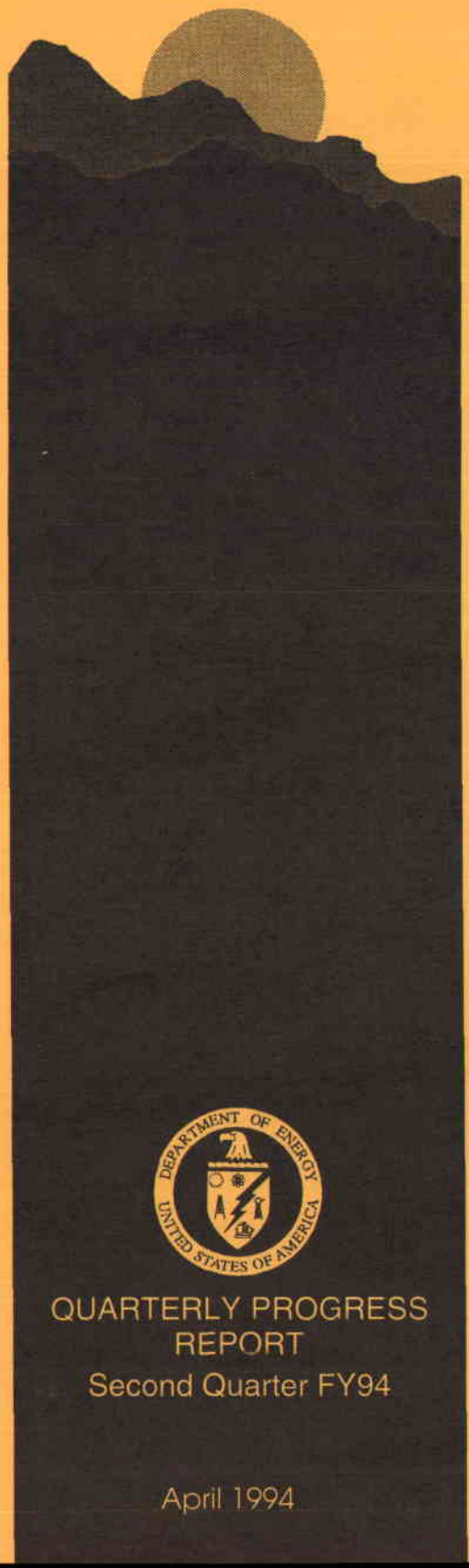
SOLAR • THERMAL • ELECTRIC •



QUARTERLY PROGRESS REPORT

Second Quarter FY94

April 1994

Sandia National Laboratories
Albuquerque, New Mexico

National Renewable Energy Laboratory
Golden, Colorado

SUMMARY OF ACCOMPLISHMENTS: SECOND QUARTER FY94

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

Solar Two

- This quarter, Bechtel completed Phase 2, Development of Major Bid Packages, of the Solar Two project.
- Demolition/removal of the the Solar One thermal storage system continued. All of the equipment has been removed. Only the rock and sand remain.
- The bids for all the major salt equipment (receiver, thermal storage, steam generator, pumps) were received and evaluated this past quarter. Rockwell was awarded the Solar Two receiver contract and began work late in the quarter.
- Top-level survey of the Solar Two heliostat field was completed and a report was sent to Bechtel. Of the 21,816 facets in the original field, 1265 need to be replaced.

Dish/Stirling Joint Venture Programs

- The SAIC and CPG USJVPs were initiated.
- SAIC has defined the design specifications for the next generation of their faceted stretched-membrane dish. The dish will have 16 facets; the focal length will be 9 to 10 meters.
- Clever Fellows Innovation Consortium was selected by Cummins as the primary engine supplier for the 7.5 kW_e DSJVP.
- Cummins Power Generation (CPG) has resumed work on their hybrid heat-pipe subcontract and is planning to start on-sun testing in July 1994.

System Operation and Maintenance (O&M) Cost Reduction

- Receiver tube-bowing phenomena were investigated.
- Optimized maintenance planning continues.
- Testing of advanced flow meters continues.
- O&M lessons-learned were provided to Solar Two project.

Concentrator Technology

- An RFP, "Heliostat Manufacturing for Near-Term Markets," was released as the first solicitation under the Solar Manufacturing Technology (SolMat) Inititative.
- Industrial Solar Technology (IST) has announced plans for a commercial solar heat project using ECP-305+ as the reflective surface for a parabolic trough. If the project proceeds, it will mark the first commercial deployment of ECP-305+.
- NREL and Monsanto Co. research resulted in a new candidate coating for solar reflector materials.
- Two of eight proposals received in response to an RFP, "Advanced Reflector Materials Research and Development," will be funded.
- NREL and CPG jointly installed and activated meteorological monitoring equipment and deployed candidate reflector material samples at an outdoor exposure test site.

Power Conversion Technology

- Tests conducted at the NSTTF demonstrated that "cold-start" of nitrate-salt receivers is feasible.
- Work on the Spain/USA joint volumetric receiver test was completed.
- The pool-boiler bench-scale dish receiver durability test program is continuing with post-test analysis.
- Hybrid dish receiver fabrication continues on schedule.
- A project with Northern Research and Engineering is underway to solarize and test a Brayton cycle power conversion system.
- On-sun testing continues on the Detroit Diesel/Stirling Thermal Motors STM4-120-based power conversion system. Phase 1, system checkout and debugging, was completed.

Reimbursables

- Sandia's Technology Transfer Center has established a process for bringing funds directly into Sandia for activities at Sandia's User Facilities.

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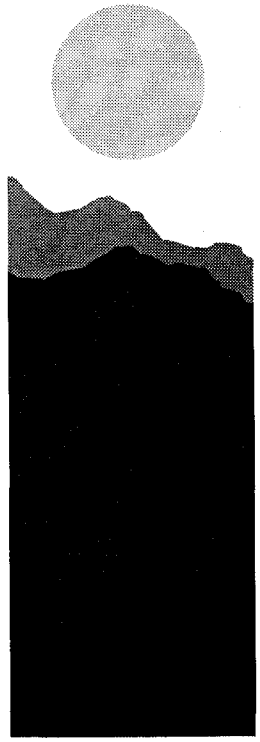


INTRODUCTION

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

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 power tower, parabolic dish/engine, and parabolic trough technologies. These joint ventures, valued at over $100M, 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

Our vision for solar thermal electric technology is the large-scale acceptance and installation of U.S.-designed and -manufactured solar thermal electric systems operating worldwide by the year 2000. We expect to realize this vision through a coordinated program of joint venture projects, technology development and validation, and market conditioning.

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 for technology development and validation to:

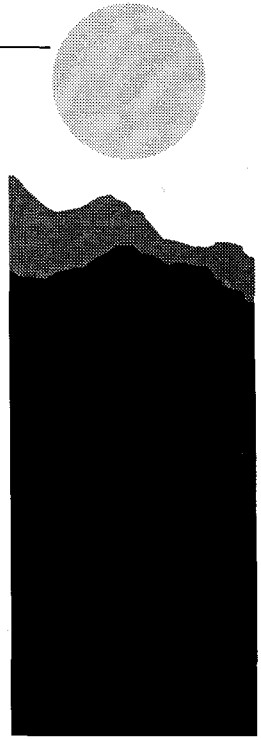
- Increase acceptance of this technology as a candidate for cost-competitive modular power generation by utilities, industry, and manufacturer/user groups, both in the U.S. and abroad,
- Develop reliable and efficient solar thermal electric systems for generation of economically competitive power that can contribute significantly to the national energy mix and thereby reduce dependence on imported energy sources, and
- Aggressively support the development of the industrial base required for this technology to penetrate the various energy applications and markets, creating new jobs and business opportunities for U.S. industry.

OUR STRATEGY

The Solar Thermal Electric Program strategy is consistent with the objectives set forth by the Office of Solar Energy Conversion in *Solar 2000—A Collaborative Strategy.*[1] The Department of Energy (DOE) and its field laboratories (Sandia National Laboratories and the National Renewable Energy Laboratory) will:

- Increase, through the following cooperative ventures, industrial participation in both the planning and execution of program elements:
  - — 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 power tower module.
  - — The Cummins Engine Company 7-kW_e dish/Stirling system, designed for both remote and grid-connected applications, will be operated at utility and industrial sites.
  - — Science Applications International Corporation and Cummins Engine Company contracts awarded under

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



the Utility-Scale Joint-Venture Program for 25-kW_e dish/Stirling, will result in at least one megawatt of dish/engine system capacity installed by utilities.

