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Solar Total Energy Project Semiannual Report April - September 1977

Howard J. Gerwin, George S. Kinoshita

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SOLAR TOTAL ENERGY PROJECT
SEMIANNUAL REPORT
April - September 1977

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ABSTRACT

This report describes activities of the Sandia Laboratories Solar Total Energy Project from April - September 1977. Highlights, descriptions of the test facilities, results of subsystems and module tests, market studies, systems analyses, and large-scale experiments status reports are summarized.

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I. INTRODUCTION

Sandia Laboratories supports the Department of Energy's Solar Total Energy Program through three separate but closely related projects: the Solar Total Energy Test Facility (STETF), Component and Subsystem Development, and Solar Total Energy Project (STEP) Management.

Solar Total Energy Test Facility (STETF)

The primary objective of the STETF project is to support the application projects of the Dispersed Power Program by (1) providing a facility sufficiently versatile to be used as an engineering evaluation center or test bed for solar energy components and subsystems, (2) establishing a facility large enough to provide realistic system design and integration experience, (3) generating performance and cost data on components and subsystems, (4) accumulating operating and maintenance (O&M) experience, (5) developing expertise in the private sector, and (6) disseminating the resulting information.

The STETF (Figure 1) consists of a systems test area referred to as the Solar Total Energy Systems Test Facility (STESTF) and a module test area known as the Collector Module Test Facility (CMTF).

The STESTF is a flexible, modular, experimental system capable of accommodating a variety of energy components and measuring their performance. The system (shown in the Figure 2 schematic) uses primary heat to generate 32 kW of electrical power; the "waste" heat provides up to 220 kW (750,000 Btu/hr) thermal power for heating, air conditioning, and other low-temperature uses. Generally the system consists of solar collector fields, fluid transfer systems, high- and low-temperature sensible heat storage tanks, heat exchangers, organic Rankine cycle (ORC) turbine/generator, cooling tower, temperature and flow sensors, computerized controls, and data acquisition and support equipment, which includes a complete weather station.

Operation of the test facility begins with circulation of Therminol 66 (T-66) heat-transfer fluid through receivers of the solar collector fields. Solar radiation focused from collectors heats the T-66 flowing through the receivers to preselected temperature ranges of 204 to 316°C (400 to 600°F).

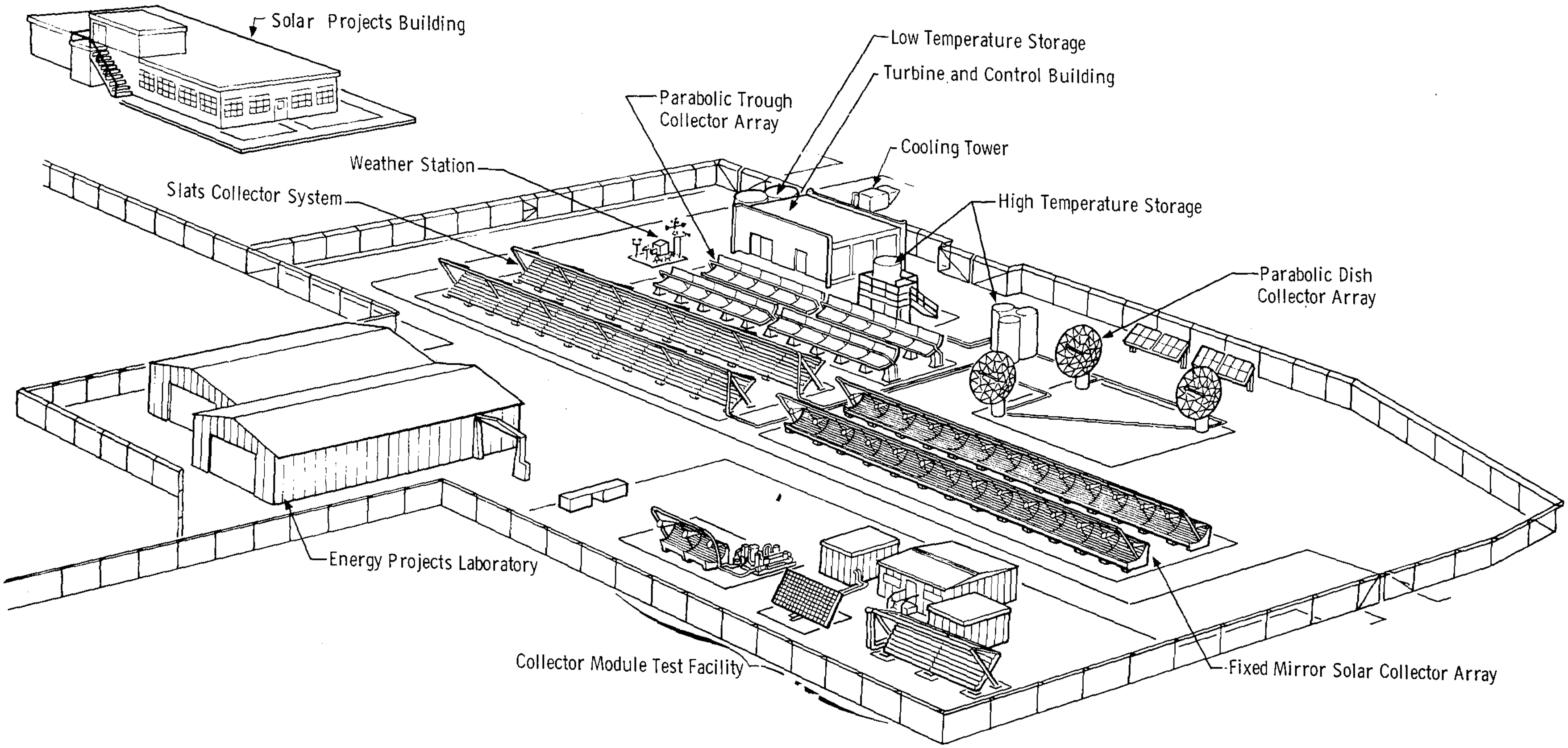


Figure 1. Solar Total Energy Test Facility

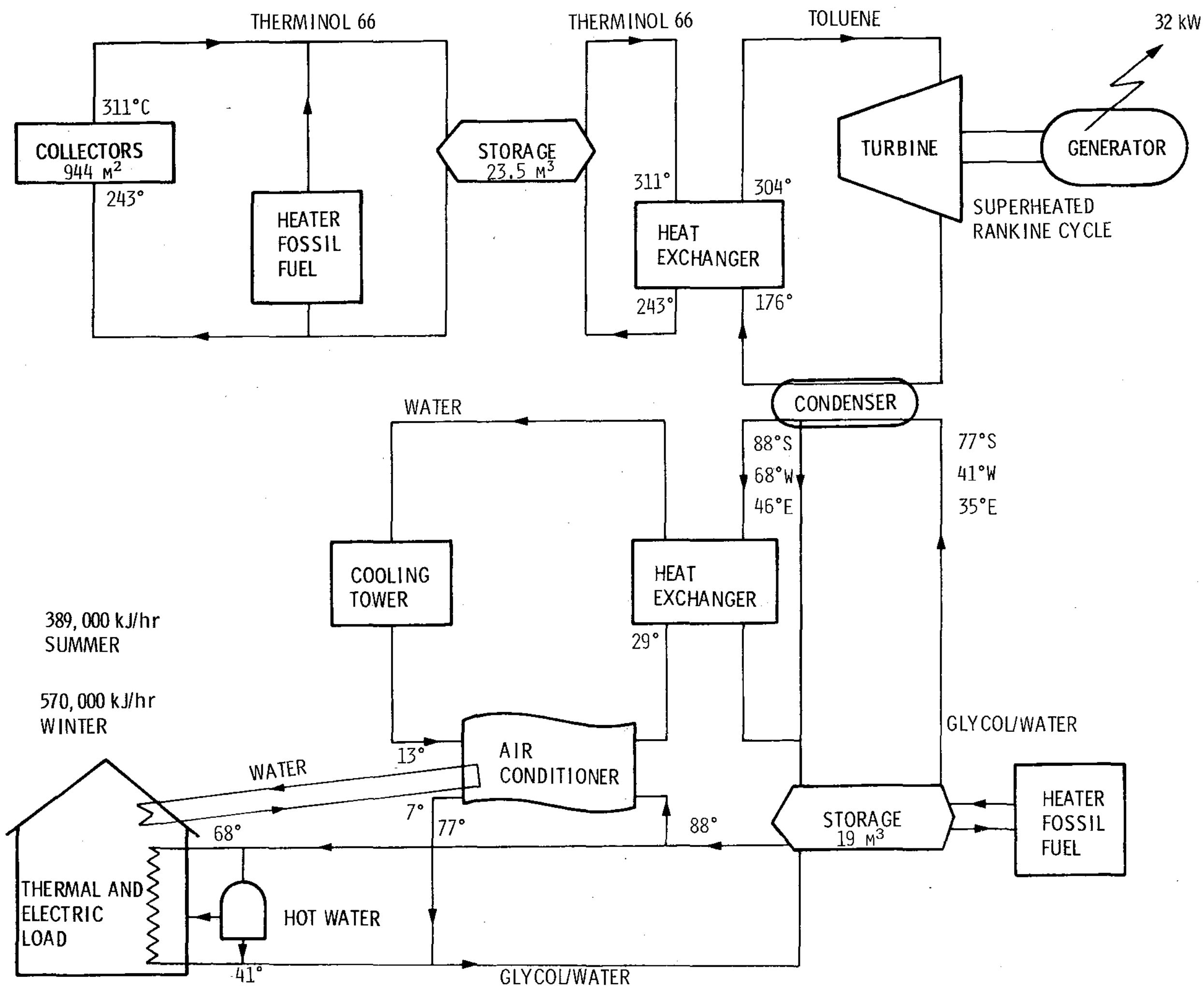


Figure 2. Cascaded Solar Total Energy System Schematic

The heated T-66 is pumped through insulated pipelines either to the high-temperature storage tanks or directly to a toluene heat exchanger. This option allows the heat-transfer fluid to be used immediately or later, as required by system demand.

Upon entering the toluene heat exchanger, the T-66 becomes the energy source for boiling and superheating toluene, which is the turbine/generator working fluid. After heating the toluene, the T-66 then returns to the high-temperature storage tanks for recirculation through the collector fields.

The superheated toluene expands through an axial-flow rotor to power the turbine/generator, which delivers a rated electrical output of 32 kW. Toluene exhausted from the turbine/generator is cooled as it passes through a regenerator and a water-cooled condenser, and then is pumped back to the heat exchanger for reheating. The condenser-cooling water goes to a low-temperature storage tank or to the cooling tower. Water from low-temperature storage is used as an energy source for heating or absorptive air-conditioning equipment.

Supplementary equipment permits operation of each module of the system independently to enable data-gathering under a variety of operating conditions.

To provide performance data rapidly on a variety of solar collector prototypes and individual modules, the CMTF is operated as part of the STETF. Three test pads can use water or T-66 heat-transfer oil at temperatures up to 330°C (626°F) and pressures to 18.3 MPa (2650 psi). The fluid loops have pumping, heating, and cooling capacities adequate for collectors of up to 45 m^2 (500 ft^2) concentrator aperture.

The overall project consists of five phases (Table I) with the work reported in this document being part of Phases IV and V. The project, which began in 1972 with research and exploratory analysis, has progressed to the operational phase in which the STETF is being used to evaluate solar energy subsystems and to provide energy for the 1100 m^2 Solar Projects Building.

TABLE I

Solar Total Energy Test Facility Project

Phase	Fiscal Year 73	74	75	76	76a	77	78
I. Background Phase	▼ 1 (completed)						
II. Exploratory Study		▼ 2, 3 (completed)					
III. Exploratory Development		▼▼▼ 4, 5, 6 (completed)	▼ 7 (completed)				
IV. Facility Construction A. Solar-to-Electric Components			▼ 8 (completed)	▼▼ 9, 10 (completed)			
B. Cascaded Components				▼ (completed)		▼ 12 (scheduled)	▼▼ 12a 16 (scheduled)
V. Facility Operation				▼ 11 (completed)		▼ 13 (completed), ▼ 14 (scheduled)	▼ 15 (scheduled)

▼ Completed
▼ Scheduled

Milestones

1. Completion of Phase 1
2. Preliminary System Design Complete
3. Economic Evaluation Complete
4. Collector Evaluation Facility Complete
5. System Analysis Program (SOLSYS) Operational
6. Baseline System Design Complete
7. Phase IV-A Proposal Submitted
8. Phase IV-A Design Freeze
9. Partial Collector Field, Storage, and Turbine-Generator Test Bed Complete
10. Phase IV-A Complete, System 100 Percent Operational

10a. Subcontracts for Collector Field Subsystems Placed
11. Initial Operation of Partial Solar Total Energy System Test Facility
12. Low-Temperature Components of Solar Total Energy System Test Facility Installed
12a. Subcontracted Collector Field Subsystems Completed
13. System Analysis Program (SOLSYS) Refined and Revalidated
14. Demonstration of Solar Project Building
15. Operation of Complete Solar Total Energy System Test Facility
16. New Collector Field Design Initiated

Phases I, II, and III, which emphasized preliminary studies and designs, are complete. Phase IV-A began in July 1974 and lasted through April 1976. It consisted of the design, fabrication, installation, and checkout of the first 200 m^2 collector field quadrant, a high-temperature stratified storage tank, a 32-kW turbine/generator and Therminol-to-toluene heat exchanger, an instrumentation and control subsystem, a cooling tower, the turbine and control building, and all necessary pumps and fluid loops to interconnect these subsystems.

Phase IV-B began in February 1976 and will be ongoing as new subsystems are added to the facility and as other subsystems on which evaluation has been completed are removed. The immediate goals of the construction phase are to increase the current capability of collecting 2×10^6 kJ/day to a capacity of about 8×10^6 kJ/day and to achieve the capability of providing 32 kW for a full 11-hr/day. The collector area is being increased from 200 to 825 m^2 (2160 to 8900 ft^2). High-temperature thermal storage capacity is being increased from $\sim$ 30 min to 3.5 hr. In addition, the subsystem for low-temperature thermal energy storage, the LiBr absorption chiller, heating equipment, and all necessary additional sensors and controls have been added to the facility. This achievement was demonstrated and a major project milestone marked in June 1977 when the Solar Projects Building was provided electrical power, heating, and cooling to become the world's first application of solar total energy to an actual load.

Phase V, overlapping Phase IV-A and concurrent with Phase IV-B, started January 1976. It consists of operating the facility in accordance with a detailed test plan to provide performance data on all subsystems and to accumulate O&M experience to form the design basis of large-scale experimental plants and future solar energy systems. During this phase, electrical power, heating, and cooling for the Solar Projects Building will continue to be demonstrated. Table II illustrates how the key system test facility milestones relate to the schedule of some of the early large-scale experiments and demonstrations within the Dispersed Thermal Power System Program.

Component and Subsystem Development

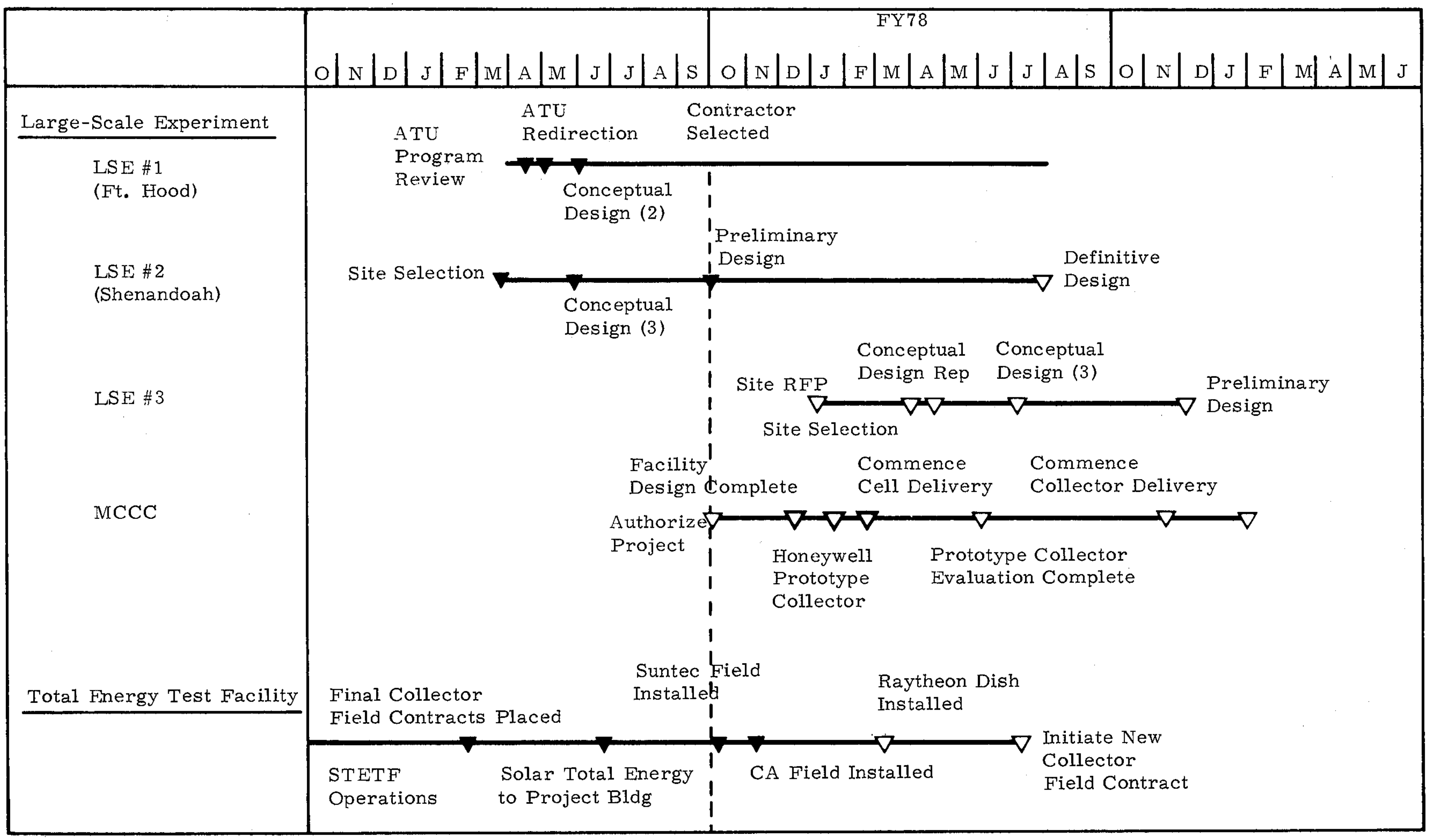
The objective of the Component and Subsystem Development Project is to develop components, subsystems, and technical information for solar systems utilizing distributed collectors. Materials studies, test methods, and instrumentation techniques are also included as these are related to the Dispersed Power Program.

STEP Technical Project Management

Sandia Laboratories is responsible for technical project management of STEP activities. This encompasses program planning assistance, monitoring, and technical direction of Department of Energy/Division of Solar Energy (DOE/DSE) contracts, and conducting comparative studies of systems, components, materials, and processes.

TABLE II

Dispersed Thermal Power Systems Summary



Some specific responsibilities include

1. updating annually a 5-yr program plan and providing annual financial operating plans to DOE for approval,
2. assisting DOE/DSE in major program decisions,
3. participating in the selection of sites and contractors for large-scale experiments and demonstration plants,
4. managing smaller contracted activities for component, subsystems, materials support, and systems engineering,
5. documenting program progress through technical reviews and reports.

Some program elements of the STEP Technical Plan in which Sandia actively participates are

1. Application Analysis,
2. Systems Engineering,
3. Large-Scale Experiments,
4. Component and Subsystem Development,
5. Test Facilities,
6. Technology Dissemination.

The first three program elements will be discussed in further detail in Section V of this report. The next two elements are discussed in Sections III and IV. The last element is covered in part in all sections.

II. OVERVIEW OF ACTIVITIES

Highlights

The following milestones and significant activities highlight the reporting period:

- World's first application of solar total energy to an actual load, the Solar Projects Building, June 24, 1977. Demonstration included electrical power plus heating and cooling.
- Furnished electrical power (only) to Solar Projects Building all day for the first time in April 1977.
- Completed installation and turnon of the Suntec (Sheldahl) SLATS collector field September 30, 1977 (Section III, Task 4).
- Connected the multiple-tank, high-temperature, 24 m^3 (6300 gal) storage system including pump, valves, and expanded pipeline network to STESTF, and successfully pressure-tested (Section III, Task 5).
- Maximized operation of STETF subsystems to accumulate O&M experience. Percentages of available working hours (sunshine or not) were as follows:

Collector Field	90%
Turbine/Generator	60%
Power for Solar Projects Building	50%

- Completed upgrading of test pads at CMTF. Completed General Atomic prototype tests; performed initial tests on Suntec module and initiated installation of Hexcel module (Section III, Task 8).
- Initiated field tests of in-situ laser-ray trace (see IV, Task 4).
- The most recent resident engineer, V. O. Staub, has completed a 4-month work period and returned to Stone & Webster, Denver office (Section III, Task 1).
- Published an interim test plan for operation of the STESTF.
- Issued 12 letter reports from the STESTF to document a variety of system and component tests (Section III, Task 2).
- Hosted 2789 visitors to the STETF (Section III, Task 1).
- Held a series of in-depth technical transfer meetings with the LSE conceptual design contractors (Section III, Task 1).
- Completed an updated version of program CYCLE called CYCLE 2. The program will perform Rankine-cycle analysis involving expansions into the wet-vapor region, which often occurs with fluids such as water (Section III, Task 6).

- Removed several receiver tubes from the STESTF for measurement of black chrome properties. Degradation of up to 11 percentage points was observed (Section IV, Task 2).
- Encountered some difficulties in tests to determine techniques for switching the turbine/generator from sensible heat storage to the gas-burner backup heater (Section III, Task 6).
- Modified the SOLSYS component model library to include an n-tank storage system routine.
- McDonnell Douglas Aircraft Company (MDAC) completed a final report on Industrial Applications Analysis and supplied copies to the LSE Conceptual Designers.
- Atomics International (AI) completed their Commercial Applications Study. The final report should be issued in early FY78.
- Initiated an Institutional Applications Analysis contract with Resource Planning Associates (RPA).
- Initiated a Residential Applications Analysis contract with the Institute of Gas Technology (IGT).
- Selected a knitwear plant (Bleyle) in Shenandoah, GA as the site of a Large-Scale Experiment (LSE). Georgia Power Company (GPC) heads the Site Project team.
- Selected the Conceptual Designers for the two LSE projects -- Stearns-Roger, General Electric, and Acurex-Aerotherm for LSE-Shenandoah; and Westinghouse and TRW for LSE-Ft. Hood. Subsequently, we selected General Electric and Westinghouse to proceed into LSE Phase III, Preliminary Design.
- Mississippi County Community College (MCCC) has been selected as a Solar Total Energy Project utilizing Photovoltiacs (PV). PV information has been supplied to MCCC. A Solar Monitor System has been loaned to MCCC so they may obtain insolation and weather data at the Blytheville, AR, campus.
- Awarded MDAC a 4-month contract to undertake design and costing analysis of small central receivers (2 MWth), one operating at 316°C (oil) and another at 427°C (steam), for use in dispersed applications.
- Completed the Utility Interface Study contract with Texas A&M. The study looks into the usefulness of Solar Total Energy Systems (STES) in reducing peak loads, capacity requirements, annual fuel reductions, and fixed cost savings for utilities.
- Revised the SOLSYS subroutines. The executive routine will be modified to simplify execution of the program and reduce its computative time.
- Used HELIOS to design and analyze solar systems.

- A computer code is being written and debugged to synthesize "optimum" solar systems, which means providing required energy at minimum cost.

- Conducted a 2-week Solar Technology Work shop to acquaint 13 members of the LSE conceptual design teams with the experimental, analytical, and programmatic activities at Sandia.

Publications and Presentations

Publications

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K. D. McAllister and S. Thunborg, Solar Total Energy System Test Facility Operational Phase Test Plan, SAND77-0690, Sandia Laboratories, May 1977.

J. L. Gardner, Sandia Solar Energy Titles, SAND77-0920, Sandia Laboratories, June 1977.

E. C. Boes, I. J. Hall, Estimating Monthly Means of Daily Totals of Direct Normal Solar Radiation and of Total Solar Radiation on a South-Facing, 45°, Tilted Surface, SAND77-0874, Sandia Laboratories, July 1977.

R. P. Stromberg and S. O. Woodall, Passive Solar Buildings: A Compilation of Data and Results, SAND77-1204, Sandia Laboratories, Aubust 1977.

R.B. Pettit, Optical Measurement Techniques Applied to Solar Selective Coatings, SAND77-0421, Sandia Laboratories, August 1977.

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B. J. Petterson, Jr., Solar Total Energy Test Facility Project - Semiannual Report, October 1976 - March 1977, SAND77-0738, Sandia Laboratories, August 1977.

T. D. Harrison, C. E. Hickox, A. Ortega, and K. Wally, Test Results: High Temperature Thermocline Storage Subsystem, SAND77-1528, Sandia Laboratories (to be published).

C. E. Hickox and D. K. Gartling, The Effects of Nonuniformities on Natural Convection in Annular Receiver Geometries, SAND77-1641, Sandia Laboratories (to be published).

Contractor Reports

Industrial - McDonnell Douglas

Industrial Applications of Solar Total Energy - Final Report (SAN-11322) April 1977.

Industrial Applications of Solar Energy - Quarterly Report (MDCG6710) January 1977.

Commercial - Atomics International

Second Quarterly Progress Report - Commercial Applications of Solar Total Energy Systems (AI-ERDA-13200) August 1, 1976-October 31, 1976.

Third Quarterly Progress Report - Commercial Applications of Solar Total Energy Systems (AI-ERDA-13203) August 1, 1976-October 31, 1976.

Residential - Institute of Gas Technology

Application Analysis of Solar Total Energy to the Residential Sector - Quarterly Technical Status Report, April 1 through June 31, 1977. Contract No. EG-77-C-04-3787, August 1977.

MDC G6531, Solar Collector Field Subsystem Program, Vols. I and II, November 1976, McDonnell Douglas (Printed SAND77-1167, August 1977).

Presentations

L. Wetherholt, "Sandia's Solar Energy Program," Belen Rotary Club, February 9, 1977.

L. Wetherholt, "Solar Energy Research," Science Teacher Section, SE District Teachers' Convention, Roswell, NM, March 18, 1977.

G. T. Treadwell, "Sandia's Solar Total Energy System Test Facility," ASHRAE, San Diego, CA, April 12, 1977.

E. E. Rush, "Solar Total Energy and Solar Thermal Test Facilities at Sandia," American Institute of Plant Engineers, Albuquerque, NM, April 15, 1977.

J. A. Leonard, "Hardware Experience with Solar Thermal Concentrators," ERDA Photovoltaic Concentrator Workshop, Scottsdale, AZ, May 24, 1977.

R. L. Champion, "Concentrators Structures, Reflectors and Testing," ERDA Photovoltaic Concentrator Workshop, Scottsdale, AZ, May 25, 1977.

B. J. Petterson, "A Portable Solar Weather Station," Solar Data Users Workshop, University of New Mexico, Albuquerque, NM, June 6, 1977.

P. D. Thacker, "Pyranometer Calibration: Leveling Errors and Cosine Effects," Solar Data Users Workshop, University of New Mexico, Albuquerque, NM, June 6, 1977.

E. C. Boes, "A Summary of Solar Resource Assessment on a National Scale," Solar Data Users Workshop, University of New Mexico, Albuquerque, NM, June 6, 1977.

L. Wetherholt, "ERDA/Sandia Solar Energy Programs," Air Conditioning and Refrigeration Wholesales Regional Conference, Albuquerque, NM, June 10, 1977.

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B. L. Butler and R. B. Pettit, "Optical Evaluation Techniques for Reflecting Solar Concentrators," Society of Photo-Optical Instrumentation Engineers, San Diego, CA, August 24, 1977.

A. C. Ratzel, C. E. Hickox, and D. K. Gartling, "Energy Loss by Thermal Conduction and Natural Convection in Annular Solar Receivers," 15th International Thermal Conductivity Conference, Ottawa, Ontario, Canada, August 1977.

R. B. Pettit and B. L. Butler, "Laser Ray Trace and Bi-Directional Reflectometry Measurements of Various Solar Concentrators," ERDA Concentrating Solar Collector Conference, Georgia Institute of Technology, Atlanta, GA, September 26-28, 1977.

R. S. Berg, "A Survey of Mirror Dust Interactions," ERDA Concentrating Solar Collector Conference, Georgia Institute of Technology, Atlanta, GA, September 26-28, 1977.

G. W. Treadwell and N. P. Grandjean, "Annual Performance Comparisons of Parabolic Trough and Flat Plate Collectors Based on Measured Isolation," ERDA Concentrating Solar Collector Conference, Georgia Institute of Technology, Atlanta, GA, September 26-28, 1977.

M. W. Edenburn and E. C. Boes, "Average Solar Radiation Available to Various Collector Types," ERDA Concentrating Solar Collector Conference, Georgia Institute of Technology, Atlanta, GA, September 26-28, 1977.

T. D. Harrison, "Solar Energy Challenge to Quality Control," Am. Soc. for Qual. Control, Albuquerque, NM, September 13, 1977.

A. C. Ratzel, C. E. Hickox, and D. K. Gartling, "Techniques for Reducing Thermal Conduction and Natural Convection Heat Losses in Annular Receiver Geometries," Heat Transfer in Solar Energy Systems, ASME Book No. 400104, ASME Winter Annual Meeting, Atlanta, GA, November 1977.

W. P. Schimmel, Jr., C. E. Hickox, and D. O. Lee, "Tracking and Shadowing Models for Solar Collection Systems," Paper 77-WA/SOL-B, ASME Winter Annual Meeting, Atlanta, GA, November 1977.

R. B. Pettit, "Evaluation of Portable Optical Property Measurement Equipment for Solar Selective Surfaces," Paper 77-WA/SOL-1, ASME Winter Annual Meeting, Atlanta, GA, November 1977.

III. STETF PROJECT DESCRIPTION AND STATUS

Task 1 - Project Management

The Sandia STETF Project has been organized into a structure of tasks and subtasks as shown in the Contents to this report. The detailed status of each project task and the results of performance tests and evaluations are described in the following subsections.

