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Solar Total Energy System Facility Project Semiannual Report April 1976 - September 1976

Solar Total Energy Test Facility Division

Prepared by Sandia Laboratories, Albuquerque, New Mexico 87115 and Livermore, California 94550 for the United States Energy Research and Development Administration under Contract AT (29-1)-789

Printed April 1977

Sandia Laboratories
energy report

F 2900-QQ8(3-74)

Issued by Sandia Laboratories, operated for the United States Energy Research and Development Administration by Sandia Corporation.

Printed in the United States of America

Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Price: Printed Copy $5.00; Microfiche $3.00

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SOLAR TOTAL ENERGY SYSTEM TEST FACILITY PROJECT SEMIANNUAL REPORT
April 1976 - September 1976

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ABSTRACT

This report describes the activities of the Sandia Laboratories Solar Total Energy System Test Facility Project during the 6-month period, April 1976 through September 1976. Included are highlights of the period, descriptions of the system and its components, including recent modifications, and the results of systems analyses and component testing.

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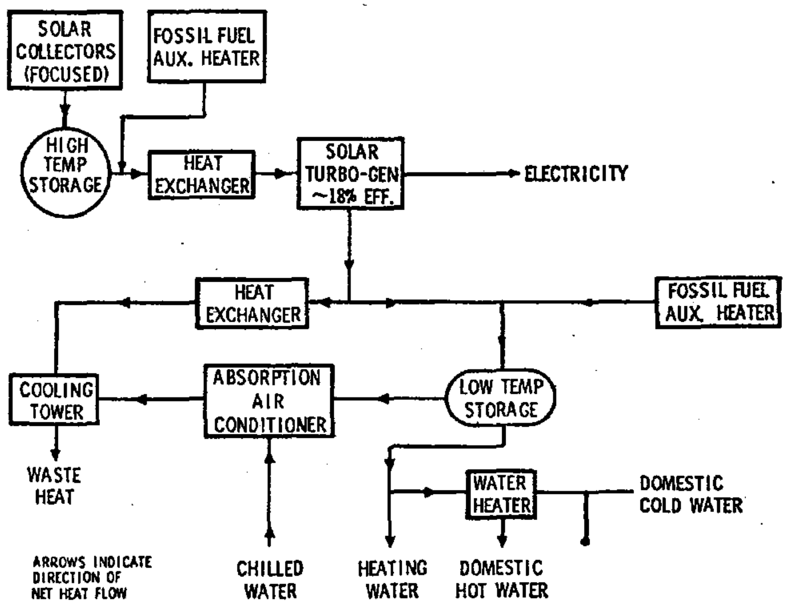

Figure 1. Solar Total Energy System Simplified Schematic

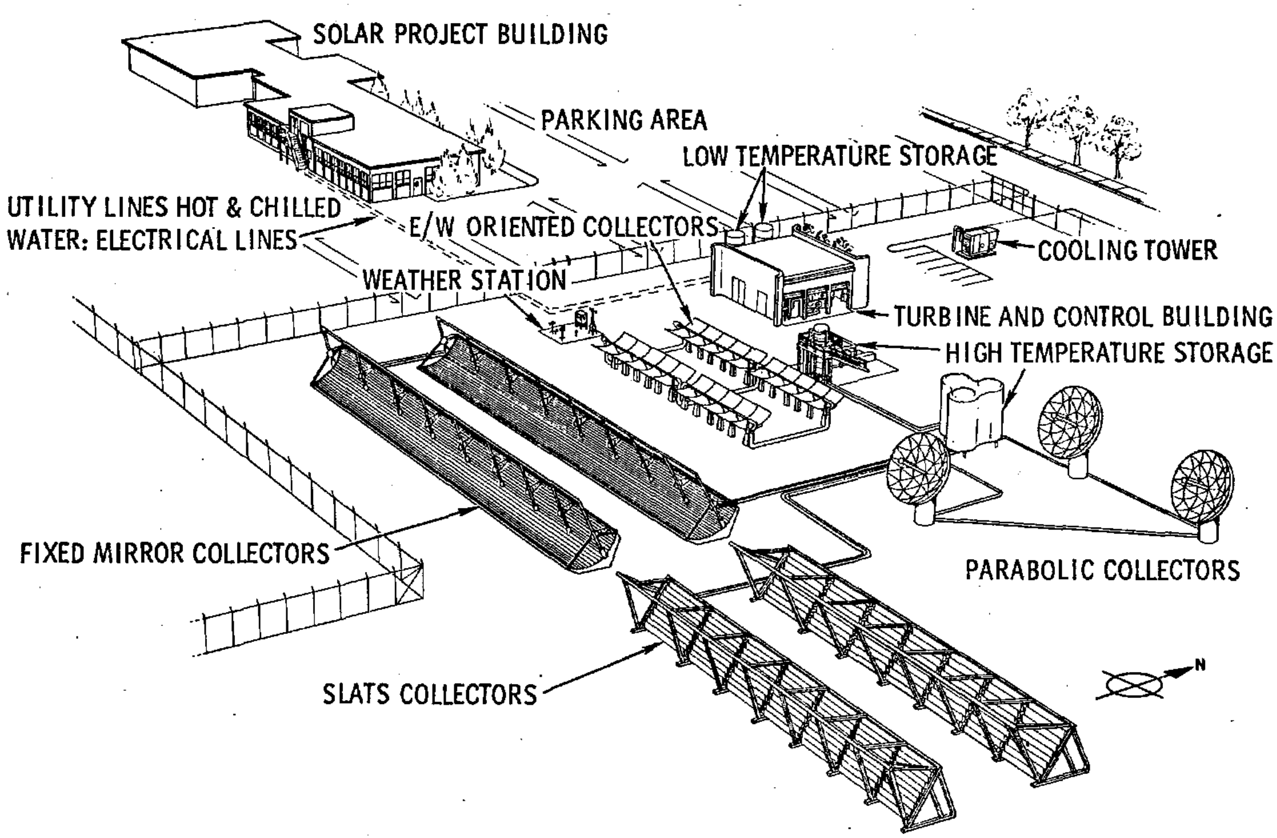

Figure 2. Solar Total Energy System Test Facility

SOLAR TOTAL ENERGY SYSTEM TEST FACILITY PROJECT
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SECTION I. INTRODUCTION

The primary objective of the Sandia Solar Total Energy System Test Facility Project is to determine and demonstrate the technical and economic feasibility of solar total energy systems for a variety of sites and loads. In support of the primary objective additional objectives of the project are (1) to construct a solar total energy system which is sufficiently versatile to be used as an engineering evaluation center or test bed for further development of individual components or other solar energy subsystems, (2) to encourage private sector participation in the program and in the development of components for the system, (3) to determine those areas of research and development that offer the greatest payoffs, and (4) to develop and validate a systems analysis computer program capable of evaluating the great number of possible combinations of total energy system configurations.

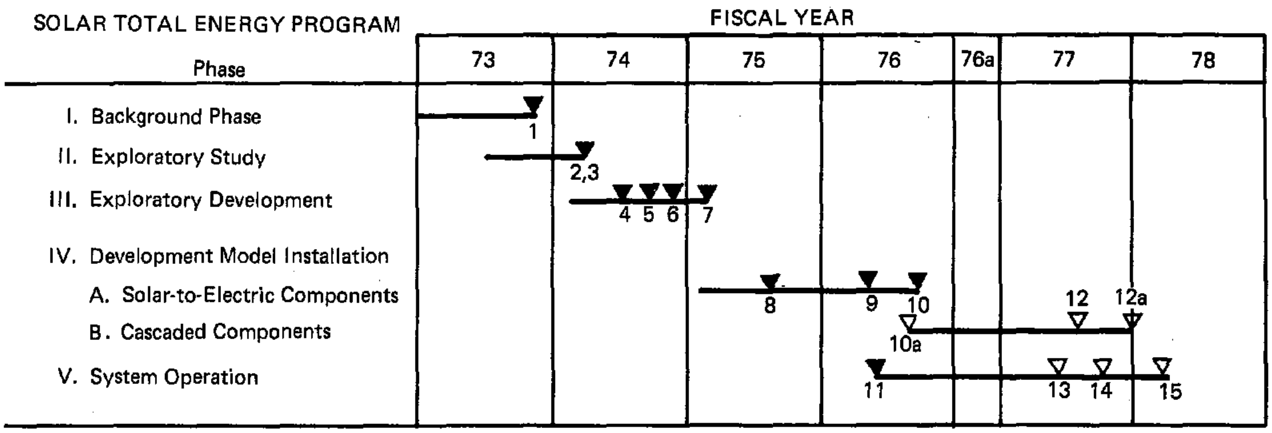
The Solar Total Energy System, depicted in block diagram form in Figure 1 and as an artist's concept in Figure 2, will operate as follows: A heat transfer fluid (Therminol 66) is heated in the receiver tubes of the solar collectors by reflected and focused solar radiation. This fluid is pumped to the high-temperature storage subsystem. On a demand basis, fluid is extracted from this storage and pumped to the heat exchanger which produces superheated toluene vapor to power the turbine/generator. The boiler can also be operated from a fossil-fuel-fired heater to insure continuity of operation during extended cloudy periods. Turbine condenser coolant is pumped to the low-temperature storage tank and becomes the energy source for the heating and air-conditioning components of the system.

The overall project consists of five phases (see Figure 3) with the work reported in this document being part of Phases IV and V. The program, which began in 1972 with background research and exploratory analysis, has progressed to the present hardware stage in which the Solar Total Energy System Test Facility is being built to evaluate solar energy subsystems and to provide energy for an 1100 m^2 office building, the Solar Project Building.

Phases I, II, and III, which emphasized preliminary studies and designs have been completed. 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, an interim-sized high-temperature stratified storage tank, a 32-kW turbine/generator and its 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 conclude late in calendar year 1977. During Phase IV-B the Solar Total Energy System Test Facility will be expanded to start full operation.

The current capability of collecting 2×10^6 kJ per day will be quadrupled to a capacity of about 8×10^6 kJ/day. The corresponding increase in collector area will be from 200 to 825 m^2 (2160 to 8900 ft^2). Thermal storage capacity will be increased from about 30 minutes to 4 hours. A subsystem for low-temperature thermal energy storage will be added, plus all necessary additional sensors and controls.



Milestones:

1. Completion of Phase I
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

▼ Completed

▽ Scheduled

Figure 3. Solar Total Energy Test System Schedule and Milestones

The Solar Collector Module Test Facility currently is capable of testing a collector module with Therminol 66 to 315°C or with water to 232°C. During the next 6 months, this capacity will be tripled to enable testing of three collectors simultaneously with either water or Therminol 66 (see Task 8).

During this reporting period preliminary design studies of the three Phase IV-B collector field subsystems were completed. A Phase IV-B thermal storage concept was selected and the design begun. Design of the low-temperature loop was completed and design of the expanded solar collector module test facility was about 75 percent complete.

Phase V, overlapping Phase IV-A, started January 1976. It consists of operating the facility under conditions which enable gathering and analyzing engineering data which can provide a basis for the design of large-scale experimental plants and future solar energy systems. During this phase, the electric power, heating, and cooling for the Solar Project Building will also be demonstrated. All of the existing system is being operated in accordance with scheduled and planned tests.

SECTION II. OVERVIEW OF ACTIVITIES

Highlights

The following significant activities and milestones occurred between April and September, 1976.

- The Sandia east-west parabolic trough collector high-temperature storage and turbine generator subsystems became fully operational in early April.
- On April 30, high wind did extensive damage to the east-west parabolic trough collector subsystem. The subsystem was again fully operational on June 11.
- The Solar Total Energy Test Facility was dedicated July 8, 1976.
- The multitank concept was selected for the high-temperature storage subsystem for Phase IV-B.
- Baseline efficiency tests were conducted with 20 collectors.
- Aperture tests to determine accuracy of focusing on the receiver were conducted with 20 collectors.
- An expansion of the capability of the solar collector module test facility was begun.
- Four contractors completed preliminary designs of collector field subsystems. Selected for inclusion in the Solar Total Energy Test Facility were:

General Atomics	Fixed Mirror
Raytheon	Parabolic Dish
Sheldahl	SLATS

- Requirements for the Phase IV-B high-temperature storage subsystem, the associated fluid loop and controls, and the interface with the contracted collector field subsystems were completed.
- A long-range test plan for the Solar Total Energy System Test Facility was outlined.
- The first "resident engineer," Dr. Robert Clarke, Suntech Division, Sun Oil Company, joined Sandia in September 1976 for a 3 to 4 month tour. These tours are being instituted as a method of transferring technology to industry.

Publications and Presentations
April 1976 - September 1976

Publications

R. L. Champion, "Solar Total Energy Program Semiannual Report, April-September, 1975," SAND76-0078, Sandia Laboratories, April 1976.

G. W. Treadwell and L. E. Torkelson, "Solar Total Energy Program Semiannual Report, October 1975-March 1976," SAND76-0205, Sandia Laboratories, June 1976.

G. W. Treadwell, "Design Considerations for Parabolic-Cylindrical Solar Collectors," SAND76-0082, Sandia Laboratories, July 1976.

A. F. Veneruso, "Simulation and Operation of a Solar Powered Organic Rankine Cycle Turbine," 76-WA/Sol-18, American Society of Mechanical Engineers, September 1976.

D. M. Mattox, "Coatings and Surface Treatments in Solar Energy Application," Plating 67, 55 (1976).

D. M. Mattox, "Applications of Thin Films to Solar Energy Utilization," J. Vac. Sci. Technol. 13, 127 (1976).

R. B. Petit and R. R. Sowell, "Solar Absorptance and Emittance Properties of Several Solar Coatings," J. Vac. Sci. Technol. 13, 596 (1976).

W. W. Shurtleff, "Solar Total Energy Control Data Acquisition System," SAND76-0506, Sandia Laboratories, to be published.

D. M. Mattox, "Optical Materials for Solar Energy Applications," to be published in Optics News.

D. M. Mattox, "Chemical Aspects of Solar Energy Utilization," to be published in J. Solid State Chemistry.

T. D. Harrison, W. R. Dworzak, and C. A. Folkner, Jr., "Solar Collector Module Test Facility and Instrumentation Fluid Loop Number One," SAND76-0425, Sandia Laboratories, to be published.

Presentations

J. A. Leonard, "Solar Total Energy at Sandia Laboratories," Thirteenth Space Congress, Cocoa Beach, Florida, April 8, 1976.

B. L. Butler, "Common Sense Applications of Solar Energy in the Home," Joint ASME-IEEE Meeting, Bozeman, Montana, April 8, 1976.

G. W. Treadwell, "Solar Collector Design Considerations," Society of American Military Engineers April Workshop Meeting, Albuquerque, New Mexico, April 29, 1976.

J. A. Leonard, "Sandia's Solar Total Energy Test Bed," System Safety Society, Albuquerque, New Mexico, May 25, 1976.

J. A. Leonard, "Course on Solar Energy Fundamentals and Utilization," Escuela Technical (architects and engineers), Madrid, Spain, May 30 - June 5, 1976.

D. M. Mattox, "Optical Materials for Solar Energy Applications," Annual Symp. of the North Central Chapt. of the Am. Vacuum Society, Detroit, Michigan, June 2, 1976.

R. L. Champion, "Sandia's Solar Total Energy System Test Facility Program," National Secretaries Association, Albuquerque, New Mexico, June 8, 1976.

J. A. Leonard, "Prospects for Solar Energy," Centro Cultural de los Estados Unidos Cultural Center), Madrid, Spain, June 11, 1976.

B. L. Butler and R. B. Pettit, "Materials Development for Solar Total Energy," ERDA Program Review Meeting, Berkeley, California, July 21-23, 1976.

G. W. Treadwell, "Design Considerations for Parabolic-Cylindrical Solar Collectors," International Solar Energy Society Annual Meeting, Winnipeg, Manitoba, Canada, August 15-20, 1976.

R. W. Harrigan, "Economic Study - Solar Total Energy," International Solar Energy Society Annual Meeting, Winnipeg, Manitoba, August 15-20, 1976.

F. Biggs and C. N. Vittitoe, "Mathematical Modeling of Solar Concentrators," International Solar Energy Society Annual Meeting, Winnipeg, Manitoba, August 15-20, 1976.

R. B. Pettit, "Specular Reflectance Properties of Mirror Materials," International Solar Energy Society Annual Meeting, Winnipeg, Manitoba, August 15-20, 1976.

SECTION III. PROGRAM DESCRIPTION AND STATUS

Task 1. Program Management

The Sandia Solar Total Energy System Test Facility Project has been organized into a work breakdown structure of tasks and subtasks. This complete structure is given in the Contents for this section. The detailed status of each program task is described in the subsections below, organized for convenience along the lines of the work breakdown structure. A chart illustrating complete program staffing is shown in the Appendix. The technical contributions of these individuals to the Project as well as their written inputs contained in this semiannual status report are gratefully acknowledged.

1.1 Program Direction

Planning and action to expand the Solar Total Energy System Test Facility to its full capability by September 1977 was the major activity of this reporting period. These activities are reflected in the milestone schedule, Figure 1-1. Control, logic, and fluid loop systems for the expanded Solar Total Energy System Test Facility were developed and documented. These are described in Tasks 2.1 and 5.1.

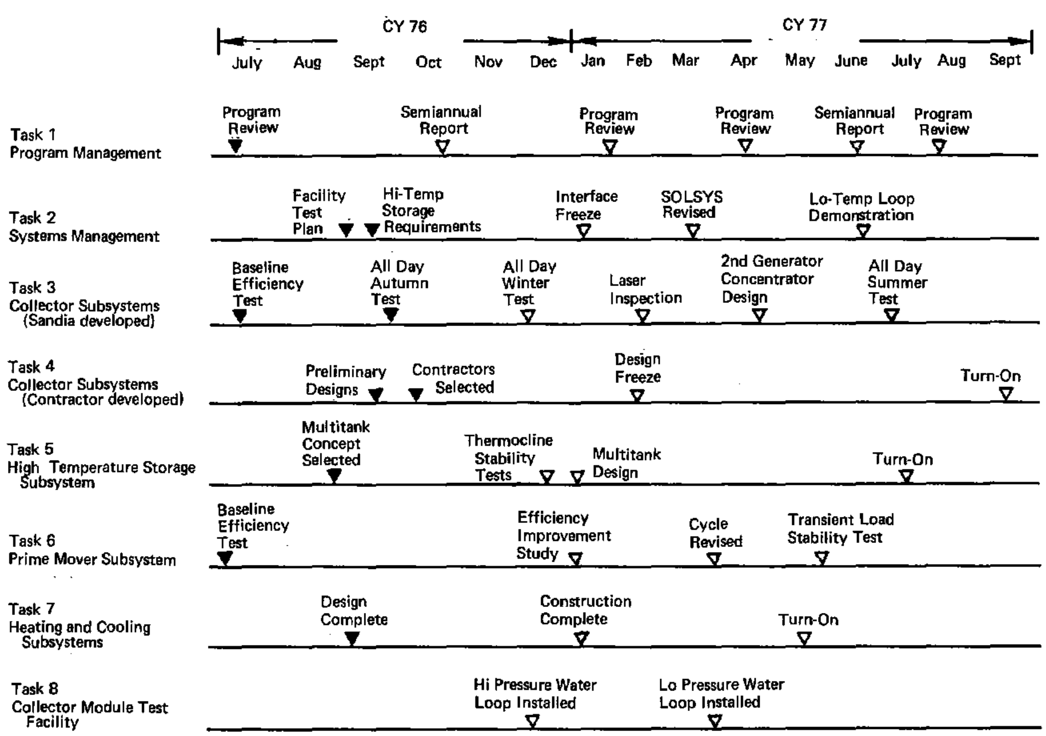


Figure 1-1. Solar Total Energy System Test Facility Milestones

A test schedule was prepared and testing of the total system, subsystems, and components of subsystems was initiated (see Tasks 2.3 and 2.4).

Efforts are continuing to develop better concentrators and receivers and to develop techniques and equipment to inspect these items, both at the point of manufacture and in the field (see Task 3).

Contractors studying candidate collector field subsystems for the expanded test facility finished their work. The results were evaluated and three concepts were selected (Task 4).

High-temperature storage concepts for Phase IV-B were evaluated. The multiple tank concept was selected and design work was begun (Task 5.1).

Design of the heating and cooling subsystem for the Solar Project Building was completed (Task 7.1).

A decision was made to triple the capability of the solar collector module test facility and design work was initiated (Task 8.1).

1.2 Adminstration

A computer program was prepared for the PDP-10 computer to record scheduled and completed day-to-day activities of the Sandia project organization. This same program will be used with some modifications to monitor progress of the design, fabrication, and installation of the three contracted collector field subsystems.

A PERT chart was prepared to schedule, identify responsibility for, and allot time to the activities required to install the high-temperature storage subsystem and the three contracted collector field subsystems. This PERT chart is currently being fed into Sandia's 1108 computer to make possible automated updating.

Seventy-four visitors were briefed and ideas were exchanged on 52 occasions. Among these 74 persons were 37 visitors from 14 foreign countries and the United Nations, as shown in Table 1-I. The remainder were officials from government agencies, professors from universities, and private companies' representatives. In addition, 80 tours (a total of 620 people) were conducted through the Solar Total Energy Test System Facility; the 620 included students, professional groups, company representatives, and interested citizens.

A combined solar thermal/photovoltaic concentrator (Figure 1-2) was fabricated by modifying one of our 2.7 x 3.7 m north-south collectors. This device, including a control console and an output console with a recorded message, was installed on the mall in Washington, D.C., as part of the bicentennial display.

