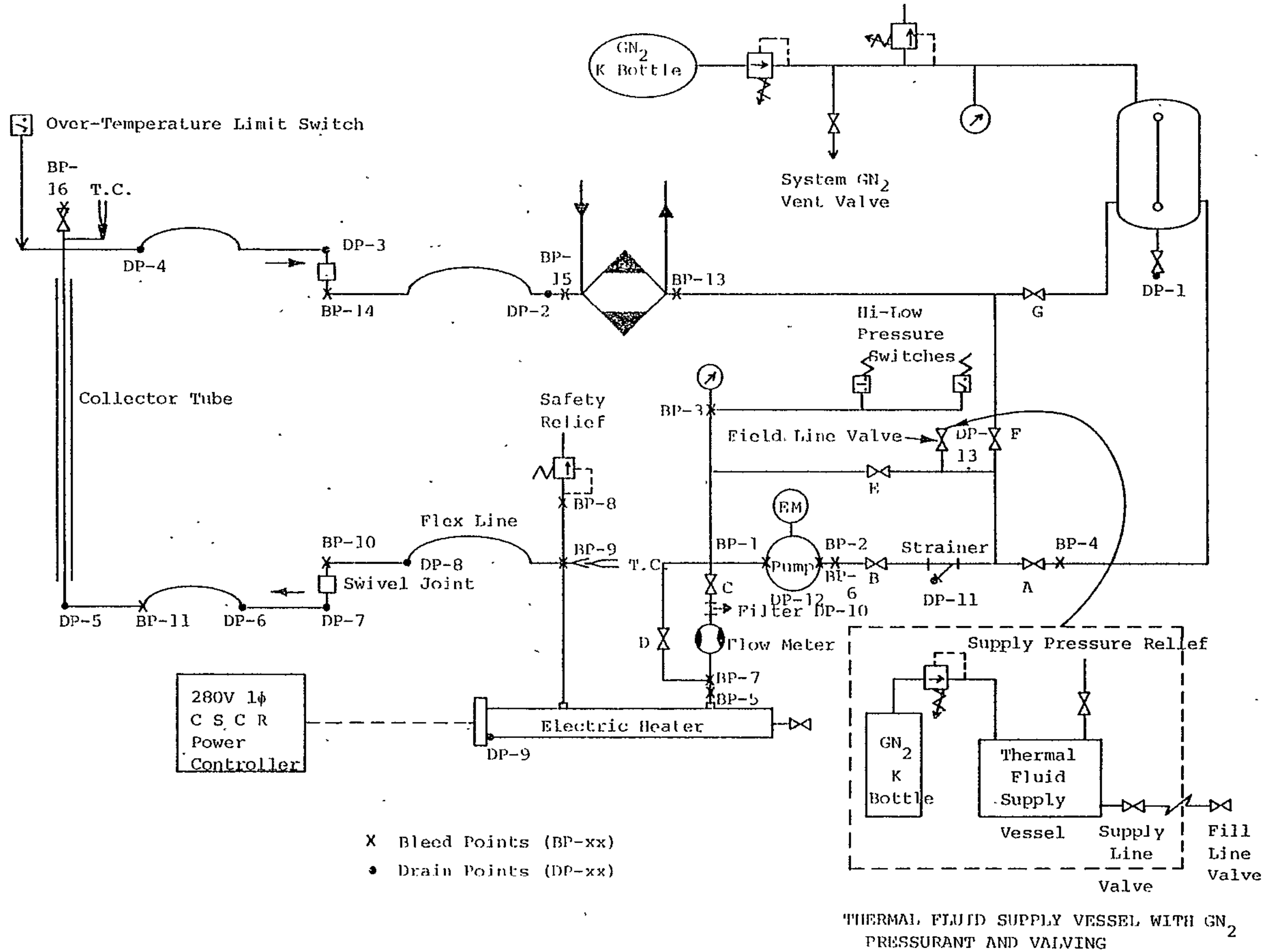


Figure B-1. Test Article Fluid Flow Loop Showing Valve, Bleed Point and Drain Point Notation

" 15. Close valves D and E.

" 16. Open valve F.

" 17. Open fill-line valve and purge system through valves F and G.

" 18. Close fill-line valve.

" 19. Close Valve F.

" 20. Remove pump drive protective cover.

" 21. Open valves A, B and E.

" 22. Open fill-line valve and purge system through valves A, B and E while rotating fluid loop pump by hand.

" 23. Close fill-line valve.

" 24. Close system GN_2 regulator.

Basic system drainage and GN_2 purge is complete. System is ready for incremental system drainage and GN_2 purge.

Incremental System Drainage and GN_2 Purge

The thermal fluid loop shall be drained and purged at incremental points in the loop where condensation or residual fluid may become trapped. Such points are all saddle points in the fluid loop. The fluid loop shall be drained and purged at the following locations in the sequency presented:

DP-1 Storage Tank Drain Line
DP-2 Flex Line at Heat Exchanger Inlet
DP-3 Ell Joint at Swivel Joint (Collector Tube Outlet Line)
DP-4 Collector Tube Outlet Flex Line
DP-5 Collector Tube Inlet
DP-6 Collector Tube Inlet Flex Line
DP-7 Ell Joint at Swivel Joint (Collector Tube Inlet Line)
DP-8 Drain Plug at Outlet of Heater Flex Line
DP-9 Electric Heater Header
DP-10 Flowmeter Filter
DP-11 Pump Strainer
DP-12 Pump Housing
DP-13 Fill-Line Valve

The step-by-step procedure for each drain location follows:

NOTE: Before opening drain points which require disconnecting the fluid loop line, the loop should be depressurized to prevent the thermal fluid from spraying. However, where possible the fluid loop should be intermittently pressurized by plugging the drain point by hand, letting the pressure build up in the system, and purging the line by unplugging the drain point. Repetition of this technique several times should be effective in blowing out residual fluid.

