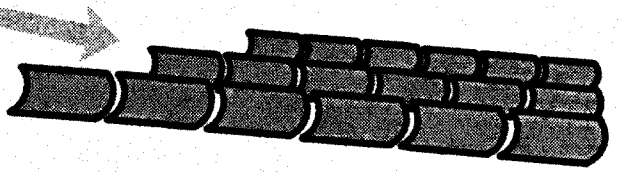
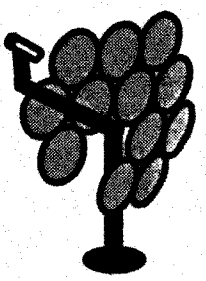
Solar Thermal Energy

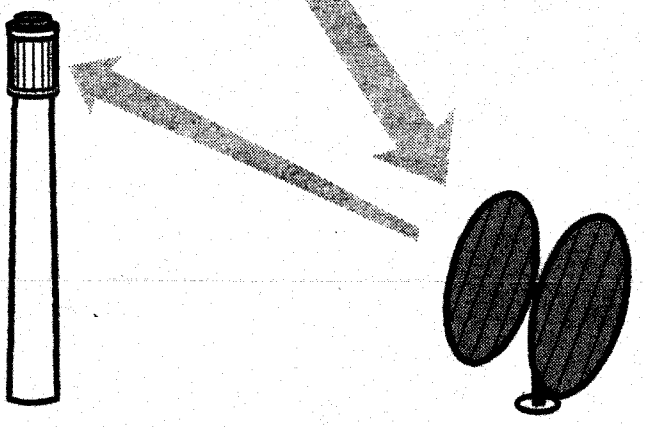


The DOE

Solar Thermal Electric Program

Quarterly Progress Report
Second Quarter, Fiscal Year 1993





Submitted by:

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June, 1993

Sandia National Laboratories

NREL

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Our Vision:

Installation of 900 MW of United States designed/ manufactured solar thermal electric systems worldwide by the year 2000.

We expect to realize this vision through the Office of Solar Energy Conversion's coordinated activities[1] in:

- *Research and Development*
- *Manufacturing*
- *Systems and Market Development*

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[1] *SOLAR 2000, Office of Solar Energy Conversion Strategy, Office of Solar Energy Conversion, United States Department of Energy, Washington, DC, February 1992.*

Program Introduction

A need for new electric generating capacity, a heightened awareness of the environmental impacts associated with energy generation and use, and increased attention to energy efficiency will lead to a greater demand for solar thermal electric (STE) and other alternative energy technologies.

To date, over 350 MW_e of STE systems have been installed in the US, representing over 90% of the world's installed solar capacity. This power meets the needs of over 350,000 people and annually displaces the energy equivalent of 2.3 million barrels of oil. In addition, key cooperative joint ventures representing 50/50 cost share between the Federal government and the private sector have been established for the power tower, parabolic dish/engine, and parabolic trough technologies. These joint ventures, valued at over $75M, strengthen the partnership among industry, utilities, and users. They are some of the current steps being taken to reduce levelized energy costs from solar thermal electric plants to between 6 and 10 cents per kilowatt-hour, thus leading to direct competition with conventional technologies.

Program Mission

The mission of the Solar Thermal Electric Program is to work with current and potential manufacturers and users of solar thermal electric technology and conduct research for technology development and validation to:

- *Increase acceptance of this technology as a candidate for cost-competitive power generation by utilities,*

- *Develop reliable and efficient solar thermal electric systems for generation of economically competitive power that can contribute significantly to the national energy mix and thereby reduce dependence on imported energy sources,*

- *Aggressively support the development of the industrial base required to penetrate the various energy applications and markets, creating new jobs and business opportunities.*

Solar Thermal Electric Program Strategy

Program strategy is consistent with the objectives set forth by the Office of Solar Energy Conversion in ***SOLAR 2000 - A Collaborative Strategy.*** The Department of Energy and its field laboratories will seek to:

- Increase, through cooperative ventures, industrial participation in both the planning and execution of program elements. Specifically,

  - the Solar Two molten salt power tower project led by Southern California Edison will provide the technical base for Solar 100, the first 100-MW_e utility-scale power tower module, which is due for installation by the end of the decade.

  - the Cummins Engine Company 7-kW_e dish/Stirling System will be commercially available by 1996 for remote and grid-connected applications.

  - contracts will be awarded under the Utility-Scale Joint-Venture Program for 25-kW_e dish/engine systems, with the last phase of this program resulting in at least one megawatt of dish/engine system capacity installed by utilities by the late 1990s.

  - the operations and maintenance cost reduction study for parabolic trough plants will be completed by 1995, thereby providing for lower levelized energy costs for power tower and dish/engine solar systems as well as trough plants.

- Utilize the analytical and experimental capabilities of the national labs to support the needs of, and to enlarge, the program's user, supplier, and decision-making constituency.

- Contribute to the DOE Conservation and Renewable Energy's goal of making solar thermal electric technology a viable option for both the domestic and international power-generation markets.

The role of the Department of Energy (DOE) in implementing the program strategy is centered on the development of improved cost effectiveness and reliability of solar thermal electric components and development of additional energy markets with high strategic or economic value to US industry. This balanced approach to technology development and validation, coupled with joint-venture projects and market conditioning, will introduce essential technological improvements while allowing industry to acquire the production experience to further lower cost. Implementation of this strategy relies on a core program of enabling: 1)high-risk research to identify and prove solar electric generation concept for trough, power tower, and dish components and processes; 2) technology development to translate research into useful prototypical hardware; and 3) industry interaction through technical assistance and joint-venture projects to validate and commercialize the technology.

This report describes the progress made during the second quarter of FY93 toward acceptance of solar thermal electric technology as a serious candidate for cost-competitive electric power generating options by utilities, industry, and other manufacturer/user groups.

Summary of Accomplishments

Significant progress toward program goals and objectives was made during the quarter. Following are selected highlights. Details may be found in the main body of the report.

Southern California Edison, acting as the agent for the non-Federal participants in the Solar Two project, and the Department of Energy's Golden Field Office finalized the Cooperative Agreement, including the Statement of Work, for Solar Two.

A dynamic simulation model of the Solar Two receiver, developed by Sandia National Laboratories, has been installed on a personal computer at Bechtel's San Francisco office.

Riveting of the Solar One mirror field was completed, thereby stabilizing the condition of the heliostats which will make up the bulk of the concentrators for the Solar Two project.

Operation of the Cummins Power Generation dish-Stirling system reached 240 hours over portions of 76 test days.

The Cummins Design Validation engine is expected to deliver a nominal 9 kW_e with the potential to reach 13 kW_e. The engine will weigh 150 kg less than the present generation Concept Validation engine.

Best and Final Offers for the Utility-Scale Joint Venture Program were received during the quarter.

An integrated site data collection network was installed at the 5 SEGS plants participating in the Operation and Maintenance Cost Reduction Program with the Kramer Junction Operating Company.

Sandia completed efficiency testing of LUZ heat collection elements and the LS2 trough. These tests will help Kramer Junction Operating Company to determine optimum replacement internals for the given elements given a variety of degraded conditions.

The Solar Thermal Design Assistance Center worked on over twenty different projects and responded to approximately 200 requests for information.

A report on six years of testing of two, state-of-the-art, glass-metal heliostats fabricated by Advanced Thermal Systems and Solar Power Engineering Company was published.

Alignment of the Faceted Stretched-Membrane Dish was completed. Testing is expected to begin early in the next quarter.

Accelerated test results indicate that very thin back protective layers of copper can greatly increase the corrosion resistance of optical films. Metalized samples maintained high levels of optical performance an order of magnitude longer than a non-metalized sample.

Fabrication of a molten salt loop was initiated to test components proposed for use with Solar Two.

Coupons from the molten salt corrosion tests reached 4000 hours of testing. All salts and all steels produced corrosion rates within acceptable limits for the Solar Two specification.

Bechtel's "residual issues" study to evaluate design, cost, and warranty issues associated with molten salt thermal storage and steam generator designs was completed. The conclusions represent important inputs to the Solar Two Project design.

Planned on-sun testing of the Cummins/Thermacore 75 kWt heat-pipe reflux receiver has been completed on one

of the Test Bed Concentrators. The testing was generally positive, but some start-up difficulties were noted. A second calorimeter-controlled receiver which incorporates design changes to remediate the start-up problems will be built and tested prior to combining a receiver with the Detroit Diesel/Stirling Thermal Motors Power Conversion System.

A 75 kWt pool-boiler reflux receiver without any surface modification boiling enhancement was constructed and successfully tested on-sun. The implication here is economic: A receiver not requiring any surface modification would be less expensive to construct and would likely operate more reliably.

A review of the Cummins' hybrid heat-pipe receiver was held. Stirling Technology Company began phase two of their hybrid pool-boiler receiver. In this phase, the receiver will be fabricated and ground-tested. This phase is scheduled to end in September 1993.

The Detroit Diesel/Stirling Thermal Motors Powers Conversion System based on the STMT-120 kinematic Stirling engine completed more than 50 hours of ground testing at power levels greater than 20 kWe. Engine/alternator efficiencies ranged between 35 and 40 percent. The completed power conversion system module was delivered to Sandia on 1 March.

Program Structure

The Solar Thermal program is structured to provide a balance of activities that exploit near-term commercialization opportunities, to improve readiness to meet long-range performance and cost goals, and to maintain a forward looking research thrust to open new applications. There are three major program elements:

I. COMMERCIAL APPLICATIONS
- A. Central Receiver Cooperative Projects
- B. Dish/Engine Cooperative Projects
- C. System Operation and Maintenance Cost Reduction
- D. Design Assistance

II. TECHNOLOGY DEVELOPMENT
- A. Concentrator Technology
  - 1 Heliostats
  - 2. Parabolic Dishes
  - 3. Optical Materials
- B. Power Conversion Technology
  - 1. Central Receiver Technology
  - 2. Dish Receiver Technology
  - 3. Dish Converter Solarization Technology

III REIMBURSABLES

Work Breakdown Schedule

I. Commercial Applications

The program emphasizes two major categories of modular solar thermal technology: power towers (central receiver systems) and parabolic dish/engine systems. These two types of systems can satisfy utility needs for capacities ranging from a few kilowatts up to 100-200 megawatts. The program also supports existing parabolic trough collector systems for the purpose of O&M cost reduction. The 354 megawatts of installed capacity represents $1.2B of capital equipment and an invaluable source of information regarding solar electric power plant operating experience. Much of this experience is appropriate for power tower and dish/engine system operations.

The program emphasizes cost-shared activities where there is significant industrial involvement in the planning and execution of the activities. These government industry partnerships represent teams which are uniquely qualified to rapidly advance each technology. The partnerships combine the manufacturing, marketing, and management skills of industry with the solar-specific experience base and analytical and experimental capabilities of the government laboratories. There are presently three major 50/50 cost-shared cooperative activities underway within the program with a total value of $75M. The private sector leaders of these joint activities are:

A. Southern California Edison and a consortium of other utilities and industry (power towers).
B. Cummins Power Generation (dish/engine systems).
C. KJC Operating Company (system operation and maintenance cost reduction).

A. Central Receiver Cooperative Projects

The goal of this project is to advance the near term commercialization of solar central receiver electricity generating facilities. The systems for a central receiver power plant have been proven through testing and analysis. The next step in the commercialization of the central receiver technology is to design, construct, and operate a demonstration plant of a size that is large enough to reduce to acceptable levels the risks (technological and economic) in building the first commercial plant.

A consortium of United States utility concerns led by Southern California Edison Company (SCE) has begun a cooperative project with the U. S. Department of Energy (DOE) and industry to convert the 10 MWe Solar One Central Receiver Pilot Plant to utilize molten nitrate salt technology. Successful operation of the converted plant, to be called Solar Two, will reduce the economic risks in building the initial commercial central receiver power projects and accelerate its commercial acceptance. Joining SCE and DOE in sponsoring this project are the following organizations: Los Angeles Department of Water and Power, Idaho Power Company, PacifiCorp, Pacific Gas and Electric Company, Sacramento Municipal Utility District, Arizona Public Service Company, Salt River Project, City of Pasadena, California Energy Commission, Electric Power Research Institute, South Coast Air Quality Management District, and Bechtel Corporation. Sandia National Laboratories is providing technical support to the project. The Solar Two Project will convert the Solar One heat transfer system from a water/steam to molten nitrate salt by replacing the water/steam receiver and oil/rock thermal storage systems with a nitrate salt receiver, thermal storage, and steam generator. The estimated cost of Solar Two, including its 3-year test period, is $48.5 million. The plant is expected to be on line in 1995.

Accomplishments

Solar Two is a cooperative project between the Solar Two Participants and DOE. The Solar Two Participants Agreement is a consortium made up of thirteen organizations led by Southern California Edison. Two key agreements are needed to officially begin the Solar Two Project. These agreements are the Solar Two Participants Agreement and the Cooperative Agreement between the Participants and DOE. The Solar Two Participants Agreement was finalized in November 1992 and has been signed by all the participants who will sign this Agreement (including Southern California Edison (SCE), Sacramento Municipal Utility District (SMUD), PacifiCorp, Idaho Power, Arizona Public Service (APS), and Salt River Project (SRP). All the other participants and contributors will sign side agreements to the Participants Agreement. **This past quarter, SCE, acting as an agent for the Participants and DOE/GO, finalized the Cooperative Agreement, including the Statement of Work for the Solar Two Project.** Now that the two key agreements have been signed, SCE can finalize the Engineering and Construction Management (E&CM) contract with Bechtel. Bechtel has been working under an interim contract for the past year. Phase One, the design and engineering phase of this six-phase project, will be completed in August 1993. The plant is still expected to be on line in late 1995.

Sandia has been working with SCE and industry to address the technical issues related to Solar Two. Listed below are some of the technical support accomplishments during the past quarter.

Sandia chairs the Solar Two Technical Advisory Committee (TAC). In this capacity, with SCE, we finalized the Policies and Procedures which govern the operation of the TAC. This document delineates the purpose, membership guidelines, structure, review process, and review documents for the TAC. The purpose of the TAC is to review project designs and documents and to disseminate information to the project participants. The Solar Two Steering Committee will approve this document.

The fourth Solar Two TAC meeting was held in Salt Lake City on January 27, 1993. The primary purpose of the meeting was to inform the members about the project. Twenty-six people attended this meeting where the project organization, Statement of Work, and TAC Policies and Procedures were discussed. In addition, receiver technical issues, the Design Basis document, Phase One design studies, and Operating Strategies were discussed by the members. During the past quarter, the TAC Operation and Maintenance subcommittee completed a review of the Solar Two Operating Strategies and an ad hoc subcommittee completed a review of the Solar Two Design Basis Document. Additional information, including a more complete design of Solar Two, is needed for both of these documents before they can be finalized. The Receiver subcommittee also completed a review of the Solar Two Receiver Specification. The specification contained much of the necessary information; however, much of the supporting information (e.g., the Design Basis Document, operating procedures, design guidelines, etc.) is needed before a final receiver specification can be released. The SCE project manager will make the final decision on how to proceed with the Design Basis Document and the Receiver Specification.

The **Solar Two Project Manager, Irving Katter, visited Sandia on March 11** for a tour of the Solar Thermal Test Facility and technical discussions. Information on the previous receiver tests, the molten salt component tests, studies of the controls, parasitics, annual performance, and heliostat facet replacement were given to Mr. Katter and discussed. The current decisions on the receiver specification, the heliostat field (replacement and additions), and the annual performance of the Solar Two plant are very important issues.

Representatives from Central and South West Services, Inc. visited Sandia on March 4. In support of the Solar Two participants, Sandia and the Solar Two Project Director, Mark Skowronski, briefed the Director for Research and the Manager of EPRI Technology Transfer from this Texas utility holding company. Sandia also provided a tour of the NSTTF. Central and South West has a $10 million research budget this year and intends to support renewable technologies. However, Central and South West did not commit to participating in Solar Two.

A dynamic simulation model of the Solar Two receiver, developed by Sandia National Laboratories, was installed on a PC at Bechtel's office in San Francisco. This model performs a detailed calculation of the dynamics of the receiver and its control system. The model has been described in previous SAND reports and conference papers (e.g., 1992 ASME solar conference). The model was installed so Bechtel could gain a better

understanding of temperature ramp rates and other issues. This information will help them write the Solar Two receiver specification which will be included in a bid package to be sent out in the near future.

The magnitude 7.5 earthquake on June 28, 1992, damaged about 4% of Solar One's 22,000 mirrors; the damage resulted from the failure of the glue bonds between a mirror and its three support plates. To prevent further loss of mirrors, the field has been stabilized by riveting all the remaining mirrors to their support plates. **Riveting of the mirror field was completed this quarter.** In addition, the contractor vented the 5000 mirrors which had not already been vented. This venting will eliminate water accumulation inside the mirrors. A survey of the field by Sandia showed that no new mirror facets had fallen. There was also some concern about dirt that is collecting in the electrical boxes at the base of the heliostats, but it has been shown that the dirt can be easily removed.

This past quarter Sandia began to assess options for replacing the mirrors damaged in the earthquake and lost to corrosion. However, further work awaits a decision on whether the Solar Two project will replace the missing facet area, which represents about 6% of the field. There are a number of options for replacing the lost mirror area. The options include using the flat glass facets from the Carrisa Plains Photovoltaic plant (however, the flat glass may become convex at higher operating temperatures); having SKI manufacture new glass facets; or adding new heliostats. We are requesting further input from the project team before we test any of the facet replacement options.

Efforts in preparation for decommissioning the Solar One Thermal Storage System continued this quarter. The Solar Two Cooperative Agreement requires that, prior to the start of Solar Two on-site work, DOE remove the Solar One thermal storage system and deliver a site free from contamination resulting from operation or removal of the thermal storage system. Dames & Moore, under contract to DOE/GO, prepared a report evaluating remediation alternatives for the site. Sandia provided DOE/GO with a detailed review of this report. Subsequently, Dames & Moore has written a conceptual work plan for removal of the system. DOE/GO expects to contract with Southern California Edison (SCE) to perform the removal work. Late in the quarter, DOE/GO and SCE held discussions on this approach.

Planned Activities for Next Quarter

- Continue to support SCE's efforts to form a Solar Two consortium of utilities, industry, and regulatory agencies and the preparation of an application for DOE cost sharing the project.

- The next Solar Two Steering Committee Meeting will be held in April 1993. The next Technical Advisory Committee meeting will be in April 1993.

- Continue technical support of SCE's efforts to define the design of Solar Two that best simulates a commercial plant and addresses the technical issues of central receivers.

Milestones (Planned/Actual)

(Jan 93/Jan 93) Hold 4th TAC meeting.

(Apr 93/Apr 93) Sign participants and co-operative agreements.

B. Dish/Engine Cooperative Projects

The objective of the dish/engine cooperative projects is to commercialize dish/engine solar thermal electric systems. The approach is to form joint ventures with industry, utilities, and other users. In January, the Dish/Stirling Joint Venture Program (DSJVP) with Cummins Power Generation, which is the archetype of the joint venture team approach, progressed from phase 1 to phase 2 on schedule and on budget. Although much of the effort during the quarter was spent "cleaning-up" phase 1 issues, significant progress has been made toward key phase 2 objectives, primarily in the engine and collector development areas.

Request for best and final offers were sent to the responsive proposers for the Utility Scale Joint Venture Program (USJVP). The amended proposals are currently being evaluated at Sandia. Avenues for proceeding with the US-

JVP are being explored.