TABLE 1-I

Foreign Visitors to Solar Total Energy System Test Facility

Country	No. of Visits	No. of People
Argentina	1	1
Austria	1	1
Australia	1	1
Belgium	1	1
Canada	2	2
England	2	4
France	3	3
India	1	1
Iran	2	4
Israel	4	7
Italy	1	1
Japan	1	8
Spain	1	1
Tunisia	1	1
United Nations	1	1
	23	37

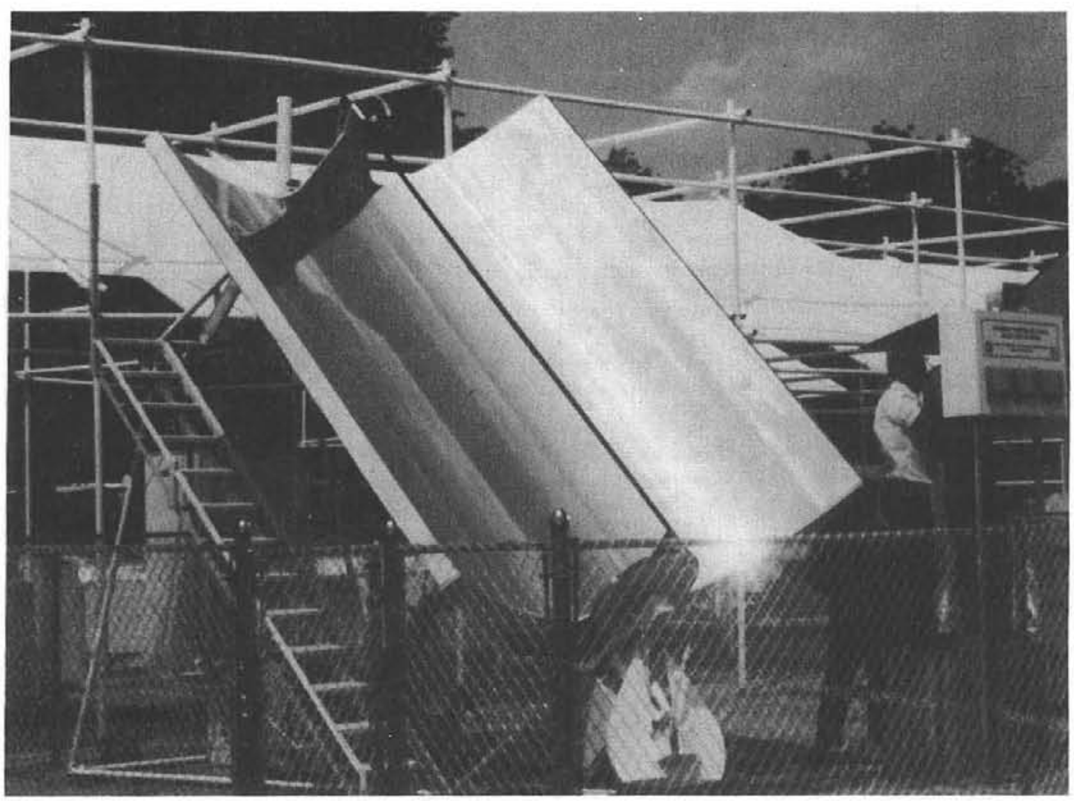


Figure 1-2. Bicentennial Display Collector

The work structure breakdown was rearranged. There were seven tasks in the last semi-annual report, but eight tasks in this report. These eight are more hardware oriented. As the result of the evolution of the project, this change facilitates assignment of responsibility, budgeting, and reporting.

Task 2. System Management

Systems engineering concentrated on preparing requirements for the new high-temperature storage subsystem and the fluid loops required to connect that subsystem to the existing system and to the new, contracted collector subsystems.

A contract was placed with EG&G, Kirtland Operations Office, to provide personnel to plan and perform tests, to do necessary repair and maintenance operations in the Solar Total Energy Test Facility and the Solar Collector Module Test Facility, and to assist with engineering tasks.

Safety and security were reviewed. When appropriate, safe operating procedures (SOP) were created to meet evolving requirements. Plans were made to realign fences and install remote-controlled locks on all gates.

2.1 Systems Engineering

The basic Therminol 66 high-temperature fluid loop between the existing system, new high-temperature storage, and new collector fields has been defined. Eight basic modes of operation are possible with the fluid loop. A piping and fluid flow schematic has been prepared for each of these modes. The three major ones are normal, storage full, and storage empty operations. The remaining five are occasional-use modes such as heating or cooling storage. A control valve statement has also been prepared which defines the operations required of all valves in the system for the eight modes. All interfaces between the old T-66 system and the new fluid loop have been defined. However, the interface between the new loop and the new collector fields has not yet been defined. The need to establish this interface, so that the A&E firm selected to design the high-temperature storage subsystem has complete requirement definitions, conflicts with the fact that detailed design of the collector fields is months away. Resolution of this problem will require Sandia to make reasonable assumptions about these interface requirements and then insure that collector field contractors design to the assumptions. The high-temperature storage subsystem is discussed in more detail under Task 5.1.

System requirements statements, valve control statements, and pipe schematics for all operational modes have been generated for the heating and cooling subsystems which connect the Solar Total Energy System to the demonstration Solar Project Building (Bldg. 832). These re-These requirements also are discussed in more detail under Task 5.1.

To establish and coordinate a more precise schedule for the design, fabrication, and installation of the high-temperature storage subsystem, the three contracted collector field subsystems, and the heating and cooling subsystems for the Solar Project Building, a PERT chart was prepared. This chart identifies required tasks, assigns responsibility for each one, estimates the time required to do it, and schedules completion dates.

2.2 Systems Analysis

The primary effort in systems analysis was directed at determining requirements for fluid loops, fluid loop controls, and the interfaces between the existing systems and the new high-temperature storage subsystems and the three contracted collector field subsystems. The results of these efforts were described under 2.1, and also in Tasks 4 and 5 of this report.

Continued testing confirms that the efficiency of the turbine/generator is less than anticipated. This creates a major problem--the increase in the collector area required to meet the 32 kW load for 11 hours. With the collector area presently being procured, the system will generate 32 kW from solar energy for only 9.5 hours in the winter, the remaining 1.5 hours having to be supplied by the fossil-fuel auxilliary heater. (In the summer less than 0.5 hour will be from the fossil-fuel heater.) Since the low cycle efficiency is a consequence of adapting an available turbine/generator to the system and not a consequence of thermodynamic limitations, the decision was made not to increase the collector area being procured at this time. While actual energy-conversion cycle efficiencies are of the order of 13 %, an excess of 20 % can be expected using a system specifically designed for the solar total energy application. Consequently, a future energy-conversion system could require less collector area on an area/kW basis than is presently required for the Solar Total Energy System Test Facility. Table 2-I compares the predicted collector daily output with that required for the presently installed turbine/generator system.

TABLE 2-I

Projected Required Output
Solar Total Energy Test System Facility
(all units are kJ/day x 10^{-6})

Collector Field Subsystem	Output		System Requirements	
	Winter	Summer	Winter	Summer
Sandia	2.14	2.39	*	
General Atomic	2.19	2.66		
Raytheon	2.04	2.73		
Sheldahl	2.26	2.89		
	8.63	10.67	10.1	11.3

*Required outputs were based on a predicted turbine/generator efficiency which was higher than the actual efficiency as determined by test. The system requirements are based on the turbine/generator efficiency as determined by test.

2.3 Test Management

A contract has been placed with EG&G, Kirtland Operations Office, to provide a test director, technicians, and other personnel to assist Sandia Laboratories on the Solar Total Energy Project In conjunction with Sandia personnel, EG&G will:

- Plan and perform tests for the Solar Total Energy System Test Facility and the Solar Collector Module Test Facility.
- Prepare reports of test results.
- Perform maintenance and repair necessary for the operation of the facilities.
- Provide engineering assistance, as required, to Sandia technical personnel.

A test schedule has been prepared. Test plans were created and tests have been performed and reports prepared on various subsystems.

A program was written in BASIC language for the HP 2116 minicomputer to prepare for a scheduled test on the Raytheon simulated receiver.

EG&G personnel have improved the location and operation of a number of relief valves, have performed maintenance and repair on pumps and control units, and have familiarized themselves with the Solar Collector Module Test Facility by replacing Therminol with water/ethylene-glycol solution and modifying plumbing in preparation for a test on Sandia's photovoltaic generator. They are progressing in the preparation of test plans, reports, and engineering activities to improve the design and operation of all test equipment and activities.

2.4 Safety

Protection of visitors and the general public from possible harm is vital. Almost as important is protection of equipment from accident or vandalism. Plans have been completed to control access to the Solar Total Energy System Test Facility. All gates in the 6-foot fence surrounding the area will be kept locked. The main gate will be provided with coded mechanical locks that will open only if the correct numbers are punched in the right sequence. These code numbers will be changed frequently to prevent their widespread dissemination. Unannounced visitors will be directed by signs to the Solar Project office where arrangements for tours can be made.

Safe Operating Procedure 1690D 7610 was issued to describe procedures to ensure the protection of visitors to the facility.

Safe Operating Procedures to assure safe and proper operations of equipment have been issued for the Phase IV-A systems, i.e., solar-to-electric components. These procedures are as follows:

- Safe Operating Procedure 03900 7602 5712, Therminol 66 Fluid Loop, Solar Total Energy System.
- Safe Operating Procedure 05700 7604.5712 Rankine Cycle Energy Conversion Subsystem (ECS), Solar Total Energy System.
- Safe Operating Procedure 03800 7604 5712 Solar Collector Subsystem, Solar Total Energy System.
- Operating Procedures for Condenser Fluid Transfer Subsystem.
- Operating Procedures for Cooling Tower Subsystem.

The philosophy was to write an SOP for the collectors and for each complete fluid loop in the system and to interlock these fluid loops by means of the overall operating procedures to ensure no damage to the system. The fluid loops can be operated individually or simultaneously. Where the operation of one loop affects the operation of another loop, the operating procedures tie them together.

Task 3. Collector Subsystems

This task is concerned with the concentrators and components of concentrators that are developed, fabricated, and installed by Sandia. Activities during this period resulted in improvements in concentrator fabrication techniques and materials, reflector materials, and receiver tube coatings, in glass envelopes to minimize heat loss from receivers, and the use of lasers to inspect reflector surfaces.

The 200 m^2 east-west parabolic trough subsystem was operated and tested. Operation of the subsystem revealed its vulnerability to wind damage and the vulnerability of the reflective surfaces to hazards during windstorms and repair and cleaning activities. Cleaning techniques to remove contamination from the reflective surfaces were developed and evaluated. A simple device was built and used to check the accuracy of the positioning of the receiver tube with respect to the focus line of the concentrator.

3.1 Development

Concentrator Fabrication Development--As described in previous reports, a pair of precision metal parabolic molds have been used to fabricate a variety of 0.6 x 1.2 m (2 x 4 ft) parabolic test sections for evaluating production processes and environmental capabilities. Haveg Industries have produced parabolas of sheet molding compound (SMC) with integrally molded ribs.

The sheet molding compound is a composite of chopped glass fibers, powdered mineral filler particles, and polyester resin, which is mixed, rolled and partially cured to a leather-like sheet of material. A pressing technique, using heated dies, flows the material to fill the closed die and starts the polyester polymerization. Thus, like the metal stamping process, a sheet of material goes in, the die closes, and a finished part emerges. The 19 mm high ribs were about 3.2 mm thick and were arranged as shown in Figure 3-1. The ribs plus the 3.2 mm thick face sheet resulted in a part which weighs 8.8 kg/m^2. At a cost of $2.20/kg of fabricated SMC material, this type of composite is similar in cost to other parabolic trough concepts. Existing press capacities could produce troughs of sizes up to about 1.5 x 2.4 m (5 x 8 ft) with 90-degree rim angles.

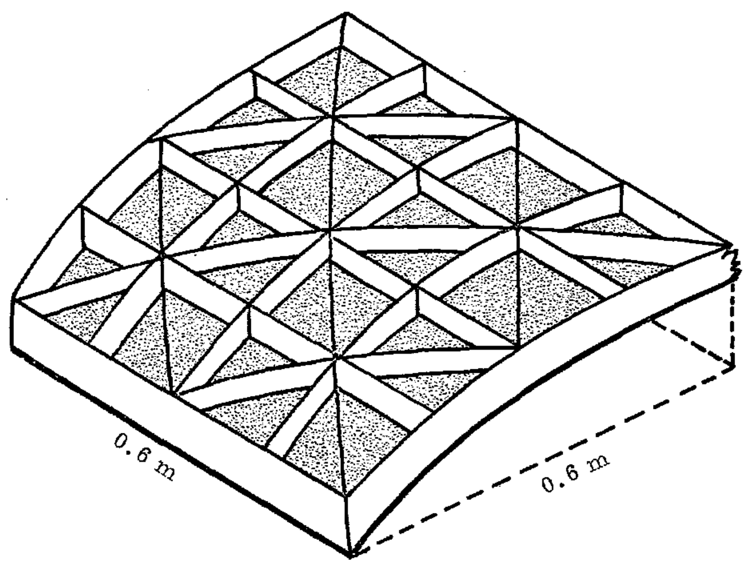


Figure 3-1. Pictorial of SMC Molded Parabola With Integral Ribs

Parabolas consisting of polyurethane foam sprayed on a male parabolic mold have been received from Sandia Livermore. They have introduced chopped glass fibers into the foam to reduce curing shrinkage and distortion. This innovation has resulted in weight reductions and may improve shape stability.

These new materials will be inspected with the laser inspection technique described in previous semiannual reports to establish their baseline optical characteristics. These parabolic test sections will be placed in accelerated or real-time environmental testing for evaluation. The effects of these tests, plus a series of simulated hail tests, will be evaluated by reinspection of the units with the laser system and detailed comparison with the initial data.

Reinspection of environmentally tortured test parabolas was initiated but the demands on the heliostat ray-trace equipment have postponed completion of this task. Each temperature/humidity chamber cycle is 8 hours long and cycles between -29° and 54° C (-20° and 130° F), spending 2 hours at each extreme and 2 hours in transition from one extreme to the other. The chamber relative humidity is controlled between 50 and 85 %. As the temperature goes below freezing, frost is formed on the test troughs. Parabolas exposed for 6 months were removed from the environmental test chamber and traced to determine if significant changes had taken place. Even though the data reduction has been delayed, the raw data scans can be compared. The before and after exposure scans of trough section SK 33 indicate that this all-fiberglass unit has changed very little. The scans of trough section SL 35 show the effects of environmentally induced debonding of the Alzak reflector from the Micarta paper honeycomb unit. The before and after traces of all exposed parabolas will be reduced to a standard deviation of the overall unit slope/error distribution and a focal length shift.

The effects of hail on solar collectors, with emphasis on parabolic reflectors, are being studied by dropping ice balls on them. The ice balls are formed by freezing water in spherical rubber molds. These balls do not have the onion skin structure common to hail, but are a reasonable substitute. Simulated hail of 12.7, 19.1, 25.4, 32 and 38 mm diameters have been produced. Photometric determinations of velocity showed that, from our 16.4 m tower, only 12.7 mm balls reach terminal velocity. The drop tower was extended and modified to permit faster and safer hail testing. The hail-drop facility now consists of a 32.8 m tall, 0.3 m diameter tube. This tube is fitted with an internal elevator bucket with a special ball-release mechanism. The balls can be dropped singly or en masse. The longer tube allows terminal velocities to be obtained with ice balls as large as 19 mm.

Various mirrors and mirror-support structures have been tested to determine their hail damage resistance. After testing the hail-damaged areas were inspected using a "Gould Surfanalizer," which measured depth vs distance on the diameter of a hail-induced dent. For ductile or malleable mirrors the dents fall into two classes, termed cone dents or spherical dents. Glass mirrors fracture without denting. Some preliminary results on Alzak (Alcoa) and FEK-163 aluminized acrylic (3M) are shown in Table 3-I. Measurements are being performed to determine the amount of reflector area rendered useless by a given hail impact. The hail tests have been used mainly as a screening procedure for mirror/structure candidates. Initial work has begun on a R&D program to provide the information necessary to improve hail damage resistance of some of the candidate material systems.

Wind-tunnel tests were conducted in March 1976 at the Vought Corporation, Grand Prairie, Texas, on a series of 1/10 scale models of a 2-m (rim-to-rim) trough. The purpose of the test series was to develop force, moment, and pressure data for parabolic troughs for virtually all combinations of pitch and yaw for winds impinging on trough collectors. The raw data have been resolved into wind axes and body axes forces and moments and into nondimensional coefficients for drag, lift, yaw, and rotational moments. The data are applicable for all nominal 90-degree angle troughs; the data can be adapted for troughs with the axis of rotation of the trough behind (beneath) the vertex or within the trough (above the vertex).

TABLE 3-I

Typical Materials Tested With Simulated Hail

Reflector	Support Skin	Structure Skin	Hail Size (mm)	Approximate Impact Velocity (m/s)	Comments
Alzak[a]	Micarta	Paper Honeycomb	19	13.7±2.1	Good hail resistance, conical dents
Alzak[a]	Melamine	Paper Honeycomb	19	13.7±2.1	Good hail resistance, conical dents
Alzak[a]	Fiberglass	Paper Honeycomb	19	13.7±2.1	Good hail resistance, conical dents
Alzak[b]	Lanan Plywood	Lanan Plywood	19	13.7±2.1	Poor hail resistance, spherical dents
Scheldahl[c]	Fiberglass	Fiberglass	19	13.7±2.1	Moderate damage, conical dents
FEK-163[c]	Aluminum	Aluminum Honeycomb	19	13.7±2.1	Heavy damage, Spherical dents
Alzak[b]	0.025 Galvanized Iron	Aluminum Honeycomb	19	13.7±2.1	Heavy damage, conical dents
FEK-163[c]	Fiberglass	Aluminum Honeycomb	19	13.7±2.1	Moderate damage, conical dents
FEK-163[c]	0.025 Galvanized Iron	Aluminum Honeycomb	25.4	19.2±0.3	Good hail resistance, conical dents
Other Materials Tested with Simulated Hail					
Glass Receiver Tube			38	16.0±0.7	Fracture, poor resistance

NOTES:

[a]Bonded

[b]Mechanical attachment (screws or tape) of reflector to support structure.

[c]Adhesive backed

A Sandia report presenting the data is being prepared.

Reflector Development and Fabrication -- A promising reflector film is 3M's FEK-163, a second-surface aluminized acrylic film with an adhesive backing. This material is an outgrowth of 3M's 5400 aluminized acrylic film. Samples of FEK-163 were applied to three of the aluminum honeycomb test sections which have been in the accelerated environmental test chamber.

After several weeks of cycling, inspection revealed some major degradation. Splits had occurred in the film material perpendicular to the trough's arc length of 1.25 m (49.25 in.). The splits ranged from 1.5 to 2.5 mm (0.06 to 0.1 in.) wide; usually two or three such splits occurred in the length of the arc. The orientation of the splits indicated tensile failure due to differential thermal expansion. With a coefficient of expansion of 16 to 28 x 10^{-6} m/m°C, the acrylic would be expected to fail when applied to an aluminum sheet at 21°C (70°F). A detailed post-mortem has not been conducted on these units and the stated conclusions are preliminary.

About 50% of the splits were centered on a "tent" produced by a grain of sand or other grit between the aluminum skin and the acrylic film. The grain may have produced both a point of stress concentration and a sharp corner or edge to initiate failure. This failure illustrates the need for extreme cleanliness in applying reflector films to a substrate.

The edges of the acrylic films at the splits showed virtually no sign of delamination or degradation of the aluminum on the second surface. The adhesive appears to have an excellent environmental capability. This testing will continue. The edges of the test sections which were on the bottom and almost constantly wet from frost and subsequent drainage of water to that area exhibited some signs of delamination and aluminum degradation.

The other, perhaps more important degradation factor noted on the acrylic films was that of fogging over virtually the entire surface of the film. The causes of the fogging can only be speculated on at this time. Reflective measurements will be made along with microscopic examination in an attempt to determine the degree and causes of the fogging.

The 3M Company has furnished samples of acrylic films which have been on outdoor exposure racks for several years in various locations. Reflective measurements are to be made on these samples and their control samples.

The specular reflectance properties of two weathered, aluminized teflon reflector materials have been obtained. The reflectors were mounted in the STESTF parabolic troughs; reflector No. 31 was installed December 12, 1975, while reflector No. 20 was installed January 23, 1976. Both reflectors were removed May 1, 1976. The reflectance properties before the outside exposure are unknown.

The specular reflectance properties were measured at two wavelengths (500 and 800 nm) for the following sample conditions: (1) as received, (2) after a water rinse, and (3) after rinsing with lens cleaner and wiping clean with soft tissue. In the as-received condition there was a very noticeable dirt layer on each reflector, especially No. 20. The water rinsing was done to simulate a simple in-the-field cleaning of the reflectors, while the final cleaning was performed to determine the "intrinsic" aged properties of the mirrors.

In addition to the specular reflectance, the hemispherical reflectance $\rho(2\pi)$, as a function of wavelength from 350 to 2500 nm was also measured. In the as-received condition, $\rho(2\pi)$ for sheet No. 31 was $\sim 1.5\%$ below the cleaned material, while $\rho(2\pi)$ for sheet No. 20 was $\sim 3.5\%$ below the clean material. After cleaning, $\rho(2\pi)$ was identical for the two samples and equal to previously measured virgin material. Thus, the hemispherical reflectivity of the weathered materials has not changed; however, the distribution of the reflected radiation has changed, as shown by the specular reflectance results.

The specular reflectance properties at 500 nm are shown in Figures 3-2 and 3-3. The results at 800 nm are similar to those at 500 nm except that the decrease in reflectance due to the dirt is less at 800 nm than at 500 nm. This is to be expected since scattering from small particles is generally inversely proportional to the wavelength.

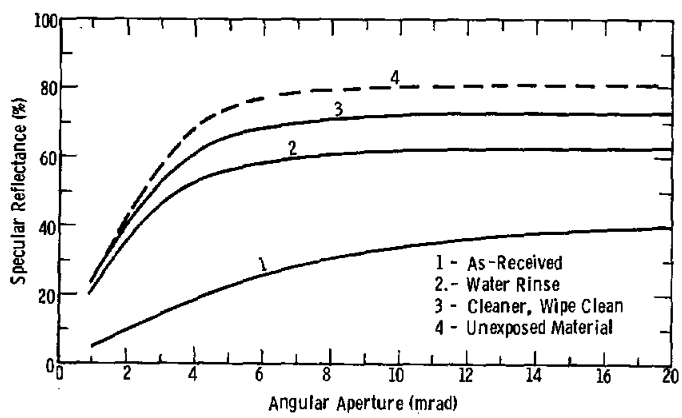


Figure 3-2. Specular Reflectance Properties of Reflector Sheet No. 20 Together with Unexposed Material at 500 nm

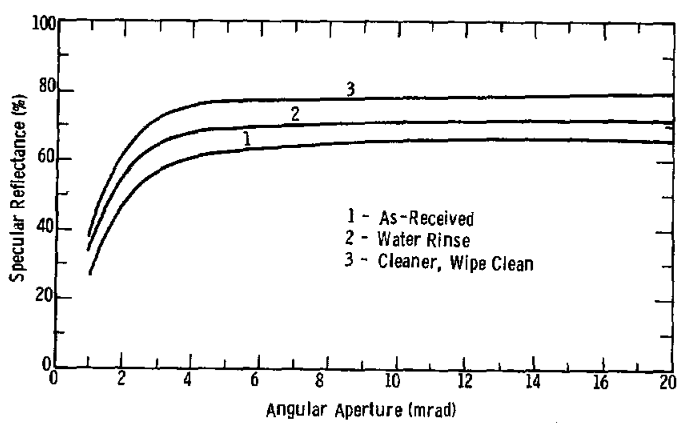


Figure 3-3. Specular Reflectance Properties of Reflector Sheet No. 31 at 500 nm

The extreme amount of dirt on sheet No. 20 reduced the specular reflectance below 30% out to 8 mrad. However, after water rinsing, the reflectance at the same aperture jumped to 61%; with more careful cleaning, the reflectance rose to 71%. For sheet No. 31, the reflectance was 66% at 8 mrad in the as-received condition, and increased to 78% after careful cleaning. Note that in both cases the reflectance never reaches the asymptotic value of 87%. For unexposed material at this wavelength, the specular reflectance at large angular apertures is only 81% as shown in Figure 3-3. Therefore, even after careful cleaning, a residual reflectance loss of 2 to 8% remained. Because the hemispherical reflectance values remain unchanged after cleaning, the decrease in the specular reflectance must be due to a change in the surface condition of the reflector. Additional experiments, involving premeasured samples, are in progress.