Table III illustrates the schedule of key activities and major milestones by tasks for the project during the reporting period. The operational phase of the project is exemplified by Tasks 2, 3, 5, 6, and 7 in which the primary activities have to do with testing and evaluating the major subsystems of the STESTF. Completion of the fabrication and installation phase is shown in Task 4, in which the collector field is being completed under three different development contracts; Task 5, in which new high-temperature storage tanks are being added to bring the storage capacity up to the design level of 3.5 hr; and Task 7, in which low-temperature thermal components of the facility have been installed, instrumented, and connected to the Solar Projects Building. (This building serves as an example total energy load for the system.) Activities at the CMTF (Task 8) concentrated on upgrading the facility by adding two fluid loops and refurbishing the existing fluid loop. The two new fluid loops were installed to provide a capability for low-temperature water and high-temperature, high-pressure water (330°C and 18.3 MPa). After the CMTF was restored to operational status, performance testing of various collector prototypes was resumed.

Table IV shows the project's milestone schedule for FY78. Some of the major events planned are the completion of installation, checkout, and testing of the Suntec and General Atomic collector fields and the Raytheon prototype parabolic dish; design of a fifth collector field; replacement of the parabolic trough collector field by an advanced design; addition of a new fluid loop at the CMTF; initiation of a long-term test facility; and procurement initiation of a new energy storage subsystem.

In keeping with the important project objective of helping to develop private sector expertise, a variety of active technology transfer activities will continue. Primary among these are briefings and tours, the resident engineer project, in-depth technical discussions and workshops, and side-by-side technical participation between Sandia staff and contractors developing collectors and other subsystems for installation and evaluation in the STETF.

We hosted many visitors during this reporting period. Members of the technical staff and the Community Relations staff gave briefings to 2789 visitors and showed them through the STETF. The technical staff accommodated 847 visitors in 217 groups. The total number contrasts with 1015 people in the previous reporting period and included 147 foreign visitors. In most cases,

TABLE III

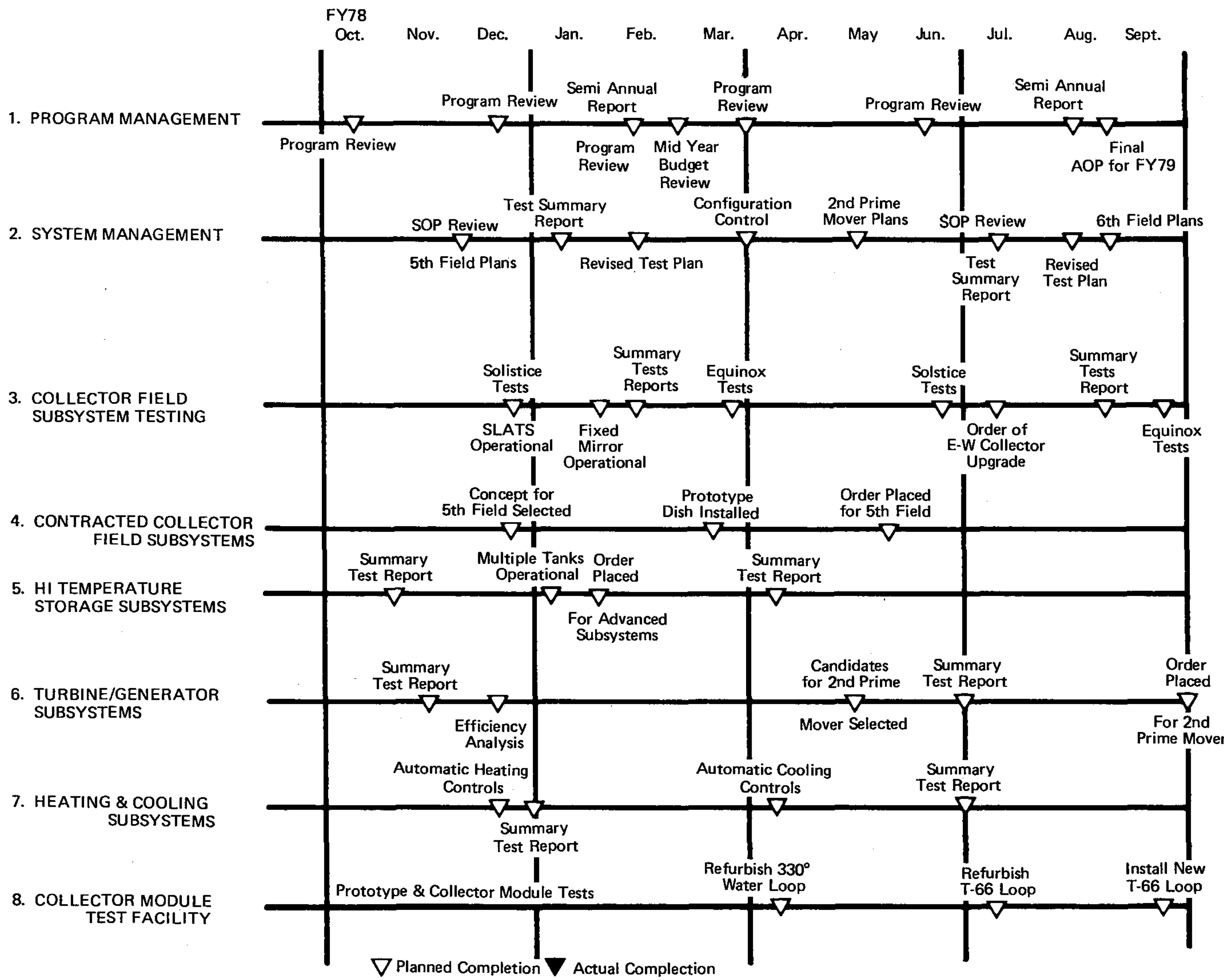
Project Milestones, April - September 1977

	APR	MAY	JUN	JUL	AUG	SEP
1. Project Management	▼ Proj. Rev.		▽ - - - - - -	- - - - - -	▼ Semi. Rpt	
2. System Management			▼ Bldg Demo.			
3. Collector Field Subsystems	2nd Gen. ▽ Conc. Des.		▼ All Day Test	In-Situ Laser ▽ Inspect. Assy - - - -	- - - - - -	▼▼ Equinox Tests
4. Contracted Collector Subsystems		Fabrication and Construction				▼ SLATS Oper.
5. Hi Temp Storage Subsystems		Phase IVB	▽ Instal. Checkout - - - -	- - - - - -	▼	
				▽ Opn - - - -	- - - - - -	- - - - - -
6. Turbine/Generator Subsystems		Transient Load ▼ Stability Tests				▼ Preheat Installed
7. Heating and Cooling Subsystems		▼ Steady State Opn				
8. Collector Module Test Facility	▼ Low Press Water Loop Installed					

▽ Planned Completion ▼ Actual Completion

TABLE IV

Project Milestones for FY78



these visitors were also escorted through the Vertical Axis Wind Turbine Facility, the Photovoltaic Component Test Facility, and the 5-MW Solar Thermal Test Facility.

The resident engineer project is continuing successfully. V.O. Staub, with Sandia on temporary assignment from May to September, has returned to the Denver office of Stone & Webster, his parent firm. The resident engineer project is a technology transfer technique in which engineers on leave of absence from private companies may reside at Sandia for 3-6 mo and participate in solar or geothermal energy projects. Inquiries from interested firms are invited.

During June and July a series of in-depth technology workshops was conducted between Sandia's STETF design and operating personnel and representatives of each of the conceptual design contractors for the Ft. Hood and Shenandoah Large-Scale Experiments; i.e., Acurex-Aerotherm, GE, Stearns-Rogers, TRW, and Westinghouse. In addition, several representatives remained in residence for brief periods for supplementary in-depth presentations and discussions of design considerations, system trade-offs, operational experiences, and performance data. A most beneficial addition to the sessions, led by Sandia staff members, was a series of presentations by representatives of firms under contract to Sandia for solar collector development. Ten such companies who shared their expertise and participated in the ensuing discussions were Del Manufacturing Company, Monterey Park, CA; FMC, Santa Clara, CA; General Atomic, San Diego, CA; Hexcel, Dublin, CA; McDonnell Douglas, Huntington Beach, CA; Raytheon, Missile Systems Division, Bedford, MA; Scientific Atlanta, Atlanta, GA; Suntec Systems, Lakeville, MN; Solar Kinetics, Dallas, TX; and Soltrax, Albuquerque, NM. Their help is greatly appreciated.

Relative to the solar collector fields being installed in the STESTF and the collector prototypes and modules being evaluated in the CMTF, it is the deliberate policy of Sandia and DOE to extend contractor responsibilities to system-level considerations wherever possible and to involve them in side-by-side participation in installation, instrumentation, checkout, operation, and analysis of results of their systems. The goal of this policy is to broaden the scope of expertise in industry beyond that required for component design and fabrication.

Table V illustrates program staffing. Technical contributions of these individuals to the project and their written inputs contained in this semiannual status report are gratefully acknowledged.

Task 2 - System Management

During this period, system management was concerned with (1) the problems associated with expanding the fluid loop required for the new collector field subsystems, (2) initiating continuous operation of existing equipment, (3) creating a format and schedule for test summary reports, and (4) establishing systems to assure safety and security for personnel and equipment.

TABLE V

Staffing for Solar Total Energy Projects

SOLAR ENERGY PROJECTS DEPARTMENT

G. E. BRANDVOLD

SOLAR TOTAL ENERGY PROGRAM DIVISION

J. F. BANAS

Project Engineers
E. L. Harley
R. W. Harrigan
R. W. Hunke
G. S. Kinoshita
W. H. McCulloch
J. C. Zimmerman

Technician
N. R. Grandjean

SOLAR TOTAL ENERGY TEST FACILITY DIVISION

J. A. LEONARD

Project Engineers
R. L. Champion
H. J. Gerwin
T. D. Harrison
B. J. Petterson
S. Thunborg
L. E. Torkelson
R. M. Workhoven

Technicians
J. E. Cannon
G. L. McCoach
R. D. Meyer
M. A. Quintana

Project Support

EG&G Field Operations
K. D. McAllister
H. B. Burress
H. W. Craig
V. E. Dudley
H. P. Marquez
G. T. Morin
P. Scoppettuolo

Theoretical Analysis
F. Biggs

System Analysis
M. W. Edenburn
C. B. Rogers

Thermal Analysis
C. E. Hickox
A. C. Ratzel

Structural Analysis
P. P. Stirbis

Computer Model
J. K. Cole
F. V. Wyatt

Data Processing
L. C. Bennett
W. W. Shurtleff

Technology Transfer
R. P. Stromberg
D. E. Haskins
S. O. Woodall

Reflector Structures
B. L. Butler
C. B. Frost
T. R. Guess
D. W. Miller
H. R. Sheppard

Reflector Materials
E. K. Beauchamp
J. M. Freese
T. M. Meyer
G. D. Miller
R. B. Pettit

Receiver Materials
R. S. Berg
D. M. Mattox
R. P. Sowell

Turbine/Generator
J. P. Abbin
J. B. Moore

Component Development
S. B. Martin

Facility Engineering
C. N. Lowe
E. E. Rush
I. N. Humble
M. H. Wempe
M. V. Nielsen

Health, Safety, Fire Prevention
J. H. Kesinger
W. E. Stocum
L. L. Young

Thermal Storage
M. R. Baer
G. J. Jones
A. Ortega
R. A. Randall
A. W. Reed

High Pressure Piping
C. E. Albright
G. R. Bachand
F. L. Baker
B. C. Brown
C. A. Knovorsky
R. E. Moll
G. S. Wallace

Tracking & Control
B. B. Conklin
J. W. Hole
S. M. Kohler
E. O. Scussel

Testing & Evaluation
J. B. Boyd
O. J. Burchett
J. C. Bushnell
P. Davis
L. G. Rainhart
F. Salazar
W. G. Self
D. W. Tipping
D. L. Zamora

System Engineering -- Installations of the expanded fluid loop, the multiple-tank high-temperature storage subsystem, the Suntec Solar Linear Array Thermal System (SLATS) and General Atomic (GA) Fixed Mirror Solar Collector (FMSC) field subsystems were nearly completed. The expanded fluid loop is described in SAND76-0662 for April - September 1976. The multiple-tank high-temperature storage subsystem, and the SLATS and FMSC subsystems are described in SAND77-0738 for October 1976 to March 1977.

A pictorial record of the field construction activity has been maintained. Figure 3 shows the STESTF as it was in January 1977. The picture, taken from the east, shows the Sandia-designed E-W parabolic trough collector subsystem in the foreground. In the middle of the picture are the high-temperature thermocline storage subsystem and the control building that houses the turbine/generator, the controls, and the heating and cooling subsystems. The excavation for the heating and cooling pipes leads from the control building to the Solar Projects Building in the background. The next picture, Figure 4, shows the test area in May as the field was being prepared for the GA and Suntec collectors.

Figure 3. Solar Total Energy System Test Facility (STESTF) - January 1977

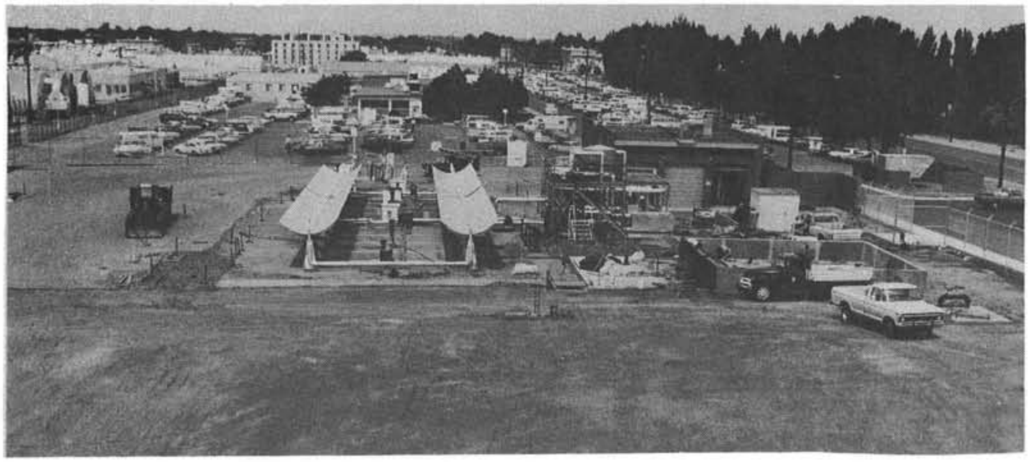


Figure 4. STESTF - May 1977

A series of three photographs taken from the west side of the test site shows the progression from foundation preparation through the erection of the collectors. Figure 5 was taken in July; Figure 6, in August; and Figure 7, the following month. The Suntec SLATS is in the foreground; the GA FMSC is at the top of the views. In the August scene, the SLATS frames are mounted, ready for the receiver tube sections that are lying on the ground. (The receiver tube sections are cloth-wrapped for emissivity coating protection.) One of the FMSC concrete troughs has been set on its footing. By early September (Figure 7), the SLATS receivers have been mounted and the remaining FMSC troughs are in place.

The next two pictures show the multiple-tank high-temperature storage site preparation (Figure 8) and basic configuration (Figure 9).

A view of the STESTF to the northwest (Figure 10) shows the new collectors, with the control building in the background.

In July 1977, when the heating and cooling subsystem was brought into operation (Section I, Task 7), it was found that several adjustments to controls were required before this subsystem could be operated automatically in conjunction with the rest of the system. Concurrent with bringing the heating and cooling subsystem into operation, it became necessary to assign all technical personnel to oversee installation of the new fluid loop. As a consequence, required adjustments are being delayed until the new fluid loop is operating smoothly.

Figure 5. STESTF - July 6, 1977

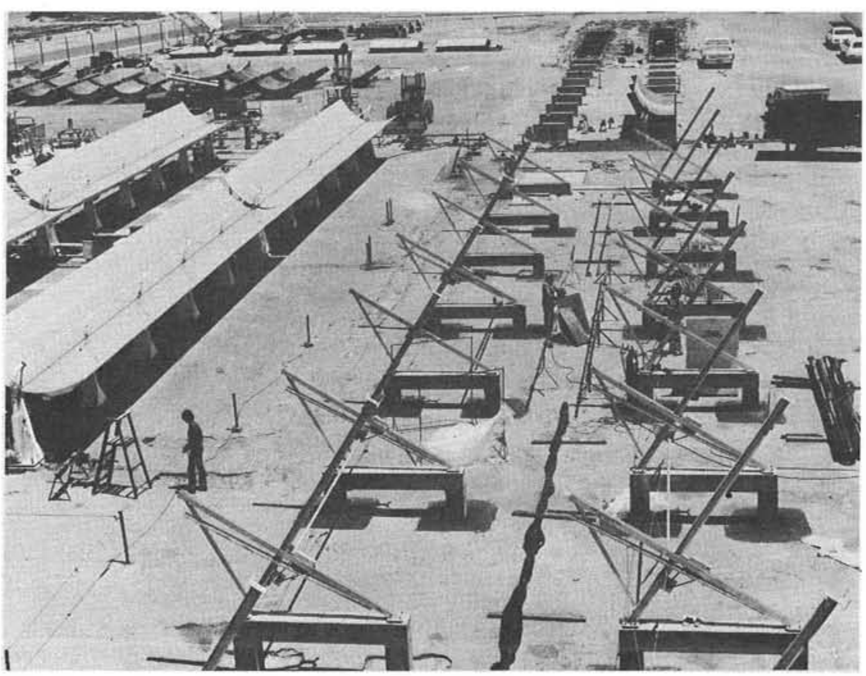


Figure 6. STESTF - August 4, 1977

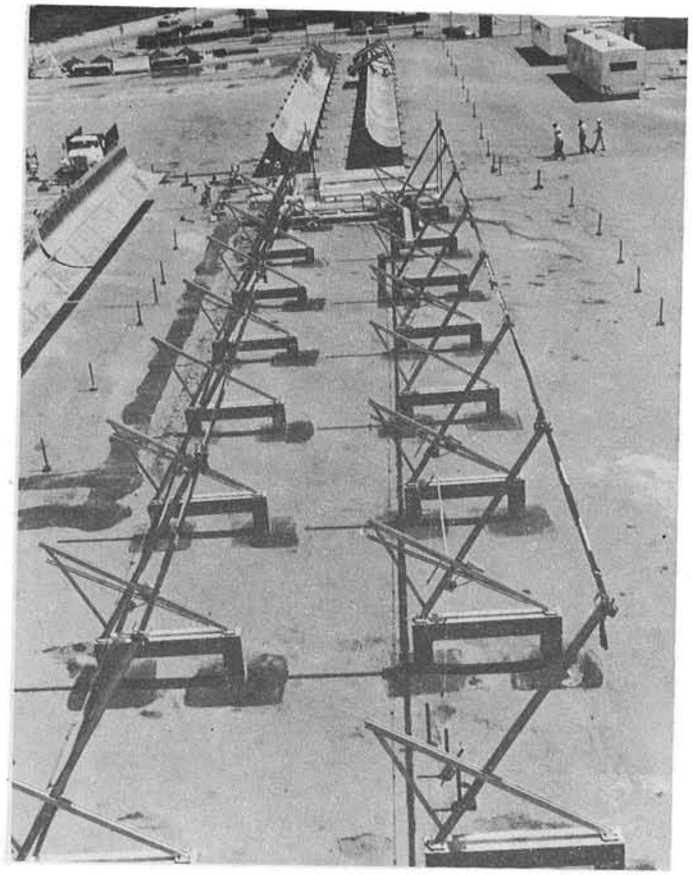


Figure 7. STESTF - September 9, 1977

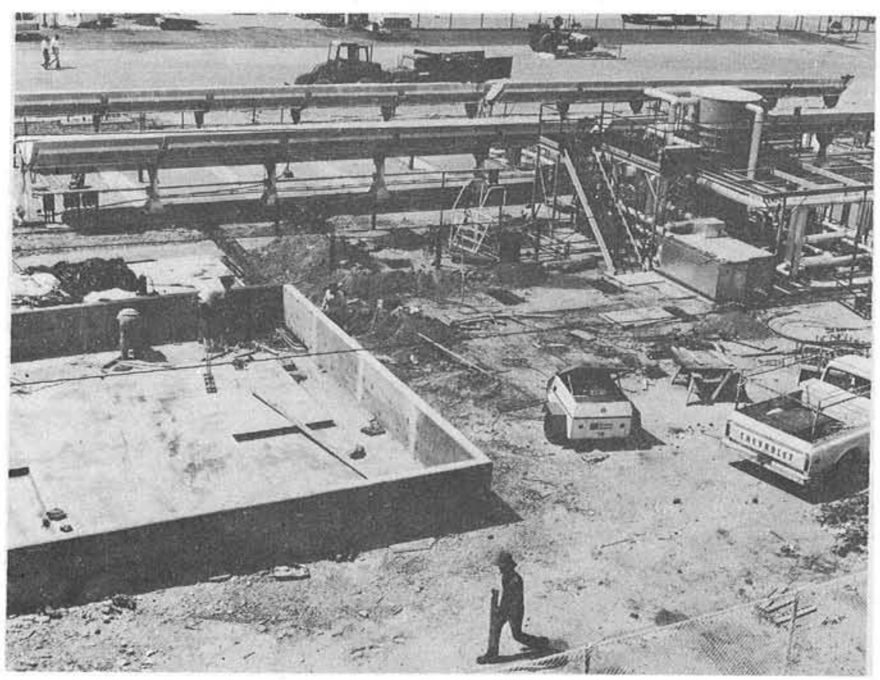


Figure 8. Multiple-Tank High-Temperature Storage Site - May 1977

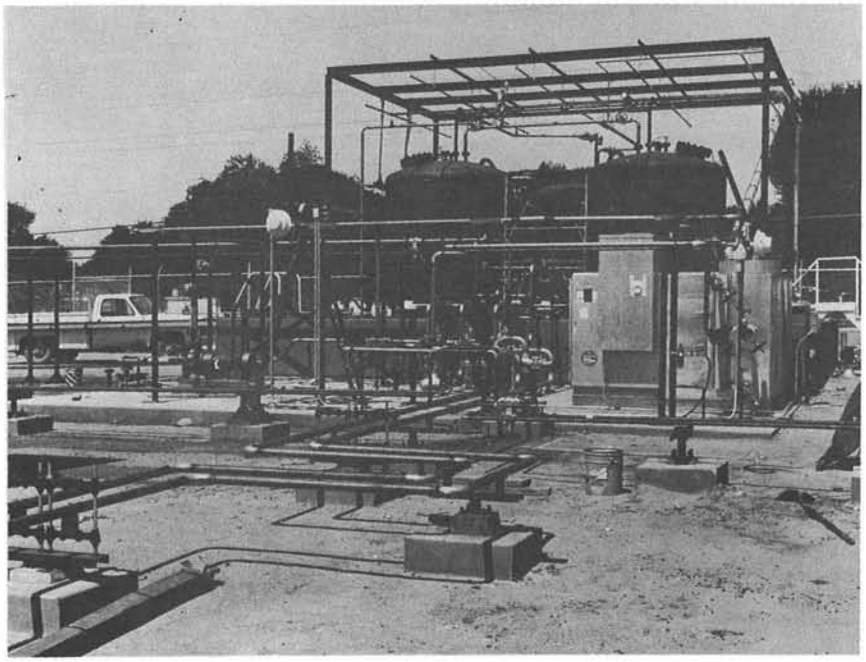


Figure 9. Multiple-Tank High-Temperature Storage Subsystem - September 1977

Figure 10. STESTF Looking Northwest

During September, the new tanks were pressure-checked with air at 100 kPa (14.5 psi); the piping of the new fluid loop was pressure-checked with air at 345 kPa (50 psi). No leaks were found. The piping was equipped with extra strainers and T-66 was pumped through the piping for 24 hr to remove accumulated foreign material. On September 16, 316°C (600°F) T-66 was pumped through the uninsulated piping until the existing temperature exceeded 93°C (200°F). (The reason for selecting 93°C is that the viscosity at this temperature is almost the same as at the operating temperature of 320°C (610°F).) The piping was then pressurized to 1 MPa (150 psi) with T-66 and checked for leaks. Leaks found in one weld joint and four valves were corrected.

From August 22 to September 12, the entire system was shut down to tie the newly installed piping into the original system. During shutdown, the following tasks were accomplished:

1. Installed bypass to allow preheating the fossil-fuel heater before switching from collector or storage to the heater. Previously, the turbine stalled while the heater and the T-66 in it were being brought to temperature.
2. Replaced two flow meters with new ones.
3. Replaced the thermocouple cabinet in the control room with a larger size to accommodate new collector field subsystems.
4. Replaced the turbine control panel.
5. Removed the Delta processor and transferred its control functions to the Hewlett-Packard minicomputer.
6. Performed maintenance and calibration on pumps, valves, and relief valves.

On September 30, the expanded fluid loop and the SLATS collector field subsystem were turned on, with the multiple-tank high-temperature storage subsystem awaiting completion of instrumentation and insulation.

System Analysis -- Continuous operation of the E-W parabolic collector field and turbine/generator continued. The available operating time is defined as an 8.5-hr working day. The percent of available time that these subsystems were operated is shown below:

	Percent	
	July	August
Collectors	27	96
Turbine/Generator	28	87
Power to Solar Projects Building	25	71

Operation in September was severely limited because of the need to shut down the existing system and tie in the new system. Operations resumed September 12. However, because extensive changes had been made to piping controls, wiring, and electronics, the start-up was phased to activate only one item at a time and determine that it was operating properly.

Continuous operation did reveal several trouble areas, most of which have been corrected and are described in subsequent sections of this report.

Test Management -- Much of this subtask effort has been spent in organizing a comprehensive system for reporting test results. A schedule of summary reports was prepared for each task except Project Management (Task 1), Collector Subsystems Contracted (Task 4), and CMTF (Task 8). Topical reports for Tasks 4 and 8 will be issued after significant tests have been completed. Contractor progress reports will emerge from Task 4, and the CMTF will issue semiannual summaries.

A test summary report (SAND77-1528) on the thermocline high-temperature storage subsystem is ready for printing. Results and conclusions are also included in the Task 5 section of this report.

Twelve letter reports were issued on the following subjects: collector performance (5), turbine/generator performance (5), and high-temperature storage (2). These reports are summarized under appropriate tasks and listed below:

Collector Performance

V. E. Dudley and L. E. Torkelson, "System Thermal Mass Test, April 4, 1977," issued June 2, 1977.

V. E. Dudley and L. E. Torkelson, "Steady-State Thermal Losses, April 25 and May 10, 1977," issued July 21, 1977.

K. D. McAllister and R. L. Champion, "Collector Efficiency Tests, March 22 and April 26, 1977," issued July 21, 1977.

K. D. McAllister, R. L. Champion, and B. J. Petterson, "Reflector/Structure Slit Aperture Test," issued Spetember 27, 1977.

K. D. McAllister and B. J. Petterson, "Collector Efficiency Tests, June 30 and July 1, 1977," issued September 27, 1977.

Turbine/Generator Performance

K. D. McAllister and J. P. Abbin, "Transient ORC Performance, December 1976 to April 1977," issued May 2, 1977.

K. D. McAllister and J. P. Abbin, "Out of Tolerance Temperature Effects, March 16 and 28, 1977," May 2, 1977.

S. Thunborg, "Solar Project Building Electrical Load Evaluation; May 1977," issued June 12, 1977.

K. D. McAllister and J. P. Abbin, "Transient ORC Performance, June 28-29 and July 8, 1977," issued September 30, 1977.

K. D. McAllister and J. P. Abbin, "Loss of Condenser Cooling Fluid, June 30, 1977," issued September 30, 1977.

High-Temperature Storage

T. D. Harrison, "Storage Tank Vacuum Jacket Effectiveness," Issued April 25, 1977.

K. D. McAllister and T. D. Harrison, "Automatic Cooler Mode Operations, April 1977," issued September 30, 1977.

Operation and Test -- As reported in the above section on Test Management, continuous operations of the facility began in July 1977 and were interrupted in August and September by the need to tie in the expanded fluid loop, the new collector field subsystems, and the new multiple-tank storage subsystem.

Safe Operating Procedures (SOPs) were reviewed. No changes were found necessary; however, extensive modifications will be required when the new subsystems are brought into operation.

Because of possible dangers from high pressures, high temperatures, and concentrated sunlight associated with the new subsystems, we formulated plans and created designs to restrict the access of unescorted visitors in the STETF.

Task 3 - Collector Subsystem

The primary effort of this task was to operate and evaluate the 200 m^2 parabolic trough collectors that were installed in December 1975 as the initial collector subsystem of the STESTF. These collectors have been operated at every opportunity during the reporting period, regardless of weather, except for down time for modifications, malfunction, and maintenance. In addition to specific tests, data were collected for all-day operation for summer solstice and fall equinox.

Collector Performance -- Collector efficiency was calculated from a series of tests performed during the reporting period.[1, 2, 3]

The four 18-m (60-ft) long collectors were connected in series; the peak efficiency of each parabolic trough quadrant is shown in Table VI for tests between March and September. Overall efficiency decreased 6% during these 6 mo to an average of 37.7%. Figure 11 shows the efficiency plot for one quadrant as a function of solar time on September 29 when the peak efficiency was 40.6%.

TABLE VI

Comparison of Collector Peak Efficiency

Date	Peak Efficiency of Each Quadrant (%)			
	NE	SE	SW	NW
March 22, 1977	43.0	40.0	39.5	38.0
April 26, 1977	42.0	37.0	37.0	37.5
June 30, 1977	41.7	39.8	41.6	40.0
July 1, 1977	42.5	41.0	41.9	40.0
Sept 29, 1977	40.6	34.5	39.7	35.8

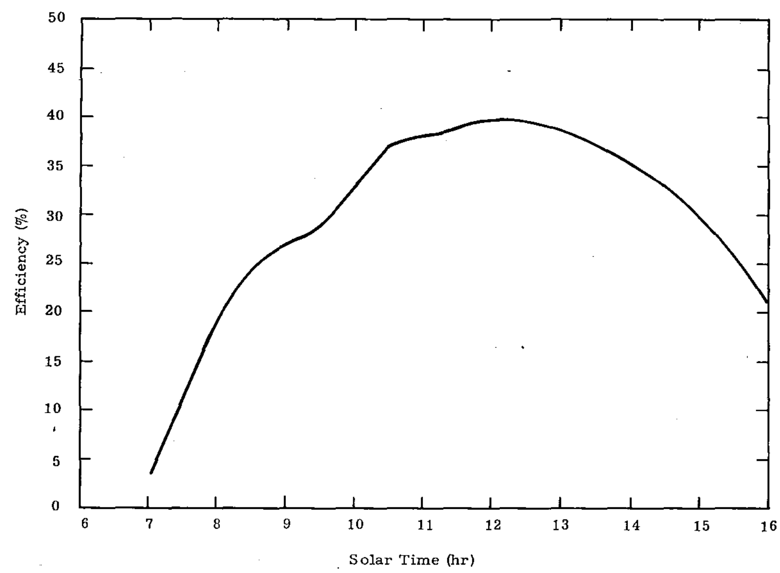


Figure 11. Collector Efficiency, Northeast Quadrant - September 29, 1977

Analyses have shown there are five factors that contribute to the decrease in collector efficiency:

1. Decrease in reflectance
2. Loss of accuracy in the parabolic trough (twisting distorted the structure)
3. Loss of accuracy of the receiver tube at the focal position of the parabolas
4. Decrease in the absorption of the receiver tube
5. Decrease in the transmittance of the receiver tube glass.