Accomplishments

Operation of the Cummins Power Generation, Inc. (CPG) dish-Stirling system continued throughout the quarter at the CPG facility in Abilene, Texas. Testing has been limited due to inclement weather. System thermal performance has steadily improved as a result of implementation of vibration isolators and receiver aperture and cone design modifications. In March, further improvements were garnered as a result of the use of a "heavier" space frame constructed from 1 1/4" 18-gage steel tubes vs. 1" 20-gage steel tubes. The main reason for the heavier tubing was to avoid resonant 60 Hertz vibrations induced by the free-piston Stirling engine. Prior to the change, space frame members had continued to fail in spite of the lower vibration levels caused by the isolators. The rate of failure incidents recorded in the Standard Engine Reliability Tracking System (SERTS) used by Cummins, dramatically decreased after the vibration isolators were implemented. Most of the incidents were related to over-temperature of the aperture plate thermocouples and excessive vibration due to the unbalanced free-piston Stirling engine. At the end of the quarter, over 240 hours of operation have been logged on a total of 76 test days. **CPG intends to continue to operate the system to determine if vibration has been reduced adequately.** Dynamic balancers and opposed engine configuration will be implemented if necessary.

The system installed at the Thermacore test site in conjunction with the Pennsylvania Energy Office was not operational during the quarter due to a leak in the heater head tube joint. In addition, subsequent attempts to braze other heater heads were not successful. Along with the vibration issue, heater head tube brazes have been the most problematic issues. To address this problem, Thermacore has identified a vendor that can electron-beam weld the heater head tubes into the head. **CPG's short-term plans call for fabricating two stainless steel heads with electron-beam welded tubes.** Attempts will also be made to salvage the Haynes 230 heater heads by electron-beam welding. For the "design validation" engines, Sunpower and Cummins are developing an all-welded design that appears to also have the advantage of lower stress.

A significant amount of effort has been directed by CPG manufacturing personnel towards the "design validation" (DV) engine. Like the "concept validation" (CV) engine, it incorporates gas bearings. However, it also uses planar springs (a kind of flexure) to provide piston centering during startup and to minimize hysteresis losses. As mentioned previously, a new type of heater head configuration will be used. In addition, the cooler and alternator configurations are being modified. The DV engine's nominal rated output is 9 kWe, although a potential to grow to 13 kWe is being designed into it. At the same time, the engine/alternator weight will be more than 150 kg less than the CV engine/alternator. The engine/alternator efficiency goal is 33% at 675°C. The use of Inconel 625 for the heater head should enable higher temperatures and efficiencies. Onan Corporation, a wholly owned subsidiary of Cummins Engine Company, is providing alternator design consulting and is assisting in the fabrication of some of the alternator and flexure parts. Much of the DV engine/alternator design was performed during phase 1, however, this still remains as the key critical path activity in phase 2. Some of the long-lead components have already been ordered and **a complete drawing package is expected to be completed by May.** Engine testing is expected to take place by late summer.

Because of the importance of the free-piston Stirling engine/linear alternator to the Joint Venture Program, Clever Fellows Innovation Consortium (CFIC) was included as a parallel Stirling engine developer. The CFIC engine technology, which utilizes flexures, virtually eliminates wear and makes possible extremely long-life engines. Cummins is paying 100% of the CFIC engine development cost. CPG plans to select either the Sunpower or CFIC engine for further development in the August 1993 time frame in phase 2 of the JVP. The CFIC engine/alternator incorporates a number of clever innovations, including a relatively low-stress heater-head configuration, flexure bearings, and a low-cost alternator. The opposed configuration of the CFIC design is also inherently balanced. A photograph of a CFIC engine/alternator mockup is shown in **Figure 1.**

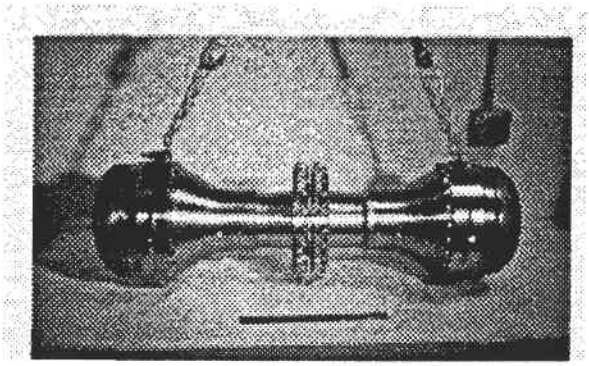

Fig. 1 Photo of the CFIC free-piston Stirling engine/linear alternator mockup.

Design and fabrication of the CFIC engine/alternator is now approximately five months behind schedule. Some delays have been caused by vendor errors in critical parts. In addition, an error was made in a linear-alternator design calculation. The linear alternator was able to produce only 4 kWe. The alternator required a redesign, resulting in an additional three-month delay. CFIC expects to initiate engine testing by June.

Cummins Power Generation has been disappointed by the progress made by Cummins Electronics (CEL) in the development of controls for dish-Stirling systems. They have therefore relieved CEL of controls development responsibility and have initiated the acquisition of personnel and consultants with the required controls background. The controls team at CPG has a lot of catching up to do. The analog load interface, remote village electrification system developed by CEL was found not to be adequate during integration testing at Sunpower and will be eventually replaced by a digital-control load interface system. In addition, the analog system was unacceptably expensive and heavy. CPG is now working with Onan who is developing a digital control system for recreational vehicle power systems. The ADA programming language used by CEL (it was originally introduced by NASA during the ASCS program) will be replaced by C++. The concentrator controls are already programmed in C++. In the next few months, CPG will again attempt to integrate the concentrator and engine controls and initiate development of digital interface remote village electrification and utility grid tie system controls. CPG also wants to implement lower-cost AC motors for the water pump application. CPG still intends to use CEL in a consulting role and in the next phase to assist with controls and sensor design and qualification.

During the quarter, **Thermacore investigated the source of the hot spots that were observed on the Durability heat-pipe receiver after approximately 450 hours of testing.** The receiver completed over 500 hours of on-sun testing in May and was subsequently sent to Sandia for limit testing. The receiver was then returned to Thermacore, where on-sun testing continued for a total test time of approximately 600 hours before it was removed and dissected. Pull tests indicated no loss of wick adhesion with the absorber wall, and permeability test, at Thermacore and Sandia, indicated no change in wick permeability over the 600 hours of on-sun testing. Although, a number of very fine cracks were detected in the wick, they were found to be shallow, relatively short, and small. Thermacore does not believe that they significantly affected wick performance. Based on results of on-sun testing of a 75 kW design at Sandia, Thermacore has incorporated "refluxing" into the next Durability heat-pipe receiver design. This next generation receiver, which is being supported by NREL, also incorporates an "artery free" design to reduce fabrication cost and complexity. The durability receiver was shipped to the Abilene test facility in late March. CPG expects to put over 500 hours on it by fall.

CPG finally received its first batch of 7-mil reflective film in early January. Unfortunately, due to an inadequate metalization thickness, **the solar weighted reflectivity is only about 81.5%.** A reflectivity of 86 % was expected. The specularity is significantly better than the 4-mil Dunmore film previously utilized by CPG. After some adjustment to the manufacturing parameter, mirrors with optical properties comparable to those made with the Dunmore film were produced and the mirrors on the two Abilene concentrators were replaced. In order to avoid the 60 Hertz engine-induced resonance, higher film tension was used on the mirrors. A modified Hartmann tester was employed on the tensioning fixture that permits real time optical characterization of the tensioning parameters.

Improvements to the focusing and defocusing valves were made during the quarter. Suction cups (the first ones were from toy dart guns) are being used to make the focusing valve more tolerant to misalignment and to avoid over-focus conditions. Automatic defocus is now being provided by pneumatically operated valves mounted on each facet. An automotive heater control valve, which is

normally open is closed by a small pneumatic pump. Loss of power causes the valve to open and the mirror to defocus in less than a minute. Lower cost and faster response options that also allow individual mirrors to be modulated are being investigated for the "DV" system.

Sandia and NREL continued to provide technical support for the JVP throughout the quarter. A distant light source characterization of the two "round robin" Cummins' facets was performed to gain insight on the proper interpretation of images for focusing during a distant light source alignment. In addition, Sandia assisted CPG with the construction of an alignment target and in the implementation of the distant light source alignment in Abilene. The Sandia Beam Characterization System (BCS) was used to quantify the advantages of the distant light source alignment technique compared to on-sun alignment. Sandia also provided sample thin-glass mirrors for the CPG facets. The glass mirrors have the advantages of high reflectivity (> 90%) and long-term durability compared to the polymer film mirrors. The initial tests were encouraging, but waviness of the glass and/or glass/membrane interactions resulted in facet slope errors that were higher than the polymer mirror facets. CPG plans to incorporate a thin-glass mirror on one of the concentrators in Abilene for long-term durability testing. NREL is coordinating the "round robin" evaluation and has performed Scanning Hartmann Optical Testing (SHOT) of the two Cummins' facets. NREL also continued weathering tests and consulting on optical films. The Sandia system performance and economic analysis model is being used by CPG for cooling system specification and other design trade-offs.

Four responses to the request for proposal (RFP) for the Utility-Scale Joint Venture Program (US-JVP) were received on October 23, 1992. The RFP solicits industry for proposals to enter into a joint venture with Sandia with the objective of developing and commercializing distributed, point-focus, solar thermal systems which can be used by utilities. The companies that submitted technically responsive proposals were solicited for best and final offers after discussions with Sandia. The best and final offers are currently being evaluated and various avenues for proceeding are under consideration.

Planned Activities for Next Quarter

- CPG will continue operation of the 5 kW_e prototype system in Abilene, Texas.
- CPG will fabricate two stainless steel heater heads with E-beam welded tubes.
- Operation of the Lancaster, Pennsylvania system will be reinitiated.
- CPG and Sunpower will finalize the drawing package for the design validation engines.
- Testing of the artery-free durability heat-pipe receiver #3 will be initiated.

Milestones (Planned/Actual)

None

C. Operations and Maintenance Cost Reduction

The nine Solar Electric Generating System (SEGS) power plants located in Southern California are the only utility-scale solar power plants currently operating in the world, with an existing capacity of 354 MW. The costs associated with operating and maintaining (O&M) solar-thermal plants have a significant influence on the economic viability of the technology. For example, O&M costs account for greater than 20% of the SEGS electricity costs. Reductions in O&M costs would enhance the marketability of solar thermal technologies currently being developed by DOE. An example of a DOE technology that would benefit is the Solar Two demonstration project and commercial central receivers power plants. Central receiver power plants have many of the same subsystems contained within a SEGS plant and the O&M of these subsystems would be similar.

The goal of this project is to reduce O&M costs associated with utility- scale solar thermal power plants. This is being accomplished by characterizing O&M costs incurred at the SEGS plants during more than 40 plant-years of operation. Research and development is then performed to reduce the cost of the most important categories. The assessment of the important categories at SEGS plants indicated that roughly two-thirds were applicable to

O&M at central receiver power plants. This guarantees that this initiative will benefit current solar thermal technology (SEGS troughs) as well as future technology (central receivers).

The project is being performed on a 50/50 cost-share basis between owners of the SEGS plants (primarily US utilities and major investment firms) and Sandia. A significant portion of Sandia's cost share is being contributed through in-kind technical support. The contract was established with Kramer Junction Operating Company (KJC) in July 1992. The work to be performed during the 3-year project was described in the Third Quarterly, FY92. The progress made during the present quarter is described in the following paragraphs.

Accomplishments

Integrated Site Data Collection Network Installed. The 5 SEGS plants at the Kramer Junction site comprise a solar power park. Power parks (multiple plants at the same site) are the expected method of deploying large scale solar power plants during the 21st century. One of the **advantages of a power park is that the services of the maintenance crew can be shared by several plants.** This increases the efficiency of the maintenance organization and reduces the cost of maintenance per plant.

In order for this improved efficiency to be fully realized, **site maintenance planners must have rapid access to maintenance data bases** at each of the power plants and a method of quickly ordering the required work and replacement parts. This is being accomplished at the Kramer Junction site through installation of an integrated data collection network. Each plant will have a PC workstation that is connected to the network server located in the site administration building.

During the quarter, **the workstations were installed at each of the plants** and connected via fiber optic transmission lines. Communication was established and the majority of the network software was developed. This integrated data collection network will form the backbone of the maintenance planning task described below.

Maintenance Planning Methodology Selected. With the advent of the PC age, **US utilities are beginning to rely upon a multitude of newly-developed software products to streamline their maintenance planning activities.** These software products bring together such activities as the master equipment list, equipment reliability histories, work order system (both corrective and preventive), purchase orders, stock issue requests, manpower planning and scheduling, inventory accounting, warehouse management, and all tracking for accounting purposes. **KJC Operating Company currently lacks such a maintenance planning system** and it is believed that implementation of one would significantly reduce maintenance costs at the site.

During the quarter, an evaluation of available software products was completed. The evaluation process was very thorough -- KJC visited several US utilities to discuss experience with the software products and several on-site demonstrations were conducted. In all, **over 200 software products were examined.** A culling procedure reduced this list to 20 products and then to the four leading candidates. After a detailed examination by many potential users within the KJC maintenance organization, it was unanimously decided that the MPAC software (The System Works Inc., Marietta, Georgia) was the superior product. This software has been implemented at over 350 sites around the world including numerous state and local government agencies such as Detroit Water and Sewage, Los Angeles Department of Water and Power, Tennessee Valley Authority, and the Pentagon.

During the remainder of the calendar year, the **MPAC software will be purchased and installed at Kramer Junction.** The software will be implemented on the Data Collection Network described above. The system should be fully on-line by November 1993.

Development of Low Cost Method of Applying Cermet Selective Surface. The demise of LUZ has removed the source for commercial-grade cermet selective surfaces for solar field receiver tubes. In addition, the performance of a central receiver could be significantly improved if a selective surface could be used. For example, **if cermet was used instead of Pyromark paint, radiation losses at a central receiver would be reduced by a factor of 5.** KJC and Sandia are working with Vapor Technology of Boulder, Colorado, to develop a lower cost method

for applying cermet coatings. This company was chosen because key individuals now working there developed the cermet machine for LUZ. The machine built for LUZ cost $3.5M. The cost estimate for a new machine proposed by Vapor Technology is $750K. In the new machine, a batch rather than continuous process method is proposed. This lowers costs because the number of vacuum chambers is reduced along with several other simplifications in the design.

During the quarter, **KJC visited Vapor Technology and successfully replicated the optical properties achieved by LUZ in Israel.** This was quickly achieved because KJC had access to the final optimized parameters for the process. Sandia measured the optical parameters for four samples.

Sample ID	Absorptance (%)	Temperature (° F)	Emittance (%)
2B	0.955	212	0.152
		572	0.232
2M	0.956	212	0.157
		572	0.252
3B	0.970	212	0.073
		572	0.120
3M	0.969	212	0.080
		572	0.132

These results indicate that a **coating with excellent optical properties was achieved.** Next quarter we will test the samples at higher temperatures and will continue to optimize the coating process.

Documentation of Testing of LS2 Trough completed. During the first quarter of FY93, **Sandia completed efficiency testing of heat collection elements** (HCEs) and the LS2 trough. These tests produced data to help KJC determine the **optimum replacement intervals** for the HCEs given a variety of degraded conditions. Two series of tests were completed: 1) as new HCE and 2) degraded HCE with vacuum broken. Test results indicated that loss of vacuum causes about a 9% reduction in heat collection efficiency and that wind has little effect on performance.

During the present quarter, **the result of the tests were documented in a conference paper** presented at the Solar 93 conference, April 25-28, Washington DC. In addition, a draft SAND report was completed.

Planned Activities for Next Quarter

- Hold mid-term project review meeting at Kramer Junction
- Prepare mid-term report that describes results achieved to date

Milestones (Planned/Actual)

(Feb 1993/Feb 1993) Complete documentation of the testing of the SEGS heat collection elements.

D. Design Assistance

The objective of this subtask is to accelerate the use of solar thermal systems through cooperative efforts with private industry by assisting and educating potential users, and by supporting industry and users in the selection, design, characterization, and demonstration of promising solar thermal systems. These efforts are categorized into three activities: 1) Direct technical assistance, 2) Testing, evaluation, and technology development, and 3) Education and outreach.

The Solar Thermal Design Assistance Center activities reported here are supported by (1) the Solar Thermal Electric Program, (2) the Solar Thermal Industrial Program, or (3) both programs. They are reported together for completeness and in recognition of the fact that boundaries are often not distinct within each activity.

Accomplishments in Direct Technical Assistance

The STDAC is providing technical assistance to the solar industry. One of the most important of these projects involves the Solar Electric Generating System (SEGS) operators. **The assistance, which is being provided to the Daggett Leasing Corporation (DLC) and the Kramer Junction Company (KJC),** consists of two major items. The first item involves the eruption of Mt. Pinatubo, whose emissions had apparently caused a significant reduction in the direct normal radiation and, therefore, a reduction in the SEGS plant revenue. The SEGS owners wanted some explanations about the problem; both DLC and KJC asked for Sandia's assistance.

Sandia has completed an analysis of existing solar radiation data including an explanation of the apparent reduction in insolation due to the volcano. The findings indicate that emissions from the volcano reduced direct normal radiation by around 20%, which approximately matched the reduction in revenue. The study also suggests that radiation levels may gradually return to normal over the next two to three years.

The second part of the effort relates to the Landers earthquake last year. The SEGS 1 & 2 facilities sustained significant damage from the earthquake and Sandia is currently performing a finite element analysis of this problem to help recommend some corrective measures. Sandia engineers recently visited the site to obtain detailed measurements of the system structure to be used as input to the models. Work on this problem will continue through this FY.

Much of the earthquake damage involved loss of reflective surface, but the original equipment manufacturer will not provide replacements and SEGS is looking for help from domestic sources. Industrial Solar Technology (IST) was contacted for help in constructing aluminum plates laminated with reflective film. Sandia and Industrial Solar Technology have agreed to a joint venture to develop the replacement mirrors.

In a related problem, Sandia has been assisting **Industrial Solar Technology (IST)** regarding the performance of the solar trough hot water system in Tehachapi, California. In late 1991, high winds began to create problems with the system. At ISTs request, Sandia engineers assisted in developing a set of suggested structural changes to the field to prevent further damage. The structural changes were implemented last quarter. More analysis is underway using the Algor finite element model. IST has conducted some destructive static load tests on some existing modules to provide calibration data for the finite element model. Work on this project will continue through this FY.

Sandia engineers are involved in several **California Energy Commission** (CEC) activities. The first involves the solar project at the prison in San Luis Obispo. Program engineers are planning to monitor the solar system that will be installed. BESICO and California Department of Corrections (CDC) have stated that they will meet late in the spring to sign the contract to install the system. A Sandia engineer may attend the meeting to discuss technical details for the monitoring system. A second effort is to assist CEC and CDC officials in developing Request for Proposals (RFPs) for third-party financed solar systems in other prisons. Work on these RFPs began in September. A third effort is to install a solar hot water performance monitoring system at Galt. This evacuated tube collector system was purchased by the State of California and they are interested in having a neutral third party measure its performance. Sandia has received a formal request from the State of California to begin monitoring the system and work on the project which began in September. STDAC engineers have developed a design of the monitoring system. However, due to delays in system construction, monitoring system installation has been delayed until next quarter.

In state related activities, STDAC engineers are assisting several states. One of these involves the **State of New Mexico Energy and Minerals Department** in two refurbishment projects. The first of these projects involves a solar system at the Northern New Mexico Community College. A cost-shared project to refurbish this solar water/space heating system is underway and includes the Department of Energy, the State of New Mexico, and the New Mexico Solar Energy Industries Association. Sandia engineers have also supplied some of the instrumentation for monitoring the system's performance.

A second New Mexico effort involves technical assistance to refurbish a 20,000 square foot system at the State Prison in Los Lunas, New Mexico. This flat-plate system is designed to heat water and spaces, but has not been operational for several years. Program engineers have provided the state

with a refurbishment plan. Consulting on the effort will continue through this FY.

Sandia is also assisting New Mexico in studying the technical and economic feasibility of repowering some existing electric power plants in New Mexico with solar energy systems. The State has asked for an analysis of two 45MW plants near Albuquerque. Work on the project has begun and the preliminary results suggest that the most cost effective method to repower existing plants with solar energy is by applying central receiver technology. A more detailed economic analysis will be completed next quarter.

