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Midtemperature Solar Systems Test Facility Experiment Manual and Test Plan

Experimental Systems Operations Division

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

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MIDTEMPERATURE SOLAR SYSTEMS TEST FACILITY EXPERIMENT MANUAL AND TEST PLAN

Experimental Systems Operations Division 4721
Sandia Laboratories
Albuquerque, NM 87185

ABSTRACT

This manual describes the Midtemperature Solar Systems Test Facility (MSSTF), outlines the procedures for selecting items to be evaluated there, defines the prerequisites for installing such items, describes typical tests performed, and lists the reports generated and disseminated from the facility.

CONTENTS

ILLUSTRATIONS

1. GLOSSARY

AFB	Air Force Base
CMTF	Collector Module Test Facility
DOE	The US Department of Energy
E-W	East-West
FMSC	Fixed Mirror Solar Concentrator
GE	General Electric
LSE	Large-Scale Experiment
MSSTF	Midtemperature Solar Systems Test Facility
NIP	Normal Incident Pyrheliometer
NOS	Network Operating System
O, M, and R	Operation, Maintenance, and Repair
ORC	Organic Rankine Cycle
RFP	Request for Proposal
SERI	Solar Energy Research Institute
SLA	Sandia Laboratories, Albuquerque
SLATS	Solar Linear Array Thermal System
SOP	Safe Operating Procedure
STF	System Test Facility
T-66	Therminol-66 Heat-Transfer Oil

2. INTRODUCTION

The MSSTF supports the Thermal Power Systems Program administered by the US DOE's Division of Central Solar Technology. The Thermal Power Systems Program is sponsoring several large demonstration projects that are designed to initiate the commercial use of dispersed solar thermal power systems by the early 1980s. Components and subsystems for these large projects must be evaluated and operating strategies for integrated systems developed. The objectives of the MSSTF are to provide engineering evaluation of midtemperature range components and subsystems and to develop operating strategies for integrated systems. To achieve these objectives, the MSSTF has the following goals:

Characterize the performance, safety, resistance to environment, and costs of O, M, and R of solar energy components, subsystems, and systems through engineering tests.

Integrate components and subsystems of representative solar energy systems into other systems large enough to encounter the problems of full-scale operating in order to (1) establish the feasibility of a variety of solar energy system applications such as industrial process heat and power generation and (2) provide technical and cost data for dispersed power systems.

Innovate by (1) identifying potential improvements in component design, system configuration, and operation and (2) encouraging such development in the private sector.

Analyze experimental data from the MSSTF and other sources to formulate conclusions helpful in designing large-scale systems and commercial applications.

Disseminate results and conclusions through reports, seminars, conferences, tour briefings, and technical interchanges with visitors to the MSSTF.

3. DESCRIPTION OF THE MSSTF

The MSSTF occupies a 20,234-m^2 (5-acre) tract within the Sandia Laboratories complex in Albuquerque, New Mexico. Photographs of the installation taken on 21 June 1979 are shown in Figures 1(a) and 1(b). The MSSTF consists of two separate facilities, the CMTF and the STF.

A photograph of the CMTF, also taken on 21 June 1979, is shown in Figure 2. The CMTF generates thermal and optical performance data for prototype collector modules. There are three test stations in the CMTF, each served by its own fluid loop and data-acquisition capability. Each station can handle one collector module with an aperture area up to 45 m^2. The fluid loop for one of the stations uses T-66 heat-transfer oil at temperatures up to 315°C. A second station is served by a fluid loop using water at 18.3 MPa and 330°C. The third station provides a rotating (sun-facing) platform with a fluid loop using heat-transfer oil at temperatures up to 425°C.

The three stations are independent so that tests on three different collector modules can be run simultaneously at the CMTF. A weather station there provides concurrent weather data.

The most important tests run at the CMTF determine collector module peak performance at normal solar incidence angle, receiver thermal loss rate, and optimum heat-transfer fluid-flow rate. Data from these tests can be used in existing computer programs to predict daily, seasonal, and annual performance. Many other types of tests can also be run, e.g., tests of collector module all-day efficiency, receiver tube thermal loss, and tracking system accuracy. From 6 to 13 weeks are required to test a collector module at the CMTF, depending on the type and number of tests to be run, the nature of the

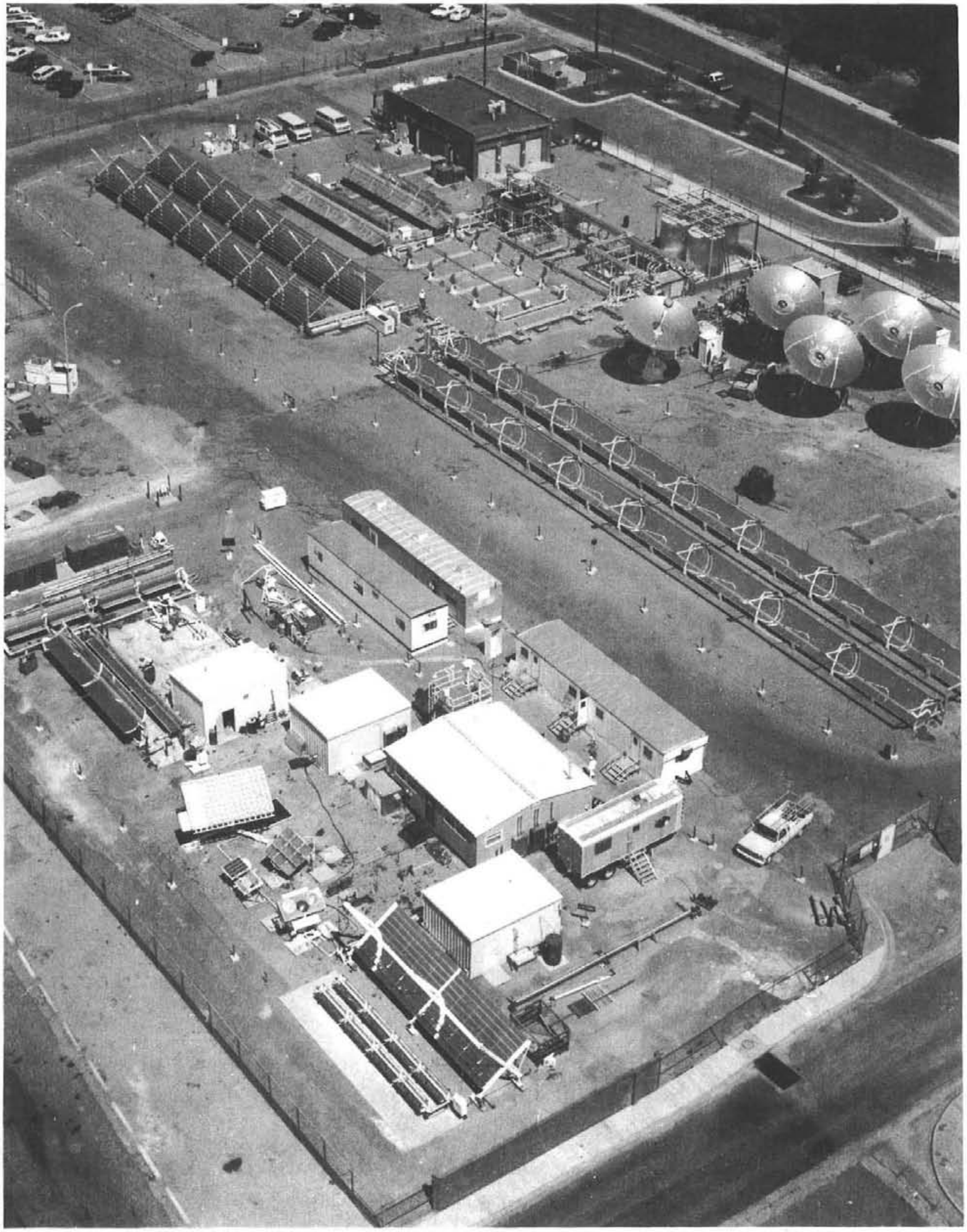

Figure 1(a). Aerial View of the MSSTF Taken from the Southeast on 21 June 1979

Figure 1(b). Aerial View of the MSSTF Taken from the West on 21 June 1979

Figure 2. Aerial View of the CMTF, 21 June 1979

collector, and the weather. A report is issued on the results of the testing of each collector module. These reports are assembled semi-annually into a summary report.