DP-1 — Expansion Tank Drain Line

Step 1. Open expansion tank drain valve.
" 2. Close valves A and G.
" 3. Open system GN_2 regulator and purge storage tank and drain line.
" 4. Close system GN_2 regulator.
" 5. Close expansion tank drain line.

DP-2 — Flex Line at Heat Exchanger Inlet

Step 1. Disconnect flex line at heat exchanger inlet.
" 2. Open valves A, D and E.
" 3. Close valves B, C, F, G and fill-line valve.
" 4. Open system GN_2 regulator and purge system (through flex line).
" 5. Close GN_2 regulator.
" 6. Close valves A, D and E.
" 7. Open valve G.
" 8. Open system GN_2 regulator and purge system.
" 9. Close system GN_2 regulator.
" 10. Reconnect flex line.

DP-3 — Ell Joint at Swivel Joint (Collector Tube Outlet Line)

Step 1. Rotate lens frame to the east and lock in place.
" 2. Disconnect line from ell at swivel joint.
" 3. Check that valve G is open.
" 4. Check that valves A, B, C, D, E and F are closed.
" 5. Open system GN_2 regulator and purge system.
" 6. Close GN_2 regulator.
" 7. Close valve G.
" 8. Open valves A, D and E.
" 9. Open system GN_2 regulator and purge system.
" 10. Close system GN_2 regulator.
" 11. Reconnect line to ell.

DP-4 — Collector Tube Outlet Flex Line

Step 1. Rotate lens frame to the west and lock in place.

" 2. Disconnect flex line on low side.

" 3. Check that valves A, D and E are open.

" 4. Check that valves B, C, F and G are closed.

" 5. Open system GN_2 regulator and purge system (through collect tube).

" 6. Open valve G.

" 7. Close valves A, D and E.

" 8. Open system GN_2 regulator and purge system (through flex line).

" 9. Close system GN_2 regulator.

" 10. Reconnect flex line.

DP-5 — Collector Tube Inlet

Step 1. Rotate lens frame to the east and lock in place.

" 2. Disconnect line at inlet to collector tube.

" 3. Check that valve G is open.

" 4. Check that valves A, B, C, D, E and F are closed.

" 5. Open system GN_2 regulator and purge system.

" 6. Close system GN_2 regulator.

" 7. Rotate lens frame to the west and lock in place.

" 8. Close valve G.

" 9. Open valves A, D and E.

" 10. Open system GN_2 regulator and purge system.

" 11. Close system GN_2 regulator.

" 12. Reconnect line to collector tube inlet.

DP-6 — Collector Tube Inlet Flex Line

Step 1. Rotate lens frame to the east and lock in place.

" 2. Disconnect flex line on low side.

" 3. Check that valves A, D and E are open.

" 4. Check that valves B, C, F and G are closed.

Step 5. Open system GN_2 regulator and purge system (through flex line).

" 6. Close system GN_2 regulator.

" 7. Close valves A, D and E.

" 8. Open valve G.

" 9. Open system GN_2 regulator and purge system.

" 10. Close system GN_2 regulator.

" 11. Reconnect flex line.

DP-7 — Ell Joint at Swivel Joint (Collector Tube Inlet Line)

Step 1. Rotate lens frame to the west and lock in place.

" 2. Disconnect line from ell at swivel joint.

" 3. Check that valve G is open.

" 4. Check that valves A, B, C, D, E and F are closed.

" 5. Open system GN_2 regulator and purge system.

" 6. Close system GN_2 regulator.

" 7. Close valve G.

" 8. Open valves A, D and E.

" 9. Open system GN_2 regulator and purge system.

" 10. Close system GN_2 regulator.

" 11. Reconnect line to ell.

DP-8 — Ell Drain at Outlet of Heater Flex Line

Step 1. Remove drain plug in ell at outlet of heater flex line.

" 2. Check that valves A, D and E are open.

" 3. Check that valves B, C, F and G are closed.

" 4. Open system GN_2 regulator and purge system.

" 5. Close system GN_2 regulator.

" 6. Close valves A, D and E.

" 7. Open valve G.

" 8. Open system GN_2 regulator and purge system.

" 9. Close system GN_2 regulator.

" 10. Replace drain plug in ell.

DP-9 — Electric Heater Header

Step 1. Loosen electric heater header and pull out to open approximately a 1/2-inch gap between header and tank.

" 2. Check that valve G is open.

" 3. Check that valves A, B, C, D, E and F are closed.

" 4. Open system GN_2 regulator and purge heater.

" 5. Close system GN_2 regulator.

" 6. Close valve G.

" 7. Open valves A, D and E.

" 8. Open system GN_2 regulator and purge system.