— The operations and maintenance cost reduction study with the Kramer Junction Company will provide 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 program to support and enlarge the technology's user, supplier, and decision-making constituency.

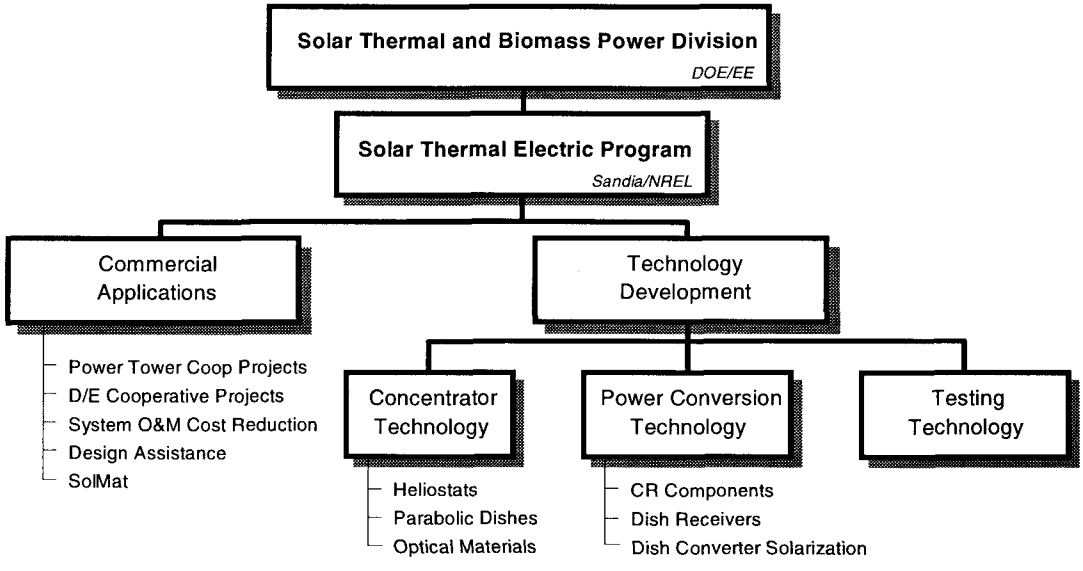
- Contribute to the DOE's Office of Energy Efficiency and Renewable Energy's goal of making solar thermal electric technology a viable option for both the domestic and international power-generation markets.

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: (1) opportunities for 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 first quarter of FY94 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.

OUR MANAGEMENT STRUCTURE

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.



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 MW. The program also supports existing parabolic trough collector systems for the purpose of operation and maintenance (O&M) cost reduction. The 354 MW 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, five major 50/50 cost-shared cooperative activities are underway within the program with a total value of $100M. 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)**

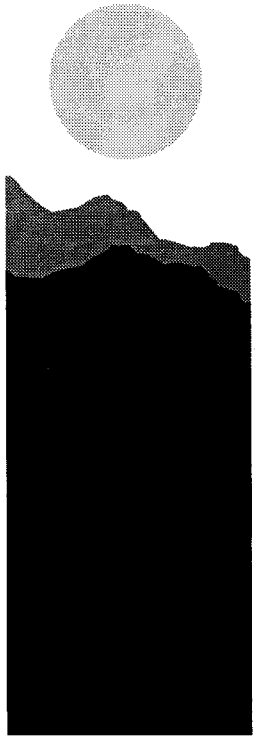
B. **Cummins Power Generation and Science Applications International Corporation (dish/engine systems)**

C. **KJC Operating Company (system operation and maintenance cost reduction)**

A. POWER TOWER COOPERATIVE PROJECTS

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

A consortium of United States utility concerns led by Southern California Edison Company (SCE) is conducting a cooperative project with the U. S. Department of Energy (DOE) and industry to convert the 10-MW_e 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 of building the initial commercial power tower projects and accelerate their 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, Bechtel Corporation, and Rockwell International. Sandia chairs the project's Technical Advisory Committee and is technical monitor for the DOE. 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 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

The major accomplishments this quarter are the completion of the Solar Two Project Phase 2, Development of Major Bid Packages, the vendor selection of most major subsystems, and the completion of the demolition and removal of the Solar One Thermal Storage System.

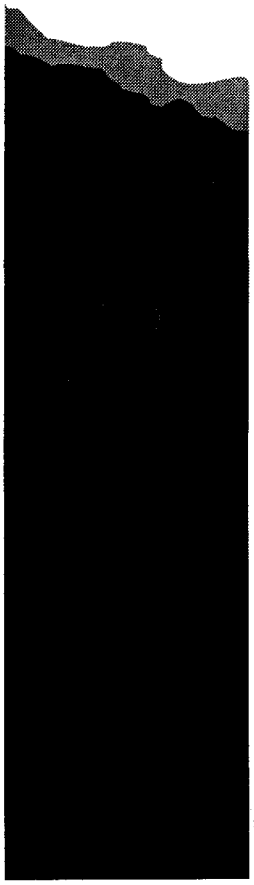
Solar Two project continues rolling along

Substantial progress has been made on the Solar Two Project in the past quarter: the plant design has been substantially refined, the cost estimates are within budget, and the Project is on schedule. Phase 2, Development of Major Bid Packages, was completed. Specifications on all the major salt equipment were prepared and sent out for bid. There were two meetings of the Technical Advisory Committee and two Steering Committee Meetings to discuss and evaluate the Project and approve the Solar Two design.

Total funding on the Solar Two Project remains slightly below required levels since PG&E withdrew from the project last fall. Nevada Power, the Edison Electric Institute, the Bureau of Reclamation, and others are still being pursued as potential Solar Two Participants.

Technical Advisory Committee activities

There were two meetings of the full Technical Advisory Committee (TAC) held this past quarter. The first TAC meeting was held in Denver, Colorado, on February 8, 1994. The objectives of this meeting were to discuss the "right sizing" of the Solar Two project, the review of the receiver proposals, and to discuss the TAC role in Solar Two. The meeting was very useful in updating the TAC on the status of the Project, in particular on the "right sizing" efforts to bring the Project within budget. Twenty-nine people attended this meeting. The second TAC meeting this quarter was held in Phoenix, Arizona, on March 16, 1994. The purpose of this meeting was to review the Phase 2 engineering and documentation of the design. The review conducted by the TAC during this meeting was very useful in identifying some technical and performance issues and helping clarify the design. Twenty-five people attended the meeting, including representatives from most Participants, Contributors, the Engineering and Construction Manager (E&CM), the DOE, Sandia, and other consultants.



In addition to the full TAC meetings, a number of TAC subcommittee meetings were held at the request of the Solar Two Project Manager. Subcommittees from the Solar Two Technical Advisory Committee conducted reviews of the receiver proposals, the Design Basis Document, the thermal storage system, the steam generator system, and the nitrate salt pumps.

On January 18-20, 1994, the receiver subcommittee conducted a technical review of the two proposals, from Rockwell and Foster Wheeler, for the Solar Two receiver. In conducting the evaluation, the subcommittee discussed concerns about the bidders' designs and proposals and then discussed whether or not their design and capabilities were "acceptable." In the end the subcommittee concluded that both bidders would be capable of building a viable receiver for the Solar Two Project; however, the subcommittee had more confidence in the Rockwell proposal.

An ad hoc subcommittee met at Bechtel on February 1, 1994, to review and discuss with Bechtel personnel the Solar Two Design Basis Document. The Design Basis Document is used by Bechtel as guiding document for the design of the plant. The subcommittee provided numerous technical comments on the document.

On February 23-24, 1994, the thermal storage system subcommittee met at Bechtel to review the two proposals for the nitrate-salt thermal storage tanks that were submitted by Pitt Des Moines and Chicago Bridge and Iron. The subcommittee provided recommendations to Bechtel on technical issues that still needed to be addressed and a recommendation to Bechtel that both vendors were capable of building the thermal storage tanks for Solar Two. The subcommittee had more confidence in the proposal submitted by Chicago Bridge and Iron.

The steam generator subcommittee meet at Bechtel on February 24-25, 1994 to review the four proposals submitted to Bechtel in response to the Request for Quotations on the heat exchangers for the steam generator. The proposals were from ABB Lummus, Joseph Oat, Yuba, and Slagle Corporation. After the review, the subcommittee provided recommendations to Bechtel on technical issues that still needed to be addressed. A number of the proposals for the steam generator were unacceptable. The subcommittee had more confidence in the proposal submitted by ABB Lummus.