Receiver Development and Fabrication -- The receiver is the device on which the reflected solar radiation is concentrated. It consists of two parts. One is a tube which contains the heat-transfer fluid being heated. The other is insulation. In most cases an important component of this insulation is glass. The glass should pass to the tube a very high percentage of the incident radiation. At the same time it should impede the loss of thermal energy by conduction and convection.

The solar-transmittance properties as a function of incident angle have been obtained for two glass envelope materials. Spectral transmittance data from 350 to 2500 nm were used to obtain the solar averaged transmittance, τ_s .

Corning 7052 glass, 2.4 mm (0.093 in.) thick: This glass is currently being used as the glass envelope in the Solar Total Energy Test Facility. Data were obtained from 0 to 70 deg. incident angle (see Figure 3-4) and have been extrapolated to 0% transmittance at 90 deg. incident angle.

Corning 0070 glass, 0.4 mm (0.069 in.) thick: This glass is treated with fluoboric acid (vapor process) to produce an antireflector coating on both sides of the sample. Because of sample size limitations, data were obtained from 0 to 48 deg. incident angle; the transmittance has been extrapolated to 0% at 90 deg. incident angle.

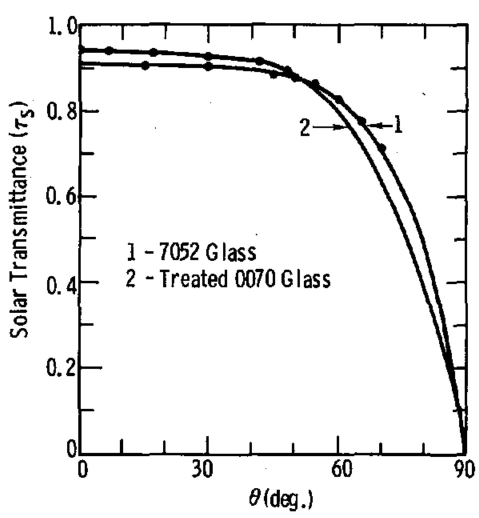


Figure 3-4. Solar Transmittance as a Function of Incident Angle For 7052 Glass and Treated 0070 Glass

The transmittance data have been curve fit to a polynomial of the form

$$\tau_s = \sum_{n=0}^{5} A_n \theta^n ,$$

where A_n is the nth coefficient and θ is the incident angle in degrees. The resulting coefficients are listed in Table 3-II.

TABLE 3-II

Polynomial Coefficients for τ_s for Corning 7052 and Treated 0070 Glass

Material	A_0	$A_1 \times 10^4$	$A_2 \times 10^4$	$A_3 \times 10^6$	$A_4 \times 10^8$	$A_5 \times 10^{10}$
7052 Glass	0.910	-8.487	1.003	-4.558	8.625	-6.745
Treated 0070 Glass	0.943	7.773	-1.182	4.424	-6.669	1.855

Difficulties experienced with the existing receiver tube design have been defined and a number of design changes have been identified to eliminate most of the current problems. These changes will result in simplified assembly, reduction of glass failure, increased evacuation pumping speed, and elimination of localized stress. It is anticipated that the proposed changes will be incorporated in all replacement receiver tubes manufactured for future use in the collector field.

Specifically the proposed changes to the existing receiver tube design consist of the following:

- Installing foreline traps and suitable valving to eliminate backflow of mechanical vacuum pump oil into the glass envelope
- Increasing the size of the vacuum pumping port to 6.6 mm at the flange and enlarging the through hole as much as possible.
- Locating all thermocouple feed-throughs in the flange.
- Using a rotatable flange to simplify field installation and eliminate alignment problems.
- Deflecting the collector tube before assembly to compensate for deflections due to static loading and asymmetric temperature distribution.
- Using stainless steel flanges to reduce corrosion.

A suggested second generation receiver tube design is currently being studied. A sketch of the proposed design, described originally by Treadwell,[1] is presented in Figure 3-6. In this design, commercial tube fittings and silicone O-ring seals replace the flanges, welded joints, expansion bellows, and glass-to-metal seals. A detailed thermal analysis is being developed for the second generation design in order to provide a means for predicting the operating temperature of the O-ring seal. The operating temperature of this seal must be limited in order to insure that a vacuum can be maintained for a reasonable length of time. An experimental program in which the receiver tube will be subjected to thermal cycles simulating actual operating conditions has been initiated. Preliminary results of this study will be available by November 1976. If the O-ring seal proves adequate in the initial study, additional studies will be performed in the Solar Collector Module Test Facility.

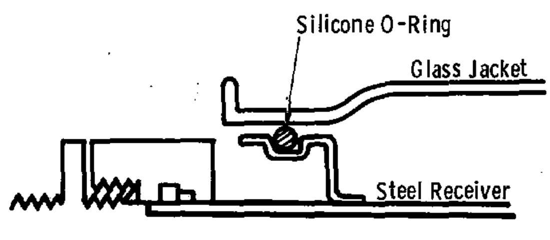


Figure 3-5. Proposed Second Generation Vacuum Seal for Receiver Tubes

Methods by which an antireflective coating can be applied to the glass envelope are also under consideration at this time. Initial developmental work has identified at least one apparently acceptable technique. The process being developed at Sandia Laboratories makes use of a vapor etch technique. Initial plans call for antireflective coatings to be applied to several test samples. These samples will then be studied for the long-term stability of the applied coating.

Inspection Equipment Development and Fabrication -- The radial scan laser inspection system, Figure 3-7, described in the previous semiannual report (SAND76-0205, October 1975 - March 1976), has been progressing according to schedule, and will undergo assembly and debugging early next year. One major component, the linear laser detector, has required considerable effort to scale it up to the 1-m length required. The radial scan system geometry depended on the availability of a 1-m linear photopotentiometer or similar detector. The largest linear potentiometers available were 7.62 cm, the size used in the much smaller laser scanner based on a translating laser with the detector located at the focus. A cooperative effort with the Baldwin Company of El Paso, Texas, was delayed when large alumina substrates for producing a 0.45 m half potentiometer could not be located. The long lead time for special order substrates forced a change to a digital, discrete-photodiode approach. The master scanner board checks each of up to 400 photodiodes placed in a line on 0.25 cm centers to see which diodes are turned on by the laser. The reflected laser beam position is monitored continuously and a signal strobed to

[1] G. W. Treadwell, "Design Considerations for Parabolic-Cylindrical Solar Collectors," SAND76-0082, Sandia Laboratories, July 1976.

the computer when a data point is read. The multiplexed photodiode array requires very few wires to carry the data and represents a compact way of achieving a printed circuit detector array. The resolution of the laser position is only 0.12 cm, inducing an error of about 0.6 milliradians.which was within the allowable detection error. One benefit of the photodiode detector is that, with suitable filtering, it is possible to use it outside in daylight. A detector of this type has been fabricated and is undergoing extensive testing. The concept has been proven and this system will be used on the full-scale radial scan system.

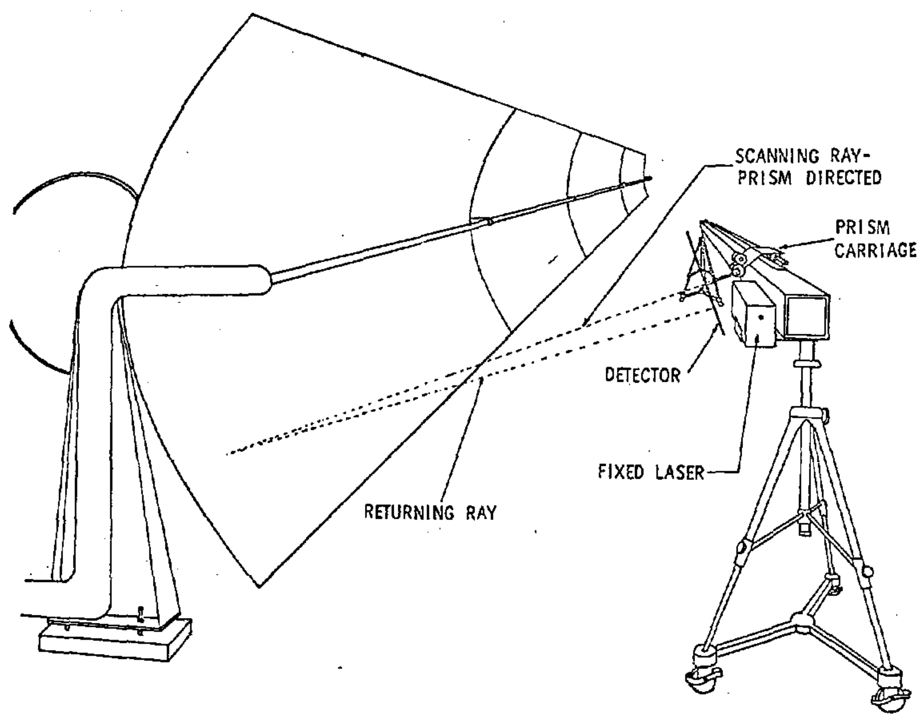


Figure 3-6. In Situ Laser Ray Trace Apparatus

3.2 Operations and Testing

Concentrators and Structure -- The 200 m^2 (2160 ft^2) field of east-west collector troughs was completed and fully functional in February 1976. Initial testing was complete in April 1976. The final major parts to be assembled were the reflector sheets which were mechanically clamped on the concave surfaces of the troughs. The reflector sheets are installed in 18.3 m (60 ft) troughs. The collector field consists of four such continuous troughs in two rows aligned on east-west axes. See Figure 3-7 for an overall view of the completed collector field. Center-to-center spacing between rows is 7.6 m (25 ft). Each of the 18.3 m troughs consists of five 2.7 x 3.7 m (9 x 12 ft) trough units, mechanically connected at the ends to form a single structural trough. The troughs have a 92 deg. rim angle with a 0.658 m (25.9 in.) focal distance. The rim angle was chosed to submerge the receiver within the trough and to clear the rim-to-rim plane. This feature has proved to be very useful when tests are performed which require equipment that spans the troughs. An example of such a test is one to determine accuracy of location of focal line (see Inspection Techniques section below).

Figure 3-7. Present Solar Total Energy System Test Facility (collector field lower left)

The alignment of the trough with respect to an east-west axis was checked with a theodolite using the planet Venus for reference. The maximum deviation from the east-west axis was 0 deg. 6 min.

Reflector Surfaces -- The reflector material installed on the 2.7 x 3.7 m troughs consists of 0.03 mm FEP Teflon aluminized on the back surface. The Teflon film is then bonded to a Mylar film to give the sandwich enough strength and structural integrity so that it may be bonded to a 0.6-mm (0.025 in.) 2024-T3 aluminum alloy panel which is mechanically fastened to the parabolic trough.

During the course of installation and subsequent routine operations, several types of damage to the Teflon film have occurred. Tools slipping during installation produced a few random cuts in the Teflon. Numerous small cuts were caused in several panels when broken glass from the receiver tube envelopes tumbled down the trough during a windstorm (see the following section). Abrasion of the Teflon surface has been caused by washing operations required by spilled Therminol and accumulated dirt. The cuts have resulted in delamination of the Teflon/Mylar films in an ever-increasing circle around the cut (discussed above). Weathering due to several months of outdoor exposure has produced a change in the surface condition of the film.

The reflector panels also appear to develop electrostatic charges which attract and hold dust particles. Wind appears to be a cause of this phenomenon. Dust attraction decreases reflectance and increases washing requirements. The electrostatic charge condition had been only observed; it has not been measured. It requires further investigation, since it has not been observed on glass or Alzak reflectors.

Repair of cuts is not effective because of the difficulty of successfully bonding to Teflon and because of the labor involved. Adhesive backed acrylic films have been applied for evaluation.

The softness of Teflon, its high degree of vulnerability to damage (cuts and abrasions), and the experience to date in nearly 10 months of outdoor exposure raises significant questions regarding the long-term environmental capability of Teflon reflector films.

Windstorm Damage and Repairs -- On the evening of Friday, April 30, 1976, there was a sustained strong easterly wind for a period of several hours. The wind was later determined to be 80 to 95 kph with gusts to 105 kph. This extended period of wind moving almost exactly down the longitudinal axis of the troughs resulted in damage to several of the reflector panels on the collectors. There was no structural damage to the collector troughs or the drive mechanisms. The outer sections of the reflector panels were torn loose to flail in the wind. This flailing resulted in five broken glass envelopes on the receiver tubes.

The reflector panels had been mechanically clamped and held down. An aluminum strip 6.3 mm thick and 25.4 mm wide was installed along the vertex line of the troughs with the screws through the strip and the reflector sheet to the trough. Each panel (0.9 x 3.2 m) was also restrained by two screws with 9.5 mm diameter washers 25.4 mm in from the outer rim and by the spring-loaded edge clamp strips along the rim. Each edge of the reflector sheet was inserted into a 3.2 mm deep slot in the edge clamp strip. Thus, for an arc length of about 1.3 m between the vertex and the screws near the rim, the panels were not restrained. The winds eventually got under the edge of some of the panels and lifted this unrestrained section of the panel which flapped until it either pulled the two outer screws out of the trough or tore the reflector sheet.

Once free on the outer section, the panels struck the glass envelope of the receiver tube and fractured it. The broken pieces of glass then tumbled down the reflector panels producing small cuts through the FEP Teflon film. The cuts ranged from 1.5 to 6.3 mm (0.06 to 0.25 in.) long, and have subsequently been the cause of deterioration of the reflector films. Moisture from rain and washing operations has caused delamination of the Teflon/mylar sandwich and total loss of reflectance in these delaminated areas, which are slowly increasing in size. Patches of adhesive-backed acrylic reflector film have been applied to some of the cuts to determine the effectiveness of this repair technique.

Spare reflector panels were used to replace the damaged panels after a modified fastening method was devised. The two western troughs were put back in service on May 18, 1976, with replacement panels and the new clamping method; the two eastern troughs had the damaged reflector panels replaced and modified on May 26, using a few less damaged panels until a new set of spares could be obtained.

The improved fastening method consists of adding transverse strips of aluminum sheet along the edges of the reflector panels which run perpendicular to the trough longitudinal axis. Where the trough structure permitted, a 19-mm strip was applied with 9.5 mm overlapping each of the adjacent panels. Holes were drilled offset from the centerline of the clamp strip so that only one of the panels would have to be drilled. Screws were installed through the clamp strip and the panel and into the trough structure. The clamp strips were preformed to a sharper radius of curvature than that of the panel, so that they would conform and apply a small hold down force on the panels when installed. At the outer ends of each trough where spacing of the panels prevented use of one 19 mm strip for two panels, the 12.7 mm strips were used.

The top surface of these aluminum clamp strips have been covered with strips of adhesive-backed acrylic reflector film to decrease the overall reflector losses which were caused by installation of the strips. The material used was 3M's 5400 aluminized acrylic film. This application will help in evaluating this material in an outdoor environment.

Receivers -- Five receiver tubes were damaged during the April 30 windstorm. Four of these still had solar absorptance values ≥ 0.94 and emittance values at 300°C from 0.21 to 0.29, therefore, these tubes were reassembled for use in the test facility. The remaining tube, plus two additional tubes that were previously rejected for low α_s values, were sent to Bendix, Kasn Kansas City, for stripping and replating. The plating conditions that gave the "best" black chrome were determined to be 2100 A/m^2 for 2-3/4 minutes (5800 A-min/m^2). The average solar absorptance value of the replated tubes was $\langle \alpha_s \rangle = 0.95$ while the average emittance at 300°C was $\langle \epsilon_{t,H} \rangle = 0.24$.

One receiver tube could not be effectively replated because (1) the solar absorptance could not be increased above a value of 0.93 even for long plating times, and (2) several areas would not replate, even after the tube was sand blasted and a nickel strike applied before the replating. This is mentioned because it is typical of the vagaries in black chrome electroplating.

Tracking and Control -- All activities have been completed on both the analog and digital tracking systems. A second generation electronic package has been installed for the analog system and is performing satisfactorily. In the design of the new electronic package, triacs were used instead of transistors as the driving elements for the dc motor. Several other changes were made which improved the overall performance of the analog tracking system.

Programs needed for the HP2100 minicomputer to acquire and manipulate data have been improved and updated to meet the needs of the testing program described in Task 2.3. Additional equipment such as A/D and D/A converters are being procured in anticipation of new requirements for data imposed by the contracted collector field subsystems (Task 4). A tracking sensitivity test was conducted which compared the actual focal position of the parabolic reflectors. The results are shown in Figures 3-8 and 3-9. The test data curve was obtained by deliberately mistracking the collector. The estimated curve is normalized to have the same maximum as the test data. The estimated curve is an indication of the expected curve shape for a perfect mirror, given our present geometry.

Inspection Techniques -- A simple device has been built and used for inspecting the reflector troughs for accuracy of reflector contour and positioning of the receiver tube. The device is shown in Figure 3-10. It consists of a framework which is placed across the rim-to-rim chord of the trough and securely attached to it. The transverse members of the frame (2 x 4 lumber) are used as slide rails for an assembly which has a 51 mm wide, 3.7 mm long aperture. The aperture assembly is also constructed of common lumber. Two sheets of black plastic has been attached to the aperture boards (one on each side) to provide shadowing of all of the trough except for the long 51 mm slit.

The entire assembly is positioned on the trough to be inspected, the trough is set for automatic tracking, and the plastic sheet is pulled over the rims to shadow the trough except for the slit. The test should be conducted near noon to avoid large incidence angles of sunlight in the focal plane. The slit is positioned near one rim and the resultant illumination of the receiving tube is observed. The narrow slit of light entering the aperture is reflected from the reflector material and appears as a bright line on the receiver tube. Perturbations on the reflector surface show as irregularities in the bright line. The results of this technique provide a good qualitative indication of the accuracy of the reflector surface. They also provide data for corrective action if consistent misses by the light beam show the receiver tube to be located away from the line of focus. (A more sophisticated laser trace technique as shown in Figure 3-6 has been developed for fine tuning.)

For this type of general inspection observers must view from the trough rim with the trough in focus. Eye protection (sunglasses of optical density 4 or better) is required for conducting such inspections. However, with the input limited to the 51 mm strip of sunlight, the total light is not excessive. The concentration ratio of the light at either rim where observers must view the operation should be near or less than 1:1 while the trough is in focus.

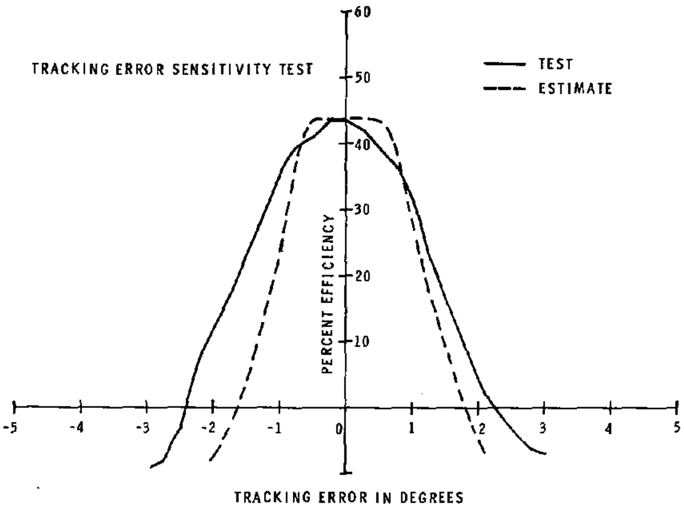


Figure 3-8. Tracking Error Sensitivity Test, Southwest Quadrant

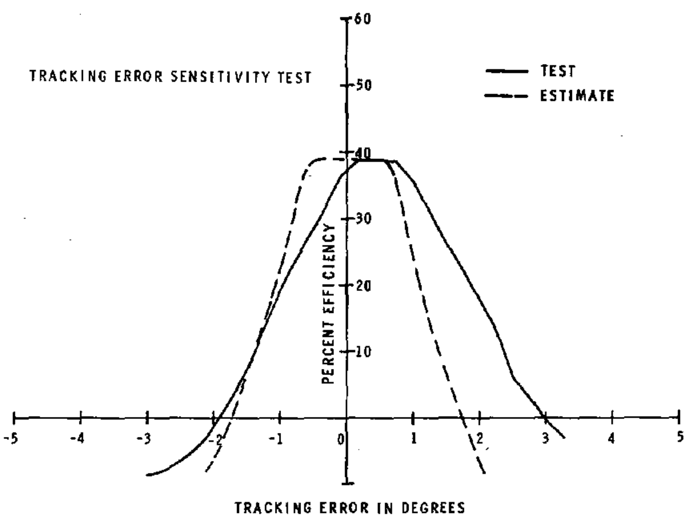


Figure 3-9. Tracking Error Sensitivity Test, Northwest Quadrant

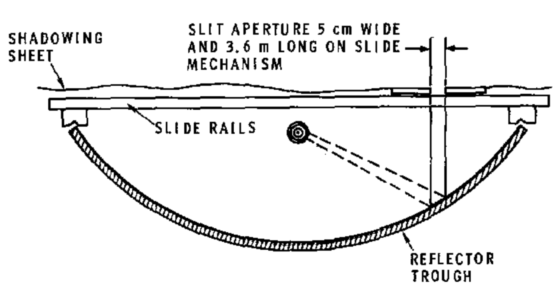


Figure 3-10. Slit Aperture Inspection Device

Slit-aperture tests have been run on two of the 18.3 m troughs. The general results confirmed that the central 1.8 m of the mechanically attached reflector panels are accurate and reflect their incident light onto the receiver tube. The outer 0.38 m on each side tends to be less accurate, with 50 to 70% of light from those areas falling on the tube and 25 to 50% of the reflection passing over or under the tube. These outer regions have the longest reflected path length from reflector to receiver, so slope errors will produce correspondingly larger miss distances at the receiver tube.