The STF consists of control and data-acquisition capabilities, solar collector fields, high- and low-temperature thermal storage facilities, an electrical power generation subsystem, a lithium-bromide absorption air conditioner, a weather station, and a cooling tower. It is configured so that individual components can be evaluated alone or with other items of equipment to supply electrical and thermal energy for a variety of loads, including a nearby 1100-m^2 office building. Items may remain on test at the STF for 1 year or more.

The collector field of the STF is designed to accept different types of collector-field subsystems simultaneously. In June 1979, five distinctly different types of collector-field subsystems were incorporated into the STF collector field:

1. <u>The FMSC Collector-Field Subsystem</u> -- This subsystem, designed and fabricated by General Atomics, San Diego, California, consists of a fixed reflector and a movable receiver. The reflector is an array of long, narrow, flat mirrors fixed to facets on the concave face of a precision-cast-concrete support. The focal line of the reflector array changes with the altitude angle of the sun. A drive system, controlled by signals from photo sensors mounted on the receiver, moves the receiver to keep it coincident with the moving focal line.

   The receiver assembly consists of flattened steel tubing with a selective black-chrome coating, mounted within a polished-aluminum secondary concentrator. The back side of the tube is insulated with silica foam.

2. <u>The SLATS Collector-Field Subsystem</u> -- This subsystem was designed and fabricated by Suntec Systems, St. Paul, Minnesota. An east-west linear array of individually

rotatable concentrating mirror segments focuses sunlight onto a fixed receiver. The receiver is an insulated box containing the absorber tube. Photo sensors mounted on the receiver control the tracking of the mirrors. The working fluid within the receiver tube is T-66. A heat exchanger transferred the energy collected by this subsystem to the T-66 in the fluid loop.

3. <u>The E-W Parabolic Trough Collector-Field Subsystem</u> -- This subsystem consists of four troughs arranged in two rows along an E-W axis. Reflective surfaces of the collectors on the west half are aluminized Teflon laminated to Mylar and bonded to aluminum sheet. The reflectors are attached to plywood troughs. Two weeks after taking the photographs shown in Figure 1a and 1b, an additional set of trough collectors designed and fabricated by Custom Engineering were installed. These collectors have glass mirrors mounted on fiberglass support structures. The steel receiver tubes, which are coated with black chrome and sealed in glass tubing, extend the full length of the troughs. The receivers in the east half have an annulus between the glass tube and the absorber tube, evacuated to a pressure of 1 kPa (0.15 psi) or less.[1] Tracking and control of the collector field is by a minicomputer that compares collector elevation angle with a calculated sun position and sends appropriate correction signals to the drive motors.

4. <u>The GE Parabolic Dish Array Collector-Field Subsystem</u> -- This subsystem, designed and fabricated by GE, consists of four parabolic dishes with two-axis, computer-controlled tracking. The reflecting surfaces of the dishes are wedge-shaped petals of polished aluminum covered with silicone film and fixed to a parabolic framework. This is the prototype collector for installation at the LSE at Shenandoah, Georgia. As shown in Figure 1, it is complete except for installation of receivers, which were installed in July 1979.

5. <u>The Raytheon Parabolic Dish Collector-Field Subsystem</u> -- The reflector surface of this subsystem, designed and fabricated

by Raytheon, Inc., consists of 228 glass mirror segments bolted to a parabolic framework. The dish is pedestal-mounted and features two-axis, computer-controlled tracking.

This variety of collector-field subsystems illustrates the flexibility of the STF design. Each collector-field subsystem can be operated independently or in conjunction with the other subsystems.

The fluid loop subsystem, which consists of valves, pumps, insulated pipelines, and flow sensors, interconnects all subsystems of the STF. The heat-transfer fluid in the loop (currently T-66) is a high-boiling-point oil that remains liquid with low vapor pressure at working temperatures of 315°C. A portable fluid loop capable of dissipating 139 kW (thermal energy) is available. With this portable loop, off-design temperature tests can be conducted on one collector-field subsystem without interfering with other tests in progress.

Two high-temperature storage subsystems maintain the temperature of the heat-transfer fluid at acceptable working levels. The first, a single-tank stratified-storage system, is insulated on the side walls and top by fiberglass bulk insulation. The second system consists of three 24-m^3 (6,120-gal) tanks with 0.6 m of bulk insulation.

It is possible to integrate a variety of thermal loads into the STF. The current load is a prime-mover subsystem that consists of two major elements, the liquid boiler and the turbine/generator. The liquid boiler is the interface between the T-66 heat-transfer fluid in the fluid loop and toluene, the turbine working fluid. The toluene is heated to 295°C and 1.9 MPa and enters the turbine as superheated high-pressure vapor. The single-stage ORC turbine is driven by the toluene vapor. The generator produces up to 32 kWe. The turbine-condenser coolant is a mixture of ethylene glycol and water and is pumped to low-temperature thermal storage. Stub-ins facilitate the quick installation of other thermal loads.

Two low-temperature thermal storage tanks store the glycol and water mixture from the turbine condenser until it is needed for operation of heating or cooling components of the heat-load subsystem. An induction-spray evaporative cooling tower can dissipate heat directly or as part of the absorption air conditioner. The cooling tower can also be used to simulate thermal loads for systems under evaluation.

Each collector-field subsystem has its own control logic. Control of other subsystems is by analog or digital signals to and from microprocessors or an HP 2100 MXE minicomputer. The minicomputer directs the scanning of sensors, stores the resulting data, and provides real-time information. The control center is located in the same building as the prime-mover subsystem.

Tests conducted at the STF emphasize the generation and collection of data on the performance of components, subsystems, and systems related to the control, transport, and use of collected solar energy under closely monitored and controlled conditions. Typical tests are listed in Appendix B.

4. PROCEDURE FOR SELECTING ITEMS FOR EVALUATION

The Supervisor, Experimental Systems Operations Division, selects items for evaluation on the basis of their potential ability to fill a defined need, solve a defined problem, or evaluate feasibility. Before any selection is made, the need and/or problem and potential solutions are discussed and coordinated with DOE, SERI, and other appropriate organizations.

Items selected for evaluation generally emerge from one of three sources:

1. Sandia, SERI, and other organizations that do research and development for DOE
2. Industry responses to RFPs
3. Industrial support

Notification of future RFPs are published in the Commerce Business Daily. From responses to an announcement, a list of firms that will receive the RFP is prepared. Before receipt of the proposals, a panel with proper expertise to evaluate the proposals is appointed, and a set of criteria is developed against which to evaluate the proposal. After receipt of the proposals, the panel prepares recommendations and submits them to the Supervisor for final selection.

Additional information may be obtained by contacting the Supervisor, Experimental Systems Operations Division, 4721, Sandia Laboratories, Albuquerque, NM 87185; Phone: Commercial--(505)264-8819, FTS--(505)475-8819.

A contract or a letter of agreement is prepared after selection of an item for evaluation at the MSSTF and before installation. Letters of agreement are generally reserved for agencies acting for

DOE. In all other cases, contracts will be used to define the agreements, interfaces, and conditions that govern the evaluation. The owner or seller of the item to be evaluated is referred to throughout this manual as the contractor.