A subcommittee of the Solar Two Technical Advisory Committee reviewed the proposals for the nitrate-salt pumps for the Solar Two Project. The subcommittee's evaluation and recommendations were discussed with Bechtel on March 4, 1994. Only two nitrate salt pump proposals were submitted to Bechtel in response to the Request for Quotations. One vendor responded to the request for "receiver

pumps" and the "salt mixing pump" and one vendor responded to the request for the "steam generator pumps" and the "salt mixing pump." As a result of the technical evaluation of the proposals, the subcommittee had a number of comments and recommendations that were provided to Bechtel.

The Solar Two Technical Advisory Committee, chaired by Sandia, will continue to support the Solar Two project at the request of the Project Manager.

Solar Two Project Phase 2 completed

This past quarter Bechtel completed Phase 2, Development of Major Bid Packages, of the Solar Two Project. The Phase 2 work was completed by Bechtel on March 1, 1994. Within Phase 2, technical specifications for all the major systems were completed and sent out for bid. In addition, Bechtel has continued to refine the Solar Two design, the plant layout has been optimized, and the Process Flow Diagrams, Piping and Instrumentation Diagrams, and General Arrangement Drawings have all been updated. The bids for the receiver, thermal storage tanks, steam generator heat exchangers, and the nitrate-salt pumps were all evaluated by both Bechtel and the Solar Two Technical Advisory Committee this past quarter. Vendors have been identified for all the major systems. Rockwell was awarded the design, fabrication, and installation of the receiver. A kickoff meeting for the award of the receiver contract was held at Rockwell on March 23, 1994. The selection of vendors for the thermal storage tanks, heat exchangers for the steam generator, and nitrate-salt pumps are pending commercial negotiations with the vendors.

Also, as part of the Phase 2 effort, a better definition of the cost estimate for the Solar Two Project was obtained. Southern California Edison and Bechtel conducted a very thorough review of the design, looking for areas of overdesign (and underdesign) to help bring the project within budget. Over 75 areas were identified where significant cost reduction could be obtained. In addition, a number of areas where items were missing were identified. The Project construction cost estimate is $39.3 million, which includes an appropriate amount of contingency for the current design status.

Sandia continued to assist the Solar Two Project Team with technical reviews of all specifications and designs, input on nitrate-salt instrumentation and components, and technical information on current test results at Sandia.

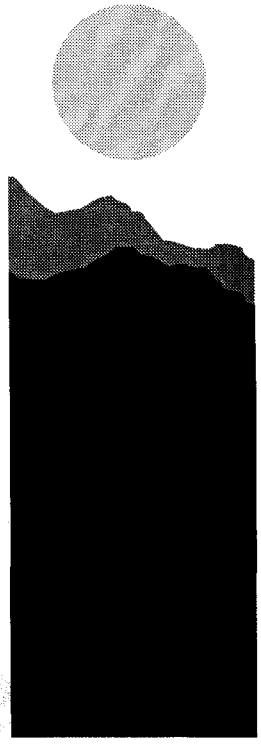
Collector field maintenance and heliostat assessment

Sandia continues to support the maintenance and assessment of the collector field at Solar Two and to evaluate "new" heliostats for Solar Two. Activities are discussed in the Concentrator Technology/ Heliostat Section.

Demolition and removal of the Solar One thermal storage system continues

Work is nearing completion on the demolition and removal of the Solar One thermal storage system (TSS). The thermal storage tank has been emptied, demolished, and removed. All equipment (piping, heat exchangers, pumps, tanks, etc.), insulation, and foundations associated with the thermal storage system have been salvaged or demolished and removed. Even the sand, gravel, and soils from the demolition project are being reused in a paving project at nearby Barstow College. Southern California Edison (SCE) evaluated and tested a number of approaches for disposing of the 6800 tons of sand and gravel removed from the TSS storage tank and the oil-contaminated soil identified and removed from the TSS area. SCE, with DOE's concurrence, concluded that the preferred approach for disposal of these materials would be incorporation into cold-mix asphalt. While an asphalt mix was being designed, a search began for a site to be paved. Barstow College was contacted and expressed strong interest in having a new parking lot paved. Paving operations at the Barstow College site began on March 14. SCE and the college held a press conference at the site on March 22. Despite miserably cold and windy conditions, college administrators, including the college president, enthusiastically participated in on-site activities.

The final step in the demolition and removal task will be to determine that the Solar One TSS area is free of contamination resulting from operation or removal of the thermal storage system. A final environmental survey of the area will be conducted early next quarter. Environmental aspects of the demolition have been coordinated with Western Technologies, the environmental firm hired by the Solar Two project as an independent third party. It will be Western Technologies' responsibility to declare the site clean and, therefore, ready for the start of on-site work for Solar Two.



Potential new Solar Two participants

Sandia hosted managers from Ogden Corporation on March 24 to provide them with information about the DOE renewable energy programs and to explore possibilities for Ogden to participate in Solar Two as an industrial partner. Ogden is a 46,000-employee company providing a wide variety of services, including operation and maintenance (O&M) of renewable energy power plants. Sandia management and staff were joined by Mark Skowronski of Southern California Edison (SCE) in providing Ogden with tours and a complete overview of the DOE renewable energy program. Additional information exchanges and participation opportunities were discussed for each technology. Ogden's primary interest appears to be in the geothermal, wind, and solar thermal trough and power tower areas.

Ogden's Power Division functions as an independent power producer (IPP) for several geothermal and hydroelectric power plants. **The division's role tends to be as an equity investment partner as well as the provider of O&M services.** The power division is looking to expand Ogden's presence in the renewable energy field by performing similar functions on additional projects. To ensure getting in on the ground floor of emerging renewable energy technologies, Ogden intends to become an equity investor and/or operator of power projects that utilize commercially ready renewable energy technologies.

Ogden is particularly interested in power tower plants. They want to explore the possibility of Ogden joining the Solar Two consortium as a participant (i.e., investor) and as the O&M services provider. Ogden sees participation in Solar Two as an excellent way to become an active player as the first commercial power tower plants are built. SCE provided Ogden with a copy of the Solar Two Participation Agreement for their review and consideration. Preliminary plans were made for other follow-on activities with Ogden, including commercialization discussions with Bechtel and visits to Solar One and the SEGS plants.

DOE/GO in launches the *Solar Two Challenge*

The *Solar Two Challenge*, a nationwide intercollegiate competition sponsored by the DOE and the Solar Two consortium, will require competing teams to design, construct, and operate small-scale, working, solar thermal central receiver models. Design proposals are due to the DOE/GO by June 24, 1994. Teams will set up and operate their models December 2-4, 1994, at the Solar Two site in Daggett, California. Prize money, which goes to the winners' schools, is $25,000 for first place, $10,000 for second place, and $5,000 for third place. Dozens of schools responded to the DOE's initial call for interest.

Late in the quarter, the DOE/GO requested that Sandia act as a consultant to the competition by providing the DOE and SCE with solar thermal technical information and, in general, helping to design the competition. Sandia met with the DOE/GO and SCE personnel on March 9 and helped develop a final version of the competition guidelines, which the DOE sent to schools on March 16. Major *Solar Two Challenge* activities through the end of the calendar year include responding to schools' technical questions; evaluating design proposals; and conducting the December competition. Sandia will support the DOE in these activities.

Study of SEGS I energy flows is underway

In order to help the Solar Two project establish an energy goal, as well as performance and reliability benchmarks, a **study was initiated to evaluate the energy flows at the SEGS I solar power plant.** Sandia has contracted with Hank Price and Associates of Denver, Colorado, to conduct this study.

Sandia and Hank Price and Associates have been working with the staff at SEGS I to perform a detailed analysis of the energy flows at SEGS I. We are categorizing the energy flows and efficiencies of all major subsystems at SEGS I. Understanding of these items at SEGS I will help the Solar Two Project define energy production goals at Solar Two. The study will be completed by the summer of 1994.

Study of tax equity issues continues

National Power Company has run their modified cash flow model for a number of solar thermal plants under a variety of taxation scenarios. This analysis supports a Sandia-sponsored study of tax equity issues associated with investor-owned solar thermal power projects. The study is being conducted jointly with the California Energy Commission (CEC) and coordinated with other efforts at CEC and NREL.

