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FY78 Annual Progress Report: Midtemperature Component and Subsystem Development Project

Lewis M. Larsen, Editor

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FY78 ANNUAL PROGRESS REPORT: MIDTEMPERATURE COMPONENT AND SUBSYSTEM DEVELOPMENT PROJECT

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ABSTRACT

This report describes the FY78 activities within the Midtemperature Component and Subsystem Development Project that supports the US Department of Energy Small Power Systems Program.

CONTENTS

CONTENTS (cont)

ILLUSTRATIONS

ILLUSTRATIONS (cont)

TABLES

Glossary of Acronymns and Abbreviations

A&E	Architectural and Engineering
CMTF	Collector Module Test Facility
CRTF	Central Receiver Test Facility
DOE	US Department of Energy
E-W	East-West
GE	General Electric
HTS	High Temperature Storage
LRTT	Laser-Ray Trace Test
MDAC	McDonnell Douglas Astronautics Company
MSSTF	Midtemperature Solar Systems Test Facility
MTI	Mechanical Technology, Inc.
N-S	North-South
O&M	Operation and Maintenance
OCLI	Optical Coatings Laboratory, Inc.
RFP	Request for Procurement
RFQ	Request for Quote
RTV	Room Temperature Vulcanizing
SERI	Solar Energy Research Institute
SLATS	Solar Linear Array Thermal System
SOLTES	Simulator of Large Thermal Energy Systems
STE-LSE	Solar Total Energy - Large-Scale Experiment
T66	Therminol 66 heat-transfer fluid
TES	Thermal Energy Storage
TMY	Typical Meteorological Year

FY78 ANNUAL PROGRESS REPORT:
MIDTEMPERATURE COMPONENT AND SUBSYSTEM
DEVELOPMENT PROJECT

Introduction

This report describes FY78 activities within the Midtemperature Component and Subsystem Development Project that support the DOE Small Power Systems Program. Small-power systems are for point-of-use applications of solar energy rather than centralized or public-utility-size applications.

The major objectives of this program are to determine areas of research and development that are unique to small-power systems in the mid-temperature range, and to develop technology that will allow initial commercial implementation of small-power systems within the 1980s.

The Sandia activities within the Small-Power Systems Program consist of four subprograms: Total Energy, Remote Applications, Midtemperature Component and Subsystem Development, and Midtemperature Solar Systems Test Facility Operation. Some application projects within these subprograms are the solar irrigation projects near Willard, NM, and Coolidge, AZ; the Small Community Solar Power Project for Crosbyton, TX; and the STE-LSEs at Fort Hood, TX, and Shenandoah, GA. The object of these programs is accelerated commercialization of solar energy systems. This will be done by demonstrating the technical feasibility in applications of large portions of the national energy market and by creating within the private sector the design and manufacturing capabilities for installing such systems.

The following summarizes the objectives, FY78 accomplishments, and planned activities for the major areas of development.

Systems Engineering

SOLTES Project

The objective of SOLTES is to provide a computer code that can simulate most systems that use solar energy as an energy source--including process heat, total energy, and power conversion. An existing Sandia computer code, SOLSYS, was studied in FY77 to see how it could be modified for simulating solar total energy systems. These studies indicated that important modifications were necessary. As a result, the first version of the computer code SOLTES (which uses some of the SOLSYS logic and thermal component models) was written and debugged in FY78.

SOLTES is a general but usable code that can simulate a wide variety of thermal energy systems, such as

Solar Power/Total Energy Systems
Fossil-Fired Power Plants/Total Energy Systems
Solar Energy Heating and Cooling Systems
Solar Hot-Water Systems
Solar Process Heat

A load management capability allows SOLTES to simulate total energy systems that simultaneously follow power loads and demands, and heat loads and demands. At user option, SOLTES automatically calculates system performance parameters and provides system energy-transfer accounting.

A national workshop to explain and demonstrate SOLTES capabilities was held September 13-14, 1978, at Sandia Laboratories, Albuquerque, NM. A user's manual, SAND78-1315, was distributed. About 60 people attended; more than 40 attendees were from universities, small consulting firms, large companies, and national laboratories other than Sandia. Responses to SOLTES ranged from favorable to enthusiastic; requests were made to continue further development of SOLTES.

Primary objectives for FY79 are to

Disseminate the present version of SOLTES
Enhance output capability
Add photovoltaic capability
Add an IBM version
Add second law of thermodynamics accounting
Add more detailed thermal-storage models
Write more detailed air-conditioner models
Write more detailed space-heating models
Add building-loads model
Add more detailed collector models

Solar Systems Design Handbook

A handbook is being prepared for the design of solar thermal power systems that use parabolic-trough collectors operating at temperatures up to 315°C. The handbook permits the design of solar systems using parametric curves and tables. It thus eliminates the need for computer simulation except perhaps for verification of projected final design performance. Some trade-off evaluations between different subsystem options treated in the handbook are:

- Collector field sizing and operating temperature vs use of collected solar energy.

- Thermal energy storage vs use of collected solar energy and its effect on collector field size.

- Shadowing vs collector spacing for both E-W and N-S collector orientations.

- Heat loss, night cooldown, and field startup vs collector spacing and deployment.

- Fluid pump parasitics vs collector spacing and deployment.

- Fluid flow control vs collector performance and quality of collected energy.

- Turbine generator operation vs collector field and storage performance.

- Trade-off evaluations of absorption vs compressive chillers.

The handbook addresses the application of parabolic trough midtemperature solar technologies to process heat, onsite power, and total energy systems. The objective of the handbook is to guide engineering firms in designing and constructing solar systems for near-term commercial market applications in the 1980s. Performance curves are generated using TMY weather tapes and actual measured component performance where possible. The handbook covers the entire continental United States as spanned by the 26 TMY tapes and develops procedures for establishing system designs in non-TMY sites.

Component cost algorithms developed during the execution of past solar total-energy application analyses and preliminary designs are inluded for use in preliminary concept evaluation. However, to assess cost-effectiveness, the designer should accumulate current component cost information at the time of design definition and use this information in determining life-cycle costs. A report outlining conceptual designs of solar total-energy systems was published.[1] A draft version of the Solar Systems Design Handbook should be ready in June 1979.

Copies of the draft will be sent to commercial A&E firms for comments. Comments will be incorporated by September and the report will then be published.

Solar Total-Energy Applications Analyses Results

Four major DOE contracts evaluating the application of solar total energy to the industrial, commercial, residential, and institutional market sectors have been completed. McDonnell Douglas, Atomics International, the Institute of Gas Technology, and Resource Planning Associates made these studies in FY77-78.

The industrial market sector, characterized by relatively constant seasonally independent energy demands, appears most favorable for near-term market initiation in the 1980s. Aside from constant-demand profiles year-round, other characteristics of the industrial market sector that favor the potential for early market initiation are:

- High thermal-to-electric ratios that allow displacement of much of the electric and thermal loads.
- Experience with O&M of high-technology systems
- Uncertain availability of current energy sources
- Less restrictive codes than for other market sectors

The most important disadvantages associated with the industrial market sector include short payback periods expected for invested capital (typically 3 to 7 yr) and possible land availability constraints associated with high energy density. Typical promising applications include fluid milk, concrete block, and food processing.

Other market sectors show reduced potential for early market penetration. Commercial market sector applications (chiefly shopping centers) tend to be severely land-limited and highly electric-intensive. Institutional applications (typically college campuses and military installations) tend to have an unfavorable balance between electric and thermal demand. No markets for residential applications were identified until after 2000. A primary deterrent in applying solar total energy to the residential sector is the high priority given it by the government in allocating preferred fossil-fuel energy resources such as natural gas and oil. Safety tends to favor photovoltaic technologies in all but the industrial sector, which handles high-temperature thermal energy.

Technology development needs that were identified by the application analyses include component reliability, improved turbine efficiencies, high-temperature heat-transfer and storage fluids, and modularized components. Many engineering firms are more concerned with reliability than cost. The industrial application analysis highlighted the desirability of the small central receiver concept in which central receivers operating at the 4-MWth peak level could use the same heliostats being developed for the much larger central power systems. The optimum heliostat field configuration is a north field. An external steam boiler or heat-transfer oil receiver would operate at about 90% thermal efficiency at 316° to 427°C (600° to 800°F).

Materials and Process Development

Black Chrome

The objectives of this effort are to improve thermal stability of electrodeposited black chrome, improve knowledge of important plating and production parameters, determine effects of substrates on optical properties and thermal stability, and optimize substrate materials.

Black-chrome-coated receiver tubes in the MSSTF degraded after continued use. Solar absorptance values decreased from initial values of 0.94 to 0.96 to values of 0.90 to 0.79. Laboratory testing confirmed thermal degradation.

Laboratory Analysis -- In the standard Harshaw process for decorative black chrome, the nominal plating bath composition is

	g/L
CrO_3	332
Acetic Acid	16
Cr^{+3}	16
Fe	8
Ba	8

The standard bath produces coatings that are stable in air at 250°C but decrease in solar absorptance and emittance at 300°C.

Trivalent chromium concentration in the bath has a pronounced influence on thermal stability. Reducing the concentration from 16 g/L to 12 and 8 g/L yields coatings for which solar absorptance remains essentially unchanged in laboratory thermal-aging tests at 350°C for 2000 h. Coatings have been plated on electrodeposited sulfamate nickel, nickel foil, and 302 stainless steel. The solar absorptance of coatings plated in baths with 8 g/L Cr^{+3} remains unchanged at 400°C for 1800 h. With the Cr^{+3} concentration at 12 g/L, the deposited coatings show no significant change in solar absorptance at 350°C, but a slight decrease was observed between 800 and 1600 h at 400°C.

Process Handbook -- Honeywell Systems and Research Center, Minneapolis, was contracted for black-chrome selective-coating development. The DOE Solar Heating and Cooling Branch and the Small Power Systems Branch jointly funded this contract. The work intends to improve coating durability; determine relationships of bath plating conditions, coating optical properties, and thermal stability; and issue a detailed process handbook for commercial electroplaters. Honeywell has duplicated the test results done at Sandia. Optical test equipment and plating-bath composition analysis as determined by both Sandia and Honeywell have been compared and agreed within ±2%.

Production Run -- Full-scale production plating using the new bath formulation of black chrome is planned for early November 1979 in support of the solar thermal irrigation project at Coolidge, AZ. Before production plating, coatings were obtained from Highland Plating, Los Angeles, CA, who used a moderate-sized bath (165 gal). All Highland coatings are unstable upon heating above 300°C in air. However, samples plated by Sandia from the same bath solution are thermally stable, in agreement with previous laboratory results. The difference between Highland and Sandia coatings must therefore result from differences in the plating process, not the bath. Variables being checked include the nickel substrate, current density variations, and the ac ripple on the dc power supply at Highland.

The FY79 schedule includes

- At MSSTF start thermal aging tests of black chrome on receiver tube sections.

- Determine microscopic differences between stable and unstable coatings using Auger sputter profiling, transmission electron microscopy, scanning electron microscopy, and infrared reflection spectroscopy.

- Determine critical process variables and start process handbook for electroplated black chrome.

- Continue production studies at Highland Plating.

Thin Glass

The primary objective of this program is to develop and fabricate a high-performance reflecting surface for solar trough concentrators (the reflecting surface uses silvered thin glass). The feasibility of this concept is to be demonstrated with a prototype unit fielded in FY79.

Using silvered glass as a second-surface solar reflector has many advantages. Elastically deformed thin glass (0.13 to 0.51 mm thick) provides a way to form trough concentrator shapes that can eliminate some of the drawbacks of glass of conventional thickness (> 1.5 mm). The simplest method for ensuring survival of thin glass during handling and elastic deformation to a concentrating profile is to laminate it to a backing material and form a flat "reflector laminate." Through proper design, subsequent bending of the flat reflector laminate to the trough shape can produce compressive stresses throughout the glass that enhance its survival. An analytical design that optimizes the thickness and properties of the adhesive and backing was performed for 0.25- and 0.51-mm-thick glass.

The first systems test of the laminated thin-glass mirror concept will begin in March 1979 with construction of a parabolic trough 6.1 m long in the MSSTF collector field. Processes for laminate fabrication are being developed and a facility for prototype fabrication is being assembled to provide mirrors for that test. To confirm the results of the analytical design, evaluate the fabrication processes and identify potential problems. Test specimens 0.3x0.3 m were constructed with varying thicknesses of glass (0.25 to 0.5 mm) and steel backing (0.38 to 1.02 mm). Among the problems encountered in constructing these samples were cutting and silvering the very thin glass. A new procedure for glass cutting by local thermal stressing has been used with good results. Special fixtures to support the glass during cleaning and spraying have been built for the silvering process. The biggest problem in fabricating the reflector laminate is the application of the uniform, bubble-free, very thin (0.051 to 0.157 mm) adhesive layer that ensures resistance to hail impact. Using a silk screen to apply the adhesive solved this problem. Equipment for fabricating 0.43x2.3-m reflector laminate is almost operational.

Thermal cycling, thermal/humidity cycling, bond strength, and reflectivity tests have been performed on the 0.3x0.3-m samples. All tests have indicated the satisfactory performance capabilities of the thin-glass laminate.

Fabrication of reflector laminate for the engineering prototype should be completed by February 1979. Characterization and testing of the laminates will continue in FY79.

Sagged Glass

The intent of the sagged-glass effort begun in FY78 was to assess the capability of the glass industry to supply curved shapes produced by sagging or other high-temperature deformation processes. The best available products were to be evaluated as replacement mirrors in some existing facilities and as optional mirror materials for new facilities.

Responses of some of the major producers of sagged glass shapes before FY78 indicated that existing technology was adequate for solar applications.

An evaluation of a parabolic-trough mirror made by Standard Bent Glass supported this belief. However, in early FY78 when RFQs were sent out for mirrors for the advanced trough and for parabolic-dish petals, some technological problems and some problems with facilities that would inhibit exploitation of the existing industry by the solar community became evident. Problems included

- Fixturing. Some manufacturers use sagging molds made from high-temperature alloy castings; these are expensive to cast and machine, and require long lead times. For 3D curves such as dish petals, it is difficult to find a machine shop capable of forming the mold. This problem has been compounded by the desire to evaluate Corning Glass Works (CGW) Code 0317 glass as a mirror material. This more refractory glass requires higher temperature processing than does soda-lime glass and increases the probability of degrading reactions between the mold and the glass. A mold material is needed that can be shaped quickly and cheaply but will survive the processing environment long enough to make a few prototypes.

- Facilities Limitations. Because major manufacturers are running at or near capacity, their ability to respond to our RFQs for prototype parts has been limited.

- Mirror Quality. Existing processes may not be able to provide the precision necessary for solar application. Also, a tester that can be used by the manufacturer to ensure quality control is needed.

- Deformation Processes. Donnelly Mirror Co. has difficulty maintaining precision for shallow curves because of viscoelastic rebound of the glass. Donnelly uses a pressing process that may make this problem worse than for free sagging. Nevertheless, some fundamental investigation of glass-deformation processes may be needed.

Much of the FY78 effort was spent trying to work around these problems. Many of the smaller companies were visited to try to determine their technological and production capabilities. Studies were also funded to try to assess the performance of specific mold materials or to develop new materials while evaluating the ability of the companies involved to produce prototypes. These studies are described below.

AstroMechanics -- To assess the capability for 3D sagging at AstroMechanics and to evaluate graphite as a mold material, several pieces of Corning's 1.5-mm (0.060-in.)-thick 0317 glass were shipped to them. They sagged and silvered one piece of this glass using an existing graphite tool in a small experimental furnace. The resulting specimen had poor specularity, attributed to the degradation of the graphite surface in the furnace environment.

Del Manufacturing Co. -- The objective of this study was to evaluate stainless-steel foil as an interface between the mold and the glass. In this concept, a mold could be made from an inexpensive material or poor quality and then surfaced with a material having good surface finish and low reactivity with the glass. Del Manufacturing Co. was asked to consider forming the foil to a 3D shape, using an existing spherical cast-iron mold to cold-form the foil, and to try to sag CGW 0317 glass on the foil-covered mold.