5. CONTRACTORS AND THE MSSTF

Facilities Available to Contractors

Access to Kirtland AFB and the MSSTF -- SLA and the MSSTF are located on Kirtland AFB, entry to which is restricted to persons on official business. Three entry gates are available to the contractor: from the west on Gibson Blvd., from the north on Wyoming Blvd., and from the east through the Sandia Laboratories gate on Eubank Blvd. Unless other arrangements are made in advance, the contractor should initially enter Kirtland AFB through the Sandia Laboratories gate on Eubank Blvd. There he will be provided with a vehicle pass, instructions for operating his vehicle(s) on Base, and directions for reaching the MSSTF.

Secured Area -- A security fence surrounds the approximately 20,000 m^2 occupied by the MSSTF (Figure 1). During working hours, entry to the area is controlled by MSSTF personnel. During nonworking hours, the area is patrolled by Sandia security personnel, who control access to the area. No security clearance is required. Pictures may be taken of any item in the MSSTF area.

Office Space and Assembly Area -- A limited amount of office space and assembly space within the MSSTF area can be made available to contractors.

Data Acquisition and Processing -- Both the CMTF and STF have minicomputers that acquire data, store it on magnetic tape, paper tape, and/or hard copy, make graphic displays, and plot the data. Data from the STF minicomputer are transferred to the NOS, a time-sharing, interactive scientific computer system that incorporates a CDC 6600 computer. A substantial library of programs and plotting techniques is available on NOS.

Weather Data -- Both the CMTF and the STF have their own weather instruments for continuous observations of wind speed and direction, temperature, and direct normal and horizontal solar radiation.

Shop and Laboratory Assistance -- Sandia has a well-equipped machine shop. Many machine shops in Albuquerque are also capable of providing most services. MSSTF personnel will assist the contractor in obtaining repairs or necessary modifications to equipment through these facilities. In addition, the MSSTF has forklifts and basket lifts. Cranes and other heavy equipment can be obtained from SLA or hired locally. Support personnel such as millwrights, plumbers, and carpenters are also available, and many laboratory services such as chemical analyses, optical measurements, and materials testing can be arranged.

Testing Guidance -- The Test Plan for the MSSTF described later in this manual is a useful guide for preparing test procedures. Additional assistance may be obtained from MSSTF personnel.

Requirements Placed on Contractors

Safety -- The safety of all personnel working and operating equipment in the MSSTF area is a primary concern. General guidance for safety within the area (use of barriers, eye protection, etc.) is contained in an SOP manual. The contractor is responsible that his personnel comply with the SOP for all activities undertaken within the MSSTF. Requirements for safety analyses, safety proof-tests, and SOPs prepared by the contractor may be specified. If so, the MSSTF personnel will supply the contractor with documentation and guidance to meet the specified requirements.

Design Report -- The terms of the contract or letter of agreement may require a design report. This document describes the design requirements and assumptions, and the calculations, specifications, and drawings necessary to meet the design requirements.

"As-Manufactured" Design Definition -- An "as-manufactured" design definition is required for all test items. The format of the required definitions may vary from a statement of size, mounting dimensions, reflective materials, and support structure to a complete set of drawings and specifications on aperture cards. The required extent of the design definition will be stated in the contract or letter of agreement. Appendix A is an example of minimum requirements.

Safety Analyses and Pressure Proof-Testing -- Safety analyses and pressure proof-testing are required of all test items. Potential hazards must be defined and design features or procedures demonstrated that will minimize the potential hazards. The analyses and results of pressure proof-testing will be reviewed to assure their adequacy.

Installation Plan -- An installation plan must be submitted. This plan shows a schedule for installation, services and material required, the person responsible for meeting each requirement, and the schedule dates.

Test Plan -- A test description is required to include as a minimum the test objective, the method of conducting the test, and the expected results.

Test Documentation -- The MSSTF project documents the results of all tests. In some cases, it may be desirable for the contractor to supplement the results with additional information. When contractor test documentation is required, it will be specified in the contract or letter of agreement.

Disassembly Plan and Schedule -- A disassembly plan and schedule may be required that shows how to take the item apart, any required packaging, and the disposition of the material.

6. CMTF AND STF INTERFACES

The Collector Module Interface at the CMTF

Test items at the CMTF usually remain on the test site less than 13 weeks, including time to install and disassemble. Because of this short time period, some standardization is required in order to ready the items for test in a reasonable time.

Information Required from Contractor -- To prepare for the test item, the CMTF needs the information requested in Appendix A. This information should be received by the CMTF staff approximately 8 weeks before the scheduled arrival of the test item.

Mounting Requirements -- The CMTF is capable of accepting a variety of mounting configurations. Mounting requirements are needed at least 8 weeks before the scheduled arrival of the test item.

Fluid Loops -- The three fluid loops (schematics shown in Figures 3, 4, and 5) deliver heat-transfer fluid at predetermined flow rates and temperatures. The temperature of the heat-transfer fluid is measured as it passes through a flow meter. From the flow meter, the heat-transfer fluid is delivered to the test item. Interface requirements should be stated on the form in Appendix A.

Instrumentation and Control -- Typically available for instrumentation at the test stations are 70 pairs of Type T thermocouple wire, 30 pairs of Type J thermocouple wire, and 20 twisted pairs to carry low-level signals.

Utilities -- Deionized or tap water for washing reflector surfaces and 110-V power for hand tools, lights, etc. are available at each test pad.