We are studying the effect that each factor has on the decrease in efficiency and will issue a report after the study is complete.

Fluid Loop Thermal Performance -- The fluid (T-66) loop consists of 73 m (240 ft) of receiver tube, 70 m (229 ft) of interconnecting piping, a reversible pump, storage tank, blending tank, and control valves. Studies were made on the thermal losses of the loop,[4,5] except for the tanks analyzed previously. (See preceding Semiannual Report, SAND77-0738.)

A simplified model (four continuous-tube and glass-envelope sections) was used to estimate the receiver thermal losses. The results are presented in Figure 12 along with data taken to determine actual loss rates for the loop. Losses obtained for forward and reverse flow should have been identical, but differences were attributed to the inaccuracies of the flowmeter and thermocouples. Recalibration will be performed to reconcile the differences.

The total loop loss was 8.9 kW (30,300 Btu/hr), with 75% coming from the receivers, 17% from piping and valves, and 8% from the uninsulated pump. Average heat loss for the piping was 127 W/m (2.2 Btu/min-ft). Since this is a test system, the plumbing was designed for versatility (extra valves, pipes, etc) so that higher-than-normal losses are inherent.

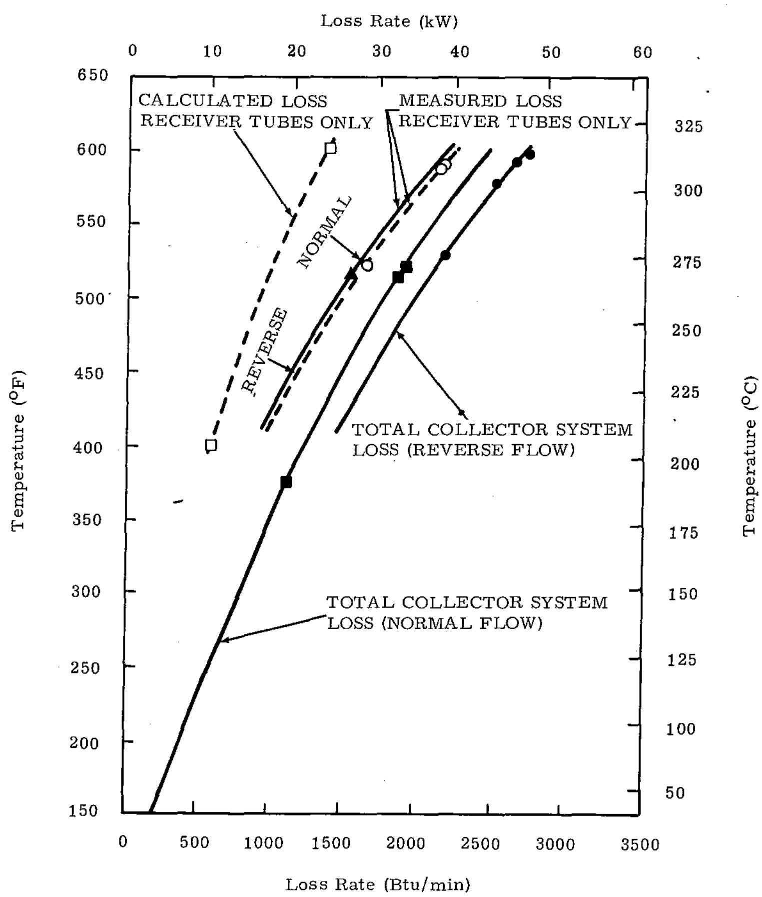


Figure 12. Total Fluid Loop System Losses

Because of the cyclical operation of solar heat, a significant portion of the daily thermal input is required to raise the temperature of the receiver, pipes, and pumps to the operating point. A thermal mass test of the parabolic trough system in April showed that ~300 MJ (370,000 Btu) was required when the fluid loop began from a temperature of 16°C (60°F). For this system and this time of year, 20% of the daily energy collected was used for warm-up. Between 9:30 a.m. (when the system was warmed up) and 4:00 p.m. (when the insolation fell below that required for 316°C (600°F) fluid output), thermal losses from the plumbing amounted to an additional 13%.

Careful attention to thermal loss factors pays significant dividends for system designers. Pipe supports, valve extensions, and flexible pipe insulation typically are fertile areas for improvements.

Reflectors -- The reflector panels installed on the troughs have continued to degrade during the past 6 mo. Many small cuts were produced in the Teflon on 6 or 7 of the 20-trough units due to tumbling pieces of broken glass from receiver tubes broken in an April 1976 wind storm. Each cut has resulted in a growing area of reflector degradation, probably due to dirt and moisture entry during precipitation and washing operations. The adhesive that bonded the aluminized Teflon to the Mylar appears to be water-soluble, allowing deterioration of it and the reflective evaporated aluminum coating. The entrapped water has delaminated the films over a large area, an example of which is shown in Figure 13. On three panels, the deterioration has reached such proportions that the entire area of Teflon from vertex to one rim has pulled loose from the aluminization and adhesive, forming a clear bubble several centimeters above the panel surface. Breaks in the Teflon surface were also caused by inadvertent damage by handling and installing the panels.

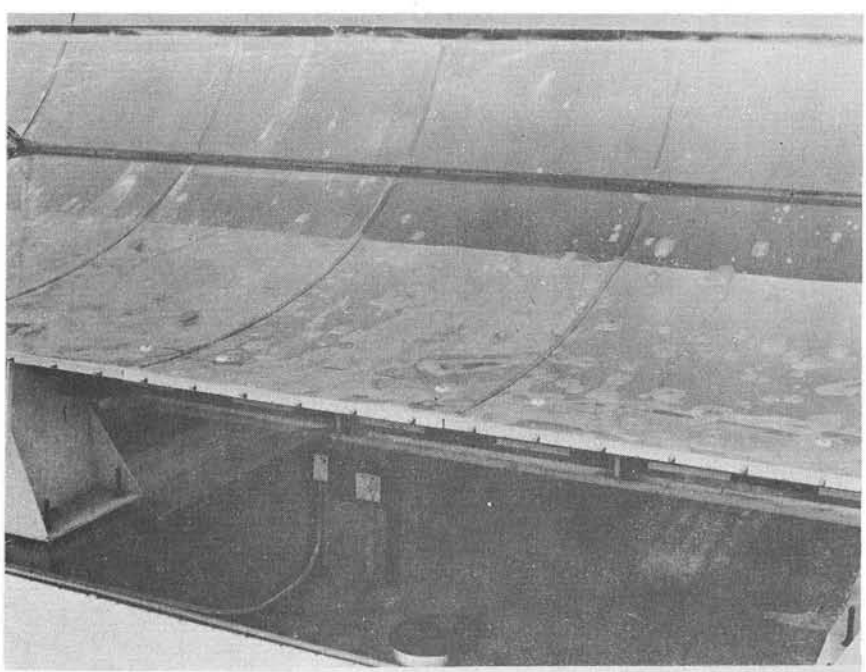


Figure 13. Degraded Parabolic Trough Reflector

Some of the damaged panels were left in place intentionally to observe long-term effects like those described above. Other cuts were repaired immediately after occurrence with patches of Scotchcal 5400R or one of 3M's adhesive-backed reflector films. In most cases these repairs were successful; the patches adhere well and completely arrest further degradation.

Replacement of the degraded panels with spares is scheduled for the near future. Reflectance measurements will be made of undamaged areas of the panels removed.

Using metallized Teflon for reflector films may not be practical for future collector applications for several reasons. The Teflon is soft and subject to cuts and abrasion that rapidly deteriorate the reflective characteristics if not immediately repaired. Normal handling and installation can be expected to produce a few cuts in the film. Washing operations that involve contact with the film, other than sprayed-on fluids, will produce abrasion scratches that permanently degrade reflectance.

Studies on other candidate film materials indicate that metallized acrylic has a harder, smoother surface than Teflon and offers higher reflectivity. However, favorable aging data will be necessary before further development of reflectors is justified.

Cleaning of Collectors -- Collector efficiency is affected by reflector and glass surface cleanliness. Performance tests, conducted before and after collector cleaning, showed a gain of 5% in efficiency. The heat gain for 1-day operation increased 5.5% as a result of washing. These results were obtained after normalizing the solar input for a small difference between adjacent days of testing. Reflectance measurements as a function of reflector cleaning were reported in the preceding Semiannual Report (SAND77-0738).

Receiver Tubes -- Concentric glass envelopes surround the receiver tubes on the parabolic trough collectors. As previously reported, modifications were made to the original receiver tube design to eliminate some of the problems encountered in installation and operation. Changes included increasing the vacuum pumping port diameter to 6.4 mm (1/4 in.), locating thermocouple feedthroughs in the steel end flange, and using a rotatable flange at one end to simplify field installation. Fifteen of the new units were fabricated at Bendix, Kansas City, and at Sandia. Two units were used to replace broken glass receiver in tubes, and an additional eight units were installed in May on the Northwest and Southwest trough collectors. Installation of these 10 units allows testing of the high-temperature (west) half of the field with vacuum. Operations were conducted without vacuum while awaiting installation of a large vacuum pump and manifold system capable of pumping the 10 units down to a vacuum of less than 1.3 Pa (10^{-2} torr). The pump and manifold were installed in August; checkout was in progress at the end of the reporting period.

Concurrently, vacuum integrity tests were run in the laboratory on the O-ring glass-to-metal seal design (reference previous Semiannual Report, SAND77-0738, for details). Although Viton^R O-rings were found to be significantly better than silicone O-rings, Viton^R permeation rates at temperatures above 93°C (200°F) were excessive. Vacuum losses varied between 4×10^{-4} Pa/s (0.18×10^{-3} mm Hg/hr) and 1×10^{-2} Pa/s (4×10^{-3} mm Hg/hr) for receiver temperatures of 274°C (525°F) and 330°C (625°F). Typical cycling tests, in which the receiver assembly was heated to between 288°C and 316°C (550°F and 600°F) for 8 hr and allowed to cool for 16 hr, yielded losses of 24 Pa (0.18 mm Hg)/cycle. These results indicate that this O-ring seal will require intermittent pumping at least once a day to maintain vacuums low enough to negate conduction heat loss. This penalty is too high; consequently, other approaches to maintaining leak-tight seals are being considered.

The black chrome coatings on the newly installed receiver tubes began to exhibit discoloration after about 200 hr of operation, particularly on the five tubes located nearest the high-temperature outlet end of the collector field. The discoloration was pronounced after another 100 hr. The coatings had changed from the rich dull black color to brownish, bronze-black tones with a few areas tending toward a green hue. Since the glass must be removed to make absorptance measurements, none were made on the new tubes. The old tubes, which were replaced, had been more severely discolored, and the average absorptivity had decreased from 0.95 to 0.84 after about 15 mo of operation.

The 10 new tubes have been operated without vacuum, but the rapidity of degradation raises significant questions regarding the cycling in air, presence of moisture in the annulus, and overheating. The effort directed toward resolving the problem is reported in Section IV.

Tracking and Control -- The original solar-tracking system for the parabolic trough collectors was described in the STEP Semiannual Report, October 1974-March 1975 (SAND75-0278). A second-generation system was designed and installed in September 1976. Improvements were made in (1) more reliable motor-driven circuit, (2) linear output sun sensor, (3) fewer electronic components, and (4) lower cost.

The system schematic, Figure 14, shows the triac motor-driven circuit. Optoisolator coupling is used: these devices became erratic during high-temperature (summer) operation. These will be replaced with higher-temperature-rated units.

The original sun sensor had four photovoltaic cells, two cells connected in series on each side of a sunshade. The two cells on each side were slanted at a 30-degree angle so the early morning sun would easily hit the cells facing east, and the afternoon sun would be captured by the cells facing west. There were two problems with this design:

1. Each cell had a different characteristic and produced a different output voltage.
2. The cells when operated in the voltage mode saturated easily and, as a result, there was no usable analog signal from the sun sensor.

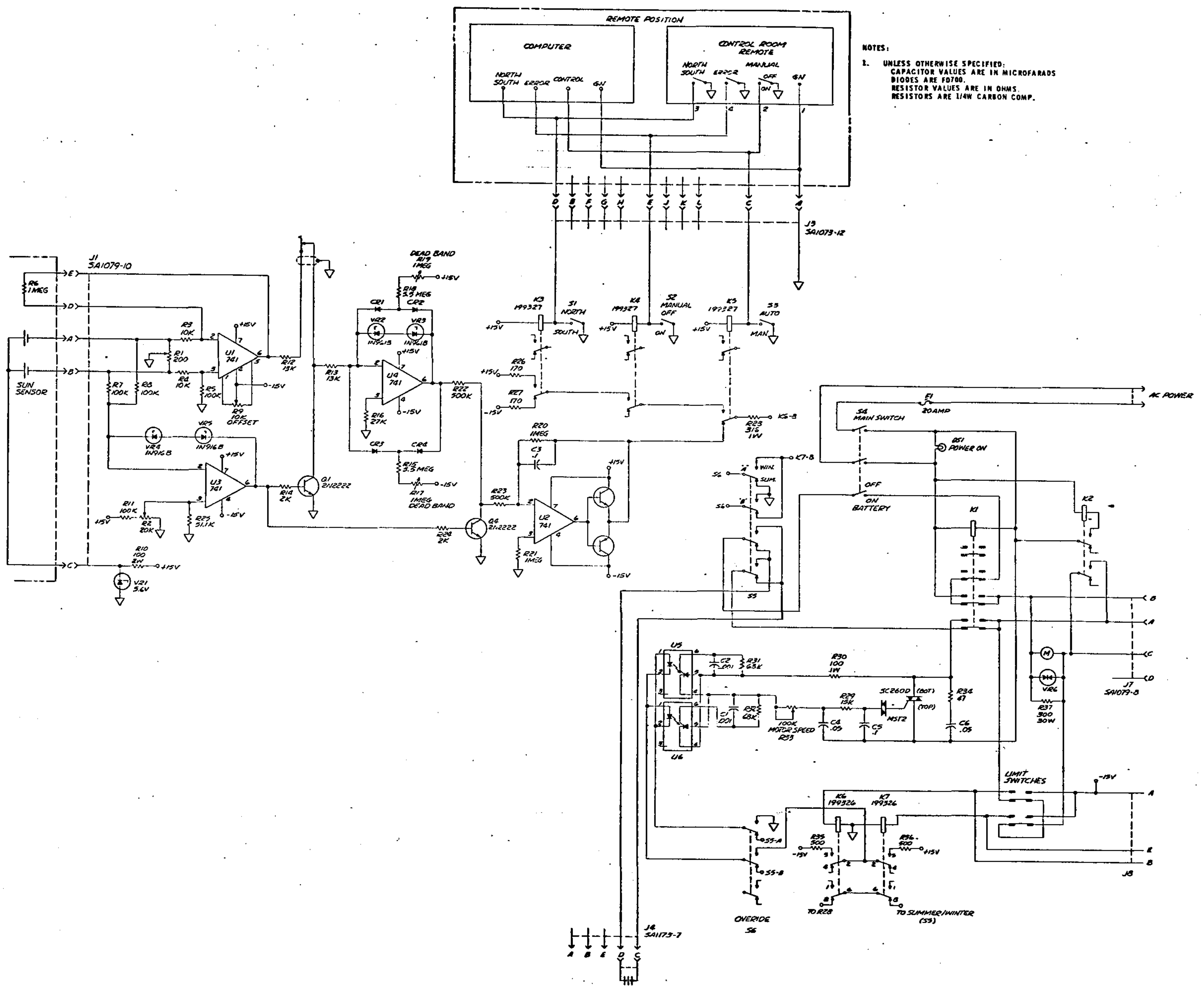


Figure 14. System Schematic for Triac Motor-Driven Circuit

To solve this problem, only one solar cell was used on each side of the sunshade. Also, the solar cells were operated in the current mode, which resulted in a definite improvement because a linear analog signal could be obtained from the sun sensor.

The solar cell mismatch problem still existed as it is difficult to get matched solar cells and to locate them accurately on the sides of the sun sensor.

Six integrated circuits, 10 transistors, 2 transformers and 2 relays were eliminated by using the triac to power the dc drive motor. By using the sun-sensor photocells in a bridge network, two more integrated circuits were eliminated.

A description of circuit (Figure 14) operation begins with the sun sensor output, which is fed into a differential amplifier U1. The balance control R1 is used as a fine adjust to bring the system into perfect focus. The output of the sun sensor's photocells is summed into Pin 2 of the U3 op amp to form the sun-intensity-level detector. R11 is used to set the threshold level for U3. When the output of U3 goes high, Q1 and Q4 are turned on, inhibiting the analog circuit from operating. Op amp U4 operates as a limit-saturated amplifier, which has a deadband, and feeds another op amp U2. The signal will be one of three states: +10 V dc, -10 V dc, or 0 V. If the output of U2 is 0 V, there is little or no signal from the sun sensor; i.e., it is within the limits of the deadband set by U4. If the output of U4 is +10 V, the output of U2 will be -10 V, which turns on the bottom transistor on the output of U2. This will apply a negative signal through R28, through contacts of K6 and K7, through contacts of summer/winter switch, through contacts of S6 to U5 and U6. Since the voltage is negative at U5 and U6, the light-emitting diode in U5 is turned on, causing the triac to conduct on one-half the ac input cycle. This causes the motor to rotate in one direction. The motor reverses when the output of U2 is positive and U6 is turned on.

Remote position controls are shown at the top of the schematic. The tracker may be operated by a computer or by a manual switch panel in the control room.

Additional sun-sensor problems came from reflections from bright objects such as buildings, snow, and clouds. These reflections change from minute to minute and cause a continuous varying error. The problem can be partially corrected by decreasing the field of view of the sun sensor, but this defeats the wide-field-of-view sun-sensor concept.

A sensor of this kind must be mechanically aligned to rotate around a true east/west or north/south axis. If it is not in true alignment, it will drift off true focus during the day.

Because of the problems with the analog tracker/sensor system, the collector field has been operated with the computer-command system. Development effort on a microprocessor-controlled system is reported in Section IV.

Operational Testing -- The policy of maximum collector operation during normal working hours was continued through this reporting period. The purpose is to provide maximum data collection under varying weather conditions, and to provide maximum real-time operation on the components. Since the collectors were controlled in the computer-command tracking mode, they could be operated even during cloudy weather without collecting energy. Operation, under this definition, was conducted for more than 90% of normal working hours for the reporting period, or ~1000 hr. Total operating time on the collector field since its installation in December 1975 has been ~1800 hr. Nonoperational periods included time for maintenance, modifications, mirror washing, and computer downtime.

Task 4 - Collector Subsystems Contracted

General Atomic, Raytheon, and Suntec are under contract to provide a variety of solar collector field subsystems for the STESTF. A summary of their activities during the last 6 mo and a report on their current status follows.

General Atomic FMSC Subsystem -- The Fixed Mirror Solar Collector (FMSC) subsystem was designed by General Atomic (GA), and a picture of the collector troughs, taken near the end of the report period, is shown in Figure 15. The concrete trough modules were installed on their footings, strip mirrors were being installed, and installation of the receiver-support hardware began.

Earlier design concrete-trough modules, cast in precision aluminum forms, used steel-mesh reinforcing. Before pouring the troughs for the subsystem, the use of steel fiber-reinforced concrete was investigated. The locally mixed fiber-reinforced concrete "ready mix" was almost three times more expensive than regular concrete, but eliminating the steel mesh and associated labor more than compensated for the higher cost. Using the fiber reinforcing is expected to result in less flaking, especially in the area of the steps that carry the strip mirrors.

The cost of casting and installing the 32 concrete-trough modules was $\$70/m^2$ of collector aperture. Less than half this cost was for material. The cost of the foundations was \$36.60/m of collector aperture, but GA considers these to be overdesigned. For future trough designs, GA would use about half the concrete used here.

The back-silvered mirror reflectors are 1.5-mm-(0.060-in.)-thick, Type 0317 fusion glass from Corning Glass Works and have a 0.95 specular reflectivity. The 51-mm-(2-in.)-wide strips have seamed edges roughened by a sander to improve adhesion of the sealer. Polyurethane enamel was used to cover the edges and back side of the strips; Scotch No. 468 transferable adhesive holds them on the troughs.

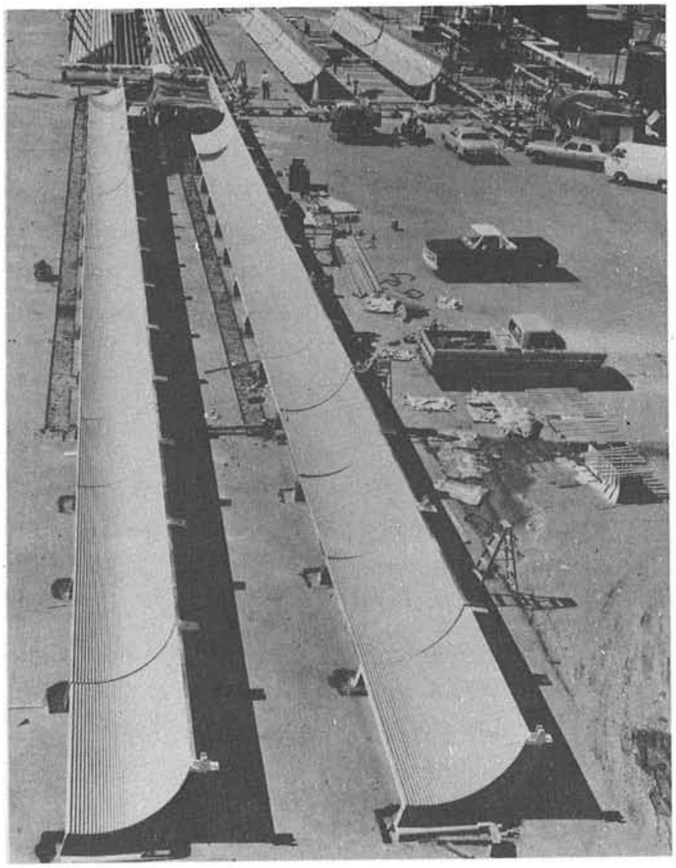


Figure 15. Fixed-Mirror Solar Collector Troughs

Good edge protection is important for this reflector concept. Since the mirror strips are narrow, loss of silvering at the edges would result in significant reduction in performance. The selected coating has proven to be superior to anything else tested in direct sunlight or in Sandia's environmental chamber. The coating samples were exposed for 3-1/2 mo in the environmental chamber before edge deterioration was found. This represents 3-1/2 yr of exposure to a severe southwest climate and indicates that development of better coatings is necessary. At Sandia there is an ongoing test program searching for better protective coatings for silvered glass.

The design analysis of the receiver completed during this reporting period resulted in a widening of the receiver aperture. The primary reasons were to compensate for mirror placement and receiver alignment inaccuracies, which were measured on the FMSC module (refer to Task 8). The trade-off was a concentration factor, larger flow cross section, and a larger shadow on the reflector. The receiver design uses a 140-mm (5.5-in.) secondary concentrator aperture and a 64-mm-(2.5-in.)-wide absorbing surface. The absorber consists of a 25 x 64-mm rectangular steel tube with a 2-mm (0.083-in.) wall thickness, which was plated with black chrome by Hyland Plating Company.

The secondary concentrator was fabricated of extruded aluminum with Kinglux bonded to the reflecting surfaces. Kinglux is a polished anodized-aluminum film with specular reflectance of 0.75, measured at an angular aperture of 18 mrad.[6,7]

To minimize heat loss from the absorber, we used Microtherm insulation; to alleviate the dust problem, we coated the Microtherm with glass cloth. Thin (25 μm) stainless-steel foil covers the absorber to help keep out dust and to act as a corner reflector.

The absorber window is made of clear Teflon, which was chosen after encountering difficulty in locating glass with a high transmissivity that would survive the thermal stresses. The transmissivity of Teflon was found to be 95%. Antistatic sprays are being evaluated to reduce the problem of static charge and dust accumulation.

Raytheon Parabolic Dish Collector -- The Raytheon Missile Systems Division is providing a parabolic dish collector, as shown in Figure 16, to be located in the northeast quadrant of the STESTF. Two additional collectors are planned for the quadrant. The collector design was completed, and fabrication is under way. The pedestal is to be shipped in December and the dish in January. Fabrication is being done at Motor Machine Company in NJ, and the dish will be reassembled on site. Installation is scheduled for completion in March 1978.

During this reporting period, Raytheon performed a detailed ray-trace analysis of the concentrator and absorber system to evaluate energy distributions during (1) normal operation, (2) operation with significant pointing errors, and (3) at the stow position. Results indicated that during normal operation the energy distribution in the aperture was consistent with previous, less-detailed analysis.

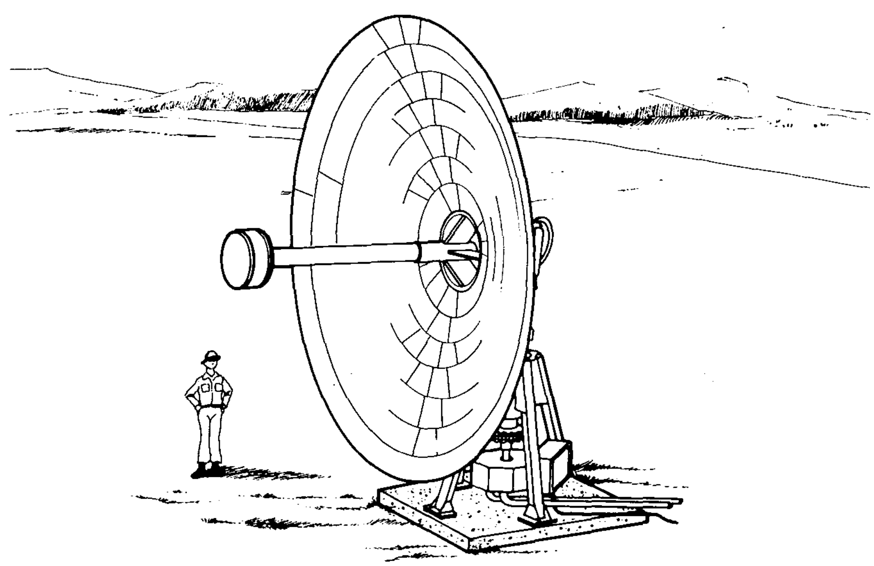


Figure 16. Raytheon Parabolic Dish Collector

The second portion of the optical analysis determined the energy levels that would impinge on the absorber support tube and absorber cover when significant pointing errors were present. These would occur during an emergency stow from normal operation and during a catch-up operation where the collector is acquiring the sun at its full intensity. Pointing errors on the order of 1 to 10 degrees were considered representative of these operational modes. The analytical results indicated that very high energy rates, on the order of hundreds of suns, will strike the absorber support tube and cover. The problem is partially alleviated by the motion of the collector; however, the calculated time-integral energy levels were enough to burn through the support post and absorber cover. Consequently, radiation shields are being designed for protection.

An error analysis was performed to determine the dimensions of the illumination in the absorber aperture. The factors that were considered were

1. Solar disk size for a perfect paraboloid.
2. Spot size dispersion resulting from nonoptimum radii of the curvature of glass segments.
3. Slope errors of the glass segments.
4. Variations in the location of the mirror support bolt holes.
5. Variations in the tilt of each mirror support.
6. Variations in the tilt of each mirror resulting from variations in the machining of the struts for the ring supports.
7. Pointing errors.

Results of the error analysis indicated that 1.2% of the energy will fall outside of a 13-cm (5-in.) annular opening, and 0.3 % of the energy will fall outside of a 15-cm (6-in.) annular opening.

The silvered, sagged glass mirrors have been ordered from the only bidder, Schott Optical Company of Duryea, PA. Mirror samples successfully passed static and dynamic simulated wind-loading tests. We conducted a series of hail survival tests and concluded that the glass is marginally capable of surviving 25-mm-(1-in.)-diameter hailstones, which exceeds the contract requirements of 12-mm (1/2-in.) hailstones.

Sandia is developing a computer-controlled tracking system for the collector. To ensure equipment survivability and personnel safety, only a few of the mirrors will be used in early operational testing.

Suntec SLATS Collector -- The contract for the Solar Linear Array Thermal System (SLATS) collector field was placed with Sheldahl, Northfield, MN, in 1976. On August 1, 1977, Sheldahl spun off a wholly owned subsidiary (Suntec System, Inc., Lakeville, MN) to handle its solar business. Virtually all personnel associated with the SLATS project moved from Sheldahl to Suntec, so that the technical relations between Sandia and the contractor did not change.

The design of the SLATS collector field subsystem is described in a previous Semiannual Report, SAND76-0662. A picture of the collector array is shown in Figure 17 and the fluid loop components in Figure 18.