The **State of Hawaii Energy Office**, in cooperation with several Hawaiian electric utilities, has requested technical support from Sandia in designing, developing and installing a solar monitoring system on the islands as part of their demand side management programs. They have also asked for consulting on the development of their demand side management system There have been a number of technical interactions so far and Sandia engineers are expected to be involved through this FY. Sandia will also work with the **Solar Energy Industries Association** to provide the training and technology transfer assistance to the utility engineers who will implement the monitoring program.

Sandia Engineers met with **Arkansas State energy officials** to discuss refurbishing an inoperative 30,000 ft^2 solar trough system at the Mississippi County Community College (MCCC) Blythsville, Arkansas. The meeting included a tour of the prison sites where the solar system could be moved. Sandia is currently analyzing the data that were gathered on the tour and are in the process of developing some recommendations to the state.

Sandia engineers are directing the evaluation of potential solar systems at several military installations. **Energy officials from Ft. Huachuca** have provided funding to the Solar Program to provide engineering assistance in analyzing several potential applications for solar thermal technology on the Fort. The analysis will be used by Ft. Huachuca officials to prepare a proposal that will be submitted to the Department of Defense for funding the projects. Four reports are in final preparation, each covering a specific solar application including water heating and air conditioning. The reports will be completed by early April 1993.

STDAC engineers are working with **officials of Luke AFB** near Phoenix, Arizona, to refurbish a 12,000 ft^2 solar thermal trough system that was designed to heat water for three airmen dormitories. This solar system, which consists of three collector fields, has been shut down since early 1980 due to drive mechanism failure. Luke officials have funded the refurbishment project. The solar program has issued a contract to Luke AFB for a report on the refurbishment effort and the performance of the system for the first year of operation. In addition, program engineers are assisting in the refurbishment of the monitoring system.

Technical support for international solar energy projects has increased within the STDAC this quarter. Sandia's Photovoltaic and Solar Thermal Design Assistance Centers are cooperating to help the **Mexican government** apply renewable technologies in Mexico. The majority of the solar thermal effort involves the development of a 30kW solar thermal electric project in Puerto Lobos, a remote village in the State of Sonora. The Mexican government has contracted to Industrial Solar Technology to supply the solar system for this oject. A used ORC engine coupled with 10,800 ft^2 IST troughs will be used for this demonstration project. The Mexicans have asked for Sandia consulting regarding the design review and monitoring of the system.

During the second quarter, a team of three STDAC engineers visited Puerto Lobos to evaluate the site environment and to provide on-site engineering consultation. The team identified several crucial design issues and made numerous recommendations on collector foundations, piping layout, thermal storage, and load management. The Mexican officials indicated that the technical support provided by the STDAC was invaluable and essential to the project's success.

During the trip to Sonora, the STDAC team was also able to establish formal contacts with several key state agencies, the Secretariat of Urban Infrastructure and Ecology and **the Secretariat of Economic Development and Productivity.** Both of these agencies are potentially large users of solar thermal technology because there are numerous buildings in this very hot climate that are heavy users of electricity for space cooling. Some state industries also use much hot water and steam. Space cooling, water and steam heating can be provided by solar thermal technology. Since the STDAC team's return from Mexico, these agencies have requested, and we have provided, educational materials about solar

thermal technology. The STDAC is also in the process of collaborating on a cooperative research effort with the University of Sonora regarding the development of a program to monitor the energy performance of the Puerto Lobos system.

Accomplishments in Testing, Evaluation, and Technology Development

Testing is continuing on the **Energy Concepts Full-Isaac** solar ice maker. The testing has followed a plan that was jointly developed by DOE and Energy Concepts. The results of the tests are being used by Energy Concepts to improve the design of the system.

Tests continue on a new model of a residential **solar distiller developed by BSAR.** This testing follows an evaluation of a previous version of the distiller, which produced information to improve its design. Many of these suggestions have been incorporated into the new model. Tests of the new model are based on a plan that was jointly developed by DOE and BSAR. Currently, the system is not operating because of problems with the freeze protection devices that were incorporated into the new system.

Testing is continuing on a solar **concentrating oven developed by Burns Milwaukee.** The purpose of the tests is to quantify the oven's performance for use in the company's commercialization activities. Currently the testing is being finalized and a final report is in preparation.

Testing will begin early next quarter on IST trough collectors. Two troughs will be tested on the rotating platform at the National Solar Thermal Test Facility. Both troughs consist of standard structural elements. However, one of the troughs uses ECP305 reflective film and the other uses aluminized SA85 film. Two receiver tubes will be tested on each trough. One tube is made of Pyrex and the other will use Solgel AR coated glass.

Sandia has continued a contract with **IST** to develop an advanced receiver. The effort involves three efforts: 1) Develop a commercial AR coating process for trough receiver envelopes; 2) Develop a black nickel process to replace black chrome; and 3) Develop a commercial evacuated receiver. The need for the work was identified through work conducted by Tom Williams at NREL.

Planned Activities for Next Quarter

- Current plans are to continue to provide direct technical support to those organizations with which they are currently working. Accelerated efforts are planned to identify other opportunities to provide this service and other technology transfer and outreach activities.

Milestones (Planned/Actual)

- There are no delays in the major milestone schedule, and no changes planned for the future.

STDAC Contacts:

Central Receivers

Baton, T.	National Research Laboratory
Beckman, Bill	University of Wisconsin
Billings, Dr. Roger E.	International Academy of Science
Brittingham, Bud	SAIC
Eisenberg, Gregg	Land and Water Fund, Colorado
Hogan, Mark	Santa Fe Consultant
Marsal, Rahimah	Individual
Shinnar, Revel	City College of the City University
Tjosvold, David	Alpha American Company

Concentrators

Charlene, Phil	3M
Whiting, Tom	Hughes Aircraft

Dish/Engine

Andohar, Sandy	Export Power Systems
Andreas, Meamann	DLR
Blocherer, Gus	NM Manufacturing Productivity
Blumenthal, P.	NASA
Godett, Ted	STM
Goldberg, Vern	WG Associates
Grondienetti, John	Orond Solar
Johansson, Stefan	Consultant
Mageed, A.	Individual
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Thill, Charlene	3M

Education

Allen, Mark	SNL
Arellano, Frank	SNL - individual
Barrett, Randy	Washington Technology Newspaper
Bertin, John	SNL
Biggs, Frank	SNL
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Donncinic	Nickelodean
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Gilbertson, Neil	SNL
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Hooper, Paul	SNL
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Martinez, Jesus	SNL
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Miller, Jennifer	Science Service
Nolan, Marty	SNL
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Ring, Dave	Taylor Middle School
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Shulties, Tom	SNL
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General Information

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Bullard, Mark	Consultant
Burns, Tom	Burns, Milwaukee
Chivelea, Robert	Consultant
Coleman, Steve	Coleman Machine Supply
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DeWitt, Linda	National Geographical Society
Edwards, Tom	EG&G
Goodman, Joel H.	Individual
Gordon, Robert	BHM Metal Products
Harris, Chris	Earth Insol
Hill, Les	SNL
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Kist, Ed	Consultant
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Martin, Larry	Maunoloa National Factory
Millar, J. H.	World Solar Power Foundation
Nail, Catherine	Nail Associates
Nunley, John	Wyoming Energy Office
Osborn, Don	SMUD
Phillips, Roland	SNL, Tonapah
Pylkannen, Thomas	Atlantis Energy Ltd., Bern, Switz erland
Rawlings, Kyle	Individual
Rollings, Cyle	Augusta Community College
Smitherman, John	Triad Enterprise
Staples, Paul	Clean Air Now in L.A.
Tan, Dave	Individual
Thornblum, Mark	Colorado State University
Tober, Sony	Douglas & Lonas & Co.
Volek, Tom	NM SEI
Wahl, Wm.	State of Rhode Island
Williams, Lee	State of New Jersey
Yurkas, Michael	Individual

IPH

Abbott, Evelyn	Abbott Solar
Allegro, Joe	Inter Sol Roof Systems
Allen, Jack	DOE/HQ
Benson, Chris	Arkansas Energy Office
Beri, Jurg	Heliodyne
Black, Sam	SEIA
Butler, Barry	BSAR
Ernst, Bill	Mechanical Technology Incorporate
Finney, Lorin	Hawaii State
Franey, Harry	CDC
Gee, Randy	IST
Goodman, Joel	Consultant
Hughes, Ken	Sierra Club
Jones, Kevin	SKI
Kelly, Quentin	World Water, Inc.
Knipfer, Dave	Gould
Konnreth, Drew	SKI
Krom, Larry	Individual
Mancini, Frank	Arizona Energy Office
Marken, Chuck	AAR Solar
Means, Dana	SW Hide Co.
Moss, Roger	SKI
Pantell, Bob	Consultant
Phil, Charlene	3M
Schurtz, Paul	SKI
Sealy, Nat	Solar Power Spas
Stein, Bill	Ft. Huachuca
Stewart, Ron	SUNY
Still, Steve	Eugene Water & Electric Board
Szoka, Mary Ann	Simko Project
Talnack, Marie	Telneck & Associates
Thomas, Susie	VA Energy Office
Trujillo, Harold	NM Energy Dept.
Walter, Kyle	Arkansas Prison
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Insolation

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Maxwell, Gene	NREL

Modelling Receivers

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Brooks, Bill	NC Solar Center
DoRenski, Joe	Pennsylvania Energy Office
Dunken, Faith	Forest Service
Durand, Steve	SWTDI, NMSU
Howard, Dave	Orona Industries
PV Form	
Chapman, Rich	PVform
Low, Andy	University of Pennsylvania
Shaffer, John	Consultant

Solar Absorption Cooling

Donnally, Mark	World Water, Inc.
Harrison, John	Florida Solar Energy Center

Solar Instrumentation

McGowen, Jack	
Richmond, Ron	Hawaii Solar Energy Association

Solar Thermal Systems

Foltz, Ross	Foltz Engineering
Foster, Fred	KJC
Franco, Enrique	Sonora, Mexico
Gill, Dr. P. S.	Tuskegee University
Hogen, Chris	EG&G
Johonson, John	Consultant
Kime, Jim	Applied Physics Laboratory
Klepinger, Marilyn	Consultant
Oshnaga, Ilene	DOE/HI

Solar Thermal Testing

Chrivos, Carla	SNL - NSTEP
Curry, Greg	Northrop
Hamdan, Amr	OTS
Malden, Miles	American Sun Co.
Mucian, Bob	Rockwell, Visit NSTTF
Myroslow, Mark	Rockwell, Visit NSTTF
Pikanen, Thomas	Atlantis Energy
Ruff, Neil	STM
Vitale, Nic	Mechanical Technology Incorporated

Storage

Gomez, Leo	SNL

Utilities

Cabanillas, Rafael	University of Sonora, Mexico
Cabrera, Ignacio	State of Sonora
Delgado, Martin	State of Sonora
Garza, Guadalupe	Public Utility Commission of Texas
Hallett, Tom	Kato Engineering
Halwagen, Tom	RI
Jackson, Makr	EaTech
Jaster, Paul	3M
Jenkins, Alec	CEC
Klein, S. A.	University of Wisconsin
Klimers, Michael	Daggett Leasing
Kulkarni, Promad	CEC

Lutton, Wayne	Daggett Leasing
Machuca, Eduardo	CIEDAC
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Moore, Shawn	Student, Fresno State
Nandy, K.	India
Nichols, Charles	Texas Dept. of Commerce
Price, Hank	KJC Operating Co.
Riley, Ann	NM State Senator
Scott, Shannon	KJC Operating Co.
Soloizano, Rodrigo	State of Sonora
Still, Steve	Eugene Water & Electric Board
Tan, Alan	HECO
Velasco, Rogelio	CIEDAC

II. Technology Development

Technology Development is the link between the Advanced Concepts and the Joint-Venture Commercialization Projects. That is, the advanced concepts that are most promising are adapted into Technology Development Projects, which, if they are successful, are integrated into Commercialization Projects by industry.

The purpose of this program element is to develop, in collaboration with the private sector and the international community, solar thermal plant components and subsystems that meet the cost, performance, and reliability standards needed by industry. Accomplishing this will require systems analyses to identify promising improvements. To make these improvements a practical reality, engineering subsystems and components will be designed, built, and tested to validate the performance and reliability assumptions made within the systems analyses.

A. Concentrator Technology

The objective of Concentrator Technology Development activities is to bring heliostat and parabolic dish concentrator designs to commercial readiness for use in solar thermal electric systems. The heliostat designs will be used in central receiver systems and parabolic dish designs in dish/Stirling applications. Because of their importance in developing high performance, cost-efficient concentrator designs, optical materials are an important part of concentrator development.

1. Heliostats

Accomplishments

SAIC's Dual-Element Stretched-Membrane Heliostat: The test data and operation and maintenance records for the Dual-Module heliostat, which was installed at Sandia's National Solar Thermal Test Facility in November of 1990, were reviewed and analyzed. A comprehensive **report documenting the heliostat's performance is currently being prepared.** Some of the highlights Measurements made of the heliostat beam quality indicate that the heliostat produced an average, noon-time, solar power on the target of 68 kW_T during the summer test period. During the beam-characterization tests, the peak flux measured on the target was 6.7 kW/m^2.

Since the heliostat is made of two large (8-meter diameter) circular facets, the facets must be canted or aligned so that the two beams lie one on top of the other at one time of day and one time of year. As the heliostat tracks the sun, the two beams will tend to diverge or separate. During our testing, the centers of the two solar images moved as much as 3 meters apart. We did not try to optimize the beam alignment but, clearly, this is an issue that will have to be addressed for future heliostats of this design.

The heliostat controller suffered from a number of failures during the 18-month test period. The main board was replaced at least five times. Also, the facet focus control was difficult to adjust and maintain.

An ARCO azimuth drive was used on the heliostat. Tracking errors ranging from 5 to 15 milliradians were observed in the azimuth drive. It has not yet been determined whether the large range of errors is the result of problems with this specific drive unit or if the drive is simply not compatible with the heliostat loading. The Low-Cost Winsmith drive may be a better option azimuth drive if it can be adapted for the Dual-Module heliostat.

Large-Area Heliostat Report Published: A report documenting the test results of the two large-area heliostats and the low-cost heliostat drive has been published, SAND 92-1381, Testing and Evaluation of Large Area Heliostats for Solar Thermal Applications by J. Strachan and R. Houser. The report describes six yeaars of testing, from 1986 to 1992, on two, state-of-the-art, glass-metal heliostats fabricated by Advanced Thermal Systems and Solar Power Engineering Company. The report documents the following for the two heliostat

designs: the optical performance, operational characteristics, performance under wind-loading conditions, drive and control performance, mirror performance, and maintenance requirements.

Planned Activities for Next Quarter

- The planned activity for the next quarter is to review and, if necessary, test the heliostat's tracking performance in order to determine the causes for large tracking errors.

Milestones (Planned/Actual)

none

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2. Parabolic Dishes

Accomplishments

New Membrane Installed on 7-Meter Single-Element Dish: A new optical membrane was installed on the SKI 7-meter diameter, stretched-membrane dish. The new membrane is actually two complete membranes. The top membrane is clear Teflon™ membrane, which is intended to help protect the underlying optical membrane. The optical membrane is made of 3M's SA 95™ (known as Silverlux™), a silvered polyester film that is used for application to lighting fixtures. SA 95™ is much less expensive than the acrylic ECP 305™ film and it also has the elasticity required for it to conform to the shape of the stainless steel on the 7-meter dish. We hope that this optical film configuration will last longer and be cheaper than ECP 305™.

About one week after the new membranes were installed, one of the **factory-made seams in the SA 95™ film separated** along the inner 80% of its length. In spite of this failure, we proceeded to measure the performance of the dish using our Beam Characterization System. Because of the split at the membrane seam, there was a substantial increase in the size of the dish image in the focal plane. As a result, the total power measurement was reduced by 18% from the 22 KW_T measured with the aluminum membrane and the peak flux was half the value previously measured. The measured reflectivity for the old aluminum membrane and the new membrane stack were 79% and 78%, respectively. The reflectivity of the Teflon™ SA 95 ™ membrane stack as measured in the field was significantly lower than the 85% reflectivity measured in the laboratory. We are attempting to evaluate this apparent discrepancy.

Testing of the Faceted Stretched-Membrane Dish: Due to inclement weather in Albuquerque during February and March and conflicting test schedules, testing of the Faceted Dish did not start as planned in March. It is currently scheduled to start in April and will be reported next month.

Even though testing of the dish did not start this quarter, a distant- light-source technique was used to align and establish a preliminary focus for the facets. Using this technique, we established a target plane along the axis of the dish but nearer to the dish than the focal plane. A light source was placed on top of the tower at the NSTTF. When the dish axis is brought into alignment with the light source, properly aligned facets will produce separate, well-defined images on the target plane. A computer code can be used to produce the facet image patterns on the target for proper alignment and focus of the facets. The size of the images provides a rough focus for the facets. Shown in Figures 2 a-b are the computer-generated target and a photograph of the properly aligned facet images on the target.

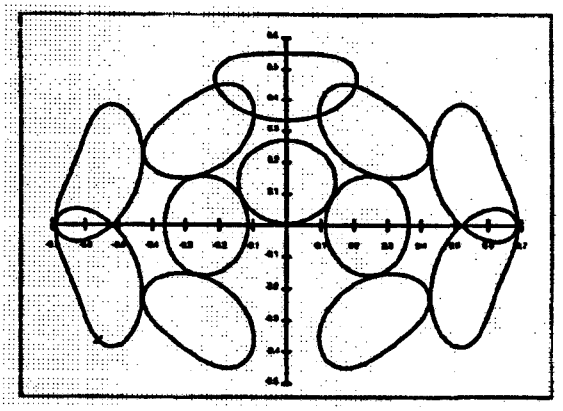

Fig 2a. - Computer generated images of the twelve facets.

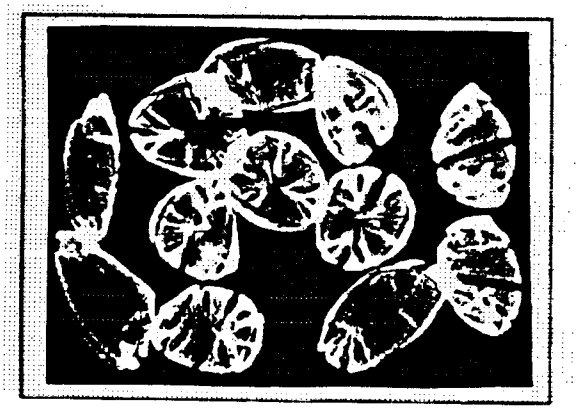

Fig 2b. - Photo of the facet images on the target.

Single-Element Dish Follow On: We have reviewed the Single-Element Dish design of Solar Kinetics, Inc., of Dallas, Texas in detail and recommended a follow-on course of action to DOE. A decision should be made soon and follow-on activities initiated.

Planned Activities for Next Quarter:

- Uncover the 7-meter dish for a long-term exposure of the layered membrane.
- Begin on-sun testing of the Faceted Stretched-Membrane Dish.
- Make a decision and initiate the follow-on activities for the Single-Element Stretched-Membrane Dish.

Milestones (Planned/Actual)

(Jan 1993/Jan 1993) Complete installation of the Faceted Stretched-Membrane Dish at the NSTTF.

(Feb 1993/Feb 1993) Complete and document the test results on the two large-area, glass-mirror heliostats and low-cost drive.

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3. Optical Materials

Achieving the long-term performance and cost goals for solar thermal technologies requires the development of advanced concentrator designs. A common element in all advanced concentrator designs is the need for optical reflector materials that are low cost, light weight, durable, and efficient. In addition to a significant long-term benefit, this task also can impact commercial applications in the short run. Advanced optical materials can be quickly implemented by industry, so that improvements in the technology base for reflector materials can contribute to immediate reductions in the energy costs of solar thermal systems.