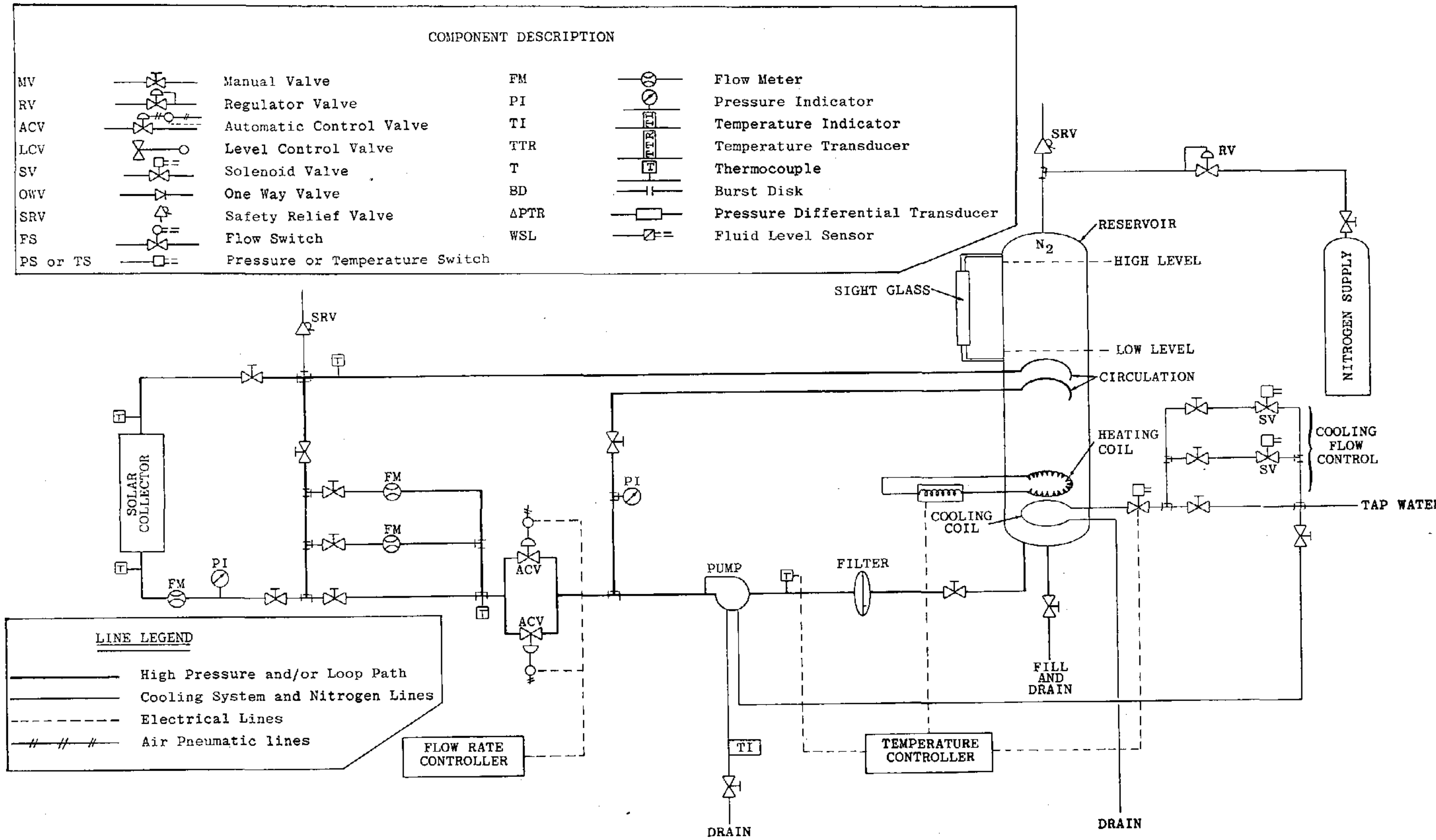

Figure 3. Schematic of Fluid Loop No. 1

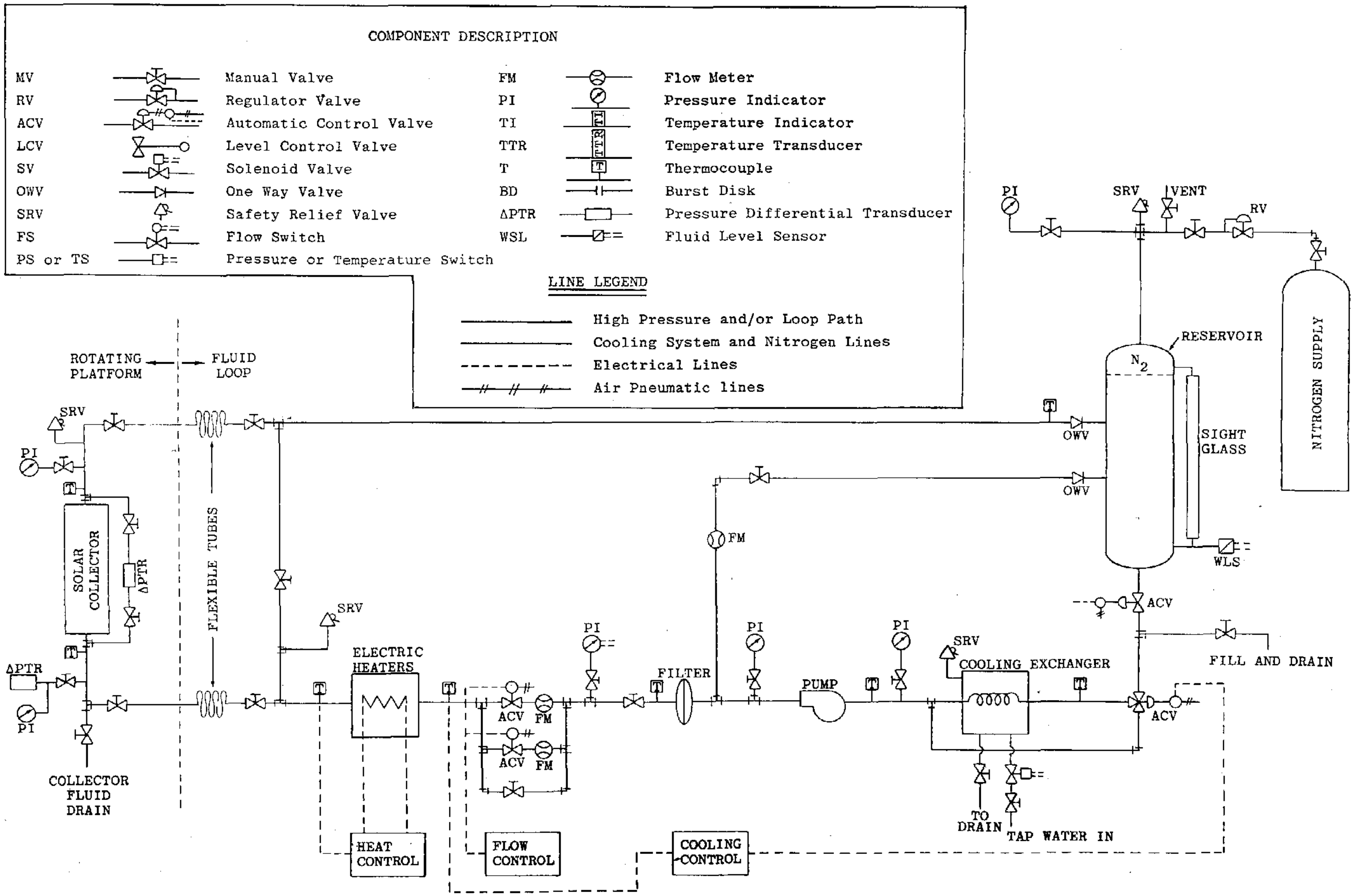

Figure 4. Schematic of Fluid Loop No. 2

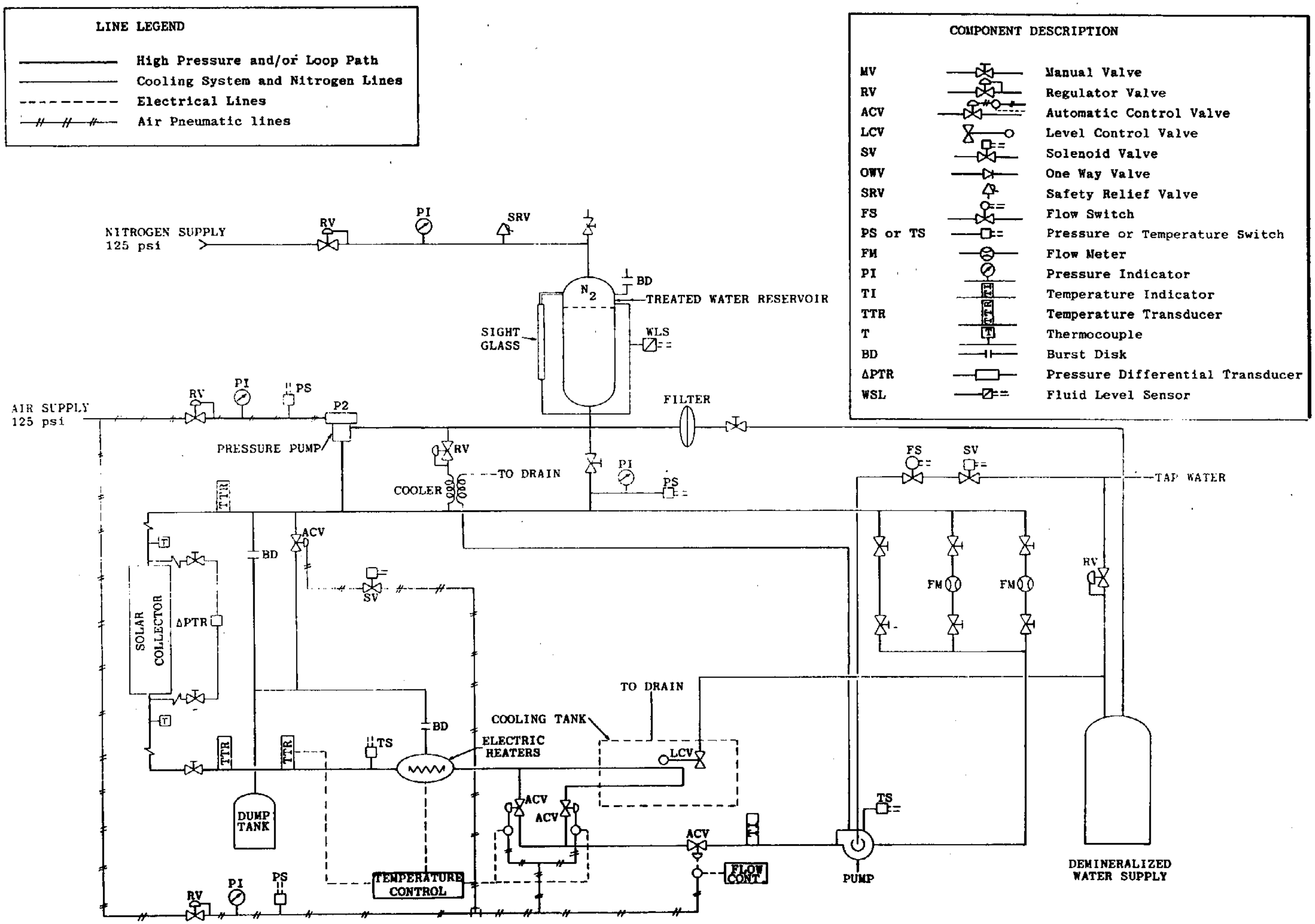

Figure 5. Schematic of Fluid Loop No. 3

Data Acquisition -- The minicomputer scans sensors and records data on paper output and magnetic tape. A small library of programs is available for data reduction, graphic displays, and plotting.

Data Analyses -- Customarily, data are processed by the HP 1000 minicomputer but may be transferred from the minicomputers to the NOS interactive, time-sharing system. The major component of this system is the CDC 6600 computer. Available on this computer are mathematical and statistical libraries and a small library of programs for processing solar test data. Arrangements can be made to allow user with a terminal to process data from any location with a telephone.

The Subsystem Interface at the STF

Each test item is treated individually. The following considerations are typical.

Fluid Loop -- Test items are connected to a fluid loop that currently uses T-66. This loop consists of insulated tubes, pumps, valves, and instrumentation necessary for the transfer of energy between the STF and the test item. Figure 6 shows a schematic of the STF.

The fluid loop can interconnect up to five collector-field subsystems, three thermal-storage subsystems, and two thermal loads, one of which currently comprises a turbine/generator and a heating and cooling subsystem. The bulkheads that interface with the collector-field subsystems are designed so that a collector-field subsystem can be isolated from the fluid loop by valves, and the energy output from the collector-field subsystem can be dissipated by a portable fluid loop. It is then possible to operate one subsystem at temperatures that are off-design for the STF without disrupting other tests. A capability is being designed into this fluid loop for its use as a testing tool anywhere.

