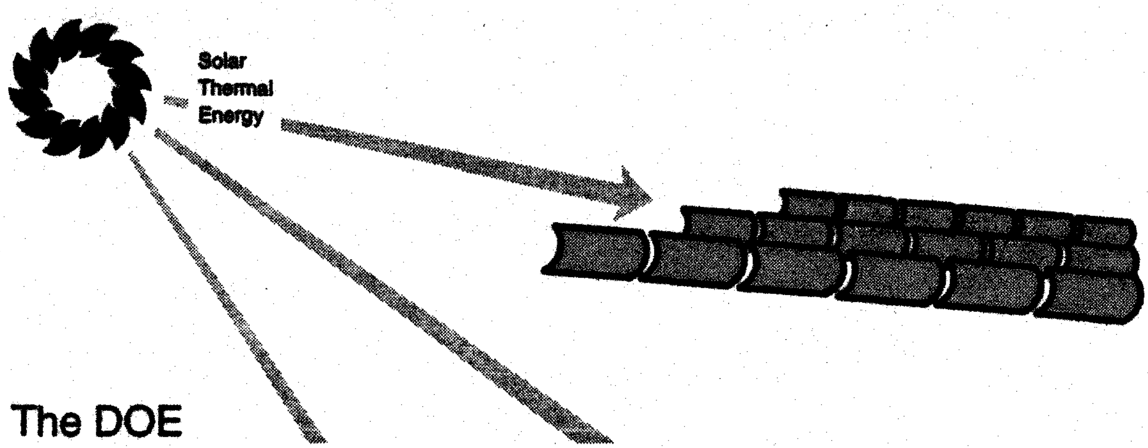
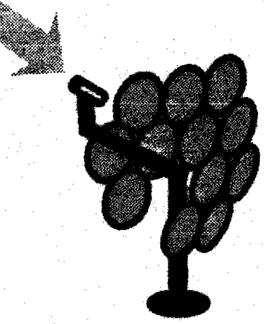


The DOE

Solar Thermal Electric Program

Quarterly Progress Report
Fourth Quarter FY93



Submitted by:

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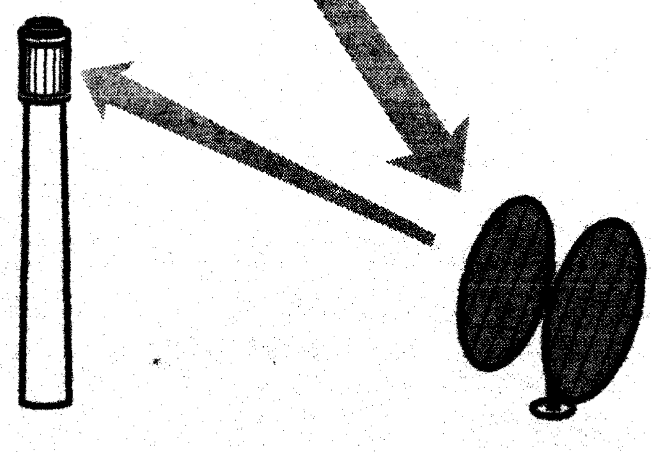
October 1993



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NREL

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Solar Thermal Electric Program Summary

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 U.S., 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.

Our Vision

Installation of 900 MW_e of U.S.-designed and -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:

- Systems and Market Development
- Manufacturing
- Research and Development

Our 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 to conduct research, 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 for U.S. industry.

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

Our Strategy

Our 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 (DOE) and its field laboratories will seek to

- Increase, through cooperative ventures, industrial participation in both the planning and execution of program elements. Successful projects include the following:
  - 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 and enlarge the program's user, supplier, and decision-making constituency.
- Contribute to the DOE Energy Efficiency and Renewable Energy's goal of making solar thermal electric technology a viable option for both the domestic and international power-generation markets.

The DOE's role in implementing the program strategy centers on the development of improved cost effectiveness and reliability of solar thermal electric components and the development of additional energy markets with high strategic or economic value to U.S. 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 the following core program: (1) opportunity for high-risk research to identify and prove solar electric generation concepts 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 third 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.

Program Structure

The Solar Thermal Electric Program is structured to provide a balance of activities that exploit near-term commercialization opportunities, improve readiness to meet long-range performance and cost goals, and 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. Operations 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**

Summary of Accomplishments: Fourth Quarter FY93

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.

Solar Two
- The Solar Two Engineering and Construction Management Agreement was finalized by Southern California Edison and Bechtel.
- Demolition/removal of the the Solar One thermal storage system was begun by Cunningham-Davis Corporation, the company contracted for the work by Southern California Edison.
- This past quarter, Bechtel has been working to complete Phase 1, Systems Engineering, of the Solar Two project.

Dish/Stirling Joint Venture Program
- Various updates/improvements were made to Cummins $7kW_e$ system.
- Operation of the Sunpower "prototype" free-piston Stirling engine/linear alternator in a test cell was initiated in Abilene, Texas.
- Cummins' $7kW_e$ system was recognized by *R&D Magazine* as one of the 100 top R&D achievements in 1993.

System Operation and Maintenance (O&M) Cost Reduction
- Updated mirror-cleaning strategies to optimize solar energy collection were tested and analyzed for Solar Electric Generating Systems (SEGS) plants.
- Software testing continues on an integrated power-park (multiple plants at a given site) data collection network, which hopes to maximize the efficiency of maintenance resources, organization, and costs shared by each plant.
- To support the Solar Two Project, Kramer Junction Company personnel discussed their experience and lessons learned about design, operations, and maintenance issues relevant to large solar thermal power plants with engineers from Bechtel National Incorporated.

Concentrator Technology
- A report, *Operational Experience and Evaluation of a Dual-Element, Stretched-Membrane Heliostat*, by John Strachan has been completed.
- On-sun testing of the faceted stretched-membrane dish with Science Applications International Corporation (SAIC) facets was completed.
- Collaborative efforts with three industrial partners, Dow Chemical, 3M Company and Martin Marietta, have produced three optical materials for evaluation for solar applications.
- Reduced silvered polymer reflector delamination was demonstrated.

Power Conversion Technology
- Feasibility experiments and analysis of molten-salt flow through "cold" piping were initiated.
- Work on the Spain/USA joint volumetric receiver test continues.
- Tax equity issues associated with investor-owned solar thermal power plants are being studied by National Power Company of Oakland, California.
- 5800-hour point was reached in the 10000-hour bench scale dish receiver durability test program.
- Hybrid dish receiver fabrication continues on schedule.
- A contract was placed with Northern Research and Engineering to develop a Brayton cycle power conversion system.
- On-sun testing continues on the Detroit Diesel/Stirling Thermal Motors STM4-120-based power conversion system.

Solar Thermal Electric Program
Quarterly Progress

I. Commercial Applications

The Solar Thermal Electric 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 200 megawatts. The program also supports existing parabolic trough collector systems for the purpose of operation and maintenance (O&M) cost reduction. The 354 megawatts of installed trough capacity represents $1.2 billion 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 that 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. Presently, three major 50/50 cost-shared cooperative activities are underway within the program with a total value of $75M. The following organizations are the private sector leaders of these joint activities:

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 design, construction, and 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 the DOE in sponsoring this project are the following organizations: Los Angeles Department of Water and Power, Idaho Power Company, PacifiCorp, 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 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 a 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 agreements.

This past quarter, the Solar Two Participants agreement with the California Energy Commission (CEC) was finalized. Currently, the Solar Two Project Participants are funded at a level of $17.5 M. However, this funding level assumes Pacific Gas and Electric Company (PG&E) participation, which has not yet been finalized. Southern California Edison (SCE) has agreed to backstop the Project to bring the Solar Two Participants funding to the $19.5 M. SCE is still pursuing funding from others, including the Bureau of Reclamation, Nevada Power, and industry.

Solar Two Phase-1 work in progress.

This past quarter Bechtel has been working to complete Phase 1, Systems Engineering, of the Solar Two Project. The preliminary specifications for all the systems have been developed, the plant layout has been defined, and preliminary Process Flow Diagrams, Piping and Instrumentation Diagrams, and General Arrangement Drawings have been prepared. In addition, the specification for the Solar Two receiver was completed and sent out for bid. Sandia, at the request of SCE and Bechtel, is consulting with the receiver vendors on the development of their receiver designs. Sandia has also supported the development of the Test and Development Plan, the analysis of parasitic loads, and the recommendations on the collector field modifications. As a member of the Solar Two Project Team, Sandia met a number of times with SCE and Bechtel to discuss the Solar Two design and project goals. The Phase-1 documentation was completed by Bechtel on September 30, 1993. The cost estimate will be completed early next quarter.

Bechtel visits solar sites.

On July 20, Sandia hosted a visit by the Bechtel Solar Two Team. The purpose of the visit was for the new Bechtel team to become familiar with the molten-salt technologies and Sandia's capabilities. **Sandia also hosted the Solar Two Steering Committee Meeting** on July 21, at the National Solar Thermal Test Facility (NSTTF). **Sandia coordinated a visit by the Bechtel Solar Two Team to the Kramer Junction solar power park on September 9 and 10.** The purpose of the visit was to provided the Bechtel team with insight into the design, operation, and maintenance of a solar power plant.

Sandia hosts TAC meeting.

A Solar Two Technical Advisory Committee (TAC) meeting was held this past quarter on August 11-12, 1993 at the NSTTF at Sandia. The purpose of the meeting was for the TAC to meet the new Bechtel Project Team, to get an update of the Solar Two Project, and for Sandia to present information on its testing and evaluation supporting Solar Two. In addition to the meetings, a tour of Sandia's Central Receiver Test Facility was given. Twenty-six people attended the meeting, including representatives from most Participants, Contributors, Engineering and Construction Management (E&CM), the DOE, and Sandia. The meeting was useful in updating the TAC on the status of Solar Two and transferring information on molten-salt central receivers to the Solar Two Participants.

Solar One thermal storage system demolition.

Demolition has began on the Solar One thermal storage system. Southern California Edison has contracted with Cunningham-Davis Corporation of Fontana, California to perform this task, which must be completed before Solar Two on-site work can begin. Cunningham-Davis moved onto the site during the week of September 13. The contract is for approximately $800K and the entire task is scheduled for completion within 90 days. The first tanker truck of oil was removed from the tank on September 22; most of the drainable oil had been removed by October 1. The oil is being transported to a refinery in Tonopah, Nevada. The next steps will be demolition of the thermal storage system heat exchangers, and removal and treatment of the 6800 tons of sand and gravel in the tank. The selected treatment option for the sand, gravel, and oil mixture is to treat it in a low-temperature thermal desorption unit located in Adelanto, California. The contractor has withdrawn samples of the sand and gravel from the tank and found that a considerable amount of oil is retained in the sand and gravel bed. In addition, the oil appears to have permeated the gravel. The sand and gravel will therefore probably require rinsing and crushing prior to thermal treatment.

Collector field maintenance and assessment. Sandia continues to support the maintenance and assessment of the collector field at Solar Two. This past quarter, **Sandia contracted with Advanced Thermal Systems (ATS) to fabricate two remote controllers (stimulators) for the Solar Two heliostat field.** These controllers will be used in a Sandia-led survey of the field. Sandia also has been developing plans and acquiring the materials to test a LUGO heliostat at the NSTTF. The LUGO heliostat structure and the glass facets were acquired this past quarter. Assembly of the heliostat can not begin until after environmental issues are resolved at our test facility.

Planned Activities for Next Quarter

- Continue to support SCE efforts to expand the Solar-Two consortium of utilities, industry, and regulatory agencies.
- Complete a TAC review of the Solar Two Phase-1 design and documentation
- Complete a top-level survey of the Solar Two collector field.
- Initiate testing of the LUGO heliostat.
- Begin Phase 2, development of Major Bid Packages, activities in Solar Two.
- The next TAC meeting is scheduled for October 25-26, 1993, in Portland, Oregon. The next Steering Committee meeting is scheduled for October 27, 1993 in Portland. Oregon.
- Complete demolition of the Solar One Thermal Storage System.

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. Progress continued on the Dish/Stirling Joint Venture Program (DSJVP) with Cummins Power Generation. Testing of the concept validation systems in Abilene, Texas and Lancaster, Pennsylvania continued. In addition, the NREL sponsored "artery free" durability heat pipe #3 surpassed 500 hours of on-sun operation at temperature and durability testing of an engine/alternator in a test cell was initiated. Contracts were negotiated with two contractors for the Utility Scale Joint Venture Program (USJVP). The USJVP contracts will be placed early in the next quarter.

Accomplishments

Cummins 5-kW$_e$ systems operational. Operation of the Cummins Power Generation, Inc. (CPG) dish-Stirling system continued throughout the quarter at the CPG facility in Abilene, Texas. The use of a "heavier" space frame construction has helped to avoid resonant 60 Hertz vibrations induced by the free-piston Stirling engine. Although the rate of failure incidents attributed to vibration that have been recorded in the Standard Engine Reliability Tracking System (SERTS) has remained low, it is still a serious concern and the design of a dynamic balancer has, therefore, been initiated. The most severe recent incident, a leak in the heat-pipe receiver, occurred in June. As a result of (1) the complexity of salvaging the sodium contaminated heater head components, (2) quality assurance problems with burst diaphragms, and (3) a decision to substitute a "concept validation" (CV) engine/alternator for the prototype engine previously used on the Abilene system, it took approximately two months to get the Abilene system operational. With the CV engine, which had been optimized for the torospherical heater head geometry and which had also incorporated the new Sunpower heat exchanger design philosophy in the cooler, system **peak performance jumped from 5.6 kW$_e$ (gross) at 925 W/m^2 to 6.1 kW$_e$ (gross) at 900 W/m^2.** At the end of the quarter, over 460 hours of operation have been logged on the Abilene system, and over 60 hours were logged on the system in Lancaster, Pennsylvania. The CV system scheduled for

California State Polytechnic University (Cal Poly) has been delayed because of legal issues. As of the end of the quarter, these issues had been resolved, foundations had been started, and system installation had been scheduled for December 1993.

Design validation engine/alternator assembly underway.

Design definition of the "design validation" (DV) engine has been completed and all of the parts for two DV engines have been ordered. Like the "concept validation" (CV) engine, the DV engine incorporates gas bearings. However, it also uses planar springs (a kind of flexure) to provide piston centering and to minimize hysteresis losses. The DV engine will also utilize a new type of heater head configuration that eliminates the need for critical braze operations. In addition, the cooler and alternator configurations have been modified to incorporate design principles learned at Sunpower. The DV engine's nominal rated output is 9-kW_e, although a potential to grow to 13-kW_e is being designed into it. At the same time, the engine/alternator weight will be more than 100 kg less than the CV engine/alternator. The lower engine/alternator weight will permit the cooling system to be mounted near the engine. In the CV system the cooling system is mounted on the backside of the concentrator space frame. The DV 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 the alternator and flexure parts. Some of the DV engine parts have been received. DV engine/alternator implementation remains as the key critical path activity in Phase 2. **Current plans call for initial checkout and testing in early November with systems integration (with the DV engine/alternators) starting in January 1994.** Because of the time required to build new engines and systems for the Phase 2 deliveries, it is anticipated that at least another three month extension (to the end of June 1994) will be requested by CPG.