Accomplishments

Accelerated test results of an innovative metallized polymer reflector indicate that very thin back protection layers of copper greatly increase the corrosion resistance of the candidate construction.

Previous accelerated exposure tests at NREL have demonstrated increased corrosion resistance of silvered polymethylmethacrylate (PMMA) film reflectors having thick protective back coatings of copper (500Å and 1500Å). A patent application has recently been filed by MRI which describes this method. Initiation of a new collaborative effort with the 3M Company is intended to incorporate the NREL innovation into a pilot-plant version of this material. Because the economic viability of incorporating back protective layers into the 3M production process is a strong function of the thickness of the coating, thinner layers of copper have been suggested.

To evaluate the effectiveness of such coatings, NREL prepared samples having protective back coatings of 0, 100, 300, and 500Å of copper; these have been subjected to accelerated exposure testing in both the solar simulator chamber and an Atlas Weather-Ometer (WOM). **Figure 3** presents solar weighted hemispherical reflectance (H_s) as a function of exposure time in the solar simulator chamber for samples having each of the coating thicknesses being tested. After roughly 250 hours, the sample without any protective backing exhibited significant optical degradation. After 2000 hours exposure, all samples having protective copper coatings (even as thin as 100Å) maintained good optical performance.

Progress has been made in attempts to replicate another optically durable reflector material construction. SiO_x has been identified as a potential low-cost, top protective coating for silvered reflector materials. Compared to other protective coatings having Si-O bonds, experimental mirrors provided by LUZ (which are believed to be silvered PET films overcoated by SiO_x) have performed

remarkably well in accelerated exposure tests in accelerated WOM exposure. A number of variations of SiO_x overcoated silver have been tried at NREL. Following sputter deposition of SiO_x over silver, samples have been post-treated in both boiling water and nickel acetate solution to try to densify and/or seal the coating. To date, no material prepared in-house having the following construction:

$$SiO_x / Ag / PET$$

has exhibited optical durability in the WOM.

Recently, analytical techniques have been used at NREL to quantify the nature of these SiO_x coatings. X-ray photoelectron spectroscopy (XPS) suggests the stoichiometry of the coating is SiO_2. Scanning electron microscopy (SEM) photographs show that thick films (~10,000Å) exhibit a highly porous structure which presumably results in poor optical durability. NREL is presently exploring alternate ways of obtaining denser SiO_x coatings to provide greater optical durability. One approach is ion-assisted deposition to be carried out under an intended subcontract with the Pacific Northwest Laboratory (PNL).

Progress has been made in collaborative efforts with industrial partners to develop alternate reflector materials. Science Applications International Corp. (SAIC) is involved in a collaborative effort with NREL to develop a directly deposited reflector material for solar applications. SAIC has pursued and demonstrated several alternative approaches to achieving a specular leveling layer including use of both an epoxy and an ester-based compound. A transfer coating technique is also being tested. In this approach, a reflective layer is deposited onto a smooth polymeric film substrate, followed by an adhesive layer. This structure is then laminated to a thin stainless steel substrate and the polymer film is peeled off, leaving behind a smooth, specular reflective coating. A top protective coating of Silvue would then be applied.

Industrial Solar Technology (IST) is presently engaged with NREL in developing a silvered Teflon ™ reflector material for solar applications. One problem has been the relatively poor specular reflectance of such silvered films. Previous analyses suggested that part of the lack of specularity may be due to the extrusion process by which the film is formed. DuPont completed an experimental extrusion run of Teflon™ film in which an extrusion aid was added in the hopes of reducing the effects of the extrusion process.

Interference contrast microscopy was used by a collaborator at the Colorado School of Mines (CSM) to compare the surface morphology of Teflon™ films formed with and without the extrusion aid. Films extruded without the extrusion aid exhibit significant one-dimensional roughness (grooves aligned with the extrusion direction) that may contribute to the high degree of near-normal scattering that has been observed. Such one-dimensional features were not evident in the film to which the extrusion aid was added. However, the size of the (random) two-dimensional surface roughness features was considerably larger for the film having the extrusion aid (compared to the film without the aid). These results were confirmed by atomic force microscopy (AFM) measurements conducted by NREL.

One important conclusion from these analyses is that the extrusion aid can greatly alter the surface morphology of the Teflon™ film. Additional work may allow significant improvement in surface roughness and thereby specular reflectance.

The 3M Company has delivered a number of samples that have been made on pilot plant equipment. Two types have primer layers between the evaporated silver and the PMMA. One primer layer is 20Å of sputtered silver and the second is a 20Å metal layer. These were mounted on painted aluminum (PAl) substrates using sheet adhesive at NREL.

Other 3M samples have 0, 100, 300, and 500Å of a protective backlayer of copper for comparison with NREL samples. The initial solar weighted hemispherical reflectance (H_S) values were all about 93%. All the 3M samples are weathering in the WOM. (See Figure 3 below)

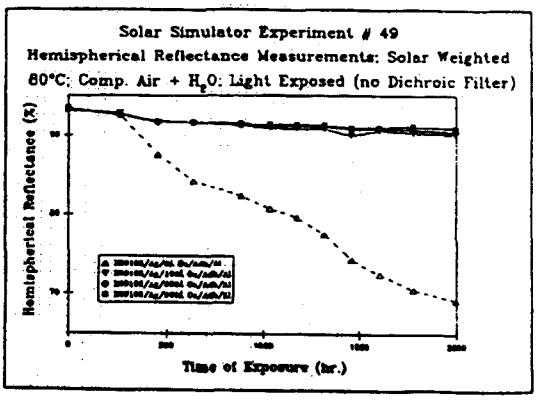

Fig. 3. Measured Solar Weighted Reflectance

A memorandum purchase order (MPO) was issued to initiate a subcontracted effort by the Battelle Memorial Institute Pacific Northwest Laboratory (PNL) for the "Development of Polymer-Silver Deposition Process for Fabricating Solar Reflector Material on Flexible Plastic Substrates." PNL will use their Polymer MultiLayer (PML) technology to fabricate samples of the following construction:

Si_3N_4 and/or PML / Ag / PML / Substrate

where Si_3N_4 is intended as a protective top hard coat. The PML is intended to encapsulate the silver reflective layer to prevent corrosion. Deposition of the PML is accomplished by a vacuum flash evaporation technique compatible with standard vacuum deposition of the reflective layer (i.e., without breaking vacuum between layers). This process has the potential for extremely high line speeds and consequent low production cost.

In addition to the samples discussed above, a number of additional candidate samples will be prepared. A variety of ion-assisted sputter deposited hard coats will be applied to silvered PET. The ion-assisted coatings will hopefully result in dense structures which will provide improved (over non-assisted) optical durability.

Planned Activities for Next Quarter

- Collaborative efforts with industrial partners to develop advanced alternate reflector materials will continue.

- Fabrication and characterization of promising candidate reflector materials will be carried out in parallel at NREL.

- Efforts at outdoor exposure test site activation will continue.

Milestones (Planned/Actual)

- Two DOE Solar Thermal Electric Program milestones titled "Initiation of Outdoor Materials Testing at Arizona Public Service's Site" and "Initiation of Outdoor Materials Testing at Sacramento Municipal Utility District's (SMUD) Site" were successfully completed. The first milestone was scheduled for completion in January 1993. Testing of reflector materials began at the Ocotillo Star Project site, owned and operated by Arizona Public Service (APS), on January 27, 1993. The second milestone was scheduled for completion in February 1993. The first set of reflective material samples was received by SMUD on February 23, 1993. Testing of reflector materials began at the Rancho Seco site, owned and operated by SMUD, at 2 PM on March 1, 1993. The staff at both APS and SMUD have demonstrated a keen interest in this project and worked hard in assisting NREL to complete these milestones.

The objective of this activity is to provide data on material durability and life at a number of locations that are attractive to prospective utilities with an interest in solar thermal electric power generation. The sites provide a way for utilities to gain direct experience with materials that may be used in early commercial power plants. Additionally, the program will provide data that will be essential to allow the use of accelerated testing to make quantitative predictions of materials' lifetimes at various sites.

This represents the initiation of the first two of several intended collaborative projects between utilities and NREL. Data gathered from these tests will be instrumental in allowing system developers to select the best reflector materials for solar concentrator applications. Test results will also enhance efforts by NREL to develop advanced optical materials which can decrease the cost of electricity generated from solar thermal energy.

Optical Materials Industrial Contacts

CONTACT	ORGANIZATION	COMMENTS
J. Affinito	PNL	Alternate reflectors
K. Beninga	SAIC	"
R. Davenport	SAIC	"
G. Davis	Martin Marietta	Reflector materials
T. Evans	Dow Chemical	Alternate reflectors
M. Featherby	SAIC	"
D. Froman	Scientech	Optical measurements
T. Gardner	Corning	Thin glass mirrors
R. Gee	IST	Alternate reflectors
B. Gregg	SDC Coatings	"
J. Heuman	Naval Weapons Lab	Building coatings
C. LaPorta	United Solar	Alternate reflectors
L. Rollings	First Inc.	Metallized Tefzel
P. Soliday	Cummins Power Gen.	Alternate reflectors
I. Susemihl	Siemens	Glass mirrors
M. Werkema	Sheldahl	Alternate reflectors

B. Power Conversion

Power conversion development efforts synchronize R&D activities with the needs of users, expanding the availability of resource data and improving system performance. Power conversion systems for both dish/engine systems and power tower systems are tested at Sandia's National Solar Thermal Test Facility. Power tower receiver development is focusing on advanced salt-in-tube receivers, molten salt film receivers, and volumetric air receivers. Dish receiver development, particularly of the reflux type, is critical to the long-life reliable operation of parabolic dish/Stirling engine systems. The heart of a solar thermal dish/engine system is the subsystem that converts thermal energy into electricity: the engine generator. While the program does not directly support development of these converter subsystems, it maintains explicit interest in them.

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1. Central Receiver Technology

The primary objective of the Central Receiver Technology Program is to advance the development and commercialization of central receiver technologies. This work will mitigate risk of central receiver systems, support industry and utility concerns by conducting research on new concepts, and performing testing and analysis of components and procedures. The key tasks within the Central Receiver Technology Program are 1) molten salt component tests, 2) molten salt stability and corrosion tests, 3) development of instrumentation to measure flux and temperature on central receivers, 4) volumetric receiver development, and 5) system studies of central receiver systems.

The major accomplishments this past quarter are: initiated fabrication of the molten salt components test loop, completed 4000 hours of salt corrosion testing, planned development and testing of instrumentation to measure flux and temperature, completed fabrication of the 200 kWt volumetric receiver, and completed the thermal storage system and team generator system studies.

Accomplishments

Fabrication of a molten salt loop was initiated to test components proposed for implementation into the molten salt system of the Solar Two central receiver system. The purpose of the molten salt experiments is to verify the use, operation, and reliability of components, instrumentation, and procedures proposed for the Solar Two project. Many of the components have been proven in a molten salt environment but additional information is required. Other components have not been tested sufficiently in molten salt. The results from these experiments will aid in the design of the molten salt systems and reduce uncertainties of the performance of untested components and operating procedures.

The existing PRE molten salt loop was modified this quarter with check valves, flanges, flow meters, and pressure transducers to test their performance. The loop includes an area to implement coupons for thermally- and flow-enhanced erosion/corrosion experiments. In addition, two wing panels from the Category B receiver have been framed, instrumented, and heat traced to test cold receiver startup procedures and conduct freeze/thaw experiments to assess damage that might occur to the panels and to test procedures to safely thaw the panels. A new

high-temperature fiberglass insulation was installed along with a lower temperature pre-formed fiberglass insulation on straight runs of piping to test their applicability to molten salt systems. The pre-formed insulation could greatly reduce the effort required to install insulation. The test setup allows for testing of other components and receiver panels at a later date as needed by industry or the utility consortium.

A plan was put together to develop instrumentation to measure flux and temperature on central receivers. The objectives of these tests are to evaluate concepts to measure flux and temperature on an external cylindrical receiver. Three concepts to measure flux (fixed lambertian target with video cameras for high precision flux measurements, relative flux measurement with photometers for flow control, and real-time measure of flux on the receiver surface with video cameras) and two concepts to measure temperature (low and high resolution IR camera measurements) are planned for testing.

In addition, **preliminary tests were conducted to evaluate the fixed target concept** for high precision measurement of the flux on the receiver. The fixed lambertian target system is a concept to map the flux on the receiver surface using a video camera and a highly reflective, diffuse target mounted at the top of a cylindrical receiver. The flux patterns on the receiver could be mapped out by sequentially moving the aim points of the entire heliostat field upward in set increments and recording the images on a white target with the video camera. The images could then be pieced together to form a composite image of the flux map. The total power on the receiver can be measured this way. Preliminary tests were conducted to evaluate this concept using a group of four heliostats and white heliostat targets on the Solar Tower at the National Solar Thermal Test Facility. Several images of the heliostats were recorded with the video system at aim points that were 0.8 m apart. A section of each image was cropped and stored in a binary file to form a composite image. Analyses of the composite image indicated the total power, peak power, and beam size were within the variations of the individual images that made up the composite. See Figures 4 and 5.

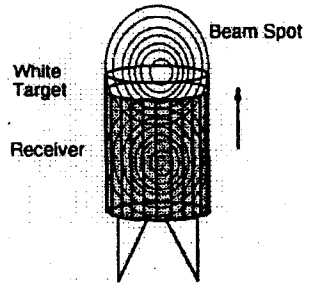

Fig. 4 - Fixed lambertian target used to map the flux distribution on an external, cylindrical receiver. The beam spot is moved upward over the white target and the image is recorded with a video camera. A post-processor can then cut out the region of interesst from each image and build a composite image.

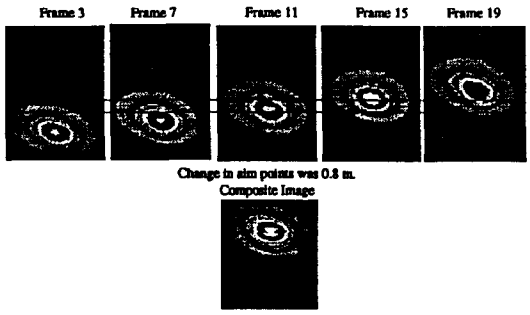

Fig. 5 - Four heliostats were moved to several aim points on the white heliostat target at the Solar Tower and their images were recorded with the video system to conduct a preliminary evaluation of a fixed lambertian target. A section of each image (the section between the lines) was taken and stored in a separate file to form the composite image.

Plans were made to prepare water-cooled white panels in the 220 bay and to install two receiver panels in the 260 bay to test photometers to measure flux for flow control, to test the video system for real time measurement of flux and to test further the fixed lambertian target concept. The wing panels in the molten salt loop will be used to evaluate the IR camera for temperature measurement.

An investigation of possible overnight conditioning methods at Solar Two was conducted. Since Solar Two will have a relatively small heliostat field it will also have a fairly low annual capacity factor (18 to 24%). The low capacity factor implies that the plant will be in a shutdown state about 3/4 of the year. It is important to reduce the thermal and electric parasitics during this time so that the annual energy output will not be extraordinarily degraded.

During the quarter, Sandia began to look at options for minimizing parasitics. To minimize thermal losses from the piping system during the shutdown

period, it was determined that the best method would be to drain the salt pipes during the shutdown period and reheat them again before startup the next morning. A promising reheat method appears to be the use of heated pressurized air, but other methods are also being considered. Results from this work will be presented to the Solar Two TAC.

The Solar One plant was not designed to minimize electric parasitic loads. Since electric parasitics were very significant on an annual basis (~33% loss) at Solar One, improvements will be necessary at Solar Two. To begin this investigation, we plan to study the parasitic load at SEGS I, which is about the same size as Solar One and has a much lower parasitic loss (~15%). Techniques employed at SEGS plants to minimize parasitics will be identified and forwarded to the Solar Two TAC.

Molten salt stability and corrosion tests are being conducted to investigate the effects of salt impurities. Eight different salts and three different materials are being tested. The coupons from the molten salt corrosion tests were withdrawn after 4000 hours and analyzed for weight loss. This completed the scheduled portion of the test. Scientists at Sandia/CA compiled all results and found that under the static conditions of the test, all salts and all steels produced corrosion rates within acceptable limits for the design of Solar Two. Specifically, metal loss measurements for the A36 carbon steel at 316°C ranged between 0.04 and 0.15 mil/yr. and did not depend on any measured impurity. For 304 stainless steel at 570°C, it was seen that the corrosion rates ranged between 0.15 and 0.45 mil/yr. and increased with increasing chloride concentration. Also, severe spallation was evident. The rate of corrosion of 316 at 570°C was generally less than that for 304, and ranged between 0.15 and 0.24 mil/yr. Unlike the 304 stainless, the corrosion of 316 was relatively independent of chloride concentration. Also, spallation was less severe. A meeting was held at Sandia on April 1 to discuss results from the molten salt corrosion experiments. In attendance were design engineers (SAIC, Bechtel), utilities personnel (SCE), salt producers (Coastal Chemical, Chilean Nitrate Corp.), and laboratory scientists. All attendees agreed that the static pot tests represent an extremely valuable first step for characterizing corrosion rates for system design and salt selection purposes. However, it was generally felt that thermal cycling tests are crucial for reliably predicting life in the Solar Two receiver. Consequently, a thermal cycling corrosion experiment has been planned. Facilities for this experiment are already under construction. Four salt pots and four different salt mixtures (chosen based on results from the static test) will be used at 570°C. Each will contain twenty-four stainless steel coupons (twelve 304 and twelve 316). The coupons will be automatically lifted from the molten salt three times daily. After the coupons have equilibrated at room temperature (about 15 min.), they will be slowly preheated to about 500°C before being reimmersed in the hot salt. This mode of operation will simulate thermal cycles and salt drainage likely to be experienced by the Solar Two receiver and associated hardware. Coupons will be removed for weight loss analysis at 100, 200, 400, 800, 1600, and 2400 hr. Also, salt composition analyses will be performed at these times. At the end of the test, one set of coupons will have seen 2400 hrs of operation and 300 thermal cycles; this corresponds to approximately one year of operation in Solar Two. Results from this test should provide reliable data for making realistic predications concerning corrosion rates. The data will also allow us to knowledgeably select the most cost-effective salt mixture for Solar Two.

The resource planning department of Arizona Public Service Company is studying how renewables could be used to supply electricity to the APS utility grid. A preliminary screening indicated that solar was their most promising renewable resource. The next step is to study the ability of solar technologies to meet the APS load demand. During the quarter, Sandia helped APS with this study by providing estimates of power flows to the APS grid for an entire year from power towers, parabolic troughs, and Stirling dish. Power flows were based on 1990 weather data collected in Phoenix and were supplied at 15-minute intervals. The APS planning department is seriously considering installing a large solar plant in Arizona after the year 2000.

SMUD is investigating the feasibility of installing a 100 MW solar power tower at the site of the Rancho Seco nuclear power plant around the year 2000. The study is being performed by California State University at Sacramento. In support of that study, Sandia supplied the DELSOL and SOLERGY computer codes and provided consultation on their use. In addition, Sandia met with SMUD and Cal State to discuss interim results documented in a draft report. The most important uncertainty identified was the quality of the insolation data. Significantly different results were obtained depending on the insolation data set used. Since modeled rather than

direct-normal data was used in the analysis, it was recommended that SMUD install a weather station to collect actual direct insolation. SMUD agreed with this recommendation and were already intending to install one in the near future. Sandia will continue to support this study.

Sandia agreed to provide additional information so SMUD can more accurately estimate plant capital and O&M costs. We will also provide information for a similar plant installed in the Mojave desert so SMUD can compare its economics with the Rancho Seco plant.