" 9. Close system GN_2 regulator.

" 10. Replace heater header.

DP-10 — Flowmeter Filter

Step 1. Check that system is at atmospheric pressure.

" 2. Remove filter element from flowmeter filter and let system drain.

" 3. Open valves C and E.

" 4. Open fill-line valve and let system drain.

NOTE: Do not purge system with GN_2.

" 5. Close valve C.

" 6. Clean filter element.

" 7. Replace filter element.

DP-11 — Pump Strainer

Step 1. Remove small drain plug in pump strainer and let system drain.

" 2. Remove large plug and strainer from pump strainer housing.

" 3. Close valve B.

" 4. Open valves A, B, F and G.

" 5. Open system GN_2 regulator and purge system.

" 6. Close system GN_2 regulator.

" 7. Clean strainer and replace in strainer housing.

" 8. Replace small drain plug in pump strainer.

DP-12 — Pump Housing

Step 1. Remove drain plugs on inlet and outlet sides of pump housing.

" 2. Open valves A and B.

" 3. Close valves C, D, E, F and G.

" 4. Open system GN_2 regulator and purge inlet side plug.

" 5. Close system GN_2 regulator.

" 6. Close valves A and B.

" 7. Open valves D and G.

" 8. Open system GN_2 regulator and purge outlet side plug.

" 9. Close GN_2 regulator.

" 10. Replace plugs in pump housing.

DP-13 — Fill-Line Valve

Step 1. Open fill-line valve.

" 2. Open valve A.

" 3. Close valves B, C, D, E, F and G.

" 4. Open system GN_2 regulator and purge system.

" 5. Close system GN_2 regulator.

" 6. Open valves F and G.

" 7. Close valve A.

" 8. Open system GN_2 regulator and purge system.

" 9. Close system GN_2 regulator.

" 10. Close valve F.

" 11. Open valves D and E.

" 12. Open system GN_2 regulator and purge system.

" 13. Close system GN_2 regulator.

" 14. Close fill-line valve.

Incremental system drainage and GN_2 purge is completed.

Phase A — System Drainage and GN_2 Purge is completed. System is ready for Phase B — Thermal Fluid Loading.

1.2 Phase B — Thermal Fluid Loading

Thermal fluid loading shall be accomplished by force feeding thermal fluid into the fluid loop through the fill-line port from a pressurized thermal fluid supply vessel.

Preliminary Set-Up

Step 1. Check that fill-line valve is closed.

" 2. Assemble thermal fluid supply vessel with associated GN_2 pressurant and valving and connect to fill line.

" 3. Set pressure relief valve on thermal fluid supply vessel to 50 psig and purge vessel with GN_2 by pressurizing supply vessel to approximately 60 psig.

" 4. Close supply vessel GN_2 regulator and depressurize supply vessel to 25 psig.

" 5. With fluid supply vessel pressurized at 25 psig, bleed supply line at fill-line valve juncture, leaving fill-line valve closed.

" 6. Perform leak test on system by:

6a. Check that all bleed point and drain point fittings are tight.

6b. Open valves A, B, D, E, F and G.

6c. Close valve C.

6d. Open system GN_2 regulator and pressurize fluid loop to 20 psig.

6e. Check that expansion tank pressure relief valve operated at 20 psig.

6f. Close system GN_2 regulator and monitor system pressure gauge for leaks. If system pressure remains stable for 10 minutes, proceed with thermal fluid loading.

Thermal Fluid Loading

NOTE: During the following steps 1 through 17, check supply vessel pressure and maintain at approximately 25 psig.

Step 1. Close valves A, B, C, D and F.

" 2. Open valves E and G.

" 3. Slowly open fill-line valve.

" 4. Bleed system at pump outlet plug and retighten plug.

" 5. Open valve B.

Step 6. Bleed system at pump inlet plug while rotating pump by hand.

" 7. Bleed system at system pressure gauge and retighten.

" 8. Bleed system at pump inlet ell and retighten.

" 9. Close valve B.

" 10. Slowly open valve D. Observe for possible fluid rise in expansion tank. If fluid rises in expansion tank, close valve D and check fluid supply pressure. Fluid should not rise to expansion tank at this condition.

NOTE: Check for fluid rise in expansion tank following each of steps 11 through 16.

" 11. When system pressure has stabilized, slowly open valve C.

" 12. Bleed system at flowmeter line connection at heater inlet. Retighten fitting.

" 13. Close valve C.

" 14. Bleed system at valve D line connection to heater inlet. Retighten fitting.

" 15. Bleed system at safety relief valve plug and retighten plug.

" 16. Bleed system at heater outlet plug and retighten plug.

" 17. Close valve E.

" 18. Increase pressure in thermal fluid supply vessel to 40 psig.

" 19. Slowly open valve E and observe for fluid rise in expansion tank. When fluid reaches 1/4-full level, close valve E.

" 20. Slowly open valve A and observe for fluid rise in expansion tank. When fluid reaches 1/2-full level, close valve A.

" 21. Slowly open valve F and observe for fluid rise in expansion tank. When fluid reaches 3/4-full level, close valve F.

" 22. Close fill-line valve.

" 23. Close supply-line valve.

" 24. Open valves A, B, C, D, E, F and G.