Alignment of the receiver tube on the four 18.3 m troughs was originally made at the specified 0.657 m (25.9 in.) focal distance from the trough vertex. On the southwest trough the slit-aperture inspection indicated that the positioning of the receiver tube was very near the actual focal line of the trough. On the northwest trough the first inspection indicated that the receiver tube was slightly low, or that the actual focal distance was a fraction of an inch longer than planned. The tube was raised 12.7 mm (0.5 in.) and another slit inspection was made. This second inspection indicated the sensitivity of the slit-aperture system by showing that the 12.7 m change was far too great; it also disclosed the repositioned tube was offset from the actual focus in the rim-to-rim plane. The receiver tube was moved again, this time in each of the two perpendicular (focal and rim-to-rim) planes. The focal distance was reduced from 0.67 to 0.66 m (26.4 to 26 in.), and the tube was moved in the rim-to-rim plane by about 6.3 mm (0.25 in.) at one end of trough and no movement at the other. An optical sighting system was used to provide a straight line alignment of the five individual 3.7 m segments of the receiver tube.

The third slit inspection of this northwest trough showed that the receiver tube was very close to the actual focus line. Changes of 2.5 mm (0.1 in.) in tube location are clearly seen in a careful inspection with the slit-aperture device. It is basically crude but simple; with care it can be a low cost, useful tool. The more sophisticated laser inspection technique described under Task 3.1 will provide quantitative data for evaluating reflectors. However, the low initial cost and simplicity of performing slit-aperture inspection make it ideal for determining whether more expensive inspection by laser is justified, and for making rough adjustments before the "fine tuning" which is possible with data from the laser.

Cleaning Techniques -- Cleaning of the reflectors remains a problem. The reflectors accumulate a layer of dust in a few days; after about two weeks, the troughs appear to be in need of cleaning.

Rinsing with a water spray removes a significant amount of the accumulated dust. An ordinary garden hose and nozzle has been used to spray and rinse off the reflectors, followed by a quick rinse using deionized water to avoid hard water spots. This method, plus leaving the collectors tilted with the rim as the lowest part so that rain will run off and serve as a natural rinse, has given reasonably long periods (several weeks) between manual washing with soft cloths or mops.

Sample reflector test sections have been prepared for use in correlating reflectance and performance with dirt accumulation. Samples were cut from wind-damaged panels and prepared for mounting on extensions of the existing troughs. The samples will be identified and specular reflectance measured. They will then be attached to the trough extensions to be exposed to the same environmental conditions as the panels on the troughs. As dirt accumulates and tests are conducted, the samples can be removed and their refectance measured. In this manner a correlation between dirt accumulation, reflectance degradation, and collector performance may be established.

Another method of cleaning which will be evaluated is that of a spray device which automatically mixes detergent and water in a washing spray followed by a clear water rinse and a deionized water rinse. An acidic chemical cleaning solution mentioned in the last report has not been attempted on the full-size troughs because of concern over its effects on the rest of the collector installation. It has been evaluated on dirty reflector samples in the laboratory and it did a thorough job if the sample was horizontal so that the fluid could stay in contact for 30 seconds or so. With the sample at a slope (which is the case for the greater part of a parabolic trough at any position), the solution ran off the sample with cleaning action little better than that of a water rinse. However, Teflon is a notoriously nonwetting material; perhaps other reflector materials which would allow wetting by the solution would be cleaned more thoroughly. There are still the problems of personnel hazards and degradation of other components with the acidic solution.

Baseline efficiency tests were conducted at solar noon with the results shown in Figure 3-11.

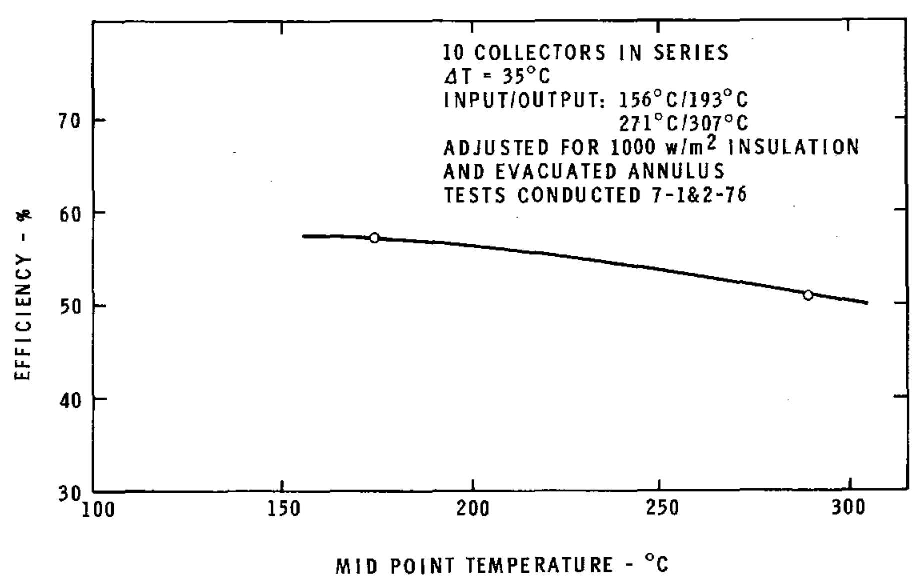


Figure 3-11. Efficiency vs Temperature

Task 4. Collector Subsystems Contracted

Sandia solicited from 52 companies proposals for collector field subsystems to be tested in the Solar Total Energy Test Facility. Sixteen responses were received. From these 16, four companies were given contracts for preliminary design of their concepts. The studies were completed and oral reports of results were given during this reporting period. Concurrently, Sandia developed criteria for evaluating the concepts studied. As of the end of the last reporting period, contracts had been placed with four companies for the preliminary design portion of the Sandia Solar Collector Field Subsystem Program. The four companies receiving contracts were the following:

General Atomic Company
McDonnell Douglas Astronautics Company
Raytheon, Inc.
Sheldahl, Inc.

The individual company concepts are illustrated in Figures 4-1 through 4-4.

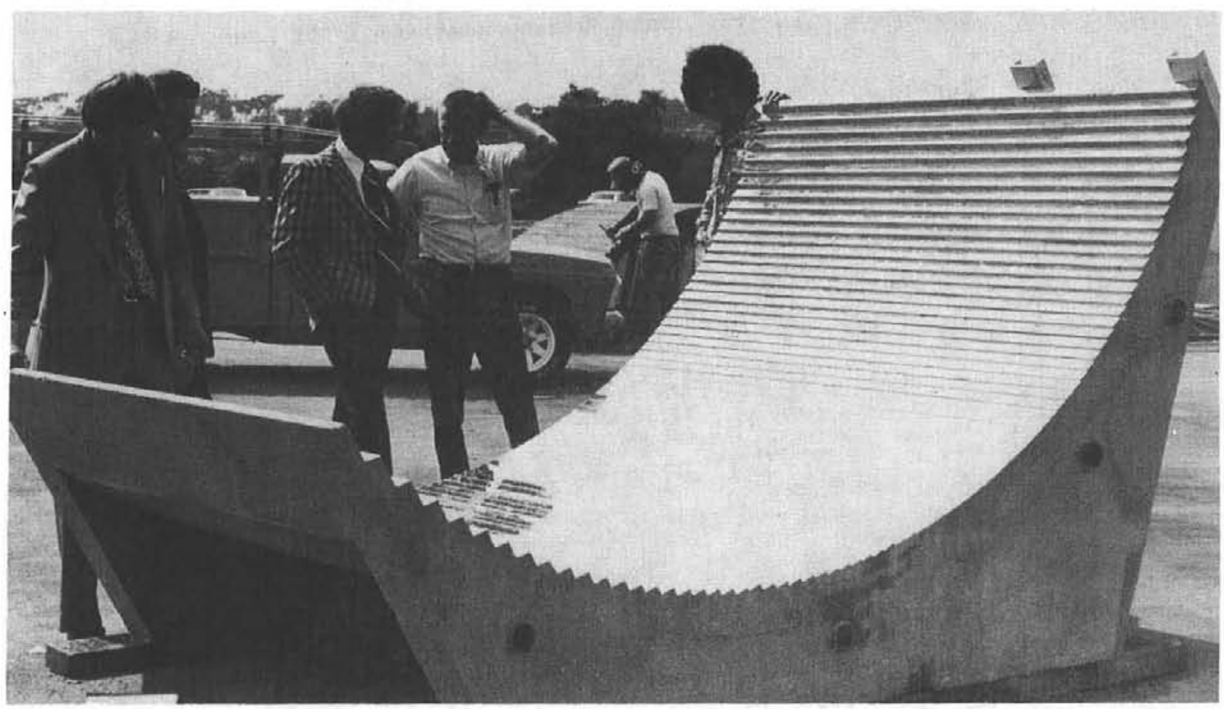


Figure 4-1. General Atomic Fixed Mirror Reflector

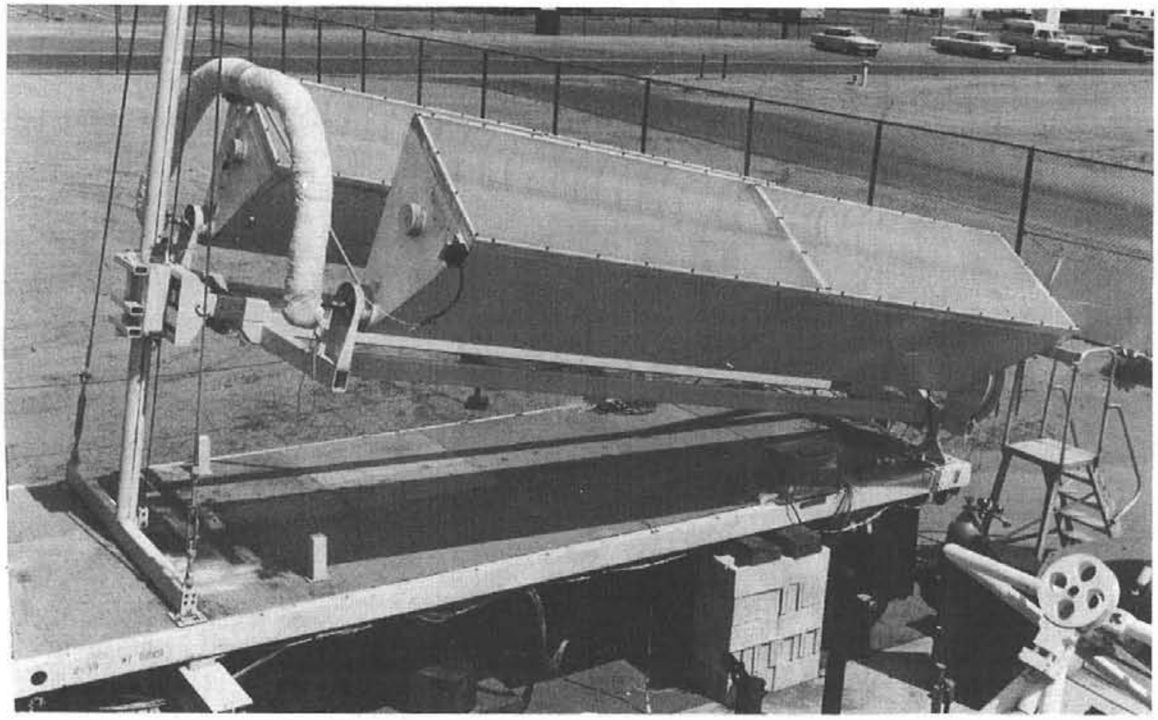


Figure 4-2. McDonnell Douglas Fresnel Lens System

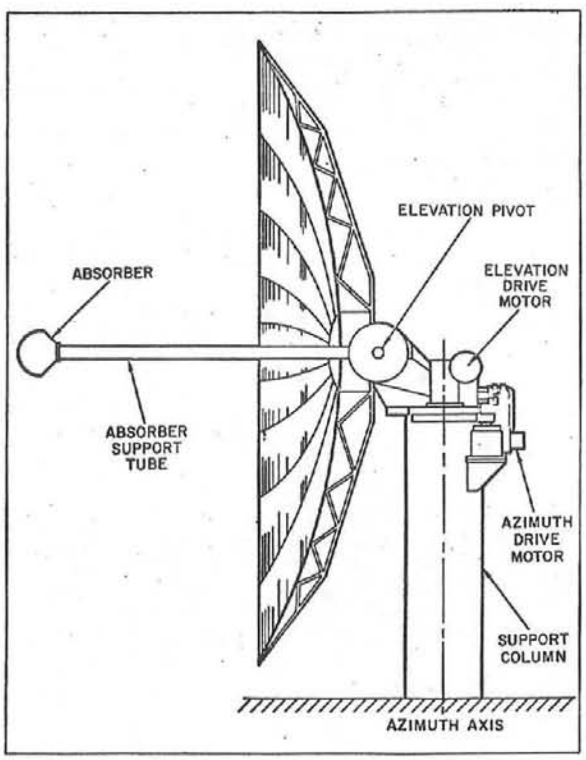


Figure 4-3. Raytheon Parabolic Dish Concentrator

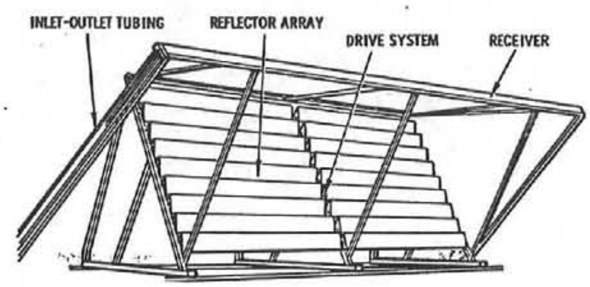


Figure 4-4. Sheldahl Solar Linear Array Thermal System

The individual contractors have made excellent progress on the preliminary designs of their solar collector subsystems. Testing of the various concepts has progressed to varying degrees. McDonnell Douglas completed a full-scale collector test at our Solar Collector Module Test Facility on August 25. Their results are described under Task 8.2 in this report. General Atomic has completed limited preliminary testing of a 1.8-m long collector module constructed at their facility. Sheldahl is in the process of gathering calorimetric heat loss data from their latest receiver design. Raytheon is about to begin a material evaluation test series for their receiver design on the Solar Collector Module Test Facility.

One of the goals of the project is to acquire data that can be used to design commercial solar total energy facilities. To provide this data for the early large-scale experiments, initial operation of the complete Solar Total Energy System Test Facility in September 1977 is scheduled. To help meet this schedule, Phase I contract extensions have been awarded to each of the contractors. These extensions will allow the contractors to continue the design and development work on their concepts before awarding the Phase II contracts for final design. The last of the Phase I contract extensions were placed September 24, 1976.

The contractors completed the presentations of their final Phase I oral reports on September 22. The results of the presentations are shown in Tables 4-I through 4-III, which compare the four concepts on the bases of design at this point in time.

The Collector Field Subsystem Contract Review Committee has completed its evaluations and has recommended that contracts be continued with General Atomic, Raytheon, and Sheldahl. When the installation of these collector field subsystems is complete the Solar Total Energy System Test Facility will have the characteristics shown in Table 4-IV.

TABLE 4-I

Comparison of Contracted Collector Field Subsystems

Feature	General Atomic	McDonnell Douglas	Raytheon	Sheldahl
Collector Area, m^2	260	190	105	260
No. of Modules	32	44	3	14
Module Size, m	2.1 x 3.8	0.9 x 4.7	6.7 (diam)	3 x 6
Specified Energy Requirements (Winter), %	112	98	99	116
Specified Energy Requirements (Summer), %	109	106	111	118
Energy Collected/Day (Winter), kJ x 10^{-6}	2.19	1.92	2.04	2.26
Energy Collected/Day (Summer), kJ x 10^{-6}	2.66	2.58	2.73	2.89

TABLE 4-II

Comparison of Contracted Collector Features

Feature	General Atomic	McDonnell Douglas	Raytheon	Sheldahl
Construction Cost, $\$/m^2$	168	270	234	194
20-Year Operating Cost, $\$/m^2$	172	258	258	172
Net Energy (Winter), kJ/m^2-day	8.425	10	12.5	8.675
Net Energy (Summer), kJ/m^2-day	10 200	13 550	21 605	11 100
Figure of Merit (Winter), $/kJ-day	0.040	0.052	0.039	0.042
Figure of Merit (Summer, $/kJ-day	0.033	0.039	0.023	0.033
Material Cost, $\$/m^2$	60	167	105	77
Material Figure of Merit (Winter), $/kJ-day	0.014	0.033	0.017	0.018
Material Figure of Merit (Summer), $/kJ-day	0.012	0.024	0.010	0.015
Concentrator Reflectivity/Transmittance	0.92	0.84	0.92	0.82
Concentrator Efficiency, %	67	71	87	68
Receiver Efficiency, %	75	70	93	79
Receiver Weight, kg/m	11.9	NA	25.3*	13.4
Heat Transfer Fluid	T66	T66	T66	Water
Warm-up Time (Winter)	NA	NA	NA	2.45 hr
Warm-up Time (Summer)	30 min	15 min	NA	2.35 hr
Land Use Factor, %	47	44	31	45
Net Energy (Winter), kJ/m^2 land)	3960	4435	3875	3910
Weight, kg/m^2	445	135	360	110
Weight Utilization (Winter), kJ/kg-day	19	73	35	78

*$kg/78\ m^2$

TABLE 4-III

Comparison of Material Usage by Contracted Collectors
(all values in kg)

Materials	General Atomic	McDonnell Douglas	Raytheon	Sheldahl
Concrete	111 970	10 010	68 585	17 725
Glass	1 730	295	1 450	85
Steel	1 130	12 045	2 995	9 620
ZrCu			95	
Aluminum	1 195	5	55	
Insulation	25	775	75	445
Acrylic		1 715		
Cast Iron		550		
Plastic				635
Total Weight	116 040	25 395	73 255	28 510

TABLE 4-IV

Projected Characteristics Solar Total Energy System Test Facility

	Area		Output (kJ/Day x 10^{-6})		No. of	Size of Modules
	(m^2)	(ft^2)	Winter	Summer	Modules	(m)
Sandia	200	2160	2.14	2.39	20	2.7 x 3.6
General Atomic	260	2800	2.19	2.66	32	2.1 x 3.8
Raytheon	106	1140	2.04	2.73	3	6.7 diam
Sheldahl	260	2800	2.26	2.89	14	3 x 6
	826	8900	8.63	10.67		

Task 5. High-Temperature Storage Subsystem

Development during this period comprised defining the storage concept to be designed, fabricated, and installed. Initial design was started. Operations consisted of evaluating the high-temperature storage thermocline subsystem already in existence.

5.1 Development

In May 1976 it was decided that the new Phase IV-B high-temperature storage subsystem would use multiple tanks.

The decision to use more than one tank was based on schedule pressures and problems predicted with other approaches. Sandia Livermore listed four problems associated with the dual-medium (rock-filled) system and estimated that 18 months would be required to evaluate them. These problems were:

- Possible fluid decomposition in the presence of the solid storage medium
- Possible heat exchanger surface fouling
- The effect of possible fouling (by fragments of rock) of the heat-transfer and fluid mechanics of the total system
- The possible migration of solid particles to other parts of the system.

Problems with phase-change storage were more challenging. However, the concept has good potential for future installations. The corrosive properties of some phase-change media are of concern. Of greater concern, however, are the heat-transfer characteristics required for operation. Preliminary calculations show that, if conventional heat-exchanger techniques are used, the amount of material required to deliver energy at the proper temperature for our systems is at least three times the amount required simply to store the energy. Development of advanced storage concepts is being sponsored by ERDA and progress will be followed closely.

It was decided to use the minimum number of tanks required to evaluate all combinations of the multitank system, which is three. The required storage is 2.48 x 10^6 kJ, plus losses, between 250° and 309° C. Our goal is to hold losses for a 24-hour period below 2% of the stored energy, or 5 x 10^4 kJ, but preliminary calculations of insulation thickness indicate that goal may be unrealistic. They show that 0.6 m (24 in.) of insulation with a k factor equal to 0.05 W/m °C (0.03 Btu/hr·ft·°F) are required to maintain thermal losses below 15 x 10^4 kJ. To meet our goal of 5 x 10^4 kJ per day maximum losses would require a thickness of between 1 and 2 metres of insulation with properties similar to those of 64 kg/m^3 (4 lb/ft^3) density Kaowool.

Flow rates from and to storage are shown in Figure 5-1 for a sunny December 21, the shortest day of the year. In the morning and in the evening insufficient energy is collected to operate the system. During the day there is an excess of collected energy which is stored. For the conditions shown in this figure, there will be at startup time (about 7 a.m.) one tank of hot fluid at 310° C, one tank of cold fluid at 250° C, and one empty tank. The hot fluid will be used and dumped into the empty tank. During the day both tanks of cold fluid will be heated by the collectors. Starting at midafternoon, the system will draw upon and exhaust one hot tank. When the system is shutdown in the evening there will be one tank of hot fluid, one of cold fluid, and one empty tank.