Durability testing of engine/alternators initiated at CPG Abilene facility.

Operation of the Sunpower "prototype" free-piston Stirling engine/linear alternator in a test cell was initiated the week of September 20 in Abilene, Texas. The "prototype" engine was built prior to the DSJVP and served as the basis for the "concept validation" designs. This engine has accumulated over 600 hours of operation on-sun and in the Sunpower test cell thus far. By the use of electric powered heat pipes in the test cell, CPG intends to accumulate several hundred more hours of durability data on this engine before initiating DV engine/alternator durability testing early next year.

Team meetings head-off potential integration issues.

The third Phase-2 team meeting of the Dish-Stirling Joint Venture Program (JVP) was held at the CPG facility in Abilene, Texas on August 18-19, 1993. The meeting focused on technical issues, integration issues, and program planning. In this extremely open forum involving all of the major players in the DSJVP, **the key issues related to component design, system integration, and schedule contingencies were freely and openly discussed.** Subtle interface issues such as integration of the heat pipe receiver and the new DV heater head design, tradeoffs between cooling system design and alternator requirements, and others were brought up and vigorously debated. Additional "no holds barred" meetings such as this one will be held every six to eight weeks for the near future and are being strongly encouraged by Sandia and CPG as a way to head-off integration problems in this critical phase of the DSJVP.

CFIC engine becoming a reality.

Because of the importance of the free-piston Stirling engine/linear alternator to the DSJVP, Clever Fellows Innovation Consortium (CFIC) was included as a parallel Stirling engine developer. The CFIC engine technology, which utilizes strap-type flexures, virtually eliminates wear and makes possible extremely long-life engines. Cummins is paying 100% of the CFIC engine development cost. Although, CPG has effectively selected the Sunpower design for their DV system, the CFIC engine/alternator incorporates a number of clever innovations that CPG would ultimately like to include in their design. **Design and fabrication of the CFIC engine/alternator has finally been completed, approximately six months behind schedule.** Most of the 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 will only be able to produce approximately 4 kW_e. However, because of the attractiveness of the CFIC alternator design from a manufacturability perspective, CPG and CFIC have decided to demonstrate the engine/alternator at a reduced power output. CFIC was nearing initial engine testing at the end of the quarter.

CPG controls make progress.

CPG has made substantial progress on the control system during the quarter. The analog load interface approach has been abandoned and load interface designs for all three applications will be replaced by a digital-control load interface system. The ADA programming language used by Cummins Electronics (CEL) was replaced by C++ and the new software is being used for power conversion system control. At the end of the quarter, CPG was integrating the concentrator and power conversion unit controls. Development of utility grid tie load controls based on pulse width modulation and/or on an internal modulation of displacer stroke is in progress. A digital-control load interface water pump system will enable the use of lower-cost AC motors for the water pump.

Thermacore/Sandia collaborate on heat-pipe receiver wick design.

During the quarter, Thermacore worked with Sandia on improving the design of the heat-pipe receiver. To minimize wick requirements in the current receiver designs, Thermacore has incorporated "refluxing." In the durability heat-pipe receiver #3, which was supported by NREL, the artery has been eliminated to reduce fabrication cost and complexity. **As of the end of the quarter, durability receiver #3 had accumulated over 500 hours on-sun in Abilene, Texas.** Because of marginal design margins predicted by Sandia, Thermacore will use both arteries and refluxing in receivers delivered in Phase 2. Sandia simulations of the Thermacore design with the WICKSOLV computer model indicates a design margin of approximately two with both arteries and refluxing. Sandia is working with CPG and Thermacore on developing stronger and more permeable wicks that can accommodate artery-free designs with acceptable design margins. Collaboration and technology transfer of the WICKSOLV model, wick properties measurement techniques, electron microscopy, and development of alternative wick designs are areas in which Sandia's receiver team is helping the JVP on this issue. See the dish-receiver technology section for additional information on the Sandia/Thermacore collaborative effort.

Sandia/NREL provide optical materials technical support to DSJVP.

Sandia and NREL coordinated optical materials support for the JVP. Sandia is working with CPG on the implementation of thin-glass mirrors for the CPG facets. Thin glass mirrors have the advantages of high reflectance (> 90%) and long-term durability compared to polymer film mirrors. NREL is providing weatherometer testing, reflectivity and SHOT measurements, and design assistance for the internal CPG efforts to develop high-performance plastic films. NREL is also working to deploy program-supported, silver-film options as they become available on CPG facets. **NREL has also offered to provide CPG with significant quantities of an enhanced version of the 3M ECP-305 film for evaluation.** This coordinated, multiple parallel path approach is seen as essential for addressing the critical optical materials issue.

CPG 7.5-kW$_e$ Dish-Stirling system receives R&D 100 Award.

The technical significance of the CPG 7.5-kW$_e$ system was recognized by *R&D Magazine* with the presentation of an *R&D 100 Award.* This international competition, which is in its 31st year, recognizes innovators and organizations for outstanding practical technical developments and identifies significant technological advances. The award was accepted at the annual *R&D 100 Award* banquet held at the Chicago Museum of Science and Industry on September 9, 1993, by CPG, Sandia, Sunpower, and Thermacore.

USJVP negotiations

Contracts for the USJVP were negotiated with Science Applications International Corporation (SAIC) and CPG. It is anticipated that the contracts will be placed in mid-October; in the meantime, both SAIC and CPG have been authorized to accumulate pre-award costs. In addition, talks have been initiated with Hydrogen Engineering Associates (HEA) in preparation to negotiating a third USJVP contract. Because of funding limitations, however, this contract will not be placed until October of 1994. At that time, sufficient funding from the DOE should become available to support a third contract.

Planned Activities for Next Quarter

- USJVP contracts will be placed with SAIC and CPG.
- A USJVP contract will be negotiated with HEA that has a starting date of October 1994.
- At least one DSJVP team meeting will be held.
- A 5-kW$_e$ "Concept Validation" dish-Stirling system will be installed at California Polytechnic University, Pomona, California.

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 electricity costs. Reductions in O&M costs would enhance the marketability of solar thermal technologies currently being developed by the 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 Quarter FY92. The progress made during the present quarter is described in the following paragraphs.

Accomplishments

Improved mirror cleaning strategies studied.

The mirrors in the solar field must be washed frequently to maintain optimum plant performance. Historical data at the SEGS plants suggest that washing mirrors every 2 weeks maintains 95% cleanliness (i.e. measured reflectivity divided by as-new reflectivity). Experiments conducted during the present quarter indicates that 98% cleanliness can be achieved by washing twice a week. To determine an optimized strategy, several issues need to be resolved including labor requirements, performance improvements, water usage, and washing rate.

During the quarter, several experiments were carried out on different mirror washing techniques. A large water truck (15,000-gallon capacity) with a high pressure spray was used to wash SEGS 3 with demineralized water; the entire field (~200,000 m^2) was completed in one night, with cleanliness increasing from an average of 91% to 95%. The water consumption, however, was four times the usual rate. Next, the same unit was used to wash one-half a solar field during the night with demineralized water plus a cleaning agent. The results showed a slight improvement, though it was not clear if the improvement was because of the slower speed or the cleaning agent. A further test showed that it was the speed of washing that was more important. Hence, the cleaning agent was not notably effective.

Another mirror cleaning problem that needs resolution is concerned with mirrors located near cooling towers. Condensation of cooling tower moisture on these mirrors have caused a tenatious dirt layer to build up and several rows of collectors are experiencing a severe degradation in performance because of it. Cleaning with a solution of hydrochloric acid may be possible, but environmental regulations prohibit its use. Lime Away and other commercial cleaning agents have been tried, but nothing practical has yet been effective. Next quarter, steam cleaning will be tried. The lesson for commercial solar plants is to locate cooling towers such that moisture emanating from them is carried away from the solar field.

Software testing continues on integrated power park data collection network.

The five 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.

Last quarter, prototype software was installed to enter daily operator logs on the network. The purpose is to improve access to data for O&M planning, to upgrade accuracy and completeness of logs, and to reduce the time involved in generating and utilizing the logged information. Initial testing was conducted during the present quarter. Results are promising but not yet satisfactory, as the new system is time consuming for the operators. Measures to correct this situation are being evaluated. A series of planned monthly reports will implemented in the near future: (a) power production summaries, (b) lost production report, and (c) incident report.

Data bases created to support optimized maintenance planning.

With the advent of the PC age, U.S. 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 preventative), 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.

Last quarter, state-of-the-art maintenance planing software (MPAC by System Works) was installed on the site data network described in the preceding topic. During the present quarter, warehouse and inventory personnel began converting stores data into an electronic data base. They are now about 60% complete. Also during the quarter, KJC personnel were trained on use of the MPAC system. The final "go live" date of December 1, 1993, is still planned for the MPAC system.

KJC personnel give guidance to Solar Two design team.

On September 9 and 10, 5 engineers from Bechtel National Incorporated visited the Kramer Junction solar power park to discuss design, operations, and maintenance issues relevant to large solar thermal power plants. The sometimes painful lessons learned at Kramer Junction were openly related to Bechtel with the hope that the same mistakes would not be made during the Solar Two project. Key individuals from Kramer Junction (lead mechanical, electrical, controls, operations, and maintenance) were available to the Bechtel team to provide insights and answer questions. Emphasis was placed on those issues that are common to SEGS plants and Solar Two. These include (a) thermal cycling effects on plant components, (b) steam generator design and performance, (c) thermal conditioning and heat trace, (d) optimized maintenance planning, (e) parasitic minimization, (f) quality assurance during construction, and (g) weather prediction. Discussions were followed by a plant tour and observation of plant startup. Bechtel was very appreciative of the time provided by the Kramer Junction staff and found the visit to be extremely valuable. The staff at Kramer will now be a phone call away to answer any additional future questions Bechtel may have.

Planned Activities for Next Quarter

- Complete status report that describes progress made on all project tasks during FY93.
- Continue to provide lessons learned to Solar Two Project.
- Fully activate maintenance planning system.
- Test cermet samples that were coated in Third Quarter FY 93.
- Begin upgrade of process control system at SEGS 3.
- Continue mirror cleaning strategies.

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

Assistance given to SEGS Operators.

The Solar Thermal Design Assistance Center (STDAC) is providing technical assistance *to the solar industry*. One of the most important of these projects involves the **Solar Energy Generating Systems (SEGS) operators.** The assistance, which is being provided to the Daggett Leasing Corporation (DLC) and the Kramer Junction Company (KJC) consists of three major items. The first item involves the analysis of solar radiation levels because of Mt. Pinatubo. Sandia's analysis of this event was introduced as evidence into hearings regarding DLC's request for a waiver to burn additional natural gas. The waiver was granted, but Southern California Edison is protesting. A final resolution is due next quarter.

The second part of the effort relates to the Landers earthquake last year. The SEGS 1 and 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. Also, the SEGS owners have begun to implement some collector modifications designed to mitigate against future earthquake damage. Sandia engineers are using the finite element model to assess whether the preventative measures may mitigate against a recurrence of the problems from the last quake (i.e., disjoining of pylon and drive shaft). There is concern that these changes may cause other problems. Results of the analysis are due at the beginning of the next quarter.

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. Sandia and **Industrial Solar Technology (IST)** collaborated in a joint venture to develop the replacement mirrors. IST has completed the development of a prototype facet and one was delivered to Sandia and SEGS for testing. A test program for this facet was developed in cooperation with IST, DLC, and KJC. Among the tests that will be performed next quarter include an optical characterization, and environmental testing in a non-destructive test chamber.

The owners of the Harper Lake, California SEGS plants have recently contacted Sandia about a collaborative effort to improve the performance of their plants. In return for Sandia's assistance, the owners promised to share information about their technology as well as details about the plant's operation, maintenance, and energy performance. A formal working arrangement will be developed this fall.

Wind response analyzed.

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 damaged part of the collectors. At IST's request, Sandia engineers have conducted a finite element analysis of the trough system in order to recommend structural improvements to the design that would prevent future damage. Analysis is underway using the Algor finite element model. A working model was developed last quarter and some preliminary results are expected shortly. Work on this project will continue through this calendar year.

State cooperative activities.

Sandia engineers are involved in several **California Energy Commission (CEC)** activities. The first involves the solar project at the prison in San Luis Obispo. The STDAC is planning to monitor the solar system that will be installed. Negotiations between BESICO and the California Department of Corrections (CDC) have been ongoing for the last 30 months, but CDC officials now believe that the contract to install the system will be signed this fall. A second effort is to assist CEC and CDC officials in developing RFPs for third-party-financed solar systems in other prisons. Russ Hewett at NREL has taken the lead to ensure that these RFPs are released in a timely fashion; RFPs for five systems are due to be released in the fall. A third project, which was initiated this last quarter, involves a demonstration of a solar absorption air conditioning system in a commercial building in Sacramento. The major objective of this effort is to compare the performance of an absorption system using flat-plate and trough technology. This project is being led by the CEC, but is a collaboration among the DOE (Sandia and NREL), Bergquam Solar, Sunsteam, and the Sacramento Municipal Utility District. Work on the project has begun: (1) the test plan for the Sunsteam trough collector is being developed (Sandia lead), (2) the Sunsteam collectors are being removed from the Norhaven building (NREL lead and cost share), and (3) the development of the monitoring system is underway (Sandia lead). A fourth effort is underway to monitor the performance of an evacuated tube, solar IPH system at Galt, a California Department of Corrections training facility.

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. Sandia engineers are assisting the State of New Mexico Energy and Minerals Department and the New Mexico Solar Energy Industries Association (NMSEIA) in three refurbishment projects. The first involves a solar system at the Northern New Mexico Community College. A second effort involves technical assistance to refurbish a 20,000-sq-ft system at the State Prison in Las Lunas, New Mexico. This flat-plate system is designed to heat water and spaces, but has not been operational for several years. STDAC engineers have provided the state with a refurbishment plan. A third project involves the two solar IPH systems at the Eastern New Mexico University. The State is providing funds to conduct the refurbishment efforts.

In addition, Sandia engineers have initiated an effort to assist the State and the NMSEIA to develop a state consortium to help New Mexico assume a prominent position regarding the application of solar technology. This effort, which involves the State Energy Office, the DOE, utilities, and state universities, will focus on leveraging the consortium's resources with those in the national programs. Two possible projects involve the State participating in the dish/Stirling and Solar Two programs.

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. 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. A similar program will be conducted in **California**.

Sandia's engineering consulting was requested to assist in the development of a sustainable energy resort development in Maho Bay, **Virgin Islands**. This resort will use the latest renewable technology to produce electricity and hot water for resort guest lodging. It will also use all recycled materials for construction. The STDAC is providing information to resort developers about the application of solar hot water systems, solar ovens, and the solar ice-maker. Sandia engineers will be on site for the opening of the resort in October. Consulting is expected to continue through this calendar year.

