DOE/NASA CONTRACTOR
REPORT

DESIGN DATA PACKAGE AND OPERATING PROCEDURES FOR MSFC
SOLAR SIMULATOR TEST FACILITY

Prepared by

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Under Contract DEN-000006 with

National Aeronautics and Space Administration
George C. Marshall Space Flight Center, Alabama 35812

For the U. S. Department of Energy

U.S. Department of Energy

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TABLE OF CONTENTS

PAGE NO.

1.0 INTRODUCTION......................................................... 1

2.0 FACILITY DESCRIPTION............................................... 2

2.1 Sun Simulator......................................................... 2
2.2 Solar System Simulator Description................................. 12
2.3 Basic Facility.......................................................... 21
2.4 Instrumentation......................................................... 21
2.5 Listing of Solar Simulator Detailed Drawings...................... 27

3.0 SOLAR SYSTEM SIMULATOR OPERATING PROCEDURES................. 31

3.1 General Prerequisites.................................................. 31
3.2 Applicable Documents.................................................. 31
3.3 Safety................................................................. 33
3.4 Emergency Telephone Numbers........................................ 33
3.5 Solar Simulator System Setup......................................... 33
3.6 Field Mapping.......................................................... 35
3.7 Start Up Procedure..................................................... 36
3.8 Simulator Power Up Procedure....................................... 36
3.9 Simulator Power Down Procedure.................................... 36
3.10 Shutdown Procedure................................................... 40
3.11 Air Loop Operating Procedure...................................... 40
3.12 Fluid Loop Operating Procedure................................... 41

4.0 REFERENCES............................................................. 44

TABLE I MEASUREMENT ACCURACY......................................... 45
TABLE II COLLECTOR PERFORMANCE MEASUREMENTS..................... 46
APPENDIX A PROCEDURE FOR FIELD MAPPING USING SCANNER
APPENDIX B DETAILED DRAWINGS
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>Test Facility Arrangement</td>
<td>3</td>
</tr>
<tr>
<td>Figure 2</td>
<td>Tungsten-Halogen Lamps</td>
<td>4</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Optical Layout of Single Lens/Lamp Combination</td>
<td>6</td>
</tr>
<tr>
<td>Figure 4</td>
<td>Lamp/Lens Illumination Array</td>
<td>6</td>
</tr>
<tr>
<td>Figure 5</td>
<td>Transmittance of Lens</td>
<td>7</td>
</tr>
<tr>
<td>Figure 6</td>
<td>Fresnel Lens</td>
<td>8</td>
</tr>
<tr>
<td>Figure 7</td>
<td>View of Exposed Lamp Housing</td>
<td>9</td>
</tr>
<tr>
<td>Figure 8</td>
<td>Lamp/Lens Cooling System Flow Arrangement</td>
<td>10</td>
</tr>
<tr>
<td>Figure 9</td>
<td>Control Console</td>
<td>11</td>
</tr>
<tr>
<td>Figure 10</td>
<td>Grid Network and Electrical Arrangement</td>
<td>13</td>
</tr>
<tr>
<td>Figure 11</td>
<td>Tilt Table with Mapping Rig</td>
<td>14</td>
</tr>
<tr>
<td>Figure 12</td>
<td>Air Loop Thermal Simulator Schematic</td>
<td>16</td>
</tr>
<tr>
<td>Figure 13</td>
<td>Air Loop Simulator Arrangement</td>
<td>18</td>
</tr>
<tr>
<td>Figure 14</td>
<td>Solar Collector Liquid Test Setup</td>
<td>19</td>
</tr>
<tr>
<td>Figure 15</td>
<td>Liquid Loop Simulator Arrangement</td>
<td>20</td>
</tr>
<tr>
<td>Figure 16</td>
<td>Basic Facility</td>
<td>22</td>
</tr>
<tr>
<td>Figure 17</td>
<td>Overall View of Simulator</td>
<td>25</td>
</tr>
<tr>
<td>Figure 18</td>
<td>MSFC Layout</td>
<td>26</td>
</tr>
<tr>
<td>Figure 19</td>
<td>Simulator Test Arrangement</td>
<td>28</td>
</tr>
<tr>
<td>Figure 3-1</td>
<td>Solar Simulator Setup</td>
<td>34</td>
</tr>
<tr>
<td>Figure 3-2</td>
<td>Solar Simulator Controls</td>
<td>37</td>
</tr>
<tr>
<td>Figure 3-3</td>
<td>Lamp Location and Circuit Breaker Assignment</td>
<td>38</td>
</tr>
<tr>
<td>Figure 3-4</td>
<td>Power Level Control Setting Versus Output Voltage</td>
<td>39</td>
</tr>
</tbody>
</table>
1.0 INTRODUCTION

As part of the George C. Marshall Space Flight Center (MSFC) role in support of the Department of Energy (DOE) program for "Solar Heating and Cooling Development in support of the Demonstration Program," a solar simulation test facility was constructed to evaluate solar collector performance under simulated outdoor operating conditions. MSFC continues to manage and operate this test facility. The primary goal of the facility is to evaluate the performance capability and "worst case" failure modes of collectors, which utilize either air or liquid transport media.