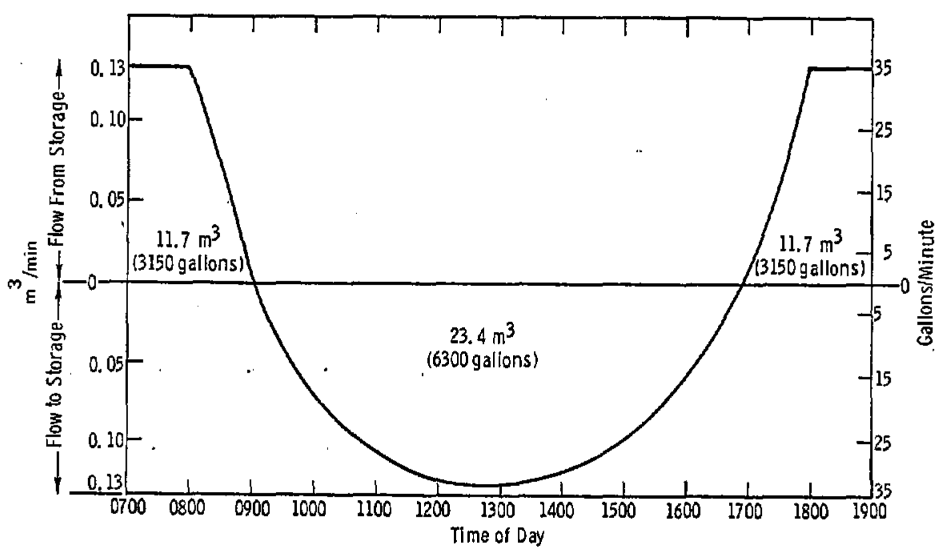


Figure 5-1. Predicted Fluid Flow to Storage, December 21

The cost of the high-temperature storage subsystem is estimated at $52,000 for tanks plus $38,000 for the required volume of Therminol 66. Because of the high cost of storage, Sandia continues to seek better methods. Investigation of phase-charge storage using Thermkeep as the medium is still underway. Initially ERDA assigned the responsibility for development of high-temperature storage to Sandia Livermore. Recently, the responsibility was transferred to NASA, Lewis. Arrangements have been made for Sandia Albuquerque to follow progress by NASA and by Comstock and Wescott, Cambridge, Massachursetts, in developing a high-temperature storage subsystem with potential for use in the Solar Total Energy Systems Test Facility.

After the multitank high-temperature storage subsystem is added to the existing system, the Solar Total Energy Systems Test Facility will have the capability of operating as two individual systems, i.e., a multitank storage system or a thermocline storage system. These two systems will be operated on an "or" basis, not on a "and" basis. The system has been designed so that in multitank operation the Sandia designed collectors, blending tank, and pump decouples from the present system and couples to the multitank system just as the contractor designed fields do. The multitank system would then be the energy supply source for the existing heater, boiler, and pump system. In thermocline operation, the system would operate as presently designed with the multitanks and contractor designed collector fields decoupled from the system. Consequently, in thermocline operations the capacity would only be about 15% of the full system capacity.

The piping schematics that follow present one way to achieve this kind of flexibility, and they will be recommended to the A&E firm selected to design the system. (The schematics also give the location of system flowmeters and thermocouples.) Eight basic modes of operation will be possible. The three major modes of operating the new high-temperature storage system will be normal operation (No. 20), storage empty (No. 21), and storage full (No. 22). The remaining five are occasional-use modes.

Normal Operation (Mode 20) -- This (Figure 5-2) is the system configuration under normal operating conditions. The normal mode has two options. Option 1 provides for the discharge of limited amounts of cold fluid, such as encountered during startup conditions, to the cold storage tank. Selection of this option will be controlled by the storage tank logic system which determines the status of storage and determines which tanks are active.

At the present time, there are unknowns about the ability of the present pump (in front of the heater) to force fluid flow to the new collector fields. (Pump pressure cannot be increased because of pressure limits on the boiler.) Consequently, the normal configuration of Mode 20 relies on the new collector cooler pump to aid in flow. Option 2 for this mode provides for the cooler pump to be bypassed if not needed. Option 2 will be manually selected.

Storage Empty (Mode 21) -- This mode (Figure 5-3) provides for operation of the system when there is no hot fluid in storage. In this mode, the existing boiler is operated by the existing

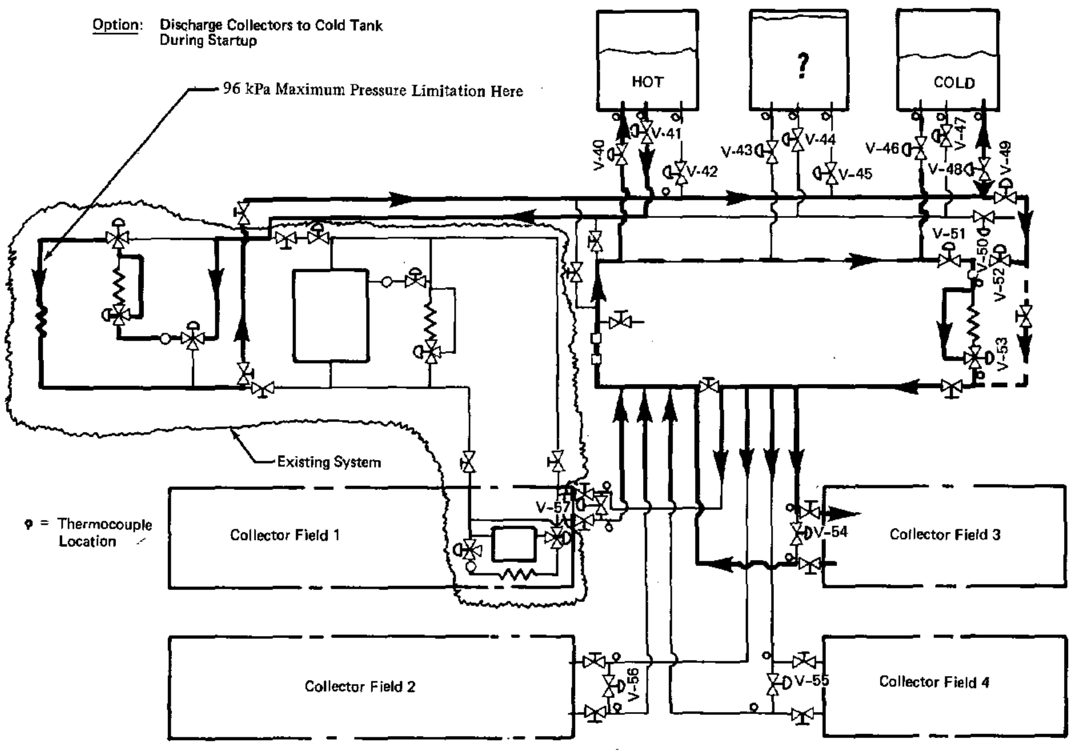


Figure 5-2. Normal Operation (Mode 20)

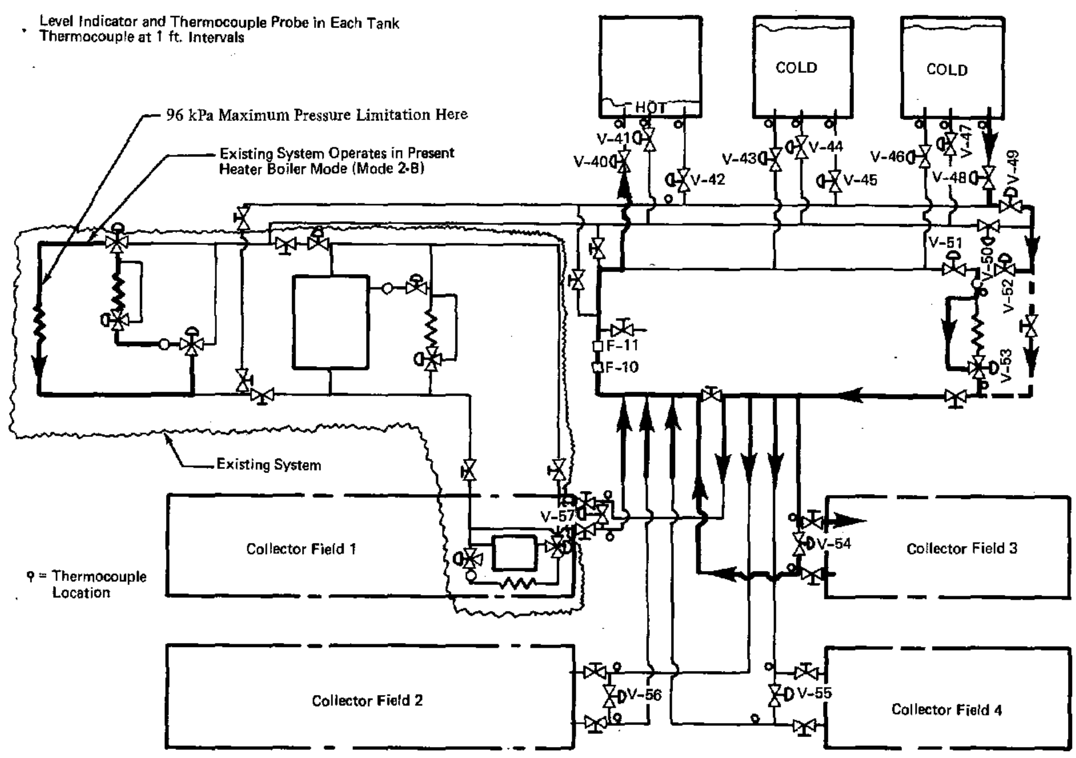


Figure 5-3. Storage Empty (Mode 21)

fossil-fuel heater (Mode 2-B), and the collectors are used to reheat storage. An option in this mode allows for bypass of the collector cooler pump, in which case flow is maintained by pumps in each collector field. This option would be manually selected.

Storage Full (Mode 22) -- This mode (Figure 5-4) provides for operations of the subsystem when storage is full and there is no place for the hot fluid from the collector to go. This mode assumes that storage will be depleted soon by the turbine and it is not worthwhile to turn off collectors and lose the thermal gradient established through them. In this mode the collectors operate through the cooler and not through storage. The boiler is operated as normally from the multitank storage. (Boiler operation is identical to current operations except that the energy comes from multitank and not thermocline storage.)

Intratank Fluid Transfer (Mode 23) -- This mode (Figure 5-5) provides for movement of fluid from one tank to the other. This mode is required for system flexibility and is not a usual operational mode. This mode will be manually selected.

Reduce Storage Temperature (Mode 24) -- This mode (Figure 5-6) allows for the cooling of storage, to ambient conditions if required. This mode is required for system flexibility and is not a usual operational mode. This mode will be manually selected.

Increase Storage Temperature (Mode 25) -- This mode (Figure 5-7) allows for heating of storage with the fossil-fuel heater, from ambient conditions to as high as 315°C (600°C). This mode is required for system flexibility and is not a usual operational mode. This mode will be manually selected.

Collector Field Preheat from Storage (Mode 26) -- This mode (Figure 5-8) allows the piping from storage to collectors to be preheated with hot fluid from storage. The ability of the collectors and storage to operate without preheat has not yet been established. At the present time this mode is required for system flexibility and is not a usual operational mode. However, the system will be so designed that this mode could be a standard operational mode, used on a daily basis, without requiring manual valve changes.

Mode 26 has five options. Option 1 allows for preheat of collectors as well as piping from storage to collectors. Option 1 will be manually selected.

Option 2 allows for bypass of the cooler supplemental pump if this pump is not needed to aid in fluid flow. Option 2 will be manually selected.

Option 3 allows for withdrawal of fluid from a cold tank simultaneously with operation of the boiler. This option is necessary if collector preheat is to be only to 243°C (470°F) Option 3 will be selectable remotely from the control room.

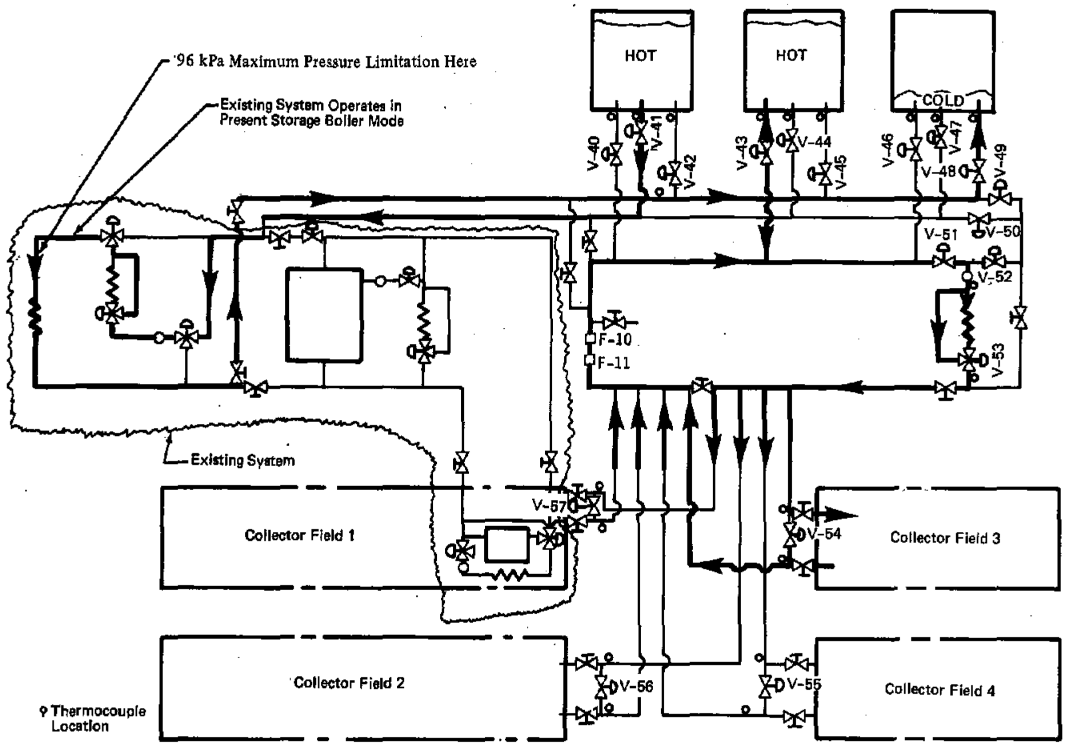


Figure 5-4. Storage Full (Mode 22)

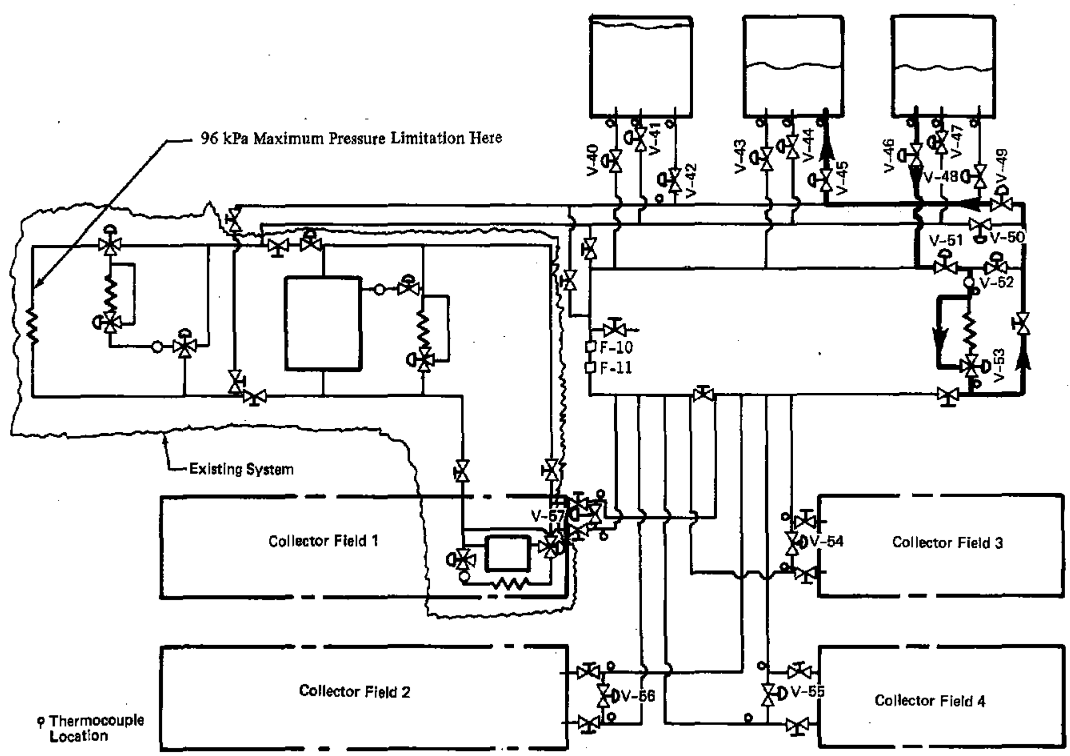


Figure 5-5. Intratank Fluid Transfer (Mode 23)

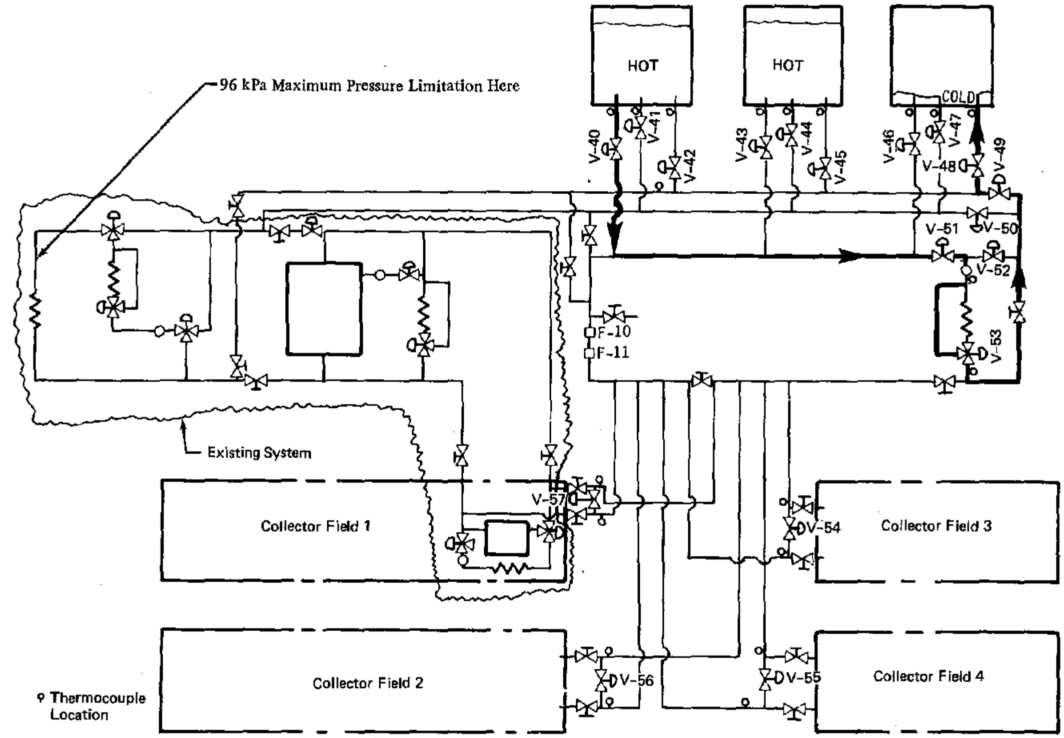


Figure 5-6. Reduce Storage Temperature (Mode 24)

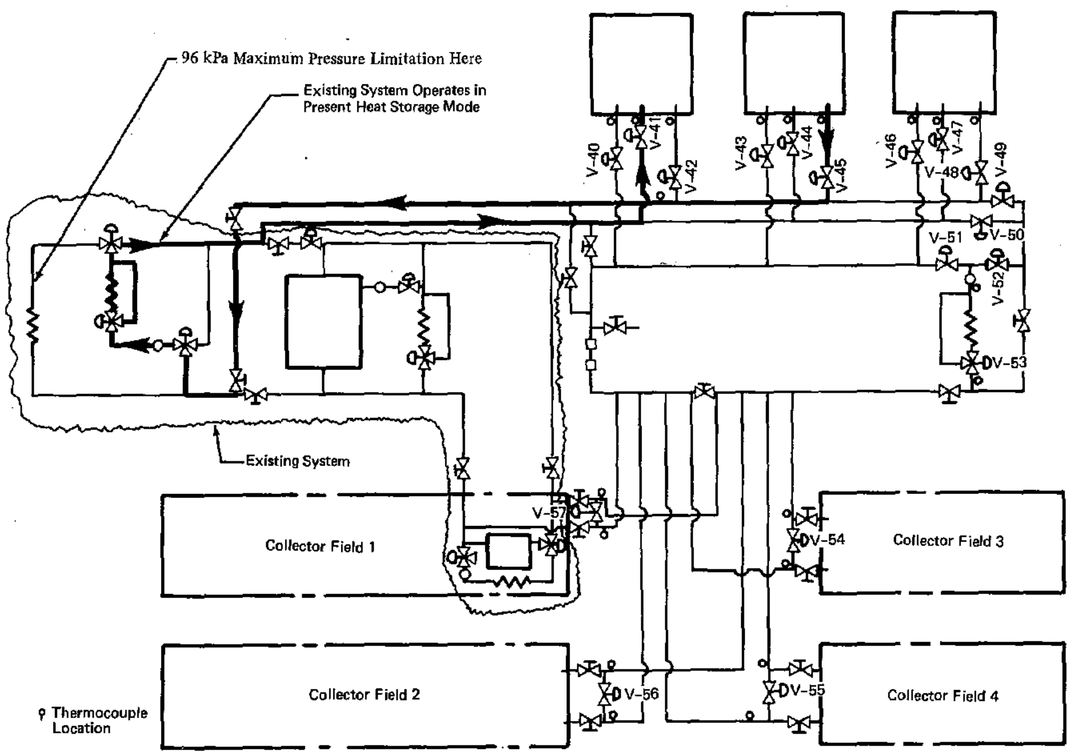


Figure 5-7. Increase Storage Temperature (Mode 25)

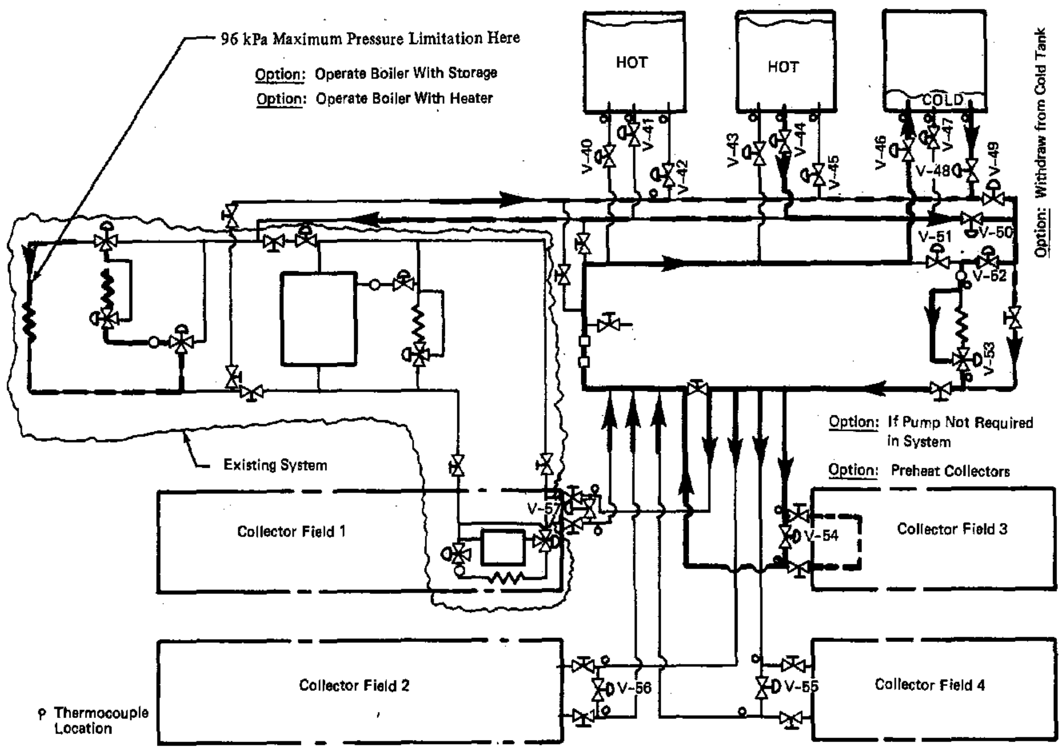


Figure 5-8. Field Preheat (Mode 26)

Option 4 allows for simultaneous operation of the turbine with heat from storage when collector preheat operations are being conducted. In this option, the boiler is operating in the existing Storage/Boiler Mode 3.