Phase B — Thermal Fluid Loading is completed. System is ready for Phase C — System Bleeding.

1.3 Phase C — System Bleeding

The fluid loop shall be bled at strategic points in the loop where residual gas may have become trapped during fluid loading. Such points are crest points in the fluid loop. System bleeding shall be accomplished by opening the fluid loop at strategic points and bleeding off trapped gas—working from the lowest points in the fluid loop to the highest points for each major leg of the loop. The system will be bled at the following locations in the sequence presented:

- BP-1 Pump Housing Outlet Plug
- BP-2 Pump Housing Inlet Plug
- BP-3 System Pressure Gauge
- BP-4 Valve A
- BP-5 Flowmeter Line at Heater Inlet
- BP-6 Inlet Ell to Pump
- BP-7 Valve D Line at Heater Inlet
- BP-8 Safety Relief Valve Plug
- BP-9 Heater Outlet Plug
- BP-10 Lower Bleed Plug at Swivel Joint
- BP-11 Flex Line on Inlet (East) Side to Collector Tube
- BP-12 Inlet to Heat Exchanger
- BP-13 Outlet to Heat Exchanger
- BP-14 Upper Bleed Plug at Swivel Joint
- BP-15 Flex Line on Outlet (West) Side to Collector Tube
- BP-16 Rotate Lens Frame to the West — Bleed Plug at Collector Tube Outlet

The following step-by-step procedure shall be followed for system bleeding at each sequential bleed point:

Step 1. Check that valves A, B, C, D, E, F and G are open.

" 2. Vent system to 5 psig by opening system GN_2 vent valve. Close GN_2 vent valve.

" 3. Open system GN_2 regulator and pressurize system to 10 psig.

" 4. Check that expansion tank thermal fluid level is approximately 3/4-full level.

" 5. Bleed system at each of the designated bleed points in the aforementioned sequence. For each location, the bleeding procedure will consist of loosening the appropriate plug or fitting, bleeding off residual gas, retightening the plug or fitting, and observing for leeks before proceeding to the next bleed point.

When system bleeding has been accomplished for all designated bleed points, Phase C — System Bleeding is completed. System is ready for Phase D — Repeat of Phase A — System Drainage and GN_2 Purge.

2.0 THERMAL FLUID LOADING PROCEDURE

Prior to loading the fluid loop with thermal fluid for test purposes, the preceding fluid loop purging procedure, as described in Section 1.1, shall have been accomplished. The thermal fluid loading procedure consists of three sequential phases:

Phase A — System Loading

Phase B — System Bleeding

Phase C — Thermal Fluid Make-Up..

2.1 Phase A — System Loading

Thermal fluid shall be loaded into the fluid loop system in the same manner as described in Section 1.2. This procedure is repeated as follows:

Preliminary Set-Up

Step 1. Check that fill-line valve is closed.

" 2. Assemble thermal fluid supply vessel with associated GN_2 pressurant and valving and connect supply line to fill line.

" 3. Set pressure relief valve on thermal fluid supply vessel to 50 psig and purge vessel with GN_2 by pressurizing supply vessel to approximately 60 psig.

" 4. Close supply vessel GN_2 regulator and depressurize supply vessel to 25 psig.

" 5. With fluid supply vessel pressurized at 25 psig, bleed supply line at fill-line valve juncture, leaving fill-line valve closed.

" 6. Perform leak test on system by:

6a. Check that all bleed point and drain point fittings are tight.

6b. Open valves A, B, D, E, F and G.

6c. Close valve C.

6d. Open system GN_2 regulator and pressurize fluid loop to 20 psig.

6e. Check that expansion tank pressure relief valve operates at 20 psig.

6f. Close system GN_2 regulator and monitor system pressure gauge for leaks. If system pressure remains stable for 10 minutes, proceed with thermal fluid loading.

Step 22. Close fill-line valve.

" 23. Close supply-line valve.

" 24. Open valves A, B, C, D, E, F and G.

Phase A — System Loading is completed. System is ready for Phase B — System Bleeding.

2.2 Phase B — System Bleeding

System bleeding of the fluid loop prior to conducting solar heating tests will differ from the previous bleeding procedure presented in Section 1.3 in that several cyclic operations shall be performed to ensure that all trapped gas is removed from the fluid loop.

An initial system bleed will be performed prior to the operation of system components, such as the pump and electrical heater. However, during system operational tests of components, system bleeding will be repeated at several stages of operational tests (see Appendix C) to ensure the removal of trapped gas in the fluid loop. The initial system bleed prior to component operational tests will consist of the following sequential operations:

1. System Bleeding
2. System Pressurization and Venting
3. System Bleeding.

The following step-by-step procedure for each basic operation follows:

System Bleeding

All system bleeding operations shall be performed at bleed points identified as BP-1 through BP-17 in Section 1.3. For convenience in performing this operation, these bleed points are tabulated as follows:

BP-1 Pump Housing Outlet Plug
BP-2 Pump Housing Inlet Plug
BP-3 System Pressure Gauge
BP-4 Valve A
BP-5 Flowmeter Line at Heater Inlet
BP-6 Inlet Ell to Pump
BP-7 Valve D Line at Heater Inlet
BP-8 Safety Relief Valve Plug
BP-9 Heater Outlet Plug
BP-10 Lower Bleed Plug at Swivel Joint
BP-11 Flex Line to Inlet (East) Side to Collector Tube
BP-12 Inlet to Heat Exchanger
BP-13 Outlet to Heat Exchanger
BP-14 Upper Bleed Plug at Swivel Joint
BP-15 Flex Line on Outlet (West) Side to Collector Tube
BP-16 Rotate Lens Frame to the West — Bleed Plug at Collector Tube Outlet.