The "residuals issues" study to evaluate design, cost, and warranty issues associated with molten salt thermal storage and steam generator designs was completed this past quarter. This study was conducted by Bechtel to obtain information on the design and cost of the thermal storage and steam generator systems for commercial size molten salt central receiver plants. In this study, Bechtel contracted with Chicago Bridge & Iron, Pitt-Des Moines, Technigaz on the thermal storage system and with Foster Wheeler, ABB Lummus Heat Transfer, Struthers Wells, and SAIC/B&W on the steam generator. The contractors provided information on the design, cost, performance, and potential problems with their designs.

One conclusion from the "residual issues" study is that all of the steam generator designs, including the u-tube/u-shell and the kettle boiler evaporators, are suitable for commercial central receiver plants. It appears that a steam generator for a 100 MWe plant could be successfully fabricated and installed for approximately $8 million. Another conclusion from this study is that both internally and externally insulated hot tanks are acceptable for commercial service; however, the internally insulated tank is the only competitive choice. A hot salt tank for a 100 MWe central receiver plant can be fabricated and installed for approximately $5 million. These conclusions are important input to the Solar Two Project design. The draft final report of this study prepared by Bechtel is currently being reviewed by Sandia.

Alternative central receiver concepts are also being evaluated, Sandia has been working on the **volumetric air receiver** and the **molten salt internal film receiver** concepts. In these areas Sandia has had built a 200 kWt volumetric receiver to be tested in Spain and we are working with the Spanish on the testing of their 500 kWt internal film receiver.

The fabrication of the Bechtel designed wire mesh volumetric air receiver absorber was completed this past quarter. Bechtel fabricated the absorber under contract to Sandia. The absorber is a layered nichrome knit wire mesh volumetric receiver, with a total of fifteen screens made up of 41 layers of nichrome (80-20 nickel chrome resistance wire) knit wire mesh. The intent of the design is to make this receiver as volumetric as possible. This is accomplished by making the receiver less dense in the front where the flux is incident and more dense in the back. Bechtel expects this receiver to have a thermal efficiency of approximately 90% at 600° C. An agreement has finally been reached with the Spanish to have the absorber tested at the Plataforma Solar in Spain. The receiver will be sent to Spain and will be tested in June of 1993.

In support of the volumetric air receiver development, Sandia has contracted with New **Mexico State University (NMSU) to test the absorber design and materials that are used in the Bechtel absorber.** NMSU is using their solar furnace to test the knit wire mesh material for transmissivity, extinction coefficients, and thermal performance. Previously the testing showed that the extinction coefficient is very close to that assumed in designing the Bechtel absorber. This past quarter, NMSU has been fabricating the knit wire mesh layers identical to the Bechtel design for testing in their apparatus. Because of the limitations of the test apparatus, numerous tests will be required with various wire mesh layer configurations to provide sufficient data to characterize the Bechtel absorber design.

The other alternative receiver being evaluated is the **molten salt internal film receiver (IFR).** The IFR is an adaptation of the direct absorption receiver concept, except to prevent fluid loss to the atmosphere the fluid (molten salt) flows on the inside of the panel. In 1989, the Spanish had fabricated (with design recommendations by Sandia) all the components for a 500 kWt molten salt internal film receiver test, to be called the Receptor Avanzado de Sales or salt advanced receiver (RAS). The components were never assembled and installed because of budget cutbacks. The Spanish have asked Sandia to work cooperatively with them on the installation, setup, and testing of RAS. This past quarter Sandia reviewed the project design and plans and made recommendations. The RAS is currently being assembled and will be tested in September

1993. The Spanish are sending an engineer to Sandia to work on the molten salt component test so that he can learn about components, heat tracing, and other issues related to molten salt systems. Sandia will send an engineer to Spain in June.

Finally, the report on the "Second Generation Study" with the Germans, on future central receiver systems was completed this past quarter. Sandia finalized the report and it is to be published as Springer-Verlag report.

Planned Activities for Next Quarter

- Begin testing the components (flanges, flow meters, pressure transducers, check valves) in the molten salt loop.
- Initiate fabrication of a test setup to thermally cycle coupons in the salt corrosion pots.
- Begin assembly of a test setup to evaluate instrumentation to measure flux and temperature.
- Continue to study over-night conditioning of Solar Two power plant.
- Ship the volumetric receiver to Spain for testing.
- Continue to work with the Spanish on the assembly of their IFR.

Milestones (Planned/Actual)

(Jan 93/Jan 93) Complete the Bechtel study of 100 MWe molten salt steam generators and thermal storage systems.

(Feb 93/Feb 93 Complete the 4000-hour molten salt corrosion and stability tests.

(Deferred until Sep 93) Complete testing of wire mesh materials at New Mexico State University.

(Sep 93/Mar 93 Finalize the "Second Generation Report.

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2. Dish Receiver Technology

Reflux receivers have the potential of improving the life and performance of dish-Stirling power generation systems. The reflux receiver provides a thermal "transformer" between the dish and engine, providing isothermal, uniform flux to the heater heads. This results in a higher average engine temperature, lower stresses, and fewer constraints on dish design. In addition, the two-phase heat transfer allows a smaller, cheaper, and more efficient receiver. The short-term objectives of the receiver development effort are the demonstration of reflux receiver technology on-sun at scales appropriate for current dish-Stirling projects and to directly compare the performance of a reflux receiver with a directly illuminated heater head through application to the STM PCS package. In the longer term, the program will pursue high performance, low cost concepts, develop design tools, develop hybrid receiver technology, and transfer the resulting technology to industry for commercialization.

This quarter, several full-scale receivers were successfully implemented and tested on Sandia's Test Bed Concentrator (TBC). The Cummins/Thermacore receiver was successfully tested, demonstrating a record thermal throughput for a heat-pipe receiver. Thermacore also completed and ground-tested an artery-free heat-pipe receiver for application to the small (7 kW_e) dish-Stirling system. This receiver concept improves the reliability while decreasing the cost of the receiver. Sandia engineers fabricated and demonstrated an "advanced" pool-boiler receiver that significantly reduces the cost of the technology. In the laboratory, smooth operation of the 10,000-hour pool-boiler bench test continued, logging 1800 hours by the end of the quarter. Fabrication of a new heat-pipe bench test incorporating a Friction Coatings wick structure is nearly completed. The design phase of the NREL-funded hybrid receivers has been completed.

During the next quarter, the second-generation pool boiler will be tested on sun, demonstrating the use of advanced materials, NaK-78 working fluid, and a modified, manufacturable design. A second Thermacore 75 kW_t heat pipe will be tested, and integration efforts with the STM4-120 will begin. Bench-scale testing of advanced wick structures will proceed.

Accomplishments

Planned **on-sun testing of the Cummins/ Thermacore 75 kW_t heat-pipe reflux receiver has been completed** on Sandia's Test Bed Concentrator (TBC-1), fulfilling a February 1993 Sandia Milestone. The Cummins/ Thermacore heat-pipe receiver is designed to deliver up to 65 kW_t to a Stirling Cycle engine, with a "nominal" input power of up to 75 kW_t. The prototype receiver is designed to be mated to the STM4-120 engine for

demonstration on the TBC. The present tests use a gas-gap cold water calorimeter to extract power and simulate a Stirling engine.

The receiver was tested several days at the full-power capabilities of the present TBC configuration. The dish supplied up to 62 kWt to the receiver. The receiver delivered up to 50 kWt to the gas-gap cold water calorimeter when the 8.6-inch diameter aperture was applied to the cavity. During this test, low insolation limited thermal input to 58 kWt. The remainder of the tests were performed with an open aperture in order to allow a full view of the heated surface with Sandia's solar-blind infrared imaging system. This system provided immediate protection against burn-through during early stages of testing. However, the open aperture (19 inches) allows significantly more thermal losses than the normal 8.6-inch diameter aperture.

The final test consisted of a **frozen sodium startup** with no preheating. The thermal input during this test was 60 kWt. The receiver performed admirably during this test, without a hint of dryout or other problems. This test demonstrates the feasibility of receiver operation without preheaters, and is made possible by the relatively thick wick employed in the Thermacore design.

Some initial cold starts that began with furnace operation exhibited warm areas that required cycling the receiver off-sun momentarily during the startup ramp. Several tests were performed to examine this behavior. It is now believed that the cause of this difficulty is a restricted vapor flow passage along the wick structure, which in turn causes a pressure gradient to be presented to the wick surface. Under certain conditions, this gradient can overcome the pumping capability of the wick, causing localized dryout. The solution to the problem would be to increase the separation between the front and aft domes. The problem disappeared when the vapor space temperature exceeded 700°C, and did not re-appear during hot restarts. The problem did not appear during uninterrupted rapid startups.

Thermacore and Sandia have worked together to model the startup problems, and have proposed two simple design changes to solve the difficulty. The wick will be thinned to 0.2-inch from 0.3-inch to minimize boiling problems in the wick at low temperatures. In addition, the gap between domes will be increased to provide a low-loss vapor flow path. Thermacore will construct a **second calorimeter-controlled receiver for testing prior to combining a receiver with the STM engine package.** In addition, the TBCs will be refurbished with new mirrors this summer. **The upgraded TBC is expected to deliver up to 80 kW_t** to the receiver, which will in turn allow the receiver to supply the 65 kWt needed by the STM engine for full-power operation.

Cummins Power Generation, Inc., (CPG) under subcontract to NREL, has **successfully completed the design, fabrication and ground testing of their artery-free heat-pipe receiver.** The objective of this work was to simplify the design of the CPG heat-pipe receivers by eliminating all of the arteries in the receiver design. In a heat-pipe receiver, arteries are small tubes that provide a means for bulk transport of the liquid metal heat transport fluid to supplement the transport provided by the sintered metal wick. Early CPG heat-pipe receivers had multiple arteries and these proved to be costly to manufacture and prone to failure because they can deprime. Progress on the CPG heat pipe manufacturing techniques and analytical tools have permitted gradual simplification from the early receivers that had both circumferential and radial arteries covering the heat absorption hemisphere, to one with only circumferential arteries, to this latest design, that has no arteries. During this quarter, CPG successfully completed ground testing of the artery-free heat-pipe receiver and shipped it to their test facility in Abilene, Texas, for a 500-hour on- sun test.

In December of 1992, a **heat-pipe solar receiver** that was designed and built at Sandia **was tested on a TBC at the NSTTF.** The receiver incorporated an STM-developed wick structure with a Sandia-developed, open-artery system. The receiver was designed for a maximum power input of 75 kWt. However, during the tests, hot spots developed on the absorber surface at power levels above 27 kWt. Subsequent tests on the receiver indicated that both of the two-artery systems were filled with hydrogen gas. To remove the gas, the receiver was heated to 620°C and the vapor pressure was allowed to drive liquid through the arteries into secondary cans at 200°C. Hydrogen is driven into liquid sodium at higher temperatures and it comes out of solution at lower temperatures. This procedure was effective at driving hydrogen out of the arteries, but the arteries would not remain filled with liquid as the heat pipe was taken through subsequent temperature cycles.

It is very likely that hydrogen gas is trapped in crevices in the arteries. Eventually the gas could be

removed from the system by shuttling liquid back and forth between the heated receiver and the cold trap, but this process could take weeks. Calculations indicate that it would require roughly 10 days for a 1-mm bubble to diffuse away in an infinite pool of liquid. In an enclosed space (such as an artery) the gas venting time will be longer. Actively flushing liquid through the artery will accelerate the gas removal process, but, at this time, we are not able to perform this operation over long periods.

Tests on the arteries indicated that they are still intact and the receiver should work if the gas could be removed. Gas venting problems will be eliminated by going to a self-priming artery design. Self-priming arteries, however, are currently more difficult and costly to construct than the open artery structures. In light of the difficulties encountered in removing gas from the arteries, future efforts will be focused on developing a cost-effective self priming artery and wick structure.

The pool-boiler bench test efforts over the last few years have culminated in several on-sun tests this spring. Results from recent bench-scale tests suggested that stable boiling might be achievable without surface modifications in a full-scale pool-boiler receiver. This variable (areal extent of the heated surface) is not addressed in the boiling literature. This hypothesis has now been confirmed in limited on-sun testing. A duplicate of the first pool-boiler receiver, but without any surface modification to stabilize boiling, was constructed and successfully tested. This receiver was built from spare parts left over from the first pool-boiler receiver and was tested on sun with a minimum of instrumentation, to inexpensively address the hypothesis. The receiver was tested both with and without added gas (approximately 1/3 torr of xenon). Without added gas, stable boiling was observed, but in two out of three boiling runs, a hot spot developed on the heated surface during the starting transient. The hot spot was detected by the IR camera each time, terminating the test and protecting the receiver. With added gas, no hot spots occurred, stable boiling was demonstrated at temperatures up to 800°C, and a series of hot restarts was successfully completed. Previous bench-scale tests of bare-walled test vessels showed no stable boiling without added gas, and only limited stability with Xenon added. Other gases (Argon, Helium) have been tried on the bench scale with no beneficial effect. Hot restart problems have not been eliminated on any bench-scale device with or without added gas. **This demonstration of stable boiling without surface modifications significantly impacts the projected costs of fabricating a pool-boiler reflux receiver.** The completion of these tests meets the September '93 milestone for testing an "advanced boiling concepts" receiver. This effort was accelerated due to the delays on the second-generation pool boiler.

Construction of the second-generation pool-boiler receiver has been completed. This receiver will boil NaK in an envelope made from Haynes alloy 230, with a Friction Coatings Corporation heated-surface modification to promote stable boiling. The NaK is liquid at room temperature, eliminating the need for electric pre-heaters. The friction coatings boiling surface was selected based on positive bench-scale results last summer. The absorber surface area and the gap between it and the rear dome are larger than in the first pool-boiler receiver, providing greater margins of safety against film boiling and flooding. The receiver, designed at Sandia, was fabricated and inspected by a commercial firm using potential limited production techniques. Delivery of the receiver was delayed by personnel difficulties at the contractor. The receiver has been installed in its mounting ring and welded connections to an emergency NaK dump tank have been completed. It has been vacuum baked, and filled with 19.5 pounds of NaK. Testing is expected to begin in early April and to be completed before the month is out. Therefore, the delays are not expected to impact the April milestone.

The first 1800 hours of operation of the durability bench-scale pool-boiler receiver have been completed. The test is running routinely around the clock, with fewer than anticipated problems and maintenance needs. The durability pool-boiler test will demonstrate the long-term boiling stability on the friction coatings boiling stabilization surface as used on the second-generation pool-boiler on-sun receiver test. In addition, it will demonstrate the long term alkali metal compatibility of Haynes 230 alloy, which is currently used on both pool-boiler and heat-pipe receivers. The test is scheduled to operate around the clock for 10,000 hours. The device cycles briefly to ambient temperature every 8 hours to simulate the diurnal cycle. Completion of the testing is expected in March 1994.

The initial problems with the SCR lamp control system were solved by the vendor. The only shutdowns since then have been caused by power outages and disk failures. The data storage media type was changed, solving the disk problems. At 1400 hours, the first set of bulbs was replaced when

one failed. This low repair frequency exceeds all expectations. The behavior of the device appears to be unchanged since the original startup. Data reduction and analysis of the first 1800 hours is continuing on a low level.

A wrap-up report on Sandia's short-term bench-scale pool-boiler-receiver tests, "Bench-Scale Screening Tests for a Boiling Sodium-Potassium-Alloy Solar Receiver," SAND92-2253, by J. B. Moreno and T. A. Moss, is in review. This report details the efforts at Sandia investigating liquid metal boiling phenomena on a bench scale, and leads up to the second-generation on-sun pool-boiler design, as well as the advanced concepts design (bare wall) pool boiler. This report will be distributed to interested parties in the dish Stirling community.

As the on-sun testing of the second-generation pool boiler is completed, the program emphasis will be shifted toward advanced heat pipe development. While the pool boiler effort has been highly successful, industry interest, especially on the joint venture programs, has been primarily concerned with the heat pipe option. This is likely due to the large alkali metal inventory and the concentrator tracking constraints associated with the pool boiler option. **The pool boiler option appears to be mature enough at this point for industry to develop it into a commercial product.** The present work will be documented and archived, as well as transferred to interested industry partners. Until more interest is shown by industry, however, we feel that it is prudent to place our emphasis on the development of advanced, high performance, commercially viable heat pipe technology. The areas needing development are design tools, long-life operation, manufacturability, and cost. The primary target will be development of **high performance wick options** that are readily manufacturable. A high performance wick reduces the requirement of the artery structure, simplifying the design, reducing costs, and improving reliability. A significant development towards these ends was the incorporation of passive refluxing into the Thermacore 75 kW_t design based on Sandia recommendations. This concept is also being applied to the artery-free 35 kW_t design to improve reliability.

At Sandia, **a heat pipe has been constructed to evaluate a new porous metal wick structure developed by Friction Coating in Sterling Heights, Michigan.** The new wick structure is applied to the substrate material through a process known as "decalcomania." With this process, it is possible to attach a porous metal structure to a dome-shaped surface without the use of special molds, potentially reducing the cost over the Thermacore process. Deformations that are encountered in using a sintered screen wick structure are also eliminated. It is expected that the capillary pumping performance of the Friction Coatings wick will be comparable to the Thermacore wick. However, the presence of braze material in the wick is expected to make the wick more robust while improving manufacturability. The construction of a bench-scale heat pipe that uses Friction Coating's porous metal structure has been completed. This system will be filled and tested at the NSTTF in the coming quarter. In addition, Sandia is investigating other wick options including reticulated metal foam and variations of the Friction Coatings process. As these processes are developed, bench-scale devices will be fabricated to test their function. At the same time, alternative artery structures will be developed. When a set of promising candidates has been tested, they will be incorporated into an advanced on-sun receiver test. Sandia expects to postpone the September milestone for an advanced heat-pipe receiver, pending results from the bench-scale tests.

Another significant area of development is the hybrid receiver, allowing operation of the dish-Stirling system during periods of low or no insolation. This development will provide greater market penetration. NREL is funding prototype development efforts with STC (pool boiler) and Cummins Thermacore (heat pipe).

A design review for the Cummins Power Generation, Inc. (CPG) hybrid receiver subcontract, Phase 1 effort, was held at Thermacore, Inc. in Lancaster, Pennsylvania, on March 18, 1993. The review was attended by CPG, Thermacore, Cummins Electronics Company, Cornell University, Southern California Gas, Sandia National Laboratory, and NREL. The objective of the hybrid receiver project is to demonstrate the feasibility of operating a heat-pipe receiver on concentrated solar energy or natural gas, and combinations of the two. This technology will open up new markets for dish/Stirling technology and will improve the economic feasibility of the technology in existing markets. CPG started in May 1992 and has arrived at a final design for their concept. The receiver is based on their 35 kW_t heat pipe but provisions have been made to supply heat from three natural gas burners located along an extended outer

cylinder located just aft of the hemispherical solar absorber dome. The concept includes combustion gas preheat to provide approximately 80% efficiency under gas operation. CPG has developed a detailed control scheme to insure continuous power delivery to the end-user while at the same time protecting the receiver from excessive thermal transients. **CPG expects to begin fabrication immediately.** Ground testing of the receiver with both natural gas and electrical radiant heat will begin in September, with on-sun testing to commence in October.

Stirling Technology Company (STC) has started on Phase 2 of their hybrid receiver subcontract to NREL. Under this phase, **STC will fabricate and ground test their solar/natural gas pool boiler receiver.** These activities are to be completed by September 1993. Completion of the STC Hybrid subcontract will continue when FY94 funding is available and will end with an on-sun test at NREL, in early calendar 1994.

Planned Activities for Next Quarter

- **Thermacore will complete the fabrication of the modified-design 75 KWt heat-pipe receiver.** The receiver will be processed and tested on Thermacore's bench-lamp array and delivered to Sandia for testing on sun. Sandia expects to test this receiver late in the third quarter. On the basis of the test results, Thermacore will conclude the integration of a similar receiver with the STM heater heads. Sandia will complete the interface design and prepare the heater heads and fixture for attachment to the receiver.