Option 5 allows for simultaneous operation of the turbine with heat from the fossil-fuel heater. In this option, the boiler is operating in the existing Heater/Boiler Mode 2-A or 2-B. This option will be preselected manually.

Collector Field Preheat from Heater (Mode 27) -- This mode (Figure 5-9) allows the piping from storage to collectors to be preheated with fluid heated by the fossil-fuel heater. Storage would operate only as an expansion tank during this mode. The ability of the collectors and associated piping from storage to operate without preheat has not yet been established. The present system, being a testbed, has more piping than would normally be required and consequently has greater preheat problems. At the present time, this mode is required for system flexibility and is not a usual operational mode. However, the system will be designed so that this mode could be a standard operational mode, used on a daily basis, without requiring manual valve changes.

This mode has three options. Option 1 allows for preheat of collectors as well as the piping from storage to the collectors; it will be manually selected. Option 2 allows the

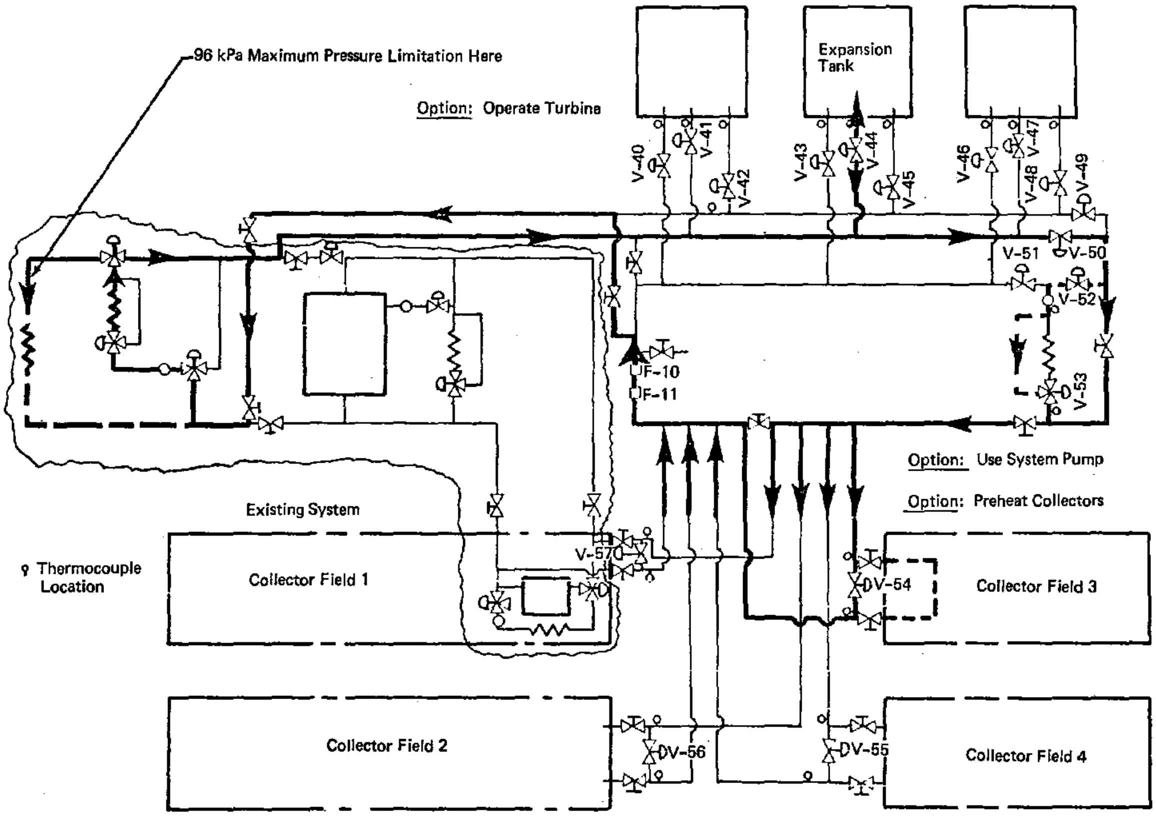


Figure 5-9. Collector Preheat From Heater (Mode 27)

supplemental cooler pump to be used to aid the heater pump in fluid flow. Option 2 will also be manually selected.

Option 3 allows the heater to be used to operate the turbine/generator system boiler simultaneously with the use of the heater to preheat the piping to the collector. This option is equivalent to present operational Mode 2A and can be selected by switches in the existing valve control rack.

The above eight operational modes are subject to the following system requirements:

- The system must sense when storage is full or empty to switch back and forth between Modes 20, 21, and 22, automatically.
- The system should be capable of operation with either 1, 2, 3, or 4 collector fields operating simultaneously. (Each of these fields will have its own pump which will interact with the system pumps.)
- Present plans are that Modes 26 and 27 will be preselected manually. However, the design should be such that they can be selected remotely (the options for these modes need not be selected remotely).
- Present plans are to require collector-field contractors to allow fluid out of collector fields only when the fluid is within temperature tolerances. This

complicates field control problems. To allow investigation of other control methods, the system should be designed so that a storage tank can be used as a startup-buffer tank for the collectors.

System control is accomplished through 18 control valves. A separate report will describe the valves and their functions.

The subsystem has been designed so that the temperature drop across, and flow rate through, all major components is continuously monitored. This information is fed to the computer so that component performance can be calculated at any time.

Two types of controls will be installed to regulate the level of the fluid in a tank. The first type will be switches controlled by float valves. The second will be pressure gages at the bottom and top of the tank. Data from these pressure sensors plus temperature data enable calculations of the fluid level. This feature will give us the capability for calibrating flow meters.

5.2 Operation and Testing

The present high-temperature storage tank used in the Solar Total Energy System Test Facility (Figure 5-10) was designed by Sandia Livermore to evaluate storage problems, particularly those associated with the thermocline concept. The high-temperature storage tank was designed to operate with a thermocline using either a low-vapor-pressure, heat-transfer liquid up to 316°C (600°F) for pressurized water up to 232°C (450°F) at 3100 kPa (450 psi).

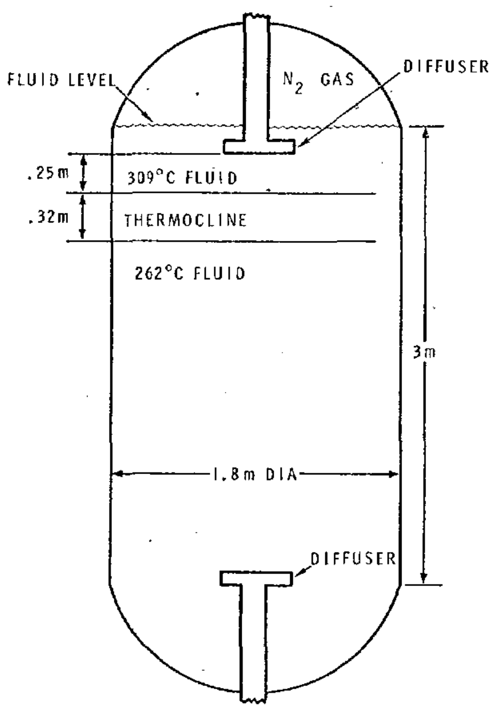


Figure 5-10. Sandia's Thermocline Thermal Storage Subsystem Schematic

The ability to establish and maintain a sharp, stable thermocline for long periods of time depends upon several factors:

- Heat loss to the environment
- Heat conduction across the thermocline
- Currents created in the liquid, producing flow across the thermocline.

It is these factors that were studied during this reporting period. The contribution of the specific phenomenon producing either smearing of the storage-tank thermocline or heat-loss paths was not evaluated specifically. Such a test would primarily measure the capability of the high-temperature storage tank to maintain a sharp thermocline.

The storage-tank liquid was heated to 277-282°C (530-540°F) using a natural gas heater. After ~16 h, it was assumed that the tank had reached thermal equilibrium and that any further temperature decrease would indicate an actual heat loss. Temperature profiles of the storage tank are shown graphically (Figure 5-11) at specified times during the test. The average temperature loss of the storage system for the 63 h of the test after thermal equilibrium had been established was 27°C. This loss appeared to be excessive.

Reasons for the high temperature loss were investigated. It is now believed that because the external pipes had been left open, circulation could occur and the oil flowed into the bottom of the tank as it cooled, thus increasing the density. The suction caused by this flow forced the lower-density oil to be drawn from the top of the tank and the process continued to occur, allowing a continuous flow, although probably a low-velocity one. Such a flow would add significantly to storage-tank heat loss.

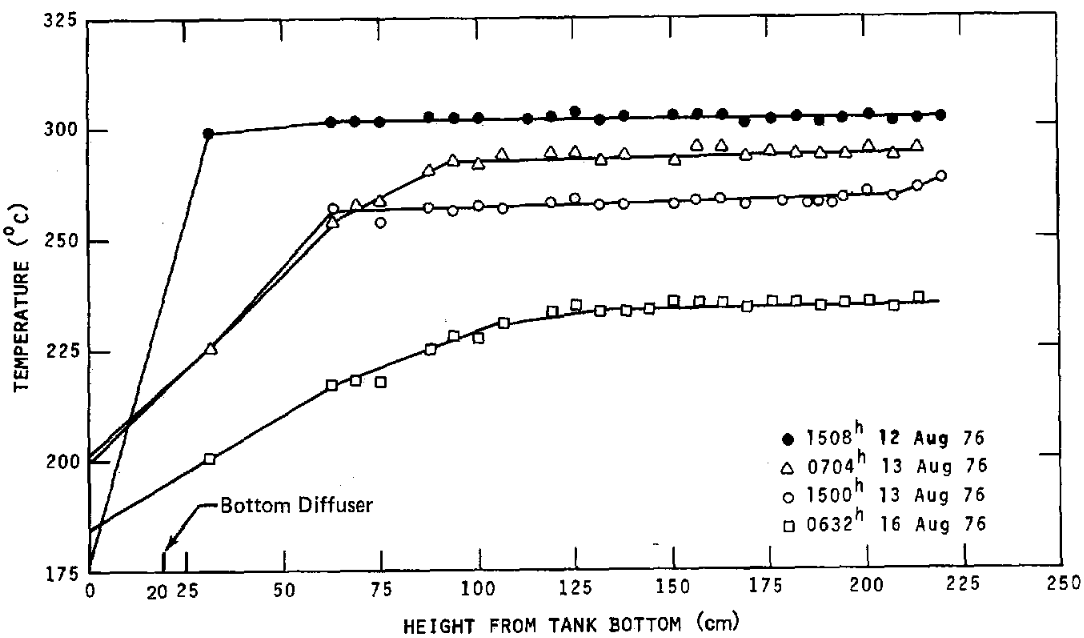


Figure 5-11. Storage-Tank Temperature Profiles, 12 to 16 Aug. 1976

The experiment was repeated with the necessary valves closed to prevent such flow. The tank oil was again heated to 282-288°C (540-550°C). All valves to the bottom of the tank were closed to stop flow into or out of the storage tank. Temperature profiles for the storage tank at various times throughout the test are plotted on Figure 5-12. The average temperature decrease for a 24-h time period was 12°C. The tank was allowed to sit undisturbed for 92 h to study long-term temperature loss. Temperature-loss curves were plotted for selected positions along the stroage tank height on Figure 5-13. These curves indicate that the temperature loss is nearly linear after the initial 12 to 16 h period.

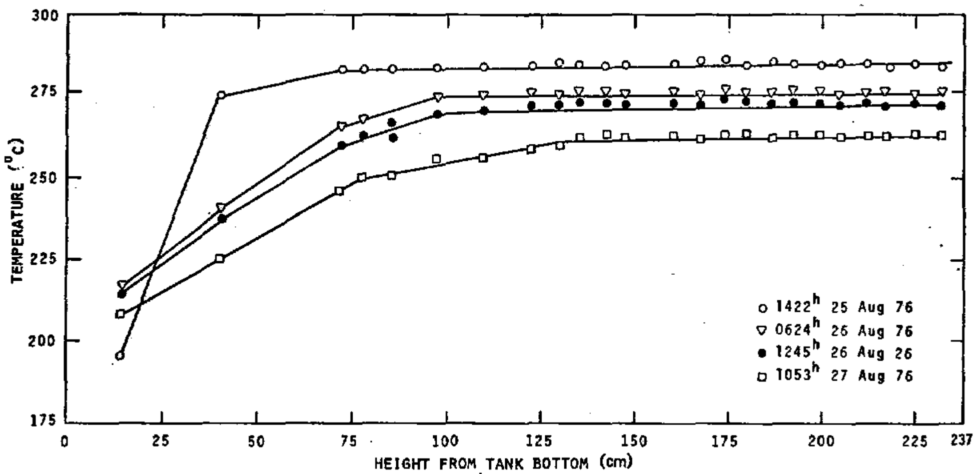


Figure 5-12. Storage-Tank Temperature Profiles, 25 to 27 Aug. 1976

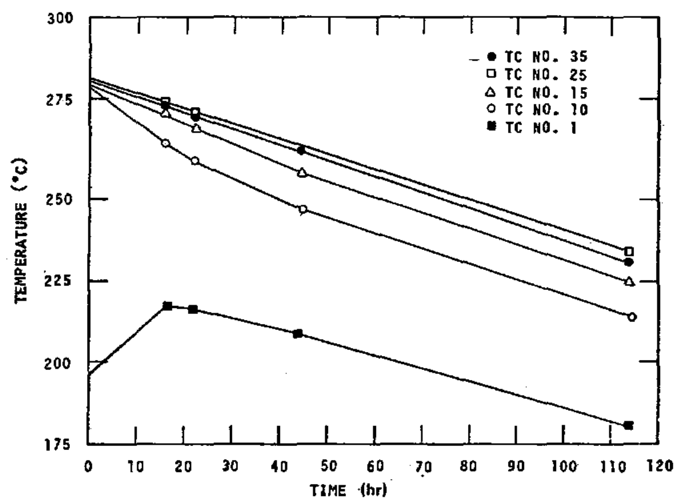


Figure 5-13. Temperature-Loss Curves, 13 to 16 Aug. 1976

A graphic comparison between temperature loss of the system with the tank valves open and closed is shown on Figure 5-14. Temperature-loss profiles for the tank are given for both instances in Figure 5-15. A common time of 24 h after heating was used for the comparison. The graph shows a considerably larger temperature decline in the test with the valves open.

It is also necessary to point out the difficulty of heating the liquid in the tank below the bottom diffuser (see Figure 5-10). All the temperature profile measurements show a marked decrease in temperature below $\sim$0.75 m from the bottom of the tank. The diffuser is located $\sim$0.2 m from the bottom. Because of the relatively high density of the cooler liquid below the diffuser, little circulation takes place and it becomes difficult to heat this portion of the liquid. However, as the tank sits, the heat conduction will increase the temperature by taking heat from the liquid just above it. This is the reason for the rather dramatic temperature-loss measurements at the bottom of the storage tank indicated on Figure 5-11.

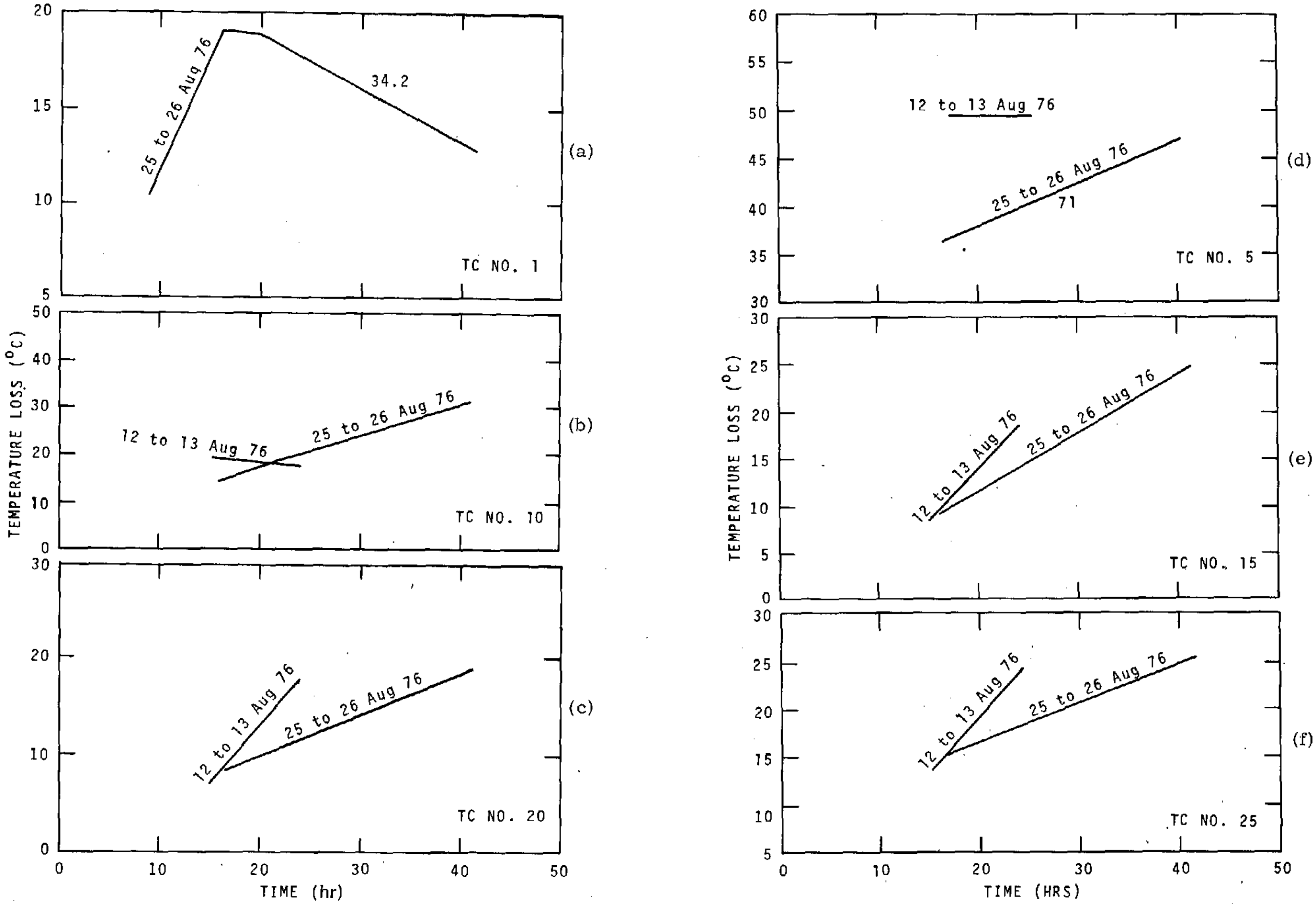


Figure 5-14. Temperature-Loss Comparison Curves Between Open and Closed Tank Valves, 12 to 13 Aug and 25 to 26 Aug 1976

An attempt was made to fill the tank completely and, after heating, the bottom portions of the tank were drained into underground storage. This was only partially successful because a much larger quantity of cold oil existed below the diffuser than could be supplied by overfilling the tank. Since the fact of a relatively cold liquid being below the diffuser is a condition that will exist in the operational mode, the inability to heat this portion of the liquid should not cause undue concern.

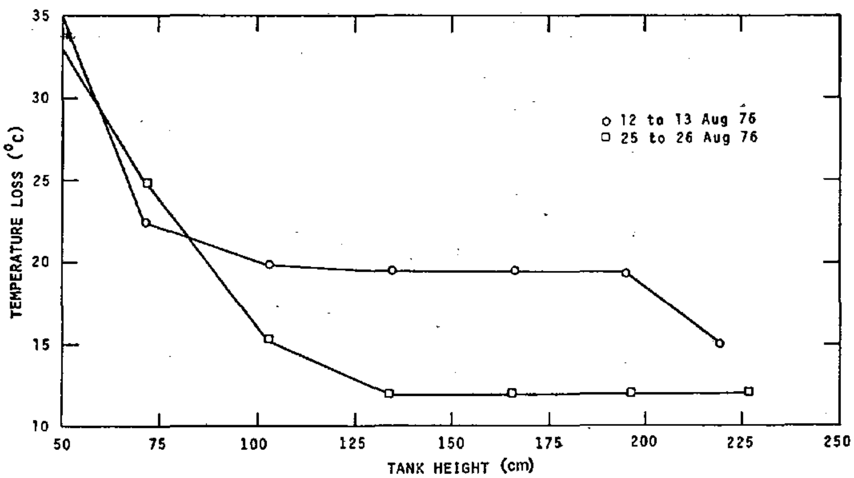


Figure 5-15. Tank Temperature-Loss Profiles for Open and Closed Tank Valves, 12 to 13 Aug and 25 to 26 Aug 1976

As a final measure of storage-tank heat loss the tank was heated to 315° C (600° F). The tank had been heated to 315° C the previous day, therefore, thermal equilibrium was assumed. The temperature profiles for the 22-h period following heating are shown on Figure 5-16. The average temperature loss was 16° C. This rate of temperature loss appears to be linear and thus can be easily predicted for a known tank temperature and length of time for the loss to occur.