Del has sagged two pieces of CGW 0317 glass on a foil-covered mold. These parts will be sent to Sandia for silvering, and testing for uniformity and curvature. Del Manufacturing has also determined that CGW 0317 glass can be sagged by using a vacuum to form the glass to the foil-covered mold. This activity should be completed by January 1, 1979. Figure 1 shows Sandia's plating facility

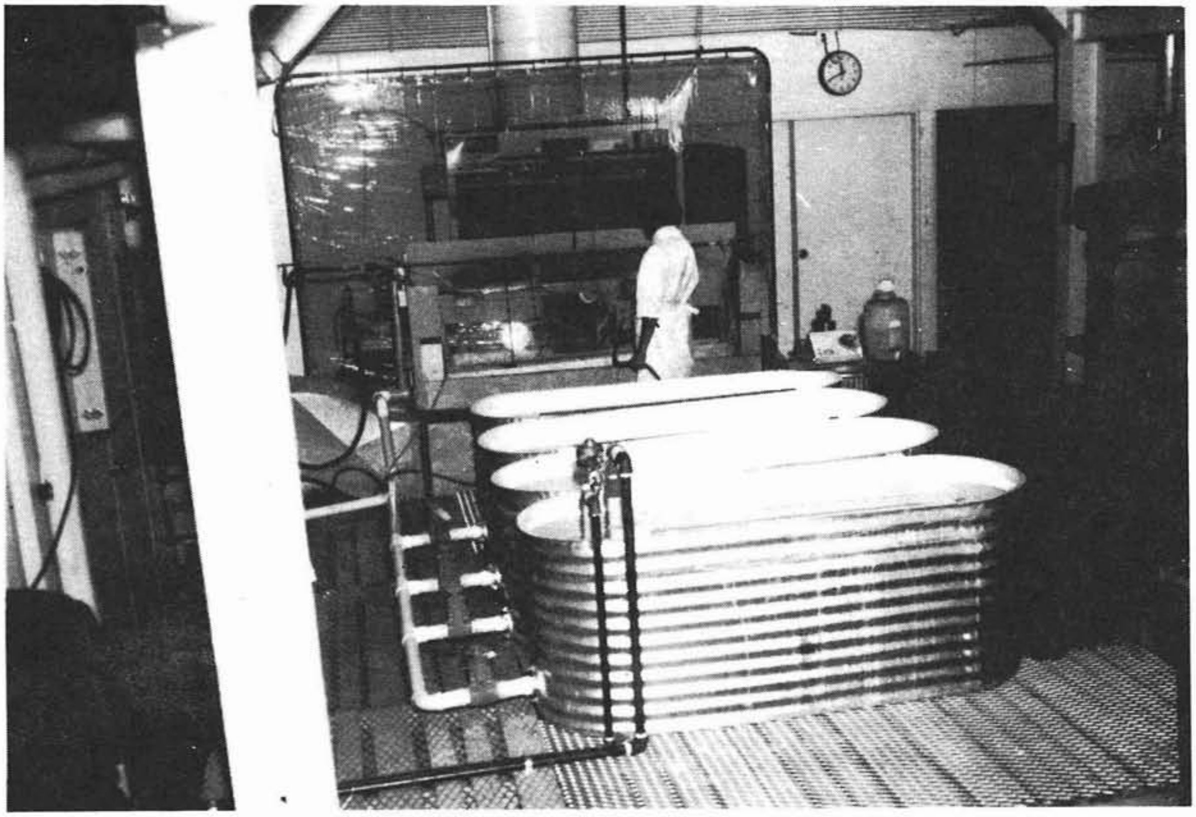

Figure 1. Sandia Laboratories Mirror-Silvering Facility

Sandia -- Sandia initiated two studies in FY78: one seeks to evaluate ceramic materials as mold materials. In FY78, castable ceramics made by Cotronics and Aremco Products, Inc. were evaluated by first forming an RTV casting against an aluminum petal from a parabolic dish and then using the casting to form the castable ceramic. Difficulties arose in obtaining suitable mold-release agents and in eliminating voids at the RTV/castable ceramic interface. The Aremco material also tended to separate. As a consequence, the mold surface did not have the requisite surface finish. For FY79, a material made by Thermo Materials Corporation, Thermosil Castable, is being evaluated.

The use of CGW Cercor honeycomb ceramic as a mold backing material with a glass ceramic surface was explored as an adjunct to this study. Corning has used this combination for simple molds. This investigation has been stalled in an attempt to find a machinist willing to use a five-axis machine for cutting this abrasive material to use the mold shape.

Sandia has also explored the use of microwave heat to sag the glass. The temperature-time control possible with such an approach might eliminate some of the problems with mold glass reactions by allowing an abrupt temperature drop to the annealing range as soon as the mold surface is contacted by the glass. It also has the potential for energy economy compared with standard heating processes. Initial runs on small plates in a microwave oven showed promise. The intent in FY79 is to find a company with a large facility and try to form some full-sized mirrors.

Standard Bent Glass -- In R&D efforts of ~4 yr ago, Standard Bent Glass Co. of Butler, PA, fabricated 10 glass panels for prototype parabolic-trough concentrators. These sagged-glass panels were 0.6x1.57 m (24x62 in.) of ASG sheet glass 3.2 mm (0.125-in.) thick. The panels were silvered in Sandia's paint shop and coated with copper, paint, and rubber protective coatings for long-term environmental capability. Figure 2 shows a pair of these glass sections mounted on a trough form.

Inspection of several of these sagged-glass panels by the Sandia's laser-ray trace-inspection system indicated that the rms slope error for these panels was typically 3 mrad. These panels thus proved acceptable. With this history of success in sagging, Standard Bent Glass was again contacted to sag panels for parabolic troughs.

Two configurations of parabolic troughs are now at stages where sagged-glass panels will be required. These configurations are the 2-m rim-to-rim advanced trough design and the replacement troughs for the existing 2.7-m (9-ft) rim-to-rim units.

Two contracts will be placed in FY79 with Standard Bent Glass for fabrication of prototype sagged panels to fit the configurations described above. The glass in both cases is CGW 0317, 1.5-m (0.060-in) thick. The blanks for sagging the panels are 1.22x1.52 m (48x60 in.). The finished (trimmed) size of the 2-m units is 1.14x1.22 m (45 (arc) x 47-7/8 in. length)). Trimmed size for the 2.7 m (9-ft) units is ~1.47x1.2 m (58 (arc) x 47.7 in. (length)).

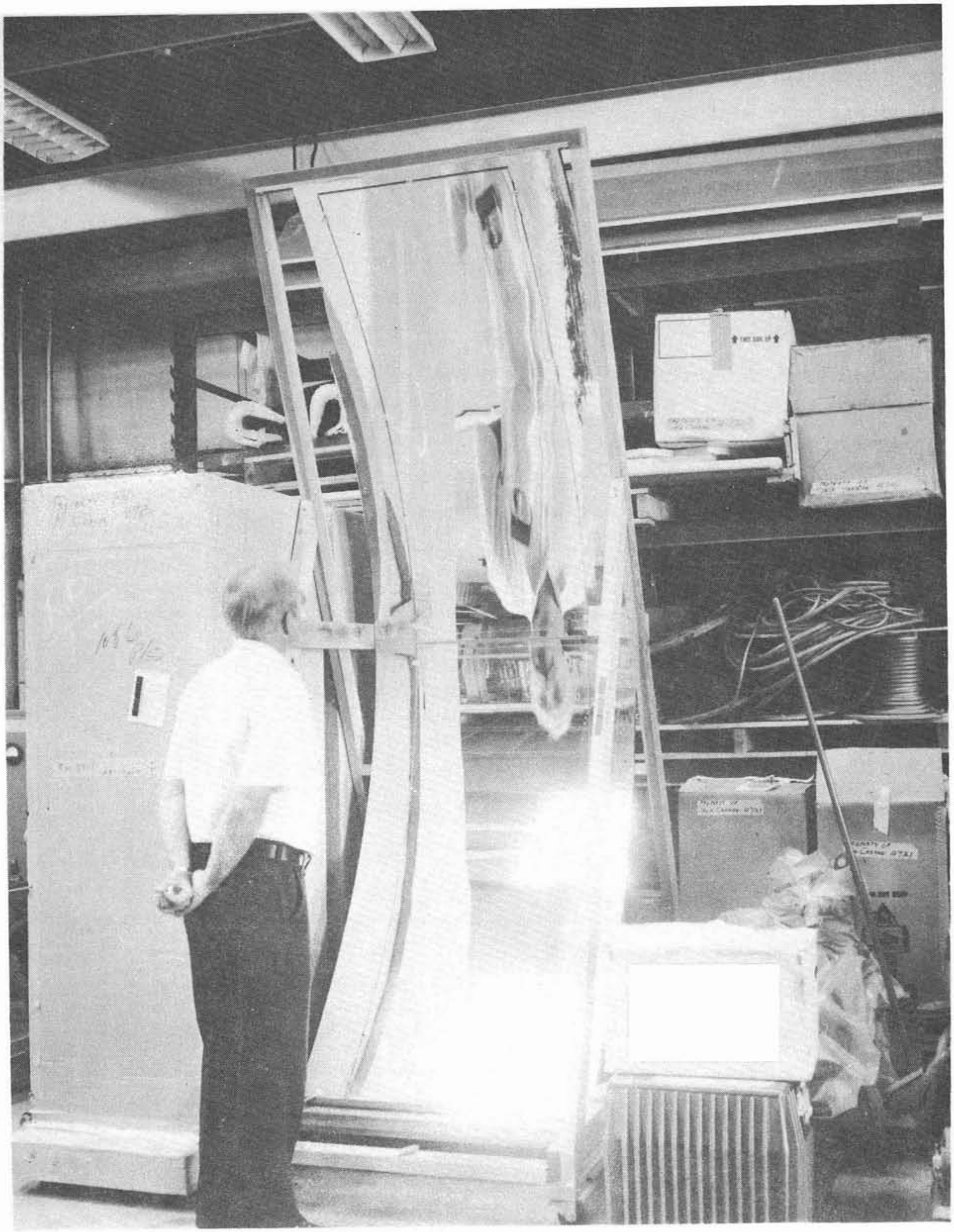

Figure 2. Sagged-Glass Sections

Standard Bent Glass has demonstrated that they can sag panels of the specified size and thickness by sagging a 1.22 x 1.22 m x 1.5-mm (48x48x0.060-in.) piece of 0317 glass to a cylindrical configuration similar to the trough sections in radius of curvature. This part appears to be acceptable in slope error and quality. Figure 3 shows this piece of 1.5 mm (0.060-in.) unsilvered glass; handling large glass panels of this thickness may present some problems. Part of this effort will be to investigate the trade-offs and problems of handling and installing large, thin-glass panels.

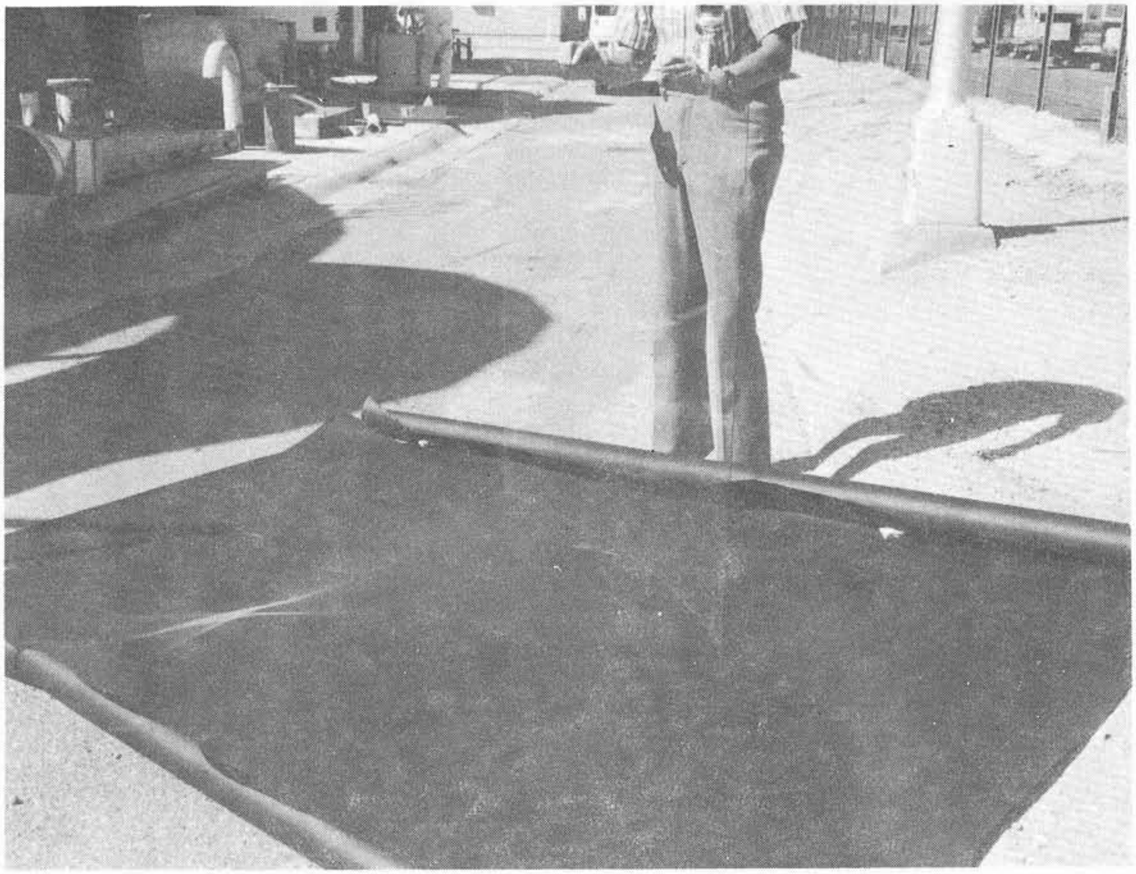

Figure 3. Unsilvered 1.5-mm (0.06-in.) Sagged Glass

Five glass panels are to be obtained for initial inspection and evaluation. If acceptable, 50 to 100 more panels are to be obtained for use in prototype trough applications. If initial parts are unacceptable, modifications in tooling or processing will be made so that acceptable parts can be produced.

Costs of tooling, sagging, and silvering will also be investigated to evaluate sagged-glass potential for future mass production of collectors.

Procurement is under way to involve a large glass fabricating company in Sandia's sagged-glass program. The companies involved must now be producing more than 0.929×10^6 m^2/yr (10×10^6 ft^2/yr) of sagged-glass units. The objectives of the glass development program are to

- Develop an understanding of the optical and mechanical quality of mass-produced sagged glass for trough applications.
- Investigate tooling and available large-scale manufacturing techniques to obtain needed data for appropriate sagged-glass specifications for future mass-procurement activities.
- Establish costing factors for mass-product sagged glass for trough applications.

Glass Panels for Parabolic Dishes

Discussions have been held with Standard Bent Glass about sagging glass to the three-dimensional contours required for parabolic-dish panels. In trough contours, the glass is only bent; in dish contours, the flat glass must be stretch-formed. "Pressing" may better describe this process, commonly used in the glass industry on much smaller parts. The present parabolic-dish configurations are relatively large (7 m dia) and therefore require very large radii of curvature in the glass. The radial radii of curvature are also different from the circumferential radii of curvature for a dish. Forming glass parts to a very large radius of curvature 10.67 to 9.14 m (35 to 30 ft) and to close tolerances ±152 mm (±6 in.) appears to be difficult. Much larger tolerances are typical with present processes. This area of three-dimensional formation to large-changing radii of curvature and to close tolerances is one that will require development, which is planned for early FY79.