At the end of the quarter, the CEC provided National Power with a compilation of input parameters for fossil-fueled power plants. During next quarter, National Power will run the fossil power plant cases;

compare the taxes paid by the fossil plants to comparable solar thermal trough and power tower plants; and complete the study by designing a "tax equalization" case under which the solar and fossil plants pay equal taxes.

Planned Activities for Next Quarter

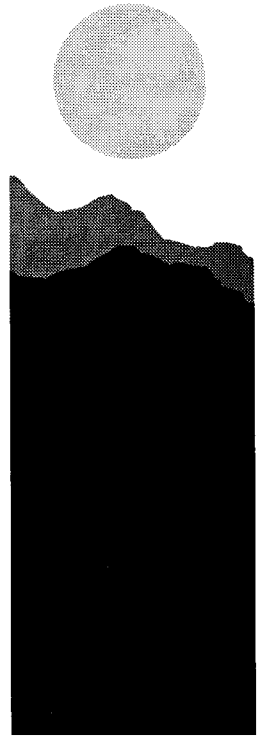
- Continue to support SCE's efforts to solicit Participants for the Solar Two consortium.
- Continue to support the DOE in the technical monitoring of this Project.
- Begin Phase 3, Engineering and Manufacturing.
- Support the DOE and SCE in the evaluation of the Solar Two Challenge proposals.
- Complete removal of the Solar One Thermal Storage System.
- The next full TAC meeting is scheduled for May 31, 1994. The next Steering Committee meeting is scheduled for June 22, 1994.
- A meeting of the Test and Evaluation and Performance Subcommittees will be held April 26, 1994.

Major Milestones

Milestone	Planned	Actual
Complete Phase 1, Systems Engineering, of the Solar Two Project.	Oct 93	Oct 93
Complete removal of the Solar One Thermal Storage System.	Jan 94	Mar 94
Complete Phase 2, Development of Major Bid Packages, of the Solar Two Project.	Apr 94	Mar 94

Resources

($k)	Sandia	NREL	DOE	Total
FTE Costs	540	0	0	540
Contracts	0	0	7260	7260
Total	540	0	7260	7800



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.

The Dish/Stirling Joint Venture Program (DSJVP) with Cummins Power Generation (CPG), underway since 1991, will develop a 7.5 kW dish/Stirling system primarily for remote application. Two new Utility Scale Joint Venture Program (USJVP) contracts with Science Applications International Corp. (SAIC) and CPG will develop 25-kW dish/Stirling systems for utility application. These are discussed separately below.

During the quarter, Cummins Power Generation, Inc. (CPG) selected the Clever Fellows Innovation Consortium free piston Stirling engine/linear alternator design for further development. Development work on the USJVP contracts with SAIC and CPG was initiated.

DSJVP Accomplishments

Cummins/Sandia review of Stirling engine programs

Sandia and Cummins Power Generation, Inc. (CPG) engineers visited Clever Fellows Innovation Consortium (CFIC) in Troy, New York, and Sunpower, Inc. in Athens, Ohio, on January 12-14, 1994. The objective of the visits was to assess the status of the two competing free-piston Stirling engine/linear alternator technologies and to see the hardware first hand. At both locations, the CPG/Sandia team was briefed on the technical status of the designs and shown the hardware. At CFIC, the engine was operated and then on the next day disassembled. Sunpower disassembled the design level linear alternator and presented a new heater head concept called the crown head.

CFIC engine

Cummins Power Generation, Inc. (CPG) has selected the Clever Follows Innovation Consortium (CFIC) free-piston Stirling engine/linear alternator for their 7.5-kW_e dish/Stirling system. Because of the importance of the free-piston Stirling engine to the DSJVP, CFIC was included as a parallel researcher, along with Sunpower, Inc., in Stirling engine/linear alternator development. Until recently, Sunpower was the leading engine/alternator design. The CFIC engine/alternator incorporates several clever innovations, including strap-type flexures, the STAR alternator, a cylindrical heater head geometry, and a low-loss piston centering approach. However, the primary reason for selecting the CFIC design is that it is significantly more manufacturable than the Sunpower design. In addition, the CFIC engine/alternator appears to be capable of efficiencies of more than 30% at a 650 °C operating temperature. The opposed engine configuration used in the CFIC design also eliminates vibrations and many of the related problems associated with the Sunpower engine/alternator. The concerns with the CFIC engine are the lack of operational hours (the engine has only about 10 hours thus far), the use of contacting seals (piston rings), and the fact that the engine has not yet delivered more than 6-kWe output. CPG immediately started ordering parts for five new CFIC engine/alternators.

Thermacore receiver installed at Cal Poly

A Thermacore durability heat-pipe solar receiver was installed on the Cummins Power Generation, Inc. CPG-460 solar concentrator at the California State Polytechnic University test site during the week of March 21. The CPG-460 was installed in early December 1993, and until last week had operated with a cold-water calorimeter. CPG plans to install a CFIC free-piston Stirling engine on the CPG-460 this summer.

Prior to the receiver installation, the CPG-460 was realigned and focused using a Sandia developed light-source technique. A photograph of the Sandia-developed alignment target is shown in Figure 1. The aperture plane flux distribution had seriously degraded since December. The Sandia light-source technique clearly indicated that facet focal lengths had decreased over time. CPG and Sandia are investigating this issue. A video technique that can greatly improve the speed and accuracy of the alignment and focusing process was also evaluated.

Cummins 5-kWe systems continue operation

Operation of the Cummins Power Generation, Inc. (CPG) dish-Stirling system continued throughout the quarter at the CPG facility in Abilene, Texas. Because of the selection of the CFIC

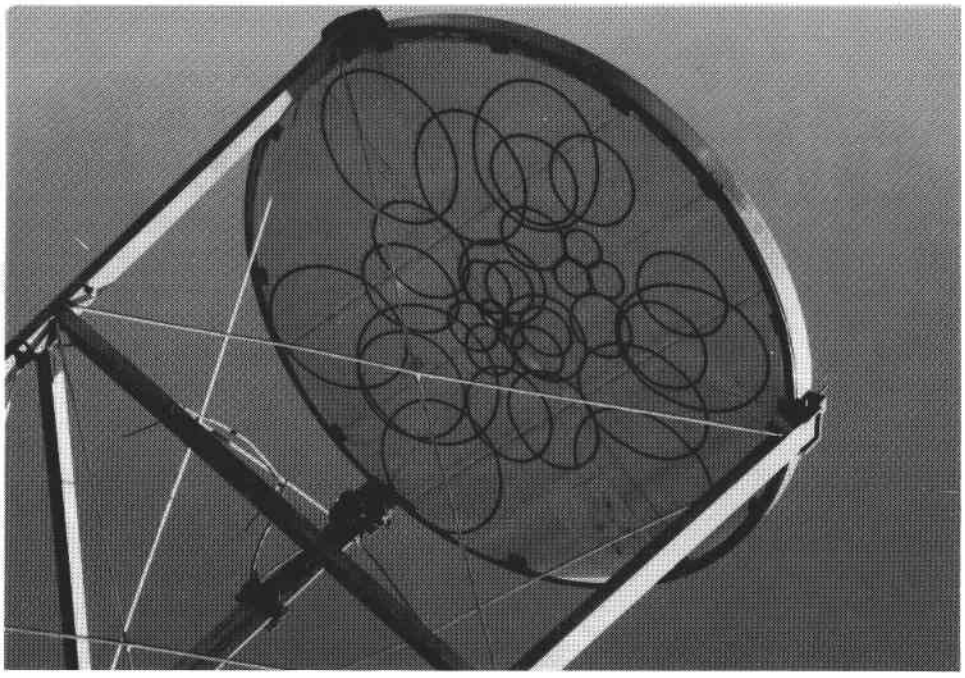


Figure 1. Sandia alignment and focus target used on the CPG-460 at Cal Poly, Pomona, California.

engine/alternator, operation of the Sunpower engine/alternator has not been a priority. However, CPG continues to run the Sunpower engine for demonstrations, and to durability test the balance of the system. The system routinely produces more than 6 kWe. In addition, the "west" concentrator has been testing a durability heat pipe receiver and has accumulated approximately 1000 hours of on-sun operation at temperature. The concentrator also operates when the sun is not shining and has accumulated nearly 2000 total hours. The Lancaster, Pennsylvania water pumping system has not operated because the water tank is frozen solid.