Interface Agreement -- The interface agreement is a specification that describes the area to be occupied by the test item, construction

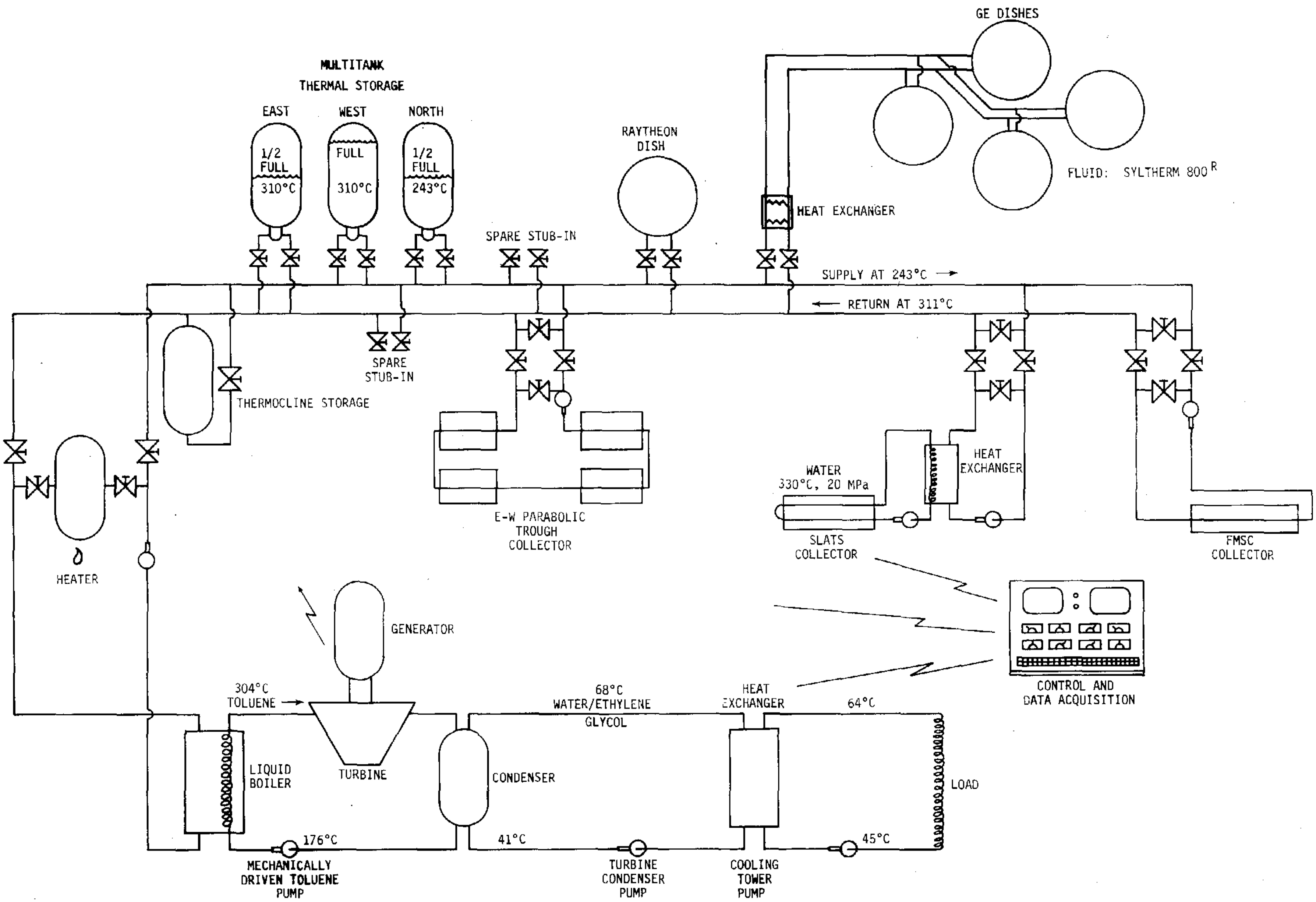

Figure 6. Schematic of System Test Facility, DOE/Sandia MSSTF

details of the test item, method of connecting to the fluid loop, and requirements for utilities, control, data acquisition, and data processing. The interface agreement normally starts with a skeleton of the requirements and evolves into a full set of specifications as the result of communication and negotiation.

Area Assigned -- Normally the test item is assigned a specific area within the MSSTF. Within this area the contractor is usually responsible for all aspects of installation.

Bulkhead -- A bulkhead is often the interface between the test item and the fluid loop of the STF. The following items are typically available at the bulkhead:

Water:	Tap water supplied through 1-in. pipe at 80 psig.
Drain:	A drain to sewer through an oil separator.
Air:	Air to operate valves is supplied at volumes up to 0.42 m^3/min (15 scf/min).
Natural Gas:	None.
Nitrogen:	0.57 m^3 (20 scf) per day at 15 psig is available.
Heat-Transfer Fluid:	T-66 supplied through 1-1/4-in. tubes with 0.065-in. wall thickness terminating in 150-lb mild steel flanges. Flow rates can be varied from 0 to 0.08 m^3/min (0 to 20 gpm). Supply temperature is 243°C. If a different heat-transfer medium is used in the subsystem, a heat exchanger must be used to transfer the energy to the T-66.
Electrical Power:	10-kW, 208-V, 3-phase Wye connection is supplied for pumping. 110-V single phase is available for control.
Instrumentation:	Typically available are 40 pairs of Type T thermocouple leads, 12 pairs of Type J thermocouple leads, and 20 twisted pairs for low-level signals.