Structural Materials Evaluation

The long-range goal of the reflector structural-materials program is to provide the analysis and testing background necessary for defining commercially producible, low-cost, accurate, dimensionally stable, and long-life concentrating solar collectors. In prior years a variety of materials have been experimentally evaluated as a data base from which to identify the most promising candidates for further evaluation. That data has been supplemented in FY78 by a design analysis that resulted in a figure-of-merit ranking for candidate materials.

The analysis, which was based upon a shell model, was formulated so that material and structural properties could be separated. In that way, various materials could be evaluated for each design type and for a given set of structural requirements. Design concepts chosen for evaluation included slabs, laminates, sandwiches, and ribbed and monocoque structures. A minimum flexural rigidity per unit length of 56500 N·m (0.5×10^6 lb-in.) was assumed based upon a 92° rim angle, 2-m (6.5-ft) aperture parabolic trough with gravity and 90-mph wind loading. Support was assumed to be rigid-end and an acceptable weight of 48.1 kg/m^2 (3 lb/ft^2) imposed.

Analytical results showed that material designs with low weight and high flexural stiffness are required for solar reflector structures. Those criteria are most easily met by sandwich, ribbed, and monocoque structures. The slab and laminate designs proved impractical for all materials. Optimum materials-design combinations were selected by trading off performance, weight, and cost for the various candidates. Additional selection factors included expected environmental stability (hail, moisture, UV resistance), thermal compatibility with a glass reflector surface, availability, fabrication energy consumption, and applicability to mass production. Materials chosen for further evaluation are listed in Table 1.

TABLE 1

Materials: Design Candidates for Solar Reflector Structures

Construction	Materials
Monocoque	Steel
Ribbed	Steel-Molding Compound or Plywood
Sandwich	Skins - Steel, Fiberglass, Plywood
	Cores - Paper and Aluminum Honeycomb Isocyanurate Foam Fiberglass Sinewave

A contract has been placed to study the effects of formulation changes on thermomechanical properties of sheet-molding compounds. Data from that program will be used in trade-off studies to optimize material formulation vs rib geometry and cost.

Experiments are being done of the materials listed in Table 1 using techniques developed in prior years. These include (1) laser-ray trace inspection, (2) temperature-humidity cycling, (3) real-time environmental exposures, and (4) hail-impact resistance. Figure 4 shows Sandia's hail-impact equipment. Each structure will also be evaluated with sagged, chemically strengthened, and thin-glass reflector surfaces. Those data are being supplemented by mechanical property measurements on as-manufactured and environmentally cycled specimens.

Four new materials programs were initiated in FY78:

(1) Modification of the laser-ray trace to use a removable reflector surface that allows separation of structure changes from reflector surface changes taking place upon exposure to environmental cycling.

(2) Moisture diffusivity measurements on forest products, sheet-molding compounds, adhesives, sealants, and coatings used in solar reflector structures. Such data make it easier to understand the degradation mechanisms during aging of these materials in solar structures.

(3) Chemical analysis of commercial sealants, coatings, and adhesives to identify trace impurities that may degrade Ag reflector surfaces.

(4) Surface analysis of degraded mirrors. The mechanisms of Ag degradation in solar reflector structures will be investigated.

Work in FY79 will optimize attractive material-design constructions for line-focusing collector applications. The analysis will be supplemented with environmental and mechanical property data. Additional objectives are to understand the aging degradation mechanisms of solar structural materials and silver reflector surfaces.

Reflector Material Evaluation

The objectives of reflector material evaluation are to appraise new or improved reflector materials, develop and expand measurement techniques, and determine the effect of outdoor weathering on reflector materials.

Satisfactory laboratory measurement instrumentation and data analysis techniques were developed to characterize specular reflectance properties of mirror materials. These properties were determined on a variety of commercially available materials. Because a relatively small amount of dust accumulation on a mirror can cause a large decrease in specular reflectance, several experiments were started to determine the magnitude of this effect. A portable reflectometer to collect field data is needed for this purpose.

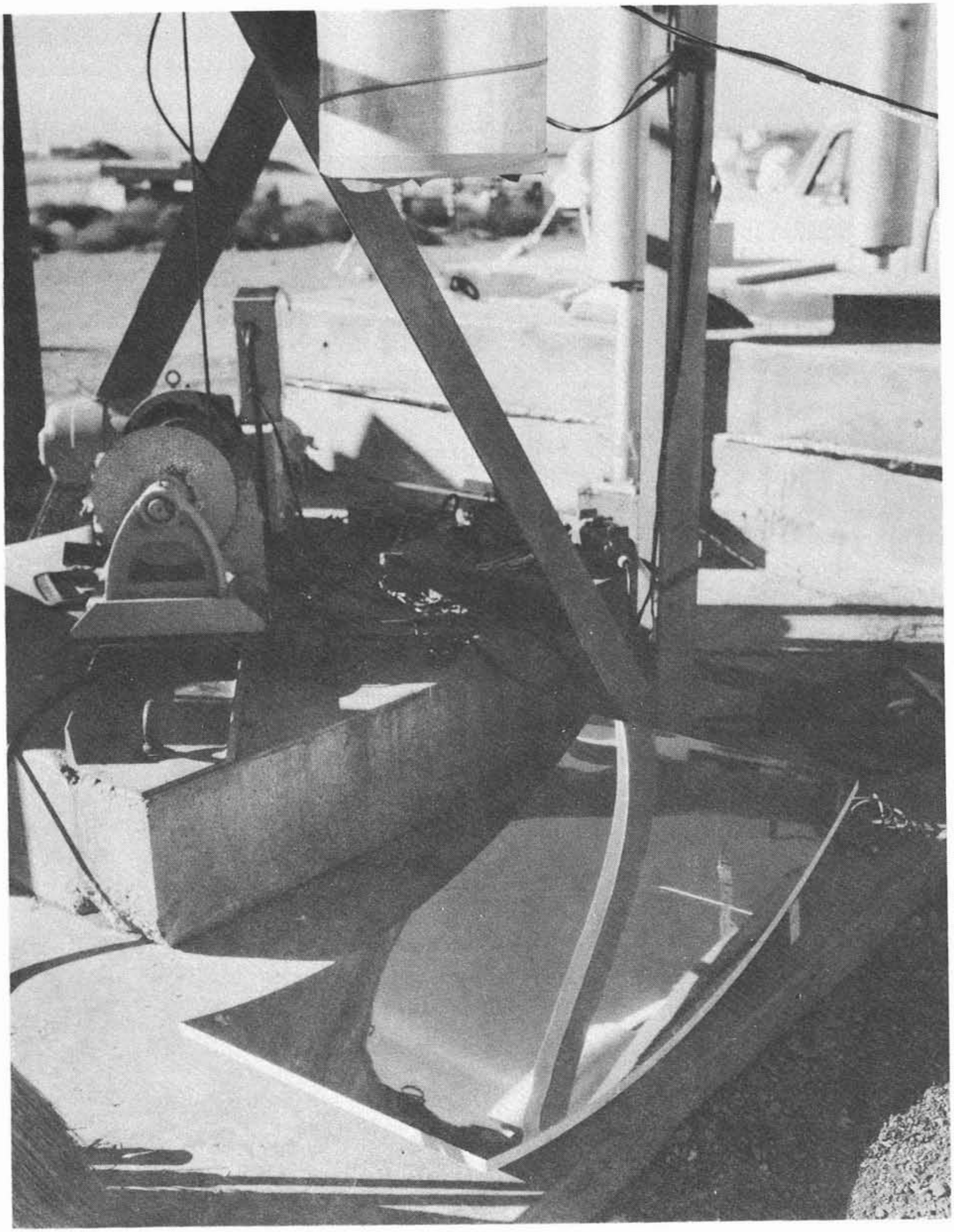

Figure 4. Sandia's Hail-Impact Gun

Significant achievements for FY78 included

1. New Materials. Several new solar mirror materials were obtained and their solar reflectance properties determined. These materials include

   - Enhanced front-surface aluminum reflectors obtained from OCLI of Santa Monica, CA. The reflector consists of an evaporated aluminum film deposited on Alcoa's Type 1 Lighting Sheet (Coilzak) and coated with a multilayer stack to enhance solar reflectance and provide environmental protection. The solar-averaged hemispherical reflectance was 0.88±0.01, while the specular reflectance at 500 nm was significantly below the hemispherical reflectance at 500 nm. Thus the specular reflectance was 0.19 reflectance units below the hemispherical value at 15 mrad and 0.13 reflectance units below at 8 mrad.

   - A silvered-glass mirror was obtained from Donnelly Mirrors of Holland, MI. From measurements of the silvered mirror and transmittance data from an identical glass blank, the solar average reflectance properties of the silver-glass interface were determined to be 0.97±0.026. Since the solar reflectance typical of chemically deposited silver is 0.95, it appears that the vacuum silvering process used by Donnelly is +2% higher, although this is within experimental error.

2. Portable Specular Reflectometer. Development of a portable specular reflectometer for field measurements of solar mirror materials has been completed (Figure 5). The instrument is designed to measure the absolute specular reflectance for a collection angular aperture of 24 mrad. Because the bandpass of the instrument is limited to a wavelength range from 400 to

700 nm, it cannot be used to measure solar average properties. Solar-average properties must be determined from other measurements. The instrument has been designed primarily to measure the specular reflectance loss from dirt accumulation and surface scratches on mirrors located in the field. Additional testing of this instrument is planned in an outdoor environment at Sandia's MSSTF and CRTF. Details of the instrument are described in a Sandia report.[2]

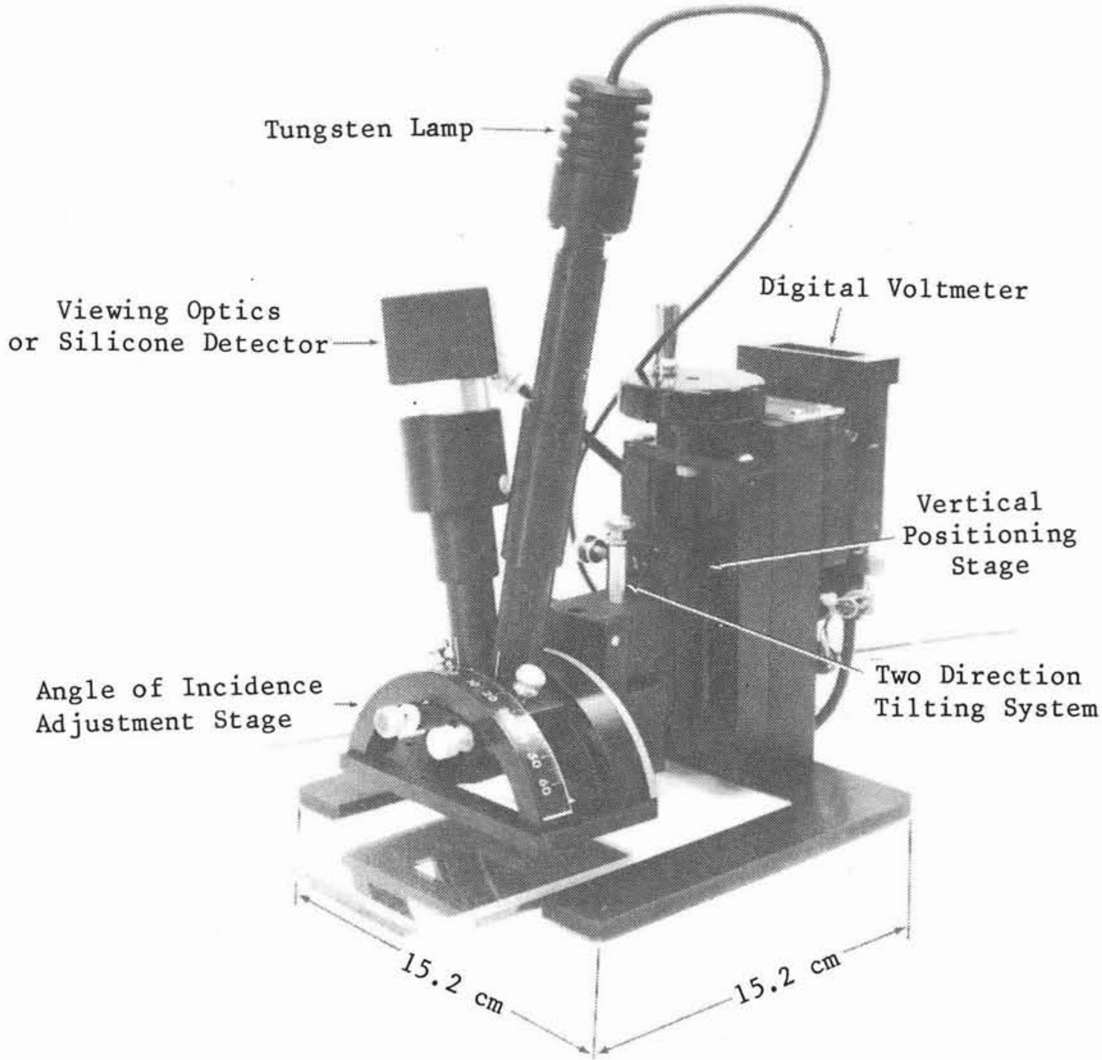

Figure 5. Portable Reflectometer for Specular Reflectance Measurements

The schedule for FY79 includes the following:

- Extend dust accumulation studies to other materials, including metallized plastics and aluminum sheet reflectors.

- Use portable reflectometer under field conditions and on curved surfaces on actual collectors.

- Determine incident angle properties of mirror materials.

- Start long-term mirror degradation testing.

Collector Development

Procurements

Hexcel -- The objective of this procurement was to establish a comparative range for performance capabilities of contemporary concentrating solar thermal collectors. The RFP was issued in December 1976 and the Hexcel collector was received in September 1977.

Figure 6 shows the Hexcel collector, a linear focus 72° rim-angle parabolic-trough configuration. The reflector is made of FEK 163, an aluminized second-surface acrylic film bonded to aluminum honeycomb panels formed to the parabolic shape. The receiver is a black-chrome-plated steel tube. The receiver tube is enclosed by a half-cylinder of Pyrex glass that faces the reflector and a half-cylinder insulated metal shield. A shadowband sensor is used for tracking.

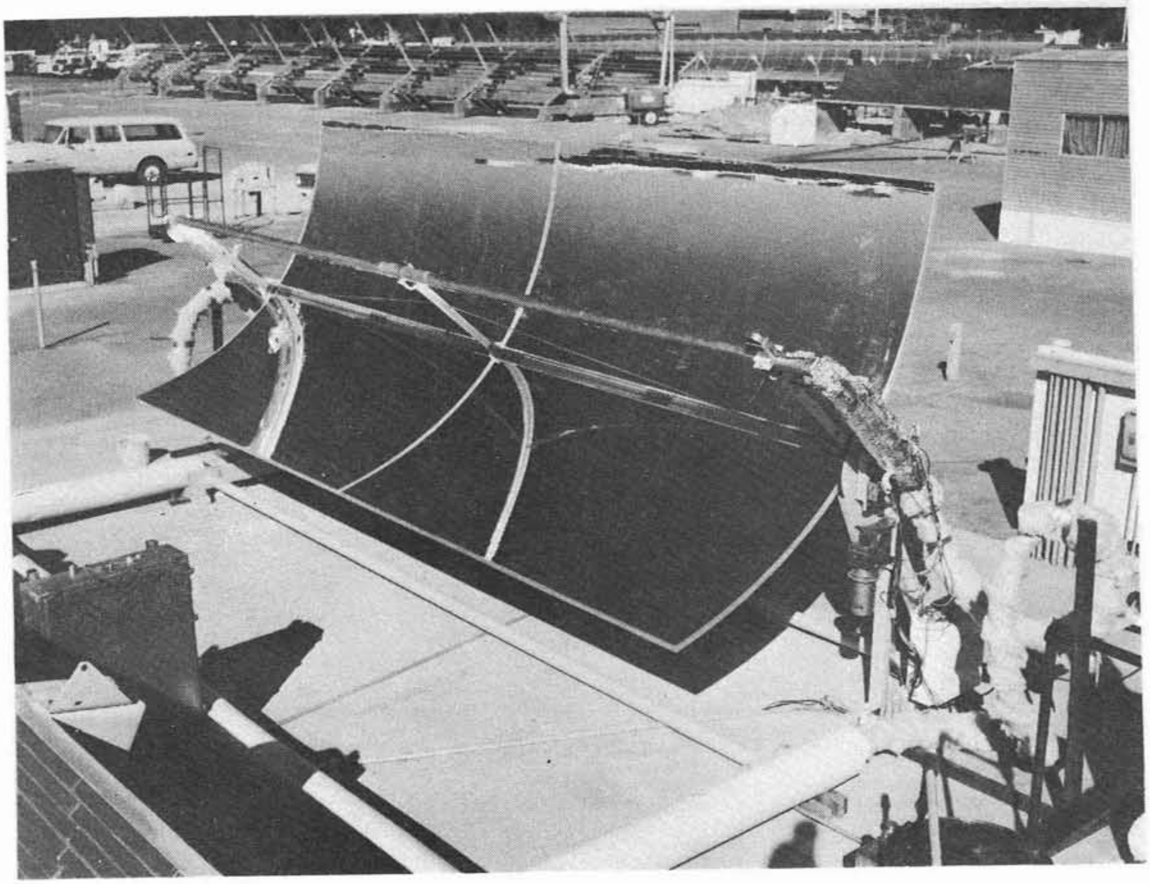

Figure 6. Hexcel Solar Collector

A Hexcel collector module was tested at Sandia Laboratories CMTF during October and November 1977. Figure 7 summarizes collector efficiency results and shows that the Hexcel collector has the highest efficiency of any linear collector yet evaluated. The collector was shipped to SERI after completion of the Sandia tests.