The stimuli for this facility are the time and labor savings derived by not being subject to the capricious nature of outdoor weather conditions, and the more critical factor of achieving complete repeatability from test to test. For example, the solar flux intensity can be set at constant levels ranging from 395 W/m² (125 Btu/hr-ft²) up to 1120 W/m² (355 Btu/hr-ft²); the wind speed can be maintained at velocities ranging from 1.3 to 5.8 m/s (3 to 13 mph); the collector fluid inlet temperature can be maintained at levels ranging from ambient temperature to 100°C (212°F) or higher depending on fluid properties and system pressurization with fluctuations limited to ± 0.1°C (% .18°F) for extended periods of time. Control of the above parameters provides excellent repeatability from test to test which can never be achieved when testing outdoors.

Environmental parameters the facility can simulate include sunfall conditions such as solar radiation intensity, solar spectrum, collimation, and uniformity, as well as solar attitude. Prevailing wind conditions of velocity and direction can also be simulated. The facility is capable of reproducing solar system conditions imposed on the collector, including transport media type and flow-rate, collector fluid inlet temperature, and geometric factors of collector tilt and azimuth angles.

Sun simulation is achieved by 405 tungsten-halogen lamps which provide a source of energy near the solar spectrum at air mass 2. Each lamp is paired with a Fresnel lens for energy collimation. This combination forms a 27 x 15 illumination array. The lamp array, which is mounted with its long axis tilted up, is attached to an apparatus capable of being tilted around a horizontal axis (Figure 1 and drawing FAC-AE-4619-M2). The array can irradiate a 1.2 x 2.4 m (4' x 8') planar surface area. Collector orientation and thermal/fluid simulations are provided by a tilt table arrangement in conjunction with either an air or a liquid thermal/fluid loop. Wind velocity and direction on the collector are provided by two portable floor fans. These elements are all housed in a thermostatically controlled high bay building within the MSFC test complex.

Typically, testing in the simulator is performed to acquire collector efficiency data, the collector time constant, incident angle modifier data, and stagnation temperature values. The techniques utilized to make these evaluations follow in general the guidelines given in ASHRAE Standard 93-77, "Methods of Testing to Determine the Thermal Performance of Solar Collectors."
INTRODUCTION (Continued)

In reference 4.1 comparison of efficiency data generated in a natural outdoor environment to those generated in the simulator are presented. These comparisons are made for a double covered, selectively coated liquid flat plate collector and single covered, non-selectively coated air collector. The comparisons indicate outdoor flat plate collector efficiency data can be reproduced in the simulator to within 6 percent of the outdoor measurement.

Similar comparison of outdoor performance for a vacuum tube collector is provided in reference 4.2. Again, the indoor/outdoor correlation is excellent for both thermal efficiency and incident angle modifier data.

2.0 FACILITY DESCRIPTION

The facility includes the capability to simulate sunlight on the collector surface as its primary feature. However, it also provides a capability to simulate other conditions imposed by the solar system (i.e., storage and heating and/or cooling subsystems inputs), as well as natural environment conditions important to collector performance such as wind simulation and solar attitude. These simulations are accomplished by the major elements of the facility, which are the sun simulator, the solar system or load simulator, and the basic facility (Figure 1). A detailed description of each of the elements is given in the following paragraphs.

2.1 Sun Simulator Description

The key element of this facility is the sun simulator. This includes the lamp housing, lens housing, lamp/lens cooling equipment, and control equipment. Descriptions of these items follow.

2.1.1 Lamps

The simulator uses 405 GE Model ENH quartzline lamps to produce the solar intensity and radiation spectrum. These lamps are rated at 250W at 120V. They use a tungsten filament with an equivalent source temperature at 1843°C (3350°F). The filament is housed in a quartz bulb filled with halogen gas which produces an energy spectrum similar to that of the sun at air mass 2 (see reference 4.1). The bulb is attached to a diachroic-coated glass reflector. This ellipsoidal reflector is mounted to the base of the bulb to limit the direction of light from the bulb. It also serves to limit infrared emission due to the selective nature of the reflector reflectivity.

Early lamps had stippled reflectors, while later versions use a faceted surface texture (Figure 2).

2.1.2 Fresnel Lenses

Each lamp is mounted in a housing immediately opposite the lens housing. Each lens/lamp combination is mounted so that it has optically coincident axes (Figure 3). Lenses are mounted with the refracting grooved
Figure 1. Test facility arrangement.
Figure 2. Tungsten-halogen lamps.
FACILITY DESCRIPTION (Continued)

2.1 Sun Simulator Description (Continued)

2.1.2 Fresnel Lenses (Continued)

surface facing the lamps. Spacing between corresponding lens/lamp pairs is 17.78 cm (7 inches). This spacing fixes the image created by the lamp 2.54 cm (1 inch) in front of the lamp reflector face and at the lens focal point. The 405 lens array is arranged in a 27 x 15 array (Figure 4).

Focusing of energy through the lens is achieved by multiple circular line grooves cut into the plastic with a groove density of 125 lines per inch. These grooves refract light rays from the lamps so that the focus of energy occurs at a point 15.24 cm (6 inches) from the lens. The spectra transmittance of the lens is shown in Figure 5.

Lenses are made of 0.6 mm (0.1625 in.) thick acrylic. Circular stock is cut to a hexagonal shape 12.7 cm (5 inches) across flats. Semi-circular notches are cut in opposite flats to allow mounting (Figure 6). The lenses are secured to the lens housing by lightly torquing the mounting bolts. The lens housing is hinged to allow access to the lamps (Figure 7). Replacement lenses can be obtained from the Lectric Lite Company of Fort Worth, Texas.