STDAC engineers are continuing to assist officials of the **Pennsylvania Energy Office** (PEO) in the analysis of performance data from a solar desiccant cooling system at the Monroe County Courthouse. This system, which was installed in the mid 1980s, has been operating and performance data have been recorded. However, the large volume of data has made analysis difficult. Some of the assistance includes interpreting the data, analyzing the performance of the system, and reporting the results in a publication. Recently, Sandia engineers identified a flaw in the current operation that resulted in a significant loss of system efficiency. Corrective procedures have been recommended and are currently being implemented. The project is expected to continue through this calendar year.

Military installation activities.

Sandia engineers are directing the evaluation of potential solar systems at several *military installations*. Energy officials from the **U.S. Army Corps of Engineers** have funded Sandia to provide engineering assistance in reviewing all potential applications for solar thermal technology at Ft. Huachuca. The analysis will involve a review of all base facilities for potential solar thermal applications with the objective of selecting about 6 to 12 applications for detailed analysis. The results of the analysis will be used to prepare proposals for funding through the DOD's Energy Conservation Investment Program.

STDAC engineers are working with officials of **Luke AFB** near Phoenix, Arizona, to finalize the refurbishment of a a 12,000-sq-ft solar thermal trough system that was designed to heat water for three airman dormitories. At present the system appears to be oversized, and Sandia is assisting in documenting the potential solar energy that is not collected and in identifying additional loads for the system. STDAC engineers have designed several possible methods to meet this need and are discussing them with base officials.

International renewables.

Technical support for *international solar energy projects* has continued 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 (IST) to supply an 11,000-sq-ft ORC solar system for this project. The Mexicans and IST have asked for Sandia consulting regarding the design review and monitoring of the system.

During the fourth quarter, STDAC engineers consulted with the Mexican engineers about the installation of the concrete footings for the trough field, which were recently completed. Currently, most of the STDAC's efforts have been spent on assisting in some details of the design of the ORC/generator electrical system and in developing a monitoring plan. The project is proceeding smoothly, but at a slow pace.

Sandia has initiated an effort to promote the use of solar ovens and ice makers in Mexico. This effort, which will be incorporated and leveraged into the DOE Solar Industrial Heat Program, will focus on helping the University of Sonora to develop expertise with the oven and ice maker technology by assisting in developing a solar lab and demonstration site on the campus. Sandia engineers will also help the University develop a test program for the solar lab and may help develop some solar engineering courses. Additionally, Sandia will work with University professors to brief Sonora state energy officials on the benefits of applying the oven and ice maker in remote villages in Sonora. The effort is expected to continue through FY94.

Testing, evaluation, and technology development activities.

Testing of a first-generation solar concentrating oven developed by Burns Milwaukee has been completed.

The purpose of the tests was to quantify the oven's performance for use in the company's commercialization activities and to advise on possible technical improvements. Some additional testing is being performed on Burn's newest generation oven, which incorporated some of Sandia's recommendations. Currently, a final report is in preparation on the performance of both the older and newer generation ovens.

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

Testing is being completed on IST's trough collectors. Two troughs have been tested on the rotating platform at the National Solar Thermal Test Facility (NSTTF). Both troughs consist of standard structural elements. However, one of the troughs uses ECP305 reflective film and the other use aluminized SA85 film. Two receiver tubes were tested on each trough. One tube is made of Pyrex and the other will use Solgel antireflective (AR) coated glass. Also, the new black nickel receiver will be tested this fall. A report will be written on the resulting improvement in performance using the AR coating, silver film, and black nickel receiver.

Testing is scheduled to begin on the Sunsteam trough. The Sunsteam trough will be used in the solar absorption air conditioning project in Sacramento and these tests will provide baseline performance information to be used in sizing the solar field. Testing was expected to begin this quarter, but Sunsteam requested a delay until next quarter to allow a complete trough system to be delivered.

Sandia has continued a 50/50 cost-shared contract with IST to develop an advanced receiver. The effort involves three efforts: (1) develop a commercial Solgel 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 AR coating work has been completed and represents a significant technology transfer success. This Solgel process was developed at Sandia National Labs and was documented in the public literature. IST, working with Sandia through this cost-shared contractual effort, have fully commercialized the Solgel process; it is currently integrated into IST's trough assembly process. Information about this technology transfer success will be publicized with a news release. Additionally, a plan is being developed to test the durability of the commercial Solgel coating. These tests will probably involve testing in one of Sandia's environmental chambers.

IST has also completed prototypes of the black nickel receiver. Prototype receiver tubes will be delivered to Sandia for testing next quarter.

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.

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Howell, Jack	University of Texas
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Scholand, Mike	Worldwatch Institute
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Concentrators	
Bates & Associates	Consultants
Bullard, Marc	Consultant
Cabanillas, Rafael	University of Sonora
Cannon, James	NMEMD
Davenport, Roger	SAIC
Gerant, Damon	Greenpeace
Goldstein, Barry	SNL
Miles, Ray	Pacific Missile Range
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Robitie, John	Macro Test Systems	Francis, Lisa	A.D. Little
Stotts, Jeff	B&W Consulting Engineers	Frye, Greg	SNL/MOA
		Galloway, Renee	Jet Propulsion Laboratory
Watson, John C.	Watson Engineering Services	Gimal, Chris	Florida Solar Energy Center
Wilkinson, Fenton	Integrity Systems	Goddman, Joel	Consultant
		Gulachenski, Edward	Quality Power Engineering
Dish/Engine		Herman, Ron	Gram, Inc.
Anders, Ian	PacifiCorp	Heumann, John	U.S. Naval Air Weapons Station
Daniels, Lonnie	Daniels Insulation		
Dougherty, Ronald L.	Oklahoma State University	Hill, R. R.	SNL
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Karth, Larry G.	Consultant	Jones, Wayne	Innovative Design
Langhoff, Peter	Indiana University	Kay, Tom	Solar Utilities Network
Lee, Jonathan	Consultant	Lankford, Bill	George Mason University
Raven, Francis	University of Notre Dame	Lathene, Chris	Alaskan Energy Office
Rhodes, Gordon	Consultant	Lefkowitz, Lester	Free-lance photographer
Spacer, John	Consultant	Lewis, Gary	Consultant
Tappan, Charles	Consultant	Manahee, Kathy	SNL/TT
Wahl, Bill	Rockwell	Martinez, Ernesto	Universidad Michuacana, Mexico
Wan, Yihhuei	NREL		
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		McGuire, Carol	Senate Budget Committee
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Augstyn, Jim	Augstyn Co.	Petersik, Tom	DOE/HQ
Bahm, Ray	Consultant	Pylkannen, Thomas	Atlantis
Bassett, John	North Carolina Power Agency	Raider, Skip	A & E, Idaho
		Rhoades, Gordon	XKD Corporation
Belasich, Deborah	SNL/TT	Romano, Joseph	AIA
Belimar, Bob	Central & Southwest Utilities	Rondaza, Mike	Energy Users News
		Rush, Marty	NREL
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Berquaam, Jim	Berquaam Energy Systems	Sampayo, Eduardo A.	Consultant
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Carson, Jim	SNL/TT	Souza, Connie	SNL
Cassel, Paul	Consultant	Stockton, Alan	Berthouse Publishing
Chapman, Rick	Consultant	Vossburgh, Paul	NEEDA Business Consultants
Cocker, Ernest	Sherman, Inc.		
Curry, Greg	Northrop	Walker, Mark	Energy & Water Development Appropriations Committee
Dallas, Charles	Sage Advance Corp.		
Daniels, Marc	SNL		
Davis, Peter	Consultant		
Dean, Frank	Consultant	Washburn, Sheryl	Smart Structures, Inc.
Dimwitty, Tom	Temanos	Washington, Clarence	SNL
Ellison, Mike	Carizza Solar	Wills, Eric	Daggett Leasing
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IPH

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Forero, Manuel	ECOPETROL, Mexico
Franey, Harry	California Department of Corrections
Gee, Randy	IST
Hunter, Nat	U.S. Army Corps of Engineers
Kulkarni, Promod	California Energy Commission
Lane, Richard	Packerland Solar
Leigh, Gerald	NMERI
Peaks, David	System Leasing Co.
Ringle, Greg	Gould Electronics, Inc.
Rosenthal, Andrew	Southwest Technology Development Institute
Schuller, Phil	Pennsylvania Energy Office
Thomas, Susie	Virginia Energy

Insolation

Michaski, Joe	SUNY
Perez, Richard	SUNY
Rymes, Martin	NREL
Skinner, Mark	University of Hawaii at Manoa

Modelling

Allegro, Joe	Inner Solar Roof Systems, Inc.
Meadows, Kirk	TRW
Miller, Troy	Consultant
Nelson, Les	SEIA/Cal.
Perez, Richard	State University of New York at Albany
Wildin, M. W.	University of New Mexico

Solar Absorption Cooling

Berquaam, Jim	Berquaam Energy Systems
Bronstein, Alan	Sunstream, Inc.
Ericson, D.	Ice-maker
Heumann, John	U.S. Naval Weapons Center
Mancini, Frank	Arizona Energy Commission

Solar Detox

Halmann, M.	Weizmann Institute of Science, Israel
Olewiler, David B.	Solar Detoxification Corporation

Solar Education

Boothby, Tom	DECD, Energy Conservation Div.
Gilbertson, Mike	SNL
Hill, Stacey	Cincinnati Education Division
Kumar, Jothi V.	North Carolina A&T State University
Lee, Kathleen	Education Research Center
Matthews, Rosemary	SE New Mexico Regional Science Fair
Smith, Brian	Fatima School
Van Heoric, Ed	Southern California Edison

Solar Furnace

Carp, Jason	Consultant
Manuola, Prof.	University of Massachusetts
Willoboughy, Will	Consultant

Solar Thermal Systems

Bahm, Ray	Ray Bahm & Associates
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Dallas, Hal	Los Alamos National Laboratory
Delgado, Martin	Sonora Center for Research & Development of Natural Resources
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Heumann, John	U.S. Naval Air Weapons Station
Johnson, Brian	NM Energy, Minerals & Resources Dept.
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Kulkarni, Promod	California Energy Commission
Langenbrunez, James	Los Alamos (ATT&W)
Machuca, E.	CIEDAC
Marcham, Chuck	AAA Solar
Lopez-Ochoa, Ignacio	Sonora Secretariat of Urban Infrastructure
Reilly, Ann	New Mexico State Senator
Robinson, Chuck	Robinson Consulting
Rovero, Chris	Meridian
Rueben, Steve	NREL
Seelye, Dane	Seelye Equipment
Stein, Bill	Ft. Huachuca
Stoffer, Roberta	DOE Information Service

Volek, Tom	NMSEIA
Wagh, Anant	Machinocraft, India

Solar Thermal Testing

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Durand, Steven	NMSU
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Fedor, Jody	Solar Commission, Ohio
Huggins, Jim	Florida Solar Energy Center
Kanalopolous, Sia	Full Circle
Kittredge, Bill	Consultant
Lopez, Chuck	Southern California Edison
Maiden, Miles	American Solar
Pylkannen, Thomas	Atlantis Energy Ltd.
Wilkinson, Fenton	Integrity Systems

National Solar Thermal Test Facility Visits

Baker, A. F.	SNL
Becker, Manfred	IEA, Germany
Beninga, Kelly	SAIC
Boehmer, Manfred	IEA, Germany
Burns, Thomas J.	Consultant
Burns, Betty	Consultant
Caledern, G.	Consultant
Carne, Thomas	SNL
Cheline, Bob	Student
Cordes, Leslie	Senate Energy Committee
DeLaquil, Pat	Bechtel
Doebling, Scott	SNL
Epstein, Michael	IEA, Israel
Gaiser, Randy	Stirling Thermal Motors
Goebel, Olaf	DLR, Germany
Gould, Bill	Bechtel
Grillo, Wolfgang	German Space Agency (DARA), Bonn, Germany
Grunwald, Reinhard	German Cancer Research Center, Heldelberg, Germany
Hesch, Maloney	Student
Hoffman, Nate	ETEC
James, George	SNL
Koenig, Eugene	SNL
Krech, Helmut	German Electron Synchrotron, Hamburg, Germany
Langhoff, Peter	Consultant
Lewandowski, Al	NREL
Litwin, Bob	Rockwell
Longenbrummer, J.	AT&T
Lopez, Chuck	SCE
Lumsden, Jesse	Rockwell
Mahanona, T.	Consultant
Meusel, Ernst-Joachim	Max-Planck Institute for Plasma Physics, Garching, Germany
Montoya, Randy	SNL
Morris, Doug	EPRI
Mucica, Bob	Rockwell
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Neumann, Andres	DLR, Germany
Nuclear Technical Confe	Educators
Prabhee, Edan	SCE
Roelf, Meijir	Stirling Thermal Motors
Roesener, Karsten	Germany
Schmitt, Jeff	AAA Solar Systems
Seligman, Justin	Student
Shirley Neff	Senate Energy Committee
Smith, David	SAIC
Stein, Bill	U.S. Army
Tamar Osterman	Senate Energy Committee
Thatcher, Dion	SNL
Townsend, Mike	Tech Reps
Vandinbroek, Jack	Bosol
Wickert, Bob	SMUD
Wilson, Sachody	Student
Yven, Jim	Rockwell
Zaroico, Alex	Bechtel

Utilities

Belimar, Bob	Central & Southwest Utilities
Cohen, Gilbert	KJC Operating Company
Eisenberg, Greg	LAW Fund
Gilmore, Jim	NRECA
Guzman, Jorge	Pueblo, Mexico
Harlon, Mark	Public Service Co. of New Mexico
Harrison, John	Florida Solar Energy Center
Lutton, Wayne	Daggett Leasing Company

II. Technology Development

Technology Development projects support the Commercialization Projects by developing, 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 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, long-lived concentrator designs, optical materials are an important part of concentrator development.

1. Heliostats

Accomplishments

Dual-module stretched membrane heliostat.

A report titled *Operational Experience and Evaluation of a Dual-Element, Stretched-Membrane Heliostat* by John Strachan has been completed and is currently in publication. The report should be published as a Sandia report next quarter.

Planned Activities for Next Quarter

No heliostat development activities are planned for next quarter.

2. Parabolic Dishes

Accomplishments

On-sun testing of SAIC's and SKI's facets.

On-sun testing proceeded for the Faceted Stretched-Membrane Dish (FSMD) with Science Applications International Corporation (SAIC) and Solar Kinetics Inc. (SKI) facets. However, two factors have impacted the testing schedule. The first factor was a request for additional testing of their dish-configuration from SAIC; and the second was the failure of the elevation-axis encoder on the dish.

The SAIC facets were the first ones installed on the dish for testing. During on-sun tests of their facets with the dish focal length at 9.0 m, SAIC requested that Sandia also evaluate the performance of the dish with facets installed at a dish focal length of 9.9 m. This request was prompted by the dish design that SAIC has proposed for the USJV Project, which is a faceted dish with a larger f/D.