Thermacore heat-pipe receiver test facility

Located at Lancaster, Pennsylvania, a Thermacore, Inc. test facility for round-the-clock testing of full-scale heat pipe solar receivers was completed; durability testing of a receiver was initiated during the quarter. The facility, which uses quartz lamps, is capable of delivering over 30 kWt through a receiver. The durability test plan calls for 4 hours at-temperature, turning off power until the receiver temperature reaches 200°C, and then turning the power back on. Thermacore is able to accumulate approximately 110 hours at temperature per week in the facility. In addition, the CPG test cell in Abilene, Texas, is being used for testing the Sunpower "C" level engine that is providing power for the CPG solid state conditioning and control system.

In addition, CPG erected a new "southwest" concentrator at the CPG Abilene test site. Initially, this concentrator will serve as a test bed for CPG's new single board computer system and new concentrator control software. Later, this concentrator will receive the first set of silvered mirror facets. Performance testing of this new mirror technology will include cold-water calorimetry and flux mapping.

CPG system controller initiates testing

CPG has made progress on the control system during the quarter. The baseline load interface designs for all three applications will be with a digital-control load interface system. During the quarter, CPG installed the integrated concentrator and power conversion unit controls on the Abilene "southwest" concentrator and initiated testing. Hardware for the utility grid tie load controls based on pulse width modulation was delivered to Abilene, Texas; debugging and testing was initiated on the grid and on the output from the Sunpower test cell engine/alternator.

Thermacore/Sandia limit test heat-pipe solar receiver

A Thermacore heat pipe receiver was tested on Sandia's Test Bed Concentrator #1 (TBC-1) for several days. This receiver successfully delivered 56 kWt to a gas-gap cold-water calorimeter. In the open-aperture configuration, this represented the maximum heat input capability of TBC-1. Some difficulties were experienced during the warm-up of the receiver. Based on

subsequent review of the test data, Sandia hypothesized that a small amount of hydrogen in the receiver could be the source of these difficulties. (See discussion in Dish Receiver Technology section.) Thermacore initiated a test to evaluate this theory. CPG has loaned Thermacore a residual gas analyzer so that Thermacore can more thoroughly process future heat pipe receivers. Sandia will be providing training to Thermacore personnel on the use of the residual gas analyzer and turbomolecular pump.

Optical materials technical support

Sandia and NREL coordinated optical materials support for the DSJVP. 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 is providing CPG with significant quantities of 3M ECP-305+ film for evaluation. During the quarter, CPG tested 0.7-mm thin-glass mirrors on one of their facets. Results from CPG's optical evaluation indicate improved optical performance, compared to the 1.0-mm glass mirrors. Sandia has an order with Naugatuck Glass Company to deliver a 60-inch diameter thin-glass (1-mm thick) sample to CPG.

DSJVP Planned Activities for Next Quarter

- Clever Fellows and CPG will build the first of the five new engine/alternators.
- CPG and Sandia will perform additional limits tests on the Thermacore heat-pipe receiver to test the residual gas theory.
- CPG will test their solid-state conditioning and control system on-sun.

SAIC USJVP Accomplishments

The objective of the Utility-Scale Joint-Venture Project (USJVP) is to develop 25-kW_e dish/Stirling systems for use in utility markets. The Energy Projects Division of Science Applications International Corporation's (SAIC) in Golden, Colorado, leads a team comprising Stirling Thermal Motors (STM) of Ann Arbor, Michigan, Detroit Diesel of Detroit, Michigan, and several utility partners. SAIC is the systems integrator and will also develop the solar concentrator, the second-generation faceted stretched-membrane dish. STM will provide their kinematic Stirling engine; Detroit Diesel is responsible for engine testing and mass-production engine design considerations. The $17.6-million dollar contract is a 50/50, 3-year, cost-shared activity between the design team and the DOE (Sandia) for Phases 1 and 2 of the project, Proof of Concept and Pre-Production Prototype Development. If the first two phases of the project are successful, then SAIC and Sandia will enter into negotiations for Phase 3, the deployment at utility sites of 1-MW of dish/Stirling systems.

SAIC is the designer of the solar concentrator for the dish/Stirling System. The next-generation of the faceted stretched-membrane dish design is well along. The solar concentrator design specification has been developed. The dish will have 16 facets, 4 more than the first-generation dish, and an increase in the focal length from 9 to 10 meters. The facets will be slightly smaller than the first dish resulting in an increase in the total dish area of about 7%. A large amount of effort has been devoted to standardizing some of the structural elements of the second-generation dish design. Consequently, the facet support structure will be made up of 11 identical radial trusses that attach to a central hub, and 10 each of 2 azimuthal ring-beam truss designs. Acquisition of materials and fabrication of facets has already started.

The first edition of a control system specification has been issued. A control scheme has been defined: the control modes specified, operating logic developed, and schematic drawings made. For flexible evaluation of system operation, the prototype system will most likely use an off-the-shelf programmable controller to operate the dish and receiver, and to interface with the STM engine controller. The initial plan for interconnection to the Public Service Company of Colorado grid has also been developed.

Engine development activities at STM are rapidly progressing. All purchased parts for the first 5 Phase-1 engines have been ordered and most have been received; about 40% of the in-house parts have been fabricated. Four of these engines will be installed in test cells for accelerated testing and the fifth will be *solarized* and delivered to SAIC for installation on the dish.

Solar-specific engine design upgrades have reduced the weight and cost of specific engine components by about 50%. A new hydraulics block design has been instituted, the front oil sump and cooler have been redesigned, and the oil-lubrication system design has been improved to operate over a wider range of elevation angles.

Direct Insolation Receiver design upgrades have also been initiated. The receiver is currently being designed for the 16-facet dish. The heater head casting process has been improved through the use of upgraded tooling; a new vendor for the supply of the bent tubing has been located and their products evaluated.

Major facilities upgrades at STM are nearing completion. New machines have been acquired and installed and the electronics shop has been upgraded. The Class 10,000 engine clean room is nearing completion; engine assembly and test-facility upgrades are about 60% complete.

A meeting to discuss the development of the alternate receiver for the dish/Stirling system was held on March 10 at SAIC's offices in Golden, Colorado. The meeting was attended by SAIC and STM personnel, representatives from STC, and by staff from Sandia and the NREL. Sandia staff presented summaries of heat-pipe and pool-boiler receiver development status; STC presented the status of their pool-boiler receiver. Discussions centered on the relative strengths/weaknesses of these two reflux receiver types relative to the ability to adapt them to the design of the STM 4-120 Stirling engine. A decision will be made next quarter on the type of alternative receiver design to pursue.

The first Quarterly Review of the SAIC/STM/DDC Utility-Scale Joint-Venture Project was held in Golden, Colorado, on March 23-24, 1994. In addition to the USJVP team members, a number of utilities and others also attended the design review meeting. The utilities represented at the meeting were Arizona Public Service, PacifiCorp, Southern California Edison, Nevada Power, Platte River Power, and Public Service Company of Colorado. Others attending the meeting were representatives from Rockwell International, Advanced Thermal Systems, and Antarctic Support Services.

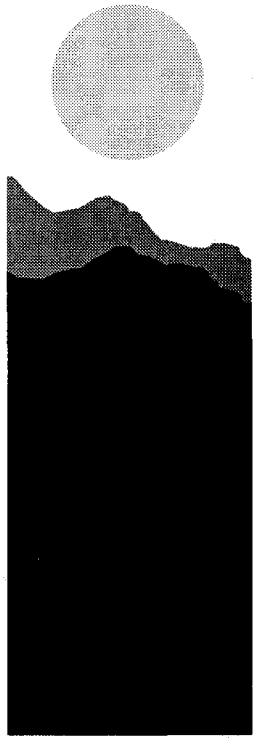
SAIC USJVP Planned Activities for next Quarter

- Complete the design drawings for the solar concentrator.
- Select the test site for the prototype system.
- Complete a failure modes and effects analysis of the power conversion system.
- Specify the design of the alternative receiver.
- Develop a preliminary system field test plan.
- Start testing in a test cell of one of the Generation II STM engines.

CPG USJVP Accomplishments

The contract between Sandia and CPG for the USJVP was placed in January 1994. This contract is for Phases 1 and 2, each of which lasts two years. The Phase-1 total cost is $8.41 million, and the Phase-2 total cost is $9.56 million. These costs will be shared 50/50 by Sandia and CPG. CPG's major sub-contractors are: (1) CFIC, which is developing the Stirling engine, (2) Thermacore, which is developing the heat pipe receiver, and (3) WG Associates, which is performing detailed concentrator design. The CPG USJVP kick-off meeting was held in February at Sandia.