Thermal Fluid Loading

NOTE: During the following steps 1 through 17, check supply vessel pressure and maintain at approximately 25 psig.

Step 1. Close valves A, B, C, D and F.

" 2. Open valves E and G.

" 3. Slowly open fill-line valve.

" 4. Bleed system at pump outlet plug and retighten plug.

" 5. Open valve B.

" 6. Bleed system at pump inlet plug while rotating pump by hand. Retighten plug.

" 7. Bleed system at system pressure gauge and retighten.

" 8. Bleed system at pump inlet ell and retighten.

" 9. Close valve B.

" 10. Slowly open valve D. Observe for possible fluid rise in expansion tank. If fluid rises in expansion tank, close valve D and check fluid supply pressure. Fluid should not rise to expansion tank at this condition.

NOTE: Check for fluid rise in expansion tank following each of steps 11 through 16.

" 11. When system pressure has stabilized, slowly open valve C.

" 12. Bleed system at flowmeter line connection at heater inlet. Retighten fitting.

" 13. Close valve C.

" 14. Bleed system at valve D line connection to heater inlet. Retighten fitting.

" 15. Bleed system at safety relief valve plug and retighten plug.

" 16. Bleed system at heater outlet plug and retighten plug.

" 17. Close valve E.

" 18. Increase pressure in thermal fluid supply vessel to 40 psig.

" 19. Slowly open valve E and observe for fluid rise in expansion tank. When fluid reaches 1/4-full level, close valve E.

" 20. Slowly open valve A and observe for fluid rise in expansion tank. When fluid reaches 1/2-full level, close valve A.

" 21. Slowly open valve F and observe for fluid rise in expansion tank. When fluid reaches 3/4-full level, close valve F.

The step-by-step procedure for system bleeding at each of the above sequential bleed points is the same as described in steps 1 through 5 in Section 1.3, and restated as follows:

Step 1. Check that valves A, B, C, D, E, F and G are open.

" 2. Vent system to 5 psig by opening system GN_2 vent valve. Close GN_2 vent valve.

" 3. Open system GN_2 regulator and pressurize system to 10 psig.

" 4. Check that expansion tank thermal fluid level is 1/2- to 3/4-full level.

" 5. Bleed system at each of the designated bleed points in the aforementioned sequence. For each location, the bleeding procedure will consist of loosening the appropriate plug or fitting, bleeding off residual gas, retightening the plug or fitting, and observing for leaks before proceeding to the next bleed point.

When system bleeding has been accomplished at all designated bleed points, the system is ready for the next sequential operation.

System Pressurization and Venting

This operation is intended to release entrained gas bubbles so that they will float to the crest points in the fluid loop where they can be removed through incremental bleeding. This operation also provides for purging the gas volume in the storage tank with GN_2. The step-by-step procedure for this operation is the same as for the standard system leak test. A description follows:

Step 1. Check that all bleed point fittings are tight.

" 2. Check that fill-line valve is closed.

" 3. Check that valves A, B, C, D, E, F and G are open.

" 4. Open GN_2 regulator and pressurize system to 20 psig.

" 5. Close GN_2 regulator and observe for leaks.

" 6. If no leaks are detected after 10 minutes, open GN_2 vent valve and bleed system to 5 psig.

" 7. Close GN_2 vent valve.

2.3 Phase C — Thermal Fluid Make-Up

This operation is intended to replenish fluid in the expansion tank and should be performed during the system bleeding when the tank fluid level drops below approximately 1/4-full level. Fluid make-up shall be accomplished by the following step-by-step procedure:

Step 1. Check that all bleed point fittings are tight.

" 2. Check that fill-line valve is closed.

" 3. Assemble thermal fluid supply vessel with associated GN_2 pressurant and valving and connect supply line to fill line.

" 4. Open vent valve on thermal fluid supply vessel and purge vessel with GN_2.

" 5. Close vent valve.

" 6. Pressurize fluid supply vessel to 30 psig and bleed supply line at fill-line valve juncture, leaving fill-line valve closed.

" 7. Close valves A, B, C, D and E.

" 8. Open valves F and G.

" 9. Slowly open fill-line valve and observe fluid rise in storage tank. When fluid rises to approximately 3/4-full level, close fill-line valve.

" 10. Close supply line valve.

" 11. Open valves A, B, C, D, E, F and G.

Phase C — Thermal Fluid Make-Up is completed. System is ready for resumption of system bleeding following standard step-by-step bleed procedure.

Initial system bleeding is completed and the thermal fluid loading procedure is completed. System is ready for Operational Tests.

APPENDIX C

COMPONENT OPERATIONAL TESTS

APPENDIX C

COMPONENT OPERATIONAL TESTS

Following the performance of step-by-step procedures presented in Appendices A and B, the system is ready to commence final "pretest" operational tests for verification of system operability and final checkout before commencing solar data collection. Operational tests will be performed by "phasing in" the various components of the system "sequentially" and verifying, at each step of the "phasing in" process, the operability of each system components before proceeding to the next component.