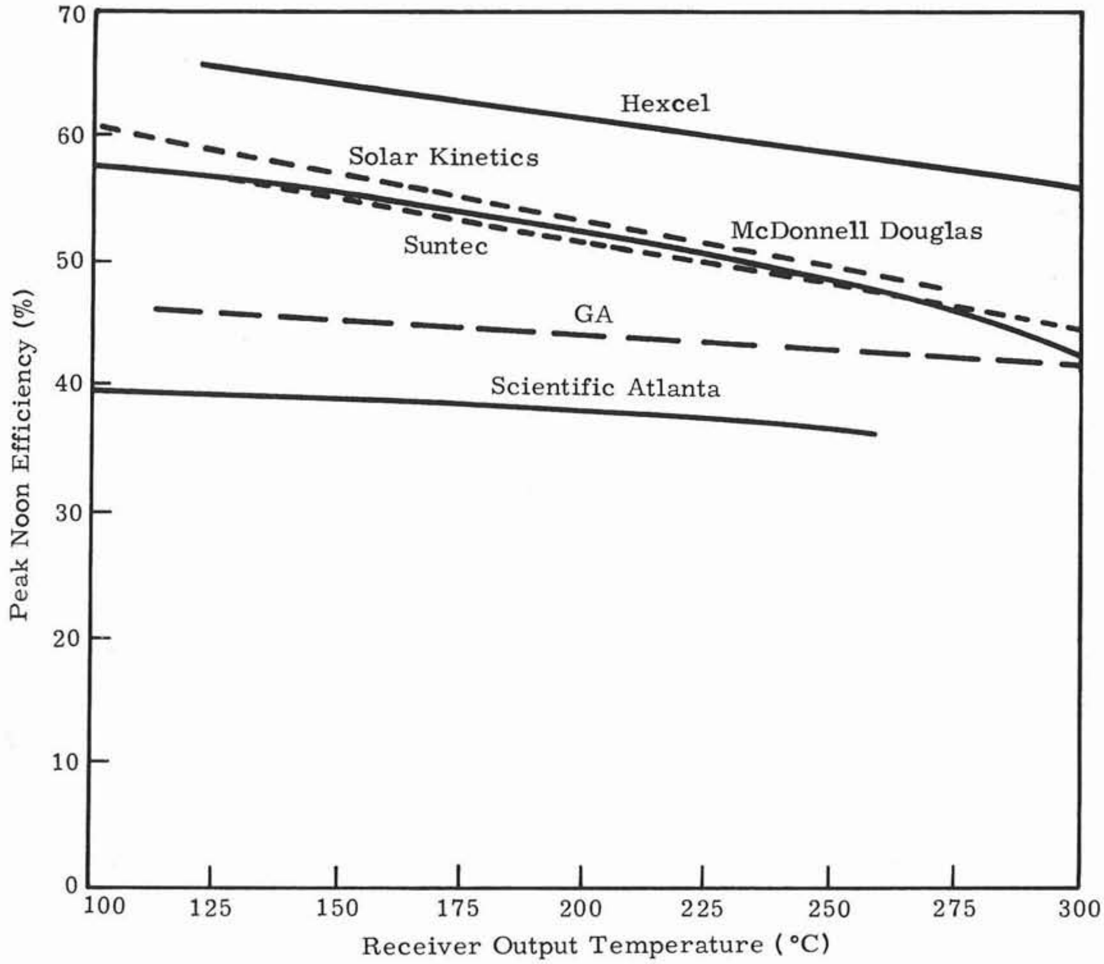

Figure 7. Comparison of Peak Efficiency vs Temperature for Several Concentrating Collectors

Scientific-Atlanta -- The objective of this procurement was to establish a comparative range of performance capabilities for contemporary concentrating solar thermal collectors. The RFP was issued in December 1976 and the Scientific-Atlanta collector was received January 1978.

Figure 8 shows the Scientific-Atlanta Collector, a faceted fixed-mirror concentrator similar in concept to the General Atomic collector. However, this collector uses sheet-metal fabrication and construction techniques. The 76-mm (3-in.)-wide mirror facets are formed from low-iron glass silvered on the back side. The receiver is enclosed by a secondary reflector to help compensate for focusing errors and to further narrow the beam onto the receiver.

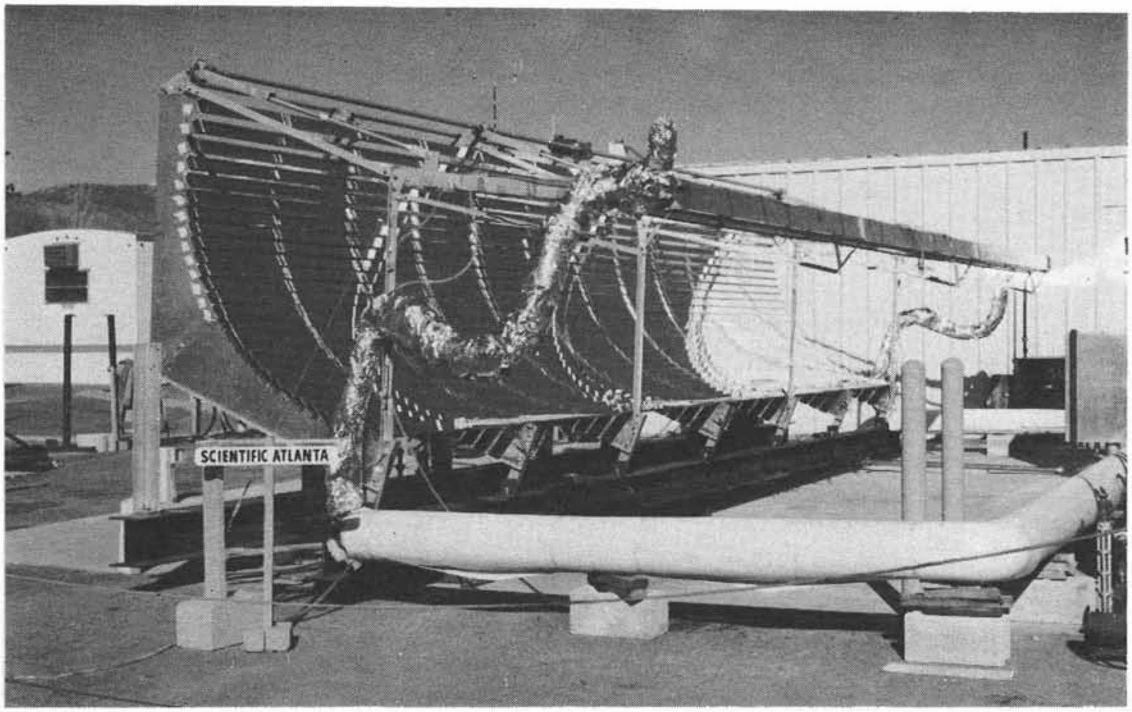

Figure 8. Scientific-Atlanta Solar Collector

The Scientific-Atlanta collector module was tested at the CMTF during March 1978. Collector efficiency results are shown in Figure 7. The alignment and stability of the mirror facets were inadequate to focus a high percentage of the reflected light onto the receiver. The poor performance in this test series does not rule out the use of sheet metal in a collector of this type. Sheet metal may have advantages in weight, cost, simple production, ease of assembly, etc.

Solar Kinetics, Inc. -- The objective of this procurement was to establish a comparative range of performance capabilities of contemporary concentrating solar thermal collectors. The RFP was issued in December 1976; the Solar Kinetics collector was received in December 1977.

Figure 9 shows the Solar Kinetics collector, a linear-focus 90° rim-angle parabolic-trough configuration. The reflector is composed of FEK244 film bonded to 1.02-mm (0.040-in.) T-6 aluminum sheet held in the parabolic shape by extruded aluminum ribs. The receiver is a black-chrome-coated steel tube enclosed within a Pyrex glass jacket in a cylindrical configuration.

Figure 9. Solar Kinetics Solar Collector

Collector tracking is done through a hydraulic-drive system that also incorporates an accumulator to defocus the collector in case of power failure.

The Solar Kinetics collector module was tested in the CMTF during January 1978. Figure 7 shows the peak efficiency results.

Polisolar -- The objective of this procurement was to establish a comparative range of performance capabilities for contemporary concentrating solar thermal collectors. The RFP was issued in December 1976 and the Polisolar collector was received in November 1977. The collector was purchased from Soltrax, Inc., the US distributor for Polisolar at that time. Soltrax has since ceased doing business.

Figure 10 shows the Polisolar collector, a linear-focus 120° rim-angle parabolic-trough configuration. The basic unit collector module consists of six parallel trough units, 3.19x0.57-m each (1.82-m^2 aperture) fastened into a rectangular framework 3.44x5.7 m. This unit collector module provides ~11 m^2 of aperture area. A sagged-glass mirror forms the reflecting surface. The receiver is a black-coated steel tube enclosed within a glass jacket in a cylindrical configuration. The trough pivots about the fixed receiver tube.

The Polisolar collector will be tested in the CMTF in FY79.

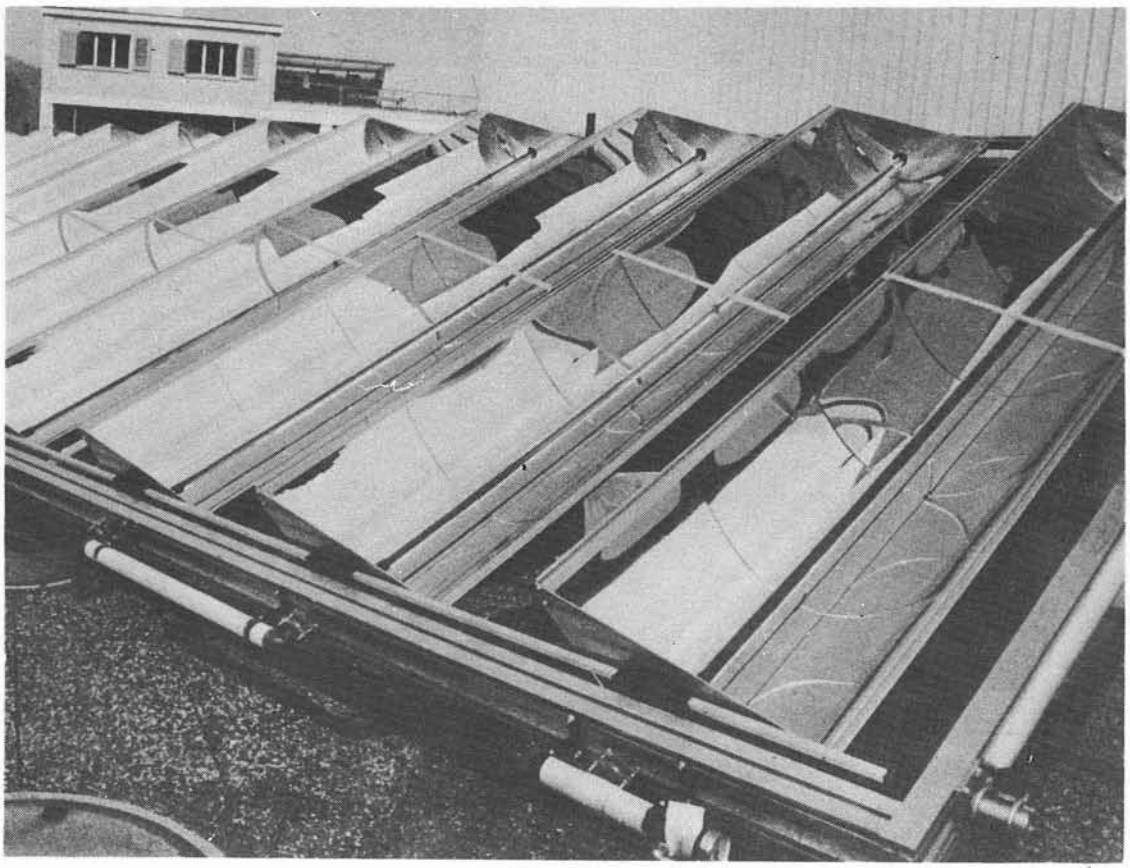

Figure 10. Soltrax Polisolar Parabolic-Trough Collector

GE -- The GE receiver contract grew out of technical proposals for MSSTF subsystems. This is an alternate design of a low-rim-angle receiver tailored to Suntec SLATS requirements. The receiver was delivered in November 1977 and installed on the Suntec SLATS module at the CMTF.

Figure 11 is a cross section of the GE receiver. This receiver, a Type 304 stainless-steel flow tube with a brazed chrome-copper absorber plate, is coated with black chrome. A window of borosilicate glass with fluoride antireflective coating covers the absorber assembly. Behind the absorber is 10 cm (4 in.) of fiberglass insulation and a steel cover.

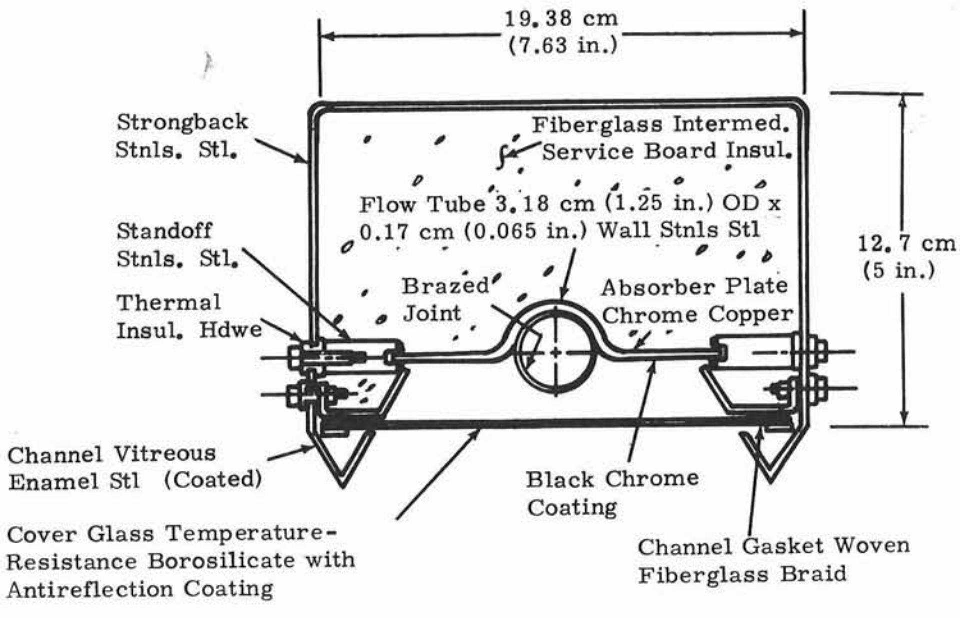

Figure 11. Cross Section of GE Wide-Aperture Receiver

The receiver will be tested in the second quarter of FY79 in the CMTF for comparison with the Suntec and Itek receivers.