The failure of the elevation-axis encoder on the faceted dish was attributed to the fact that it was heated and, as a result, pumped moisture into the enclosure. A shield was added to the new encoder to protect it from heating. This delayed testing for about one month.

The following describe the current SKI and SAIC testing status:

- Six of **Solar Kinetic's facets** for the faceted-stretched membrane dish were **heat treated** in preparation for their installation on the dish for on-sun testing during the next quarter.
- **Flux mapping and calorimetry of the faceted stretched-membrane dish with SAIC facets was completed.** Figure 1 is the power from the dish in the receiver plane as a function of the receiver aperture diameter. The two curves shown in the figure (they almost overlay one

another) are from two days of testing with the Beam Characterization System (BCS). The power values from the BeamCode software (dashed lines) were calibrated to the power measured with a 50.8 cm-diameter (20 in-) aperture of the cold water calorimeter. The curves agreed well with calorimetry measurements made at the two smaller apertures shown on the figure. Using the calorimetry measurements, we found the peak-flux levels to be 2875 and 2845 suns for September 29 and 30, respectively. We completed testing of the SAIC facets at the 9-m focal length.

- Realign facets on the FSMD for a longer focal length and perform flux mapping and calorimetery. This will be done next quarter.

Round robin facet testing completed.

On-sun testing of the two round robin facets was completed in July 1993. The results of this testing and CIRCE2 modeling will be included in the round-robin evaluation and a test report along with similar measurements made at NREL with other test systems. This will serve as a quantitative comparison of the most common methods used to characterize reflective optical systems.

Planned Activities for Next Quarter

- Realign the faceted stretched-membrane dish for evaluation of the longer-focal length SAIC dish.
- Perform calorimetry and flux mapping of the SAIC facets at the longer focal length.
- Install SKI's facets on the faceted stretched-membrane dish in preparation for testing.
- Reduce the data from the round-robin facet tests.

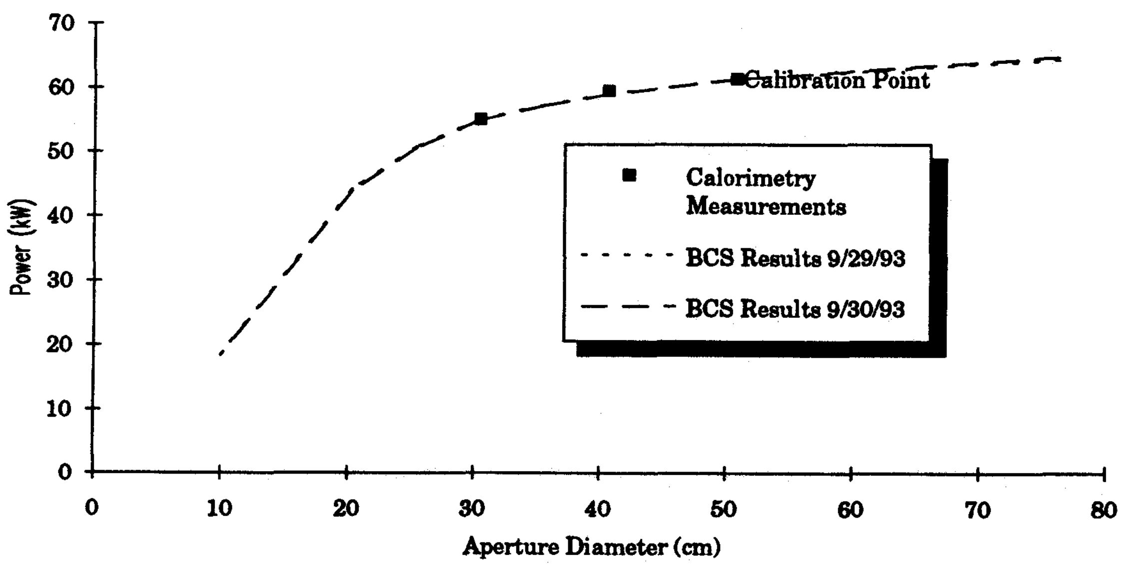

Figure 1. Power-Intercept Curve for SAIC Facets on the Faceted Stretched-Membrane Dish.

3. Optical materials

Accomplishments

On-site meeting for industrial partners.

NREL hosted an on-site meeting for interested industrial partners on August 25, 1993, to provide an update on advanced reflector material development and to discuss commercialization issues important to the solar manufacturing industry. Twenty six attendees from industry, the national labs, and the DOE were present. Initial feedback from attendees was very favorable. Results of recently completed collaborative efforts in advanced reflector development by a number of NREL subcontractors were presented. Planned activities by other newly initiated subcontractors were also described. A strategic plan for development of solar reflector materials was presented and copies of the draft document were distributed for industry comment.

Five-year strategic plan.

A 5-year strategic plan was written to guide future development of the optical materials effort. The strategic plan stresses three thrust areas: (1) identification and development of new advanced candidate materials, (2) testing of candidate materials, and (3) support for industry. The plan has been distributed to key members of the solar and polymer film industries for their review and comment. Once their input has been incorporated, the final document will be presented to the DOE. The feedback to date from the industry has been highly positive. Results from this strategy have already included a broader number of attractive concepts under investigation, increased industry interest in this research area, and the establishment of more rapid approaches to screen out undesirable materials and commercialize attractive ones.

Collaborative efforts with industry.

Progress has been made in collaborative efforts with industrial partners to develop alternate reflector materials. A Final Program Summary Report was received from the 3M Company that documents their efforts to develop a "Weatherable Silver Polymer Reflective Film" under NREL subcontract ZA-2-11031-1. During this collaborative effort, experimental vapor coatings of 6-in.-wide, 3.5-mil thick PMMA films were carried out to study the effect of silver thickness, prime coats, and copper back coats on the resistance to corrosion and delamination failure of enhanced versions of their ECP-305 product, and to explore the feasibility of commercial scale-up of promising concepts. Important findings included the following:

- Better adhesion of vapor deposited silver to PMMA is obtained for thinner layers of silver.
- Accelerated exposure testing demonstrated that back coats of copper provide greatly improved corrosion resistance.
- An alternate construction consisting of a laminated PMMA/adhesive/Ag/PET/adhesive structure was investigated; this reflector has performed well in tunneling tests, but improved corrosion resistance must be achieved.
- A releasable film based on the alternate laminated film construction was developed; initial test results are promising.
- Engineering cost estimates for a variety of candidate film constructions were very encouraging; for production rates in the 1- to 3-million-sq-ft range, the cost of several reflector material types could approach $\$1/ft^2$.

A follow-on subcontract was placed with Industrial Solar Technology (IST) to further *Development of Silvered Teflon™ Reflective Materials.* Under this effort, 300 sq ft of the most promising reflective film developed under their previous subcontract will be provided to NREL for field testing. Cummins Power Generation (CPG) has expressed a great deal of interest in using this material for demonstration purposes in several of their facets for dish/Stirling applications. Soiling and cleaning data will continue to be gathered on the metallized Teflon™ samples that are presently being tested in Brighton, Colorado. IST will also continue to investigate ways to improve specular reflectance of their reflector material concept.

Innovative, all-polymeric reflective material.

A sample of an innovative, all-polymeric reflector material was received from the Dow Chemical Company of Midland, Michigan. The sample is 60-mils thick and comprises 5000 alternating, coextruded layers of low-cost, commercially available, transparent thermoplastics. The reflectance of this sample is being measured; Dow claims the value approaches 90 percent throughout most of the visible spectrum. Because this concept is an all-polymeric design, degradation of optical performance caused by corrosion of metallic reflecting layers is not of concern. Another attractive feature of this approach is that such reflector materials can be directly thermoformed into useable structures, thereby reducing costs associated with support elements.

Expanded outdoor-exposure test program.

Progress has been made with NREL's expanded outdoor-exposure testing program. Several additional sets of samples have been optically characterized and placed into test. Two different types of glass mirrors are being tested. The first is a thin (0.7 mm) glass material provided by Nagatuck; the second is Advanced Thermal Systems laminated glass mirrors. Three candidate metallized polymer reflector materials developed in collaboration with industrial partners have also been introduced into test. These include samples from Industrial Solar Technology (IST) having the structure: Teflon™ / 1500 Å Ag / 300 Å Cu, and from 3M having the structure: PMMA / adhesive / 1000 Å Ag / PET, and 3M's removable/replaceable polymer reflectors. All samples were placed in test at NREL, Arizona Public Service (APS), and the Sacramento Municipal Utility District (SMUD) in California. Exposure racks have been delivered to an intended fourth site in Abilene, Texas. Meteorological monitoring equipment was installed and activated at SMUD and APS.

Alternative reflector materials: R&D progress.

A report titled *Progress in Development of Advanced Reflector Materials during Fiscal Year 1993* was written to document work in this area at NREL during FY93. This report was submitted to the DOE to complete an August 1993 milestone—"Document alternative reflector materials R&D progress." The milestone report summarizes collaborative cost-shared R&D with industrial partners, as well as parallel efforts at NREL in which several promising innovative candidate reflector material constructions were prepared and investigated.

Planned Activities for Next Quarter

- A subcontract extension will be placed with the 3M Company to obtain a commercial version of an enhanced ECP-305 reflector material. This product will be field tested by Cummins Power Generation (CPG) for the facet elements of their dish/Stirling system being developed under a Joint Venture Project (JVP) with the DOE.
- 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.
- Meteorological monitoring equipment will be installed at the NREL outdoor test site and the Abilene, Texas, site will be activated.

Industrial Contacts

CONTACT	ORGANIZATION	COMMENTS
J. Affinito	PNL	Alternate reflectors
C. Balazs	Dow Chemical	Alternate reflectors
K. Beninga	SAIC	Alternate reflectors
B. Benson	3M	Alternate reflectors
B. Butler	SAIC	Alternate reflectors
S. Cox	Courtaulds Films	Metallized polymers
D. Dahlen	3M	Alternate reflectors
R. Davenport	SAIC	Alternate reflectors
G. Davis	Martin Marietta	Alternate reflectors
J. Disam	Shott Glass	Thin glass
T. Evans	Dow Chemical	Alternate reflectors
M. Featherby	SAIC	Alternate reflectors
D. Froman	Scientech	Reflectance samples
R. Gee	IST	Alternate reflectors
R. Goodman	Libby Owens Ford	Glass mirrors
J. Langenbrunner	ATT&W	Alternate reflectors
W. Loeffler	Teledyne Wah Chang	Thin glass
P. Maschwitz	Courtaulds Films	Metallized polymers
K. May	IST	Alternate reflectors
M. McGlaun	Cummins Power Gen.	Alternate reflectors
D. Morris	EPRI	Alternate reflectors
D. Press	Shott Glass	Thin glass
J. Ross	Armstrong	Hardcoats
J. Sandubrae	SAIC	Alternate Reflectors
P. Schertz	SKI	Alternate reflectors
W. Schrenk	Dow Chemical	Alternate reflectors
P. Soliday	Cummins Power Gen.	Alternate reflectors

B. Power Conversion Technology

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 provides testing and solarization support to industry.

1. Central Receiver Technology

The primary objective of this activity 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 power tower systems.

Accomplishments

The major accomplishments this past quarter are: the continued testing of the molten-salt component test loop and the receiver panels, infrared (IR) tests of the receiver temperature measurement system, initiation of the molten-salt corrosion thermal cycling tests, and the testing of the 250 KW volumetric air receiver test at the Plataforma Solar de Almeria.

Feasibility of molten-salt flow through "cold" piping.

Experiments were conducted this quarter to determine the feasibility of starting molten-salt flow through a receiver panel preheated to below the salt freezing point. The purposes for conducting the tests were to determine if we are able to minimize the amount of startup time required for the receiver and check if we can flow salt through "cold" piping. In the flow loop, salt is pumped from a sump through a series of four flanges and a check valve then is to divert back to the sump or up the riser to a surge tank at the top of the structure. From the surge tank the salt flows through four serpentine passes in the panel test section. Photographs of the system are shown in Figure 2.

The molten sodium nitrate and potassium nitrate (60/40) salt freezes at approximately 420°F and when it comes in contact with piping or a surface below that temperature, the possibility of freezing exists. During startup of a molten-salt central receiver, the receiver is preheated with heliostats to bring the panel temperatures up to the molten-salt temperature. Because of non-uniformities of the heliostat beams, especially close to dawn, for the east side heliostats and because of uneven convective loss, the receiver temperature may vary drastically around the receiver and locally. It is very likely that some areas will be near 1000°F while others may be below 200°F.

We conducted 19 panel experiment this quarter to determine the operating conditions that will allow the panel to fill without trapping air or experiencing frozen salt plugs. In a typical panel experiment, the panel is preheated with heliostats, then the surge tank is pressurized, and salt flows through the panel. The panels have four passes total, each pass

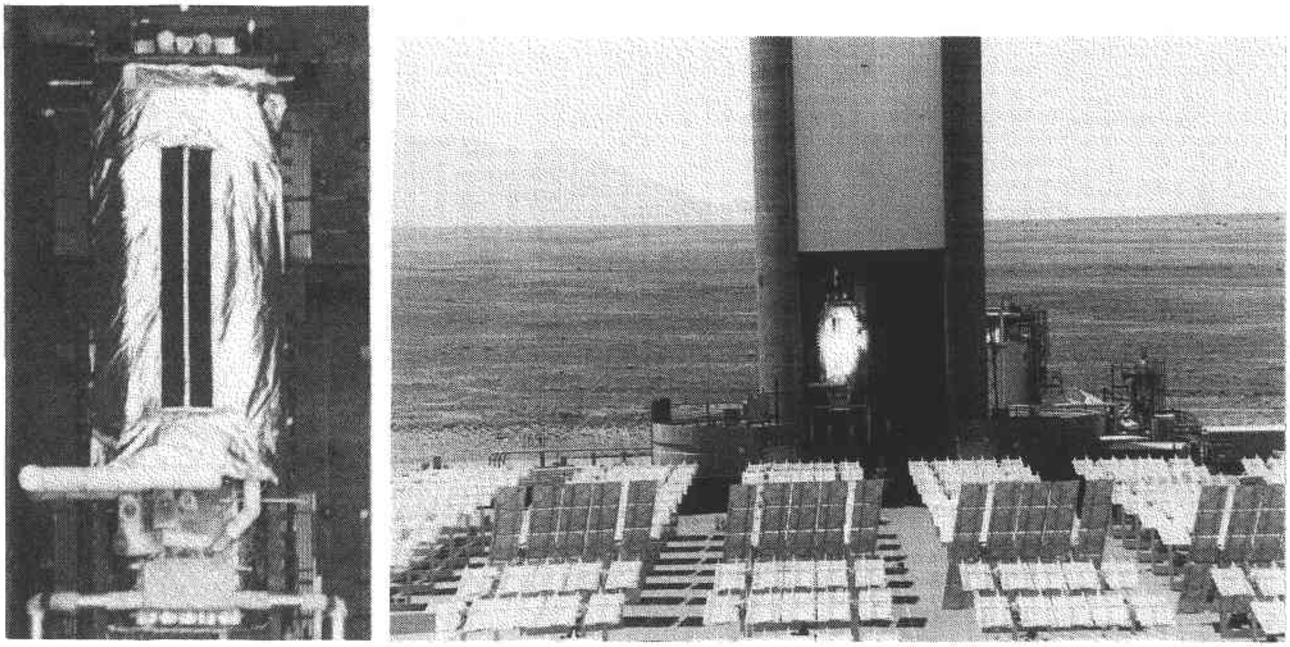

Figure 2. Molten-salt panel experiment at the NSTTF: (left) panel itself and (right) heliostats aimed at the panel at the base of the solar tower.

consisting of six tubes. Thirty-six back-tube thermocouples, at least one on every tube, are distributed evenly along the length of the tubes. By monitoring the back-tube temperatures, we can determine if the molten salt passed through each tube. Because of the unique setup of this system, we can only fill the panel in a serpentine fashion. Figure 3 is a plot of the thermal response of the receiver tubes. The panels were preheated for 14.3 minutes prior to initiating salt flow, bringing the average panel temperature to 530°F. Note how the temperatures rapidly come to the molten-salt temperature. Even though we used a dynamic aiming strategy, there were significant variations in the measured temperatures, as much as 300°F. These results indicate that there will be areas on the receiver that the temperature will be below the salt freezing point despite efforts to heat the panels uniformly. Further testing has shown that the salt flow can be started through the panel with the panel temperature as low as 200°F. Testing next quarter will determine the minimum amount of preheat necessary to initiate salt flow.