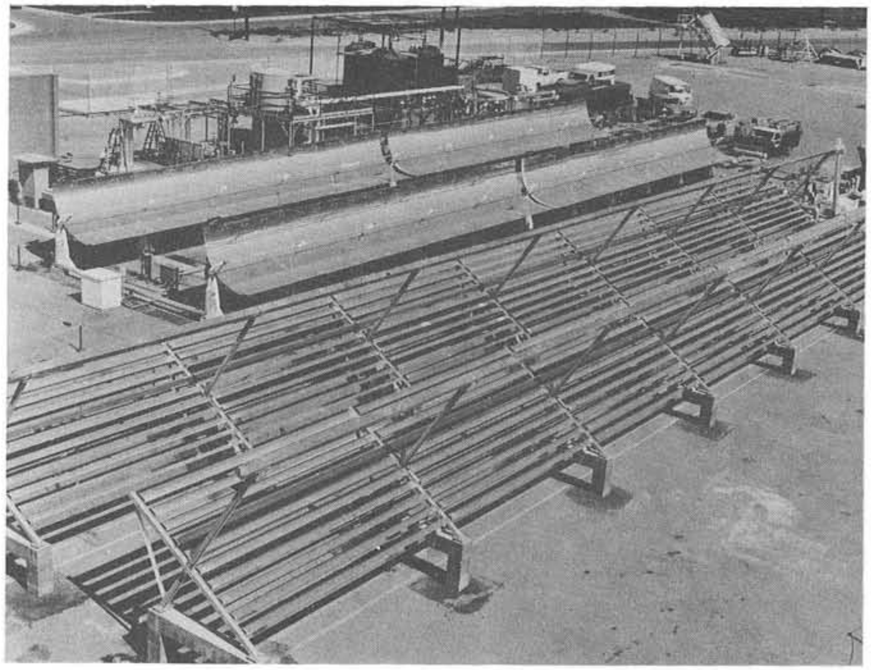


Figure 17. Solar Linear Array Thermal System

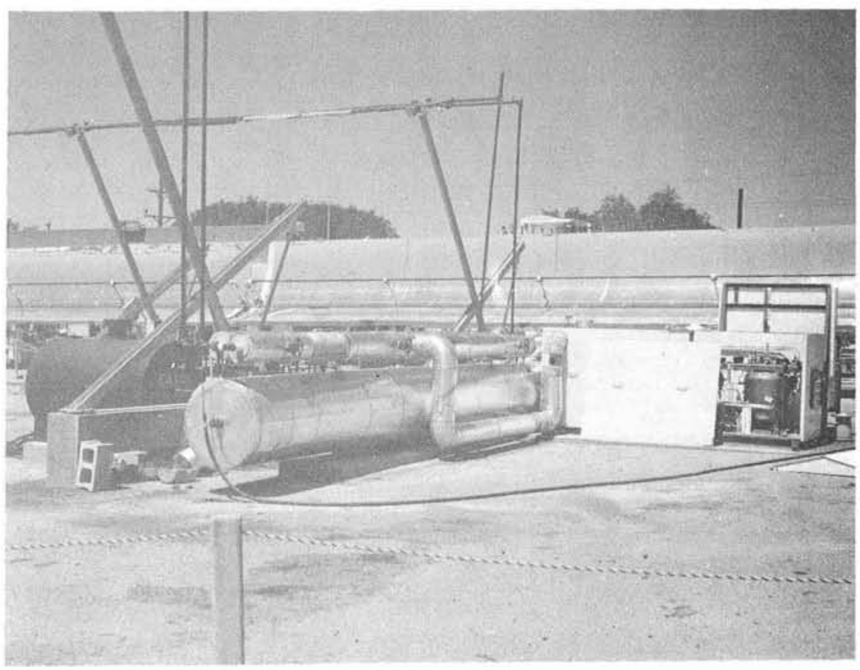


Figure 18. SLATS Fluid Loop

On September 30, 1977, the SLATS collector field subsystem was operated in automatic mode, and heat-transfer fluid (water) was heated to 148°C (300°F).

As planned, the subsystem was then defocused and examined. The following defects were discovered:

1. There was a short-to-ground in the water pump motor connector, which created a bias voltage that affected the electronic controls. The connector will be repaired.
2. The anchor fixtures, which prevent the receiver piping from expanding to the east, failed to hold. There was no damage, but the fixtures must be modified.
3. Minor problems with focusing individual mirrors were corrected during the warm-up to 148°C.

Repairs are being made and, if testing resumes on October 10, maximum temperatures will be increased by increments of 28°C. This cautious approach to operating temperature (338°C) is designed to gather data at lower temperatures and also to detect problems before they can cause serious damage.

Actual warm-up time was not compared with predicted time because there was an intermittent thin cloud cover that caused solar insolation to vary between 400 W/m^2 and 900 W/m^2.

The pictorial history, depicted in System Engineering of Task 2, shows that the subsystem is comprised of modular elements. These modular elements were fabricated either at Suntec, Barber Nichols (Denver), or Bomac Mechanical Contractors (Albuquerque) and shipped to the STESTF for installation. The concrete foundation was poured by Flinchum Construction (Albuquerque).

The receiver pipes were coated with black chrome by Olympic Plating. The 3-m (10-in.) lengths (dictated by the size of the plating tanks) were welded into 6-m lengths in the Bomac shops. These 6-m lengths were then hoisted into place on the support structure where the welding was completed. Sandia assisted with certification of welders, development of weld schedules, and procedures for radiographic examinations. Weld quality for this high-pressure system was confirmed by in-process checks, visual inspection, radiographs, and by pressure testing at 31 MPa (4500 psi). Approximately 3 wk passed between the time that the first section of piping was hoisted into place and the pressure test was completed.

In future design iterations, two items should be given special attention. First, the receiver piping has large physical and thermal mass because of the high-operating temperature. The operating temperature of 338°C (640°F) and pressure of 20.7 MPa (3000 psi) were dictated by the need to transfer the energy collected by water to T-66 at 320°C (608°F). As discussed in a previous semiannual report, SAND76-0662, a reduction of a few degrees in operating temperature substantially reduces the mass of the receiver piping.

The second item is the maximum wind-load requirement. Because of local weather history, it was specified that the structure should survive a 40-m/s (90-mph) wind. Observations made during windstorms indicated that a mirror 0.6 m (2 ft) above-ground would be clear of most wind-borne objects (small rocks, tumbleweeds, etc) capable of damaging the mirror. During the 8 mo that the SLATS module has been in the CMTF, this 0.6-m clearance has proved to be reasonable.

With the SLATS subsystem, the ground slopes to the west 0.6 m in the 43 m (140 ft) between supports. At the west end, the lowest mirror is 1.2 m above-ground. As shown in Figure 19, the calculated shear force on the top pier of the foundation is 3990 km (8800 lb), which has a moment of 47,700 Nm (35,200 ft-lb), and this results in the triangular bearing force shown. The foundation must be large to reduce the forces to values the local soil conditions will tolerate. To avoid a larger pad, the designer connected two piers with a rigid beam to distribute forces in a more nearly rectangular pattern, as shown in Figure 20. While the two-pier design is an improvement, it still is a massive structure that adds $40/m^2 to the predicted construction cost of $194/m^2 (see Table IV-II of SAND76-0662).

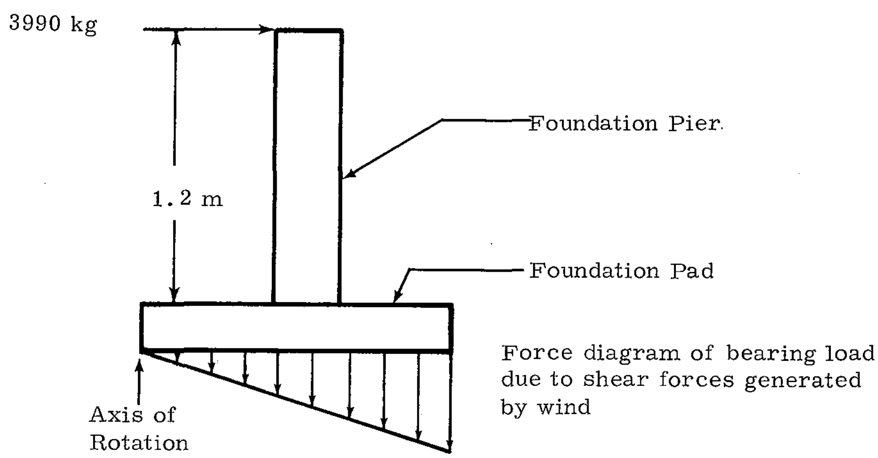


Figure 19. Force Diagram - Single-Pier Design

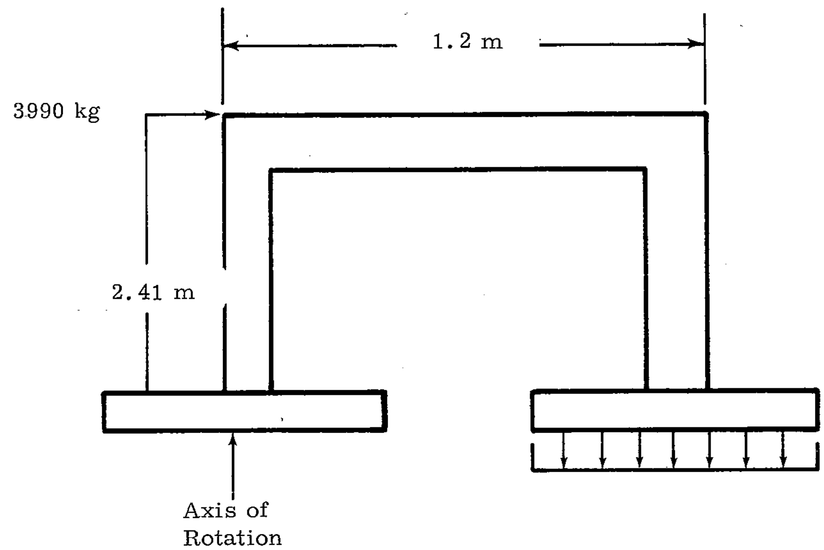


Figure 20. Force Diagram - Two-Pier Design

Task 5 - High-Temperature Storage Subsystems

The major effort in this task was directed toward procuring and installing of the multiple-tank high-temperature subsystem, including instrumentation and insulation. Also, a study was completed on the existing thermocline tank, explaining the reasons for the high energy losses.

Development -- Development activity was primarily concerned with the details of multiple-tank installation, instrumentation, and insulation. A September 9 photograph is shown as Figure 21. Attention was given to the design, support, and insulation of the tank-mounting feet. Compression tests had shown that Johns Manville Marinite XL insulation can easily withstand the compressive loads exerted by the tanks through the tank feet. Since a greater thickness of Marinite would not result in excessive compressive stress, 50 mm (2 in.) of Marinite was used rather than 2.5 mm as previously planned. This will decrease the heat loss through the supporting structure.

When the tanks are heated to 316°C (600°F), the tank diameter can increase by as much as 9.5 mm (3/8 in.). Therefore, there was concern that this relative motion of the tank feet could damage the Marinite insulation from shear forces or abrasion. A design was developed in which the tank feet rest on the Marinite insulation, which in turn rests on a thin steel sheet that covers the concrete pad. This arrangement allows slight movement of the insulation on the sheet metal during tank expansion without insulation damage. The weight of the tanks prevents lateral movement due to wind forces.

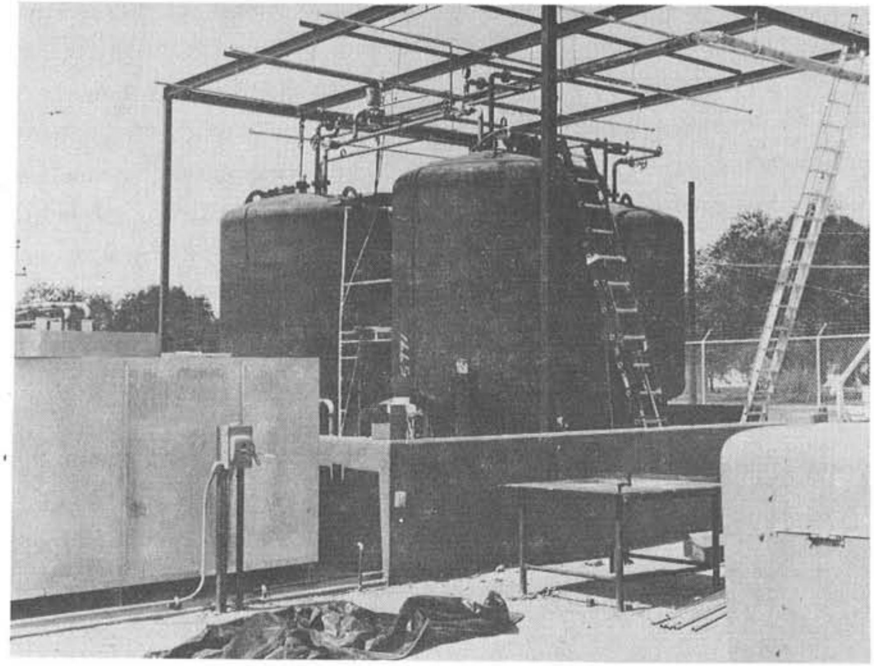


Figure 21. Multiple-Tank, High-Temperature Storage (Before Insulation)

The three tanks for the multiple-tank subsystem were delivered directly to the site and set up on the load-bearing Marinite insulation. Preparatory work was performed inside the tanks before connecting them to the thermal storage system. When the "wells" were welded in the bottom of the tanks during manufacture, a lip remained that would have retained liquid and prevented complete drainage. A 19-mm (3/4-in.) hole was drilled through each lip to allow the tanks to be completely drained. Each tank was cleaned of scale, cuttings, dust, and other debris, then closed to prevent further contamination.

Pressure-relief valves and nitrogen lines were attached at the flange on top of each of the tanks. Installation of the deluge-type fire-extinguishing system is in progress.

Allison Engineering designed a cover for the top of the insulation on the multitanks that will allow access to the manhole and the instrument probe flanges. The cover will be made of sheet metal and will rest on 20 cm (8 in.) of foam glass insulation.

During the 3-wk shutdown, the multitank-storage subsystem was connected into the existing system. Pressure tests were conducted in which the tanks were tested to 103 kPa (15 psi) with no leaks detected. The interconnecting piping, with the tanks shut out of the system, was tested to 345 kPa (50 psi) at 93°C (200°F) while pressurized with T-66. Four leaks were detected and repaired. Insulating the interconnecting piping was begun; the tank insulation is on site, ready to be installed.

Level sensing and thermocouple probes were ordered for the thermocline tank before an order was placed for probes for the multiple-tank subsystem. When the thermocline tank probes were received, we discovered that they leaked through the mounting flanges. They were returned for rework. We decided to go ahead with the order for the probes for the multitank system because of schedule considerations. The level probes for both the thermocline tank and the multiple tanks were received, and level probes have been installed in the multiple tanks. The thermocouple probe for the thermocline tank was received with 8 of the 36 connectors broken off. An additional three thermocouples did not function properly, but most of the defective units were repairable. The thermocouples for measuring tank surface temperatures have been received, but the probes have not yet arrived.

An electronic fluid level control system has been developed for the multiple tanks. This automatic controller is rack-mounted in the Building 833 control center and is ready for checkout when the probes have been installed and connected. A brief description of the control system is presented.

The fluid level controller is intended to provide automatic fluid storage and transfer in the Normal Storage Empty and Storage Full Modes. To this end, it senses the temperature of the fluid returning from the collector field and samples each tank to determine fluid temperature and level. Based on these inputs, the controller then attempts to define the operating mode and routes fluid to and from the three storage tanks. If the controller senses loss of fluid from the system or encounters a situation it cannot deal with, it transmits an alarm to the operator and shuts its control outputs off. Most operating conditions (input received vs output desired) are stored in a memory that can be changed to reflect new operating requirements.

The principal subsystems of the controller are shown in the block diagram of Figure 22.

1. The input insolation and signal-conditioning section processes the signals from the sensors to a format suitable for the controller, and provides electrical isolation from them.
2. The fluid loss detector monitors the total mass of fluid in the tanks and sounds an alarm if it falls below a programmed level.
3. The comparators and hysteresis section provides digital outputs to the system depending on fluid temperatures and tank levels, and provides delay in switching out of the Storage Full and Storage Empty modes.
4. The clock, memory, and latches block provides the basic control instructions to the unit depending on the state of the system.
5. The overfill logic modifies control commands from the memory to prevent tank overflow.

6. The output logic and relay isolation circuits provide alarms, commands, and input information through relay contacts to keep the controller electrically separate.

7. The power supplies provide system dc power.

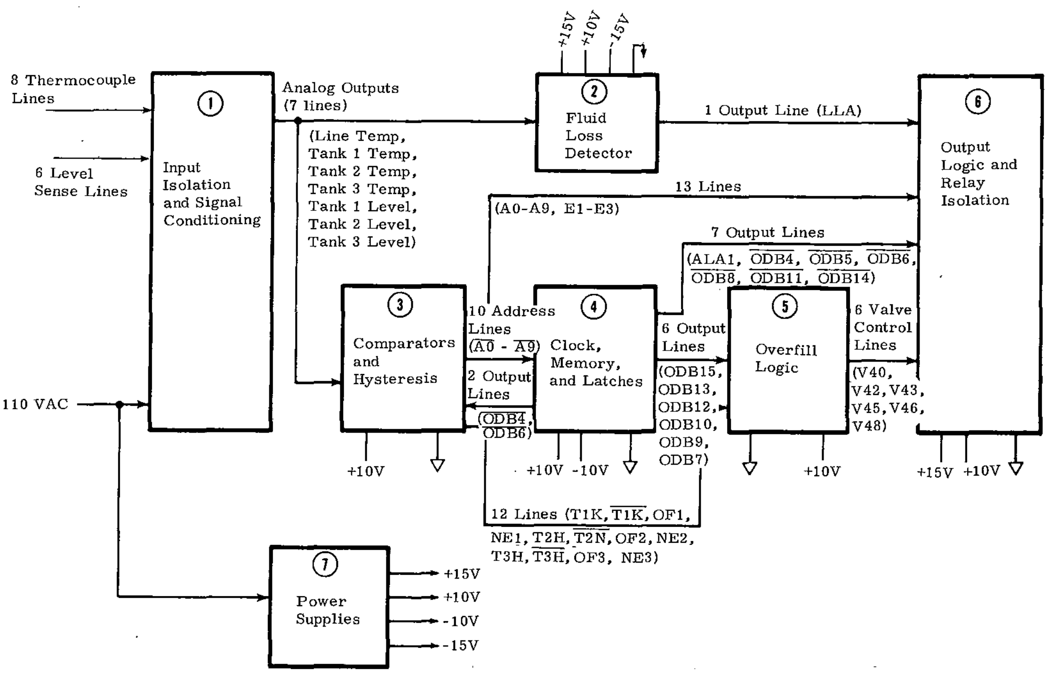


Figure 22. Fluid Level Control Block Diagram

Operation -- A report (SAND77-1528) summarizing and analyzing the results of tests conducted on the STESTF thermocline storage subsystem between August 1976 and June 1977 will be published. The purpose of these tests was to determine the effectiveness of the insulation and stability of the thermocline. The experience with this thermocline thermal-energy storage tank has led to some major conclusions summarized below. It should be noted that additional experiments in other circumstances will complement and/or modify these conclusions.

The fundamental conclusion is that thermocline storage systems are technologically feasible; i.e., the thermocline can be established and is stable enough to serve as the energy source for a turbine system.

In practical situations, the thermocline cannot be considered as having zero thickness. Allowances must be made in tank volume for the degradation of the thermocline.

Under specific test conditions, the vacuum-foil insulation did not prove to be an effective means of insulating the tank and may not be practical for large installations.

In the design of a thermocline storage system, consideration must be given to minimizing the conduction of heat along the tank wall by minimizing the wall thickness and/or by inserting and effective thermal insulator between the wall and the fluid.

Inlet and outlet diffusers must be carefully designed to minimize vertical mixing of the fluid while the storage system is being charged and discharged.

A functional test of the automatic oil-cooler system was run to verify correct operation.[8] The purpose of this cooler is to dissipate excess heat coming into the thermocline tank. Problems developed because the oil pump lost its prime when not operated for 2 days and both air-operated control valves failed to operate smoothly. The pump-priming problem was solved by raising the oil level in the tank; one valve problem was corrected by repairing the air-supply system. The other valve needs to be repaired or replaced. A conclusion drawn from this test is that "automatic" equipment must be checked periodically to verify proper operation.

During collector efficiency tests, some problems with the blending tank became apparent.[9] Fluid coming from the thermocline storage did not seem to blend with fluid already in the blending tank. When the blending tank fluid was hot, the cold fluid from storage came through the blending tank and settled to the bottom; from there it was pulled into the collector field. The problem could be solved by (1) improving the diffuser system in the blending tank, (2) putting fluid from storage into the top of the blending tank, or (3) installing a smaller blending tank with a new diffuser system. The smaller blending tank would also reduce the amount of cold fluid that requires heating on start-up by reducing the thermal mass of the system.

Task 6 - Turbine/Generator Subsystem

The turbine/generator task was largely devoted to resolving operational problems on the organic Rankine-cycle turbine and 32-kW generator unit in the STESTF. On April 26, the turbine/generator system provided electrical power to the Solar Projects Building for the first time. Thermal storage was brought up to temperature by the collectors and the turbine was operated under varying building loads for 1-1/2 hr.[10] Nominal building load appeared to be about 25 kWe, with a maximum spike load exceeding 50 kWe, occurring when the air-circulating fan was switched on.

The boiler flow-control valve system was modified such that the control signal for the valve is now a function of the turbine throttle-valve position in addition to the turbine inlet pressure used before. As reported previously, the flow-control valve operation was unstable under various operating conditions, particularly under varying electrical load. With the new control scheme, the valve operation is stable except at no load; the system accepts load changes of 30 kWe with stable operation within 2-3 min as compared with 30-45 min (if stability was obtained at all).

A preliminary study of need for an emergency condenser-cooling water system was completed.[11] The analysis indicates that an emergency source of cooling water would probably not be required to prevent overpressuring the condenser (and blowing the burst disk), particularly if the condenser overpressure-shutdown safety set point is lowered. The worst condition would occur when the turbine was operating with summer condenser conditions, and cooling water circulation was lost but the turbine continued to run. This situation was purposely carried out with the condenser overpressure-safety shutdown switch adjusted from 69 kPa (10 psig) at 127°C (260°F) to 21 kPa (3 psig) at 110°C (230°F) for a series of three tests.

These tests were run in which the cooling water was shut off while the turbine was operating. The condenser was initially at the hot (77°C/88°C glycol/water) summer condenser conditions for the tests. In two cases, the turbine shut down due to a turbine under-speed safety trip, caused by the higher-than-usual condenser back-pressure; and, in the other case, the turbine shut down due to a condenser overpressure safety trip 1 min after the condenser cooling water was shut off. All shutdowns resulted in boiler pressure being vented to the condenser. Maximum pressure in the condenser occurred 3-4 min after water shutoff; the worst case resulted in the condenser pressure rising to 100 kPa (15 psig). (The condenser burst disk is rated at 138 kPa.) These tests demonstrated that the thermal and volumetric capacities of the condenser are adequate to contain the depressurized toluene from the boiler, and that a backup condenser cooling system is not needed.

The turbine system will successfully sustain operation when switching from the fuel-fired heater-to-storage heat input, but the turbine stalls when going from the storage-to-heater mode.[12] This appears to be due to the fact that the heater and associated piping have a large thermal mass that quenches the boiler with cold T-66. Methods to overcome this problem were outlined as follows:

1. Fire up heater in the morning for a short period concurrent with system start-up. The heater might retain enough heat for a successful start-up within a subsequent period of up to 11 hr.
2. Crack the heater exit bypass valve V2 (refer to Figure 23) before using the heater for warmup.
3. Provide a parallel bleedpath (dotted line in Figure 23) from the heater entrance to the storage return line that would be opened for warmup before using the heater.

A test of the first fix was attempted May 10. The heater and piping were brought up to 310°C (590°F) in heating the storage system, and the entire system was allowed to cool down for 11 hr. The turbine was then run from storage at 32 kWe with summer condenser conditions, the heater start-up sequence initiated, and the storage-to-heater mode switch actuated when the heater flame-indicator lit. The turbine shut down, however, because of low boiler pressure 30 s later. T-66 temperature at the heater outlet indicated 49°C (120°F) initially, although T-66 temperature into the boiler did not fall below 138°C (280°F) at the time of shutdown. Further testing revealed that the heater piping cooled from 310° (590°F) to 150°C (302°F) in 1 hr and fell below 93°C (200°F) in 4 hr, which ruled out the preheat method.

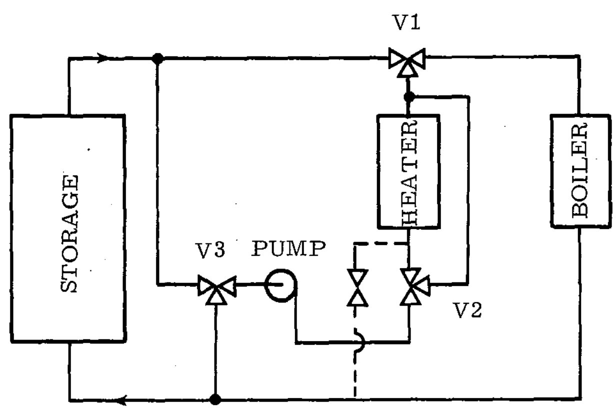


Figure 23. Schematic of Storage Heater, and Boiler Subsystem

A test of the second fix was attempted in late May. The primary problem here is to determine what the valve V2 opening should be to allow the shortest heater warm-up time (minimum energy waste) and still have sufficient flow to the boiler for the turbine to carry full load. Control circuitry was modified in an attempt to try this method of switchover but proved unsuccessful due to a closed setting on the valve V2 in one case and an unexplained lack of control of the condenser coolant flow in the second case. During the latter part of June, two more attempts were made to switch over from storage-to-heater. One test was aborted due to insufficient hot fluid in storage, and the second test proceeded smoothly until a control card for the heater failed, causing the heater to shut down. During July, the turbine heater control was modified for cooling the printed circuit boards, and three more switch-over attempts were made. The first two attempts were aborted when the storage system ran out of heat before operation could be stabilized (present storage capacity is limited to 30 min at full load), and the third attempt failed when the heater shut down due to an overtemperature safety trip signal. As before, all attempts were initiated by opening the three-way T-66 to circulate from storage to the heater in parallel with the flow to the boiler. One problem with this method is that normal temperature gradient is reversed in the heater, which can cause overtemperature.

Another series of tests was run in August to switch from storage-to-heater, but all tests were unsuccessful. In two tests, the turbine shut down due to a toluene sniffer safety trip when the heater pilot light was lit. This was apparently caused by noise on the sniffer signal line that came from the spark igniter on the heater. This was corrected by shielding the wiring. In another test, the turbine shut down due to low boiler pressure, as in prior tests. Another test was somewhat successful in that the switchover was made, but the load had to be reduced from 26 kWe to 16 kWe to prevent underpressure, and a large amount of manual control was required to keep the heater from overheating the T-66. As a result of these tests, preheating the heater by cracking the three-way T-66 valve was determined not feasible under automatic control.

The third option for switchover consists of adding a new valve and bleedline to the heater inlet and circulating T-66 from storage for preheat (as in the second option), but the flow would be established in the opposite direction. This will allow the temperature gradient in the heater to be established in the proper direction for good control. Evaluation testing could not be carried out in September due to insufficient T-66 in the thermocline storage tank. This lack of T-66 is apparently due to a sneak path or leak to the new multiple-tank storage system. An answer to the switchover problem is expected soon.

On June 15, the burst disk on the Graham heat exchanger ruptured, venting ~ 75 L (20 gal) of toluene from the system. No damage or injuries occurred. The boiler overpressure was apparently caused by a failure of an air compressor, which allowed the air-operated toluene liquid flow-control valve to open fully and flood the boiler. Normally, a relief valve between the boiler and regenerator would have bled off the pressure, but this failed to operate and was later found to be clogged with system corrosion products. An electrical solenoid bypass valve was likewise inoperable due to a loose connector. The relief valve has been cleaned, reset, and reinstalled and a new valve ordered. The old valve did not have the proper temperature capability and required a "pigtail" for heat isolation. The new relief valve line will be replumbed to eliminate the pigtail, which should prevent the buildup of foreign material. The foreign material removed from the old valve and samples of the toluene from the system and new toluene were submitted to the materials group for analysis. The electrical connector on the solenoid valve has been safety-wired to prevent loosening.

A version of program CYCLE, CYCLE2, was made operational on Sandia's CDC6600 time-sharing system. CYCLE2 will perform Rankine cycle analyses involving expansions into the wet vapor region, which often occurs with fluids such as water.

New flowmeters for the T-66 circulation loops were ordered in July and received in August. The new meters are of the rotating element type as opposed to the drag-plate type presently used. Efficiency measurements for the Rankine engine as given by the toluene loop measurements have always been 1 to 2 points low as compared with the T-66 loop measurements, and the drag-plate flowmeters are the major suspects for the discrepancy. After the new flowmeters were installed, efficiency tests indicated better agreement between the toluene and T-66 heat rate measurements.

Task 7 - Heating and Cooling Subsystems

In the STESTF, the energy rejected by the turbine/generator is at a higher temperature than that rejected in conventional electrical generating systems. This rejected energy is used to heat and cool the 1100 m^2 Solar Projects Building.

During this reporting period, construction was completed on the heating and cooling fluid-transfer system. Instrumentation and controls have been given a preliminary checkout.

The Arkla absorption chiller was operated at nominal conditions. To run parametric tests on the chiller, a larger-hot-water pump will be installed, and we will modify the controls on the fossil-fueled hot-water boiler. The larger water pump is required to run the chiller at full-rated capacity, and the modified boiler controls are needed to provide hot water to the chiller at a more uniform temperature.

During this report period, both hot and chilled water have been supplied to the Solar Project Building, using solar energy as the source.

Pneumatic controllers for the turbine condenser coolant were replaced by electronic controllers using immersion thermocouple sensors. The thermocouple sensors have a shorter time constant than the pneumatic sensors, enabling the system to reach stable conditions in less time. This is especially useful on start-up and during parametric testing.