7. THE MSSTF TEST PLAN

The evaluation of a collector module at the CMTF or of a subsystem integrated into the STF is a complex process involving a large array of equipment, several different organizations, and many skilled people. It is the responsibility of the MSSTF not only to use these resources efficiently but to ensure the accuracy and integrity of the data acquired during the evaluation tests. The chief instrument used to coordinate activities is the MSSTF Test Plan.

The MSSTF Test Plan includes seven elements:

- Test Schedule
- Configuration Control
- Test Control
- Test Descriptions
- Data-Acquisition and Processing Equipment and Procedures
- Test Reports
- Safety Procedures

The first six of these seven elements are discussed in the following paragraphs. Safety procedures were discussed earlier in this document.

Test Schedule

The test schedule is in two parts. The first is the long-term schedule for the entire MSSTF that lists chronologically all projected activities. The second part consists of the short-term schedules for each specific subsystem. Schedules are prepared jointly by the contractor and MSSTF personnel. All tests to be performed on subsystems under evaluation at the MSSTF are entered on this schedule.

Configuration Control

All items accepted for evaluation at the MSSTF are inspected in accordance with the Quality Program Plan[2] to confirm that the drawings and specifications accurately reflect the physical configuration of the item. Changes made to the item during the evaluation period are entered as dated changes into the drawings and specifications for verification of the configuration at the time each test is conducted.

Test Control

Control in testing is achieved and maintained by accurate, precise measurements and assured repeatability of test results. Accuracy and precision in measurement are in turn achieved and maintained by the calibration of all measuring instruments in accordance with the Quality Program Plan. To attain repeatability of test results, the engineers, technicians, and operators conducting the tests must have adequate skill and training and must perform accurately the procedures prescribed in the operating descriptions for that test. Operating descriptions are prepared for all subsystems and components being tested. Audits are performed in accordance with the Quality Program Plan to assure that skill levels are adequate and that procedures detailed in the operating descriptions are followed.

Test Descriptions

Test descriptions prepared at three successive levels of increasing detail are written for each subsystem being tested. The first level consists of selecting the type of test to be conducted. Appendix B lists the types of tests conducted at the MSSTF and briefly describes for each test the general objectives, the procedures, and the expected results.

Having selected the type of test to be conducted, the responsible engineer prepares pretest memoranda to describe the specific test conditions for each subsystem and the parameters to be measured, together with their expected range of values.

From the test memoranda, the third level is prepared. The equipment and instruments needed for the tests are identified and operating descriptions prepared. The operating descriptions are the detailed instructions that are issued to the technicians and operators performing the test.

Data-Acquisition and Processing Equipment and Procedures

From the test descriptions, the data-acquisition and processing requirements are identified. The CMTF and the STF each has a minicomputer for scanning, acquiring, and processing data from sensors. During a test, real-time outputs are available on both computer graphics and hard copy outputs and are simultaneously recorded on magnetic tape.

Test Reports

Five types of reports are issued by the MSSTF. A brief description of each follows.

The Design Report that describes items tested at the MSSTF is prepared in SAND document format (the format prescribed for official reports published by Sandia Laboratories). About 750 copies are printed and distributed according to US DOE Technical Information Center's Distribution Category UC-62. Copies are also distributed to various organizations within the DOE, SERI, and Sandia Laboratories plus organizations involved in the development and manufacture of equipment for solar application.

The Letter Report describes the results and/or the analysis of a test or a series of tests. Reproduction is limited to about 20 copies, with distribution within DOE Headquarters and national laboratories directly involved in the solar thermal program.

The Test Summary Report is issued to consolidate, analyze, summarize, and draw conclusions from the Letter Reports and other available information acquired during the period under consideration. The number of copies and distribution is the same as for a Design Report. The SAND document format is used.

The Incident Report documents any unusual event of potential interest to designers and users of solar applications. The event may be favorable (such as survival of a test setup after a severe storm) or unfavorable (such as accidental damage to a collector). Distribution is limited to about 20 copies, to include DOE Headquarters and SERI.

The Topical Report describes the results of studies that emerge from activities of the MSSTF project. A topical report may, for example, address some aspect of receivers or reflectors or summarize incident reports. The number of copies and distribution is usually the same as for Design Reports but may vary according to interest in the subject.

8. SUMMARY OF CAPABILITIES AND DESCRIPTION OF THE CMTF AND STF

CMTF

Collectors --

1. Types -- Line-focus and distributed-point-focus collectors
2. Numbers and Size -- Three modules of up to 45 m^2 (484 ft^2) concurrently
3. Total Aperture Area -- Up to 135 m^2 (1453 ft^2)
4. Mounting Structures -- Two on individual footings, one on turntable
5. Time on Test -- Approximately 13 weeks

Energy Management --

1. Temperature Range -- Up to 330°C with water and 425°C with oil
2. Pressure Range -- 18.3 MPa (2600 psi) with water and up to 1.4 MPa (200 psi) with oil
3. Heat-Transfer Fluids -- Water, T-66 (currently), and Syltherm 800®
4. Flow Rates -- Up to 1 L/s (15 gpm)
5. Load Application -- Heat exchanger to water
6. Supplementary Sources -- Electric heaters to raise heat-transfer fluid to required test temperatures

Storage --

None

Data-Acquisition and Management --

1. Computer -- HP 1000 system
2. Data Channels -- Typically, for each of 3 collector modules there are 70 channels for Type T thermocouples, 30 channels for Type J thermocouples, and 20 channels for low-level signals
3. Sample Rate -- Function of number of channels in use: slowest rate = 4 min
4. Transducers -- Type T, Type J, and Type E thermocouples, flow meters, and pressure gauges
5. Accuracy -- Thermocouples $\pm 1\%$, flow meters $\pm 5\%$
6. Meteorological Data -- Wind direction and velocity, direct solar radiation, and ambient air temperature
7. Storage -- Magnetic tape and disk on both HP 21 MXE and CDC 6600; hard copy from printer, scope, or plotter
8. Analyses -- Real-time on HP 1000, after test on HP 1000 and CDC 6600

System Control --

1. Type -- Function of test: may be controlled by computer, microprocessor, sensors, or manually
2. Operator Qualification -- Technicians with electronics and mechanical background approved by responsible engineers
3. Safety -- SOPs required for all equipment; pressure safety analyses required when judged necessary
4. Quality Program -- Quality Programs Plan requires configuration control, calibration, written procedures, and periodic audits for compliance
5. Test Plans -- Written test plans are required for all tests

STF

Collectors --

1. Types -- Line-focus and distributed-point-focus collectors
2. Numbers and Size -- Five subsystems, each with maximum collection capability of 5×10^5 kJ/h (~200 m^2 each)

3. Total Aperture Area -- Collection capability of 2.5×10^6 kJ/h ($\sim 1000\ m^2$)
4. Mounting Structure -- Individual foundation
5. Time on Test -- Approximately 1 year

Energy Management --

1. Temperature Range -- Up to 315°C, may go higher by using heat exchangers between test item and test facility fluid loop
2. Pressure Range -- Up to 0.6 MPa (75 psi)
3. Heat-Transfer Fluid -- Currently T-66; test item may use any heat-transfer fluid by using heat exchanger to isolate the test item from the system fluid loop
4. Flow Rates -- Up to 3 L/s (45 gpm)
5. Load Applications -- Heat exchangers to dissipate energy, 32-kW turbine/generator, and heating or cooling a 1100-m^2 office building
6. Supplementary Sources -- Natural gas heaters capable of supplying 0.6-MW, 208-VAC, 3-phase power; water, air, and nitrogen at each test station