2.1.3 Lamp/Lens Cooling

Cooling is provided by ingesting room air through eight household type fiberglass filters. The air then passes between the lenses and the lamps and through orifices in the lamp housing located adjacent to each lamp. Deflectors at the outlet of these orifices direct cooling air across the lamp base and into a tapered plenum immediately behind the lamp housing. The heated air is mixed in the plenum and drawn off through a 63.5 cm (25 inches) diameter duct. From the duct, the warm air may be either exhausted outside during the warm summer months or returned to the high bay building for heating purposes in the winter months (Figure 8).

A variable position damper, located in the exhaust duct upstream of the fan, is used to control the cooling air flowrate. The damper position is manually set at the control console to maintain the lamp base temperature at or near an average of 288°C (550°F). A 283 m³/min. (10,000 cfm) constant speed fan supplies air flow for this system. Opening and closing of the damper changes the flow resistance to allow the flowrate to be adjustable from a low of 125 m³/min (4400 cfm) to a high of 311 m³/min (11,000 cfm). See drawing E-SKM-815 for details.

2.1.4 Controls

Lamp voltage control (and flux intensity) and cooling flowrate is provided through a control panel located immediately adjacent to the simulator (Figure 9). Simulator flux intensity control is manual, utilizing a 150 kVA Research Incorporated voltage controller. The device is a three-phase 208 V SCR voltage controller shown on drawing FAC-AE-4619-E-1, modified by manufacturer's part #D477035 and D-46996E. Lamps are connected
Figure 3. Optical layout of single lens/lamp combination.

Figure 4. Lamp/lens illumination array.
Figure 5. Transmittance of lens.
Figure 6. Fresnel Lens
Figure 7. View of exposed lamp housing.
Figure 8. Lamp/lens cooling system flow arrangement.
2.0 FACILITY DESCRIPTION (Continued)

2.1 Sun Simulation Description (Continued)

2.1.4 Controls (Continued)

selectively to each of the three voltage phases by zones so that each quadrant of the sun simulator is on opposite voltage phases. Figure 10 shows the lamp electrical phase arrangement as well as the lamp/lens number scheme. Selective location of lamps within phases is used in an attempt to smooth non-uniformities in flux intensity resulting from voltage disparities between phases.

2.2 Solar System Simulator Description

This simulation element includes the collector orientation positioning and solar system boundary condition simulation by the fluid loops, including transport media flowrate and temperature.

2.2.1 Orientation Simulation

Simulation of orientation is provided by a variable attitude tilt table to which the collector test item is mounted. The table provides a kinematic capability to set varying collector tilt angles and azimuth angles. Sun azimuth and control of incidence angle positions may be simulated using the tilt table along with an azimuth adjustment structure. The tilt table is capable of continuous adjustment of tilt angles from 0 to 72 degrees from the horizontal. Azimuth adjustments from 0 to 60 degrees can be achieved either by rotating the entire tilt table or by use of a special azimuth adjustment structure mounted on the tilt table.

The table surface is 2.4 x 1.5 cm (8 x 5 ft) in plan form. It consists of a 6061 aluminum angle structure to which a 142 by 244 cm (56 x 96 in.) sheet of 1.9 cm (0.75 in.) varnished plywood is bolted to form the collector mounting pad (Figures 11a and 11b).

2.2.2 Fluid/Thermal Loop Simulation

Fluid/thermal simulation is provided by an open-air loop (Figure 12). In this loop the transport media flowrate can be varied from 0 to 4.5 STD m$^3$/min. (0 to 160 STD cfm). Control with ± 2% of the desired flowrate, at steady state, can be achieved. Collector inlet air temperature can be varied from near ambient to 93°C (200°F) and controlled to within ± 0.6°C (± 1°F).

The air load simulator is an open-flow loop drawing room air in and supplying it to the collector. The basic hardware in this loop consists of:
Figure 10. Grid network and electrical arrangement.
Figure 11. Tilt table with mapping rig.
Figure 11. (Concluded).

b. rear view detail
Figure 12. Air loop thermal simulator schematic.
2.0 FACILITY DESCRIPTION (Continued)

2.2 Solar System Simulator Description (Continued)

2.2.2 Fluid/Thermal Loop Simulation (Continued)

1. A $\frac{1}{2}$ hp 115 blower/motor combination.
2. A 230V proportional heater controller.
3. Four 3.75 kW strip heaters.
4. ASHRAE standard nozzle and test section.
5. Two 20.34 cm (8 in.) gate valves.

Figure 13 depicts the arrangement of air loop hardware.

The liquid loop normally utilizes a 50% by volume (52.7% by weight) ethylene glycol (Prestone II)/water mixture with corrosion inhibitor. For this fluid, flowrates may be varied from 0.02 to 0.25 m$^3$/h (6 to 67 gal/h) with ±2% control of the flowrate at steady state. Inlet temperature control of $0.6^\circ$C ($\pm 1^\circ$F) can be achieved for these flowrates over a range of ambient to $104^\circ$C ($220^\circ$F) with the water/glycol mixture. Energy collection rates of up to 2632 W (9000 BTU/H) can be accepted while meeting these conditions. These conditions can be met while encountering fluid resistances up to 138,000 N/m$^2$ (20 psig).