Itek -- The Itek receiver contract grew out of technical proposals for MSSTF subsystems. This is an alternate design of a low-rim-angle receiver tailored to Suntec SLATS requirements. The receiver was delivered in December 1977. Shipping damage was repaired and the receiver placed in storage until test time is available in the CMTF.

Figure 12 shows the Itek design. The absorber tube is 4130 alloy steel coated with Pyromark Series 2500 black paint. The tube is located in a deep mirror-lined cavity that acts as a secondary concentrator. A Pyrex window reduces conventional thermal losses. The back surface of the tube is insulated with Min-K.

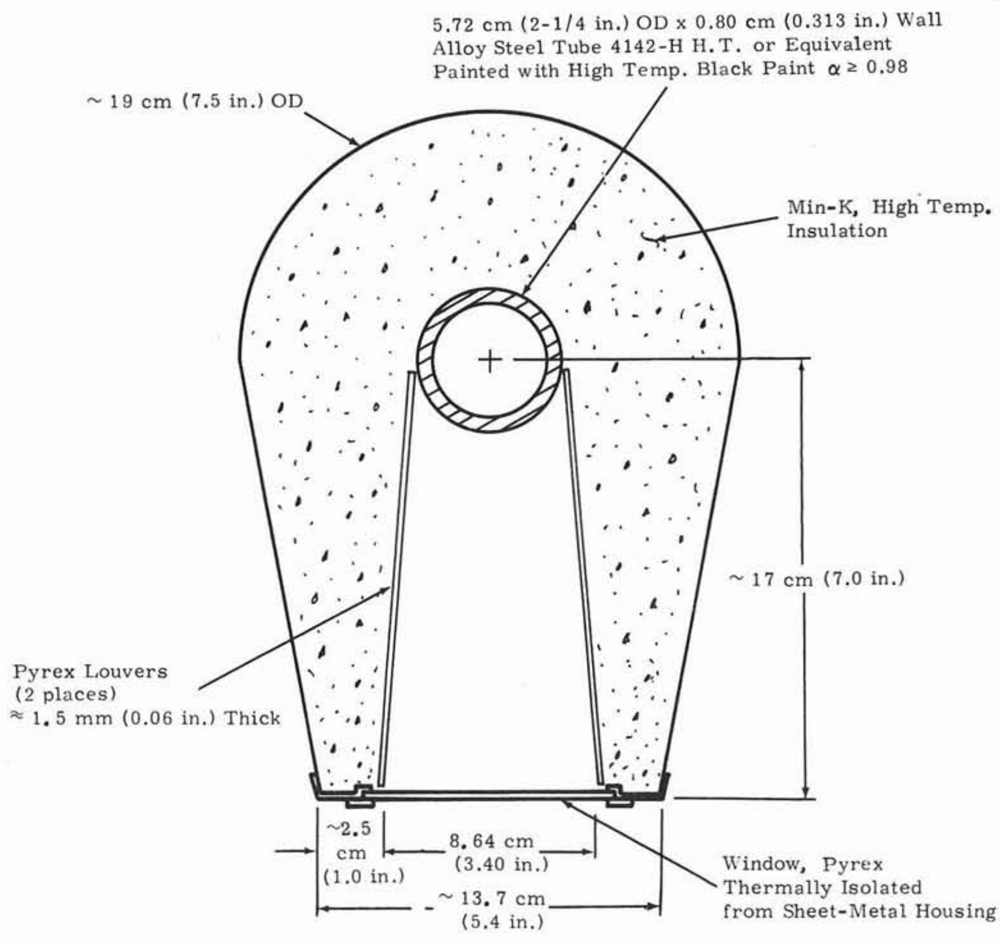

Figure 12. Cross Section of Itek Receiver

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The receiver will be tested after completion of the GE receiver for direct comparison with the Suntec and GE receivers.

FMC -- The contract for developing a Fresnel-belt solar collector was completed with delivery of the test unit. This contract was placed in March 1977 to design, fabricate, and test a collector concept conceived by FMC using a Fresnel-belt reflector that moves on a cylindrical path to track the sun's movement. The receiver tube is fixed at the center of the cylinder; thus no flexible plumbing connections are required. The FMC design is shown in Figure 13.

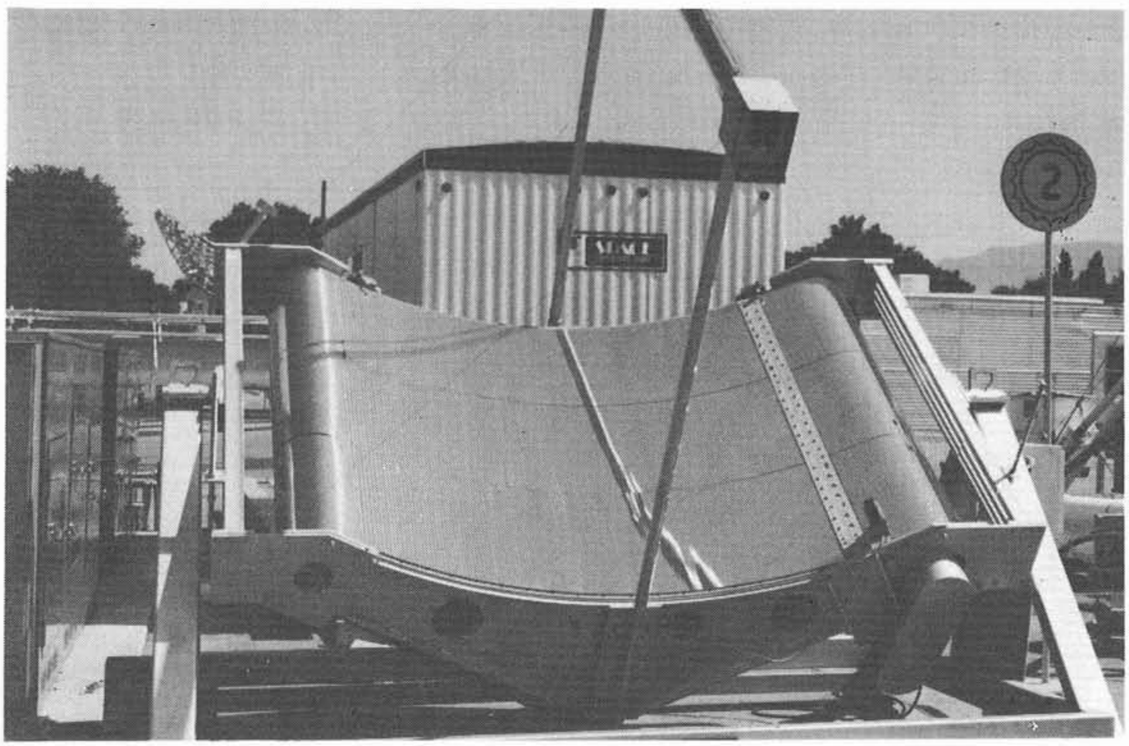

Figure 13. FMC Solar Collector

The reflector material consists of narrow 12.7-mm (1/2-in.) strips of glass mirrors with a front-surface metallization and a protective overcoat. OCLI supplied the mirrors. The mirror strips are attached to a 0.6 m (24-in.)-wide belt of stainless steel that moves on the cylindrical surface; they are bonded to the steel belt with a rubber material to allow flexing as the belt moves. Each mirror strip is tilted at a separate angle to reflect incident sunlight to the receiver assembly at the center of the cylinder.

In large collector fields, the orientation would be E-W with the aperture of the cylindrical section tilted to latitude angle. The small test unit had a N-S axis with polar axis and a declination tilt adjustment. The Fresnel-belt concept is limited in its tracking capability because the N-S test unit could operate only 2 h on each side of solar noon. It is also essentially a fixed-aperture unit, except for a potential capability for weekly or monthly declination adjustment.

The receiver tube of the test unit is a unique arrangement in which the 2.7-mm (1/2-in.)-dia steel tubes were nested in a semicircle within a 127-mm (5-in.)-dia glass envelope. Heat-transfer fluid flow proceeded through the outer tubes in sequence and finally through the center tube just before exiting. The glass envelope could be evacuated. For a field installation, the receiver tube would consist of only three tubes within the glass envelope. Flow would be continuous through the full length of the collector array in the manner typical of parabolic-trough receiver tubes. No testing will be conducted on this large field-receiver design; only analysis has been done.

The Fresnel-belt collector unit has been installed on the T66 test loop of the CMTF and some preliminary testing done. There are problems in the thermocouple instrumentation, so no valid performance data has been accumulated. Testing in FY79 is planned both with and without vacuum in the receiver envelope so that performance can be characterized.

<u>Del Manufacturing</u> -- A contract for developing a parabolic-trough solar collector using sagged-glass mirrors for the reflector material was placed with Del Manufacturing Co. in the spring of 1977. The contract required design analysis, fabrication, delivery installation, and testing a collector module with 11.89 m^2 (128 ft^2) of aperture.

Individual collector units are 0.61x2.44 m (2x8 ft) with a rim angle of ~110°. The troughs rotate about the fixed receiver tube. Each 0.61x2.44-m (2x8 ft) unit incorporates 16 pieces of sagged (pressed) glass in two configurations. Each glass mirror is 0.61 x 0.22 m x 3.2 mm (24x8-1/2x0.125 in.) and is silvered on the second surface. The 0.61-m (24-in.) dimension is oriented parallel to the trough length; the 0.22-m (8-1/2-in.) dimension is the parabolic arc with two pieces required to complete the arc between the vertex and one rim. Four pieces of 0.22-m (8-1/2-in.) wide glass are required for the rim-to-rim reflector.

The structural frame of the collector was designed to minimize material, use standard structural steel elements (square tubing, angles, etc), and provide adequate torsional rigidity so that several units can be driven in series with one motor. The Del design is shown in Figure 14.

Del designed and fabricated an initial model, then tested it briefly on their test loop. A redesign improved torsional rigidity. The later version was fabricated, delivered to Sandia, and installed for testing on the high-pressure water loop of the CMTF.

Del personnel directed testing to establish performance characteristics. A final report is in preparation. Table 2 summarizes basic performance.

Table 2

Peak Solar-Noon Efficiencies for Del Collector

Outlet Temperature (°C)	Peak Efficiency at Solar Noon (%)
115	63
175	57
254	48
291	40.5

The Del collector has been selected for installation in several major projects, including process heat and heating and cooling applications.

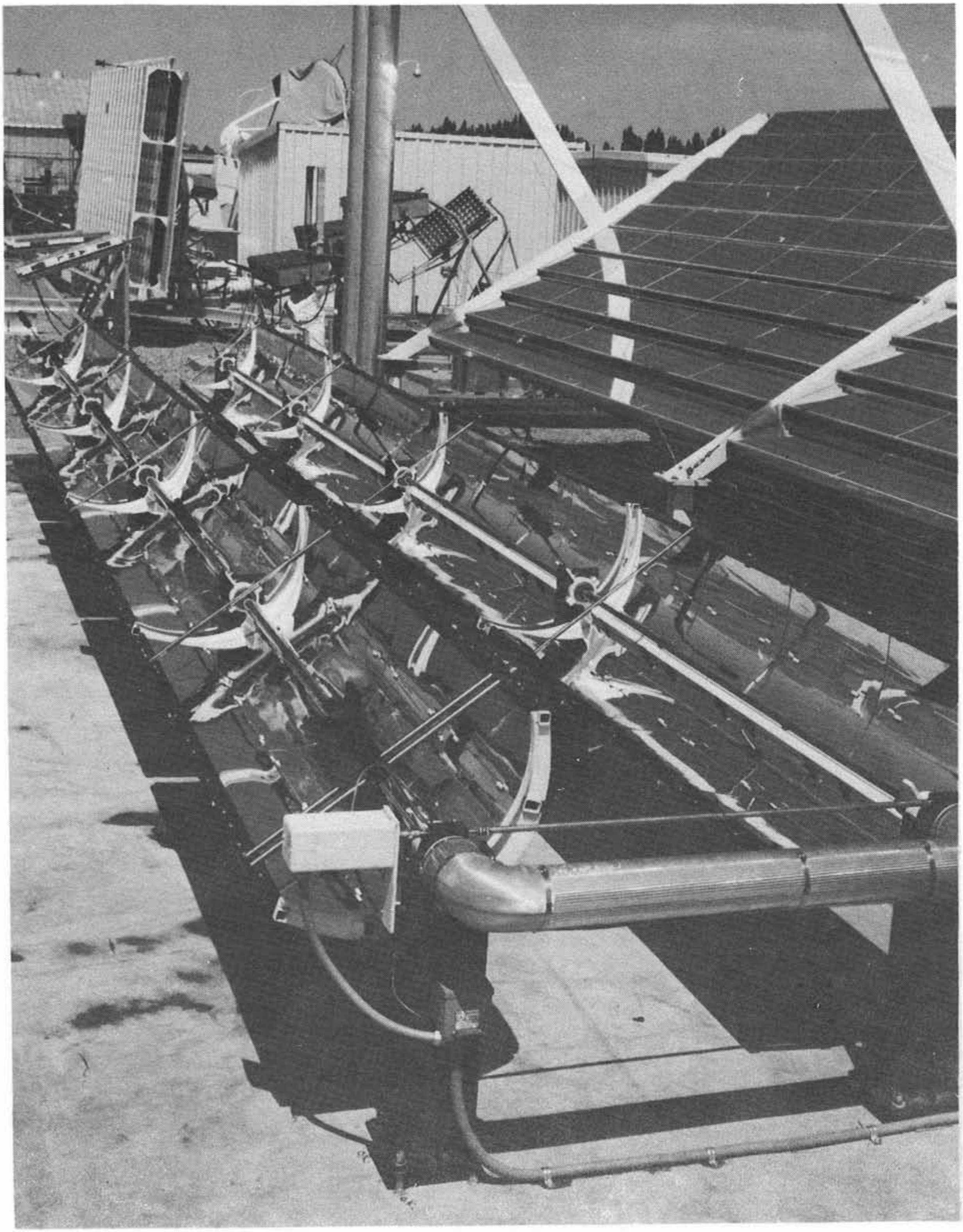

Figure 14. Del Solar Collector

A series of hail tests were conducted on a Del collector unit in August using 12.7-, 19-, and 25.4-mm (1/2-, 3/4-, and 1-in.)-dia ice balls to simulate hail. The hail was dropped from 27.4-m (90 ft) to approximate terminal velocities. The collector was located under the hail-tube outlet so that impacts were made at a variety of incidence angles and at locations in the center, along the edge, and on corners of the 0.61 m x 0.22 m x 3.2-mm (24x8-1/2x0.125-in.) glass panels. Both sides of the glass were impacted to establish hail resistance in both normal operating and storage positions. No damage was sustained by the reflector panels due to impact of 12.7 (1/2-) and 19-mm (3/4-in.) hail. The receiver-tube glass envelope withstood all impacts by all three sizes of hail with no damage.

One glass panel was broken by a single near-normal impact of a 25.4 mm (1-in.)-dia ice ball near the curved 0.22-m (8-1/2-in.)-long edge. Subsequent single 24.5 mm (1-in.)-dia drops completed the destruction of the panel. About 40 other 24.5 mm (1-in.)-dia ice balls were dropped later (including salvos of 10 or 12 balls) at all locations and near-normal incidence angles to the glass panels. There was no further damage.

Results of the hail test indicate the Del collector is highly resistant to 12.7 (1/2-in.) and 19-mm (3/4-in.)-dia hail and is also resistant to 24.5 mm (1-in.)-dia hail. Edge conditions of the glass can be expected to play an important part in the hail resistance of glass reflectors.