- **The on-sun testing of the second-generation pool-boiler receiver will be completed early in the quarter.** The testing will be limited to proof-of-concept tests and brief performance testing. The results will be used to refine Sandia's CIRCE and AEETES models. Durability testing will not be performed due to personnel and site constraints. The results of these tests as well as the bare-wall receiver tests will be documented. The initial results will be reported at the Intersociety Energy Conversion Engineering Conference in Atlanta, August 1993. A comprehensive report will detail the tests and wrap up Sandia's current pool boiler efforts.

- **Testing will continue on the 10,000-hour pool-boiler bench test.** If testing continues to progress, we expect to have completed nearly 4000 hours of testing by the end of the quarter. Sandia will also fill and begin testing the first series of advanced heat-pipe bench-scale tests. The Friction Coatings wick will be combined

- **Advanced wick development will continue.** Friction Coating, Inc., samples will be bench-tested. Additional options will be identified and pursued. Application of wicks to domes will be studied.

Milestones (Planned/Actual)

(Dec 92/Dec 92) Complete planned on-sun testing of Sandia 75 kW_t heat pipe.

(Feb 93/Feb 93) Complete planned on-sun testing of Thermacore 75 kW_t heat pipe.

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3. Power Conversion System (PCS) Technology

In cooperation with industry, Sandia has been engaged in a program to solarize, test, and evaluate power conversion devices that have the potential to be utilized in commercial solar thermal electric point focus systems. The goals of the program are to engage in projects that directly support on-going commercialization efforts; to develop solar thermal power conversion systems that are candidates for commercialization; to identify and respond to solar-specific design issues; and to increase the general industry knowledge base on system integration, packaging, and system testing techniques.

Accomplishments

This program has two facets. The first involves the evaluation of advanced solar energy conversion concepts that are submitted through the Sandia Solar Thermal Design Assistance Center (STDAC). **The concepts are evaluated for general viability and the potential for use in commercial solar thermal systems.** Two engine concepts were evaluated during this quarter. Neither concept was mature enough to be considered for inclusion in the Solar Thermal Program. The principal investigators were directed to government and industrial organizations that may consider assisting them with further technical development.

The main thrust of this program is the evaluation of existing engines that demonstrate characteristics that are favorable for solar applications. The heat input systems of promising engines are replaced with solarized versions, control systems and parasitic systems are designed and fabricated, the systems are performance mapped, and the measured system performance is published in public journals for comparison with existing systems. A completed Power Conversion System (PCS) can either be tested on a bench-type setup in the Engine Test Facility (ETF) or on the Test Bed Concentrators (TBC) located at the Sandia National Solar Thermal Test Facility (NSTTF).

Two projects are currently in progress to develop solarized versions of existing engines. A statement of work has been negotiated with the Northern Research and Engineering Corporation (NREC) to develop a Brayton cycle PCS. The project builds on the highly successful co-generation (Turbogen) system developed by NREC with funding from the Gas Research Institute and Southern California Gas. The German DLR will supply a volumetric solar receiver for the NREC PCS if hardware is fabricated. The project has been structured to consist of two phases. Phase I is a technical and economic feasibility study to determine the systems' potential for commercialization when mated with a point focus concentrator. A decision point has been built into the project at the end of Phase I. If the technical characterization or the economic study indicate that the system is not viable for solar use, Sandia has the option to terminate the contract before hardware is fabricated (and most of the project cost is incurred). Phase II, if the option is exercised, will include system fabrication, on-sun testing in Germany and the USA, and an evaluation of the system performance. The contract for this work is in the final stages of placement.

A Stirling cycle PCS is currently ready for testing on-sun at the NSTTF. A cost-shared project with Detroit Diesel Corporation (DDC) and its sub-contractor, Stirling Thermal Motors (STM), is nearing completion. The project consisted of developing a PCS based on the upgraded STM4-120 engine. Most of the work on the project was performed by STM. A directly illuminated solar receiver (DIR), a package support structure, the cooling system, the control system, the engine interface to an induction generator, and the environmental protection packaging were all designed and fabricated (Figure 6).

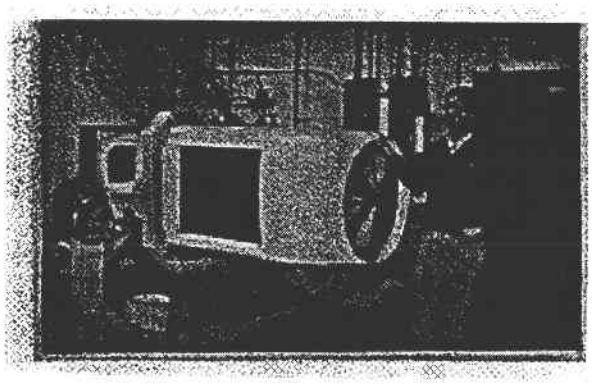


Fig. 6 - Completed DDC/STM PCS ready for testing at STM.

The PCS interfaces to the TBC and the Sandia data acquisition systems were negotiated and documented in an Interface Control Document (ICD) maintained by Sandia. The power conversion system was tested for 50 hours at power output levels of greater than 20 kWe with engine-alternator efficiencies ranging from 35-40% using a natural gas-fired heat input system. The completed PCS with the DIR was tested for 25 hours of incident-free operation using a quartz lamp array to provide the heat for the system (Figure 7).

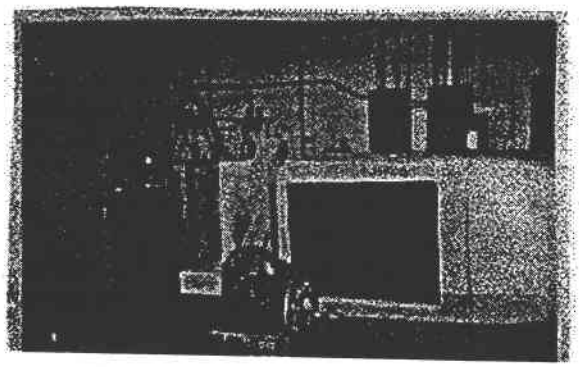


Fig. 7 - DDC/STM PCS testing with the quartz lamp array.

The PCS performed very well during these tests at STM. The PCS is rated at an output level of 25 kWe. The completed PCS was received by Sandia on March 1, 1993. The PCS has been installed on TBC1 and is awaiting the first sunny day to begin on-sun testing .

The on-sun test plan was developed during this quarter for the DDC/STM PCS. The testing will be conducted in three phases. The first phase is a system checkout and shakedown test. The PCS will be run initially at relatively low receiver temperatures and low power levels until the system is determined to be stable. The receiver temperatures and power input will be gradually increased until the high operating temperature and

the rated power input of the TBC is reached. The second phase of the test plan is designed to allow a performance map of the PCS to be generated. The performance of the PCS will be measured at various power input levels and receiver control temperatures. The results will be modeled using a statistical regression technique. The third phase of the plan will be used to expand the performance map to include engine cycle pressure as a control variable and to investigate special operating conditions.

Planned Activities for the Following Quarter

- A contract will be negotiated with the Northern Research and Engineering Corporation (NREC) to solarize an existing Brayton-cycle engine. The contract details will be negotiated and the contract placement procedure will be initiated.
- The National Research Energy Laboratory (NREL) contract details will be negotiated and all contracting requirements will be completed.
- The DDC/STM PCS (on-sun) testing will begin and the testing will be conducted according to the published test plan.
- Support for the STDAC will continue and promising power conversion system designs will be evaluated for possible incorporation into the PCS development program.

Milestones (Planned/Actual)

(Mar 1993/Mar 1993) Accept delivery of the DDC/STM Solar Power Conversion system. Begin final preparations for on-sun testing.

III Reimbursables

Reimbursable activity has been very limited in FY93 and mostly involves planning and preparation for tests scheduled in FY94. The timing of the turndown in this activity is rather fortuitous, however, since facility personnel who have supported-reimbursable programs in the past two years are quite busy preparing for Solar Two- related tests to be conducted next quarter.The objective of the reimbursable programs is to make the unique capabilities of the National Solar Thermal Test Facility available to users outside of the DOE Solar Thermal Electric program. Organizations such as Northrop, McDonnell Douglas, PDA, General Dynamics, David Taylor Research Center and Johns Hopkins University Applied Physics Laboratory, have used the facility with funding from the Air Force, Navy, Army, and the Defense Nuclear Agency. Commercially-funded organizations have included Science Applications International Inc., Atlantis Energie, Ltd., and Northrop.

All work is performed on a full-cost recovery basis. These funds help offset the operating and maintenance costs of the NSTTF and paid all costs for operation and maintenance of the heliostat field and solar tower in FY91 and FY92.

Accomplishments:

Large-scale test of volumetric air receiver. Meetings were held with Atlantis Energie, Ltd. of Switzerland to discuss the installation and test requirements for a new volumetric air receiver that is being designed by Atlantis. The receiver will be tested at the National Solar Thermal Test Facility in the January/February 1994 time frame. An earlier design was tested in two previous test series in May 1990 and March 1992.

User Facility Designation. Solar thermal personnel are working with Sandia's technology transfer organization to establish a process for obtaining the DOE Designated User Facility and other user resource designations for the NSTTF and the Solar Thermal Design Assistance Center. One goal is to enable Sandia to accept funds directly from non-DOE organizations for use of these DOE-approved facilities without requiring DOE/AL to process each individual case as must now be done through the Work for Others programs. Some laboratories, such as Los Alamos, already have this capability for their approved User Facilities, but are interested in obtaining approval of additional User Facilities. At the present time, requests for test facility support take several months to process and must have a budget exceeding $50,000. This precludes timely and affordable interaction with industry and other users, especially small business.

Technology Transfer

Publications

In Progress:

Adkins, D.R., *"High-Flux Testing of Heat Pipes for Point-Focus Solar Collector Systems," SAND92-2346C* Proceedings of the 1993 National Heat Transfer Conference, August 8-11, 1993, Atlanta, Georgia.

Adkins, D.R., R. C. Dykhuizen, *" Procedures for Measuring the Properties of Heat-Pipe Wick Materials," SAND92-2347C,* 28th IECEC Proceedings, August 8-13, 1993, Atlanta, Georgia.

Andraka, C.E., et.al., *"NaK Pool-Boiler Bench-Scale Receiver Durability Test: Test Design and Initial Results,"* to be presented at the 28th Intersociety Energy Conversion Engineering Conference, August 8-13, 1993, Atlanta, Georgia.

Andraka, C. E., et.al., *"Testing of Stirling Engine Solar Reflux Receivers,"* to be presented at the 28th Intersociety Energy Conversion Engineering Conference, August 8-13, 1993, Atlanta, Georgia.

Cameron, C.P., *"A Summary of Recent Activities at the National Solar Thermal Test Facility," SAND92-1348A,* presented at 1993 ASME/ASES/SOLTEC Energy Conference, April 4-8, 1993.

Cameron, C.P., *"High Heat Flux Engineering in Solar Energy Applications," SAND93-0229C* to be presented at the SPIE 1993 International Symposium on Optical Applied Science and Engineering , July 11-15, 1993.

Chavez, J.M., G. J. Kolb, et.al., *"Second Generation Central Receiver Technologies: A Status Report,"* April 1993.

Dudley, V., et.al., *"Test Results for the LUZ LS-2 Solar Collector,"* Draft Report, February 1993.

Kelly, Bruce, *"Resolution of Thermal Storage and Steam Generator Issues for Central Receiver Power Plants,"* Bechtel National Inc., SAND Contractor Report.

Kolb, G.J., J. M. Chavez, P.C. Klimas, et.al., *"Evaluation of Second Generation Central Receiver Technologies,"* submitted to 1994 ASME Solar Energy Conference to be held in San Francisco in March 1994.

Moreno, J.B. and T.A. Moss, *"Bench-Scale Screening Tests for a Boiling Sodium-Potassium-Alloy Solar Receiver,"* SAND92-2253, Sandia National Laboratories, Albuquerque, New Mexico.

Moreno, J.B., et.al., *"First On-Sun Test of a NaK-78 Pool-Boiler Solar Receiver,"* to be presented at the 28th Intersociety Energy Conversion Engineering Conference, August 8-13, 1993, Atlanta, Georgia.

Peterka, J. and R. G. Derickson, *"Wind Load Design Methods for Ground Based Heliostats and Parabolic* Dish *Collectors,"* SAND92-7009, Sandia National Laboratories, Albuquerque, New Mexico, October 1993.

Powell, M.A. and K.S. Rawlinson, *"Performance Mapping of the STM4-120 Kinematic Stirling Engine Using a Statistical Design of Experiments Method,"* to be presented at the 28th Intersociety Energy Conversion Engineering Conference, August 8-13, 1993, Atlanta, Georgia.

Ralph, M.E. ,C.E. Cameron and C. Ghanbari, ***"Thermal Effects Testing at the National Solar Thermal Test Facility,"*** SAND92-2167C, Sandia National Laboratories, Albuquerque, New Mexico.

Romero, V.J., ***"CIRCE2/DEKGEN2: A Software Package for Facilitated Optical Analysis of 3-D Distributed Solar Energy Concentrators - Theory and User Manual,"*** SAND91-2238, Sandia National Laboratories, Albuquerque, New Mexico.

Stine, W.B. and M.A. Powell, ***"Proposed Guidelines for Reporting Performance of a Solar Dish/Stirling Electric Generation System,"*** to be presented at the 28th Intersociety Energy Conversion Engineering Conference, August 8-13, 1993, Atlanta, Georgia.

Strachan, J. W., and R. M. Houser, ***"Testing and Evaluation of the Large Area Heliostats for Solar Thermal Applications,"*** SAND 92-1381, Sandia National Laboratories, Albuquerque, New Mexico, February 1993.

Strachan, J., ***"Revisiting the BCS: A Measurement System for Evaluating the Optics of Solar Collectors,"*** at the International Instrumentation Symposium, ISA, Albuquerque, New Mexico, May 1993.

Meetings and Presentations

Adkins, D.R., ***"Procedures for Measuring the Properties of Heat-Pipe Wick Materials,"*** to be presented at the 28th IECEC, August 9, 1993, Atlanta, Georgia.

Andraka, C.E., et.al., ***"NaK Pool-Boiler Bench-Scale Receiver Durability Test: Test Design and Initial Results,"*** to be presented at the 28th Intersociety Energy Conversion Engineering Conference, August 8-13, 1993, Atlanta, Georgia.

Andraka, C. E., et.al., ***"Testing of Stirling Engine Solar Reflux Receivers,"*** to be presented at the 28th Intersociety Energy Conversion Engineering Conference, August 8-13, 1993, Atlanta, Georgia.

Bean, J.R. and R. B. Diver, ***"Performance of the CPG 7.5 KW_e Dish/Stirling System,"*** to be presented at the 28th IECEC, Atlanta, Georgia.

Cameron, C.P., ***"A Summary of Recent Activities at the National Solar Thermal Test Facility," SAND92-1348A,*** to be presented at 1993 ASME/ASES/SOLTEC Energy Conference, April 4-8, 1993.

Cameron, C.P., ***"High Heat Flux Engineering in Solar Energy Applications," SAND93-0229CC*** to be presented at the SPIE 1993 International Symposium on Optical Applied Science and Engineering , July 11-15, 1993.

Grossman, J.W., Scheduled panel session speaker, Solar Concentrator Research and Testing, The ASME International Solar Energy Conference Washington, DC., April 4-9, 1993.

Kearney, D., ***"O&M Cost Reduction for Solar Thermal Electric Plants,"*** to be presented at SOLTECH 93, Washington, DC, April 1993.

Kolb, G.J., ***"Thermal Cycling of Thermal Energy Storage Tanks Proposed for the Solar Two Central Receiver Power Plant,"*** to be presented at ASME Solar Energy Conference, Washington, DC, April 1993.

Moreno, J.B., et.al., ***"First On-Sun Test of a NaK-78 Pool Boiler Solar Receiver,"*** to be presented at the 28th

Intersociety Energy Conversion Engineering Conference, August 8-13, 1993, Atlanta, Georgia.

Pacheco, J.E., *" Flow Stability in Molten-Salt Tube Receivers,"* Solar Engineering 1993, to be presented at the 1993 ASME International Solar Energy Conference, Washington, DC, April 25-28, 1993, pp. 407-413.

Powell, M.A., *"The Dish/Stirling Solution: Solar-to-Electrical Energy Conversion,"* to be presented at the Public Symposium at Arkansas State University, Jonesboro, Arkansas, April 22, 1993.

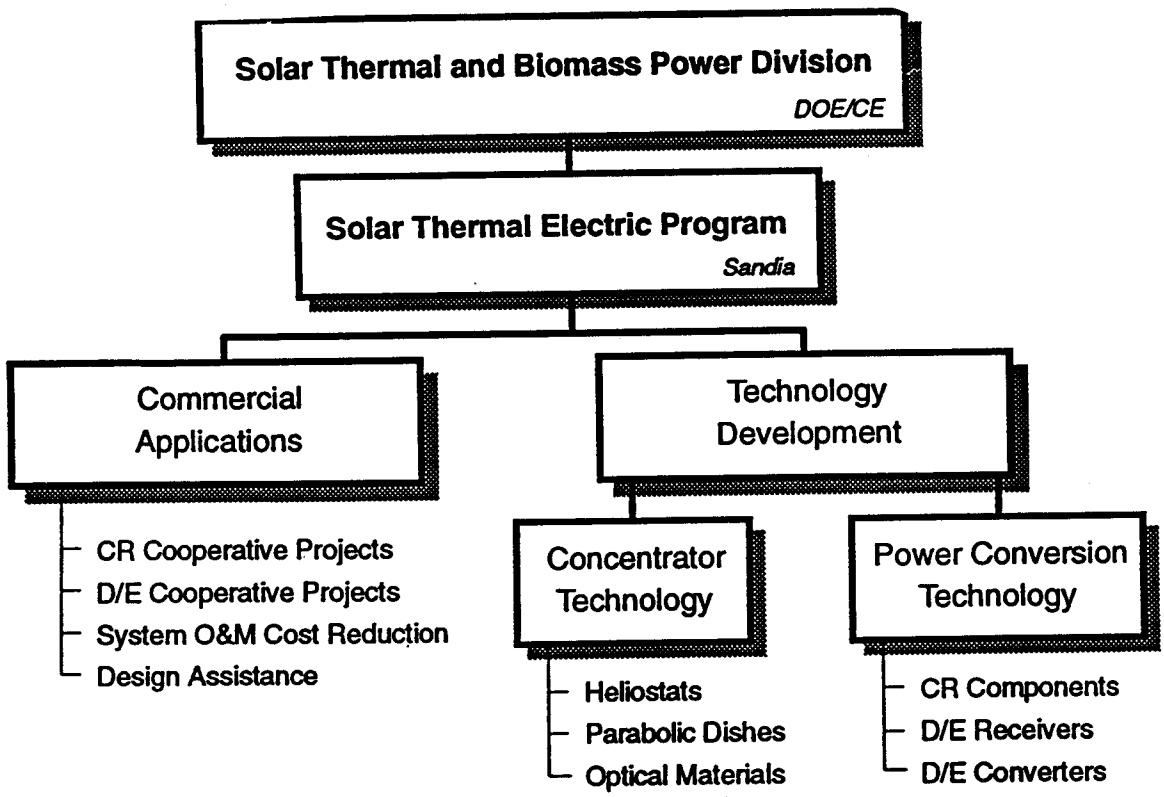
Ralph, M.E., C. P. Cameron, and C.M. Ghanbari, *"Thermal Effects Testing at the National Solar Thermal Test Facility,"* to be presented at the 39th International Instrumentation Symposium, ISA, Albuquerque, New Mexico, May 1993.