Three "significant" changes have been made in the CPG approach to the USJVP since their final proposal. First, Sunpower has been eliminated as the source for the back-up engine. They have been replaced by Northern Research and Engineering Corporation (NREC), which is developing a solarized 30-kW_e Brayton engine under another Sandia contract. The volumetric receiver for this engine is being developed by the German Aerospace Research Establishment (DLR). Second, the baseline design has been changed from 25 kW_e to 30 kW_e. This is has been done in an attempt to achieve economies of scale. And third, the concentrator design has been opened up to include consideration of a wide range of technologies. Originally, CPG was proposing to develop a concentrator based on the 5-foot stretched membrane facet being used in the DSJVP.



CPG USJVP Planned Activities for Next Quarter

- Finish evaluation of concentrator technologies and select a baseline design.
- Begin design of the 30-kW_e CFIC Stirling engine. (This is being delayed until nominal operation of the 7-kW_e CFIC engine is achieved in the DSJVP.)
- Begin design of the 90-kW_{th} Thermacore heat pipe receiver.
- Begin design of the 30-kW_e NREC Brayton engine.
- Begin design of the 100-kW_{th} DLR volumetric receiver

Major Milestones

Milestone	Planned	Actual
Award USJVP contracts to SAIC and CPG.	Dec 93	Jan 93
Install a CPG "C" dish/Stirling system at Cal Poly.	Dec 93	Dec 93 (dish only)
Award a USJVP contract to HEA, subject to contract negotiations *(negotiations underway; award delay until fall is likely).*	May 94	
Operate a CPG "D" dish/Stirling system in Abilene, Texas.	Jun 94	
Install a CPG "D" dish/Stirling system at Georgia Power.	Jul 94	
Install a CPG "D" dish/Stirling system at Cal Poly.	Aug 94	
Conduct Phase 2 review of the DSJVP.	Aug 94	

Resources

($k)	Sandia	NREL	DOE	Total
FTE Costs	900	50	0	950
Contracts	4950	0	500	5450
Total	5850	50	500	6400

C. SYSTEM OPERATION AND MAINTENANCE COST REDUCTION

The nine Solar Electric Generating System (SEGS) power plants located in Southern California are the only utility-scale solar power plants currently operating in the world, with an existing capacity of 354 MW. The costs associated with operating and maintaining (O&M) solar thermal plants have a significant influence on the economic viability of the technology. For example, O&M costs account for greater than 20% of the SEGS electricity costs. Reductions in O&M costs would enhance the marketability of solar thermal technologies currently being developed by the DOE. An example of a DOE technology that would benefit is the Solar Two demonstration project and commercial power tower plants. Power tower 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 power tower plants****. This guarantees that this initiative will benefit current solar thermal technology (SEGS troughs) as well as future technology (power towers). The project is being performed on a 50/50 cost share basis between owners of the SEGS plants (primarily U.S. 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 Company Operating Company (KJC) in July 1992. The work to be performed during the 3-year project was described in the Third Quarterly Report FY92. The progress made during the present quarter is described in the following paragraphs.*

ACCOMPLISHMENTS

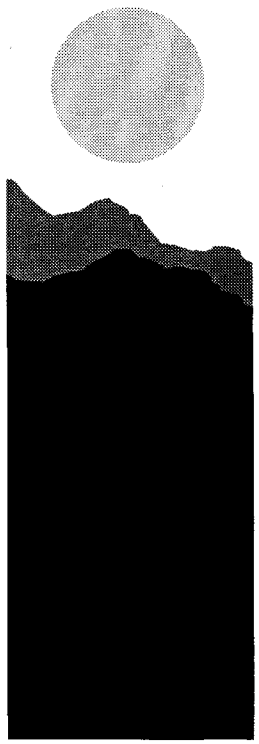
Receiver tube bowing phenomena investigated

Last quarter, it was reported that an analysis of energy losses at Kramer Junction indicated that the most important loss was because of degraded receiver tubes (also called heat collection elements or HCEs). The most significant degradation mechanism occurs when the glass sleeve surrounding the metal receiver tube breaks. Based on tests completed at Sandia in 1993, a broken sleeve increases heat loss by a factor of 2 to 5, depending on wind speed.

Currently, approximately 10% of the HCEs at Kramer Junction have broken glass sleeves. HCEs have not been replaced by KJC since the LUZ bankruptcy because of a warranty fund covering shortfalls in performance at Kramer Junction due to broken sleeves. Because this warranty fund is due to expire in a few years, KJC has developed an action plan to reduce the number of broken HCEs to 1% by the end of 1995 and to maintain that value in subsequent years. This will be accomplished by purchasing new HCEs from Solel in Israel and reducing the frequency of HCE breakage at the site.

To reduce the frequency of breakage, a thorough understanding of the root causes for failure is necessary. One of the dominant failures identified is caused by contact of bowed receiver tubes with the glass sleeve. It is known that severe tube bowing can occur if the temperature difference between the heated-side of the receiver tube is 50°C hotter than the non-heated side. During the present quarter, Sandia performed a preliminary analysis to determine if this temperature difference could occur during the expected operating conditions at the Kramer Junction SEGS plants.

To perform the analysis, Sandia first constructed a dynamic simulation model of a typical LS2 delta-T loop at SEGS VI. The model was readily created by making several modifications to the receiver model previously developed by Sandia for the Solar Two project. The LS2 model consists of set of approximately 100 ordinary differential equations that are solved with the SYSL simulation software. Preliminary comparisons between the analytical model and experimental data from SEGS VI indicates good agreement. Sandia then performed an analysis of the potential for tube bowing by calculating the front-to-back temperature difference on the HCE tube during a sudden return of full sun following an extended cloud outage. The analysis indicates that tube bowing may occur (>50 °C delta T) if minimum flow is less than 40 gpm per loop. Initial indications from



personnel at KJC indicates that the minimum allowable flow may be as low as 25 gpm. This suggests that there may be a problem with minimum flow algorithm implemented at Kramer Junction. Next quarter, we will investigate the flow algorithm and determine if a problem truly exists.

Optimized maintenance planning continues

With the advent of the personal computer 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.

Incorporation of a state-of-the-art maintenance planning tool into the KJCOC organization is one of the largest and most monetarily intensive tasks within this O&M Cost Reduction Program. Full implementation is expected to result in a significant reduction in maintenance costs (~20%).

State-of-the-art maintenance planning software (MPAC by System Works) is now installed at the Kramer Junction power park; however, final phases of implementation as a working tool are not yet complete. This system dramatically changes the way of doing maintenance, and it is never easy to impose a new system on a functioning organization. During the present quarter, the process continued, and slowly but surely the remaining steps to complete implementation are being accomplished. The MPAC is a complex package of tools, and it is fully expected that there will be ongoing modifications in procedures and usage as further experience is gained.

Solar field maintenance planning showed progress in several areas. Two meetings on the definition of the software were held with a potential vendor to define the requirements and structure. Equipment was received for the wireless transmission of data from a roving solar field technician to the central data storage unit.

Testing of advanced flow meters continues

Accurate measurement of flows within the solar field and in the steam plant are critical to the analysis of solar field and power plant efficiency. Historically, four types of flow meters have been utilized with varying degrees of success: annubar type, insertion turbine, orifice, and low loss flow nozzle. Each type of flow meter has advantages over the others, but none has proven to provide accurate and reliable readings in a consistent manner over time. A combination of many factors contribute to this: impurities in the heat transfer fluid, lack of appropriate preventative maintenance, physical damage to flow meters, improper installation, improper flow calculation, improper temperature correction, the high temperature of normal operation, freezing of the dead leg fluid on differential pressure flow meters, or lack of spare parts. Similar types of problems have also occurred during tests of molten-salt power tower systems at the National Solar Thermal Test Facility (NSTTF).

Many recent advances have been made in flow-measurement technology. Therefore, the objective of this task is to identify the best new technology that is appropriate for solar application. Because the temperature of the heat transfer oil at the entrance to a SEGS parabolic trough field is nearly identical to a molten-salt power tower (550 ^{O}F), the flow device chosen for parabolic trough application may also be usable at a power tower.

Last quarter, two new flow meters were installed in the inlet to the east field at SEGS IV: (1) vortex-shedding type made by EMCO and (2) an ultrasonic type manufactured by Panametrics. During the present quarter, data was collected from these new flow meters as well as the older annubar and turbine types. This data will be fully analyzed in April, but preliminary results indicate that the turbine meter is reading 10% higher than the other 3 meters. This is somewhat puzzling and needs verification because historical experience suggests that turbine meters are quite accurate if well-maintained.