Design Studies

Boeing -- The Boeing design study contract was issued September 1977 as a result of the novel collector RFP. The objective of this procurement was to stimulate the development and evaluation of novel designs for solar thermal collectors operating in the mid-temperature (230° to 330°C) regime.

The Boeing collector concept consists of an air-inflated cylinder of lightweight plastic. The top half of the plastic cylinder is transparent, while the bottom half is coated internally with a reflective film. A black-chrome absorber tube with fins approximating a triangular cross section is used. Since the circular reflector shape does not provide a sharp focus of reflected energy, the triangular receiver section intercepts a larger part of this energy.

This concept offers a very lightweight design, and thus the potential for a low-cost collector. In addition, the light weight should contribute to low transportation costs and simplify rooftop installations. However, performance potential is also relatively low. Figure 15 illustrates this collector concept. The project was concluded at the end of the preliminary design phase.

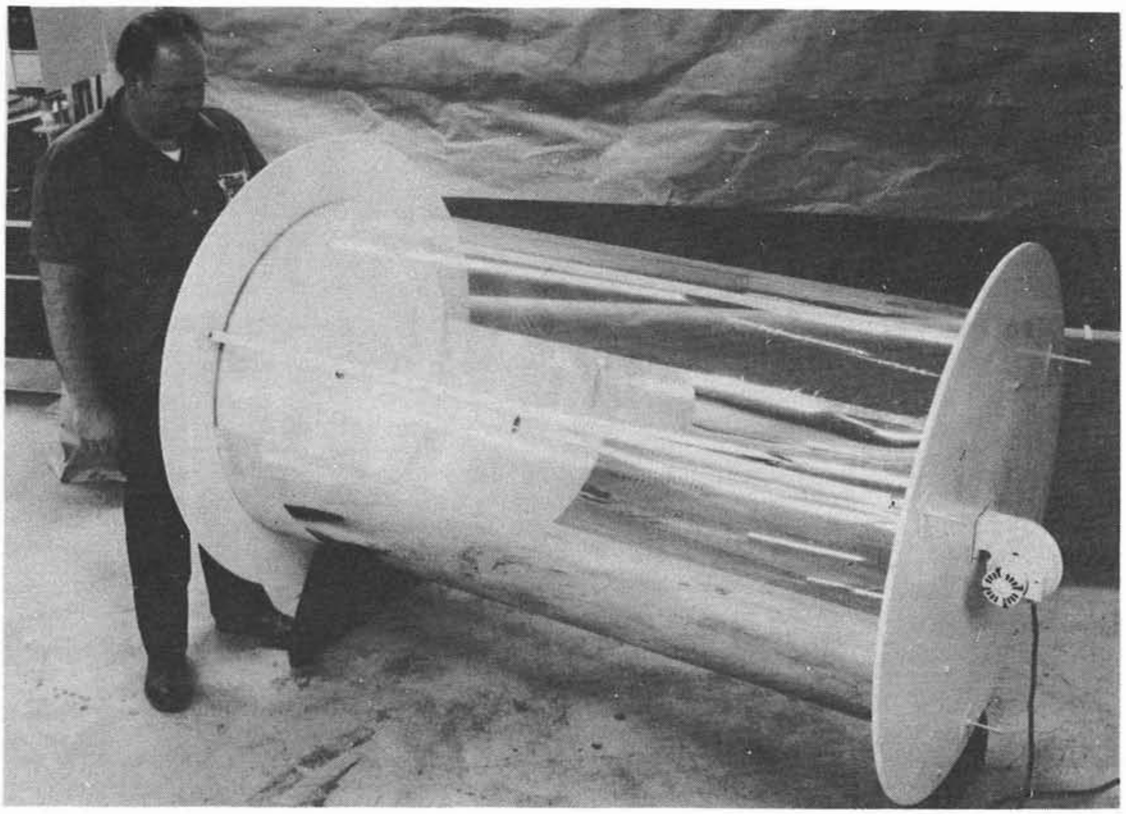

Figure 15. Air-Supported Collector Mockup (34-in. dia x 5 ft)

McDonnell Douglas -- The MDAC design study contract was issued September 1977 as a result of the novel collector RFP. The objective of this procurement was to stimulate development and evaluation of novel designs for solar thermal collectors operating in the midtemperature range.

The MDAC collector concept is a point-focusing system using a series of Fresnel lenses and disk receivers mounted on a pedestal. The design consists of 3-m^2 lenses in an array mounted in a rectangular framework. Behind each lenses is 0.3-m-dia flat disk receiver. The receiver is mounted behind a low-iron glass cover plate and backed with bulk fiberglass insulation to minimize thermal losses. The pedestal mount provides for asimuth-elevation tracking to maximize the energy intercept capability of this system. However, with cast-acrylic lens, system optical efficiency is limited to ~70%. Figure 16 illustrates this collector concept. The project was terminated at the end of the preliminary design phase.

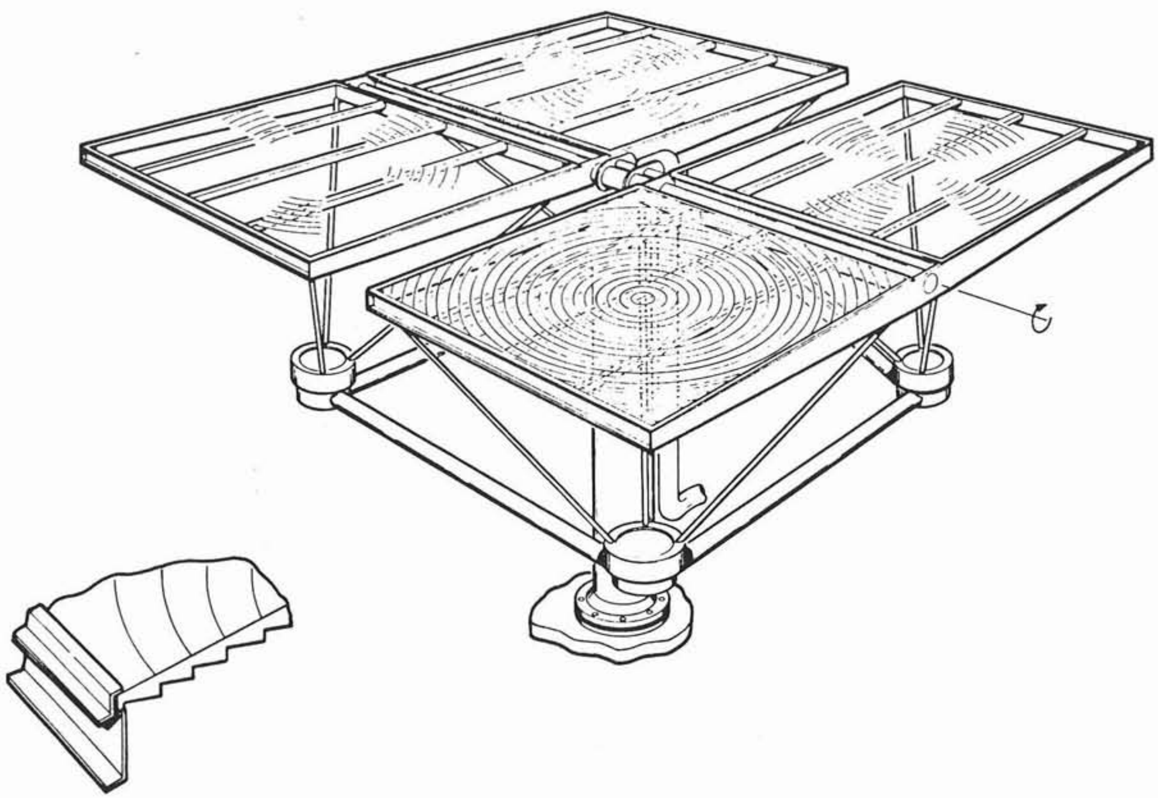

Figure 16. Large Circular Fresnel Lens Collector Assembly

Trough Development Project

Line-focus collectors have not yet been developed to their full potential in performance, life, or cost. One of the last ways left to substantially reduce collector cost is mass production, using mass-production tooling and techniques. To ensure that line-focus collectors have been adequately developed before massive investments in tooling are made, the Trough Development Project was initiated in FY78. Development of line-focus technology to its full potential is the major objective of this program. Attaining this objective means establishment of a realistic high-performance, long-life target for the line-focus collector industry. It will also allow potential mass-production manufacturing to acheive insight into mass-production problems.

5

The trough development project consists of three major elements:

1. In-house design of an engineering prototype collector to investigate promising design configurations and to demonstrate the feasibility of a collector operating at 316°C (600°F) and 60% noontime efficiency. This engineering prototype collector design will be based on immediately available technologies and fabrication techniques.

2. Design and demonstration of three parabolic-trough collectors, each based on a different manufacturing technology with mass-production potential. These collectors will require more time for their design since they will be based on evolving technologies.

3. Technology transfer to industry and commercialization of some collector components.

The general program approach is as follows:

- Select a Line-Focus Concept Generically. Since there are not sufficient resources to develop all concepts simultaneously, one must be selected as most important. The first concept developed will be a line-focus parabolic-trough suitable for E-W or N-S use in a horizontal plane.

- <u>Investigate In-House Design and Fabrication of Engineering Prototype Collector</u>. This collector prototype will investigate promising design configurations and confirm that a collector operating at over 60% noontime efficiency can be built. The design of this collector will be compromised where necessary in order to use immediately available technologies and fabrication techniques.

- <u>Select Three Viable Manufacturing Concepts for Further Development</u>. Previous work has shown that satisfactory reflector structures can be fabricated using several different technologies. Concepts based on sheet-metal, sheet-molding compound, and sandwich-construction processes have been selected for further development.

- <u>Develop a Collector Design for Each of the Three Manufacturing Concepts</u>. This design, based on industrial inputs, requires developing a detailed in-house analytical capability and supporting hardware development to investigate problem areas. These designs will differ from the Engineering Prototype Collector in that they will be based on technologies that do require further development simultaneously with the design of the collectors; also, the design will be oriented toward the modular group of collectors best suited for a collector field and not toward a single collector.

- <u>Stimulate Commercialization</u>. Many potential collector manufacturers are not interested in the design and fabrication of all components of a collector system. Activities must therefore be initiated to ensure that components such as trackers, drive systems, control systems, collector field components, and foundations are developed and commercially available to collector manufacturers.

- Award RFP for Fabricating Each of the Three Collector Concepts. These RFPs will be in two phases. Phase 1 will allow the manufacturers to redesign the designs furnished (within limits) to facilitate mass-production techniques. Phase 2 will authorize fabrication of prototypes using production or quasiproduction tooling. In effect, Phase 2 will allow manufacturing development from which more realistic mass-production cost estimates can be made.

- Test and Evaluate Prototype Collectors. Testing and evaluation will be conducted at the CMTF.

- Encourage Technology Use. Activities will begin that encourage manufacturers to use all or part of the developed technology in their own marketing designs.

Figure 17 presents schedules and major milestones of the Trough Development Project.

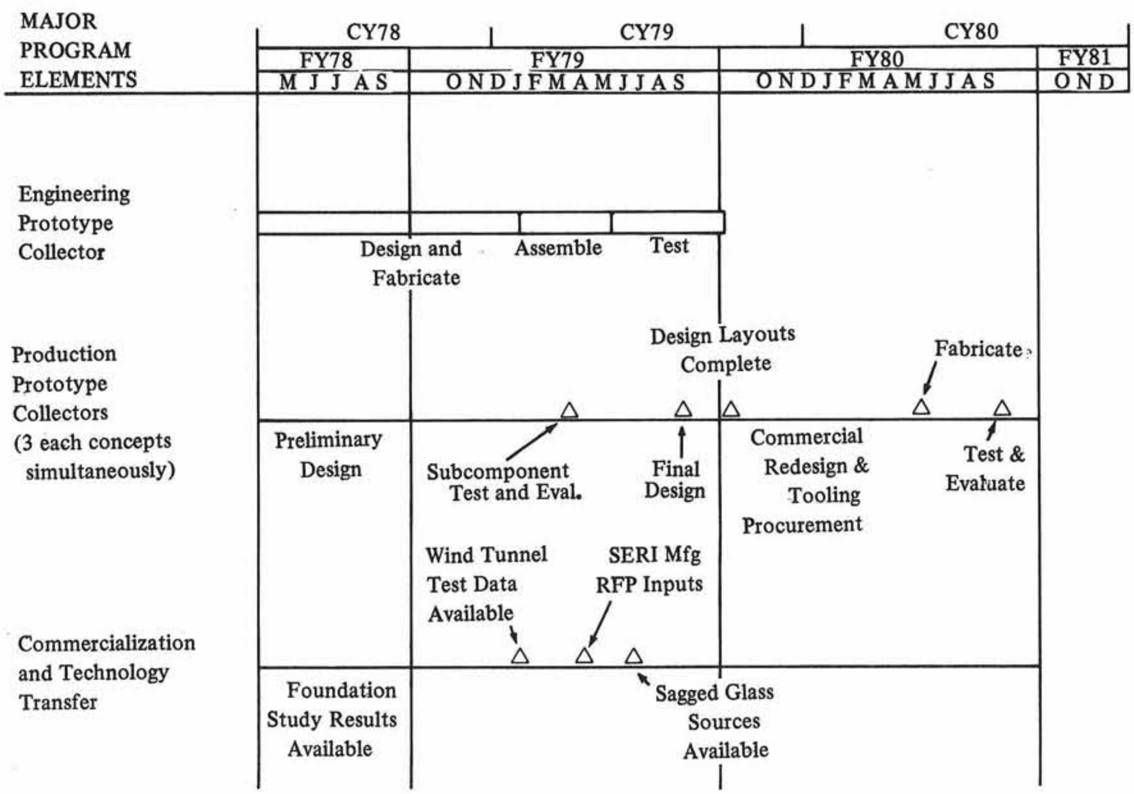

Figure 17. Trough Development Project Schedules

Program Status -- A detailed program schedule/milestone chart has been prepared that breaks the Trough Development Project into 15 separate subtasks, with a single individual responsible for each subtask. The subtasks are Program Management, Engineering Prototype Collector, Receiver, Tracking, Drive, Foundations, Sheet-Molding Compound Design Layout, Sheet-Metal Design Layout, Sandwich-Structure Design Layout, Glass Support, Stress Analyses, Thermal Analysis, Field Control, Materials Development, and Glass Development. Significant program decisions have been made concerning wind loads, foundation requirements, and scope of the controls work.

Refinements in interpreting the 40 m/s (90-mph) wind survival requirements have been made to allow for (among other things) altitude scaling and wind fences that reduce aerodynamic forces by ~50%. The major effect of these new interpretations is that all new collector fields will require a wind fence of 50% porosity to survive 40 m/s (90-mph) winds.

The foundations study has indicated that foundation costs can be safely reduced from present costs of >32.29/m^2 (>\$3/ft^2) of aperture area to <\$10.76/m^2 (<\$1/ft^2).

Collector tracking has expanded from controlling collector tracking to tracking and fluid control for a typical field of collectors. Plans are to control tracking and fluid control from a single microprocessor system.

A test specification[3] is being developed to provide definitive requirements for performance-test qualification of line-focus, parabolic-trough thermal solar collectors. Tests are also being developed to qualify collectors for environmental exposure, accelerated life, and acceptance and field inspection.

Status of Engineering Prototype Collector -- The objective of the Engineering Prototype Collector project is to demonstrate a high-performance parabolic trough with a potential for long life. Glass is being used for the reflector to meet this objective. Exotic high-cost technology such as high-vacuum receivers will not be used.