Most of the transport media used in solar systems may be used in this fluid loop with corresponding alterations in the thermal/fluid loop simulation capability. Hardware in the liquid loop includes:

1. A 110V, 1/3 hp fluid pump.
2. A 230V proportional heater power controller.
3. A 230V, 18 kW submersion heater.
4. A shell type single pass liquid/liquid heat exchanger.
5. A fluid reservoir.
6. A rotometer visual flowmeter.
7. A valve controller.
8. Miscellaneous hand valves.

Figure 14 is a schematic of the loop arrangement. Figure 15 is a photograph depicting the layout of hardware in the liquid loop.
Figure 13. Air loop simulator arrangement.
FIGURE 14. SOLAR COLLECTOR LIQUID TEST SET UP
Figure 15. Liquid loop Simulator arrangement.
2.0 FACILITY DESCRIPTION (Continued)

2.3 Basic Facility

In addition to the previously discussed simulation capabilities of solar flux and attitude and fluid loop simulation, the basic facility also provides both external wind and sun positional simulation capabilities. The sun altitude position simulation is provided by the design of the floating illumination array mount. This floating arrangement allows varying the housing angle from horizontal to 72 degrees above the horizontal. Control of this simulated solar altitude is achieved by manually adjusting a chain hoist attached to the illumination array. Since the flexible cooling air exhaust duct connected to the array has a limited travel, alternate duct position connections are provided. Three position connections are available to accommodate low, mid, and high solar altitude positions (Figure 16).

Wind simulation is provided by two fans. The two 1/4 hp, 76 cm (30 in.) diameter blade fans are mounted 182 cm high. The fans are three-bladed with a 1140 to 860 rpm range. Velocities from 1.3 to 5.8 m/s (3 to 13 mph) can be achieved with the fans by selecting different fan speeds. Two fans are used to achieve better velocity uniformity across the test plane. Wind is normally directed into the collectors from the south, but mobility of the fan allows direction simulation from any angle.

All elements of the simulator, with the exception of the control console (Figure 17), are housed in a mild steel structure surplused from a previous test program. The structure is 8.5 m (28 feet) in height, with a 4.3 m (14 feet) square plan form. The frame structure is covered on all sides except the north side with a blue plastic tarpaulin. A mobile glare shield (Figure 1) is situated behind this open side and in front of a visitor viewing area to protect the eyes of passersby and limit spurious radiant energy inputs from other sources to the test item. This shield is constructed from angle iron structure and covered with the same tarpaulin material.

The entire simulator structure is housed in Building 4619. The simulator is located in the west end of the high bay portion of the building. This building is located near the corner of Rideout and Fowler Roads of MSFC (Figure 18).

2.4 Instrumentation

The instrumentation/data acquisition system available (modified LSIII-2 computer with twelve bit analog to digital resolution) has a capability of 256 channels of analog or digital data. Instrumentation for collector test items includes absolute and differential temperature measurements, flowrate measurements, absolute and differential pressure measurements, wind velocity, as well as total solar radiation measurements (diffuse and direct radiation measurements are not normally recorded but may be acquired for special tests). These measurements use a number of different type sensors.
Figure 16. Basic Facility.
b. rear view detail

Figure 16. (Continued).
Figure 17. Overall view of simulator.
Figure 18. MSFC layout.
2.0 FACILITY DESCRIPTION (Continued)

2.4 Instrumentation (Continued)

depending on media, measurement type, and location of measurement. Table II details these measurements along with type and estimated accuracy of sensors. Overall measurement accuracies and minimum unit readout capabilities are given in Table I.

Facility peculiar instrumentation includes nine surface mounted thermocouples on simulator lenses, a cooling air outlet temperature, six lamp bulb base temperature measurements, and the lamp array voltage output. Figure 19 depicts illumination array with details of lamp and lens instrumentation locations. A list of typical collector performance measurements are listed by name in Table II.

In addition to data recordings, before each test observations are made concerning each collector. These observation data include spectral property measurements, which in some cases cannot be made because of the adverse effect of collector disassembly in its subsequent testing or further use. For those collectors for which measurements can be made, five points on the cover and absorber (one in each corner and one in the center) are used to acquire the average readings.

2.5 Listing of Solar System Simulator Detailed Drawings

Working drawings of the Solar Simulator were created by Management Services, Incorporated under NASA AE Contract Number NAS8-21769. A list of these drawings follows.

<table>
<thead>
<tr>
<th>Drawing Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAC-AE-4619-E-1</td>
<td>Solar Simulator Lamp Array and Equipment Power Plan</td>
</tr>
<tr>
<td>FAC-AE-4619-E-2</td>
<td>Solar Simulator Lamp Array and Equipment Wiring Lists and Selections</td>
</tr>
<tr>
<td>FAC-AE-4619-M1</td>
<td>Solar Simulator Lamp Array and Equipment Plan and Sections</td>
</tr>
<tr>
<td>FAC-AE-4619-M2</td>
<td>Solar Simulator Lamp Array and Equipment Plan, Sections, and Isometric</td>
</tr>
<tr>
<td>FAC-AE-4619-M3</td>
<td>Cables Installation For Solar Simulator Plan Elevation</td>
</tr>
<tr>
<td>FAC-AE-4619-S1</td>
<td>Solar Simulator Lamp Array and Equipment Structural and Architectural</td>
</tr>
<tr>
<td>FAC-AE-4619-S2</td>
<td>Solar Simulator Lamp Array and Equipment Structural Sections and Details</td>
</tr>
<tr>
<td>FAC-AE-4619-S3</td>
<td>Solar Simulator Lamp Array and Equipment Structural Sections and Details</td>
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Figure 19. Simulator test arrangement.
b. Lamp base temperature detail.