A similar flow meter task is currently being performed at the NSTTF in support of the Solar Two project. The tests at the NSTTF are using vortex-shedding and ultrasonic meters (but these meters are not commercial-scale like the ones at KJC) and are measuring flows of molten salt. Because of the similarity of these tasks, the Solar Two and O&M projects routinely share respective results.

O&M lessons learned provided to Solar Two project

As stated in the introduction of this quarterly update, there are many similarities among the systems as well as between the operation and maintenance of parabolic trough and central receiver power plants. Consequently, the O&M Cost Reduction Project provides consultation to the Solar Two Technical Advisory Committee on a regular basis.

During the present quarter Gilbert Cohen, a senior engineer at (KJCOC), attended and provided input at two Technical Advisory Committee meetings in Denver, Colorado, and Phoenix, Arizona. Gilbert's comments were incorporated into the Design Basis Document as well as the Test and Evaluation Plan.

Planned Activities for Next Quarter

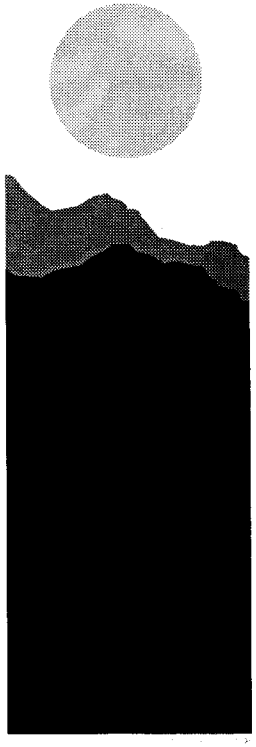
- Determine if frequency of tube bowing can be reduced by modifying SEGS flow algorithms.
- Continue to implement maintenance planning system.
- Complete tests of cermet samples that were coated in 3rd quarter of FY 93.
- Continue testing of flow meters.
- Continue to provide lessons learned to Solar Two Project.

Major Milestones

Milestone	Planned	Actual
Document FY93 O&M Cost Reduction Activities.	Oct 93	Dec 93
Implement O&M evaluation and analysis software on site network.	Apr 94	
Complete the final report describing progress made in FY94.	Sep 94	
Complete documentation of historical frequencies and causes of equipment outages at Kramer Junction.	Oct 94	

Resources

($k)	Sandia	NREL	DOE	Total
FTE Costs	88	30	0	118
Contracts	782	0	100	882
Total	870	30	100	1000



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 include direct technical assistance to users; testing, evaluation, and technology development; and education and outreach.

The Solar Thermal Design Assistance Center (STDAC) activities reported here are supported by (1) the Solar Thermal Electric Program, (2) the Solar 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 STDAC is providing technical assistance to the solar industry. One important project provides assistance to the UC Operations Services, the operators of the Harper Lake SEGS power station. The purpose of the work is to help solve some operational problems and increase the plant's profitability. Some of the problems include a need for identifying misalignments with the mirror facets and the solar collection arrays (SCAs), leaking bonnet gaskets on some of the valves, broken and discolored receiver envelopes, ram pins that were dislodging from the drive rods, flexhose failures, oil freezes, wind damage, and excessive time to measure mirror reflectivity. Because of our work at Kramer Junction and IST's Tehachapi system, we are able to immediately address some of these problems without violating any of the existing proprietary information agreements with these two organizations. For example, we informed them of the success at Kramer in replacing flexhoses with ball joints; we provided them with the specifications for the ball joints. We also discussed techniques for preventing oil freezes and bonnet leaks. Also, we loaned them one of our newly developed reflectivity measuring devices for trial on their site. Other problems will involve a small amount of investigative effort on our part. For example, they will send us some of the broken ram pins and discolored receiver envelopes. We will examine them and suggest solutions.

A growing problem at the plant is wind induced mirror breakage along the peripheries of the SEGS IX solar field. Unlike the SEGS facilities in Daggett and Kramer Junction, the plants at Harper Lake do not have a perimeter wind fence. We have begun a literature search of wind screens and are investigating whether stowing procedures can be altered to mitigate further damage. Recommendations will be made to Harper Lake personnel next quarter.

One of their most significant problems involves misalignments of the mirror facets and the SCAs. We told Harper officials about our effort with the other SEGS operators to develop a simple technique to detect these misalignments. This new technique involves flying over the field and videotaping or photographing the image. The images should contain visual evidence of misalignments. We should be ready to test this technique sometime this spring and we offered to include Harper in the effort. In fact, Wayne Luton of Daggett Leasing experimented with a similar technique at SEGS I and II. The technique was successful, but had some problems. Next quarter we will use the results of this work to help us plan our development effort.

Wind response analyzed

Program engineers have been assisting Industrial Solar Technology (IST) regarding the wind damage to the solar trough hot water system in Tehachapi, California. At IST's request, Sandia engineers conducted a finite element analysis of the trough system in order to recommend structural improvements to the design that would prevent future damage. A working model was developed and last quarter we gave some preliminary results. IST reviewed the results and requested material testing to validate some of the assumptions made in the development of the model. Material testing has been completed and showed that we should make some changes to the finite element model. The finite element analysis will continue through this fiscal year. The final results will be published in a Sandia report.

State cooperative activities

STDAC engineers are assisting several states. In the state of New Mexico, we are assisting the Energy, Minerals, and Natural Resources Department and the New Mexico Solar Energy Industries Association (NMSEIA) in four refurbishment projects. As a result of these efforts, New Mexico is initiating a program to refurbish all of their non-operating, state-owned solar systems.

Also, during this quarter, the New Mexico legislature appropriated funds for the creation of an energy research alliance. The alliance will involve major state entities that are dealing with energy such as the utilities, the national labs, the universities, and the energy industries. Although its operational structure and purpose is not yet fully defined, one proposed objective of the alliance is to help the state assume a prominent position in the application of solar technology. Two possible projects involve New Mexico participating in the dish/Stirling and Solar Two programs.

We are assisting the state to develop the alliance; an initial meeting was held this quarter. The state has asked Sandia to develop a conceptual plan of how the alliance will work. This plan will be developed and presented to state officials next quarter.

Sandia engineers are participating in three California Energy Commission (CEC) activities. The first effort assists CEC officials in developing Request for Proposals (RFPs) for third-party financed solar systems in prisons. A second effort is underway to monitor the performance of an evacuated tube, solar industrial process heat (IPH) system at Galt, a California Department of Corrections training facility. The monitoring system is installed; performance data are being collected and will be reported for the next year.

The third project concerns solar air conditioning and its use as a utility demand-side management option. Initiated last year, the project involves a demonstration of a solar absorption air conditioning system in a commercial building in Sacramento. This project is a collaboration between the CEC, the DOE solar programs, Bergquam Solar, and the Sacramento Municipal Utility District.

Another effort, a CEC initiative, seeks to implement a new commercialization program to accelerate the market adoption of solar absorption air conditioning systems. Last quarter, Sandia participated in a CEC-sponsored focus group designed to (1) identify barriers to its commercialization and (2) determine a prioritized list of action items to address the barriers. Sandia is working with the CEC to use the results of the meeting to develop and implement the CEC commercialization program.

Military installation activities

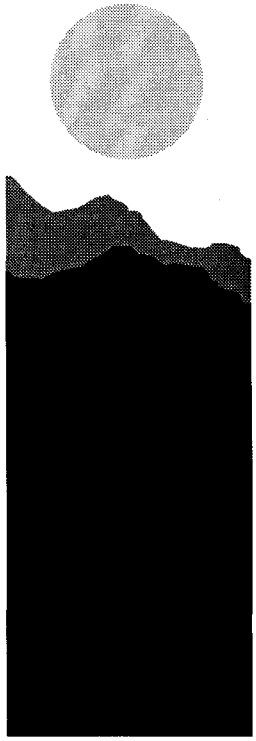
Sandia engineers are directing the evaluation of potential solar systems at several military installations. Energy officials from the U.S. Army Corps of Engineers funded us to provide engineering assistance in reviewing potential applications for solar thermal technology at Ft. Huachuca. The analysis involves 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 Department of Defense's (DOD's) Energy Conservation Investment Program. The first phase of the effort, a preliminary review of all the base facilities, was completed and several potential applications were identified. A final report was completed and delivered this quarter.