Storage --

1. Multitank -- A system of three 24-m^3 (850-ft^3) tanks capable of storing 880 kWh thermal between 243°C and 310°C. For testing, the temperature of the stored fluid may be set at any value up to 310°C
2. Thermocline -- A 3.7-m^3 (130-ft^3) tank heavily instrumented with thermocouples to evaluate thermal storage subsystems that rely on differences in density to separate cold from hot fluid; maximum temperature capability: 425°C

Data-Acquisition and Management --

1. Computer -- HP 21 MXE
2. Data Channels -- 600 are available. At each of 7 bulkheads, there are typically 40 channels for Type T thermocouples, 12 channels for Type J thermocouples, and 20 channels for low-level signals

3. Sample Rate -- Function of number of channels in use; slowest rate = 4 min
4. Transducers -- Type T, Type J, and Type K thermocouples, flow meters, and pressure gauges
5. Accuracy -- Thermocouple = $\pm1\%$, flow meter = $\pm5\%$
6. Meteorological Data -- Wind direction and velocity, direct and horizontal solar radiation, ambient air, and dew-point temperature
7. Storage -- Magnetic tape and disk on both HP 21 MXE and CDC 6600. Hard copy from printer, scope, or plotter
8. Analyses -- Real-time on HP 21 MXE, after test on CDC 6600. Use of remote terminal connected to CDC 6600 by telephones is possible from anywhere in United States. A library of programs for processing test data is available

System Control

1. Type -- Function of test: May be controlled by computer, microprocessor, sensor, or manually
2. Operator Qualification -- Technicians with electronics and mechanical background approved by responsible engineers
3. Safety -- SOPs required for all equipment; pressure safety analyses required when judged necessary
4. Quality Programs -- Quality Program Plan requires configuration control, calibration, written procedures, and periodic audits for configuration

References

1. T. D. Harrison, G. N. Bond, and A. C. Ratzel, Design Considerations for a Proposed Vacuum Solar Annular Receiver, SAND78-0982 (Albuquerque: Sandia Laboratories, 1978).

2. T. D. Harrison, "Quality Program Plan, Midtemperature Solar System Test Facility," Sandia Laboratories, Albuquerque, N.M., January 1979.

APPENDIX A

Collector Module Information Sheet

COLLECTOR MODULE INFORMATION SHEET

Manufacturer ______________________ Contract No. __________

Collector Identification ______________________________

Contracting Agency ______________ Contract Officer ______________

Program Manager ______________ Test Engineer ______________

Maximum Thermal Output (kJ/h) ______________________________

	Temperature	Pressure	Flow
Operating Range:	______	______	______

Receiver Tube: ID ________ OD ________ Hydraulic Radius ________

Aperture Area ______________ Focal Length ______________

Secondary Aperture Area ______________________________

Module: Overall Size ________ Maximum Height ________ Total Weight ________

Tiedown: (90 mph Wind) Type ______________ Number ______________

Shear & Tensile Loads/EA ______________________________

Solar Radiation Hazard Area (>1 sun) ______________________________

Electrical Power Required ______________________________

Other Utilities ______________________________

Instrumentation to be Monitored ______________________________

Thermocouple: Type ______________________ No. __________

Pressure: Type ______________________ No. __________

Other ______________________________

Type Heat Transfer Fluid ______________________________

Fluid Connections:	Size	Type	Location
Inlet	______	______	______
Outlet	______	______	______

COLLECTOR MODULE INFORMATION SHEET (Continued)

Manufacturer ____________ Collector Identification ____________

Type Tracking ____________

Expected Accuracy ____________

Tracking Axis ____________

Travel Limits ____________

Type Drive ____________

Moving Parts Hazards ____________

Emergency Defocus: Sensor ____________ Power ____________

Concentration Ratio ____________

Definition of ____________

Optical Materials ____________

Primary Reflector (Refractor) ____________

Secondary Reflector ____________

Receiver Coating ____________

Receiver Cover Glass ____________

Receiver Cover Glass Coating ____________

Remarks ____________

APPENDIX B

Typical Tests Performed at the MSSTF

APPENDIX B

TYPICAL TESTS PERFORMED AT THE MSSTF

Collector-Field Subsystem Tests

Performance -- Nine performance tests are outlined in the following paragraphs.

1. Instantaneous Peak Efficiency -- This test determines instantaneous collector-field subsystem efficiency during peak solar radiation. A series of observations of thermal power collected and simultaneous solar radiation intensity shall be made not more than 1 hour each side of solar noon. The specific expected result is the maximum value of the ratio of thermal power output to solar radiation normalized to 1,000 W/m^2 NIP reading. Any weather conditions such as low temperature or high winds that may affect the results are considered.

2. All-Day Efficiency -- Test objectives are to determine efficiency at discrete times for a full day of operation and the amount of energy collected in a day. The collector-field subsystem shall be operated in the automatic mode from sunup to sundown. At discrete intervals, thermal power out and NIP values shall be acquired. The total output of the collector shall be measured along with the cumulative solar energy as determined by integrating NIP observations. Specific expected results are a curve that shows (1) collector-field subsystem efficiency during the period of operation and (2) a ratio of thermal energy collected to the cumulative NIP observations. Weather conditions are considered and their effects related to test results.

3. Morning Startup -- The goal of this test is to determine for a variety of operational conditions the optimal morning startup times for collector subsystems. If a collector is turned on too early, the

energy required to achieve and maintain temperature in the fluid loops and the parasitic power for pumping, control, instrumentation, etc. exceed the energy collection capacity of the collector. The test must be repeated at various times during the calendar year and under differing operating conditions. The expected result is the determination of optimum startup times for representative operational modes as a function of calendar date.

4. Response to Transient Cloud Cover -- This test evaluates the reaction of the collector-field subsystem to transient cloud cover by positioning collectors to simulate cloud cover and/or by observing the effects of clouds during routine operation. A description is made of the actual or simulated cloud cover coupled with such data as NIP observations. The time from appearance of the cloud cover to collector shutdown is measured along with energy collected. When cloud conditions change, heatup time is noted along with the reaction of the collector to temperature changes because of heatup and the capability of the controls to handle such a situation. The test is expected to yield information that enhances capability to design hardware control strategies for transient conditions.

5. Evening Shutdown -- This test determines how much energy above supply-line temperature the collector produces between the time that the fluid in the return line drops below the specified output temperature and the time that the fluid drops to the supply line temperature, and how the collector moves to the stowed position. During normal shutdown, operators observe the quantity and temperature of fluid produced at temperatures above supply-line temperature, and they also observe all aspects of the reflectors moving to the stowed position. The expected result is information leading to a strategy for getting the most usable energy from the collector.

6. Parasitic Energy Usage -- This test obtains parasitic energy requirements for all phases of collector operation. Integrating meters measure pumping, tracking, and instrumentation energy used during all phases of operation. The expected result is data that clearly show the energy required for collector operation.

7. Tracking and Focusing -- This test evaluates the performance capability of tracking and focusing equipment. With the aid of suitable instrumentation, measurements are made of the time and accuracy with which tracking and focusing equipment acquire and hold the collector in focus. Observations during this test are expected to be of use in comparing the merits of various tracking concepts and in defining problems associated with existing tracking and focusing concepts.

8. Control Systems -- This test evaluates the capability of a control system to start up, operate, and shut down a collector-field subsystem, normally in conjunction with other tests. The expected result of this test is a determination of the merits and deficiencies of a particular control system.

9. Receiver Thermal Energy Loss Test -- This test, which measures the thermal energy lost by the receiver, is performed under a variety of ambient temperature and wind conditions. Normally, heat-transfer fluid is run at the usual output temperature and flow rate in the reverse direction of flow through the receiver. Thermal energy loss is determined from the flow rate and change in temperature of the heat-transfer fluid. The expected result of this test is a measurement of thermal losses from the receiver under different operating and weather conditions.