Figure 19. (Continued).
c. lens temperature detail

Figure 19. (Concluded).
### FACILITY DESCRIPTION (Continued)

#### 2.5 Listing of Solar System Simulator Detailed Drawings (Continued)

Additional MSFC Solar Simulator Drawings are listed below:

<table>
<thead>
<tr>
<th>Drawing Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC 12 SK751</td>
<td>Solar Simulator Wiring</td>
</tr>
<tr>
<td>20 M 33640</td>
<td>Lens Mounting Plate, Solar Simulator (one sheet)</td>
</tr>
<tr>
<td>20 M 33641</td>
<td>Lamp Assembly, Sun Simulator (two sheets)</td>
</tr>
<tr>
<td>20 M 33643</td>
<td>Support, Lens Mounting Plate, Sun Simulator, (two sheets)</td>
</tr>
<tr>
<td>20 M 33644</td>
<td>Frame, Lamp Assembly, Sun Simulator, (one sheet)</td>
</tr>
<tr>
<td>20 M 33645</td>
<td>Hood Assembly, Sun Simulator, (two sheets)</td>
</tr>
<tr>
<td>20 M 33646</td>
<td>Solar Simulator Assembly (two sheets)</td>
</tr>
</tbody>
</table>

Detailed Solar Simulator drawings are in Appendix B.
3.0 OPERATING PROCEDURES

3.1 General Prerequisites

3.1.1 Prior to operating the Solar Simulator Test Facility, authorization shall be obtained from the responsible Test Facility Manager.

3.1.2 Prior to applying power to the solar simulator, the sun screen must be positioned between the solar simulator and the visitors' booth located on the north side of the bay area of Building 4619.

3.1.3 Prior to operating the facility for the purpose of testing, verify that all instrumentation and equipment to be used for the test have a current calibration label and that the calibration period will not expire before the expected conclusion of the test.

3.2 Applicable Documents

3.2.1 OSHA 22066 General Industry Safety and Health Regulations

3.2.2 MM 1700.4 Safety and Environmental Health Standards

3.2.3 MM 8800.1 Environmental Quality Manual

3.2.4 MMI 1700.11 Protection of Personnel and Property

3.2.5 NMI 1711.2 Reporting, Investigation, and Action on Mishaps Involving MSFC Employees, Resources and Property

3.2.6 MMI 5300.4 Metrology and Calibration

3.2.7 MSFC STD 146 Color Coding

3.2.8 SHC 2008 Master Test Plan for the Solar Heating and Cooling Project

3.2.9 SHC 3006 Composite Solar Simulator Requirements Solar Heating and Cooling Development Program

3.2.10 SHC 3007 Instrument Program and Components List (IP&CL) for the MSFC Solar Energy Test Facility

3.2.11 NBS TN-899 Development of Proposed Standards for Testing Solar Collectors and Thermal Storage Devices

32
3.0 OPERATING PROCEDURES (Continued)

3.3 Safety

Primary responsibility for compliance with all safety regulations/precautions applicable to the operation of this facility is vested in facility supervisors. This does not relieve the simulator operator from responsibility for safety during simulator operation.

3.4 Emergency Telephone Numbers

Medical Center 453-2390

Fire 117

Ambulance 112

3.5 Solar Simulator System Setup (Test Table Tilt Angle Equals the Tilt Angle of the Lamp Array)

The following is the procedure to be used for determining the system setup parameters to be used for collector testing. Figure 3-1 shows the simulator testing setup and defines the symbols used.

3.5.1 A test flux level will be specified in the test requirements. Before the test specimen is mounted on the test table, a field map will be required to determine if the simulator power controller is set to produce the proper flux level. This procedure is described in Section 3.6 and will have to be performed iteratively until the required flux level is obtained.

3.5.2 Mount the test specimen centered on the test table.

3.5.3 Measure the distance from the top of the test table to the top surface of the collector. Record this distance ($d_c$).

3.5.4 Using the following formulae, compute $h_{test}$ and $L_{test}$.

$$h_s = (d_{test} + d_c + d_t) \cos \theta$$

$$L_{test} = (d_{test} + d_c + d_t) \sin \theta$$

$$h_{test} = h_s + h_{table}$$

where:

$$d_{test} = 9 \text{ ft.}$$

$$d_t = 1.5 \text{ in.}$$

$$h_{table} = 4 \text{ ft. 1 in.}$$

$\theta$ = Tilt angle
Figure 3-1. Solar simulator setup.
3.0 OPERATING PROCEDURES (Continued)

3.5 Solar Simulator System Setup (Continued)

3.5.5 Using the chain hoist located at the right side of the simulator lamp array, adjust the array to the required tilt angle and the height (htest) as measured from the binding posts located on either side of the center of the lamp array.

3.5.6 Attach a plumb bob to each binding post mentioned in Step 3.5.5, and place a mark on the floor directly under each.

3.5.7 Draw a chalk line connecting the two points and bisect the chalk line.

3.5.8 Construct a line perpendicular to the line drawn in Step 3.5.7 and passing through its center. This line should extend at least a distance (ltest) in a northerly direction.

3.5.9 Measure off a distance equal to ltest from the base line in Step 3.5.5 along the line drawn in Step 3.5.8, and mark this point.