Strachan, J., Revisiting the BCS: *A Measurement System for Evaluating the Optics of Solar Collectors,* to be presented at the International Instrumentation Symposium, ISA, Albuquerque, New Mexico, May 1993.

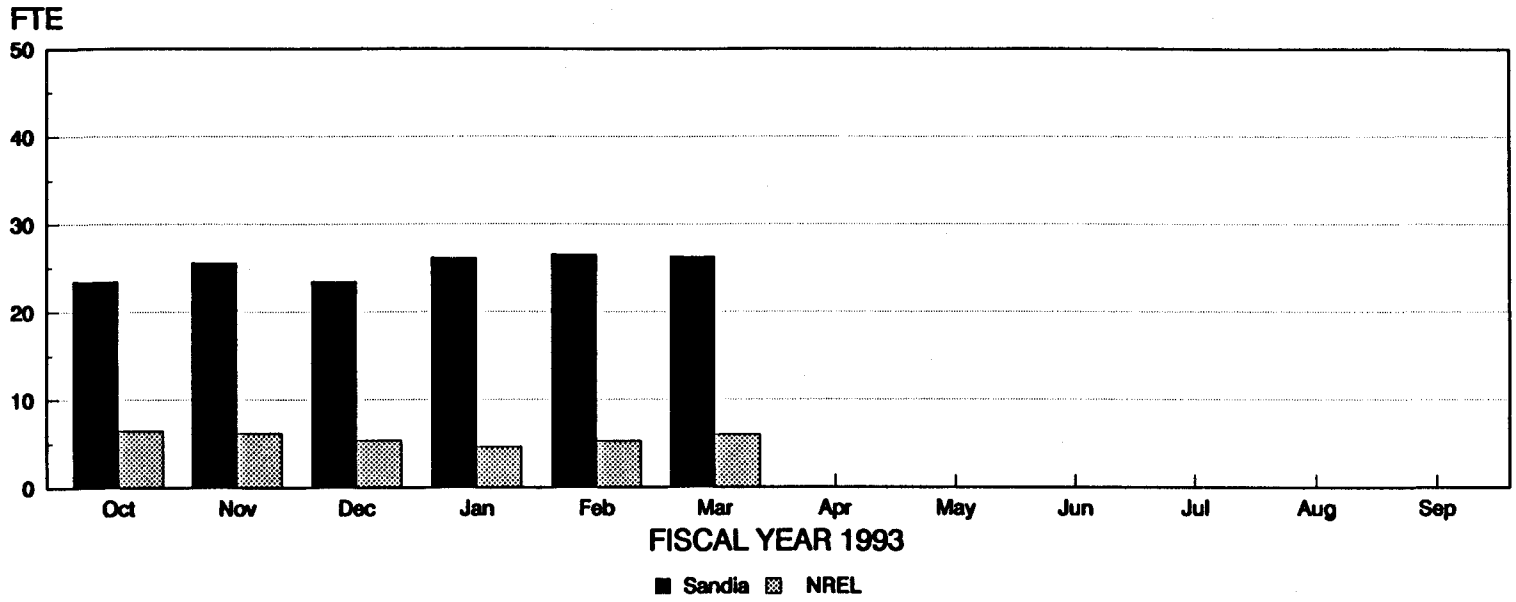
Management Structure Summary

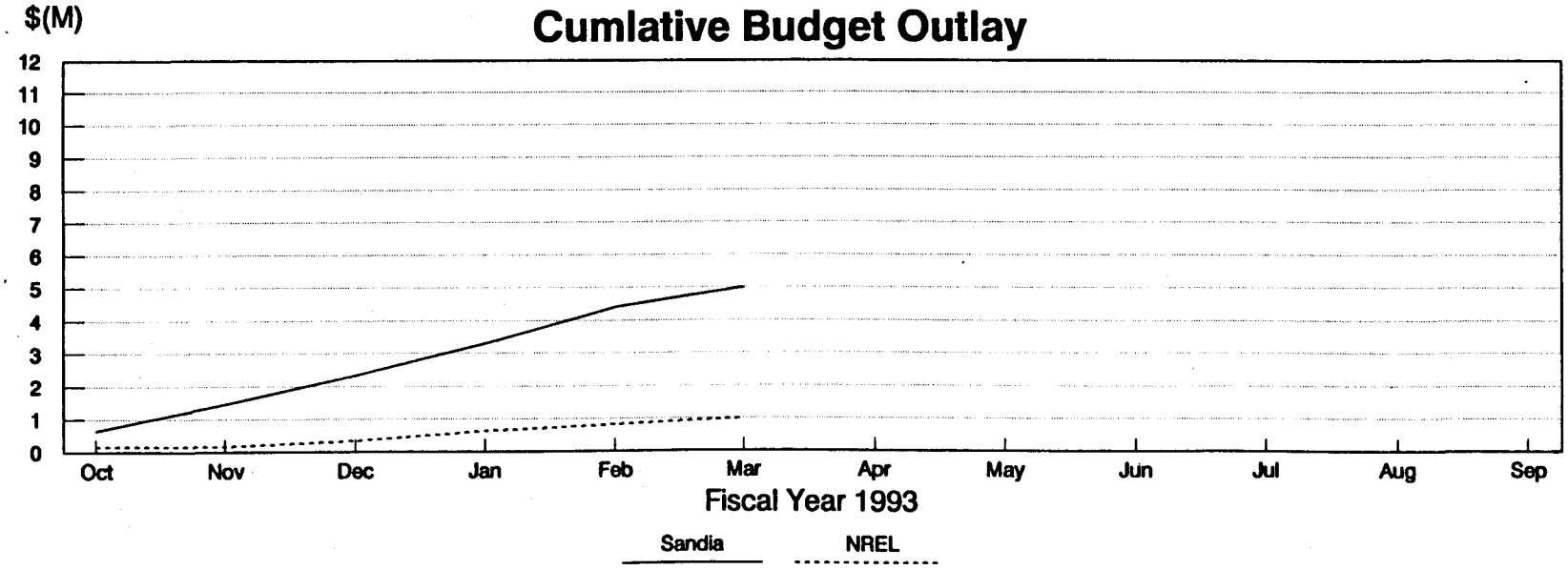
Field Management - Structure and Responsibilities

Specific implementation of the Solar Thermal Electric Technology Program is assigned to two field laboratories, Sandia National Laboratories in Albuquerque, New Mexico, and the national Renewable Energy Laboratory in Golden, Colorado. Sandia National Laboratories is the Program's lead laboratory. Together, these two field laboratories are responsible for implementation of the research and development plans that have been formulated to meet the objectives of the program. Activities are conducted both in-house at the laboratories and through subcontracts placed with private industry, other research organizations, and universities.



MONTHLY MANPOWER LEVEL





Significant Accomplishments Summary

Major Milestones

FY1993	Planned	Actual
• The participants Agreement, E&C Agreement, and DOE Cooperation Agreement will be finalized so that the Solar Two project can be officially started.	Nov 1992	
• The Fourth Technical Advisory Committee meeting will be held. TAC meetings will be held quarterly thereafter.	Jan 1993	Jan 1993
• Authorization to proceed to final design and construction, based on completed plant layout and cost estimate.	Apr 1993	
• Solar One thermal storage tank removed.	Jun 1993	
• Replacement facets for Solar Two heliostat field selected.	Aug 1993	
• Conduct Phase I review of CPG joint venture program.	Nov 1992	Nov 1992
• Deliver CPG "prototype" water pumping dish/Stirling system to the California Polytechnic University test site.	Dec 1992	
• Demonstrate the remote village electrification application at the CPG Abilene, Texas facility.	Dec. 1992	
• Complete evaluation of proposals for the utility scale joint venture program.	Jan 1993	Jan 1993
• Demonstrate the utility grid-tie application at the CPG Abilene, Texas facility.	May 1993	
• Award contract(s) for the utility-scale joint venture program.	Jul 1993	
• Sandia will complete documentation of the testing of the SEGS heat collection elements.	Feb 1993	Feb 1993
• Survey of advanced selective surface coatings for SEGS plants and central receivers will be completed.	Jan 1993	
• Mid-term report that describes advancements in FY93 SEGS tasks 1-7.	Mar 1993	
• Data acquisition system to facilitate SEGS maintenance planning will be implemented.	Jun 1993	

• Evaluation of cyclic stresses in the power block will be completed.	Jul 1993	
• Final report that describes advancements in FY93 SEGS tasks 1-7.	Sep 1993	
• Participate in SOLTECH 93 meeting.	Apr 1993	
TASK II		
• Complete documentation of the test results on the two large-area glass mirror heliostats and the low-cost drive.	Feb 1993	Feb 1993
• Completion of testing and documentation on the first prototype of 100-m^2 dual-module stretched-membrane heliostat..	Aug 1993	
• Complete installation of the Faceted Stretched-Membrane Dish at the NSTTF.	Nov 1992	Nov 1992
• Conduct Final Design Review for the Single-Element Stretched-Membrane Dish design.	Nov 1992	Nov 1992
• Place contract to fabricate a Single-Element Stretched-Membrane Dish.	Mar 1993	
• Complete testing of FSMD with the elastically-formed SAIC facets.	May 1993	
• Complete testing of FSMD with the plastically-formed SKI facets.	Sep 1993	
• Identify procurement process and technical approach for additional alternative reflector.	Nov 1992	Nov 1992
• (Key) Initiation of outdoor materials test at Arizona Public Service or alternate site.	Jan 1993	Jan 1993
• Installation of materials test racks at Sacramento Municipal Utility District or alternate site.	Feb 1993	Mar 1993
• Document status of outdoor testing activities.	Apr 1993	
• Document alternative reflector materials R&D progress.	Aug 1993	
• Complete the Bechtel study of 100 MW_e molten salt steam generators and thermal storage systems.	Jan 1993	Jan 1993
• Complete the 4000-hour molten salt corrosion and stability tests.	Feb 1993	Feb 1993
• Complete testing of wire mesh materials at New	Sep 1993	

Mexico State University.

• Complete testing of the Bechtel volumetric air receiver at the Plataforma Solar (subject to SolarPACES approval.	Jun 1993	
• Publish the Second Generation Central Receiver report.	Sep 1993	
• Complete planned on-sun testing of Sandia 75kW$_t$ heat-pipe receiver.	Dec 1992	Dec 1992
• Test 10kW$_t$ hybrid receiver on sun.	Aug 1993	
• Complete fabrication and begin testing Sandia advanced-wick heat-pipe receiver.	Sep 1993	
• Complete fabrication and begin testing on-sun boiling stability advanced concepts receiver.	Sep 1993	
• Complete fabrication of the Detroit Diesel/STM PCS.	Dec 1992	
• Complete integration of the PCS with a test bed concentrator.	Feb 1993	
• Complete on-sun tests for the PCS with the directly illuminated receiver.	May 1993	
• Complete integration of the PCS with an alkali metal solar receiver (subject to DDC/STM contracting agreement..	Aug 1993	

Procurement Summary

SOLAR THERMAL ELECTRIC SUBCONTRACTS

Task	Specific Contract Subject	Contractor	Lab Contract Number	Present Contract Value ($K)	Prior Year Funds ($K)	FY 1993 Funds ($K)	Total Costs to Date ($K)	Period of Performance	Contractor Type	Major Reports	Project Monitor
IA	Molten Salt System Study	Bechtel	SNL87-5142	$159	$1260	$33.1	$130	01/92-03/93	Large	TBD	J. Chavez
IB	Dis JVP	Cummins	SNL69-7763	$7000	$3500	$2300	$2682	06/91-03/94	Large	Phase Reports	R. Diver
IB	US-JVP	Competitive	SNLAB-8717	$10,000	-0-	$2458	-0-	05/93-05/98	Large	TBD	M. Powell
IIB	Tech Trans Documentation	SEIA	SNL42-5186	$175	$55	$90	$135	02/92 -03/93	non-profit TT Rpts.	Three	D. Menicucci
IC	O&M cost reduction	Kramer Junction Company	SNLAB-0227	$3162	$650	$700	$216	07/92-09/95	Large	TBD	G. Kolb
II	Solar Test Support	EG&G	SNL05-4912	$850	$190	$250	$583	12/88-10/93	Large	N/A	C. Cameron
II	Electrical Support Service	J & S Electric Co., Inc.	SNL75-7415	$351	$70	$82	$253	02/89-02/94	Serv. Support	N/A	L. Gillette
IIA1	NSTTF Technician Services	Ewing Technical Design	SNL63-5487	$1350	-0-	-0-	$250	04/89 - 04/93	Serv. Support	N/A	E. Rush
IIA1	Coll. Supp. Struc. & Ped.	WGAssoc	SNL62-0292	$390	-0-	$391	$256	09/89 - 12/92	Small	TBD	T. Mancini

Procurement Summary (continued)

Task	Specific Contract Subject	Contractor	Lab Contract Number	Present Contract Value ($K)	Prior Year Funds ($K)	FY 1993 Funds ($K)	Total Costs to Date ($K)	Period of Performance	Contractor Type	Major Reports	Project Monitor
IIA1	Stretched-Membrane Dish Dev.	Solar Kinetics, Inc.	SNL55-2495	$1740	$500	-0-	$1740	04/88-12/92	Small	88-7035	T. Mancini
IIA3	Direct Optical Materials	SAIC	NREL YF-2-11191	$130	$130	-0-	$57	03/92-05/93	Large	TBD	G. Jorgenson
IIA3	Optical Materials	3M	NREL 2A-2-11031-1	$139	$139	-0-	$38	9/10/92-6/9/93	Large	Final Report	G. Jorgensen
IIA3	Optical	IST	NREL	$139	$1	-0-	$76	04/92-04/93	Small	TBD	G. Jorgensen
IIA3		PNL	DAT-3-132268-01	$70	-0-	$70	-0-	3/93-4/94	Govt	Final Report	G. Jorgensen
IIB2	Heat-pipe	Cummins	SNL AB3348	$145	$145	-0-	$10	08/92/04/93	Large	Monthly	C. Andraka
IIB3	2nd STM4-120	Stirling Ther. Motor	SNL75-8851	$425	$80	-0-	$410	04/89 - 02/93	Small		M. Powell
IIB3	ASCS Design	NASA LeRC	DOE Inter-agency	$6169	$1035	-0-	$4800	01/89 - 01/93	Govt	--	M. Powell
IIB3	Stirling Engine Solarization	Detroit Diesel Company	SNL67-9086	$318	$211	$107	$190	01/92-02/93	Large	TBD	M. Powell
IIB3	Dish/ Stirling	Cal Poly Pamona	SNL67-3678	$88	$9	-0-	$85	11/91-05/93	Univ	One	P. Klimas

NOTE - This list contains subcontracts exceeding $50,000.

19-JUL-93
C:Qtly.ah1

Distribution:

DOE/HQ:	R. Annan
	G. Burch
	S. Gronich
	R. Shivers
	J. Kern
	N. Haque
	M. Reed.
DOE/AL:	G. Tennyson
	N. Lackey
DOE/Golden Field Office:	P. Kearns
	R. Martin
NREL:	T. Williams (15)
	S. Hauser
	B. Marshall
	R. Stokes
SANDIA:	D. Arvizu
	C. Cameron (12)
	P. Klimas (5)
	C. Tyner, (25)

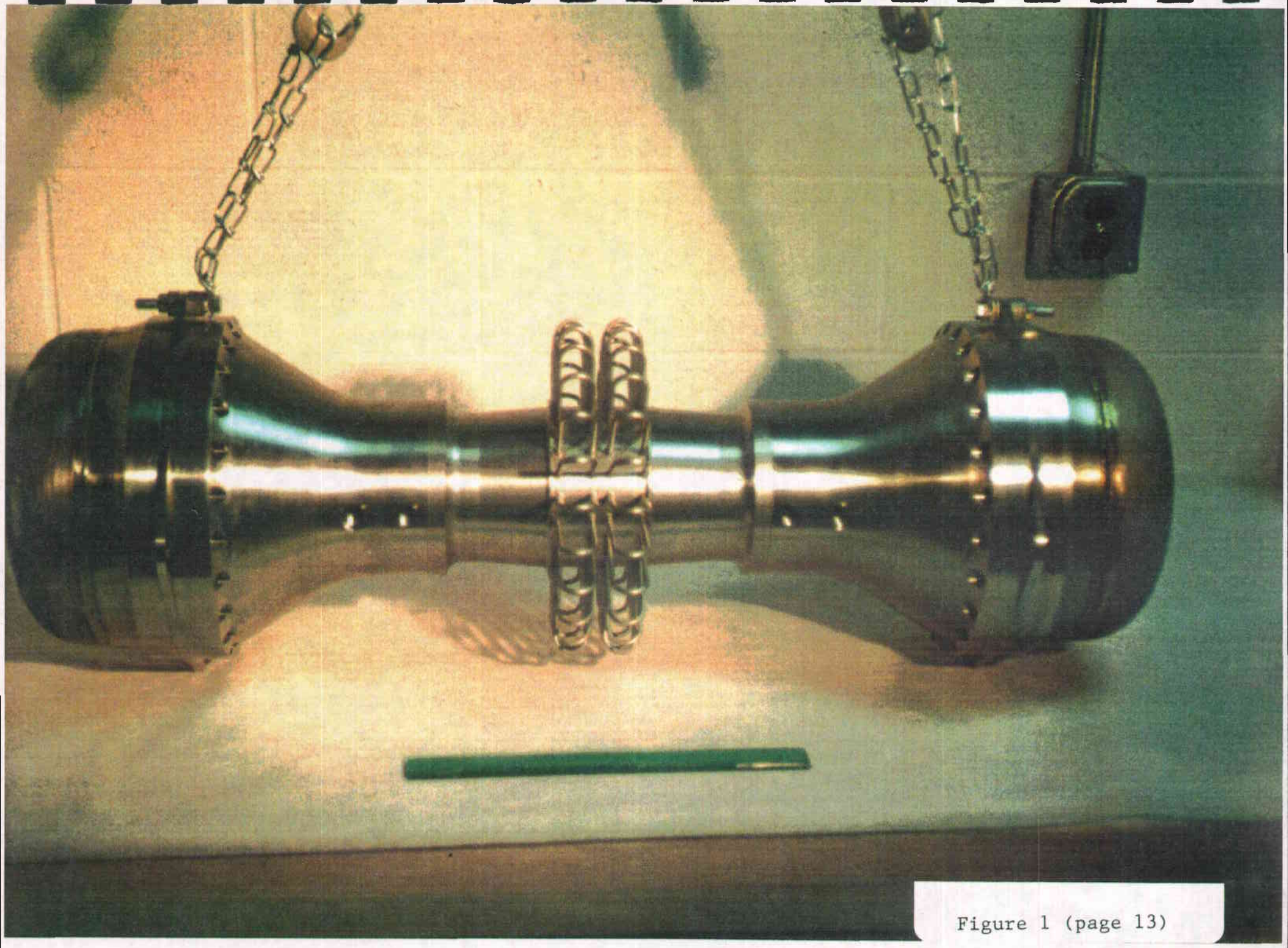


Figure 1 (page 13)