Thin glass bonded to a steel backing sheet and elastically deformed to the parabolic-trough shape is the baseline design. The 2x6-m parabolic trough is a steel skin with aluminum core honeycomb structure. The honeycomb structures have a proved history of accurate surfaces and environmental stability from the structural materials evaluation project. Detailed finite-element structural analysis shows the glass will survive 40 m/s (90 mph) wind loads and will have acceptable deflections during 13.4 m/s (30 mph) wind-operate conditions. Figure 18 is a sample plot of stress in the glass near a support rib. A contract for six trough structures was placed with Hexcel in September 1978.

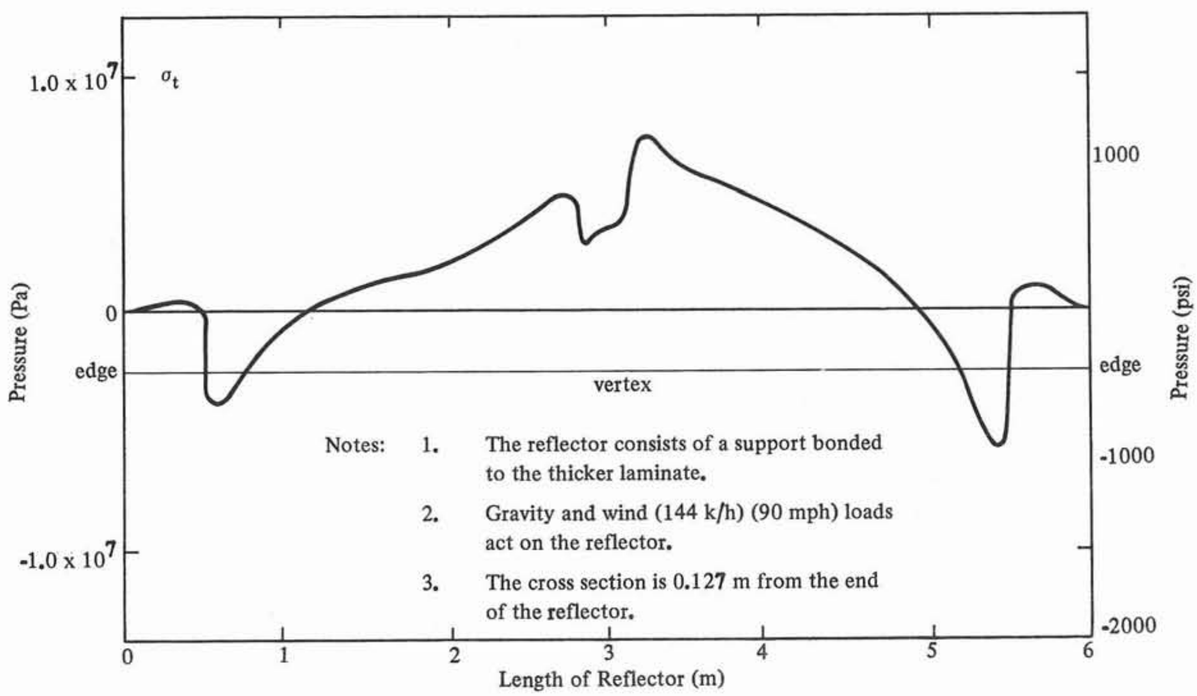

Figure 18. Stress Along Cross Section of 6-m-Long Reflector With Support Mechanism

Detailed all-day performance analysis has resulted in the selection of a 25.4-mm receiver tube enclosed in a 48-mm Pyrex glass tube with air in the annulus. Figure 19 is a typical plot of all-day efficiency as a function of operating temperature.

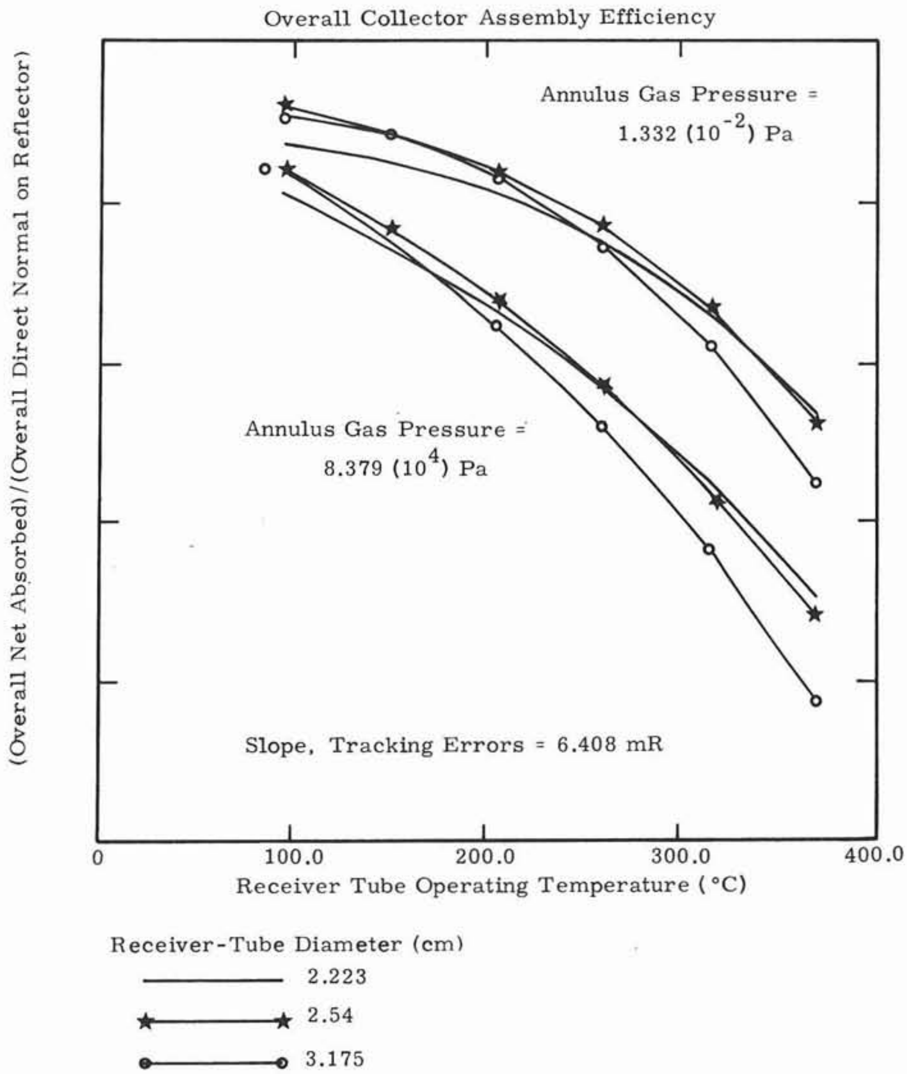

Figure 19. All-Day Collector Efficiency

A microprocessor-controlled tracker using a fine-wire flux sensor wrapped around the receiver tube will be evaluated on the prototype. Essential elements of the controller were breadboarded in the laboratory, and the flux-sensing wire was tested on the Solar Kinetics collector in the CMTF. Figure 20 shows the laboratory test setup.

Detailed drawings of the support and drive system have been completed and quotes on piece parts are being obtained. The collector should be assembled and ready for test in the CMTF by April 1979. It is expected to demonstrate a noontime efficiency of 60% at 300°C. Initial performance testing will be completed in May 1979 to support the Industry Trough Development Project.

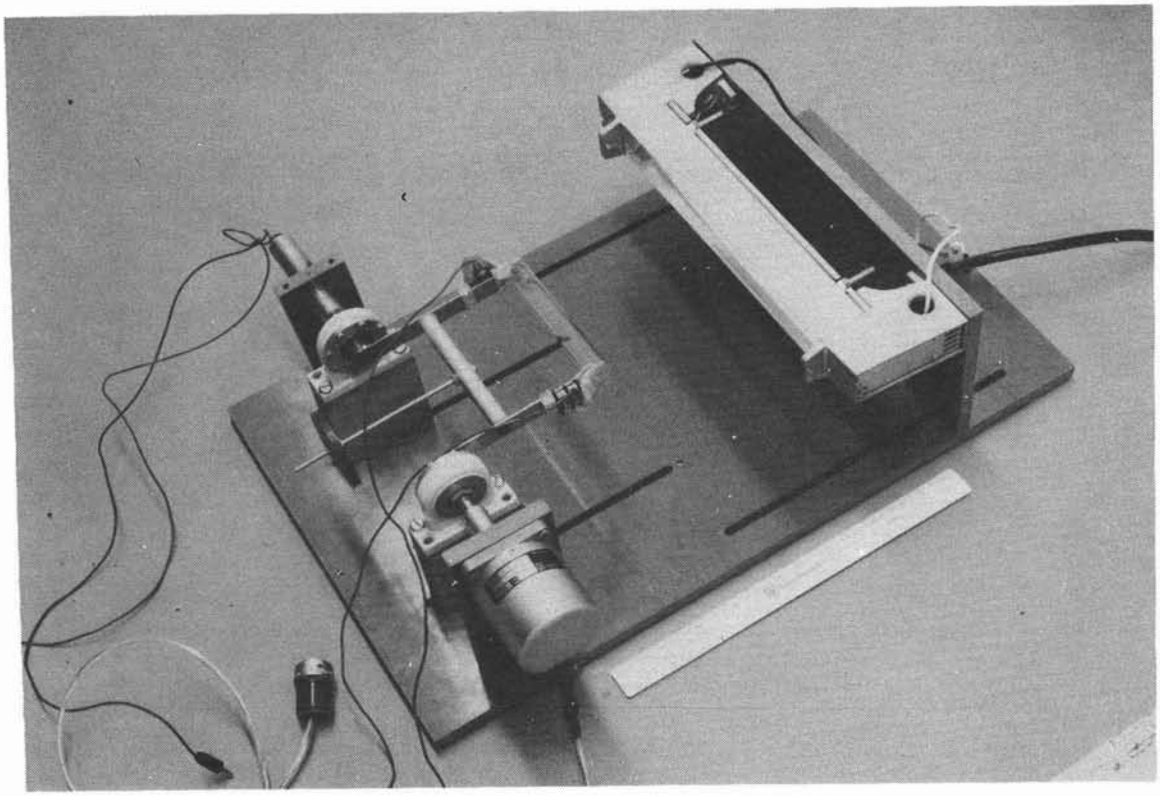

Figure 20. Flux-Sensing Tracker Lab Test Breadboard

Storage Development

Silicone Fluid Testing

Objectives of this effort in support of the Shenandoah LSE are to

- Obtain sufficient information to rank various materials in terms of their compatibility with Syltherm 800 fluid.
- Determine the fluid degradation as a function of temperature.
- Ultimately obtain sufficient data to calculate what fluid losses can be expected in the Shenandoah system.

The first series of tests began in March 1978 with 13 vessels containing granite rock, taconite, and various types of steel and iron. These tests were terminated prematurely because of problems in the vessel design. A new series of tests began in June with granite and taconite but also including a series to determine the effect of pressure on fluid losses. That series consisted of 12 vessels, all of which have since been terminated. Because of some data generated during these tests, additional tests of various scrap steels in several states of cleanliness and several quantities of surface area were started. Over the past year, 12 materials have been evaluated for compatiblity with Syltherm 800. The behavior of the fluid has been examined at three temperatures and five pressures. Results have been gathered from more than 41,000 vessel hours of test.

A fairly reliable order ranking of acceptable materials and a good understanding as to what is necessary to minimize fluid losses are now available. It is also known that cover gas pressure has no significant effect on fluid losses and that virgin steel is the material most compatible with the fluid. Figures 21 and 22 show the laboratory apparatus used to conduct the above tests.

Vessels are being fabricated to determine the effects of vapor space and surge tanks on fluid losses. Direct correlation between static tests and actual thermal storage system losses will then be possible. By March 1979 there should be sufficient information to calculate fluid losses for any desired heat-sink material in contact with Syltherm 800. A final report will be published in April 1979.

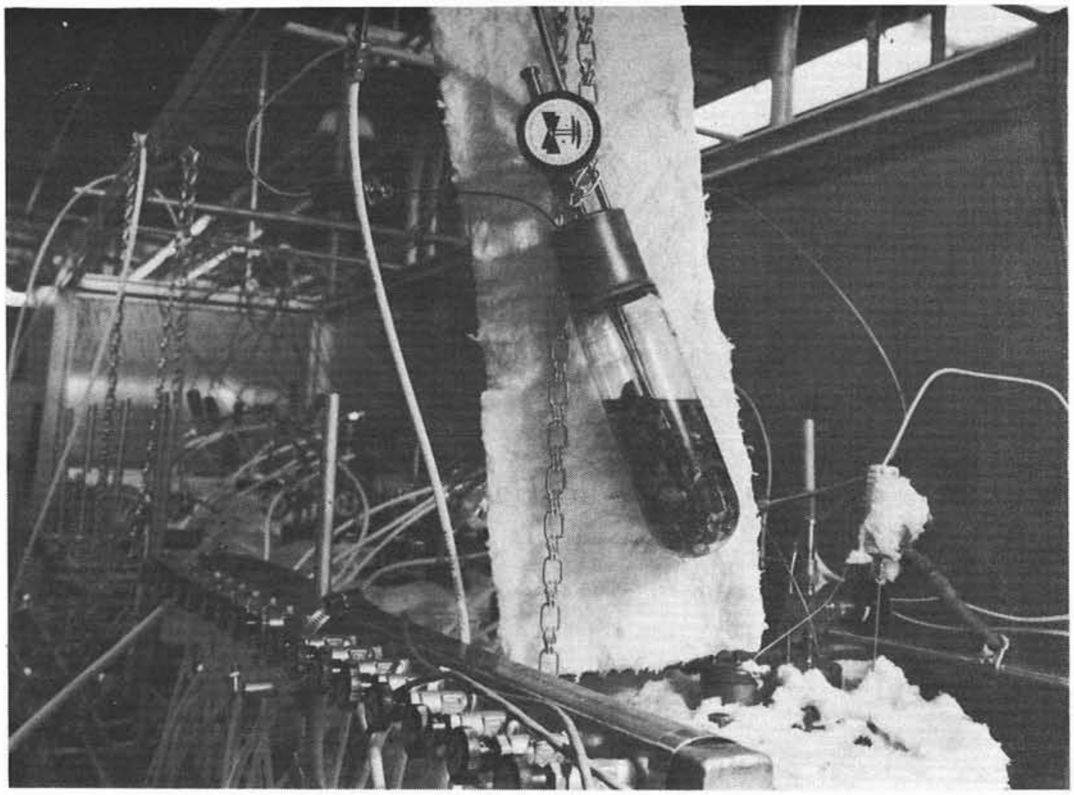

Figure 21. Silicone Fluid Test Equipment

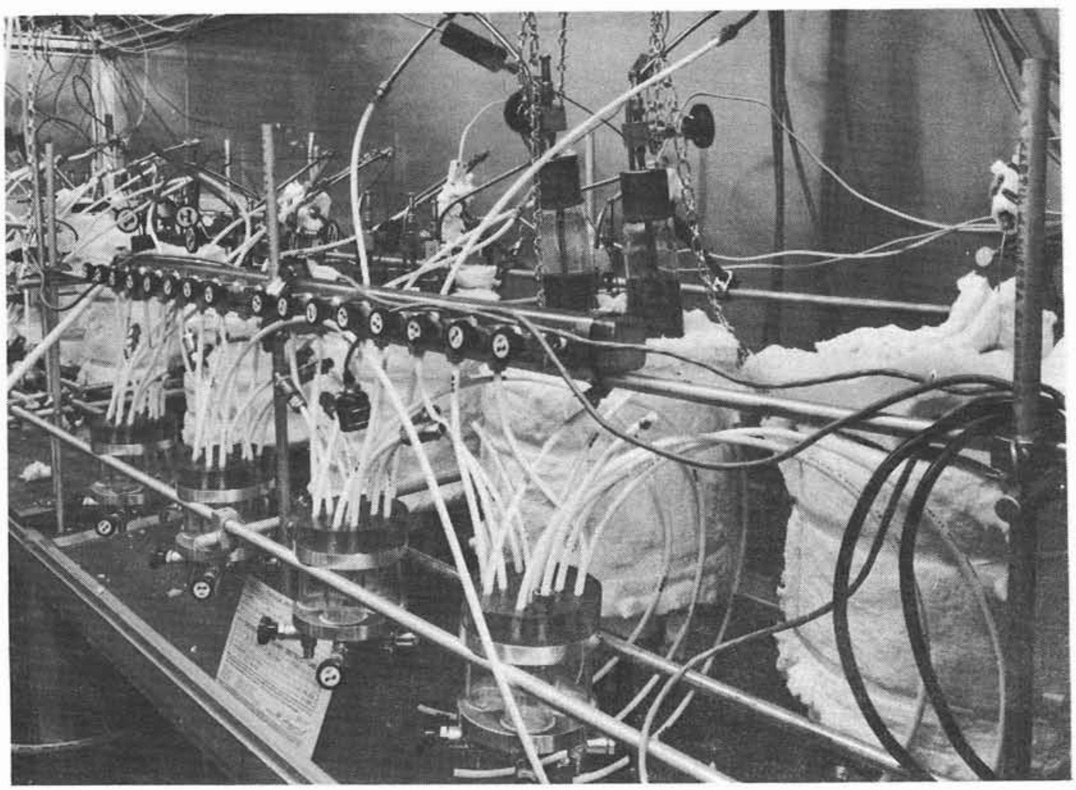

Figure 22. Another View of Silicone Fluid Test Equipment

Trickle-Oil Experimentation

This effort intends to assess GE's design concept for the HTS subsystem within the STE-LSE at Shenandoah, GA.