Task 8 - Collector Module Test Facility

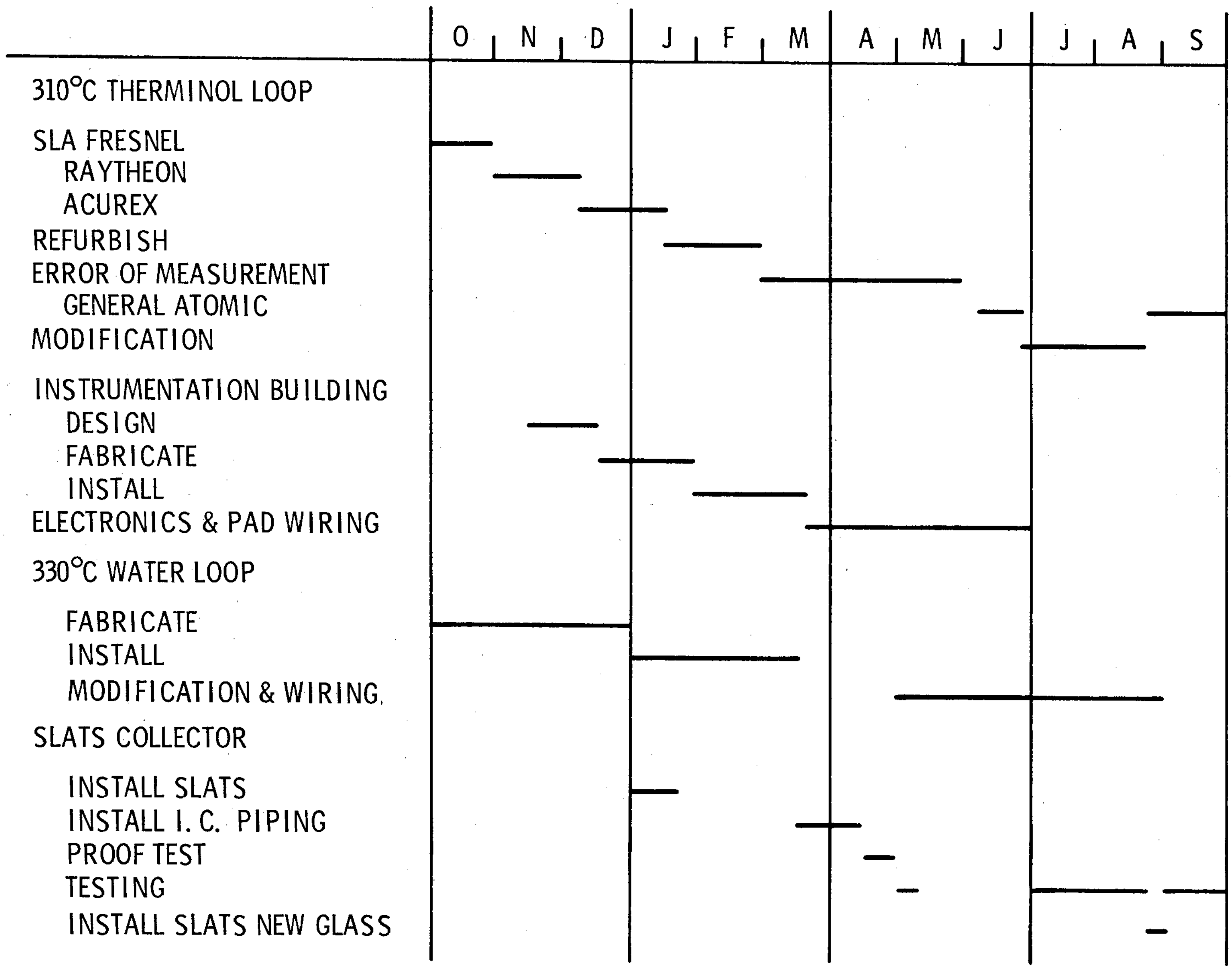
The CMTF consists of three test loops and associated instrumentation and control equipment capable of performing functional tests on solar collector modules. Figure 24 shows a layout of the facility. One of these test loops has been operated by the Photovoltaic Projects Division for evaluating photovoltaic generator arrays, and these activities will be presented in a separate report.

During this report period, significant facility modifications were completed, and modules were tested on the 315°C Therminol-66 loop and on the 330°C pressurized water loop. CMTF Total Energy activities for FY77 are summarized in Table VII.

Development and Modification -- Several modifications to the instrumentation and control system were completed. Additional instrumentation leads were installed between the test pads and the signal conditioning and recording equipment. A switch was installed that may be used to disconnect power to all loops in an emergency. Compressed air lines and separate "quiet" power lines for instrumentation were installed.

TABLE VII

FY 77 COLLECTOR MODULE TEST FACILITY ACTIVITIES



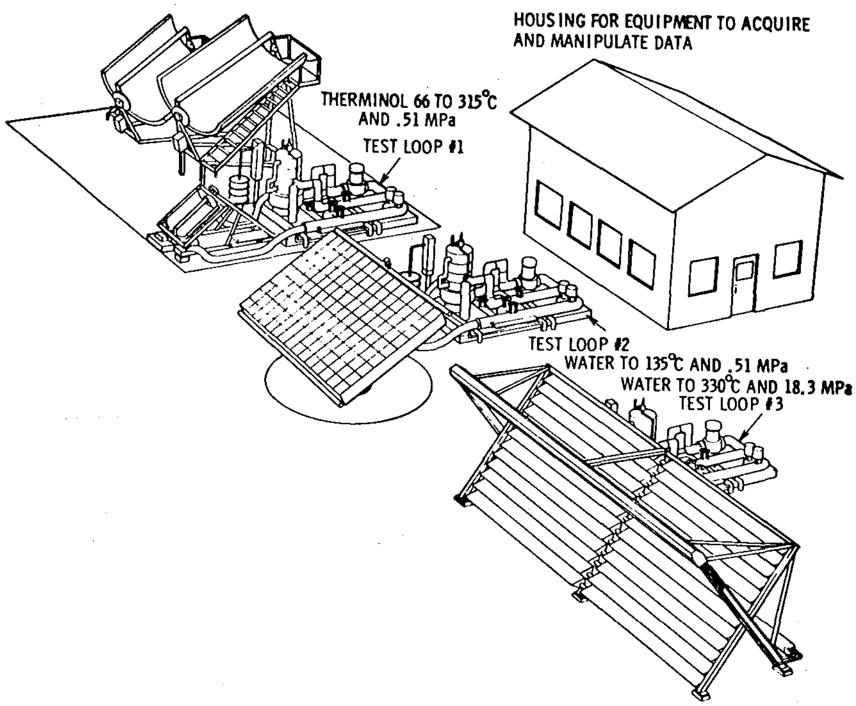


Figure 24. Solar Collector Module Test Facility

Provisions were made for supplying emergency power (115 V ac) to collectors under test and to defocus the collector if the normal power fails, an overtemperature setting is reached, or there is a loss of fluid flow.

To prepare the proper interface between modules and test loops, a Collector Module Information Sheet has been generated, and a copy is included in the the Appendix. Contractors with modules to be tested are requested to submit this form and a detailed test plan well in advance of hardware delivery.

Preliminary approval was obtained to acquire a larger capacity minicomputer-controlled data system to meet the requirements of the CMTF.

A schematic of the 315°C Therminol-66 test loop is shown in Figure 25. Recent modifications to the loop include the following:

1. Static mixers, with pressure-measuring ports and thermocouple probes, were inserted in both sides of the module under test to improve measurement accuracy.
2. New flow-control-valve trim hardware was installed to get stable flow rates, especially pertinent in evaluating smaller modules.

3. A bypass line was added to allow circulation without having a module connected.

4. Swage lock fittings were incorporated into the flowmeter calibration and module test connections for more efficient operations.

5. To aid in the stabilization of operating fluid temperatures, a manually controlled cooling water system was incorporated.

6. The 70-μ filter was not offering sufficient protection for the pump, and 20 μ was too constrictive at low fluid temperature. Two 40-μ filters in parallel have been found to operate satisfactorily.

7. A pressure-relief valve was installed to protect the module under test; the original relief valve could have been isolated from the module.

8. Because of cooling-water contamination in the T-66 pump, through leaky seals, a change was made to cool the pump with a separate supply of T-66. A water/T-66 heat exchanger cools the oil in this closed loop.

The 330°C water loop schematic is in Figure 26, and the following improvements have been made:

1. The piping location was revised to accept a standard turbine flow meter.

2. The temperature transmitters were replaced with those of the correct operating range.

3. A water-cooled jacket was added to protect the back pressure regulator from being exposed to damaging water temperatures above 260°C.

4. A new hydraulic intensifier was ordered with higher pumping rate and mildly corrosive liquid capability in an attempt to gain longer service life than has been achieved.

5. The fluid loop pneumatic valves were switched from bottled nitrogen to the newly installed compressed air supply.

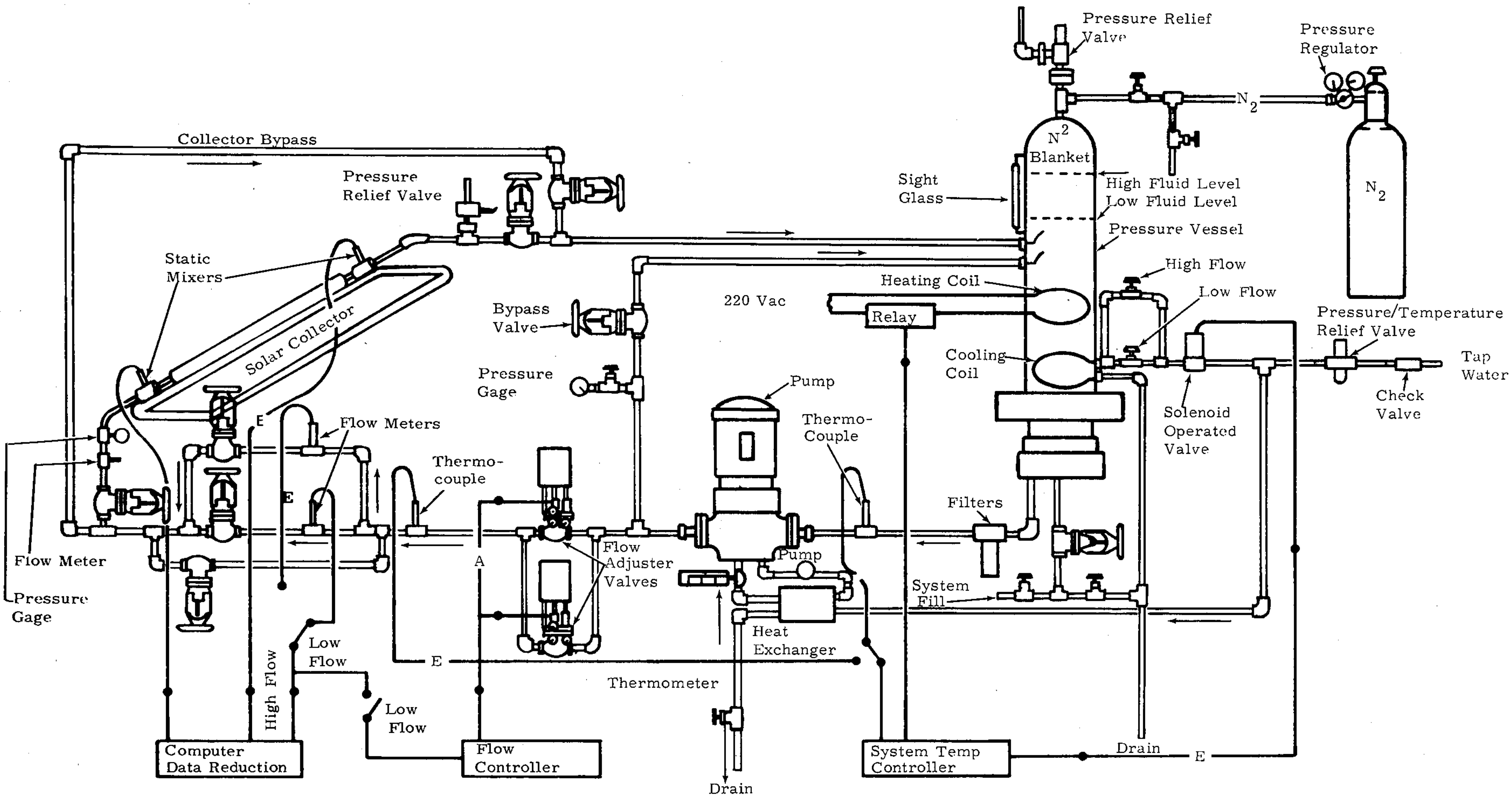


Figure 25. 315°C Therminol-66 Module Test Loop

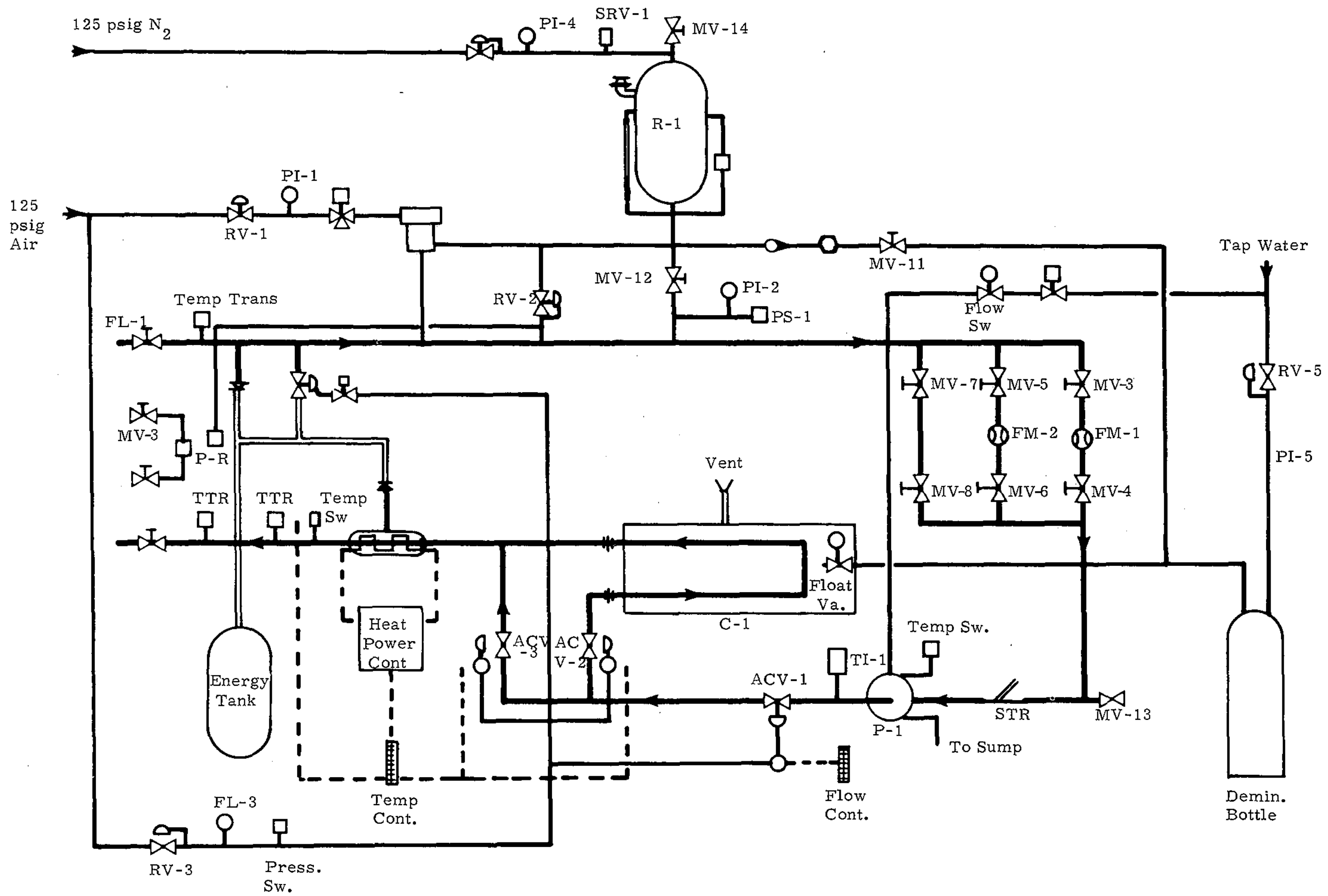


Figure 26. 330°C Water Module Test Loop

Component Designation

MV	-	Manual Valve
FM	-	Flow Meter
P	-	Pump
RV	-	Regulating Valve
FL	-	Flange
PI	-	Pressure Indicator
ACV	-	Auto. Control Valve
R	-	Reservoir
F	-	Filter
C	-	Cooler
PS	-	Pressure Switch
Cont.	-	Controller
SRV	-	Safety Relief Valve

Line Designation

- 1" High Pressure
- 1-1/4" High Pressure
- N_2 or Water
- Vent or Drain
- Electrical Lead

Operations -- The GA FMSC was tested on the 315°C T-66 loop. Two 3.7-m-(12-ft)-long trough sections, Figure 27, were checked out with increasing fluid temperatures until 316°C was achieved. Thin (1.5-mm), low-iron content glass mirrors were temporarily placed over the originals and the efficiency (at 193°C, 19 L/min) increased from 37 to 44%. Curves of efficiency for various conditions are presented in Figure 28. Tracking system errors and focusing problems caused up to 20% image spillover at the receiver, which limited the peak efficiency.

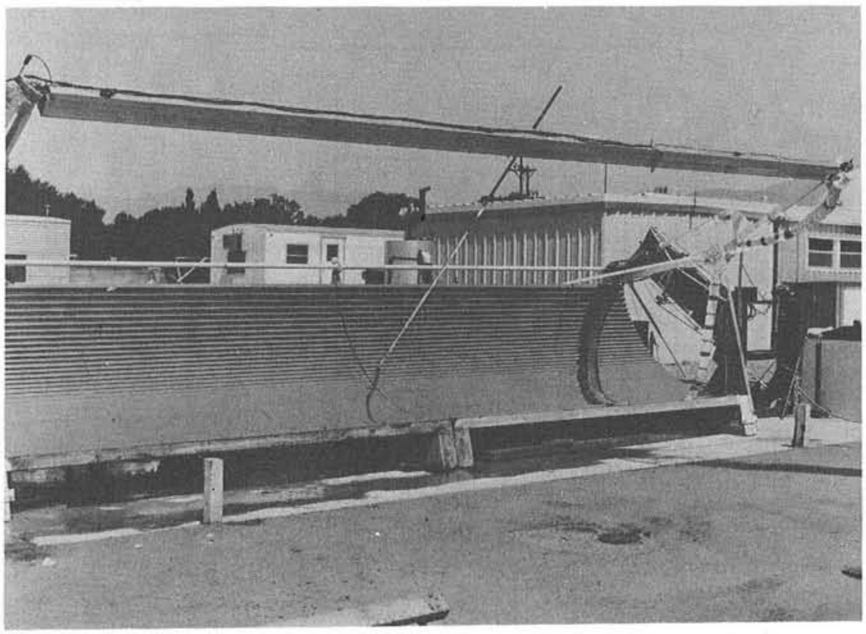


Figure 27. General Atomic FMSC Trough Test Setup on 315°C T-66 Loop

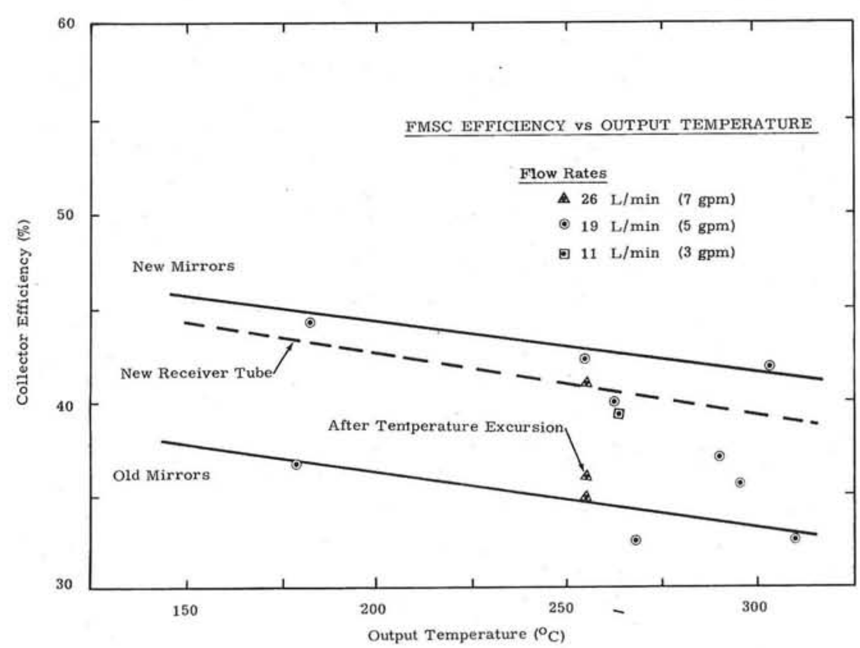


Figure 28. Fixed Mirror Solar Collector Module Efficiency

Two operational problems caused over-temperature excursions during the FMSC testing. The first incident occurred when the receiver was brought into focus before the T-66 was flowing. A spare tube was used to replace the damaged one which failed due to overpressure. The second occurrence, 4 days later, was caused by a momentary power outage, wherein the circulating-pump relay dropped out and was not reset. Flow stopped and the tube temperature reached 480°C (900°F), which degraded the black chrome coating and melted the plastic film convective barrier. As a result, the efficiency decreased by ~ 13%.

Heat loss was measured on the FMSC receiver and the results are shown in Figure 29. One data point was taken with the convective barrier removed. Without the barrier in front of the receiver tube, the heat loss increased by 80%.

The FMSC flowmeter and the fluid loop flowmeter (Ramapo) were calibrated with T-66 at 121°C using the measured volume/time system described in the preceding semiannual report (SAND77-0738). Test results are shown in Figure 30. The FMSC meter had a maximum error of 10% at low (4 L/min) flow rates; the maximum error of the Ramapo meter was ~ 5% above 30 L/min (8 gpm).

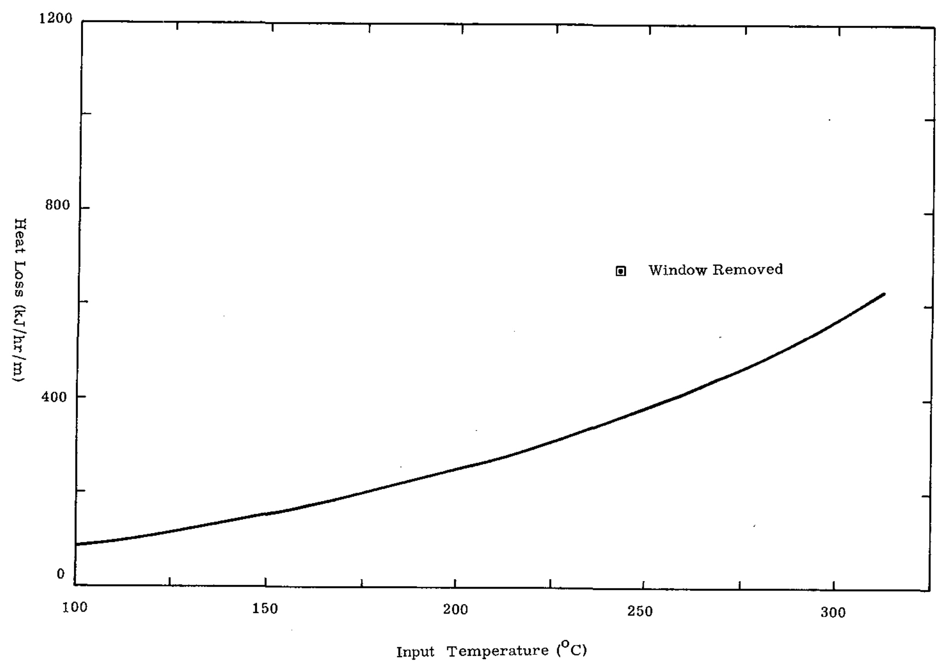


Figure 29. Fixed Mirror Solar Collector Module Efficiency

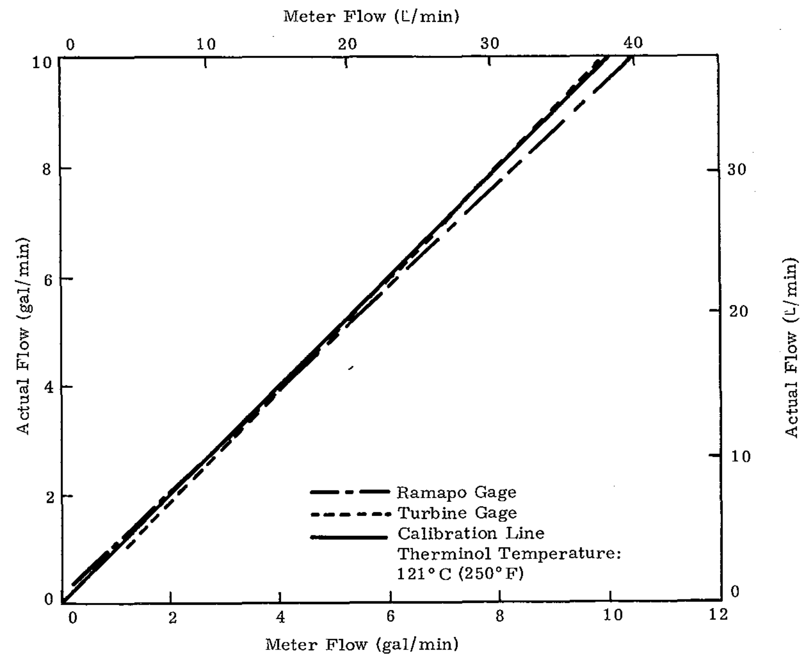


Figure 30. Flowmeter Calibration

A 15.9 m^2 (171 ft^2) parabolic trough collector module from Hexcel was received in September and is shown in Figure 31. This unit will be tested on the 315°C T-66 loop as soon as the plumbing connections are made.

The Suntec SLATS module was operated in April on the 330°C water loop after a successful pressure test of 27.6 MPa (4000 psi). For an input temperature of 135°C (275°F) and flow rate of 30 L/min (8 gpm), the efficiency was 46%. Further testing was delayed because of facility modifications. When module testing resumed July 14, the second surface aluminized Teflon reflectors had deteriorated to the point where focusing was difficult and efficiency had dropped to ~30%. Image scatter on the receiver is shown in Figure 32. Following the replacement of the Teflon reflectors with back-surface-silvered, low-iron-content glass mirrors, efficiency and heat loss tests were performed. The efficiency increased to 52% for the same operating conditions as the earlier tests. A plot of efficiency is presented in Figure 33, and heat loss data are summarized in Figure 34. Because of various control and hardware problems that occurred during this testing, plans are to repeat this series. Figure 35 shows the SLATS module with the glass reflectors installed.