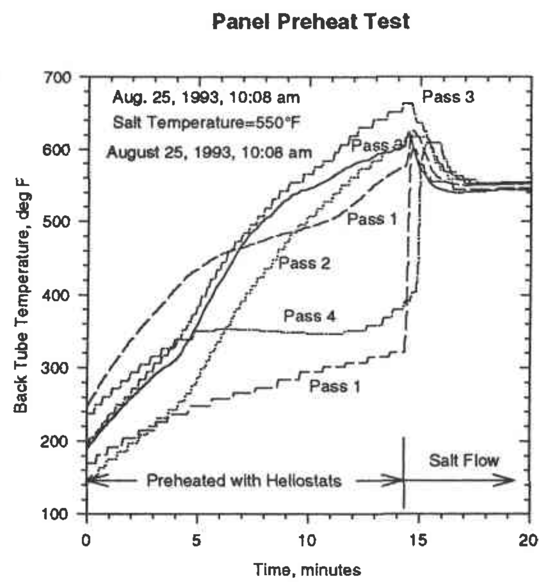

Figure 3. Temperature response of the panel tubes when preheated with heliostats and with salt flowing through tubes.

In addition to conducting the reduced panel temperature tests described above, we have performed several tests to determine if we can start a receiver panel with cold manifolds and cold safe ends (the transition tubes between the headers and the receiver tubes). The manifolds are electrically heat traced in order to maintain the headers and safe ends above the salt temperature during the night and shut down. The heat trace can result in significant parasitic power consumption, so it is desirable to determine the feasibility of starting the headers cold. We conducted several experiments where we turned off the heat trace in the afternoon and conducted a panel test the next morning with the manifolds cold. The temperature responses of the headers and safe ends are shown in Figure 4(a) along with the ramp rates in Figure 4(b). Note the safe ends experience a peak temperature ramp rate of approximately 18°F/s and the headers peak at about 9°F/s.

Also this quarter, we determine that we were able to flow through a cold 2-in.-diameter schedule-40 pipe without freezing. Despite the fact that these cold start tests show the feasibility of starting flow with cold pipes and the headers, the ramp rates, especially in the tube to header junctions, could result in severe thermal stresses and premature failure. Finite element analysis will be conducted next quarter to analytically model the thermal response and calculate the stresses induced in the receiver tubes, headers, and piping undergoing thermal shock.

IR cameras prove useful.

Tests with infrared (IR) cameras were conducted this quarter. During the panel preheat experiments, two infrared cameras were used to view the temperature profiles of the heated panels and determine their applicability to the instrumentation needs for central receivers. The IR cameras were Inframetrics brand, one operating in the 3-5μm wavelength range and the other in the 8-12μm band. These cameras proved to be extremely useful in determining the temperature profiles across the receiver during preheat and for finding tubes where there was flow blockage. Figure 5 shows an example of the temperature distribution of a panel as view with the Inframetrics 600 IR camera.

Pyromark paint properties.

Reflective and Angular Properties of Pyromark Measured. Properties of Pyromark paint were measured this quarter to determine if the paint behaves like a Lambertian surface. Characterization of the paint is important for determining the applicability of using detectors to measure the reflected light off the receiver surface and infer the incident power and flux on a central receiver. A rotating table and collimated light source was used to move a flat metal sample painted with Pyromark relative to a CCD video camera (the detector). The reflectivity was found to behave diffusely over a wide range of view angles and light incident angles. These results indicate that for a cured Pyromark paint surface the angular dependencies of the surface reflectivity should not limit the desired measurements. Tests planned next quarter are aimed at determining the feasibility of several proposed concepts to measure flux and power on a receiver panel.

Thermal cycling corrosion testing.

The static corrosion testing demonstrated the need for thermal cycling in the corrosion testing. **Consequently, the corrosion test apparatus was modified this past quarter to conduct the thermal cycling corrosion testing.** The goal of these tests is to determine if the temperature cycles characteristic of the operation of a solar power plant cause oxide spallation and accelerated corrosion. The test apparatus uses four "pots," operating at 1070°F, with salts with different chloride levels. There are 36 metal coupons in each pot. The coupons are automatically pulled from the salt every eight hours to simulate the diurnal cycling in a central receiver power plant. The 100 hour tests were completed this past quarter. These coupons will be analyzed for corrosion development and loss.

Design, cost, and warranty issues.

The "residual issues" study to evaluate design, cost, and warranty issues associated with molten-salt thermal storage and steam generator designs was published this past quarter. This study—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—will aid in the selection of the systems for the Solar Two Project.

International test activities.

Alternative central receiver concepts are currently being evaluated: Sandia has been working on **volumetric air receiver** and **molten-salt internal film receiver** concepts. In order to research these concepts, Sandia had a 200-kW_t volumetric receiver built to be tested in Spain. Also, we are working with

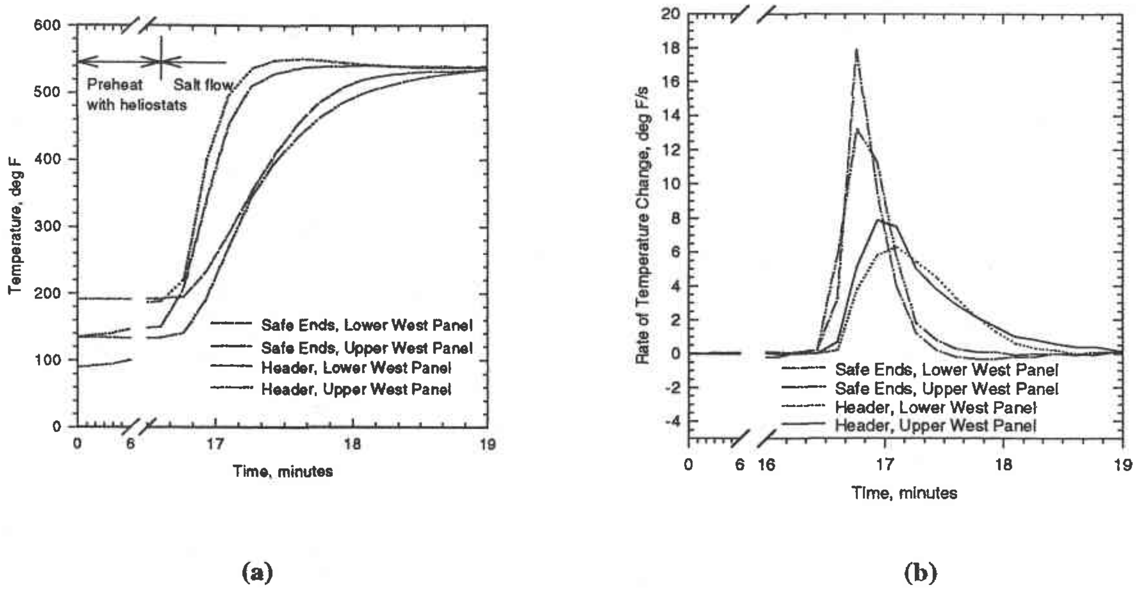

Figure 4. (a) Temperature of safe ends and headers during a cold manifold test and (b) temperature ramp rates.

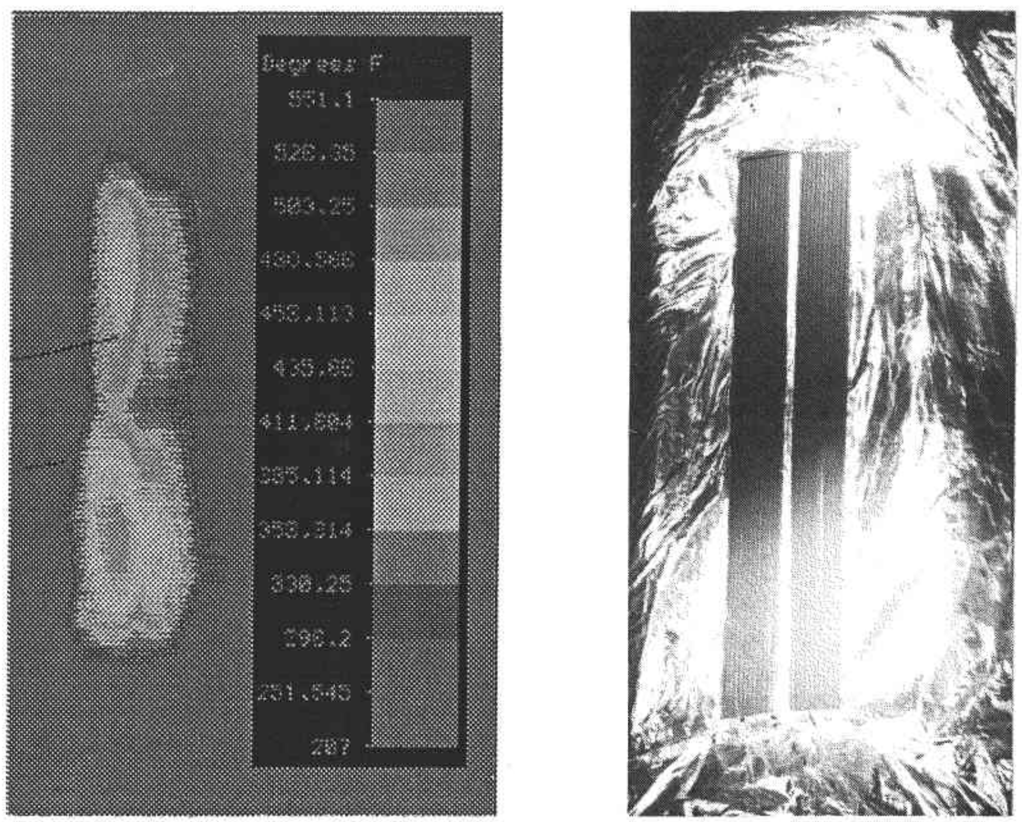

Figure 5. Temperature profile of a receiver panel as measured with the Inframetric 600 camera: (left) image of the panel as seen through the camera and (right) photograph of the panel.

Spanish personnel to test Spain's 500 kW_t internal film receiver.

The Bechtel-designed and -built wire-mesh volumetric air receiver absorber is undergoing testing at the Plataforma Solar de Almeria. The absorber, which is a layered nichrome knit wire mesh volumetric receiver, with a total of 15 screens made up of 41 layers of nichrome (80-20 nickel chrome resistance wire) knit wire mesh, has been tested to temperatures of 565°C and power levels of 200 KW_t. Early test results show thermal efficiencies of about 70% at 565°C. However, the test results are still being analyzed. Additional tests will be conducted at higher temperatures. The absorber appears to be holding up well in the high temperature high flux environment. The absorber is being tested as a cooperative program between the Spanish, the U.S. DOE, and Bechtel. The testing is expected to be completed at the end of October.

New Mexico State University test activities.

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 in their solar furnace. **This past quarter, NMSU completed performance testing of the absorber.** The absorber has been tested up to temperatures of 600°C with performance factors (efficiencies) of approximately 70%. However, because of artifacts of the test set up, we can expect performance factors of 6-10% higher in a larger absorber. **NMSU has also developed a model to evaluate the results of these tests and the tests in Spain.** The model is predicting 5-12% higher performance factors than those measured in the testing. The model is being validated with the results of the furnace testing. Additional tests to evaluate heat transfer coefficients are being conducted. NMSU is currently completing the report on the testing and model development.

Molten-salt IFR.

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; expected to prevent fluid loss to the atmosphere, the fluid (molten salt) flows on the inside of the panel. Sandia is working with the Spanish to complete the fabrication and testing of a 500 kW_t molten-salt internal film receiver test, to be called the Receptor Avanzado de Sales (RAS) or salt advanced receiver. This past quarter, all the molten-salt piping was installed and heat traced. Water flow testing of the receiver panel and manifolds was completed. Water flow testing allows the identification of leaks and areas of nonuniform flow; these problems will be corrected before the panel is mounted on the tower. A test plan has been completed and most of the instrumentation has been installed. Testing of the RAS will most likely begin in January.

Solar-investment tax equity issues.

Sandia has contracted with National Power Company of Oakland, California to conduct a study of tax equity issues associated with investor-owned solar thermal power projects. National Power will compare fossil plants to solar trough and central receiver plants in terms of the taxes each plant pays to each taxing authority (local, state, and federal) under a variety of tax treatment scenarios (investment tax credit, property tax exemption, etc.).

This study is being conducted jointly with the California Energy Commission (CEC) and is being coordinated with other efforts at CEC and NREL. States such as California are starting to view solar tax preference items in terms of an equity issue, rather than as solar subsidies. The CEC is particularly interested in this study because the date draws near for some of California's solar tax credits and exemptions to either be renewed or expire. Input and review of assumptions and results are being sought from a variety of interested parties, such as CEC, NREL, and the solar industry. The first meeting under this contract was held in Oakland on July 1 with National Power and CEC. The initial task, developing an agreed-upon set of input parameters for the base cases for each technology, is nearing completion. National Power has modified their cash flow model to incorporate the additional tax analysis parameters required for this study.

Planned Activities for Next Quarter

- Complete the thermal cycling corrosion test.
- Analyze the results of the testing of the Bechtel/Sandia volumetric receiver.
- Complete the test report on the performance testing of the volumetric receiver absorber at NMSU.

- Prepare a test report for the Sandia/Bechtel absorber test
- Complete the installation of the RAS (internal film receiver) at the Plataforma Solar de Almeria.

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 Stirling Thermal Motors (STM) power conversion system (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.