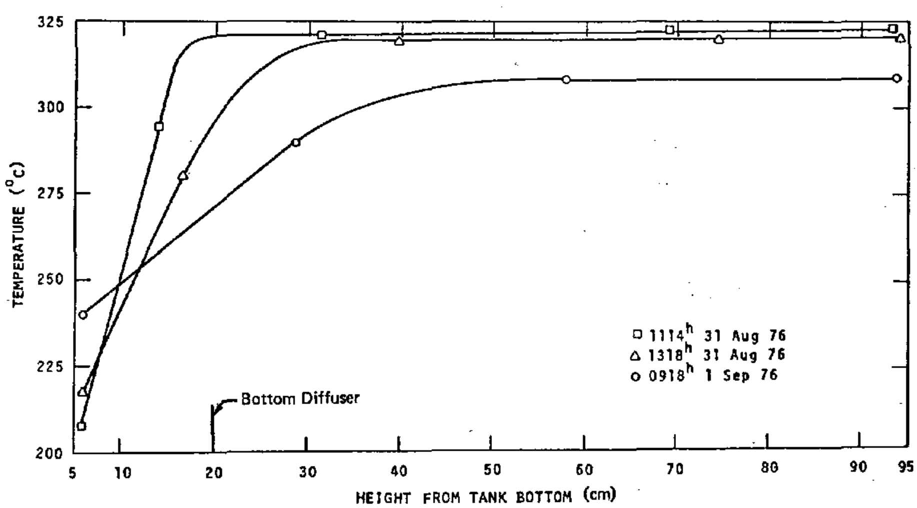


Figure 5-16. Temperature Profiles for 22 h Period Following Heating, 31 Aug to 1 Sep 1976

The next test to be conducted was one to measure the thermocline static stability. If the hot and cold liquids in the tank are not allowed to mix, the energy available from sensible heat storage in them can be used efficiently. The high-temperature storage tank makes use of the concept of a natural thermocline established between the hot and cool Therminol, employing the density differential to establish and maintain the thermocline.

During the solar day the cool liquid is pumped from the bottom of the storage tank through collectors where it is heated, the resultant hot liquid being pumped to the top of the tank. When insufficient solar energy exists to provide the required energy, the hot liquid is pumped from the top of the tank, the heat extracted, and the cool liquid returned to the bottom of the tank.

There are periods of time when heat is neither being removed nor stored. These periods will exist after closedown time in the evenings or over a weekend. Therefore, it is necessary to understand the behavior of the thermocline under these static conditions, which is the primary purpose of the static stability tests.

Once established, a thermocline ideally would remain indefinitely. Several factors may degrade the thermocline, two of which involve heat conduction across the thermocline and convection currents created as the cool and hot liquids both interact with the storage-tank walls. The sharpness of the initially established thermocline also can be affected by diffusion, which can destroy it if it causes circulation within the tank.

It was felt that static stability may differ as a function of hot (315°C) or cold (243°C) storage-tank conditions before establishing the initial thermocline. A thermocline was placed at mid-tank position to study this effect, first starting with a hot tank and then a cold one. A third test was conducted with the thermocline placed near the top of the storage tank to determine whether position within the tank would have any significant effect.

At the beginning of the first test, the storage-tank temperature was 238°C (~460°F). The gas heater was used to heat the entire storage-tank liquid to 313°C (596°F). A thermocline was then established from the bottom of the tank by removing liquid from the top and circulating it through the oil cooler to the bottom. Then the thermocline was moved to about mid-tank position, the initial thermocline profile, as established, being reasonably sharp (Figure 5-17). The thermocline was allowed to remain static for 16-1/4 h. The final thermocline profile is also shown on Figure 5-17.

As can be seen from the figure, at the end of the test the thermocline had almost completely smeared out. It is possible that some of this smearing could have occurred because of the flow discussed earlier. Later tests on static stability reveal the same smearing of the thermocline, so any effect from this flow is an unknown quantity.

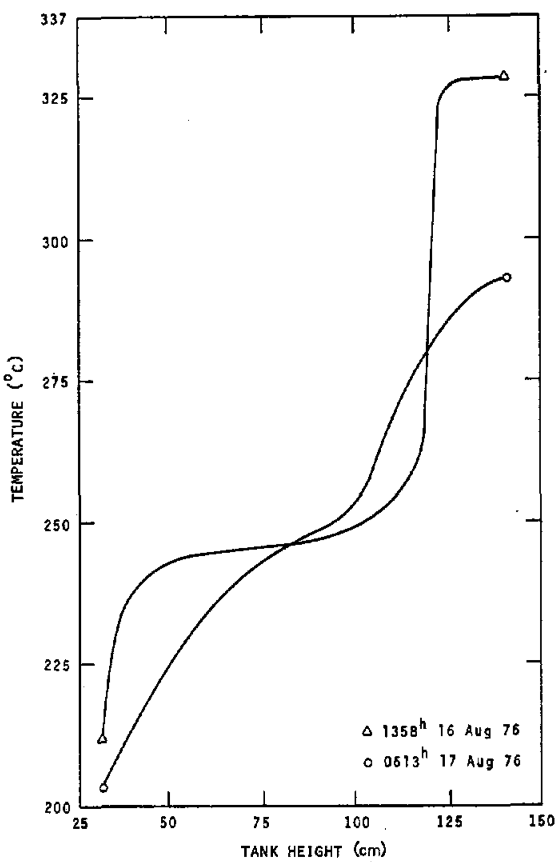


Figure 5-17. Thermocline Profiles (hot storage-tank liquid) After 16-1/4-h Period, 16 to 17 Aug 1976

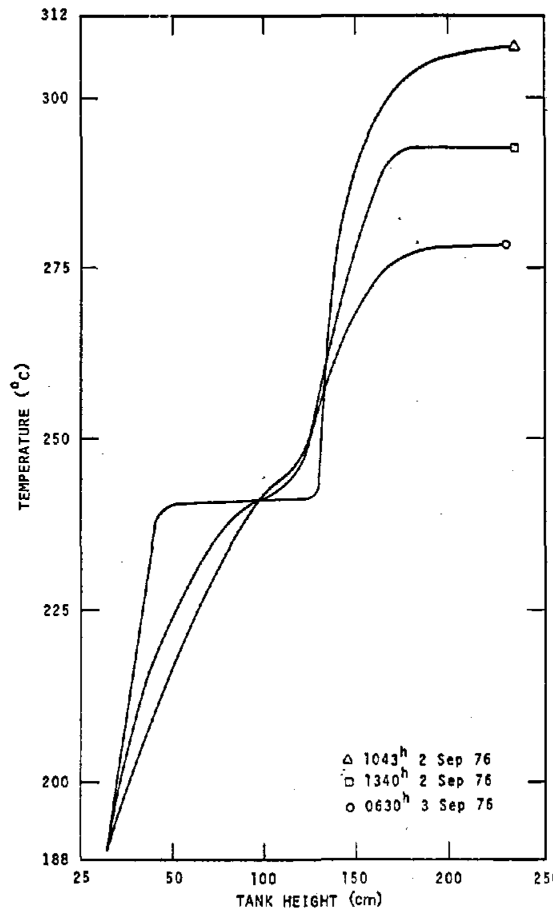


Figure 5-18. Thermocline Profiles After 20-h Period (cold storage-tank liquid), 2 to 3 Sep 1976

The second test was initiated with the storage-tank liquid at 243° C (470° F). The cool Therminol was pumped from the bottom of the tank, heated with the gas heater, and returned to the top of the tank. Thus, the thermocline was established at the top of the storage tank and then moved to mid-tank position. The tank remained in a static condition for slightly over 20 hours. The initial thermocline and the resultant after the 20-h period can be seen on Figure 5-18. The external valves to the tank were closed during this period. Again the thermocline almost completely disappeared.

The final test was begun with a tank full of hot oil at 315°C (600°F) to determine any influence of thermocline position on static stability. Again, the hot oil was pumped from the top of the storage tank through the oil cooler to the bottom of the tank. The thermocline was moved from the bottom position to about one-quarter from the top of the tank. After remaining static for a 20-h period, the thermocline again appeared amost completely smeared out (Figure 5-19).

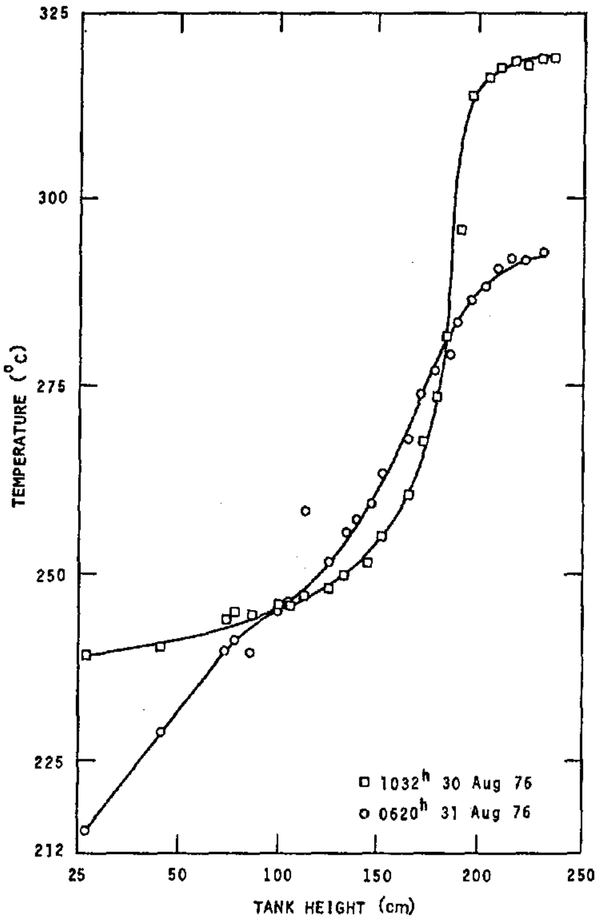


Figure 5-19. Thermocline Profiles (hot storage-tank liquid) After 20 h Period, 30 to 31 Aug 1976

These tests indicate that the thermocline does not exhibit stability under static conditions for more than a few hours. After about 16 hours the thermocline no longer exists. A temperature gradient remains throughout the height of the liquid. This gradient demonstrates that the thermocline has been destroyed, although complete mixing of the liquids has not occurred, and that the thermocline destruction is probably due to conduction and convection across it.

The high-temperature storage subsystem exhibited a considerably larger heat loss than had been expected. The reasons for this excessive heat loss and possible procedures for reducing it are not understood at this time. There does appear to be more loss from the bottom of the tank; however, because of the inability to heat that portion of the liquid below the diffuser, no specific study was made of the loss paths and definitive loss rates.

The thermocline does not have a static stability capability. The temperature profiles show that the thermocline begins to smear out almost immediately after it is established. This smearing continues to occur and after overnight storage, the thermocline has almost completely disappeared. Studies will be made to determine what phenomena (or combination of phenomena), cause this.

The degradation of the thermocline is in excess of that due to diffusion effects acting alone. This suggests the need for a thermal analysis to determine heat flow paths to the external environment. Preliminary analyses have begun, but cannot be completed until exact details of the construction of the thermocline storage tank can be obtained. It is anticipated that a complete set of drawings will be available within a few weeks.

A series of laboratory model studies of the thermocline storage concept are being planned. The primary purpose of these experiments will be to determine the behavior of a thermocline under actual operating conditions. A realistic model will be constructed and inflow and outflow conditions modeled in an appropriate manner.

A system study of a typical solar collector/Rankine cycle system has been initiated in an effort to evaluate the effectiveness of thermocline as well as multitank storage concepts. The planned study makes use of techniques developed by Lee, Schimmel, and Abbin.[2] Their initial work will be modified to account for storage as well as the kinetics of heat transfer processes important to the efficient operation of the system.

Task 6. Prime Mover Subsystems

The Solar Total Energy System Test Facility generates electrical power by transferring the thermal energy collected in the Therminol 66 to toluene which is vaporized. The vapor propels a turbine which turns a generator to produce electricity. Most of the effort during this period was used to measure conversion efficiency and to identify areas of strength and weakness.

6.1 Development

Only minor development activities were conducted. These are included under Section 6.2.

6.2 Operation and Testing

The turbine, storage, and collectors were operated together as a system for the first time on April 20. Total operating time was about four hours with about one hour of this at 32 kW_e from storage. Peak power was 35 kW_e for a period of about 10 minutes. The only turbine system problems encountered were continuous running of the auxiliary lube pump, generator coupling noise, and unstable operation of the flow (pressure) control valve.

The auxiliary lube pump problem was traced to a wiring error which has been corrected. The generator coupling was checked and found to have a TIR of 0.7 mm vs the 0.3 mm allowable. The equipment repair section of the shop did an excellent job of correcting the runout to less than 0.07 mm, and they also pinned the generator to the main turbine frame to prevent future shifts. A new flow-control valve was ordered on April 23. The original valve was oversized by a factor of 10 or more and acts in a "bang-bang" fashion.

Final versions of the Safe Operating Procedure and Pressure Safety Analysis Report were signed off and distributed on April 28.

An attempt was made on May 10, 1976, to run the turbine system at design conditions in the indirect heating mode, similar to tests run in December 1975 in the direct-fired mode. Several problems were encountered, however, which delayed testing. The first problem encountered was poor condenser cooling caused by air trapped in the water coils and a cooling water pump motor which

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[2] D. O. Lee, W. P. Schimmel, Jr., and J. P. Abbin, Jr., "Sizing of Focused Solar Collector Fields With Specified Collector Tube Inlet Temperature," SAND74-0295, Sandia Laboratories, November 1974.

overheated and shut off intermittently. The motor apparently did not overheat in December due to the lower ambient air temperature. The pump motor has been replaced by a larger unit and the pump itself was replaced with a unit which better matches the condenser loop flow conditions. The turbine condenser was reworked with valves and line taps to allow the condenser coolant loop to be evacuated and filled completely. Another problem which showed up was in the Therminol 66 flowmeters which gave erratic readings and would not hold their calibration. The net result was that no dependable data on heat input to the toluene system could be taken, which in turn did not allow efficiency measurements based on the T-66 flow. The flowmeters were removed, cleaned, vacuum-impregnated with T-66 and installed above the pipes to make them self-cleaning and now appear to be working much better, although zero shift still appears to be a problem.

While the system was down, the burst disks came in for the toluene boiler exit line and one was installed. New "Pressuretroll" overpressure safety switches were ordered, and a verification test of the heater stack overtemperature safety system was performed for the fire prevention engineers.

On June 8, an attempt was again made to run the turbine system at design conditions in the indirect heating mode to obtain baseline efficiency measurements. The first problem encountered was the condenser vacuum pump which broke a vane and quit pumping. An auxiliary vacuum pump was then installed and the system restarted. Shortly thereafter, the burst disc on the toluene side of the Graham heat exchanger blew, venting toluene vapor through the roof of Building 833. This disc had been installed just before the tests. Although the noise frightened personnel in the area, no vapor cloud was visible within 30 seconds of the burst, and there did not appear to be a safety problem. Between 40 and 75 litres of toluene were required to refill the system. Examination of strip chart records showed that the heater pressure was up to 1.9 MPa (280 psi) at the time of the burst but further investigation indicated that, although the 321 stainless steel disc was rated at 2.5 MPa (365 psi) at 22° C, the burst strength degrades significantly with temperature and the mounting of the relief line and disc was such that a heat-pipe effect heated the disc to about 260° C. New discs were ordered made of Inconel which will maintain its strength at temperature and not require replumbing of the relief line.

Sundstrand provided new silver-phenolic vanes for the vacuum pump to replace the original carbon vanes, with which they had also had trouble. The pump was repaired and the burst disc line was temporarily plugged (there is another spring-type relief valve in parallel with this line) and the testing resumed on June 23 and June 24, 1976. The baseline efficiency runs were made and the results are summarized in Figure 6-1. In general, at full load, it appears that the unit is about 0.3 to 0.5 percentage points more efficient under summer and winter operating conditions than in the December 1975 tests in the direct gas-fired mode. This was anticipated as a result of the installation of the smaller generator cooling fan. However, under the fall/spring (most efficient) operating conditions the full-load efficiency appeared to be unchanged. It was noted that, during the fall/spring condition tests, the condenser vacuum pump ran almost continually but the condenser pressure never got below 20.6 kPa (3 psia) while during December, under the same conditions, the pressure was about 6.8 kPa (1 psia). Possible reasons for the higher pressures in December are an air leak at a thermocouple connection, wrong setting on the vacuum pump low-limit switch, and/or failure to close the bypass valve between the turbine inlet and the condenser.

The condenser air leak at the thermocouple connection was fixed, and the vacuum low-limit switch set point was reduced from 20 to 26 mm Hg. These changes did not appear to improve the condition. The vacuum system was checked by itself and the system would pump down to about 10.3 kPa. The turbine bypass valve remains to be checked, and this will be done as soon as replacement metal gaskets arrive.

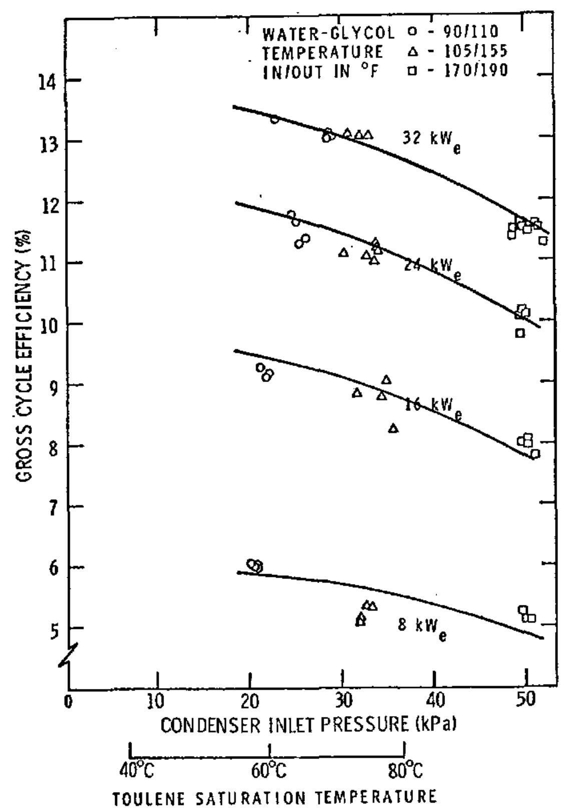

Figure 6-1. Turbine Efficiency vs Toluene Saturation Temperature

When the facility was formally dedicated on July 8, 1976, the turbine system was operated for this event.

The Inconel burst disk was installed on the Graham T-66/toluene heat exchanger on August 4. This disk is rated at 2.38 MPa (345 psig) at 343°C (650°F) and replaced the 321 stainless steel version which failed in June. Following the installation of the new burst disk, the turbine system was run with the new toluene flow-control valve. Unfortunately, the new valve did not overcome the stability problems of toluene boiler pressure and mass flow encountered with the old valve, although the system stability seemed to be improved. The flow-control valve signal gain was then reduced and the amount of gain, rate and integral control varied on the T-66 controller, all of which further improved system stability. One possible fix is to tie the toluene and T-66 flow-control signals together to some extent since the greatest instability exists when these two signals get out of phase.

During September, numerous tests were run switching from one mode of boiler heat input to another at fixed electrical load. Switching from storage only to the gas-fired heater (Mode 1 to Mode 2-B) and back did not pose any significant problems. Switching from the heater-boiler mode (Mode 1) to the heater supplying both the boiler and storage (Mode 2-A) resulted in the instability of toluene and T-66 flow noted previously. This instability makes energy balance and efficiency measurements extremely difficult, but may not really be a problem as far as actual function of the system. During these tests gross efficiency was measured against toluene inlet pressure, the results of which are also shown in Figure 6-1.

Plans for the coming months involve finding optimum boiler pressure levels for the different condenser pressures experienced in winter, spring/fall, and summer operating conditions, and continued stability testing under different combinations of heating mode, electrical load, and condenser conditions.

Task 7. Heating and Cooling Subsystems

Initially the collected solar energy is used to produce electricity for the Solar Project Building (Bldg. 832). Energy rejected by the generator is at a higher temperature than that rejected in conventional electrical generating processes. In the Solar Total Energy Test Facility the rejected energy will be used to heat or cool this 1100 m^2 (12,000 ft^2) building.

During the reporting period the controls, fluid loops, and thermal storage system required to use the rejected energy were designed. Absorption refrigeration will be used to cool the building in the summer. A 1.3 MJ/h (100-ton) unit manufactured by Arkla Servel which uses lithium bromide water solution is in place and ready to be hooked up.

The insulation of the Solar Project Building was extensively modified to reduce both the volume to be heated and cooled and the rate at which heat is lost or gained through walls or ceiling.

Work will soon start on installing the fluid loops, controls, and thermal storage subsystems required to use the energy rejected by the turbine/generator subsystem to control the temperature in the Solar Project Building.

7.1 Development

The design of the heating and cooling subsystem for the Solar Project Building has been completed. The subsystem was designed by the consulting engineering firm of Bridgers and Paxton from fluid flow and control schematics furnished by Sandia. The system schematic is presented in Figure 7-1. The system interconnects the existing turbine/generator fluid transfer system to the existing heating and cooling system in the Solar Project Building.

The subsystem has nine operational modes as described below.

Heat Simulator/Storage Mode 6

Heat the Solar Project Building load simulator heat exchanger with heat from storage.

Heat Building/Heater Mode 7

Heat the Solar Project Building with heat from storage.

Heat Building/Heater Mode 8

Heat the Solar Project Building with the fossil-fuel water heater.

Air Conditioner/Storage Mode 9

Operate the air conditioner with heat from storage.

Air Conditioner/Heater Mode 10

Operate the air conditioner with the fossil-fuel water heater.

Air Conditioner/Storage/Heater Mode 11

Operate the air conditioner with heat from storage and simultaneously operate the air conditioner load heater with heat from the fossil-fuel water heater.

Air Conditioner/Load Heat Exchanger/Heater Mode 12

Operate the air conditioner and air conditioner load heater simultaneously with the fossil-fuel water heater.

Heat Storage Mode 13

Heat storage with heat from the fossil-fuel water heater.

Cool Storage Mode 14

Cool storage with the Solar Project Building load simulator heat exchanger.