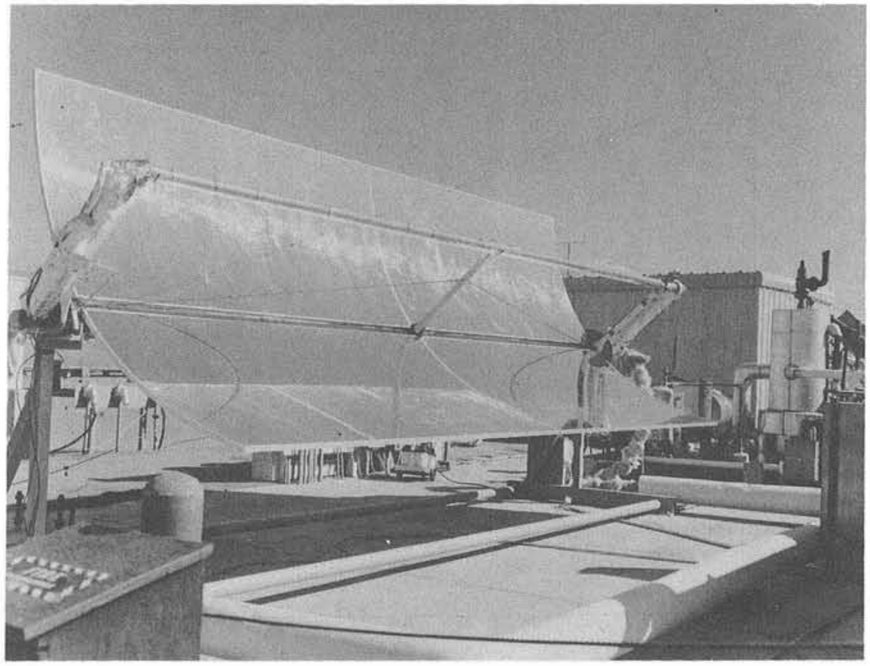


Figure 31. Hexcel Collector Module

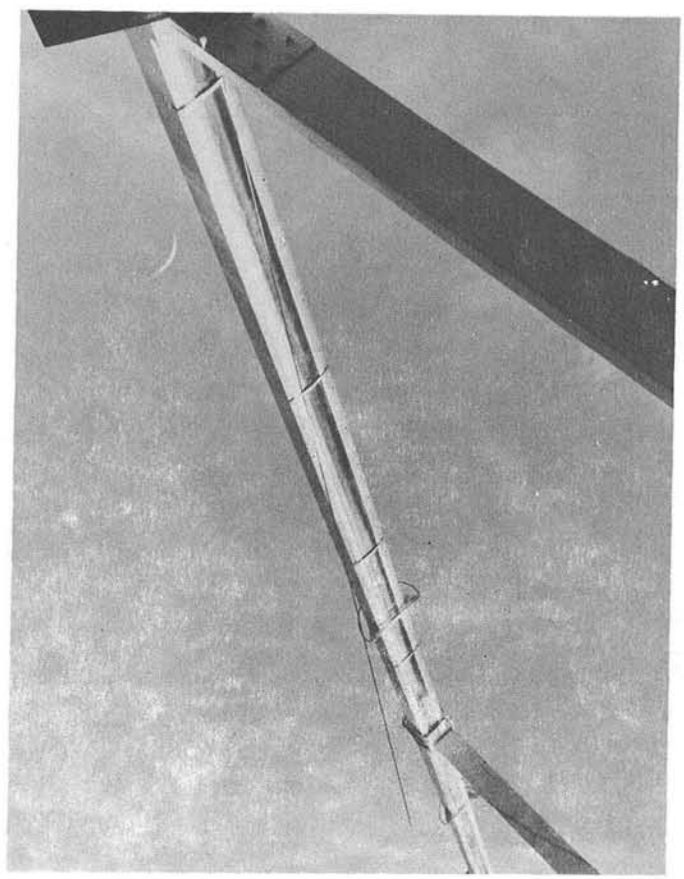


Figure 32. SLATS Receiver

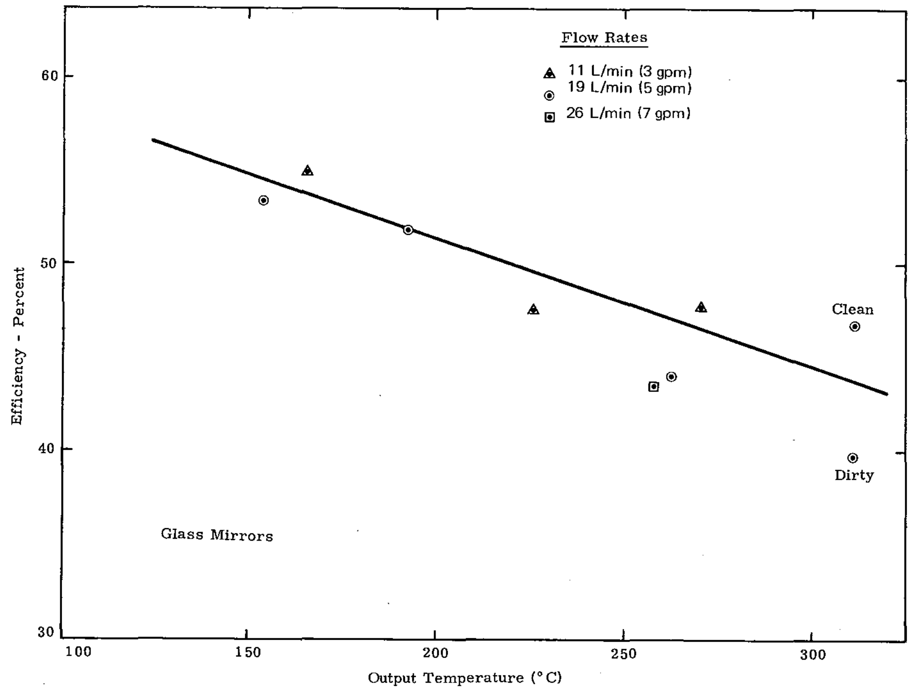


Figure 33. Solar Linear Array Thermal System Module Efficiency

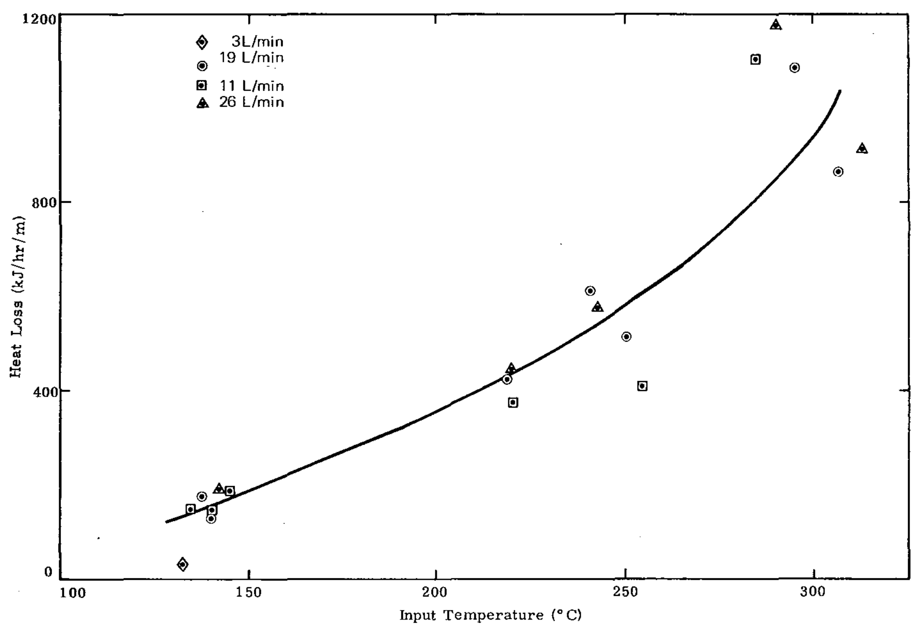


Figure 34. Solar Linear Array Thermal System Module Heat Loss

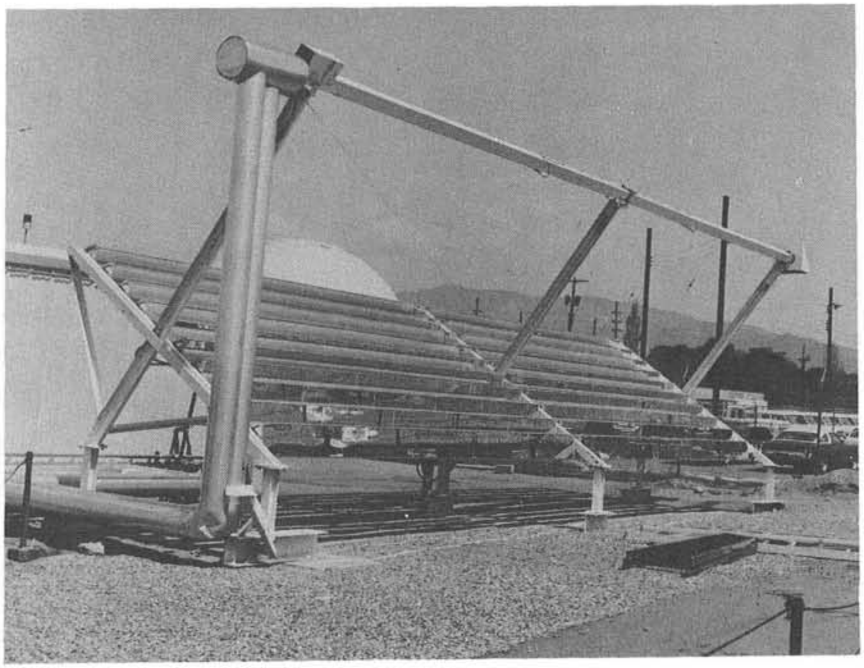


Figure 35. SLATS Collector Module

The following conclusions were drawn from recent testing at the CMTF:

1. Automatic defocus capability should be included for concentrating collectors, unless a critical stagnation temperature analysis indicates there is no problem.
2. Low-iron-content glass mirrors show the best performance for collectors tested.

IV. COMPONENT AND SUBSYSTEM DEVELOPMENT

The Component and Subsystem Development project is concerned primarily with the development of materials, components, subsystems, and technical information related to solar projects utilizing distributed collectors. In-house activities include materials characterization and the analytical studies of collector components. Collector modules are procured from industry for evaluation and distribution of comparative test results.

Task 1 - Project Management

Late in this reporting period, Component and Subsystem Development activities were organized into a work-breakdown structure of tasks. This report will follow the task format.

Task 2 - Materials and Processes

Materials and Process Development activities are directed at understanding and improving materials for use in solar energy systems. The effort is organized to support solar components and subsystems, which include reflectors, receivers, and heat-transfer loops.

Reflective Materials -- The reflective materials effort centers on understanding reflectance properties of metallized plastics and glasses and polished metal surfaces. Glass mirrors have been shown to have the best specular reflectances, and an advanced thin- and sagged-glass program has been started to achieve 95% specular reflecting mirrors, either by elastic cold forming or plastic hot forming.

Thin Glass -- The potential of silvered thin glass for solar reflectors was first demonstrated with small specimens of Corning's microsheet glass (0211). These specimens not only showed the superior environmental protection given to the second surface silver by the glass, but emphasized the fact that reflectors protected by glass are more scratch-resistant and easier to clean than those protected by organic films or coatings. Although the 0211 formulation has the advantage of having no iron to decrease its solar transmission, the die drawing process by which it is made introduces some waviness and variations in thickness that are not acceptable for concentrating reflectors requiring a high degree of specularity.

Specimens of Corning's 0317 fusion glass, which had a nominal thickness of 1.5 mm (0.06 in), were silvered and gave solar average hemispherical reflectivity of 0.95. Flatness, measured with the laser-ray trace technique, was the same as float glass.

A glass development program has been initiated to determine the feasibility and market-penetration potential of thin, elastically deformable glass.

Polymer Coating -- There has been considerable interest in the use of polymers for protective coatings on mirrors. Several silicone polymers deposited by the plasma-polymerization technique are being explored for this application. Silicone polymers applied by conventional techniques are known to be tough, heat-resistant, abrasion-resistant, and inherently antistatic. The plasma-polymerization technique allows the deposition of thin, ripple-free, and optically superior coatings. Several silane and siloxane polymer thin films have been deposited on both aluminized and silvered glass mirrors.

Both the specular reflectance out to 15 mrad and the hemispherical reflectance properties of the coated mirrors were studied. The width of the specular beam is characterized by a standard deviation of < 0.5 mrad, which is the same as for the uncoated mirror. Thus, the coating does not change the specular beam profile. In addition, the specular reflectance values were the same as the hemispherical reflectance values. This indicates that there is very little large angle scattering in the coating. The coatings will next be subjected to environmental aging.

Dirt Abatement -- Dirt may decrease the specular reflectivity of a mirror by 20%. Cleaning is both costly and potentially damaging to the mirrors. A literature study has been completed which indicates that active dust repulsion may be possible.

Studies of the mechanisms of dust accumulation and adhesion have shown that there are several factors that affect dust-surface interactions, including charging, electron affinities of the dust and surface, properties of the mirror surface (such as morphology and electrical conductivity), ambient conditions such as temperature and humidity, and time of residence of the dust on the surface. By controlling these parameters where possible, it should be possible to significantly reduce dust particle adhesion. In some cases, it should also be possible to repel dust particles that have settled. Experiments are being performed to test these ideas.

In general, techniques for repelling dust particles that do not involve actual washing must be continuous. Continuous repulsion is required because adhesion forces are time-dependent and can grow to very large values when particles are left on a surface for periods of 1 hr or more in humid environments, or overnight in environments such as Albuquerque. Dust-control techniques under consideration include electrostatic charging techniques, wind-turning vane techniques and streamlining, and several surface treatments. The principal surface treatment involves coating the surface with a transparent conducting material. These materials are of interest because of their abrasion resistance, chemical inertness, optical transparency, electrical conductivity, and electronic properties. Materials presently studied are SnO_2 and In_2O_3 - 9 m/o SnO_2, coatings that have been applied to several kinds of substrates commonly used in solar applications, such as glass, Mylar, and acrylic.

Dust-exposure experiments are being performed in a low-velocity, atmospheric-pressure wind tunnel. The tunnel is being fitted with a dust injection and dispersion unit for use with Arizona desert dust (an impure silica dust with a known particle size distribution). The unit is designed to expose samples to considerably larger dust fluxes than they would receive in normal "good weather" exposure, but without producing particle-particle interactions. This environment provides a very reproducible exposure to conditions similar to those encountered in actual field situations in the Southwest.

Receivers -- Receiver subsystems require selective coatings for maximum concentration of solar energy. Black chrome materials may become unstable and decrease in absorptance. The temperature at which this happens depends on the processing. Thermal aging studies on black chrome are reported.

Black Chrome Coatings -- The solar absorptance (α_s) and emittance (ϵ) properties of a black chrome-coated receiver tube from the STESTF where measured after the visual appearance of the tube changed to an amber color. The tube was located in position No. 18 in the collector loop (i.e., the third tube from the outlet); thus, it was operated close to the maximum fluid temperature of 310°C.

After glass envelope removal, optical measurements (Gier-Dunkle)[13] were taken on the surface facing the reflector. The solar absorptance (α_s) ranged from 0.78 to 0.86 and averaged 0.84 for seven measurements, or a decrease of ~ 10% from start-up. The 300°C emittance value averaged 0.19 - within the range measured before installation.

This decrease in α_s contrasts with earlier thermal aging studies carried out in the laboratory for the black chrome coating.[14] In these tests, no change was measured for plated panels after 800-1000 hr at 350°C in air. Because of the discrepancy in results, flat panels that were plated by Bendix (at the same time as the receiver tubes) were tested in the laboratory at temperatures of 250°C, 300°C, 350°C, and 400°C in air. In addition, electroplated black chrome samples from Olympic Plating, Highland Plating, and Harshaw Chemical were tested.

Test results are plotted in Figure 36. The 250°C unit changed less than 3% in 700 hr, and the 400°C sample decreased by 7% in 620 hr. The 300°C and 350°C specimens varied over a wide range; the cause for such variability is being explored. There was no significant diffusion or change in the electroplated nickel substrate, but Auger composition profiles showed that the black chrome coating had oxidized.

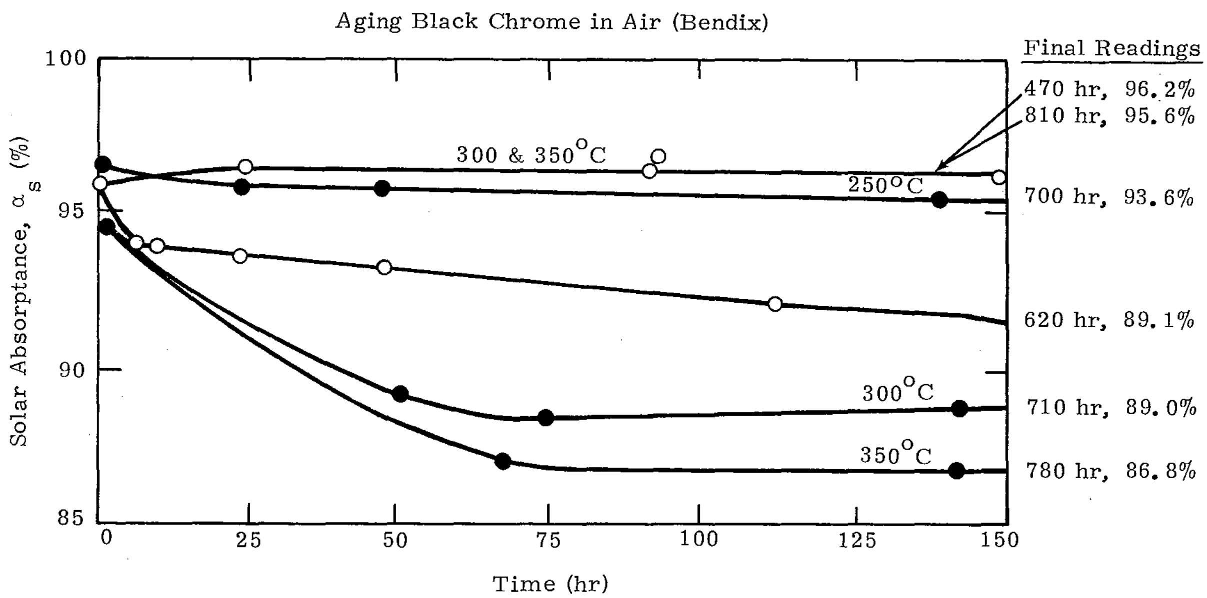


Figure 36. Solar Absorptance of Black Chrome Samples

A study has been initiated to understand the relationship between thermal aging behavior and the composition and structure of the black chrome coating. Electroplating bath parameters such as temperature, composition, run-in, and current density, will also be considered.

Optical Measurements -- At present, four manufacturers provide portable instrumentation for solar absorptance (α_s) and emittance (ϵ) measurements. These companies are: (1) Devices and Services Corporation, Dallas, TX; (2) Gier-Dunkle Instruments, Inc., Santa Monica, CA; (3) Lion Research Corporation, Newton, MA; and (4) Willey Corporation, Melbourne, FL (also supplied by Technology Applications Lab, Satellite Beach, FL). The general characteristics of these instruments, together with their current costs, are listed in Tables VIII (absorptance) and IX (emittance). Performance and accuracy of the Gier-Dunkle Solar Reflectometer and Willey Alpha Meter has been evaluated for α_s measurements; the Gier-Dunkle Infrared Reflectometer and Willey Ambient Emissometer, for ϵ measurements. Detailed results have been reported,[13, 15] and brief summaries follow.

TABLE VIII

Solar Absorptance Instrumentation

Manufacturer	Cost (dollars)	Model	Radiation Source	Detector	Comments
Devices & Services Company	500 plus voltmeter	1A	Sunlight	Thermopile	Requires 20 cm sq sample; accuracy unstated
Gier-Dunkle	9,000	MS-251	Xenon lamp	Thermopile	Errors as large as 0.03 absorptance units for black chrome
Lions Research Corporation	6,000	R25C	Mercury; tungsten	Phototubes; lead sulfide	Reflectance at discrete wavelengths (filters); stated accuracy: 0.02
Willey Corp.	1,000	2150	Projector lamp	Silicon	Errors as large as 0.11 for black chrome

TABLE IX

Emittance Instrumentation

Manufacturer	Cost (dollars)	Model	Radiation Source	Detector	Comments
Devices & Services Company	500 plus voltmeter	AE	Heated cavity	Differential thermopile	65°C emittance requires 6 cm sq sample; stated accuracy: ±0.01
Gier-Dunkle	13,500	DB-100	Heated cavities	Thermocouple	100°C emittance Error: 0.02 emittance units for black chrome Modified for 300°C emittance
Lions Research Corporation	7,000	E25B	Sample	Thermopile	Rack mounted; cooling water Stated Accuracy 0.0 - 0.1: ±0.01 0.1 - 0.2: ±0.02
Willey Corp.	1,500	2158	Heated cavity	Thermopile	Linear relationship for black chrome at 100°C

A. Gier-Dunkle Solar Reflectometer -- This instrument has a small but significant zero offset that can introduce a substantial error in measured α_s values. However, this offset is easily measured and incorporated in the calculation of the α_s values. The measurement spectrum of this reflectometer corresponds closely to a xenon lamp spectrum, which approximates the solar spectrum. This difference can lead to errors in measured values, especially if the reflectance spectrum of the sample is selective. However, for a series of electro-deposited black chrome coatings with α_s values between 0.85 and 0.96, the maximum deviation between the absorptance values determined with the reflectometer and the true solar absorptance was ±0.03 absorptance units. The average deviation was ±0.01 absorptance units.

B. Willey Alpha Meter -- This instrument uses a Kodak projector lamp as the light source. Combining the lamp spectrum with the response curve of a silicon photocell, which is the detector, gives a measurement spectrum that peaks at ~ 0.8 μm and has a sharp cutoff at ~ 1.1 μm. The cutoff removes the infrared portion of the lamp spectra (~ 25% of the solar spectrum is above 1.1 μm). Measured absorptance values for the electrodeposited black chrome samples were in error by as much as +0.11 absorptance units. This discrepancy is a direct result of the limited wavelength range of the measurement spectrum of the instrument.

To correct this problem, a PbS detector was mounted in the instrument at a point symmetrically opposite the silicon detector location. In this operational mode, the solar absorptance of the black chrome coatings was calculated by weighting the absorptance value measured with the silicon detector by 75% and the absorptance value measured with the PbS detector by 25%. The resulting solar absorptance values were within ±0.03 absorptance units of the true value. It should be pointed out that including the reflectance measured with the PbS detector in this way for a different solar coating may not provide accurate α_s values.

C. Gier-Dunkle Infrared Reflectometer -- This instrument is normally used for room-temperature emittance measurements. However, by removing an internal filter, the measurement spectrum shifts to ~ 100°C blackbody spectrum. The accuracy of the instrument in this mode was checked for a variety of materials by comparing measured ϵ values with ϵ values determined calorimetrically. Measured emittance values were within the measurement accuracy of both techniques, which is less than ±0.02 emittance units for emittance values below 0.50. By replacing the internal filter with a sapphire filter, the spectrum was modified so that the 300°C emittance properties of the black chrome coating could be measured. This result has been previously reported.[16, 17]

D. Willey Ambient Emissometer -- The Willey Ambient Emissometer is designed to measure the 100°C emittance properties of flat materials. The accuracy of the emissometer was determined for several electrodeposited black chrome samples. The total hemispherical emittance at 100°C of each sample had been determined calorimetrically. The emittance values determined with the Willey Emissometer are consistently higher than the $\epsilon_{t,H}$ (100°C) values. However, the relationship between the two emittance values is linear with

$$\epsilon_{t,H}(100^{\circ}C) = 0.81\,\epsilon\ (\text{Willey})$$

over the range studied:

$$0.10 \le \epsilon_{t,H}(100^{\circ}C) \le 0.42\ .$$

Using this equation gives calculated emittance values within ±0.01 emittance units of the correct values. The accuracy of the emissometer was not checked for other coatings; thus the validity of the above equation is not known for coatings other than black chrome.

Component Compatibility and Corrosion -- Investigations were made into reported solar energy component problems; i.e., a magnetically driven pump and a freon turbine loop.

The second water pump on the American Technological University (ATU) solar test facility failed in a short time, and leak-test analysis at Sandia showed a leak at the edge of a machined weld. Since it could not be ascertained as to whether the hole was caused by corrosion or poor fabrication, the unit was returned to ATU for sectioning before continuing the postmortem.

The cause of a malfunction in the Willard irrigation turbine loop was traced to a clogged pressure-relief valve. Much of the corrosion was iron oxide, with small amounts of aluminum and copper. The Freon 113 was found to be clean. The conclusion drawn was that water had contaminated the piping before the system was put into operation.

The freon is being periodically sampled for H_2O and HCl, and the using filters are designed to absorb water and acid from Freon 113.

Task 3 - Advanced Collector Development

The object of advanced collector development is to study, develop, test, and evaluate solar-collector components, subsystems, and controls to improve collector technology and the data base for system design.

Receiver Development -- With respect to possible improvements to annular receiver designs, a computer model was completed that can be used to compare single- vs double-glass jacket designs and also consider such effects as (1) antireflection glass coatings, (2) evacuated annular spacing, and (3) use of gases other than air in the annular space. The following comments result from an analysis using a 90-degree, 3-m rim length parabolic cylindrical trough with a 25-mm-diam black chrome-coated receiver tube:

1. A single glass-jacketed receiver tube is more efficient than a double-glass design. Although the heat loss is reduced by employing two glass jackets, heat-loss savings cannot overcome the decreased loss of absorbed energy resulting from transmittance reductions for two-glass over one-glass jackets. Further, although evacuating the annulus between the glass envelopes is feasible, the major heat loss through this space is by radiation rather than conduction, and therefore heat-loss savings by evacuation of the space are negligible.

2. Comparative cases of antireflection coatings vs evacuation of the annular space indicate that the two techniques improve overall collector efficiency nearly equally. Questions pertaining to vacuum maintenance, antireflection coating durability, and comparative costs should be used to determine which method should be utilized to improve collector performance.

   For the models considered, efficiency improvements over those obtained for a properly sized annular receiver can amount to nearly 5% by employing a vacuum of < 0.13 Pa (10^{-3} mm Hg). Lesser overall efficiency improvements may be obtained by oversizing the annular space and evacuating so that convection is suppressed, or by utilizing cover gases such as argon.

Improved Sun-Tracking and Control System -- A new sun-tracking and control system is being developed for use with parabolic trough collectors. Several possible improvements to the original system have been identified:

1. Heat-flux sensors to replace the photocell sensors
2. Basic clock control with heat-flux sensor override
3. Digital control for all system functions, including sun tracking.

The heat-flux sensor would be located at the receiver tube to provide more direct control of the concentrated sunlight heating the absorbing fluid. By using the clock control, system start-up and shut-down operations would be automatic and allow for continued tracking during brief periods of cloudiness. During periods of high insolation, the heat-flux sensors would be used to maximize thermal input. Finally, full digital control of the tracking system and associated emergency shut-down procedures could be achieved with the use of a relatively inexpensive microprocessor (μP) controller. This approach should increase system reliability and ease of maintenance.

Several techniques of flux measurement have been studied, and specific measurement variables that have been considered are:

1. The change in absorber fluid temperature as it flows through the receiver tube. This is the most direct approach. However, there are long time lags ($\sim$ 30 s) between flux changes and temperature changes. Precise control of the pointing angle would be difficult.

2. Changes in the heat-flux distribution as a function of pointing angle. Theoretically, the heat-flux pattern (intensity as a function of location around the receiver tube circumference) varies in a distinctive way as the reflector pointing angle varies. However, it was found that ripples in the reflectors and collector tube sag tend to smear the patterns and render this technique undependable.

3. Transient temperature response of the receiver tube skin. Because of the "skin effect," the ac resistance of the receiver tube at, say, 100 kHz consists of the resistance of only the tube skin ($\sim$ 0.03 mm). A change in skin temperature would be accompanied by a change in ac resistance. Since the temperature of the fluid in the pipe is relatively constant, a transient change in skin temperature is attributable to a change in heat flux. This method has two major problems: less than one-half of the receiver tube is strongly illuminated and much of the skin is heated only by conduction. The result is an unacceptably slow response. This conclusion has been verified by lab experiments. Even if the entire pipe was illuminated, skin temperature response time of several seconds is calculated. This is because radiation heating of the skin is partially offset by conductive heat flow inward away from the skin.

4. Transient response of a fine wire positioned near the receiver tube. A change in flux should result in a change in wire temperature and resistance. Since the illuminated area is proportional to diameter, and the volume (and heat capacity) is proportional to the square of the diameter, the time constant of the wire response to a change in flux may be made arbitrarily short by going to finer wire. Laboratory experiments indicate that time constants of < 1 s are readily obtainable with fine wires ($\sim$ 0.1 mm). Experiments performed have been conducted with commercially available ceramic-insulated, silver-plated copper wire. Ceramic insulation is ideal for the long-term, high-temperature environment.

Silver plating is required to prevent corrosion of the copper. Ceramic-insulated stainless wire is more desirable in terms of handling strength and corrosion resistance. A commercial source of this wire is being sought.

Because of the promising laboratory results, the fine-wire flux-sensing approach has been selected for testing under field conditions. Initially, a Suntec receiver at the CMTF will be used as the test bed.

In addition to the previously mentioned reliability and maintenance factors, a μP controller would be versatile. Being programmable, the functions performed by the controller could be easily altered to fit the changing needs of the system. The controller would handle tracking and associated emergency functions. However, with little additional hardware, it could assume other tasks such as the logical operations required for fluid flow and storage control. A μP controller could perform arithmetic operations on sensor data and could incorporate a clock function.

A disadvantage of a μP controller is the engineering effort required for initial programming and checkout. However, total cost over the life of the system is expected to be less for the μP controller than for more conventional control circuitry.

To acquire the knowledge necessary for specifying commercially supplied controllers for solar total-energy system applications, a prototype μP controller is being assembled. The RCA 1802 "COSMAC" μP was chosen for this application. It is one of two CMOS technology μP's presently on the market. CMOS devices tend to be relatively insensitive to noise, temperature, and supply voltage variation. Orders for μP's, memories, and I/O devices to cover several controllers for laboratory and field experiments have been placed. A working knowledge of COSMAC programming language is being obtained through a study of sample programs contained in COSMAC literature. A COSMAC Evaluation Kit has been obtained that contains a μP and associated electronics that assemble into a small microcomputer. A laboratory test rig containing a dc motor, a sensor platform, and a quartz lamp has been constructed. This rig will be used in tests of controllers and flux sensors.

Collector Evaluation -- Hexcel Corporation, Scientific-Atlanta, Inc., Solar Kinetics, Inc., and Soltrax, Inc., are all under contract to provide collector modules for testing on Sandia's CMTF to establish performance characteristics. Each contractor provides a test plan, a test director, and appropriate support personnel for approximately 1 mo of testing and a final report. The contractors have been given wide latitude in formulating the test plans. However, basic performance data will be obtained at a variety of temperatures centered around 230°C (446°F) at various times of the day. Out-of-focus thermal-loss data are also obtained. Test plans have been received from Hexcel and Solar Kinetics.

Short collector modules have significant end losses caused by nonilluminated portions of the receiver at times other than solar noon. The end losses are less significant for long rows of collectors, such as would be used in a field. The CMTF computer does not presently have sufficient capacity to reduce the data except for solar noon tests.

Delivery schedules of the collector modules have been adjusted to match CMTF availability. Manufacturers have used the additional time for continued development, and progress on the four collector modules is satisfactory. The Hexcel unit was received, and measurements of the black chrome coating on the receiver tube showed 0.79 to 0.92 for absorptivity and 0.16 and 0.22 for emissivity. The lowest absorptivity reading was at the outlet end of the receiver and is believed to be caused by overheating during preliminary tests at the supplier's plant.

Collector development contracts placed with Del Manufacturing Company, Monterey Park, CA and FMC Corporation, Santa Clara, CA have proceeded through analysis and design phases with some fabrication of the critical parts of prototype units. Del completed the framework of their final design prototype after fabricating and testing scaled-up units similar to their 0.3-m (12-in.) troughs. Considerable knowledge was gained from the scaled-up units. Del has installed a laser optical bench on a large surface plate to aid in assembly and inspection of their trough units. Fabrication of the collector is scheduled for late fall and early winter, with testing on the high-temperature water loop of the CMTF to follow.

The FMC Fresnel belt-collector project has required more analysis and materials development than originally estimated. Various materials combinations have been investigated in the search for a flexible reflector belt that will meet the collector requirements. The belt will be fabricated from a thin stainless-steel sheet to which are bonded with flexible adhesive narrow (1.25-cm) glass mirror strips. The adhesive thickness allows positioning of the mirror strips at their required angles. The reflective strips are front surface aluminized glass with a protective coating, all furnished by Optical Coatings Laboratory, Inc. (OCLI). Reflector samples have been placed in a test chamber for accelerated aging after original specular reflectance measurements of 0.94 were made.

Fabrication of the FMC prototype is scheduled for midwinter with testing planned for April.

Two solar receiver contracts were an outgrowth of technical proposals for STESTF subsystems. Some of the proposals not accepted for contract placement contained features that warranted further development. Contracts for promising receiver tube designs were placed with General Electric Space Division, Valley Forge, PA and with Itek Optical Systems Division, Lexington, MA. These receivers are to be tested on the Suntec SLATS module at the CMTF. Completion of tests on the GE and Itek receivers will provide direct comparison of three receiver designs.

The GE design is shown in cross section in Figure 37. This receiver, consisting of a Type 304 stainless-steel flow tube with a brazed chrome-copper absorber plate, is coated with black chrome. A window of borosilicate glass with a fluoride antireflection coating covers the absorber assembly. Behind the absorber is 10 cm (4 in.) of fiberglass insulation and a steel cover. The Itek design is shown in Figure 38. Its basic elements are similar to the GE design, except for a deep mirror-lined cavity for directing the energy to the absorber tube and glass louvers to minimize convection. The absorber tube is 4130 alloy steel, coated with Pyromark Series 2500 black paint.

Delivery of both receivers is expected in November 1977, and testing will begin as soon as the Suntec tests are completed and the facility can be modified to accommodate the single-pass fluid circulation pattern of the GE and Itek receivers.

Novel Collectors -- In an attempt to stimulate innovative collector concepts, a Request for Proposal (RFP) was sent to 79 potential sources. The collectors are to be suitable for use in large fields of distributed collectors with outlet temperatures greater than 230°C (446°F). Twenty proposals were received, and a technical evaluation committee recommended four sources for Phase I contracts. Phase I includes economic and performance analyses and preliminary design.