1. Electrical Heater Checkout (Pump Deactivated)
2. Pump Operation
3. Pump Packing Adjustment (Pump Activated)
4. Electrical Heater Checkout (Pump Activated)
5. Flowmeter Checkout (Pump and Heater Activated)
6. Heat Exchanger Checkout (Pump Activated)
7. System Shutdown and System Bleed (Pump Deactivated)
8. Integrated System Operation and Shake Down (Pump Activated)
9. System Shutdown and System Bleed (Pump Deactivated).

The step-by-step procedure for each of the above sequence of operations follows. See Figure C-1 for nomenclature.

1.0 ELECTRICAL HEATER CHECKOUT (PUMP DEACTIVATED)

This checkout is to be performed with the fluid loop loaded with thermal fluid and the pump not operating.

Step 1. Check that breakers 1, 2 and 3 are in OFF position.

" 2. Set heater internal SCR controller to 500°F.

" 3. Set heater remote controller to 100°F.

" 4. Set temperature limit switch to 200°F.

" 5. Open heater controller cabinet and manually reset cabinet handle interlock.

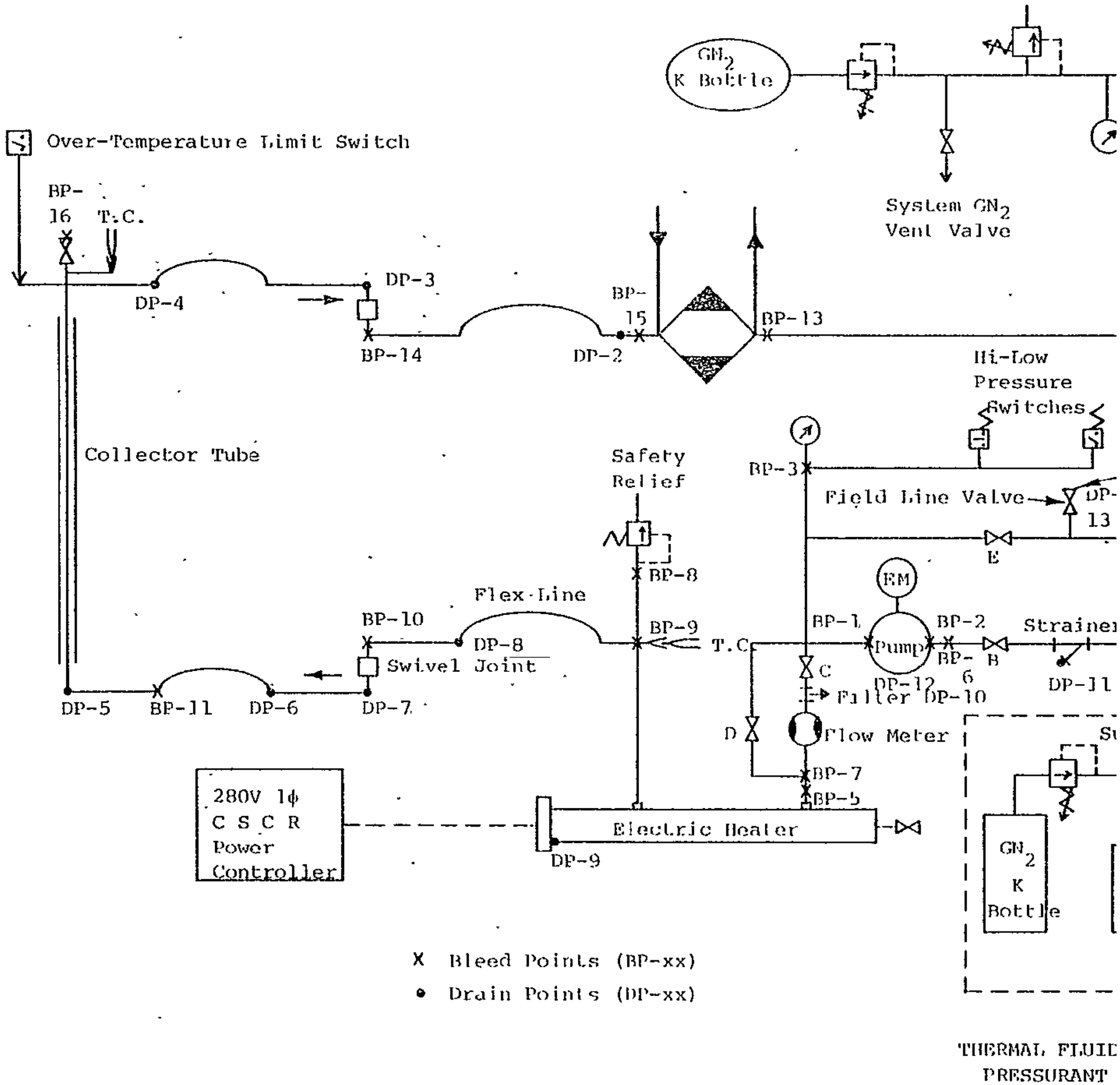


Figure C-1. Test Article Fluid Flow Loop Showing Valve, Bleed Point and Drain P

Step 6. Attach current monitor to load side of SCR controller.