Safety Features -- The purpose of this test is to determine whether safety features incorporated into the control system of a collector-field subsystem adequately protect personnel and equipment. Anticipated problems such as loss of fluid flow and loss of power are simulated in the subsystem on an occasional random basis. The results are expected to enhance the safety of new solar energy systems.

Resistance to Environment -- This test determines how the various elements of the collector survive in the environment. Periodic observations are made on the condition of reflector surfaces, the shape of support structures, the location of the receiver with respect to focus, the selective coating, relays and switches, and the presence of corrosion. The expected output of this test is a data bank that can be used in selecting components for new designs.

O,M, and R -- The purpose of this test is to obtain data on O, M and R. The test procedure is to record the frequency, time, and estimated cost of all such activities in a log maintained for each subsystem. This log includes observations of unusual events such as hailstorms, high winds, and severe cold that may affect O, M, and R. The expected result is an enhanced ability to predict O, M, and R costs and the mean time between failure for similar items in solar-energy applications.

Fluid Loop Tests

Performance -- The purpose of this test is to measure thermal energy losses from the fluid loop when the fluid is flowing and when it is not. The usual procedure for conducting this test is to derive thermal losses from the fluid loop. Energy into the system, energy used by the turbine/generator, and losses from other parts of the system are all calculated by direct measurement. The quantity of energy required to balance the equation, energy in = energy out, is assigned to losses from the fluid loop. Components of the fluid loop (such as valves, pumps, and sections of pipe) are appropriately instrumented to determine their contribution to overall loss. Expected data from these tests will help in selecting insulation, insulation configuration, valves, and pumps to minimize thermal losses from the fluid loop of a solar-energy application.

Safety Features -- This test ascertains the quality and reliability of safety devices, e.g., a valve that automatically closes after a spill of heat-transfer fluid. Emergency conditions are simulated periodically. The expected result of this test is enhanced safety in the MSSTF plus experience for use by designers of solar energy systems.

Resistance to Environment -- The purpose of this test is to determine the actual operating life of the pumps, valves, and insulation that are components of the fluid loop. This test is conducted by periodically recording in a log the effects of the environment on all elements that comprise the fluid loop. In addition, records are also made of the effects of unusual environmental conditions such as severe hailstorms. The expected output of this test is a data bank to be used by designers in selecting components for fluid loops.

O,M, and R -- The purpose of this test is to obtain O, M, and R data. The test procedure is to maintain a log of all O, M, and R activities, with special attention to unusual events. The expected result is an enhanced ability to predict O, M, and R costs and the mean time between failure for similar items in solar-energy applications.

Thermal Storage Subsystem Tests

Performance -- The goals of this test are to determine thermal energy losses under static and dynamic conditions and various environmental conditions and to devise strategies for minimizing losses. Observations of temperature are made at selected positions in the subsystem with respect to time. Expected results are (1) data that reveal loss rates under both static and dynamic conditions and (2) a definition of the paths followed by the escaping energy. These data will assist designers in selecting the optimum storage concept for the needs of the applications.

Safety -- This test is designed to assure the safety of thermal storage subsystems within the MSSTF and to collect data for the design of future applications. The test is conducted by simulating hazards such as a fire, a spill of large quantities of heat-transfer fluid, or the introduction of contaminants into thermal storage (e.g., oxygen in the ullage). Expected outcomes are to identify and minimize hazards within the MSSTF and to generate knowledge useful in future designs.

O,M, and R -- This test generates data on the cost of O, M, and R. A log of all O, M, and R activities is maintained. The expected result of the test is data for better cost predictions for the O, M, and R of thermal storage subsystems.

Energy Use

Performance -- Typical performance tests using the prime-mover subsystem as an example are described in the following paragraphs.

1. Boiler Efficiency -- This test determines the efficiency with which the boiler transfers thermal energy from the heat-transfer fluid to the turbine working fluid and also the parasitic energy used by pumps that feed the boiler. During turbine/generator operation, observations are made of flow rate, temperatures, changes in temperature, and energy consumed by pumps. Expected results from this test are knowledge to aid in liquid-boiler design and the generation of control strategies to achieve maximum performance.

2. Turbine/Generator Efficiency -- This test evaluates turbine/generator efficiency under a variety of load, working-fluid, and condenser pressure conditions. Included in the test will be changes in the condition of the working fluid and the load. The turbine/generator is operated under a variety of conditions, and appropriate observations are made of input thermal power, output electrical power, condenser conditions, etc. The desired result of this test is data not only to characterize the performance of the turbine/generator but also to aid in creating strategies for maximizing turbine/generator performance.

3. Energy Available from Condenser -- This test measures the amount of useful energy that can be extracted from the condenser while the turbine/generator is operating. The expected result is a measurement of the energy between an upper and a lower temperature value that can be extracted from the condenser and used in a variety of applications. The two temperatures are determined by the needs of the simulated thermal load.

4. Parasitic Energy -- This test measures the amount of electrical parasitic energy used to (a) bring thermal energy to the turbine/generator, to (b) control the turbine/generator, and to (c) extract thermal energy from the condenser. The test is conducted concurrently with other testing. Expected results are data for determining areas of potential reductions in parasitic energy.

5. Control -- This test measures the response to changed conditions of the controls for the fossil fuel heater, the liquid boiler, the turbine/generator, the condenser, and the load-switching equipment. Normally, this test is conducted concurrently with other tests. Special tests are defined and conducted when conditions warrant. Expected results are better operational control of the STF and data useful to designers of solar-energy applications.

Safety -- The goal of this test is to evaluate safety features that are part of the prime-mover subsystem. The procedure is to simulate emergency conditions and observe the response of the safety protection. Expected results are safer working conditions in the MSSTF and data for better designs of future solar applications.

O,M, and R -- The purpose of this test is to obtain data on O, M, and R. All O, M, and R activities are recorded in logs. The expected result of this test is information for better predictions of O, M, and R costs of future solar-energy applications.

System Operation Tests

The goals of system operation tests are to develop optimal control strategies and useful energy production from the thermal energy collected by the collectors. The STF can be operated with a variety of configurations and control strategies. Baseline configurations and control strategies are established against which variations are compared. System tests are conducted in 24-hour multiples. Test plans are prepared and coordinated for each subsystem. In this manner, system and subsystem tests are conducted simultaneously. Expected results are data on subsystems and an evaluation of a particular system configuration operated with a particular control strategy. No tests on safety, resistance to environment, or cost of O, M, and R are scheduled at the systems level. These tests are all conducted at the subsystems level, and a systems test comprises the sum of these results.

Collector Module Tests

Collector Module Configurations -- This activity determines the "as-manufactured" design definition of collector modules assembled at the CMTF under the direction of the manufacturer's representatives, with no adjustments or modifications by Sandia personnel. Assembly is observed by CMTF personnel, and Sandia inspection organizations help to determine whether there are deviations from drawings, specifications, or descriptions furnished by the manufacturer. The expected result is a description of the collector module being evaluated. Operational observations and comments made during testing by CMTF staff are included in the test reports.

Collector Module Peak Efficiency -- The objective is to determine the peak efficiency of a collector module over its design operating temperature range, which must extend above 200°C (392°F). Peak performance data are taken when solar radiation is greater than 900 W/m^2 with the radiation incidence normal to the plane of the collector aperture. Some all-day efficiency tests are run at constant flow and temperature conditions. From this, daily energy collection is predicted for the module as if it were part of a 30-m row. A new rotating collector mounting platform permits a wide range of off-normal incidence angle performance tests. Meteorological observations are made continuously. Results should provide a basis for comparing the performance of different collector modules.

Collector Module Thermal Loss -- This test measures the thermal energy lost by the collector receiver at various receiver temperatures across its operating range. Thermal losses are correlated with varied weather conditions. Results should provide data that (when combined with efficiency characteristics and other properties) assist prediction of all-day or long-term performance.

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