GE proposed in their preliminary design for the STE-LSE an HTS subsystem concept known as trickle oil. This design called for a number of trickle-flow packed-bed HTS modules, and offered a potential cost advantage over other HTS schemes by lowering the overall fluid inventory required for operation. This factor became even more significant when the decision was made to change the heat-transfer fluid from T66 to Syltherm 800 and obtain improved thermodynamic performance for the STE-LSE. However, no direct experimental evidence of trickle-flow HTS operation was known to exist.

GE designed and tested a prototype sub-scale rock and trickle-flow TES subsystem using a water and glycerine mixture as the working fluid. These tests confirmed the concurrent Sandia studies--that this concept produced inhomogeneous three-phase three-component TES operation with inherent limitations on scaling for both physical size and rate of energy transfer.

The Fluid and Thermal Sciences Department at Sandia experimentally determined the precise thermophysical properties of packed-bed TES configurations. They measured time-dependent characteristics for both fully filled and partially filled trickling-flow modes. These tests showed that the fully filled packed-bed TES scheme behaved as a homogeneous two-phase/two-component system and matched analytic predictions of performance. Energy-transfer processes for this mode could be confidently scaled to the LSE.

However, the trickle-flow experiments revealed inhomogeneous indirect TES behavior having three-phase/three-component elements. The spatial inhomogeneity reduced the contact area for the trickling fluid and thus lowered the thermodynamic reversibility of this type of TES. This feature made any direct attempt at scaling the trickle-flow TES to meet LSE design requirements speculative. Figure 23 shows the thermal energy storage experiment equipment used at Sandia for the above work.

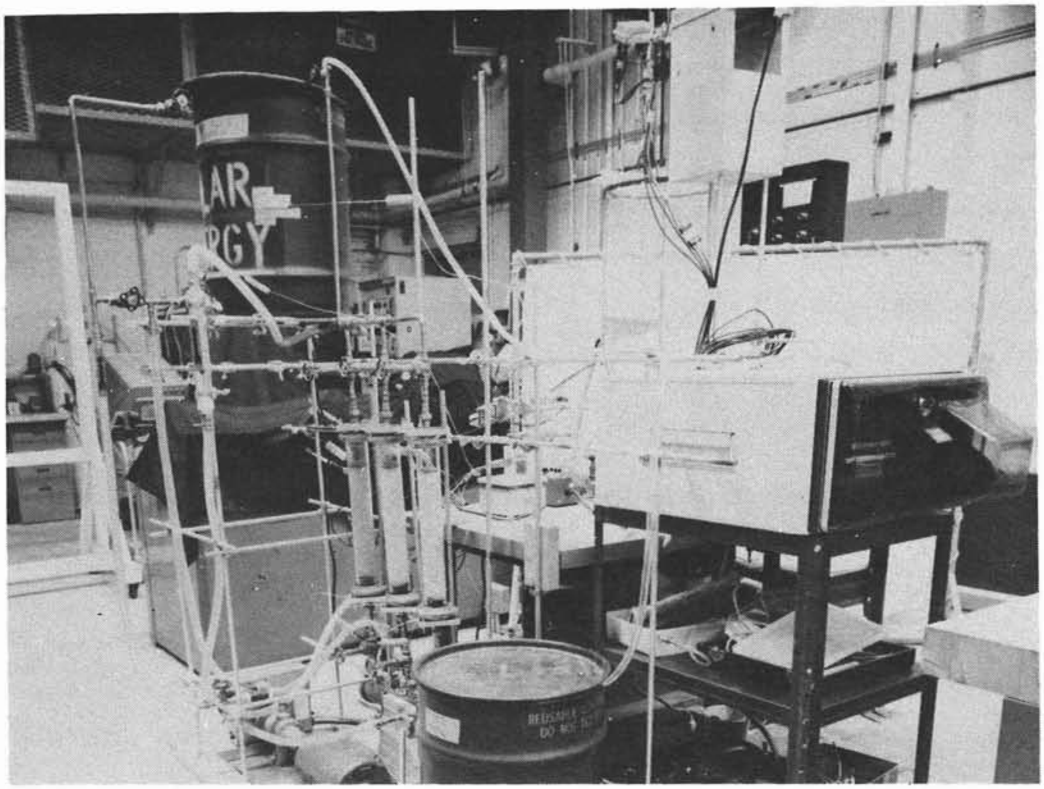

Figure 23. Sandia Thermal Energy Storage Experiment Equipment

In FY79 a full-sized HTS test facility to be incorporated into the Sandia MSSTF will be designed and fabricated. The module will be instrumented to study direct TES operation, using an all-liquid thermocline in either a homogeneous or partitioned mode, or an inhomogeneous or unpartitioned mode. This study will enable study of full-sized direct TES schemes in transient charge and discharge conditions.

Prime-Mover Development

The primary objective was to obtain an extraction steam turbine-generator set that met the requirements for the STE-LSE. The secondary objective was to encourage development of a relatively small turbine with improved performance characteristics capable of being scaled up from 400 kWe to a 1 to 10-MWe range.

In March 1978 RFQs were sent to 13 potential suppliers. Six companies quoted. A contract was placed with MTI May 1. The design study was completed August 1978, and detail design is under way.

Originally, the high-pressure preextraction section was to be a double-row Curtis stage, with the low-pressure section a single-reaction stage. Because of extraction and exhaust pressure changes, the turbine was redesigned and now is a four-stage pressure-compounded design. The high-speed bearings and rotor shaft are designed. The gears for stepping down from 42,000 rpm to 1,800 rpm have been designed and ordered, and the generator has been ordered. The control system has been blocked out and the design is under way.

Most of the detailed design will be completed by January 1979. Component fabrication and assembly will be completed by August 1979. Testing will be completed by November 1979, followed by shipment and installation at Shenandoah, GA.

O&M Characterization

Collector-Cleaning

Accumulation of dust and other contaminants on the surfaces of concentrating solar collectors is a potential major problem. Contamination on the reflectors and on the glass envelopes around (or in front of) the receiver tubes can reduce the specular reflectance (or transmittance) characteristics of the collector and thereby greatly reduce its performance. Since specular reflectance is crucial in calculating collector efficiency, effects of contamination and ways to clean collectors must be determined.

An RFP was issued requesting proposals on a project to investigate cleaning agents and cleaning techniques for solar collectors and heliostats. To narrow the scope so that immediate application could be made to some of the pending major solar installations, the proposal was directed to look at the geographical locations of the desert Southwest and the

Atlanta, GA region. Reflector materials to be considered were glass with second-surface silver and acrylics, both aluminized films and Fresnel lenses. The proposal required identification of contaminants with possible investigation of adhesion mechanisms plus development and demonstration of recommended cleaning techniques. The definition of cleaning techniques is to include water requirements, water flow rate, water pressure, detergent and dilution ratios, nozzle sprays, dwell time for detergent solution, rinse techniques, environmental impact limitations, etc.

A contract was placed with McDonnell Douglas of Huntington Beach, CA after evaluation of the competitive bids. The contract is getting under way with the installation of test racks of mirror materials at four locations for obtaining information on contamination and rates of accumulation. MDAC has contracted California State University at Fullerton and McGean Chemical Company for support in contaminant identification and cleaning-agent selection, respectively.

This investigation should provide significant support in cleaning for the LSEs as well as other major solar installations.

Laser-Ray Trace Test Program

The objective of the LRTT Program is to characterize solar reflectors by their slope error. This is done primarily by reflecting a laser beam from the mirror and comparing its return location to the theoretical prediction. Other techniques (notably grid-imaging) are being considered and/or implemented.

Before FY78, a prototype indoor system capable of testing 0.61x1.22 m (2x4-ft) parabolic troughs was in use, and a larger in-the-field system was being designed and built.

During FY78, the prototype indoor system was modified and used extensively on parabolic troughs, quasiflat heliostats, and other reflectors. Based on our experience, a larger, more general system for indoor testing was specified and is being built under contract by EG&G. It should be installed in November 1978 and be available for use December 1978. It will handle various tests, including troughs and petals from parabolic dishes. Figure 24 shows the Sandia Indoor LRTT Facility Prototype.

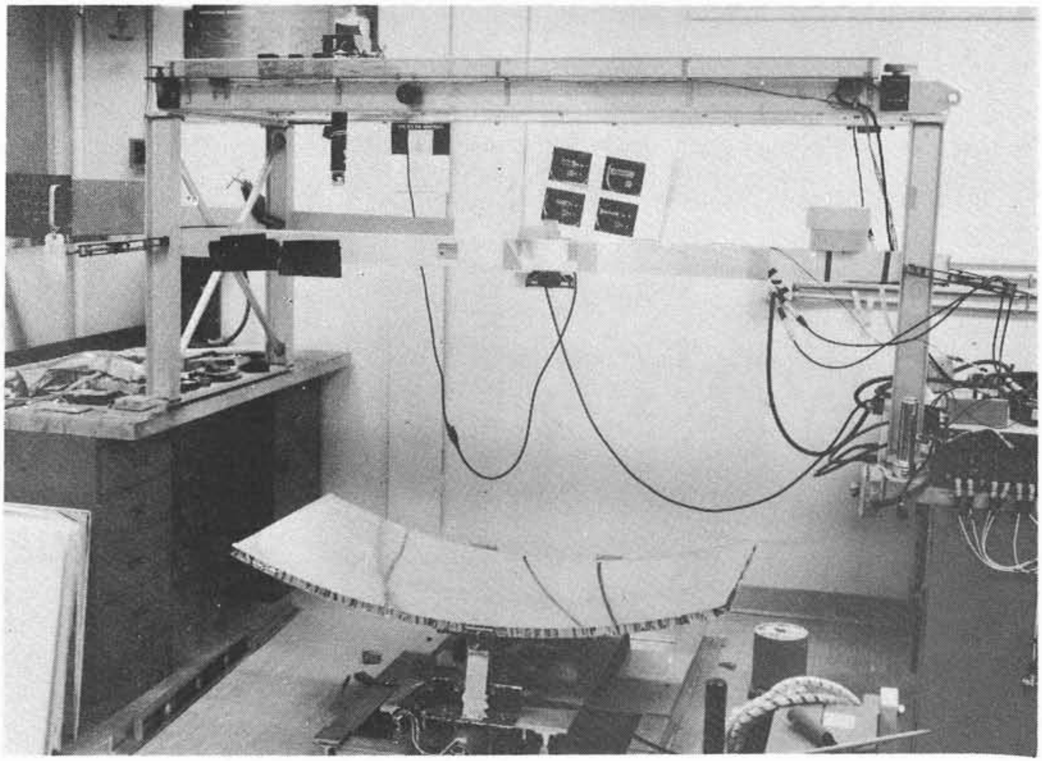

Figure 24. Sandia Indoor LRTT Prototype

During FY78, the field system was constructed and slope error data taken on the Southeast quadrant of the Sandia parabolic collectors in the MSSTF facility. An improved version is being designed based on experience gained with this device that will be available early in 1979. We expect to test the entire Sandia collector field and selected collectors at Willard, NM in FY79. Figure 25 shows the field tester aligned to a Sandia collector module.

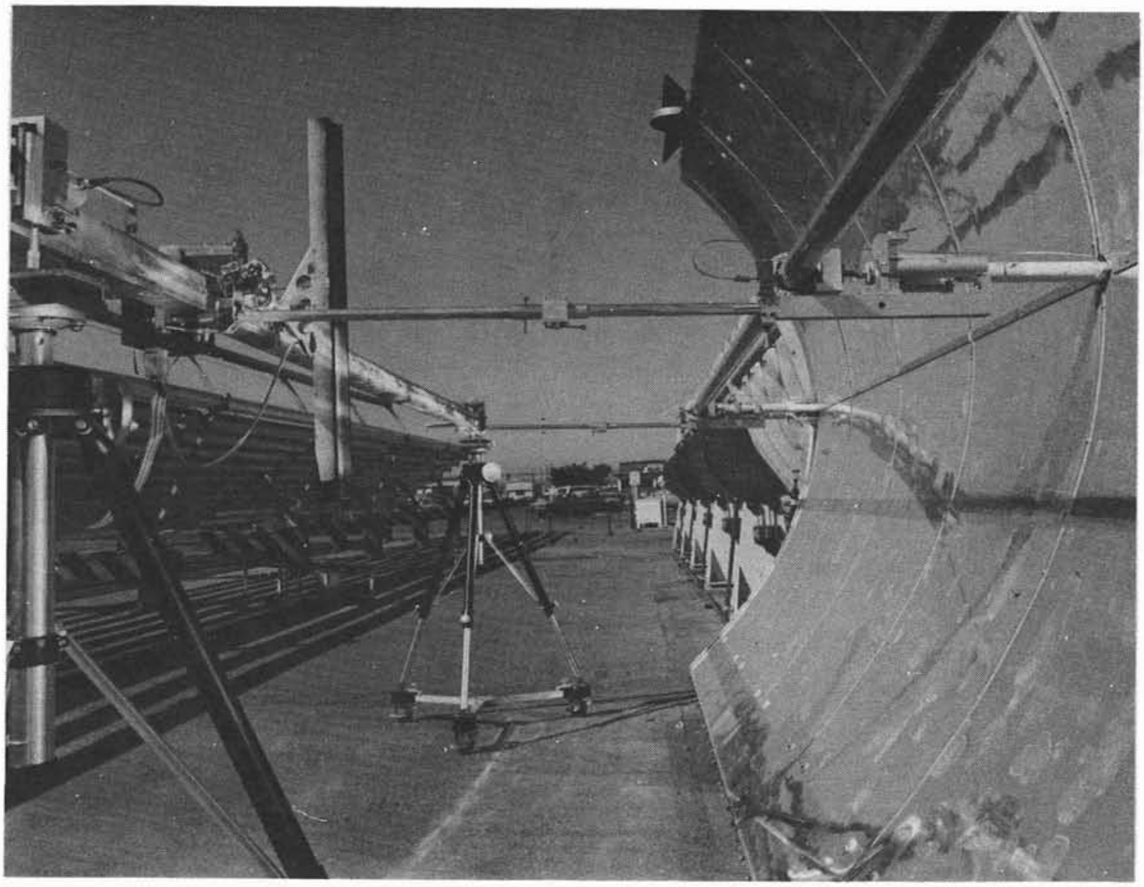

Figure 25. Sandia Field LRTT-Aligned Sandia Collector

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3. Methods of Testing to Determine the Thermal Performance of Solar Collectors, ASHRAE 93-77, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, United Engineering Center, 345 East 47th St., New York, NY, 10017.

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