3.5.10 Center the test table (left to right) over the line drawn in Step 3.5.8 and located so that the pivot point of the table is directly over the mark made in Step 3.5.9.

3.5.11 Set the test table tilt angle to the angle required for testing. The flow systems should now be set up, all instrumentation should be hooked up, and the system should be ready for testing.

3.6 Field Mapping

A field map should be taken prior to any series of tests and after any test during which a significant number of lamps have been burned out.

3.6.1 The simulator lamp array should be set up as described in Step 3.5.4 through Step 3.5.11, using 9-3/8 in. for dc in the equations listed in Step 3.5.4.

3.6.2 Set the lamp power to give approximately 300 BTU/Hr·Ft².

3.6.3 Use the pyranometer to take readings at intersections of a one foot grid on the table, a total of 32 readings.

3.6.4 If maximum or minimum readings vary by more than plus or minus 10% of the average, exchange one-half of the bulbs from high intensity areas and low intensity areas.

3.6.5 Repeat Step 3.6.3 and 3.6.4 until all readings are within 10% of the average.

3.6.6 An alternate mapping scheme using scanner is described in Appendix A.
3.0 OPERATING PROCEDURES (Continued)

3.7 Start Up Procedure

3.7.1 Arrange with Data Collection Group to monitor simulator operation.

3.7.2 INSURE THAT SCREEN IS BETWEEN SIMULATOR AND THE VISITORS' BOOTH.

3.8 Simulator Power Up Procedure

3.8.1 Open cooling water hand valve on the power controller console (A on Figure 3-2).

3.8.2 Close main supply breaker (480 volts) located on power duct above the door to Room 158A, Building 4619.

3.8.3 Close main circuit breaker on Panel AA-3.

3.8.4 Close control circuit breaker (No. 2) on Panel AA-3.

3.8.5 Close exhaust fan circuit breaker (No. 18) on Panel AA-3.

3.8.6 Check over-temperature meter relay for a setting of 200°F (B on Figure 3-2).

3.8.7 Set air flow damper to maximum open position (C on Figure 3-2).

3.8.8 Start exhaust fan using start button on fan control panel (D on Figure 3-2).

3.8.9 Set level potentiometer on power controller console to "0" (E on Figure 3-2).

3.8.10 Close main circuit breaker on power controller console (F on Figure 3-2).

3.8.11 Check Panel AA-1 and Panel AA-2 to insure that all lamp circuit breakers required for simulator operation are turned on (See Figure 3-3).

3.8.12 Close main circuit breaker on Panel AA-1.


3.8.14 Gradually increase level potentiometer on power controller to desired operating point (See Figure 3-4).

3.8.15 Adjust air flow damper to obtain the prescribed operating temperature as monitored on the computer.

3.9 Simulator Power-Down Procedure

3.9.1 Set level potentiometer on power controller to "0".

3.9.2 Open main circuit breaker on Panel AA-1.
Figure 3-2. Solar simulator controls.
### BREAKER BOX AA-1

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**FIGURE 3-3 LAMP LOCATIONS AND CIRCUIT BREAKER ASSIGNMENT**
FIGURE 3-4 POWER LEVEL CONTROL SETTING VERSUS OUTPUT VOLTAGE
3.0 OPERATING PROCEDURES (Continued)

3.9 Simulator Power-Down Procedure (Continued)

3.9.3 Open main circuit breaker on Panel AA-2.

3.9.4 Open main circuit breaker on power controller console.

3.9.5 Set air flow damper to maximum open position.

3.9.6 When lamp base temperature is below 100°F, as observed on computer, stop exhaust fan using stop button on fan control panel (G on Figure 3-2).

3.9.7 Open exhaust fan circuit breaker (No. 18) on Panel AA-3.

3.9.8 Open control circuit breaker (No. 2) on Panel AA-3.

3.9.9 Open main circuit breaker on Panel AA-3.

3.9.10 Open main supply breaker (480 volts) located on power duct above the door of Room 158A, Building 4619.

3.9.11 Close cooling water hand valve on the power controller console.

3.10 Shut-Down Procedure

3.10.1 Notify Data Collection Group that simulator operation has been completed.

3.11 Air Loop Operating Procedure (Refer to Figure 12 and Figure 13)

3.11.1 Prior to operating the air loop assure that:

1. The air inlet to the blower is open.

2. The air heater is OFF.

3. The air blower is OFF.

4. The gate valve nearest the blower is open.

5. Gate valve A is closed.

3.11.2 Turn the main power switch ON.

3.11.3 Turn the blower ON.

3.11.4 Slowly open gate valve A until the system air flow rate, as measured by the Hastings Air Meter, approximates the air flow desired for the test.

3.11.5 Set power controller to proper set point for desired temperature.

3.11.6 Turn heaters ON.
3.0 OPERATING PROCEDURES (Continued)

3.11 Air Loop Operating Procedure (Continued)

3.11.7 Adjust heater controller as necessary to obtain desired collector inlet temperature.

3.11.8 Adjust gate valve A as necessary to obtain proper flow test parameter.

3.11.9 Allow collector air inlet temperature and flow rate to stabilize.
Note: Once the system is stable; i.e., test parameters solar flux, flowrate, and collector inlet temperature have not varied significantly for 15 minutes and are at the values required for a particular test, test data recording should begin. Solar flux should not vary more than ± 9 w/m² (+ 3 BTU·Hr/Ft²) over the test period. The air flow rate should not vary more than ± 1% over the test period. Similarly the inlet air temperature should not fluctuate beyond ± 0.5°C (± 0.9°F) during the test. Test data should be recorded continually for a minimum of 15 minutes or twice the collector time constant, whichever is greater, when testing for collector thermal efficiency.