Accomplishments

Operation of the bench-scale durability pool boiler continued. Several promising advanced wick structures are under development and testing for application to future heat pipe receivers. Sandia's receiver wick modeling capabilities were improved to better match the current receiver technology. Documentation of this spring's receiver tests continued. The next-generation Thermacore $75kW_t$ heat pipe fabrication is continuing, and testing is expected next quarter. Sandia's Test Bed Concentrator #2 (TBC-2) was relustered, restoring like-new power capabilities.

10000-hr pool-boiler durability test.

The first 5800 hours of operation of the durability test for the bench-scale pool-boiler receiver have been completed. The test is running routinely around the clock. 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, and will be complete in the spring of 1994. The device cycles briefly to ambient temperature every eight hours to simulate the diurnal cycle. No changes in the boiling or startup behavior have been observed. Completion of the testing is expected in March 1994.

The lamp-assembly and phone line problems reported last quarter have been fully resolved, and the test has progressed with a minimum of downtime. The initial test results of the durability bench test were reported at the Intersociety Energy Conversion Engineering Conference (IECEC) conference in August in Atlanta. Sandia has begun to specify the post-test analysis requirements, and is now negotiating these tasks with potential laboratories including Sandia Livermore and several outside vendors.

Friction Coatings wick.

At Sandia, **testing of the Friction Coatings bench-scale heat pipe has been completed.** The wick structure on the heat pipe was developed by Friction Coatings Inc. of 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. The Friction Coatings wick had an effective pore radius of 69 μm, a thickness of 0.9 mm, and a permeability of 40 μm^2. The presence of braze material in the wick is expected to make the wick more robust while improving manufacturability.

Sandia's system for testing bench-scale heat-pipe receivers was upgraded to deliver more power to the test vessels. The previous system used a 6-bulb array that could deliver roughly 1800 Watts to a 10-cm long section of the test vessel. At times, this power was inadequate to achieve the desired operating temperature. The new 12-bulb array can deliver over 4000 Watts to a 20-cm long section of the heat pipe. This new system allows us to simulate higher thermal loads over larger areas, so the comparison to actual heat pipe receivers is improved. Tests were performed on Friction Coatings wick structure using the new lamp array. The tests showed that earlier tests performed with the six-lamp array were very close to the limits of the wick structure. A complete analysis of the 12-bulb array tests is still underway.

A heat pipe with a stacked screen wick structure was tested with the new lamp array to determine if the tailored stacking process can provide a wick structure that optimizes both the effective pore radius and the permeability. (Dynatherm used a similar approach. We tested several options to determine the best combination of screens.) The wick that was tested in the heat pipe consisted of 3 single layers of 100-mesh screen that were sandwiched between single layers of 325-mesh screen. An earlier study demonstrated that it is possible to spin-form sintered stacks of screens into dome shapes. Because the screens are shaped before they are attached to the evaporator dome, the disturbance to the structure is reduced in comparison to hydroforming techniques. The thickness was 0.8 mm, the permeability was 81 μm^2, and effective pore radius was 51 μm for this wick. For these properties, the wick supports uniform flux loads of 60 W/cm^2 for a distance of roughly 12 cm. This wick structure would be suitable for use on a full-scale, 75-kW receiver when used in conjunction with a fairly simple artery structure.

The permeability of this composite structure is greatly improved, in comparison to a stack of 325-layer screens of a similar thickness, because of the large voids created by the coarse screens. By isolating the 100-mesh layers between the 325-mesh screen, the effective pore size of the wick when it is saturated is established by the fine screens on the surface, and the diameter of the coarse wires along the edge (approximately). In contrast, with adjacent multiple layers of coarse screen, the effective pore size of the screen is established by the pores of the coarse screen.

Friction Coating developed and delivered an array of wick structure samples, and the properties of the wicks were measured at Sandia. The properties are summarized in the following table.

Sieve Size (-/+)	Pore radius (μm)	Thickness (mm)	Permeability (μm^2)
50/80	142	1.05	267
80/100	123	0.77	141
80/100	130	1.1	185
100/140	89	0.75	93
100/140	77	5.7	42

Particle size and the composition of agents used to reduce shrinkage were varied in these specimens to obtain a range of wick properties. Only the 100/140 structure in this array would be considered for a evaporator surface wick in heat pipe receiver. The coarser layers may be suitable for use in an artery or a reservoir wick. (A reservoir wick is a structure that can store liquid during normal operation of the heat pipe, and then release the liquid during transient power conditions.) These property measurements will be used in designing heat pipe receivers in the near future. Friction Coatings is preparing a more extensive matrix of samples, due at Sandia in October. These samples will investigate the effect of wick thickness on manufacturability and performance. Friction Coatings is also refining techniques to apply selected coatings to a dome for use in a full-scale receiver.

Reticulated vitreous carbon wick.

Sandia continues to pursue advanced wick structures that can out-perform current technology or reduce manufacturing costs. **A contract was placed with ERG, Materials and Aerospace in Oakland, CA to develop a wick structure using their Reticulated Vitreous Carbon (RVC) materials.** The structure of RVC is ideal for wicks and, during one phase of its formation, RVC is pliable so it can easily be formed into curved shapes. RVC can be attached to substrates (such as solar-receiver domes) by electroless nickel plating. The electroless nickel plating should also protect the RVC from sodium.

ERG prepared four samples of nickel-coated RVC that were supposed to be delivered to Sandia in July. ERG indicated, however, that they were having difficulties in attaching the RVC wick structures to a substrate. At our request, the samples will be delivered to Sandia without substrates. All of the required tests can still be performed on the samples without substrates; a decision can then be made with regards to pursuing this wick option.

Thermacore 75kW$_t$ heat pipe.

Development of the second Thermacore/Cummins 75kW$_t$ heat-pipe receiver has continued. All of the shell parts have been manufactured. However, measurements of the wick permeability on previous receivers, both at 30kW$_t$ and 75kW$_t$ rated power, led to concerns about the wick structure. The measured permeability was only 3 to 19 μm^2, whereas the design was based upon a permeability of 35 μm^2. Sandia, Cummins, and Thermacore jointly decided not to complete fabrication of the receiver until the permeability issue is resolved, delaying product delivery. Thermacore began a small development effort to investigate the effect of various sintering parameters upon the resultant wick structure. This effort also impacts the 7.5kW$_e$ joint venture program.

Wick model.

Sandia has begun a collaborative effort with Thermacore to improve the wick modeling effort. This work will include Thermacore's porous structure boiling model in the Sandia liquid-flow analysis program. This should allow more accurate modeling of this type of heat pipe wick structure. The boiling code has been incorporated into Sandia's model, and is undergoing testing and debugging. The first application of the revised program will be in support of the 7.5kW$_e$ Dish-Stirling Joint Venture program.

Steam cleaner fabrication.

The latest (permanent) version of **the steam cleaner has been qualified for production cleanup of liquid-metal-contaminated parts** This system uses dry steam with a hot nitrogen purge to clean sodium and NaK-78 contaminated parts generated by our receiver and engine development programs. This method results in **a smaller, less hazardous waste stream** than previous disposal methods. Cleaning the parts also allows re-use and post-test examination. Reaction completion was verified on early samples by sectioning the part and testing for residual liquid metal. The part cleaning process is very rapid, with most parts cleaned within minutes.

Thermacore artery-free heat-pipe receiver.

On the basis of the experiences and design of the 75-kW$_t$ receiver, Thermacore developed an artery-free receiver design for application to the USJVP project. This has the potential of reducing the receiver costs significantly. **Cummins has continued daily on-sun testing of the artery-free heat pipe, which has accumulated nearly 500 hours of at-temperature operation.** Initial difficulties with warm areas have been resolved, and the testing is continuing uneventfully. Testing will continue unless the concentrator is needed to test a more advanced model receiver.

Hybrid receiver development.

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 Thermacore (heat pipe).

During this quarter, Cummins Power Generation, Inc. (CPG) reported little progress on their hybrid program. Early in their Phase II effort, CPG began to realize that costs for the fabrication and testing of their hybrid heat pipe would be significantly greater than anticipated. At that point, they scaled back their effort. By mid-September, CPG began to quantify these newly anticipated cost overruns and to consider modifications to their program. Details of the modified program, as well as the impact on the joint-venture program (JVP), will be presented to NREL staff in mid-October. CPG believes that they can initiate ground testing in December, with on-sun tests to follow in January 1994.

Stirling Technology Company (STC) continues to make excellent progress in their development of a hybrid pool-boiler receiver. During this quarter, STC completed fabrication and assembly of their receiver and started ground testing. STC demonstrated operation of the receiver in a solar-only mode (using radiant lamps to simulate solar heat input) to NREL, Sandia, and Southern California Gas representatives on August 30. Recently, STC has begun testing the receiver in the natural-gas-only mode and in a combined solar/natural-gas mode. Tests conducted with simulated solar heat have proven successful operation in the range 2.5 kW$_t$ to 10 kW$_t$ heat input to the pool, at pool temperatures up to the design value of 740°C. Stable boiling was demonstrated with the simulated solar heat input. In addition, warm restarts at 500°C were demonstrated at full heat input. Tests with natural gas were performed at full power, 10 kW_t, and a pool temperature of 700° C. Stable operation of the burner and re-ignition were both demonstrated, at a pool temperature of 600°C, with no flashback in the burner. Finally, simultaneous operation of the natural-gas burner and the simulated solar heat input was demonstrated at full power with approximately equal heat input from both heat sources. This testing completed a planned FY93 milestone: "Evaluate boiling startup and stability, convective heat transfer, and burner operation of the STC pool-boiler receiver."

Test-Bed Concentrator updates.

Sandia's Test Bed Concentrator #2 (TBC-2) was relustered this summer, improving expected full-power delivery to approximately 80kW_t. The mirrors were resurfaced with 1-mm-thick low-iron glass mirrors using a 3-M brand laminating adhesive sheet. The edges were then sealed with silicon, and the mirrors replaced on the dish. Evaluation of the dish, expected early in the next quarter, is awaiting repair of the elevation drive. Estimates and CIRCE models predict that the delivered power on a 1000 W/m^2 day will improve from 65 kW to 80 kW. A similar glass-mirror technology is being considered and implemented on prototype facets by Cummins and SAIC on their dishes. Sandia engineers are proactively cooperating with these industry partners to transfer the emerging technology, changing the polymer mirror paradigm, which has been a barrier to product realization.

Planned Activities for Next Quarter

- Thermacore will complete the fabrication of the modified-design 75-kW_t heat-pipe receiver. The receiver will be processed and tested on Thermacore's bench-lamp array and delivered to Sandia for testing on sun. On the basis of the test results, Thermacore will conclude the integration of a similar receiver with the Stirling Thermal Motors (STM) heater heads. Sandia will complete the interface design and prepare the heater heads and fixture for attachment to the receiver.
- Testing will continue on the 10,000-hour pool-boiler bench test. If testing continues to progress, we expect to have completed about 8000 hours of testing by the end of the quarter.
- Development of advanced wick options will continue. Friction Coatings will continue development of fabrication techniques to attach their wick to a dome suitable for the Thermacore 30-kW_t heat pipe. After Sandia has tested the full matrix of wick samples, Friction Coatings will incorporate the selected wick into a bench-scale device. ERG will fabricate and deliver small wick samples for evaluation at Sandia. Other wick options will be pursued as they are identified.
- Documentation of the second-generation and advanced-concepts pool-boiler receiver tests will be completed.
- The Sandia heat pipe wick model will be combined with the Thermacore boiling model, and the resulting program will be used to evaluate the 30-kW_t and 75-kW_t Thermacore/Cummins heat pipe receivers, as well as other receivers under development at Sandia.
- Cummins will continue to test the artery-free heat pipe receiver in Abilene as dish availability permits. In addition, operation of complete systems in Abilene and Lancaster PA will continue to accrue hours on full-scale heat pipe receivers.
- Stirling Technology Company plans to finish their tests on the hybrid pool-boiler receiver; the receiver will then be shipped to NREL for installation and on-sun testing at the High Flux Solar Furnace.
- The relustered TBC-2 will undergo alignment and characterization. The updated data acquisition system and thermal instrumentation will be tested during calorimetry, and compared to pre-lustering calorimetry results and equipment.

3. Dish Converter Solarization 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

Two projects are currently in progress to develop solarized versions of existing engines. The projects both involve solarization and on-sun testing of engines developed primarily for co-generation applications. The on-sun testing is designed to verify the predicted power conversion system (PCS) performance and determine the suitability of the engines for solar applications.

Brayton cycle power conversion systems.

A contract has been placed with Northern Research and Engineering Corporation (NREC) to solarize and test 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 PCS. The project has been structured for execution in two phases. Phase 1 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 1. 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 2 will include the design, fabrication, and on-sun testing of an ~25 kWe Brayton PCS. The result will be a fully evaluated Brayton system that could potentially be used in the USJVP.

The kick-off meeting for the NREC Brayton Solarization Project was held in early September. The details of the economic analysis and the technical input required to develop the analysis were discussed. An agreement was reached between NREC and Sandia on the division of labor for Phase 1: Sandia will develop the economic model and NREC will provide the technical performance and cost data required as input to the model. Also, NREC expressed their strong interest in developing a commercialized PCS and in supporting the USJVP program in some manner.

Stirling cycle power conversion systems.

Phase I of a cost-shared project with Detroit Diesel (DDC) and its sub-contractor, Stirling Thermal Motors (STM) is nearing completion. This project consisted of integrating a 25 kW_e Stirling engine (an upgraded STM4-120) with a direct illumination receiver, an engine cooling system, an induction generator, and an engine control system into one package. This integrated package is a called a power conversion system (PCS) (see figure 6).

Prior to delivery to Sandia, the engine was tested with gas-fired heater heads and then the entire PCS was tested using quartz lamps for the heat input to the receiver. The engine performed quite well during these tests.

Testing of the PCS will be done three phases. Phase I consists of system checkout and debugging. Power and temperature levels started out relatively low (600 °C). Two of the specific objectives of this phase is to verify control stability and to verify a reasonable temperature distribution on the direct illumination receiver. An infrared camera system is used to view the receiver's temperature distribution. For this reason, the 220-mm aperture is removed. This increases thermal losses tremendously, but allows a full view of the receiver during these shakedown tests. The infrared system has been a great asset in these tests. After all personnel involved are satisfied with these tests, the 220-mm aperture will be re-installed and the engine will be operated at full input power.

Phase II consists of performance mapping the PCS. Power output, PCS, and system efficiencies will be mapped as a function of power input (mirror area) and receiver temperature.

Phase III is optional and will be performed only if time and resources permit. The purpose of this phase is to map the PCS at different cycle pressures and to identify anomalies in performance because of less than ideal conditions such as cloud transients and dish tracking errors.