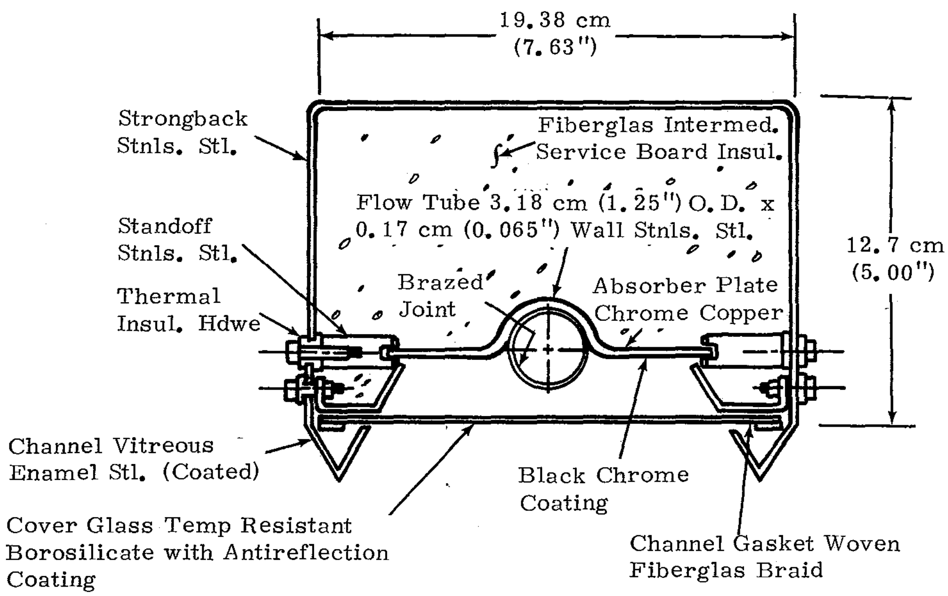


Figure 37. Section View of GE Wide-Aperture Receiver

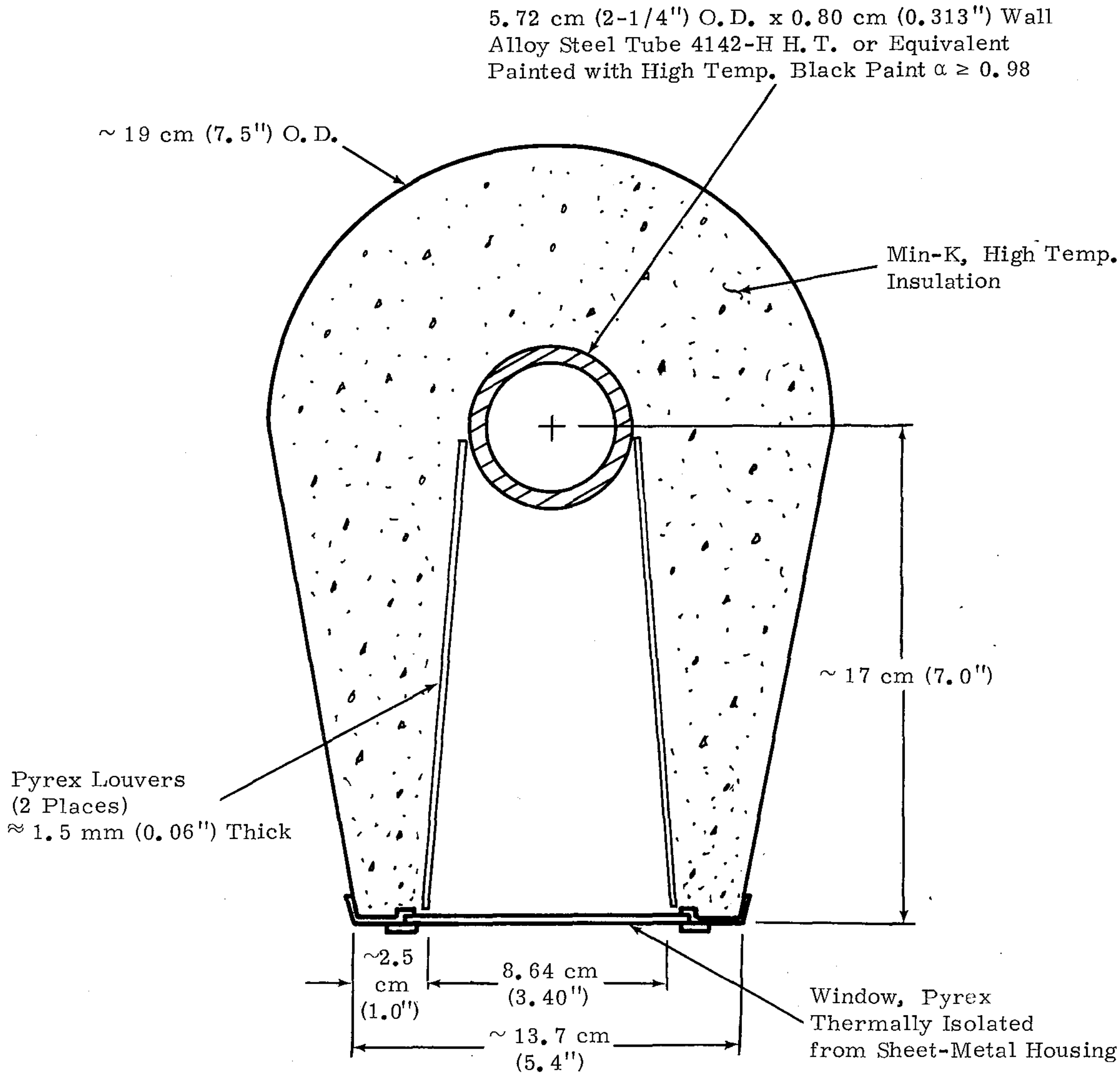


Figure 38. Section View of Itek Receiver

The recommended sources and concepts are:

1. Boeing Engineering and Construction -- The Boeing concept is an inflatable cylindrical collector fabricated from a thin plastic film. It is a very low mass design that has low cost potential. The performance is also relatively low since the cylindrical reflector gives a lower concentration ratio than can be obtained with a parabolic reflector. One-axis tracking is employed. The concept is similar to a nontracking design investigated by Tabor in Israel in the early 1960s. Figure 39 is a photograph of a mockup of the collector. A Phase-I development contract was placed in September.

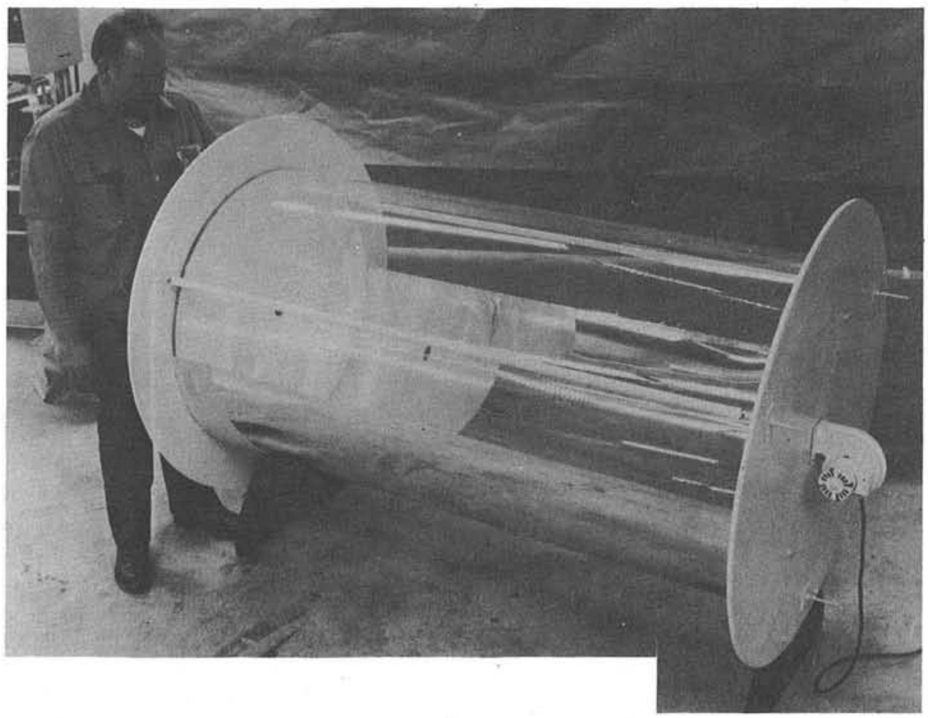


Figure 39. Boeing Air-Supported Collector Mockup

2. Scientific-Atlanta, Inc. with Georgia Tech -- The Scientific-Atlanta concept is a formed-dish point-focusing collector based on an existing 5-m communication antenna. The reflective surface is an aluminized acrylic film bonded to the formed dish. This contract was not awarded since the concept will be investigated by General Electric and Scientific-Atlanta as a part of LSE II.

3. New York State Energy Research and Development Authority (NYSERDA) with Rensselaer Polytechnic Institute and Grumman Corporation --The NYSERDA concept is a point-focusing system mounted on a carousel using curved slates to focus the energy. The structure is open and has distributed mounting points so that mass (and hence cost) is potentially low. Figure 40 is a sketch of the concept. The Phase I activity will determine if the concept is still attractive after it is engineered in some detail. Contract negotiations are under way for this project.

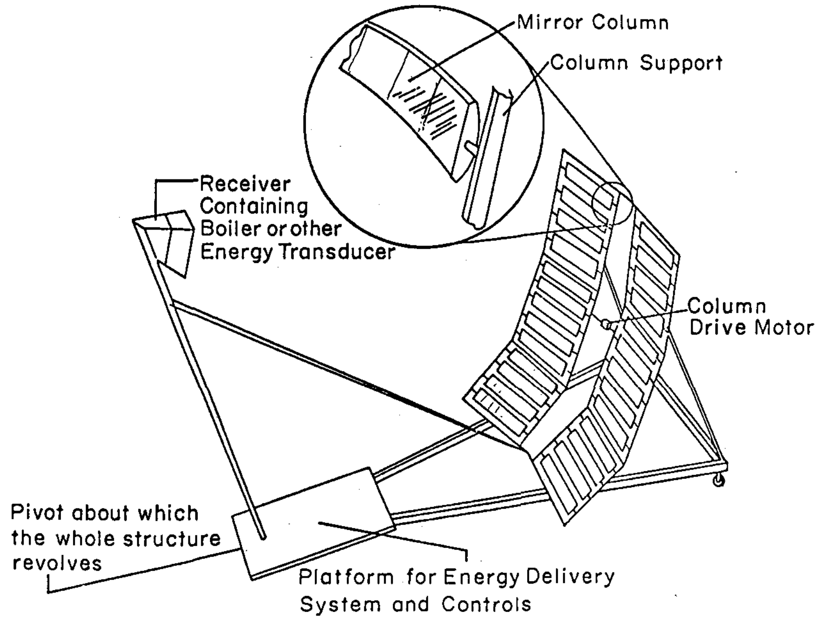


Figure 40. Perspective View of NYSERDA Proposed Collector

4. McDonnell Douglas Astronautics Company (MDAC) -- The MDAC concept is a point-focusing system using four separate Fresnel Lenses and receivers mounted on a pedestal. Figure 41 is a sketch of the concept. The Phase-I contract was awarded in September.

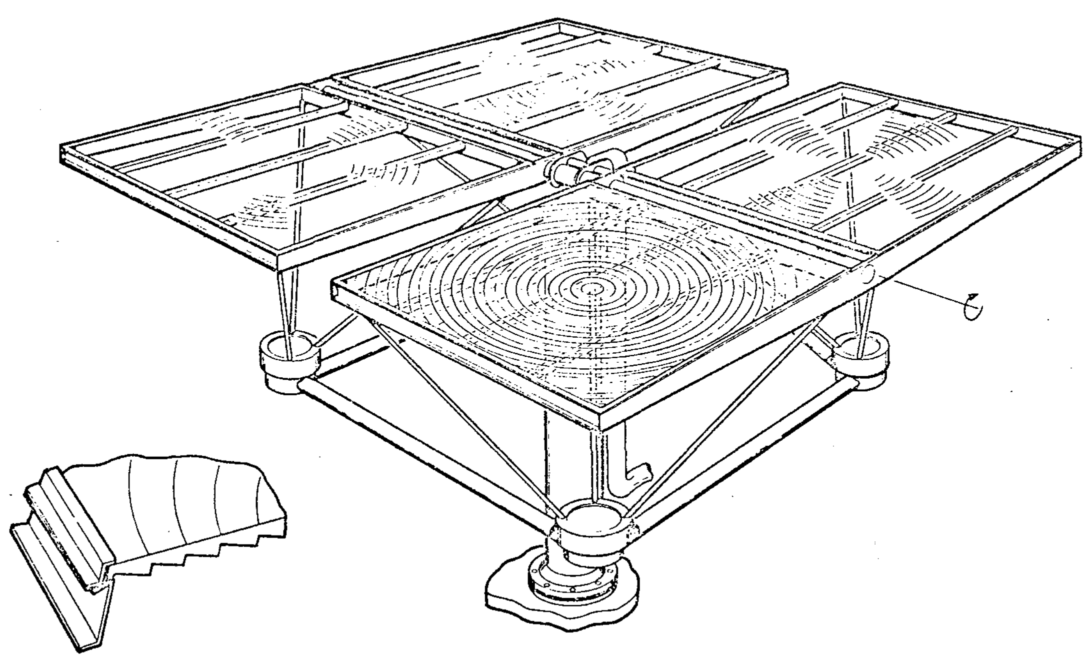


Figure 41. McDonnell Douglas Large Circular Fresnel Lens Collector Assembly

Parabolic Dish Systems Study -- A study contract for a parabolic dish systems performance and cost trade-offs was placed with Raytheon in March. The objective of this study was to determine the feasibility of integrating numerous 10-kW solar-powered generator sets into a grid and comparing that system performance and cost with a comparable multidish system that provided collector solar-thermal energy to a single large (150-kWe) turbine/generator. The study required basic definitions of the two systems, including dish design (Cassegrain or prime focus), field layout, prime mover/generator parameters, and electrical system integration. United Engineers provided definition of the electrical system interconnections, the required components, and assessed the problems of bringing multiple generators on-line. Subsequent to system definitions, United Engineers will provide cost estimates of system fabrication and installation. The Raytheon final report is to be published in November.

Task 4 - Maintenance Equipment Development

Equipment and procedures for maintaining solar collectors are developed and/or evaluated for use on solar total-energy applications in this task.

In-Situ Laser -- The concept of the in-situ laser ray trace inspection apparatus has been described in detail in previous semiannual reports (SAND76-0205, SAND76-0662, and SAND77-0738). Functionally, a laser beam is directed onto the reflector by the scanning mechanism, and the returning reflection strikes a detector bar that determines the actual displacement of the laser. The data processor compares actual displacement to theoretical displacement to determine reflector surface errors.

Development work during this reporting period was centered on solving the following four major problem areas:

1. Provisions were made to monitor the laser beam during its passage through the laser support apparatus and to detect distortions, deflections, etc, of the laser support structure. This information was fed to the microprocessor, and compensations were made.

2. A computer program for automatic data processing was developed. This program reduced the raw data and automatically presented the results in chart form. It also determined the statistical data required for other ray trace programs.

3. The detector was modified to prevent saturation by the high-ambient-light levels encountered in a field installation as compared to those encountered in a laboratory installation.

4. Fixtures were designed and fabricated to enable rapid and accurate alignment of the laser system to the STESTF reflector being tested.

Cleaning Collectors -- As previously reported, the presence of dirt, dust, and other contaminants on a reflector surface degrades the specular reflectance. Measurements taken on reflector samples removed from collector troughs have provided specific evidence of decreased specular reflectance. Total (hemispherical) reflectance is virtually unchanged, indicating that the dirt scatters the light. Similarly, the shape of the specular reflectance curve plotted against the angular aperture is unchanged by dirt, indicating that it effectively decreases the intensity of the reflected energy. Therefore, the presence of reflector contaminants is a real problem requiring investigation. Large and small collector fields must be cleaned at intervals to maintain acceptable performance.

Development of cleaning techniques and cleaning agents is a continuing project with potential for excellent economic benefit to collector systems. Experience with Sandia's 200-m^2 collector field has indicated that regular cleaning is important in maintaining high reflectance, and that frequent cleaning makes the operation more effective. Biweekly cleaning with a spray-on rinse-off technique, followed by a deionized-water rinse, has given satisfactory results.

Contact was made with six major chemical or cleaning companies who market cleaning agents for many industrial applications. Several representatives indicated little or no interest because of the lack of a ready market. One or two companies indicated a longer range view toward a future market and appeared to be challenged by the technical problems of developing a suitable cleaning agent. Present plans include issuing an RFP for investigation of the mechanism of dirt attachment and means of cleaning reflective surfaces. Coordination with other solar applications groups is also vital.

V. STEP DESCRIPTION AND STATUS

Technical Project Management

Sandia Laboratories, Albuquerque, has been selected as the Technical Project Manager; i.e., Sandia sees that technical goals and schedules are realistic, and that the technical effort is making proper progress. Sandia is also responsible for some in-house technical activities. The in-house technical effort is to develop and maintain technical expertise within and in support of the STEP management staff, and to undertake tasks for which capability does not exist in the industrial sector. Also, in-house projects evaluate (analytically or experimentally) the results of contracted work and supplement work performed under contract to others. Sandia is given specific responsibility for the following:

1. Providing annually an updated 5-year program plan for DOE/DSE approval.
2. Providing an annual financial operating plan for DOE/DSE approval.
3. Assisting DOE/DSE in major program decisions.
4. Assisting DOE/DSE in evaluating and placing major contracts for large-scale experiments and demonstration plants by participating in the choice of contractors and applications.
5. Soliciting, awarding, and administering other smaller contracted activities for component, subsystems, systems, materials support, and systems engineering.
6. Providing day-to-day technical management of all contracted efforts.
7. Establishing a program of technical reviews and reports that adequately documents the progress of the program.

The Technical Plan for achieving STEP objectives is divided into seven program elements.

1. Mission Analysis
2. Application Analysis
3. Systems Engineering
4. Large-Scale Experiments and Demonstrations
5. Component and Subsystem Development
6. Test Facilities
7. Technology Dissemination

Mission Analysis is primarily an Aerospace Corporation activity to identify preferred solar-power plant functions and how the functions are related to scale and location.

The next three elements will be discussed in more detail in succeeding paragraphs. Elements 5 and 6 are discussed in Sections III and IV. The last element is covered in part in all sections.

Systems Engineering and Technology Dissemination activities will be reported with the Project Management activity.

Project Management, Systems Engineering, and Technology Development Dissemination -- Project Management, in this activity context, refers primarily to updating the program plan and providing DOE/DSE with an annual appraisal of financial costs of the STE program to be administered by Sandia.

Systems Engineering has as its objective the effective technical coordination of technology development, projected applications, and STES demonstrations. Both analytical and experimental information on performance, cost, and availability of components and subsystems is provided. These studies also identify development areas needed to support projected applications. This activity provides the technical expertise to maintain an effective program.

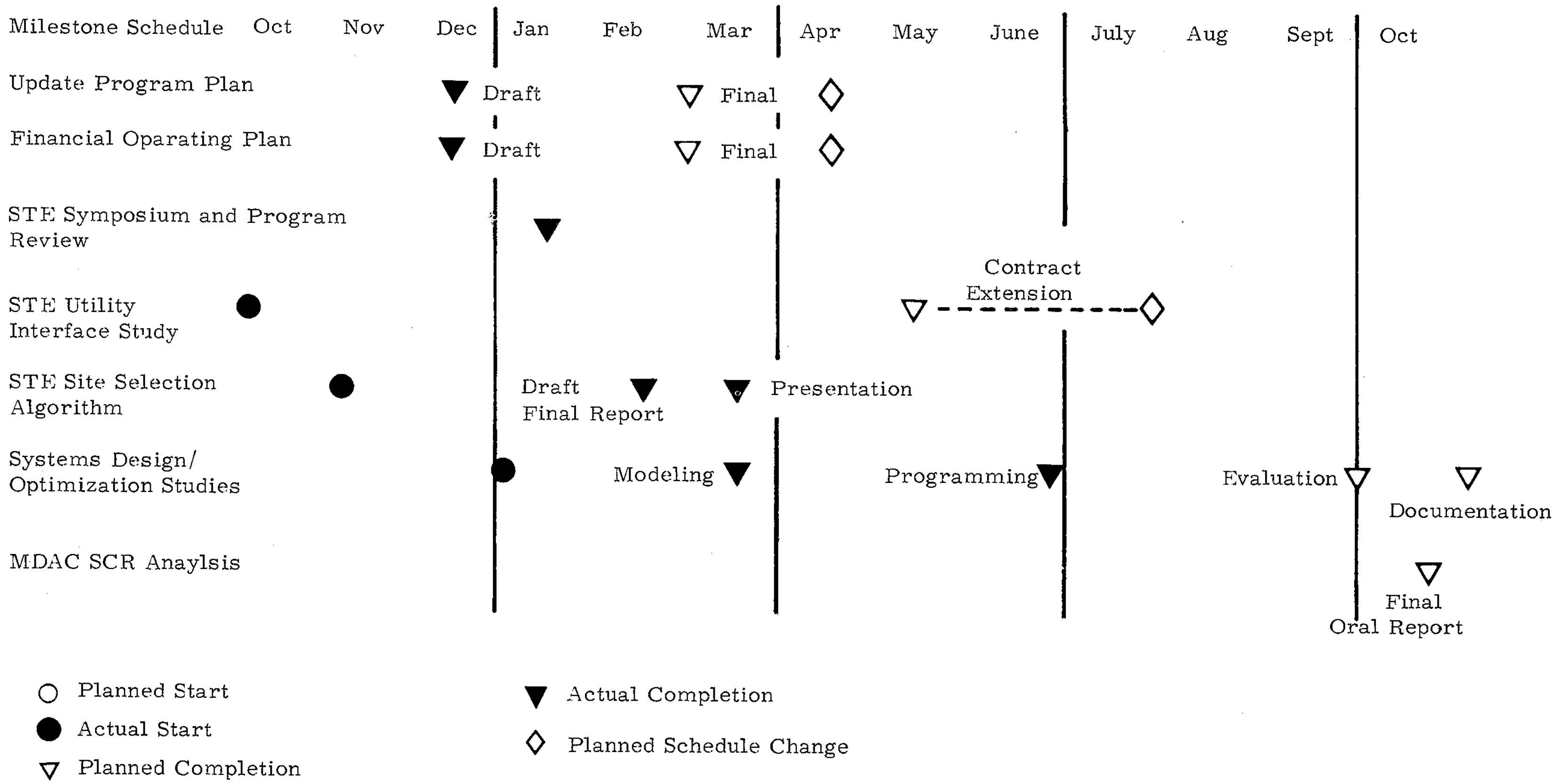
Technology Dissemination is the program element that involves industrial, academic, and other organizations in commercialization of STE systems. To accomplish this, Sandia uses information exchange, on-site visitations, private sector technical assistance, and liaison with both private and government sectors on the state-of-the-art to preclude duplication.

Table X shows the milestone schedule for activities within the Project Management, Systems Engineering, and Technology Development Dissemination elements during this reporting period.

Utility Interface Study -- A solar system-to-utility interface study was contracted to Texas A&M University. The basic premise of the study was that solar systems offer the greatest benefits when operated in parallel with an electric utility. When planning and operation are coordinated with that utility, reduced fuel consumption and generating capacity accrue to the utility. The objective of the study was to evaluate the utility economics of solar systems. Breakeven costs were computed as a reference for evaluating the economic feasibility of parallel operation. Using 1975 fuel costs, breakeven costs for a 100-unit 2 MWe solar supplement were calculated to be $448/kW. Assuming 1985 fuel costs, a breakeven value of $854/kW is calculated. Addition of high-temperature storage increases breakeven costs to $494/kW and $891/kW for 1975 and 1985 fuel costs, respectively. Collector size increase to twice the original, increased breakeven costs to $849/kW and $1556/kW. Increasing the number of installed solar units decreased breakeven cost. The final report is available through DOE/TIC under Contract No. 05-4563.

TABLE X

Milestone Schedule - Project Management Systems Engineering, and Technology Development



Small Central Receiver -- A cost definition study of a small central receiver was initiated after the industrial applications analysis showed that, given the large central receiver costing estimates, central receiver technology appeared superior to line-focusing concepts for STE. This study, being performed by McDonnell Douglas (MDAC), is scheduled for completion in late October with a duration of 3-1/2 mo. Contract midterm review was held in early September. The objective of this contract is to execute two-point designs (oil receiver at 316°C (600°F) and steam receiver at 427°C (800°F)) for central receivers operating at a peak power level of 2 MWth. Point designs were chosen to allow enough design definition of the receiver for weight estimation of detailed tower costing.

The most significant tentative conclusion is that the heliostat design developed for the large central receiver program can be used with slight modification for small central receivers in the power range of 2 MWth. If this conclusion is verified, the STE program will directly benefit from all the heliostat cost reductions because of production rates established for the large central receiver-program pilot and demonstration plants. A separate large heliostat development and manufacturing project may not be required for small central receiver applications. A second tentative conclusion is that a north field configuration with external receiver is optimum for a 2 MWth system.

SOLSYS -- The Solar System Simulation Computer Program (SOLSYS) is composed of five parts.

1. Executive Program
2. Component Model Library Subroutine
3. Information Library Subroutine
4. Control-Component Library Subroutine
5. Miscellaneous Function Library Subroutine

Revisions to SOLSYS have been initiated to simplify component models to reduce computer time. An n-tank storage system routine was added to the component model library. A preprocessor routine will be added to the SOLSYS executive routine within the next 6 mo to permit a more convenient and rapid method for generating simulated solar systems for analysis.

System Design/Optimization Study -- Determining the minimum-cost solar total-energy system that will deliver the energy required for a particular application is the purpose of the STES Analysis work in progress at Sandia. Three tasks must be completed to permit system cost determinations:

1. Develop a model to size the components that will deliver the required energy.
2. Gather information on energy cost, component cost, and component performance so that the annualized cost of any STES can be determined.
3. Develop a computer code to design the least-cost system using the modeling and cost information.

Figure 42 shows the functional relationship of the many components included in the model that provide a wide range of possible configurations to meet the load requirements of many different applications. In keeping with the minimum cost system philosophy, components such as the collector may shrink to zero size should input conditions such as low-fuel and electricity costs and high-collector costs prevail.

Generally, the computer program is run three times for each application. The first run produces a solar total-energy system with components sized to meet the load requirements of that application. The second run produces a system in which all energy requirements of the application are met by a fossil-fueled system. The third run is a conventional system that meets electrical and thermal requirements of the application by buying electricity and fossil fuel. Solar collectors and all turbines are reduced to zero size for this system.

Prevailing cost conditions (e.g., for fossil fuel, electricity, collectors, and turbines) may cause higher level systems such as the STE to degenerate into lower level systems such as the conventional. The computer program should be ready for initial runs by mid-January 1978.

Applications Analysis -- Application analysis has as its objective the identification of potential applications called "sites" for design, construction, and operation of solar total-energy large-scale experiments and demonstrations. Applications analysis is characterized by three activities: application characterization, application assessment, and site selection.

Characterization of the site includes site evaluation (determining total load requirements, environmental impact, the problems of utility interfacing, the effect of conservation measures on load requirements, etc), market penetration (evaluation of the market potential and energy displacement cost of the potential application), and conceptual design (advanced engineering designs that may consider components and subsystems in advance of availability).

Assessment consists of comparing and evaluating the results of the application characterization with the mission analysis studies conducted by Aerospace. The purpose of this activity is to verify results and possibly update mission analyses of market potential.

Site selection (application of an STES) is based in part on cost sharing, potential for demonstrating commercially viable applications of solar total energy, and visibility to the general public.

The Application Analysis program element calls for four separate contracts to be issued to perform the analyses: industrial, commercial, residential, and institutional/recreational applications.

Table XI shows the milestone schedule for activities within the Application Analysis program during this reporting period.