" 7. Check that fluid loop pressure is 17 psig.

" 8. Check that tracker manual motor control is in OFF position.

" 9. Set Breaker 1 to ON position and observe SCR controller output current to ensure that heater system is not activated.

" 10. Set "main starter" toggle switch to ON position and observe SCR controller output current to ensure that heater system is not activated.

" 11. Jog "main starter" START button, then jog STOP button and observe SCR controller output current to ensure that heater system is not activated.

" 12. Set "main starter" toggle switch to OFF position.

" 13. Set breaker 3 to ON position.

" 14. Set "main starter" toggle switch to ON position.

" 15. Jog "main starter" START button, then jog STOP button and observe SCR controller output current. Intermittent current to heater corresponding to "main starter" jogging should be observed. Observe that alarm sound continuously during jogging operation.

" 16. Set "main starter" toggle switch to OFF position.

" 17. Set breakers 1 and 3 to OFF position.

2.0 PUMP OPERATION

This operation is intended to provide both pump checkout and fluid circulation so that entrained gas bubbles may be convected to crest points where they can be removed through incremental bleeding. The step-by-step procedure for this operation follows:

Step 1. Check that all bleed point fittings are tight.

" 2. Check that fill-line valve is closed.

" 3. Close valve C.

" 4. Open valves A, B, D, E, F and G.

" 5. Check that hi-low pressure switches are set at 40 psig and 10 psig, respectively.

" 6. Check that GN_2 relief valve is set at 20 psig (TAG).

" 7. Check that system safety relief valve is set at 60 psig.

" 8. Open GN_2 regulator and pressurize system to 20 psig. Close system GN_2 regulator and observe for leaks. If no leaks are detected after 10 minutes, open GN_2 vent valve and vent system to 5 psig.

Step 9. Open GN_2 regulator and pressurize system to 10 psig at expansion tank and observe that fluid loop pressure is 17 psig.

" 10. System is ready to initiate pump operation as follows:

10a. Set tracker manual motor control switch to OFF position.

10b. Set breaker 1 and breaker 2 to ON position.

10c. Check that breaker 3 is in OFF position.

10d. Set "main starter" toggle switch to ON position. Observe audible alarm.

10e. Press "main starter" START button and observe that pump operation is initiated. Monitor system pressure gauge and note system pressure rise. Continue to monitor system pressure gauge until system pressure either (1) stabilizes below 40 psig or (2) reaches 40 psig, at which time the pump should be cut off by either pressing "main starter" STOP button or opening breaker 2. If system pressure stabilizes below 40 psig, continue with step 11. If pump cut-off is necessary due to pressure rise to 40 psig, check that valve positions are as noted in steps 3 and 4 and reduce GN_2 pressure to 5 psig and repeat step 10.

" 11. Monitor pump drive housing stuffing box for temperature increase or pump drive binding. If pump drive housing heats up, loosen packing gland nuts.

3.0 PUMP PACKING ADJUSTMENT (PUMP ACTIVATED)

Step 1. While maintaining pump operation, carefully tighten the packing gland nuts to reduce any leakage. Make sure that during this adjustment period that the temperature of the stuffing box does not increase. An adjustment of approximately 1/8 turn at a time is maximum.

" 2. Allow approximately 15 to 20 minutes between adjustments. If during this period, heating occurs such that the stuffing box is uncomfortable to the touch (140°F), back off on the adjustment nuts and pump to run until stuffing box cools, then start adjustment again.

" 3. Several hours of operation may be required to achieve proper adjustment. Packing gland adjustment should be checked several times during the initial operation involving the pump.

4.0 ELECTRICAL HEATER CHECKOUT (PUMP ACTIVATED)

Step 1. Check that pump is operating satisfactorily.

" 2. Check that breakers 1 and 2 are in ON position and that breaker 3 is in OFF position.

Step 3. Check that heater internal SCR controller is set at 500°F.

" 4. Check that heater remote controller is set at 100°F.

" 5. Check that temperature limit switch is set at 200°F.

" 6. Open heater controller cabinet and manually reset cabinet handle interlocks.

" 7. Attach current monitor to load side of SCR controller.

" 8. Check that tracker manual motor control is in OFF position.

" 9. Check that valves A, B, D and G are open.

" 10. Close valves C, E and F.

" 11. Set breakers 1 and 3 to ON position.

" 12. Set "main starter" toggle switch to ON position and observe audible alarm.

" 13. Press "main starter" START button and observe SCR controller output current and heater activation.

" 14. Monitor fluid loop thermocouples on data logger and observe temperature increase.

" 15. Continue system operation and observe that system temperature at thermocouple no. 4 stabilizes at approximately 100°F.

" 16. Set heater remote controller to 200°F.

" 17. Observe system temperature increase as indicated by fluid loop thermocouples. Note temperature stabilization slightly below 200°F.

" 18. Set heater remote controller to 250°F.

" 19. Observe system temperature increase to slightly above 200°F and heater shutdown due to temperature limit switch tripping. Note fluid loop thermocouple readings at the point of heater shutdown for future reference. Observe continuation of pump operation following heater shutdown.

" 20. Set breaker 3 to OFF position.

" 21. Set temperature limit switch to 400°F.

" 22. Set heater remote controller to 200°F.