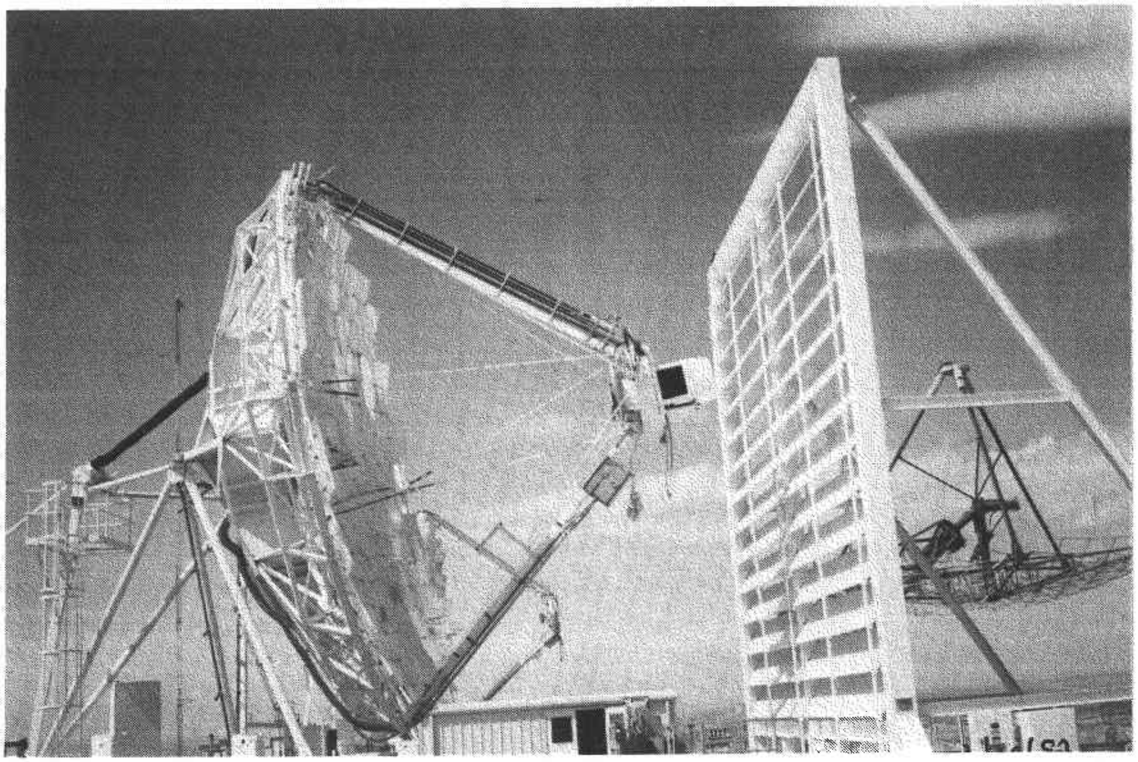

Figure 6. PCS mounted on a TBC-1 Concentrator.

At this point, we are near the end of Phase I. As described in the previous quarterly report, the engine was returned to STM for rebuild after experiencing a lubrication failure (see previous report for details). No engine problems have been experienced with the rebuilt engine, although a second oil cooler has been added. We have gradually stepped up the operating temperature from 600°C to 700°C. Because of the open aperture, peak power has been limited to the 10-11 kW_e range. Investors in STM and representatives from industry have visited while the engine was under test and have been very pleased and impressed with the entire package.

The biggest technical obstacle at this time is the temperature gradient across the receiver. Data collected indicate that this gradient is approximately 100°C. From previous experience with the Vanguard system, STM consultants expected the gradient to be in the 20-30°C range. After much data analysis and internal discussions, Sandia personnel believe that the gradient is not real and the indicated temperatures are in error because of the method of thermocouple attachment. Presently, the thermocouples are inserted into small pieces of tubes that are brazed to the back of the receiver tubing. This method is believed to cause significant errors because of poor thermal contact and the possibility of direct flux heating these uncooled "thermowells." We verified the problem by spot-welding intrinsic TCs onto one segment of the receiver. An on-sun test conducted the last week in September confirmed this theory. The PCS has been removed from the concentrator and the heater heads have been removed. Next the thermocouples will be oven-brazed in place to ensure good thermal contact. Then Phase I will be complete. Presently, contractual problems have delayed the testing somewhat. This problem is also being addressed.

Sandia personnel also performed a finite element analysis to determine the temperature gradient from the front to the back surface of a given receiver tube. The results indicate that this gradient is approximately 100°C. Because of this gradient, the operating temperature, which is controlled on the highest rear-surface thermocouple, will probably be limited to our present control temperature of 700°C.

After testing with the direct illumination receiver (see figure 7) is completed, the PCS will be retro-fitted with a heat-pipe receiver and system performance will be remapped. This will allow a direct comparison of direct illumination receivers with heat-pipe receivers—a test that has not been done before in the DOE program. The results of this comparison will also be very valuable to the upcoming JVPs and industry. The exact time frame is not known yet, as it depends on the outcome of several upcoming heat-pipe receiver tests. However, we do expect this test to be started in FY94.

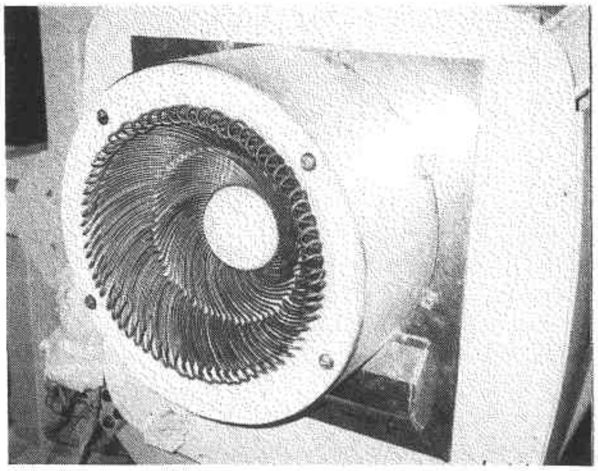

Figure 7. Direct Illumination Receiver on PCS package.

Planned Activities for Next Quarter

- Continue on-sun testing of the STM4-120 PCS with a DIR.
- Continue refining dish/Brayton economic model.
- Initiate preliminary designs of four dish/Brayton power systems for the purpose of obtaining cost data and operational parameters.
- Complete final report on the DDC/STM PCS development, design, fabrication, and bench-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, because 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 (NSTTF) available to users outside of the DOE Solar Thermal Electric program. Organizations such as Northrop, McDonnell Douglas, PDA Engineering, 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

User Facility status.

The National Solar Thermal Test Facility (NSTTF) at Sandia National Laboratories is listed as a DOE Designated User Facility (DUF) in current DOE publications. However, obstacles to the use of the NSTTF as a DUF are that currently all funding must come through DOE/AL as Work for Others projects and that Sandia places a minimum of $50,000 on the size of Work For Others projects. Neither of these constraints apply at Los Alamos National Laboratory (LANL), where access to Designated User Facilities are handled directly by the laboratory for projects ranging in size from $2,000 to several hundred thousand dollars. Furthermore, the paperwork can be processed internally at LANL in as little as three days. In contrast, Work For Others paperwork requires several weeks for processing by Sandia and DOE/AL.

The NSTTF has recently been asked by Northrop Corporation to calibrate some flux gauges at our Flux Gauge Calibration Station (16kW$_t$ solar furnace). Calibration to the solar spectrum is required by Northrop and is not available from the private sector. Northrop is also a valued customer of the NSTTF, having conducted several hundred thousand dollars worth of testing in the past. The estimated cost of this activity is only $4,000. Thus, it falls below the minimum for a Sandia Work For Others project. Jerry Hanks of Technology Transfer has agreed to take this on as a test case to see if Sandia can adopt procedures similar to those at Los Alamos. Sandia's financial organization is already working to establish appropriate procedures. Our goal is to increase facility access for industry—especially small business—for industry-funded projects.

Large-scale test of volumetric air receiver.

Discussions are continuing to prepare for a Large Scale Test of Atlantis Energie Ltd.'s Volumetric Air Receiver at the NSTTF. The test schedule has slipped again because of other priorities and funding constraints at Atlantis. The test is now scheduled for June 1994.

Technology Transfer

Publications:

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, GA.*

Adkins, D.R., and R.C. Dykhuizen, **"Procedures for Measuring Properties of Heat-Pipe Wick Materials,"** SAND92-2347C, *Proceedings of the 28th Intersociety Energy Conversion Engineering Conference, August 8-13, 1993, Atlanta, GA.*

Andraka, C.E., et al., **"NaK Pool-Boiler Bench-Scale Receiver Durability Test: Test Design and Initial Results,"** *Proceedings of the 28th Intersociety Energy Conversion Engineering Conference, August 9, 1993, Atlanta, Georgia.*

Andraka, C.E., et al., **"Testing of Stirling Engine Solar Reflux Receivers,"** *Proceedings of the 28th Intersociety Energy Conversion Engineering Conference, August 9, 1993, Atlanta, Georgia.*

Bean, J.R., and R.B. Diver, **"Performance of the CPG 7.5-kW$_e$ Dish-Stirling System,"** *Proceedings of 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,"** *Solar Engineering 1993,* eds. A. Kirkpatrick and W. Worek (presented at the 1993 Amercian Society of Mechanical Engineers/American Solar Energy Society/SOLTEC Energy Conference, Washington, D.C., April 1993), ASME, United Engineering Center, New York, NY, 1993. SAND92-1348C.

Chavez, J.M., et al., **"The Solar Two Project,"** *Proceedings of the 5th Sede Boqer Symposium on Solar Electricity Production, February 1993.*

Chavez, J.M., G. J. Kolb, et al., ***Second Generation Central Receiver Technologies: A Status Report,*** Verlag C.F. Müller, Karlsruhe, Germany, April 1993.

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,"** *Proceedings of the 28th Intersociety Energy Conversion Engineering Conference, August 9, 1993, Atlanta, Georgia.*

Muir, J.F., et al., ***The CAESAR Project: Experimental and Modeling Investigations of Methane Reforming in a Catalytically Enhanced Solar Absorption Receiver on a Parabolic Dish,*** SAND92-2131, Sandia National Laboratories, Albuquerque, New Mexico, July 1993.

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.

Ralph, M.E., C.P. Cameron, and C.M. Ghanbari, **"Thermal Effects Testing at the National Solar Thermal Test Facility,"** *Proceedings of the 39th International Instrumentation Symposium, Instrument Society of America, Albuquerque, New Mexico, May 1993.*

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

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.

Stine, W.B., and R.B. Diver, ***A Compendium of Solar Dish/Stirling Technology,*** SAND93-7026, Sandia National Laboratories, Albuquerque, New Mexico.

Publications in Progress:

Cameron, C.P., ***High Heat Flux Engineering in Solar Energy Applications,*** SAND93-0229C, Sandia National Laboratories, Albuquerque, New Mexico.

Diver, R.B., et al., ***The Lustering of TBC-2,*** SAND93-XXXX, Sandia National Laboratories, Albuquerque, NM.

Dudley, V., et al., ***Test Results for the LUZ LS-2 Solar Collector,*** draft report, February 1993.

Grossman, J.W., ***Development of a 2f Optical Performance Measurement System,*** SAND 93-1533C, Sandia National Laboratories, for presentation at the 1994 ASME International Solar Conference, San Francisco, California, March 27-30, 1994.

Jorgensen et al., **"Polymers for Solar Energy Devices,"** *Functional Polymers for Emerging Technologies,* American Chemical Society.

Kelly, B., ***Resolution of Thermal Storage and Steam Generator Issues for Central Receiver Power Plants,*** Bechtel National Inc., SAND Contractor Report, Sandia National Laboratories, Albuquerque, New Mexico.

Moreno , J.B. et al., ***On-Sun Test Results from Second-Generation and Advanced-Concepts Alkali-Metal Pool-Boiler Receivers,*** SAND93-1251, Sandia National Laboratories, Albuquerque, New Mexico.

Pacheco, J.E., ***Concepts to Measure Flux and Temperature for External Central Receivers,*** SAND93-2504C, for presentation at the 1994 ASME International Solar Energy Conference, San Francisco, CA, March 27-30, 1994.

Powell, M.A., and K.S. Rawlinson, ***Performance Mapping of the STM4-120 Kinematic Stirling Engine Using a Statistical Design of Experiments Method.***

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.

Schissel, P., et al., **"Silvered-PMMA Reflectors,"** *Journal of Solar Energy Materials and Solar Cells.*

Stine, W.B. and M.A. Powell, ***Proposed Guidelines for Reporting Performance of a Solar Dish/Stirling Electric Generation System.***

Strachan, J., ***Operational Experience and Evaluation of a Dual-Element, Stretched-Membrane Heliostat.***

Meetings and Presentations:

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

Adkins, D.R., ***Procedures for Measuring the Properties of Heat-Pipe Wick Materials,*** presented at the 28th Intersociety Energy Conversion Engineering Conference, August 9, 1993, Atlanta, Georgia.

Adkins, D.R., and R.C. Dykhuizen, ***Procedures for Measuring Properties of Heat-Pipe Wick Materials,*** SAND92-2347C, presented at the 28th Intersociety Energy Conversion Engineering Conference, August 8-13, 1993, Atlanta, GA.

Andraka, C.E., et al., ***NaK Pool-Boiler Bench-Scale Receiver Durability Test: Test Design and Initial Results,*** 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,*** 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,*** 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 1993.

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

Chavez, J.M., et al., ***The Solar Two Project,*** presented at the 5th Sede Boqer Symposium on Solar Electricity Production, February 1993.

Grossman, J.W., scheduled panel session speaker, Solar Concentrator Research and Testing, the ASME International Solar Energy Conference Washington, DC, April 1993.

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Kolb, G.J., ***Thermal Cycling of Thermal Energy Storage Tanks Proposed for the Solar Two Central Receiver Power Plant,*** 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,*** 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*, 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,*** 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,*** presented at the 39th International Instrumentation Symposium, ISA, Albuquerque, New Mexico, May 1993.