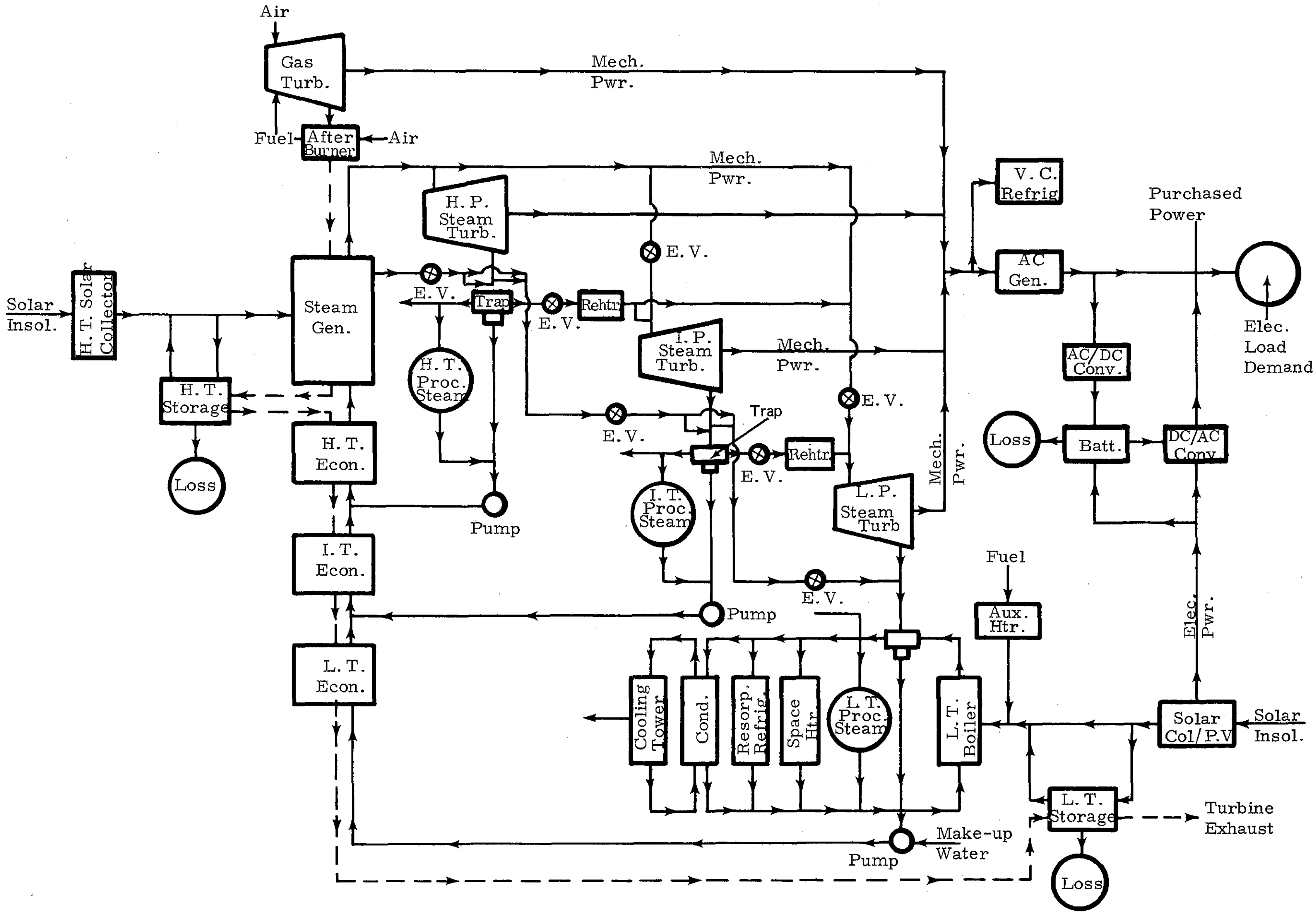
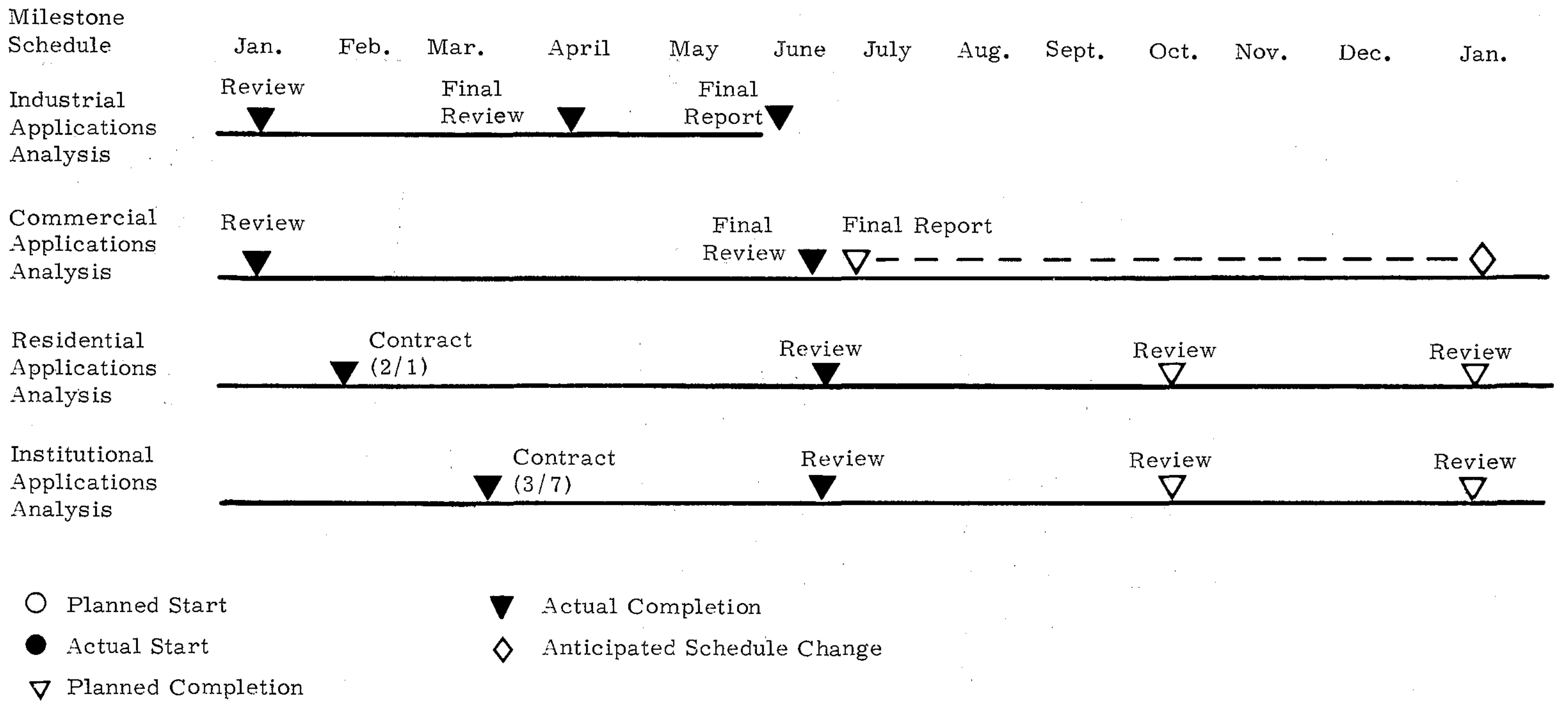


Figure 42. Solar Total Energy System

TABLE XI

Milestone Schedule - Applications Analysis



Industrial Applications -- Applications of solar total energy to the industrial sector were studied by McDonnell Douglas (MDAC) under Contract No. EY-76-C-03-1132. This contract has been successfully completed, and their final report (comprising five volumes) is scheduled for release by NTIS in mid-December under the title "Industrial Applications of Solar Total Energy - Final Report," SAN-11322, April 1977.

In their study, MDAC obtained partial load information from more than 100 actual industrial firms. Much of the information was incomplete, and only 25 load profiles were complete enough to allow first-level conceptual designs. From the 25 first-level conceptual designs, MDAC chose five industries for more in-depth design followed by market analysis. The results of the market analysis for the first industries studied (meat packing, fluid milk, sugar beet, asphalt materials, and concrete block) are shown in Figure 43. These limited market projections have been used by MDAC to project total industrial STE markets as shown in Figure 44. Basically, the total industrial market was reduced to eliminate very high-temperature applications, small applications that were not cost-effective, and applications thought incapable of capitalizing on STE systems. To arrive at a solar total energy market potential, the rate at which STE could penetrate this market was estimated.

In summary, the important conclusions of the MDAC study are tabulated in Table XII. While the economics and performance of small central receivers appeared more favorable than line-focusing collector systems, these results were based upon extrapolations of data for large central receiver systems. Since MDAC's results strongly suggested the value of small central receiver STE systems, they have suggested that a future effort verify the economics in their study (see Systems Engineering) by addressing the question of costs of central receiver systems designed for small applications.

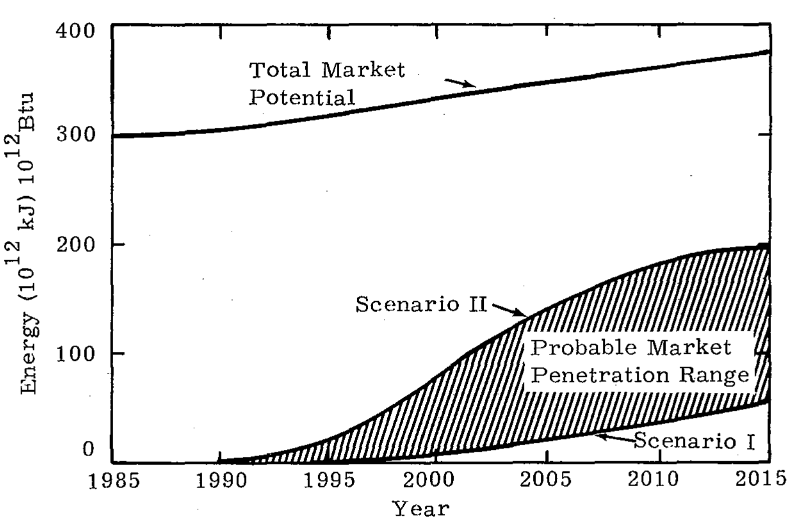


Figure 43. Central Receiver Probable Market Penetration Range

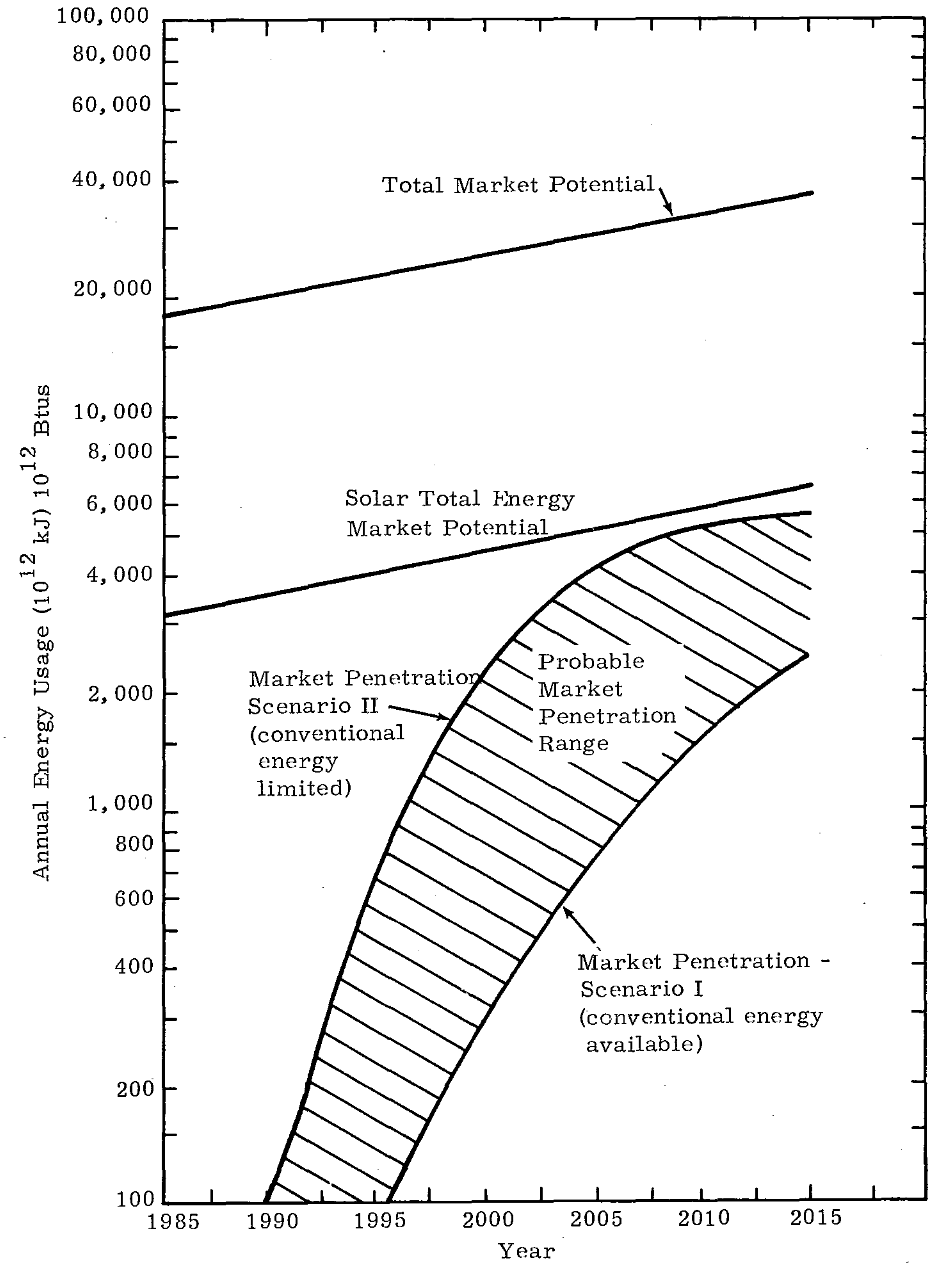


Figure 44. Projected Market Penetration of STES for Industrial Applications; Central Receiver Configuration

TABLE XII

Industrial Applications Analysis Conclusions (MDAC)

Significant Market Potential

- STE can displace 7 to 17 percent (2.5 to 5.5 quads) of industrial energy use by 2015.
- Comprised of Diverse Applications
- Initial Commercialization Expected 1985 - 1990

Technical Development Required

- Small Central Receiver Technically and Economically Superior
- Lack of Economic and Performance Definition on Small Central Receiver
- High-Performance Organic Rankine Cycles Need Development
- Limited Land Availability Requires High-Performance STES

Commercial Applications -- The study of STE application to the commercial sector has been essentially completed by Atomics International under Contract No. E(104-3)-1210. Unfortunately, delays have occurred in the revision of their final report, and a final report is not available at this writing.

The commercial market potential projected for solar total energy units larger than 200 kWe is presented in Table XIII with shopping centers holding the most promise. Several factors limit approach to this potential. Perhaps the most severe is land availability; simply put, all commercial applications appear severely land-limited. On the average, the areas of the roof plus parking space (which could be covered by collectors) for a shopping center are about equal to the total commercial floor area. Given this constraint, the simplified calculation presented in Table XIV demonstrates the problem. A typical energy demand in a shopping center is 100 W/m^2, while the Albuquerque solar resource is on the order of 7 $kW/m^2/day$. Thus, even in the best of cases (central receiver technology), the ratio of the area required to the area available is about 8, assuming a 23 percent ground cover ratio. Atomic International points out that adherence to the energy-conservative ASHRAE 90-75 Standards would improve this ratio to less than 4.

Although significant market potential exists, there is doubt as to STE's capability to penetrate this market extensively since STE systems will pick up only a fraction (50% in the most favorable scenario; possibly 10-20% if current energy use patterns persist) of the user's energy needs. In addition, the low-thermal demand of the commercial sector compared to electrical demand makes the value of cascading energy questionable and appears to favor on-site electric-only power generation. Photovoltaic systems are somewhat favored in commercial applications, given the safety hazards involved in high-temperature fluids near people. Table XV summarizes the tentative conclusions of the commercial sector applications analysis.

TABLE XIII

Commercial Sector Market Potential

	1975				1990**			
	No. Units	Gross Leaseable Area 10^7 m^2 (10^8 ft^2)	Capacity (MWe)	Equivalent Oil Displacement (bbls/day)	No. Units	Gross Leaseable Area 10^7 m^2 (10^8 ft^2)	Capacity (MWe)	Equivalent Oil Displacement (bbls/day)
1. Shopping Centers								
Census	18,500	24 (26)	26,000	560,000	39,000	51 (55)	42,000	900,000
Technically Penetrable*	-	22 (24)	24,000	520,000	-	34 (37)	28,000	600,000
2. Office Buildings								
Census	366,000	40 (43)	34,000	690,000	750,000	86 (92)	55,000	1,100,000
Technically Penetrable*	-	3 (03)	2,400	48,000	-	3 (03)	1,800	36,000
3. Other***								
Census	365,000	62 (67)	22,000	550,000	560,000	9.9 (107)	26,000	670,000
Technically Penetrable*	-	17 (18)	5,500	140,000	-	20 (21)	5,200	130,000
4. Total Commercial Sector								
Census	750,000	126 (136)	84,000	1,800,000	1,350,000	236 (254)	123,000	2,670,000
Technically Penetrable*	-	42 (45)	32,000	710,000	-	57 (61)	35,000	766,000

*Greater than 200 kWe

**Assumes implementation of Ashrae 90-75 standards

***Includes hotels and motels ($\lesssim$ 3 stories), warehouses, nursing homes, etc.

3

TABLE XIV

Application of STE to Commercial Uses

Energy Demand

$$100 \text{ W/m}^2_{\text{floor}} \times 17 \text{ hr} = 1700 \text{ W} \cdot \text{hr/m}^2$$

Solar Resource

Direct Normal Insolation (kW hr/m$^2_{coll}$/Day)	Collection Efficiency	Electrical Conversion Efficiency	Power (W hr/m$^2_{coll}$/Day)	Solar Technology
7	.6	.23	966	Central Rec.
7	.3	.23	483	E/W Linear
7	.85	.15	900	PV, fixed 40°

Sample Calculation

$$\frac{\text{Collector Area}}{\text{Floor Area}} = \frac{\text{Energy Demand}}{\text{Solar Resource x Ground Cover Ratio}} = \frac{1700 \text{ W hr/ m}^2_{\text{floor}}\text{/Day}}{966 \text{ W hr/m}^2_{\text{coll}}\text{/Day} \times 0.23} = 8$$

TABLE XV

Commercial Applications Analysis Conclusions (AI)

Limited Market Potential

- Market potential of 1.6 quads by 1990 or 28 percent of total market, but severe land constraints limited ultimate penetration to less than 50 percent of market potential in most optimistic case
- Noncascaded systems appear most competitive
- Average shopping center less than 1.5 MWe
- Energy Conservation can cut projected energy usage by one-half

Technical Development Required

- P/V systems most cost-effective for small systems
- No significant economic advantage of line focusing over small central receiver
- Lack of economic and performance definition on small central receiver
- High-performance ORC needs development

Residential and Institutional Applications Analyses -- During this reporting period, these two applications analyses began. The contractors are Resource Planning Associates (RPA) and Institute of Gas Technology (IGT) for the institutional and residential market sectors respectively. The effort to date has consisted mainly of load profile identification and collection. IGT has made a computer tape available through Oak Ridge of typical simulated residential loads. Both contractors will be initiating conceptual design and market analyses in the upcoming review period.

Large-Scale Experiments (LSE) -- LSEs are experiments to accelerate development of the technical base for demonstration projects at minimum programmatic risk. LSEs are designed to develop experience with large hardware systems and to develop engineering capability for future demonstrations. The lack of a representative turbine system in sizes below 200 kW is the constraining element that has established LSEs to be in the 200 to 500 kW size. Because of the experimental nature of LSE installations, the user will continue to be dependent on conventional utility sources; i.e., LSEs may or may not meet total electrical and thermal load requirements of the energy user.

LSEs and Demonstrations will culminate in the construction and operation of sizable facilities. Each project proceeds through prescribed phases from site selection, conceptual, preliminary, and definitive design to construction, and finally to system operation. The planned program for LSEs calls for three generically different technologies. It is intended that the LSE-Demonstration program schedule be such that completion of the definitive design phase of an LSE occurs in time to impact the preliminary design of its Demonstration. To date, two LSEs (Ft. Hood, TX and Shenandoah, GA) have proceeded to the preliminary design.

LSE-Ft. Hood -- The LSE-Ft. Hood is an example of an STES for a residential application. This experiment will provide electricity, heating and cooling, and domestic hot-water needs of a troop complex on this military reservation.

This program began in 1973-1974 under management of the National Science Foundation (NSF), who initiated the national solar energy program that is now under direction of DOE's Division of Solar Energy (DSE). With NSF funding, American Technological University (ATU) undertook in 1974 to assess the energy requirements of the military base, gather insolation data, investigate applicability of available solar technology, and assess the feasibility of solar application to this military reservation. This study was concluded in March 1975. A conceptual design of a Solar Total Energy System for Ft. Hood was initiated by ATU in April 1975 under Energy Research and Development Administration (ERDA) funding. During the 18-month contract (concluded in September 1976), additional insolation data were obtained, energy requirements were further assessed, efforts towards developing a computer program for STES modeling and an engineering test program were started.

In support of the LSE-Ft. Hood effort, a solar engineering test module (SETM) of a linear focusing collector was installed at Ft. Hood in November 1976. In November 1976, ATU was given a $2,326,854 contract to provide by November 1977 a preliminary design (Phase III) of the STES for Ft. Hood. ATU selected Brown and Root as their architectural and engineering (A&E) firm. The 87,000-troop complex was selected as the site for application of the LSE. However, subsequently a decision was made to restructure the LSE-Ft. Hood organization, and two conceptual design teams (Westinghouse and TRW) were selected in May 1977 to provide a conceptual design for the complex. ATU chose to support this effort as site coordinator. Westinghouse was chosen to proceed with the preliminary design in September 1977.

System requirements delineated for the LSE-Ft. Hood are the following:

1. the system will supply peak electrical loads, while the base load will be obtained from the utility;
2. the electrical-generation system will be sized based on the collected solar energy;
3. a fossil-fuel back-up system will be included to supply peak load requirements;
4. a thermal storage system will be included to handle conditions unique to the electrical and thermal loads of this site and to local meteorological conditions;
5. the system shall be designed to operate in parallel with conventional energy supplies;
6. the STES shall, by solar-derived energy, supply 60 to 100 percent of thermal requirements of the site. The thermal load is defined to be the winter heating, summer cooling, and domestic hot-water requirements of the application;
7. the system will be a site-specific design.

The Westinghouse conceptual design recommends

1. a parabolic trough collector with a total aperture area of 13,950 m^2 (150,000 ft^2) oriented N-S;
2. a dual-turbine power-conversion system with steam extraction on the first and full condensing on the second for enhancing cycle efficiency;
3. a high-temperature storage system consisting of three tanks that store sensible heat in a liquid and is sized for 24-hour operation;
4. two-stage absorption chillers, which require less collector input energy than a single stage;
5. use of hot water in place of the existing steam system for increased system efficiency, to supply domestic hot water, and for winter heating.

The LSE-Ft. Hood project is currently in negotations for the preliminary design phase (Phase III) contract.

LSE-Shenandoah -- In April 1977, Georgia Power Company (GPC) was officially selected as the site participant (Phase I) for the second LSE. The application is a knitwear plant in Georgia in a new industrial park of a recently started community development called Shenandoah. In May 1977, three design teams (Stearns-Roger, GE, and Acurex-Aerotherm) were selected to provide, within four mo, a conceptual design (Phase II) of an STES for this application. GE was selected in September 1977 to pursue the preliminary design (Phase III).

The STES for Shenandoah has the following estimated load requirements (based on expansion of the current 2300 m^2 (25,000 ft^2) plant to 3900 m^2 (42,000 ft^2):

1. Electrical load = 259.2 kW
2. Process Steam Load = 1.7×10^9 J/hr (1.6×10^6 Btu/hr; 1380 lb/hr, 113.6 psia, 337°F)
3. Heating Load = 5.6×10^8 J/hr (526,807 Btu/hr)

   Note: During plant operation, the internal heat gain amounts to $1 \times 10 \times 10^9$ J/hr (991,570 Btu/hr).
4. Air Conditioning = 1.8×10^9 J/hr (145 tons)
5. Domestic Hot Water = 1.1×10^7 J/hr (1×10^4 Btu/hr)

Major energy savings and interface agreements were reached with the user to effect efficient use of energy from the STES as shown in Table XVI.

TABLE XVI

Energy Conservation Features of the Bleyle Plant

	Original Design	As Built
Electric Demand (kWe)	383	259
Process Steam (kg/hr)	1000	627
Heating Load (therms)	8.5	5.3
Air Conditioning (tons)	235	145

- Air-conditioning economizer
- Roof insulation 'U' factor equal .03
- Wall insulation 'U' factor equal .05
- 4-ft earth berm
- Rotate building to E-W orientation
- Reduced building height
- Increased lighting and motor voltage
- Reduced window area
- Selected fluorescent lighting
- Central hot-water heating
- White wall and ceiling paint
- Reflective aluminum roof
- Various process system refinements

The General Electric conceptual design proposes

1. a parabolic dish collector field having a total of about 7200 m^2 (75,000 ft^2) of aperture area. A dish with its high-concentration ratio makes effective use of the limited area;
2. an extraction-ported fully condensing turbine that will provide the thermal loads during electricity generation;
3. a multitank, multimedia storage system that uses a trickle-oil concept to economize on the volume of heat-transfer fluid required;
4. possible use of a high-temperature, heat-transfer fluid (Dow Corning Silicone B) that might provide gains in system efficiency.

A meteorology station was installed in September at Shenandoah and is being operated by Georgia Tech on a contract basis. Data from this weather station will be compared with the Atlanta data used in formulating a solar year model (SYM) to correlate Atlanta solar and weather data to Shenandoah conditions. These comparisons will be made at 6-, 12-, and 24-month periods.

The SYM project synthesizes from existing insolation data for Atlanta the best, most representative year from a 23-year period, based on the monthly average solar radiation data. This model year will be used in determining the preliminary design of the STES to be implemented at LSE-Shenandoah.

LSE-3 -- Activity related to this LSE has been limited in scope due to budgetary considerations. Decisions at DOE/DSE preclude initiating any plans toward an active project at this time. In the interim, reviews of program and technical requirements are being conducted to define program elements that should be pursued in the next LSE program. Current thinking for LSE-3 is to

1. use a small central receiver,
2. use an organic Rankine-cycle power-conversion system,
3. reverse the "design to application" procedure and select a load to match the capability of a solar-system design, and
4. select the site in an optimal insolation zone.

The matrix of Figure 45 shows the areas that are, or have been, covered in existing STES applications.

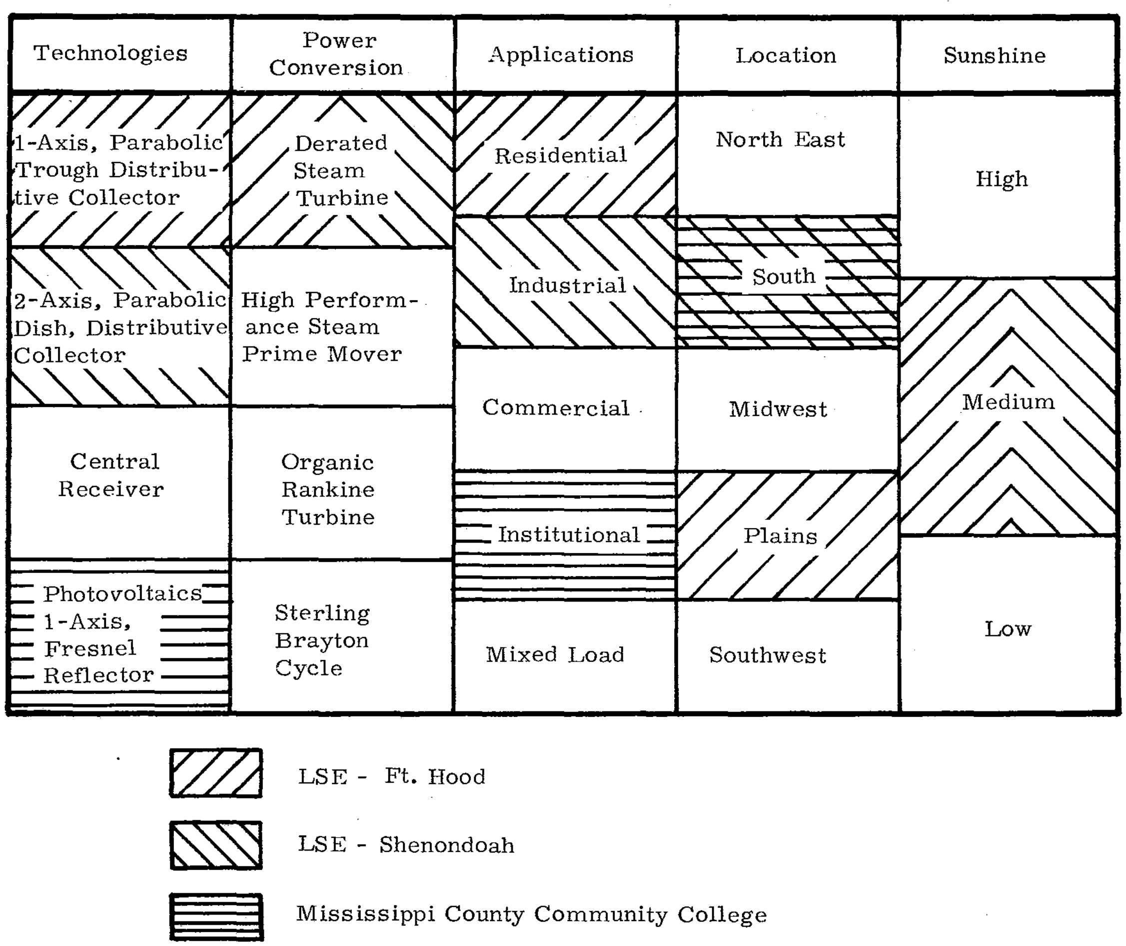


Figure 45. LSE Matrix

Mississippi County Community College -- The Mississippi County Community College (MCCC) project is to design and construct a solar photovoltaic-conversion system to supply all electrical and thermal energy requirements for a facility at the main campus of the college at Blytheville, AR. The system is being designed for an electrical generating capacity of 225 to 300 kW.

The project was authorized under a fixed-ceiling grant in response to an unsolicited proposal and will be for 2 years. Funds were provided for development of a photovoltaic-concentrating collector by Honeywell, Inc. and a REDOX storage battery by GEL, Inc. Provisions have been made to evaluate and use other collectors and storage batteries if the development projects are not successful. Funding included procurement of solar cells.

The project, which interfaces with the Arkansas-Missouri Power Company, includes energy conversion measures and automated power conditioning and control. The University of Arkansas is providing systems analyses and a meteorological program. Oak Ridge Operations Office, DOE, administers the grant with primary technical support from Oak Ridge National Laboratory (ORNL). Sandia will provide technical assistance to ORNL upon request.

The grant for the project was awarded in September. An evaluation of the project was made before awarding the grant, which resulted in reducing the scope of the project from two campuses to one, increasing cost estimates, and providing backup for collector and storage system development. A statement of work consolidating the proposed provisions with additional requirements for conservation and storage was accepted by MCCC as a reference document for the project.

The prototype Sandia Solar Monitoring System has been allocated for use by the University of Arkansas to make insolation measurements at Blytheville, AR. This system is being renovated and modified to meet project requirements. An agreement for a 1-year loan of the equipment was negotiated with the college.

During the initial phases of the project, project personnel and Sandia's photovoltaic group informally exchanged information on photocells and collectors.

5

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APPENDIX

COLLECTOR MODULE INFORMATION SHEET

Manufacturer ____________________ Contract No. __________

Collector Designation ____________________

Contracting Agency ____________________ Contract Officer __________

Program Manager ____________________ Test Engineer __________

Maximum Thermal Output (kJ/hr) ____________________

Operating Range: Temperature __________ Pressure __________ Flow __________

Receiver - - - - ΔT __________ ΔP __________ Length __________

Dimensions: E-W N-S

Aperture -- __________ __________ Total Weight __________

Footprint -- __________ __________ Total Height __________

Free Area -- __________ __________

Tie Down: (90 mph wind) Type __________ Number __________

Forces ____________________

Solar Radiation Hazard Area (>1 sun) ____________________

Electrical Power Required ____________________

Other Utilities ____________________

Instrumentation to be Monitored

Thermocouple - Type ____________________ No. __________

Pressure - - - Type ____________________ No. __________

Other - ____________________

Fluid: Type ____________________ Quantity __________

Fluid Connections: Size Type Location

Inlet __________ __________ __________

Outlet __________ __________ __________

Remarks: ____________________

____

____

COLLECTOR MODULE INFORMATION SHEET

Manufacturer______________________________

Collector Designation______________________________

Type Tracking______________________________

Expected Accuracy______________________________

Tracking Axis______________________________

Travel Limits______________________________

Type Drive______________________________

Moving Parts Hazard______________________________

Type Defocus______________________________

Concentration Ratio______________________________

Definition of______________________________

Optical Materials______________________________

Primary Reflector (Refractor)______________________________

Secondary Reflector______________________________

Receiver Coating______________________________

Receiver Cover Glass______________________________

Receiver Cover Glass Coating______________________________

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