" 23. Reset SCR controller breaker.

" 24. Set breaker 3 to ON position and observe that fluid loop temperature stabilizes at alightly less than 200°F.

" 25. Maintain system status in preparation for flowmeter checkout to follow.

5.0 FLOWMETER CHECKOUT (PUMP AND HEATER ACTIVATED)

Step 1. Check that valves A, B and D are open.

" 2. Check that valves C and F are closed.

" 3. Open valve E approximately 50 percent (1-1/2 turns)

" 4. Set heater remote controller to 250°F.

" 5. Stabilize flowmeter inlet temperature at 200 to 250°F.

" 6. Check that flowmeter electrical connections are intact and turn on flowmeter power supply.

" 7. Slowly open valve C while monitoring flowmeter output. If flowmeter output is detected with valve C slightly open, recheck flowmeter electrical system. If flowmeter output is detected, continue opening valve C until:

(a) Flowmeter reading indicates 2.5 gpm,

OR

(b) Valve C is full-open.

If (a) in step 7, continue to step 8.
If (b) in step 7, omit step 8 and go to step 9.

" 8. Open valve E until flowmeter indicates 0.25 gpm. Go back to step 6.

" 9. Slowly close valve D until:

(a) Flowmeter indicates 2.5 gpm,

OR

(b) Valve D is fully closed.

If (a) in step 9, continue to step 10.
If (b) in step 9, omit step 10 and go to step 11.

" 10. Open valve E until flowmeter indicates 0.25 gpm. Go back to step 9.

" 11. Assure that valve D is fully closed.

" 12. Slowly adjust valve E until the flowrate is 1.25 gpm.

NOTE: Open valve E to decrease flowrate.
Close valve E to increase flowrate.

" 13. Slowly increase set point temperature on heater remote controller to 300°F while maintaining approximately 1.25 gpm.

NOTE: As fluid temperature changes, make the necessary correction in interpreting fluid flowmeter readings.

Step 14. Let fluid loop stabilize at 300°F and 1.25 gpm.

" 15. Slowly open valve F and monitor flowmeter indicated flow rate. Maintain flow rate at 1.25 gpm by adjusting valve E until valve F is fully open.

" 16. Slowly close valve G and monitor flowmeter indicated flow rate. Maintain flow rate at 1.25 gpm by adjusting valve E until valve G is fully closed.

" 17. Slowly close valve A and monitor flowmeter indicated flow rate. Maintain flow rate at 1.25 gpm by adjusting valve E until valve A is fully closed.

" 18. Open valve D full-open.

" 19. Close valve C.

" 20. Open valves A and G.

" 21. Close valve F.

System is ready for heat exchanger checkout.

6.0 HEAT EXCHANGER CHECKOUT (PUMP AND HEATER ACTIVATED)

Step 1. Check that valves A, B, D and G are full-open.

" 2. Check that valves C and F are closed

" 3. Close valve E.

" 4. Slowly turn water flow on to heat exchanger and monitor heater SCR controller output and thermocouple readings. Increase water flow and note water valve turns until:

(a) Water flow is full-open,

OR

(b) Temperature at heater outlet starts to substantially decrease.

" 5. Set breaker 3 in OFF position.

" 6. Continue heat exchanger cooling and observe system temperature drop.

" 7. When fluid loop temperature drops to approximately 100°F, open valve F.

" 8. Close valve G, then close valve A.

" 9. Open valve E.

" 10. Continue pump operation and heat exchanger cooling until temperature drops to 100°F. Then cut off heat exchanger cooling water supply.

7.0 SYSTEM SHUTDOWN AND SYSTEM BLEED (PUMP DEACTIVATED)

Step 1. Press "main starter" STOP button and set "main starter" toggle switch in OFF position.

" 2. Set breakers 1 and 2 in OFF position.

" 3. Open valves A, B, C, D, E, F and G.

" 4. Vent system to 5 psig by closing system GN_2 supply valve and GN_2 vent valve.

" 5. Check that expansion tank is at least 1/4-full level.

" 6. Set system GN_2 regulator to 10 psig, open system GN_2 supply valve and pressurize system to 10 psig at expansion tank (17 psig at fluid loop gauge).

" 7. Bleed system at each of the designated bleed points in their proper sequence. For each location, the bleeding procedure will consist of loosening the appropriate plug or fitting, bleeding off residual gas, retightening the plug or fitting, and observing for leaks before proceeding to the next bleed point.

BP-1 Pump Housing Outlet Plug
BP-2 Pump Housing Inlet Plug
BP-3 System Pressure Gauge
BP-4 Valve A
BP-5 Flowmeter Line at Heater Inlet
BP-6 Inlet Ell to Pump
BP-7 Valve D Line at Heater Inlet
BP-8 Safety Relief Valve Plug
BP-9 Heater Outlet Plug
BP-10 Lower Bleed Plug at Swivel Joint
BP-11 Flex Line to Inlet (East) Side to Collector Tube
BP-12 Inlet to Heat Exchanger
BP-13 Outlet to Heat Exchanger
BP-14 Upper Bleed Plug at Swivel Joint
BP-15 Flex Line on Outlet (West) Side to Collector Tube
BP-16 Rotate Lens Frame to the West — Bleed Plug at Collector Tube Outlet.