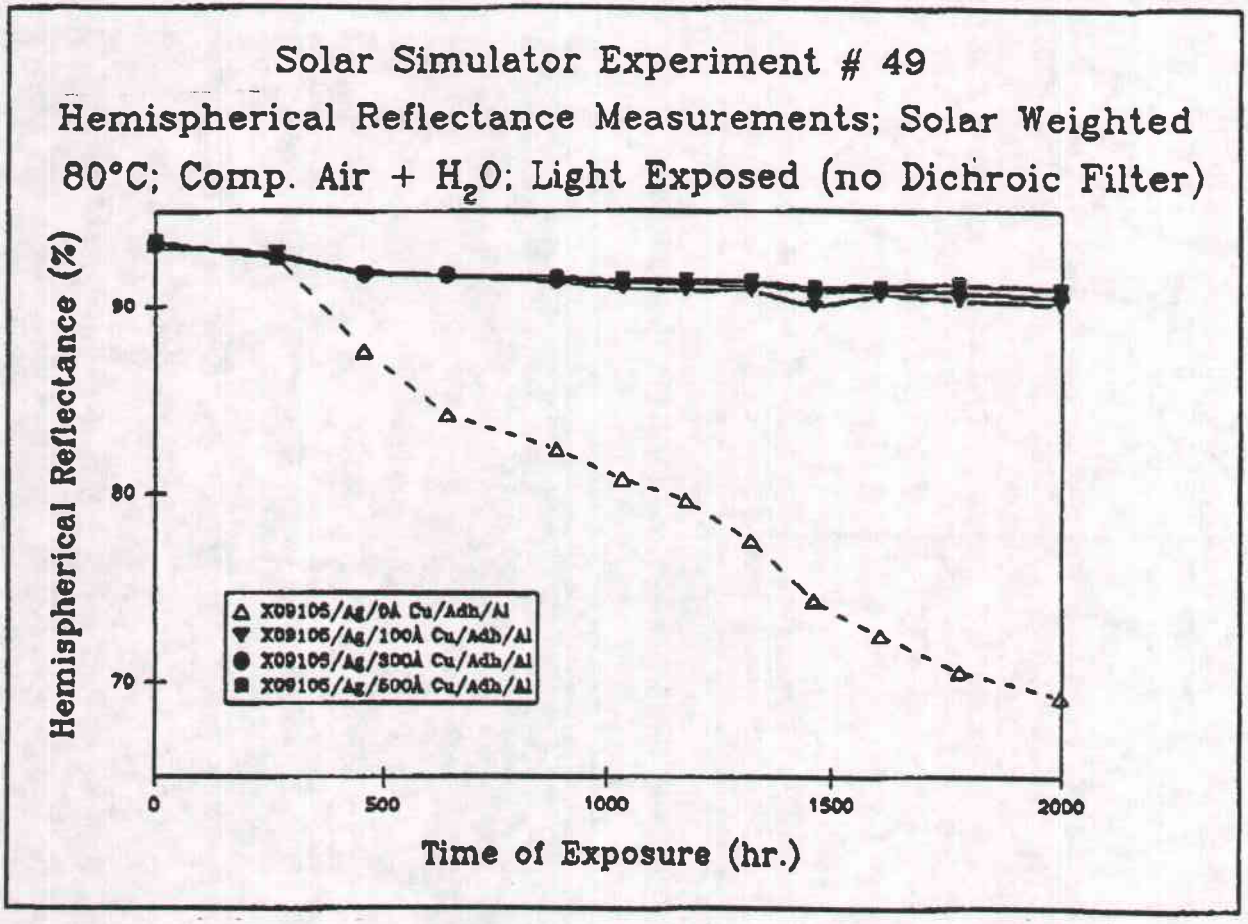
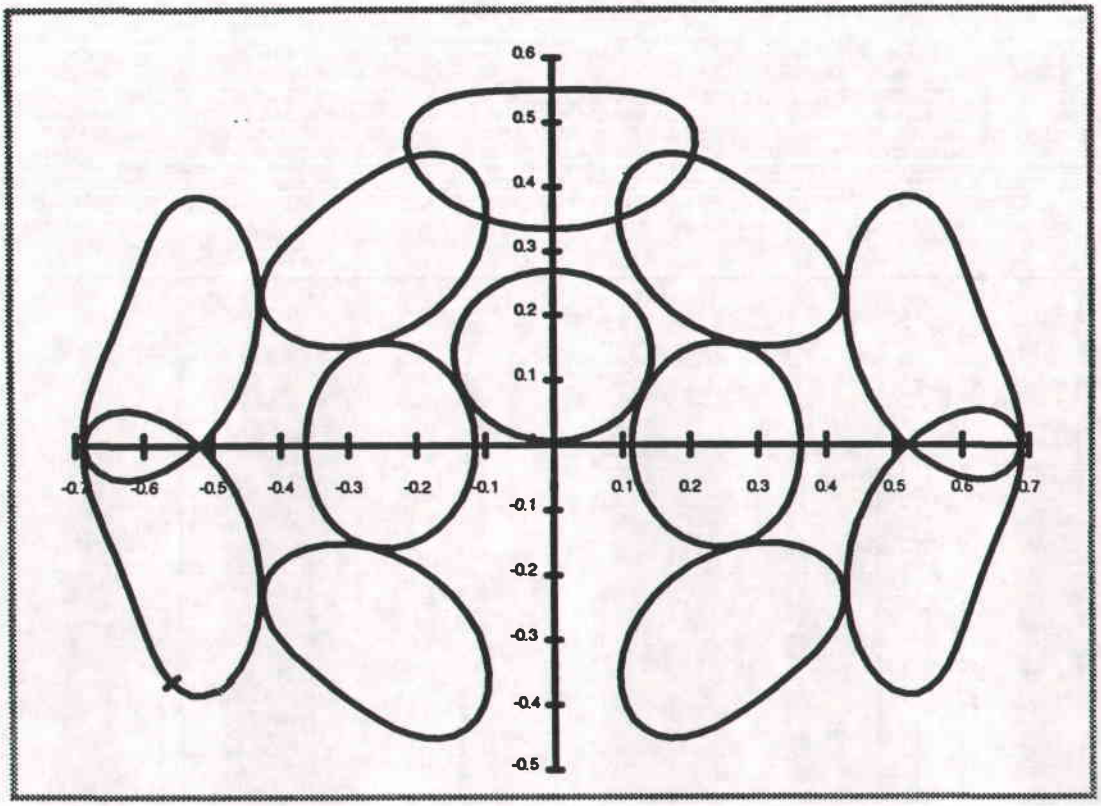
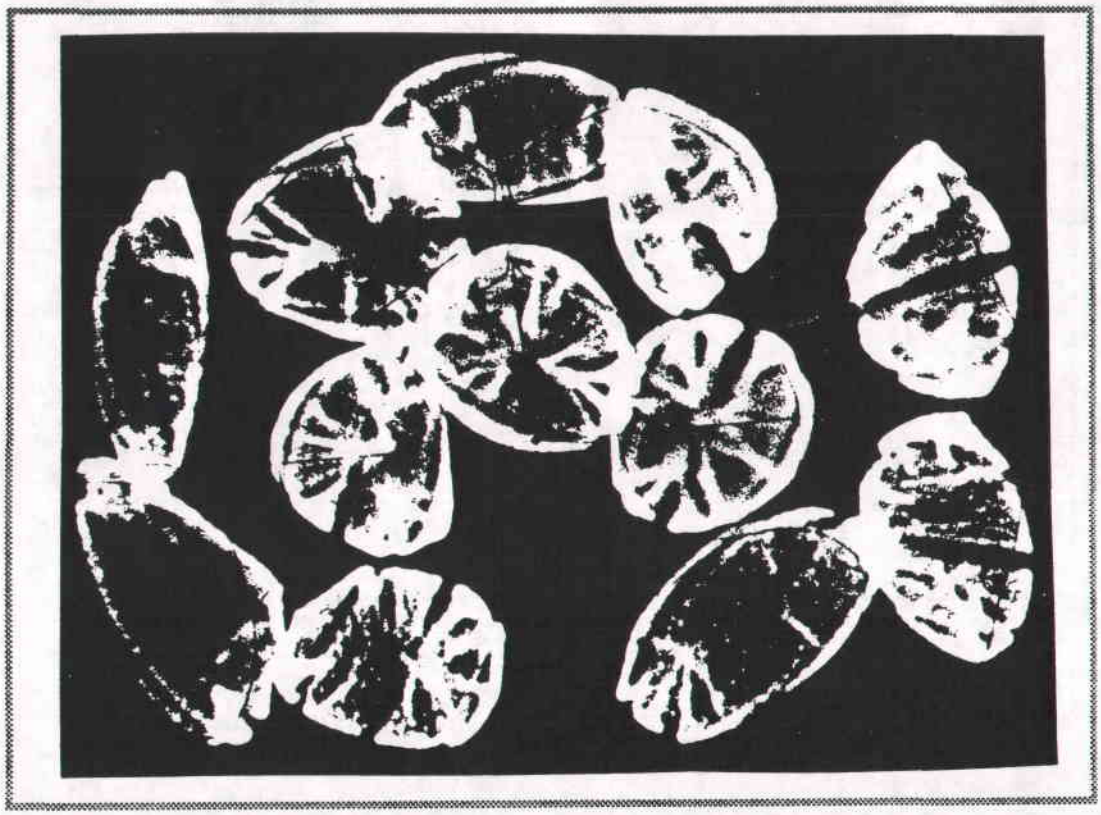


Figure 3 (page 25)



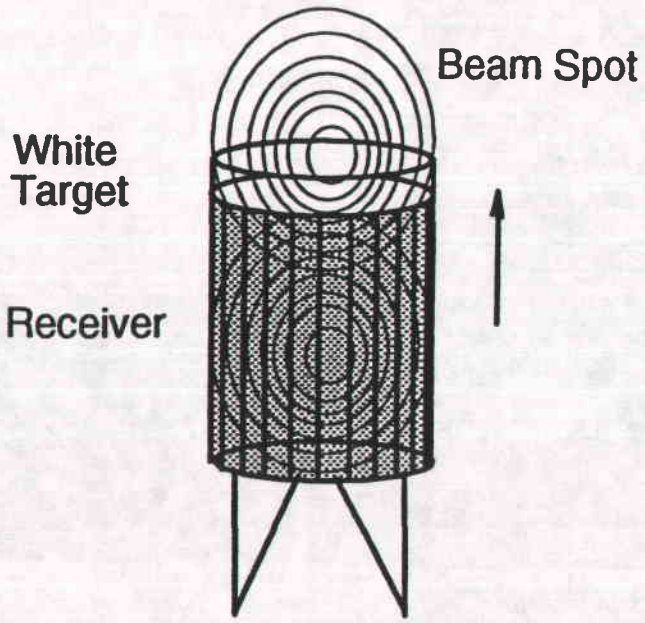
a. Computer-Generated Images of the Twelve Facets.



b. Photograph of the Facet Images on the Target

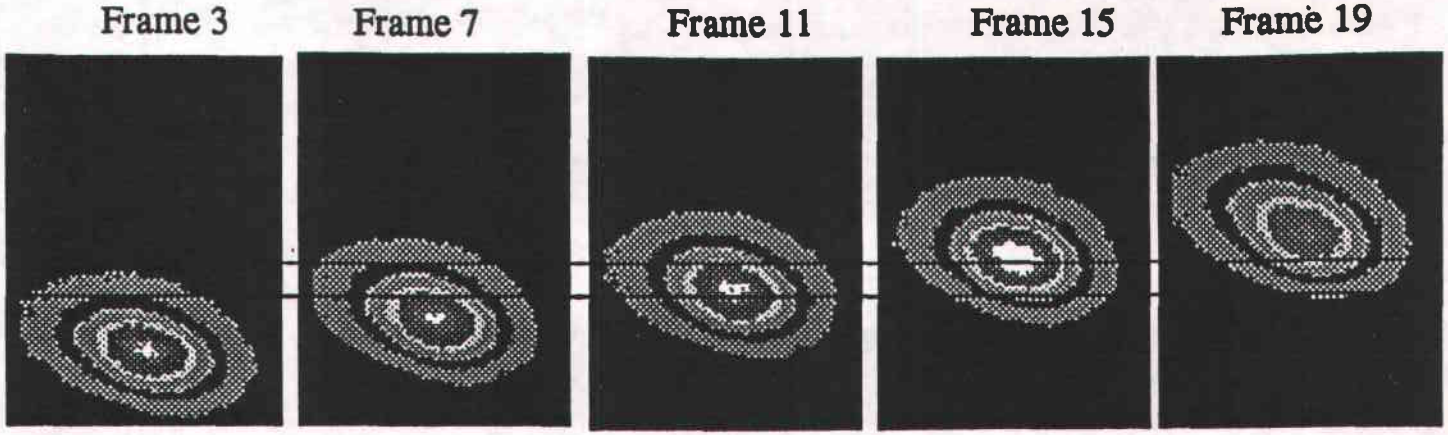
Figure II A.2-1 Alignment of Facets on the Faceted Stretched-Membrane Dish

Figure 2a-b (page 23,24)



Solar Two Receiver

Figure 4 (page 28)



Change in aim points was 0.8 m.

Composite Image

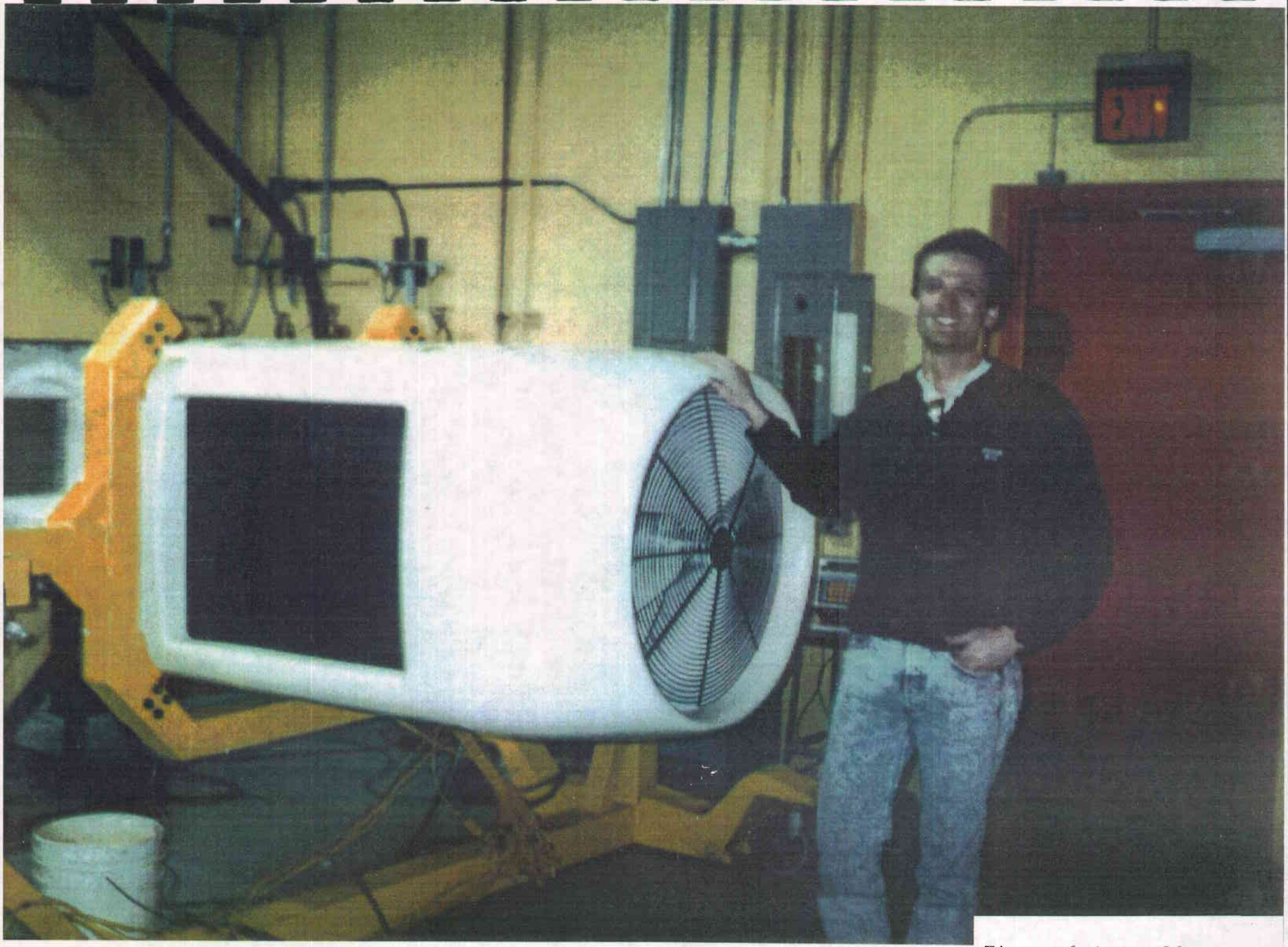


Figure 6 (page 36)

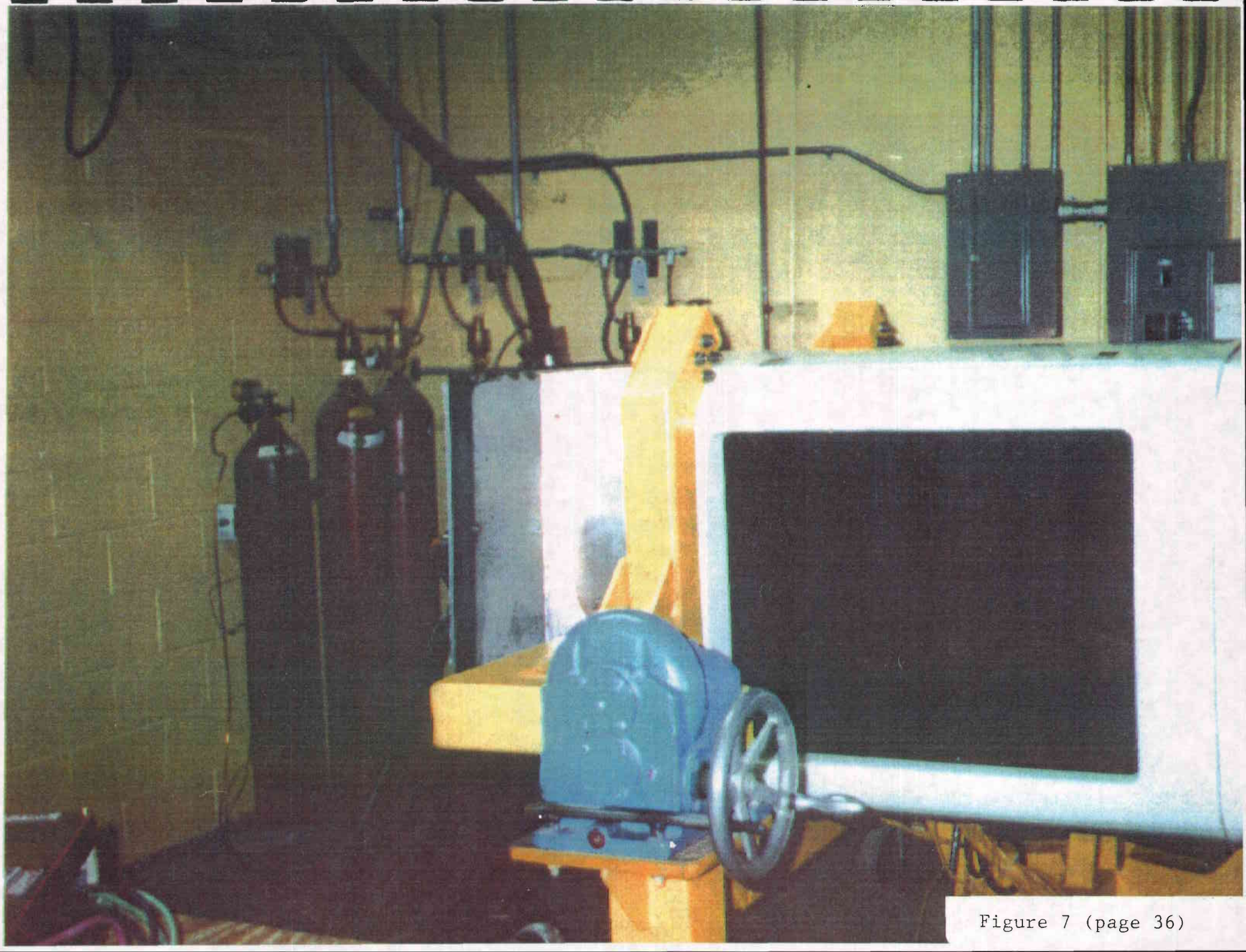


Figure 7 (page 36)