3.11.10 After testing is completed:

1. Turn OFF the heater power.
2. Turn OFF the blower.
3. Close gate valve A.
4. Turn OFF the main power switch.

3.12 Liquid Loop Operating Procedure (Refer to Figure 14 and Figure 15)

3.12.1 Prior to operating the liquid loop assure that:

1. Liquid reservoir is at least 75% full.
2. Liquid pump is OFF.
3. Liquid heater is OFF.
4. Hand valves HV-2, HV-3, HV-5, HV-6, HV-7, HV-9 and HV-10 are OPEN.
5. Hand valves HV1, HV-4, HV-8, HV-11, HV-12, HV-13 and HV-14 are CLOSED.

3.12.2 Turn main power switch ON.

3.12.3 Turn liquid pump ON.

3.12.4 Set power controller to proper set point for desired temperature.

3.12.5 Turn heater ON.
3.0 OPERATING PROCEDURES (Continued)

3.12 Liquid Loop Operating Procedure (Continued)

3.12.6 Turn exchanger controller switch to manual and set control to -15°C (5°F) below desired operating temperature.

3.12.7 Using exchanger controller manual switch, position valve slider to mid-range.

3.12.8 OPEN HV-8.

3.12.9 Slowly OPEN HV-1.

CAUTION: A surge of liquid could cause damage to collectors.

3.12.10 Adjust HV-1 to obtain .0315 x/s (0.5 GPM) as indicated on the minimum reading flowrator. Maintain this setting until system is clear of air.

NOTE: If system is being used with Solar Simulator, power up simulator before proceeding to next step.

3.12.11 After system is clear of air, adjust HV-8 as necessary to obtain a temperature of approximately -15°C (5°F) below desired collector inlet temperature.

3.12.12 Adjust heater controller as necessary to obtain desired collector inlet temperature.

3.12.13 Allow collector liquid inlet temperature to stabilize at proper temperature test parameter.


3.12.15 Adjust HV-1 as necessary to obtain proper flow test parameter.

3.12.16 Turn exchanger controller switch to AUTO.

NOTE: Once the system is stable; i.e., test parameters solar flux, flowrate, and inlet temperatures have not varied significantly for 15 minutes and are at the values required for a particular test, test data recording should begin. Solar flux should not vary more than ± 9 w/m² (+ 3 BTU·Hr/ft²) over the test period. The liquid flowrate should not vary more than ± 1% over the test period. Similarly, the inlet fluid temperature should not fluctuate beyond ± 0.5°C (+ 0.9°F) during the test. Test data should be recorded continually for 15 minutes or twice the collector time constant, whichever is greater, when testing for collector thermal efficiency.
3.0 OPERATING PROCEDURES (Continued)

3.12 Liquid Loop Operating Procedure (Continued)

3.12.17 After testing is completed:

1. Turn OFF the heater power.

2. Turn the exchanger controller switch to MANUAL.

3. OPEN HV-4, and HV-8.

4. CLOSE HV-3 and allow system to flow until liquid temperature is below 150°F.

5. Turn OFF liquid pump.

6. Turn OFF main power switch.

7. CLOSE HV-6.
4.0 REFERENCES

4.1 DOE/NASA TM 78165

4.2 DOE/NASA CR 161421
   Comparison of Indoor-Outdoor Thermal Performance for the Sunpak Evacuated Tube Liquid Collector.

4.3 ASHRAE 93-77
   Methods of Testing to Determine the Thermal Performance of Solar Collectors.
TABLE I. MEASUREMENT ACCURACY

<table>
<thead>
<tr>
<th>Type</th>
<th>Media</th>
<th>Accuracy</th>
<th>Minimum Readout</th>
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<td>Thermocouple</td>
<td>Liquid</td>
<td>±0.5°C (±0.9°F)</td>
<td>±0.06°C (±0.1°F)</td>
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<tr>
<td>Thermopile</td>
<td>Air</td>
<td>±0.06°C (±0.1°F)</td>
<td>±0.4°C (±0.7°F)</td>
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<td>Resistance</td>
<td>(Liquid and Air)</td>
<td>±0.3°C (±0.5°F)</td>
<td>±0.006°C (±0.01°F)</td>
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<td>Flowrate</td>
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<td>±0.00001 kg/s (±0.1 lb/h)</td>
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<td></td>
<td>Air</td>
<td>±2% of FS (210 cfm) (0.1 m³/s)</td>
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APPENDIX A

PROCEDURE FOR FIELD MAPPING USING SCANNER
1.1 **Field Mapping Subsystem**

The solar simulator field mapping subsystem consists of:

- A support frame which mounts on the test table. (Figure A-1).

- A lateral scanner bar which supports the detector carriage and may be moved to set vertical positions over the test table.

- A photo transistor detector and amplifier. (Figure A-2).

- A detector carriage which is driven by a servo motor and scans from left to right or right to left. (Figure A-3).

- Power supplies for the detector amplifier and servo motors.

- Strip chart recorder.

- Console (Figure A-4).

1.2 **Field Mapping**

A field map should be taken prior to any series of tests and after any test during which a significant number of lamps have burned out.