The above nine operational modes are subject to the following system requirements:

- The system must sense when storage is full or empty and switch back and forth between Air Conditioner/Storage Mode and Air Conditioner/Heater Mode automatically. This switching should be unaffected by the simultaneous use of the fossil-fuel heater to heat the air conditioner load heater as in the Air Conditioner/Storage/Heater and the Air Conditioner/Load Heat Exchanger/Heater Modes.
- The system must sense when the storage is full or empty and switch back and forth between the Heat Building/Storage Mode and the Heat Building/Heater Mode automatically.
- The Solar Project Building is typical of many commercial buildings which, at certain times of the year require heating and cooling in the same day but nor simultaneously. Under these conditions the storage tank will be maintained at 88° C (190° F). Consequently the heating system must be able to use energy at 88° C or 68° C (190° F or 155° F).
- Primary mode of operation for the fluid transfer system is with a two-tank, hot- and cold-storage mode. However, the system should be capable of operating from one tank operating in a thermocline mode.
- The system shall not be required simultaneously to heat the building and operate the air conditioner.

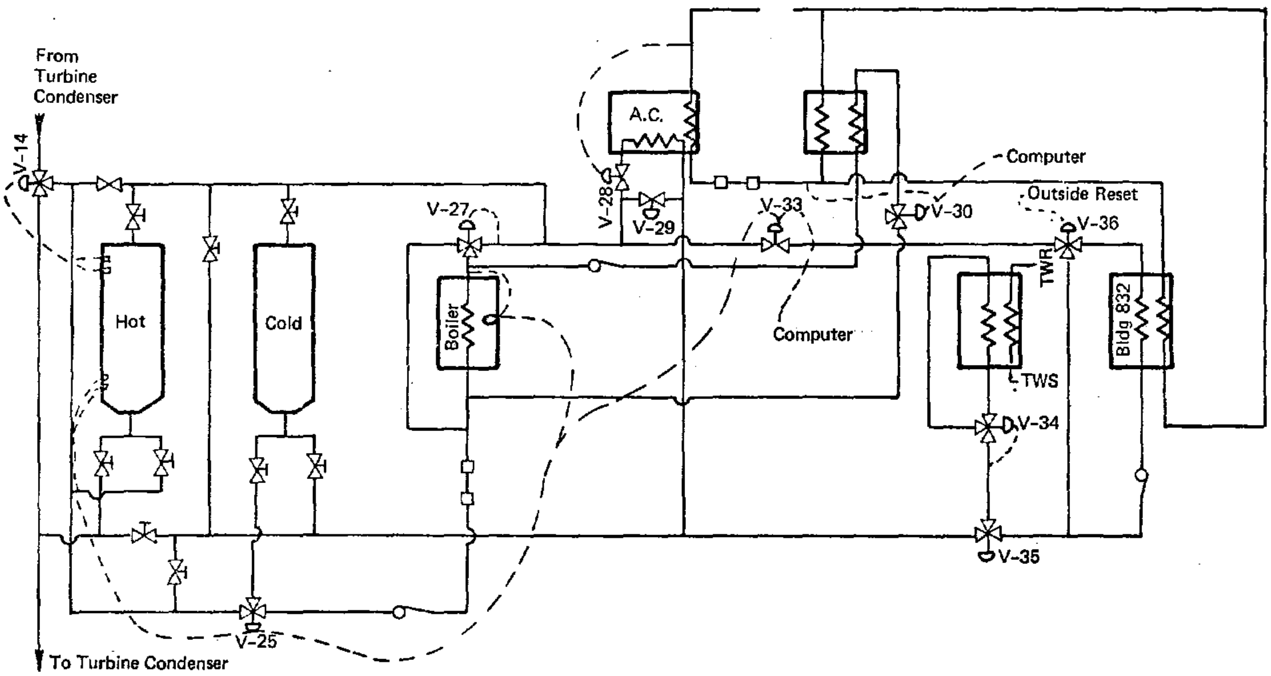

Figure 7-1. Schematic of Heating and Cooling Subsystem, Solar Project Building

System control is accomplished through 10 control valves. The basic function of each will be discussed in a future technical report.

The boiler control is an essential part of the fluid system control. The boiler is set up to maintain the fluid at 93° C (200° F) as long as the flame is on. Flame activation will be manual or automatic, manual when the mode of operation is such that use of the boiler is scheduled and automatic when use of the boiler is random (as when the hot fluid tank is emptied and the system shifts automatically to the cold tank). Provisions have been made so that, in a thermocline storage operation, the heater can be activated when the thermocline tank runs out of hot fluid as determined by the tank thermocouple probe.

The system has been so designed that the temperature drop across and flow rate through all major components is monitored continuously. These data are fed to the computer so that component performance can be calculated at any time.

The heating and cooling of the Solar Project Building is not completely dependent on the Solar Total Energy System Test Facility. In this way, testing in the Facility can be more flexible and not controlled by demands for heating or cooling from the building. Automatic sensors and equipment to switch from solar operation to utility company operation have been incorporated. Electrical switchover is by automatic monitoring of building voltage, and heating and cooling switchover is by automatic monitoring of flow switches and thermostats in the heating and cooling fluid lines to the project building.

Cooling System -- The cooling system has been discussed in detail in previous reports. Essentially it is the 1.3 mJ/h (100-ton) Arkla absorption air conditioner which is derated to 0.8 mJ/h (62 tons) when operated with 88° C water. The air conditioner is so installed that it can be operated to cool the Solar Project Building or can be operated separately in an air conditioner test program.

Low-Temperature Storage -- A simple two-tank system, one tank for hot fluid and one for cold, containing only enough liquid to fill one of the tanks, was selected for low-temperature storage. However, provisions have been made so that one of the tanks can be operated in a thermocline storage mode. The tanks are conventional, nonpressurized water tanks which will be insulated with spray-on urethane foam after installation. The Solar Total Energy system requires that 19,000 litres of water be stored overnight, so each tank has that capacity.

7.2 Operation and Testing

Solar Project Building Modifications -- At the time Bldg. 832 was chosen for the Solar Project Building it had an excessively high electrical, heating, and cooling load per unit area of floor. It was decided it would be more economical to remodel the building to have loads more typical of residential structures than to build sufficient collector fields, etc., to meet the existing loads. Modifications to the 1100 m^2 (12,000 ft^2) building are presently under way which (1) reduce the electrical load from 90 kW to less than 32 kW, (2) reduce the peak heating load from 883,000 to 570,000 kJ/h (837,000 to 540,000 Btu/h), and (3) reduce the peak cooling load from 581,000 to 389,000 kJ/h (54 to 31 tons). These modifications are 95% complete and should be finished by the scheduled date of November 1, 1976.

Task 8. Solar Collector Module Test Facility

Sandia maintains a test capability to facilitate the development and design of collectors and collector components. Currently, this facility has the capability of supplying either water or Therminol to a test item at predetermined temperatures and flow rates.

Increasing activity in the field of energy projects has created a need to expand the facility to accommodate test items which use Therminol, high-temperature water and low-temperature water. Plans were formulated for the expansion, the design of the new facility (Figure 8-1) is nearly complete, and items with long lead times have been ordered.

During this reporting period, a McDonnell Douglas fresnel lens collector was tested on the existing facility.

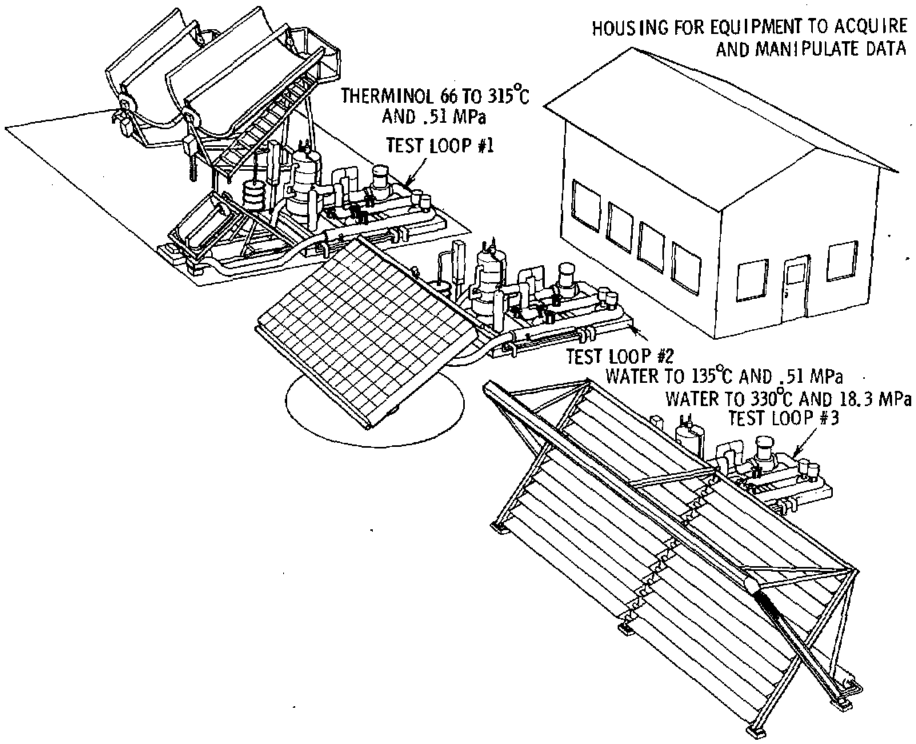

Figure 8-1. Future Solar Collector Module Test Facility

8.1 Development and Modifications

Plans were developed for the expansion of the Solar Collector Module Test Facility, the purposes of which are:

- To obtain data on collectors and collector components purchased by Sandia or ERDA
- To obtain data on collectors and collector components which are involved in a project in which Sandia or ERDA has a vital interest.

By March 1977, the Collector Module Test Facility will have the following fluid capabilities (see Figure 8-1):

Loop 1 -	Therminol to 315° C (600° F),	0.51	MPa (75 psi)
Loop 2 -	Water to 135° C (275° F),	0.51	MPa (75 psi)
Loop 3 -	Water to 300° C (625° F),	18.3	MPa (2650 psi)

Loops 1 and 3 will normally be used for collectors and collector components. Loop 2 will normally be used for photovoltaic generators. Test Loops 1 and 3 will use an HP 2116 minicomputer to acquire, manipulate, and reduce data. To the current 100 channel A/D converter will be added another one of the same capacity to increase data acquisition capability.

Test Loop 2 for photovoltaic generators will have an HP 9640A minicomputer to acquire, manipulate, and reduce data. This data acquisition system will be capable of acquiring 155 data points per photovoltaic array. It is anticipated that the usual test will consist of two arrays.

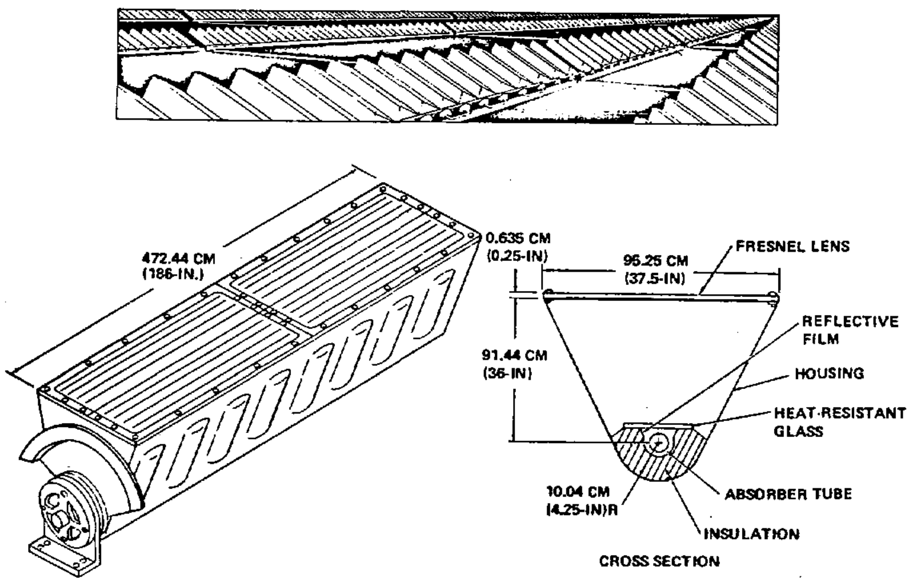

Figure 8-2. MDAC Fresnel Lens Concept

Test Loops 2 and 3, which use water (or water and ethylene glycol), will be protected from the elements (particularly freezing) by instrumentation covers. These covers are essentially 4.5 x 6 m insulated buildings which can be heated to about 5° C in the winter. They will be so constructed that they can be moved off the loop when heavy maintenance such as a pump change is required.

The controls for the loops, the computers, and other data acquisition equipment will be housed in a facility of 84 m^2 (900 ft^2) minimum area to be located on the present site of the A1 trailer which now houses the HP 2116 computer and controls for Test Loop 1.

Three piers with top surfaces flush with the ground will be available for mounting test specimens for Test Loop 2. These will be configured to accommodate the mounting arrangement in current use for the photovoltaic generators.

Six piers with top surfaces flush with the ground will be available for mounting test specimens on Test Loop 3. These will be configured to accommodate the Sheldahl SLATS Collector.

Special equipment to calibrate flow meters will be available. This will consist of a container mounted on a load cell to make it possible to weigh the fluid passing through a flow meter during a time interval.

The following items of data will be recorded as a minimum on all collector tests:

Collector Identification	Ambient Temperature
Local Time	Flow Rate
Solar Time	Temperature In
Solar Insolation, Total Horizontal	Temperature Out
Solar Insolation, Direct Normal	Pressure In
Wind Direction	Pressure Out
Wind Speed	Comments

These data will be transferred from the tape output of the HP 2116 to magnetic tape suitable for input to the CDC 6600 computer. Other acquired data will be stored, retrieved, and manipulated in accordance with the needs of the job.

The Solar Total Energy Test Facility Division will coordinate and schedule the use of the Solar Collector Test Module and will maintain the test equipment. Maintenance, repair and modification of the test item is the responsibility of the agency to whom it belongs. The Solar Energy Projects Division will prepare computer programs required to test collectors. The Photovoltaic Systems Project Division is responsible for computer programs required to test photovoltaic generators.

The agency which owns the test item will be responsible to assure that it can be safely tested. Required as a minimum are analyses and proof tests which assure safe operation at maximum temperatures and pressures. Also required are analyses which show that the test item will survive a 145-kph (90-mph) wind in the operating condition.

The agency for which the test is being performed must submit a detailed test plan which explains the purpose of the test, and schedules and itemizes the data to be taken.

Normally 5 weeks will be set aside for the test of a collector. This block of time includes 3 days to set up, 4 weeks to test, and 2 days to tear down. During July and August the time allocation will be lengthened to 6 weeks because of anticipated inclement weather.

Sandia's HP 2116 minicomputer will store acquired data on tape and provide printouts of raw data and reduced data. In addition, data may be transferred to magnetic tape on the CDC 6600 computer for more sophisticated analyses. Sandia will maintain a log of test activities. The test agency to whom the test item belongs is responsible for furnishing to the Solar Total Energy Test Facility Division a complete report on the test within 30 days after completion of the test.

Twice a year, minimum, blocks of time will be set aside to calibrate equipment, particularly flow meters and thermocouples.

The Solar Total Energy Test Facility Division will issue Safe Operating Procedures and assure that only qualified personnel operate the equipment in accordance with the procedures.

Four separate descriptions of the facility will be prepared and published. One description will describe the total facility and the capabilities of each loop in a general fashion. It will be suitable for general distribution. The other three descriptions will each describe a loop in sufficient detail to facilitate the establishment of an interface between that loop and an item scheduled for test on that loop. Distribution of these three descriptions will generally be limited to organizations scheduled to perform tests.

8.2 Operations

Design is complete for the piers, pads, and instrumentation covers required for Test Loops 2 and 3. All items with lead times of 8 weeks or more have been ordered and several have been received.

Barber-Nichols, Denver, was awarded the contract for the design and fabrication of the high-pressure equipment for Loop 3. The design of the equipment is complete. Fabrication has started with delivery scheduled for January 1977.

The first item to be tested on the high-pressure water loop, No. 3, will be the SLATS 37 m^2 (400 ft^2) collector with a planar receiver. Assembly and installation of this equipment is scheduled to start January 3, 1977.

The HP 9460A minicomputer has arrived. An 8.5 x 9.7 m (28 x 32 ft) building will house the HP 2116 and HP 9460A minicomputers and their associated equipment. It is scheduled to be complete in January 1977.

The Safe Operating Procedure for Loop 1 was updated and greatly expanded to include procedures such as the one for changing from Therminol to water. This latter can be hazardous because acetone is needed to flush out the Therminol. A fire exit was added to the A1 trailer.

Between July 12 and August 26, 1976, tests were performed on the first model of the McDonnell Douglas Astronautics Company (MDAC) Fresnel Lens distributed collector. The test plan and test direction were furnished by MDAC. Sandia reviewed the test plan and furnished personnel to operate the test loop and to assist MDAC with setup and teardown of the test item.

Preliminary test results confirm the MDAC performance projections, operational features, and maintenance simplicity of the cast acrylic refracting solar concentrator for total energy applications. The collector efficiencies, corrected for insolation and off-nominal absorber tube spectral characteristics, were about 63 and 43% at 65° and 315°C (150° and 600° F), respecitvely. When corrected by MDAC for additional known and suspected test hardware off nominal values, efficiencies approaching 48% at 315°C are projected by MDAC for systems using 1 m wide, F1 lenses. Sun acquisition and automatic tracking in two axes have been demonstrated well within the tolerances required for operational systems. The case acrylic lens has proven tolerant of handling and operational conditions and simple to clean.

The test hardware consisted of two collectors, drive systems, and a sun sensor mounted on a flat bed trailer, shown in Figure 4-2. Each collector consists of a Fresnel lens, housing, and absorber assembly as shown in Figure 8-2. The collector controller and data acquisition system was housed in an adjacent instrumentation trailer.

The primary test objectives were to obtain data on collector efficiency, collector component temperature, and tracking control system performance. Collector efficiency data were obtained for various parametric conditions including absorber subsystem configuration, fluid flow rates, fluid temperature, and tracking accuracy. In addition, thermal loss data were obtained at various elevation angles to evaluate the effectiveness of the glazing in reducing convection losses. Collector component temperature data were obtained for both normal conditions and for simulated tracking-motor failure. The tracking control system measurements included sensor calibration using earth rate as an error source, control electronics offsets, variations in motor power-on time vs tracking accuracy, and collector rotational rates during slow operations.

Preliminary test results indicated satisfactory performance for this stage of the development. The collector drives and automated tracking system acquired the sun and reliably heated the Therminol 66 heat transfer fluid to 315° C.

The preliminary plot of measured collector efficiency vs fluid temperature is shown in Figure 8-3. Also shown is the data correction for specification level absorber tube spectral coating, the major test hardware anomaly verified to date. The measured absorptivity of $\alpha = 0.88$ was below the $\alpha = 0.95$ level which has been achieved and maintained reliably by Sandia. This correction reflects readily achievable performance following Sandia-developed process controls.

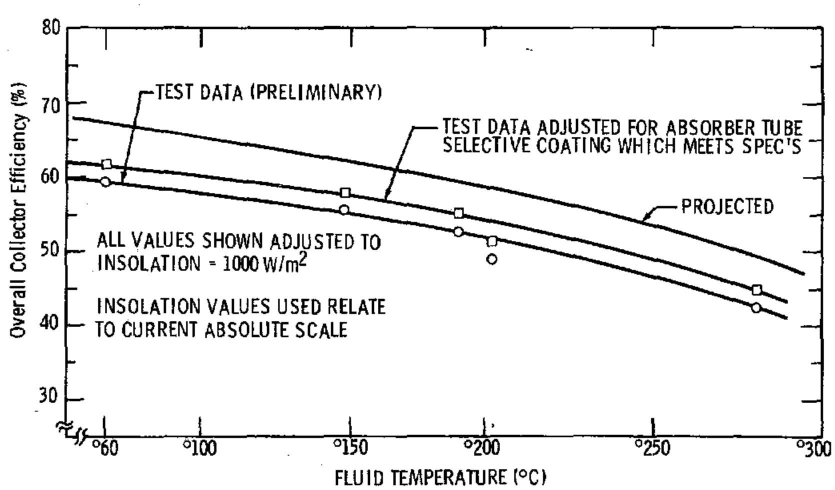

Figure 8-3. Overall Efficiency of Fresnel Lens Solar Collector

The projected performance curve reflects the resolution by MDAC of other test hardware anomalies as well as component level development. The other anomalies, the effects of which are still to be resolved, include: moisture in the fiberglass insulation in some test runs due to heavy rains entering defective seals; periodic tracking errors in the facility pyroheliometer data; heat transfer fluid contamination due to fluid breakdown at high temperature in the presence of water. During the efficiency measurement tests, the temperature change across the collectors ranged from 0.5 to 3.9 °C, depending on insulation and fluid flow rate. The measurements were made with calibrated thermocouples. Part of the scatter of efficiencies is attributed to the low ΔT being measured. Additional variations are attributed to the anomalies previously discussed.

In addition to tracking energy collection, thermal loss tests were conducted by pointing the collector away from the sun and measuring losses from the fluid, heated by the facility, flowing through the absorber tube. These tests were conducted in the low- and high-elevation attitudes with no effect on losses. This substantiates the suppression of convection by the absorber-glazing configuration chosen.

Additional data were obtained on system pressure drop and component temperature during a full range of nominal and off-nominal operating conditions. These included off-axis tracking, sun acquisition and defocus at various slew rates, and nontracking sun precession rates. The data indicate that pressure drops were within predicted and maximum rated temperature. No excessive stress or deflections were observed during normal tracking operations or during off-normal and simulated failure conditions.

The tracking control system performed within design goals with a demonstrated accuracy of better than 1 milliradian. Servo motor control algorithms were verified and motor power requirements measured. The output of the sensor was verified linear over its operational range. Slew rates were verified within specification.

Setup, operation and teardown of the MDAC fresnel lens test item revealed the need to have available more documented information on the characteristics of the test loop to establish interfaces between the test item and the test loop. Examples of such information were thread types and sizes for plumbing and signal outputs from weather instruments, thermocouples, flow meters, and pressure gages, the information judged to be most useful in the establishment of interfaces was assembled into document form by two summer hires from the University of New Mexico. This document will be published soon.

SECTION IV. APPENDIX

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