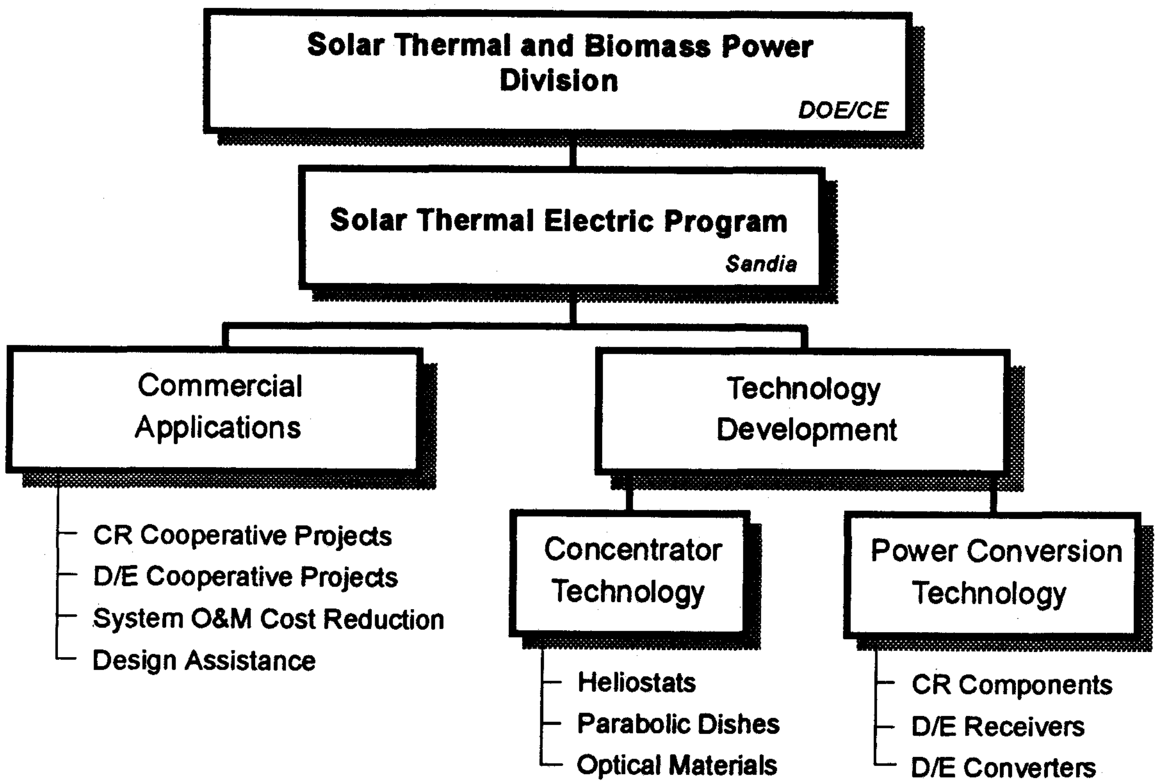
Strachan, J., ***Revisiting the BCS: A Measurement System for Evaluating the Optics of Solar Collectors,*** presented at the International Instrumentation Symposium, ISA, Albuquerque, New Mexico, May 1993.

Wendelin, T., and G. Jorgensen. ***An Outdoor Exposure Testing Program for Optical Materials Used in Solar Thermal Electric Technologies,*** to be presented at the 1994 ASME Solar Energy Conference, San Francisco, California, March 27-30, 1994.

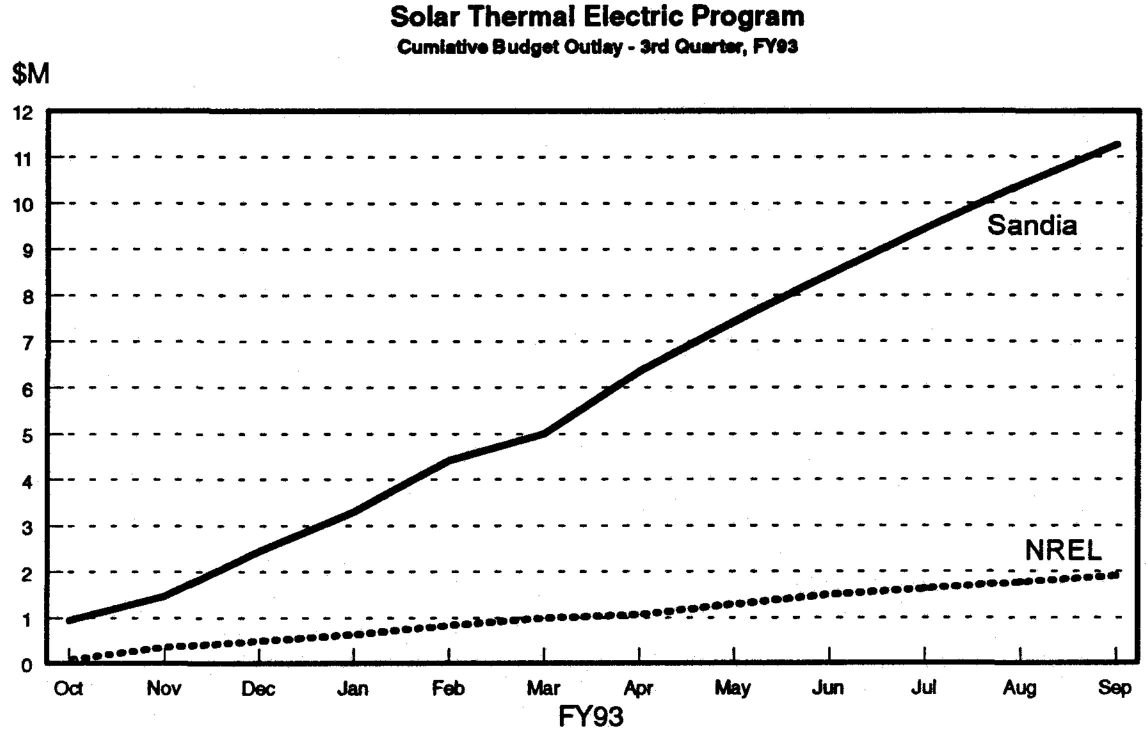
Management Structure Summary

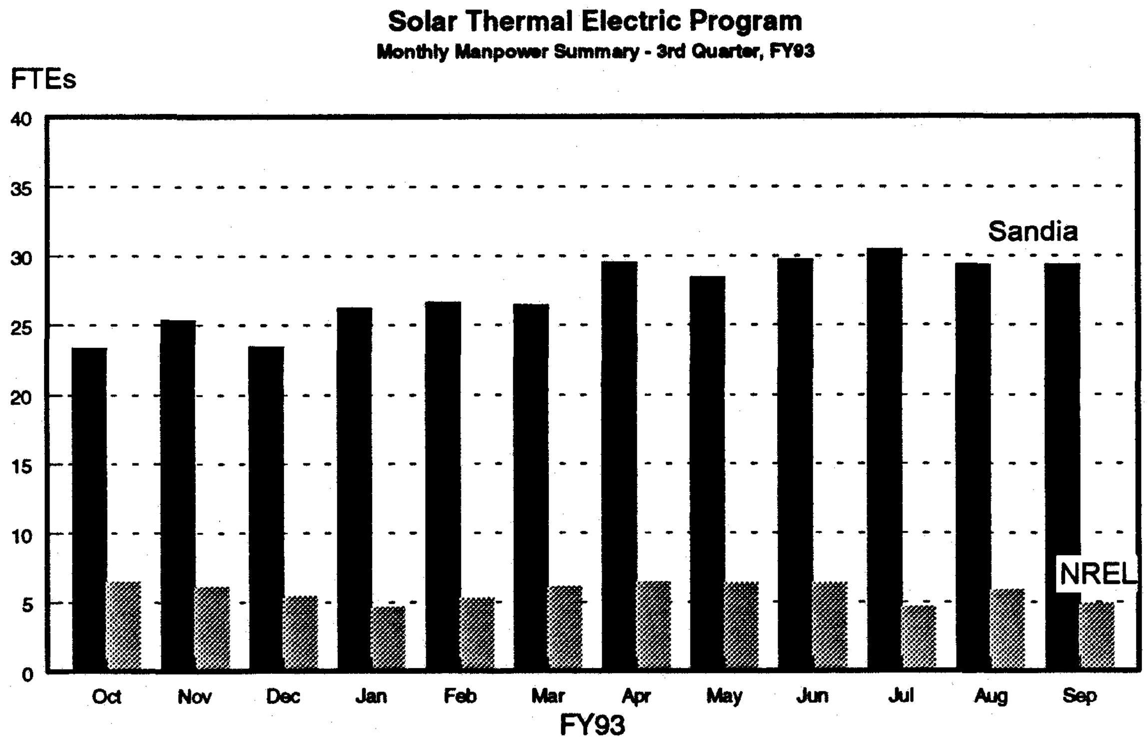
Field Management - Structure and Responsibilities

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.



Budget Summary





Major Milestone Summary

Task	Milestone	Planned	Actual
I. A.	The participants Agreement, E&C Agreement, and DOE Cooperation Agreement will be finalized so that the Solar Two project can be officially started.	Apr 1993	Jun 1993
	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.	Jul 1993	Delayed until Oct 1993
	Solar One thermal storage tank removed. Initiated Jul 93.	Jun 1993	Delayed until Dec 1993
I. B.	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.	May 1993	Delayed until Dec 1993
	Demonstrate the remote village electrification application at the CPG Abilene, Texas facility.	May 1993	Delayed until FY94
	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.	Jul 1993	Delayed until FY94
	Award contract(s) for the utility-scale joint venture program.	Aug 1993	Delayed until Oct 1994
I. C.	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.	Jun 1993	Jun 1993
	Document FY93 O&M Cost Reduction activities.	Oct 1993	Delayed until Dec 1993
I. D.	Participate in SOLTECH 93 meeting.	Apr 1993	Apr 1993
II. A. 1.	Complete documentation of the test results on the two large-area glass mirror heliostats and the low-cost drive.	Feb 1993	Feb 1993
	Complete testing and documentation on the first prototype of 100-m^2 dual-module stretched-membrane heliostat. In press, Oct 1993.	Aug 1993	Sep 1993
II. A. 2.	Complete installation of the Faceted Stretched-Membrane Dish at the NSTTF.	Jan 1993	Jan 1993
	Conduct Final Design Review for the Single-Element Stretched-Membrane Dish design.	Nov 1992	Nov 1992
	Review Single Element Dish Project, recommend direction to proceed.	Apr 1993	Apr 1993

Major Milestone Summary (cont)

Task	Milestone	Planned	Actual
II. A. 2. (cont)	Complete testing of FSMD with the elastically-formed SAIC facets. Underway.	Jun 1993	Sep 1993
	Complete testing of FSMD with the plastically-formed SKI facets.	Sep 1993	Delayed until Mar 1994
II. A. 3.	Identify procurement process and technical approach for additional alternative reflector.	Nov 1992	Nov 1992
	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	Apr 1993
	Document alternative reflector materials R&D progress.	Aug 1993	Aug 1993
II. B. 1.	Complete the Bechtel study of 100 MW_e molten-salt steam generators and thermal storage systems.	Mar 1993	Mar 1993
	Complete the 4000-hour molten-salt corrosion and stability tests.	Feb 1993	Feb 1993
	Complete testing of wire mesh materials at New Mexico State University.	Sep 1993	Sep 1993
	Complete testing of the Bechtel volumetric air receiver at the Plataforma Solar (subject to SolarPACES approval). Underway, delayed until Oct 93.	Jun 1993	Oct 1993
	Publish the Second Generation Central Receiver report.	Apr 1993	Apr 1993
II. B. 2.	Complete planned on-sun testing of Sandia 75kW_t heat-pipe receiver.	Dec 1992	Dec 1992
	Complete planned on-sun testing of Thermacore 75kW_t heat-pipe receiver.	Feb 1993	Feb 1993
	Complete planned on-sun testing of Sandia 75kW_t second generation pool boiler receiver.	Apr 1993	Apr 1993
	Complete fabrication and ground testing of the CPG artery-free heat pipe receiver.	May 1993	May 1993
	Complete fabrication and begin testing of boiling stability receiver.	Sep 1993	Mar 1993
	Evaluate boiling startup and stability, convective heat transfer, and burner operation for the STC pool boiler receiver.	Sep 1993	Sep 1993
II. B. 3.	Complete fabrication of the Detroit Diesel/STM PCS.	Dec 1992	Feb 1993
	Complete integration of the PCS with a test bed concentrator.	Feb 1993	Apr 1993
	Complete on-sun tests for the PCS with the directly illuminated receiver. Underway.	May 1993	Delayed until FY94
	Complete integration of the PCS with an alkali metal solar receiver (subject to DDC/STM contracting agreement). Delayed until FY94.	Aug 1993	Delayed until FY94

Procurement Summary (contracts over $50k)

Task	Specific Contract Subject	Contractor	Lab Contract Number	Present Contract Value ($k)	Prior Year Funds ($k)	FY93 Funds ($k)	Total Costs to Date ($k)	Period of Performance	Contractor Type	Major Reports	Project Monitor
IA	Molten Salt System Study	Bechtel	SNL 87-5142	159	159	-0-	159	01/92-03/93	Large	Final	J. Chavez
IB	Dish JVP	Cummins	SNL 69-7763	6968	3500	2675	4129	06/91-03/94	Large	Phase	R. Diver
IB	US-JVP	Competitive	SNL AB-8717 & AI-1530	28400	2383	773	-0-	05/93-05/98	Large	TBD	D. Gallup/ T. Mancini
IC	O&M cost reduction	Kramer Junction Company	SNL AB-0227	3154	650	700	951	07/92-09/95	Large	Phase	G. Kolb
ID	Tech Trans, Documentation	SEIA	SNL 42-5186	315	55	260	315	02/92-03/93	Non-profit	Three TT Rpts.	D. Menicucci
ID	Commercial-ization Support	Meridian	SNL AG-4595	175	-0-	175	28	06/93-06/95	Large	Final	P. Klimas
II	Solar Test Support	EG&G	SNL 05-4912	770	470	300	720	12/88-10/93	Large	N/A	C. Cameron
II	Electrical Support Service	J & S Electric Co., Inc.	SNL 75-7415	351	240	111	306	02/89-02/94	Serv. Support	N/A	L. Gillette
IIA1	NSTTF Technician Services	Ewing Technical Design	SNL 63-5487	1947	1350	597	1519	04-89-04-93	Serv. Support	N/A	E. Rush
IIA2	Stretched-Membrane Dish Development	Solar Kinetics, Inc.	SNL 55-2495	1814	1814	-0-	1809	04/88-12/92	Small	88-7035	T. Mancini

Procurement Summary (cont)

Task	Specific Contract Subject	Contractor	Lab Contract Number	Present Contract Value ($k)	Prior Year Funds ($k)	FY93 Funds ($k)	Total Costs to Date ($k)	Period of Performance	Contractor Type	Major Reports	Project Monitor
IIA3	Direct Optical Materials	SAIC	NREL YF-2-11191	130	130	-0-	38	03/92-05/93	Large	TBD	G. Jorgensen
IIA3	Optical Materials	3M	NREL 2A-2-11031	139	139	-0-	38	9/92-6/93	Large	Final	G. Jorgensen
IIA3	Optical	IST	NREL	139	-0-	76	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	G. Jorgensen
IIB1	Vol Rec Test	NMSU	SNL AD-2165	66	25	41	62	09/91-09/93	Univ	Final	J. Chavez
IIB2	Heat-pipe	Cummins	SNL AB3348	231	200	31	199	08/92-03/94	Large	Monthly	C. Andraka
IIB3	2nd STM4-120	STM	SNL 75-8851	439	439	-0-	439	04/89-02/93	Small	Final	M. Powell
IIB3	Stirling Engine Solarization	Detroit Diesel Company	SNL 67-9086	319	244	75	319	01/92-02/93	Large	TBD	S. Rawlinson
IIB3	Dish/Stirling	Cal Poly Pomona	SNL 67-3678	146	79	67	83	11/91-05/94	Univ	Final	P. Klimas
IIB3	STM Engine	DDC	SNL AE-5963	132	33	99	82	03/93-09/93	Large		S. Rawlinson
IIB3	Brayton Engine Solarization	NREC	SNL AG-0408	153	-0-	153	-0-	8/93-2/94		Phase	D. Gallup

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