1.2.1 The simulator lamp array should be set up as described in steps 3.5.4 through 3.5.11 using 9-3/8 inches for $d_c$ in the equations listed in step 3.5.4.

1.2.2 Mount the mapping frame on the test table. A pair of mounting holes in the frame should be aligned over the horizontal centerline of the table.

1.2.3 Mount the scanner bar in the holes in the frame over the horizontal centerline of the table. These holes will now be the zero (0) reference point for vertical scans.

1.2.4 Connect the cable assembly from the scanner console to the detector carriage (Figure A-4).

1.2.5 Power up the 15 volt power supplies in the scanner console and adjust both supplies to read 15 volts.

1.2.6 Turn on the 400 cycle supply in Building 4619.

1.2.7 Turn on the power to the chart recorder, turn off the chart drive mechanism, and raise the pen.
1.2.8 Turn on the simulator in accordance with startup procedure (3.7). Allow the simulator to reach its operating temperature.

1.2.9 Move the detector carriage to the center of the scanner bar. Insure that the three-position scanner switch is in its center position.

1.2.10 Cover the detector and zero the galvanometer using the bias control. Zero the chart recorder.

1.2.11 Uncover the detector and adjust the gain control until the chart recorder pen is at about 80% of full scale. Repeat step 1.2.10 to check for zero.

1.2.12 Repeat steps 1.2.10 and 1.2.11 until the recorder reads zero when the detector is covered and approximately 80% when uncovered. Record this level on the chart recorder by lowering the pen and running the chart drive for a short time.

1.2.13 Switch the scanner switch to the L R position. The carriage should move to the right reference side of the table (that is the right side of the table when looking at the simulator). The carriage should stop at the end of the carriage and the red indicator lamp should light.

1.2.14 Place the pyranometer on the carriage bar over the center of the table and take two readings from the computer printout of the flux level. Write these flux level readings on the chart recorder paper next to the mark recorded in Step 1.2.12.

1.2.15 Set the scanner switch to the R L position, start the chart recorder and lower the pen. Press the button next to the read indicator lamp until the lamp goes out. The carriage will now scan from right to left and stop on the left hand side of the table lighting the read indicator. Stop the chart recorder, raise the pen, and mark the vertical position (in this case, "0") and R L on the chart recorder paper to indicate a right to left scan.

1.2.16 Set the scanner switch to the L R position, start the chart recorder and lower the pen. Press the button next to the red indicator lamp until the lamp goes out. The carriage will scan from left to right and stop on the right hand side of the table, lighting the red indicator. Stop the chart recorder, raise the pen and mark the vertical position and L R on the chart recorder paper.

1.2.17 Move the scanner bar down six (6) inches and repeat steps 1.2.15 and 1.2.16, marking the chart with -6". Continue this process moving the bar 6 inches at a time and repeating steps 1.2.15 and 1.2.16 until -48" is scanned.

1.2.18 Now move the bar back to the zero point and repeat steps 1.2.15 and 1.2.16. Repeat step 1.2.17 only in a positive direction (up the table).
1.2.19 Review the chart recorder data to insure that the L R chart is a mirror image of the R L data. If it is not, or if the two "0" maps do not agree, check the mapping system and the simulator. Then remap the field. If it is, proceed with the data analysis.

1.2.20 Using the right to left scans and a scale similar to the one below, read off the chart recorder amplitude at the points indicated on the scale.

```
-14 -12 -10 -8 -6 -4 -2 +2 +4 +6 +8 +10 +12 +14
```

1.2.21 Record the reading in tabular form from the +48'' through "0" to the -48'' scan and forward this data along with the level measured in step 1.2.12 and the flux level measured in step 1.2.14 for analysis.
Figure A-1. Uniformity measurement apparatus.

Figure A-2. Detector circuit.
Figure A-3 Scan motor control circuit.
Figure A-4.

Flux mapping console
APPENDIX B

DETAILED DRAWINGS
LAMP CONNECTIONS
Typ 81 Places

WIRE PULL IN PVC TUBE

Facility Inspection: Inspector TBD

Connector: MTR-22-15
Connector: MB-25-18

Terminal Block
16-pin series
10-pin terminals

13-pin connector
1 or 14 required

10 connectors
Ambrosiet WAY
Part 72 Venom
or Venom

Wire Ambrosiet 132
Ph. NO Venom

Solar Simulator

EC12 75/L
**Title and Subtitle**
Design Data Package and Operating Procedures for MSFC Solar Simulator Test Facility

**Authors**

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Washington D.C. 20546

**Abstract**

This report provides design and operational data for the MSFC Solar Simulator Test Facility. This simulation test facility was constructed to evaluate solar collector performance under simulated outdoor operating conditions. The primary goal of the facility is to evaluate the performance capability and "worst case" failure modes of collectors, which utilize either air or liquid transport media.

The test facility is capable of simulating several environmental parameters such as solar radiation intensity, solar spectrum, collimation, and uniformity, and solar attitude. The facility is also capable of simulating wind conditions of velocity and direction, solar system conditions imposed on the collector such as transport media type and flow rate, collector fluid inlet temperature, and geometric factors of collector tilt and azimuth angles.

Testing in the simulator is performed to acquire collector efficiency data, the collector time constant, incident angle modifier data, and stagnation temperature values.

**Keywords**

Unclassified

**Distribution Statement**
Unclassified-Unlimited

**Price**
NTIS

For sale by National Technical Information Service, Springfield, Virginia 22151.