Sandia has been assisting officials of Peterson AFB near Colorado Springs, Colorado, to help identify and analyze potential applications for solar thermal systems. Two applications have been identified and the analysis is nearly complete. A final report will be delivered next quarter.

Additionally, Sandia is working with engineers at McDill AFB near Tampa, Florida, to identify and analyze solar thermal applications. The base has $300,000 available for solar thermal projects that meet the DOD's Energy Conservation Investment Program acceptance criteria. Work on this project will continue through this fiscal year.

In addition, the U.S. Corps of Engineers, Mobile District (COEM) invited us to help review and refine the basic methodology that the Corps uses to assess the applicability of solar systems within Department of Defense (DOD) facilities and installations. The COEM asked for Sandia's help based on our reputation for providing "forthright and unbiased information about solar thermal technology."

The COEM is the lead Corps of Engineers (COE) organization for renewable energy; they are responsible for, maintaining the



methods and procedures used by all DOD installations (except some Navy facilities) regarding feasibility assessments, standard design, and application of solar thermal systems. Based on a recent internal study, the COEM determined that they should review and update three of their standard methods including a solar economic analysis program, a best case analysis of solar thermal potential, and the COE's standard solar design specifications. Their major concern is that the default cost, design, and application guidance used in the three methods may unfairly represent solar thermal potential in various applications. Their particular concern is that the current feasibility assessment tools are too general to properly screen solar applications. Thus, appropriate applications may be overlooked while inappropriate ones may be receive detailed and expensive follow-up studies. They asked Sandia to critically review all three methods and recommend specific improvements.

This project is strategically important to the DOE solar program because this Corps of Engineer methodology is used by most U.S. military installations throughout the world to decide whether solar technology is applicable. Improvements to these tools may result in a significant number of new solar applications within the DOD in the near future. The COEM will fund the effort.

International renewables support

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. During this quarter, most of the STDAC's efforts were spent promoting the use of solar ovens, ice makers, and dish/Stirling systems in remote areas of Mexico. Initial efforts are focusing on the University of Sonora. Sandia is helping the university 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. Later, the dish/Stirling system will be promoted. The working relationship between Sandia and the University is documented in a Memorandum of Agreement, which is currently in the process of being signed.

Sandia's solar thermal electric program staff is also collaborating with staff from Sandia's photovoltaic program regarding the application of solar thermal technology within the USAID/Mexico program. In this multi-million dollar program, solicitations will request renewable energy systems to be installed in Mexico. We are participating in planning meetings and will cooperate in the execution of the program.

Testing evaluation activities

Sandia has been conducting environmental tests on a complete LS-2 replacement facet built by Industrial Solar Technology. This facet is needed as a replacement for broken glass mirrors in the SEGS plants. The SEGS operators asked for Sandia's assistance in developing a replacement for these broken facets because the supplies of the original glass facets are no longer available.

Sandia cost-shared the development of these facets with IST. These new facets are constructed of two pieces of aluminum sheet metal sandwiched around a paper-based honeycomb substructure. 3M's ECP305 silvered polymer reflective film is used as the reflector. The edges are sealed with a polymeric caulk. These new facets are designed for superior strength to the glass facets with about half the weight. The environmental tests were to determine how well the silicon seal protects the cardboard from moisture, which could destroy its structural integrity. The tests, which were performed in one of Sandia's environmental chambers, involved extreme temperature and humidity cycling over a 6-week period. (Cycling conditions ranged from -40 °F to 150 °F with relative humidity ranging from near 0% to about 95%.) The tests were developed in cooperation with IST, DLC, KJC, and Sandia, and closely resemble the acceptance tests LUZ Corporation used for the original mirror facets.

To determine whether moisture had infiltrated the facet and distorted the optical quality, Sandia developed a simple optical characterization technique. The technique uses a video imaging camera and far-field viewing techniques to quantify the overall distortion in the reflector. This technique was applied to the facet before and after the chamber tests and the results indicate that the facet was not affected by the environmental tests. The final results of the test will be reported next quarter. Sandia will

work with the SEGS owners to determine the next set of tests for the facet, which may involve populating a LS-2 collector with these new facets and testing it on Sandia's rotating platform. These tests can be compared to previous tests of an original LS-2 collector to help assess whether these new facets are appropriate replacements for the LS-2's original glass mirrors.

Sandia is also working with IST and KJC to develop a cost-effective approach to replacing broken LS-2 receiver envelopes. The objective is to develop a system that will allow the envelopes to be replaced without removing the receiver tube. Experiments in the next quarter will be conducted with split-glass envelopes that have shown some promise for this kind of application.

SOLTECH 94 conference

Seven solar thermal electric sessions were presented at SOLTECH 94, which was held at Ponte Verde Beach, Florida. The sessions included the following subjects: Overview of the DOE's Solar Thermal Electric Program, Solar Two, International Opportunities, Reflective Films, Parabolic Troughs, Dish/Stirling Joint Ventures, and Utility Scale Joint Ventures. Although no exact figures are available, it appeared that attendance at the solar thermal electric sessions were higher than in previous years. Moreover, many of the attendees commented positively about the content and presentations in the sessions.

A special session was called by the Kramer Junction Company (KJC) immediately after the parabolic trough session. KJC rolled out a high level business plan to re-establish a trough power plant capability through a U.S.-led consortium.

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.

STDAC Contacts

CENTRAL RECEIVERS

Bohn, Mark	NREL
Brower, Mark	North Carolina Solar Systems
Chen, Gary	Consultant
Dagan, Eldad	Israel
Dainert, Walter	Consultant
DeLaquil, Pat	Bechtel
Dochat, George	MTI
Dussigen, Petre	Consultant
James, Bob	SAIC
Kusignonich, John	Carrisa Solar
Mitchkey, George	Seattle Consultant
Perry, Richard	SUNY
Phelan, John	U of Colorado
Shaefer, John	Schafer & Assoc.
Vignola, Frank	U of Oregon

CONCENTRATORS

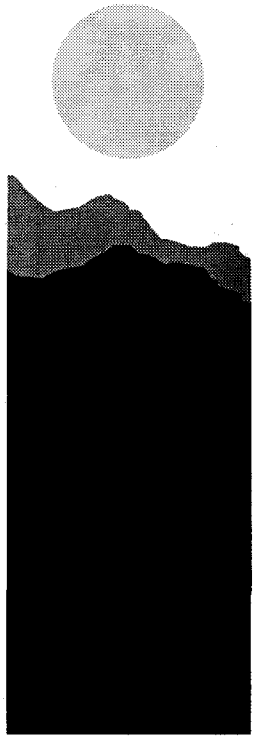
Appenzeller, Michelle	Consultant
Dacey, Jerry	Consultant
Fritsch, Bryan	Thermacore
Poulsen, Mark	Consultant
Stuffurn, Bill	Consultant

DISH/ENGINE

Beninga, Kelly	SAIC
Blackwell, Rod	SAIC
Bolin, Ray	Ray Bolin & Assoc
Borton, Dave	Consultant
Dolmier, Steve	Northern Power Systems
Gorman, Dave	Sustainable Energy Sys.
James, Robert	SAIC
Jamieson, Charles	Big Island Resource Conservation & Development
Johansson, Stefan	STU
North, Wilson	SAIC
O'Gallagher, Joe	U of Chicago
Ruff, Niel	STM
Skomak, Rachael	SAIC
Skowronski Mark	SCE
Smith, Pete	NRECA
Stine, Bill	Cal Poly
Stone, Ken	McDonald Douglas
Swanson, Dave	Kalina Circle Engine
Welch, Jim	STM
Williams, Dave	SAIC

GENERAL INFORMATION

Allen, Jerry	SNL
Benedict, Timothy	Tritech Inc.
Betton, Guy	RETI
Bielek, Tim	Consultant



Booth, Michael	E&R Corp
Burns, Bryan	SNL
Campbell, Jay	Allied Scientific
Chabot, Ernie	DOE/HQ
Conon, Gloria	SNL
Cooper, Robert	USAF
Coruy, John	Consultant
Dahl, Doug	NREL
DeNunzio, Lisa	DOE/HQ
Dohner, Jeff	Consultant
Durand, Steve	SWTDI
Eisenhood, Bill	KOB TV
Eley, Dave	SNL
Erdalli, Yucel	Marmara Research
Ford, Kim	SNL/TT
Gernadoz, Mike	Energy User News
Greulich, Frederick	SNL
Hague, Nabilah	DOE/HQ
Harkness, Tim	Consultant
Hughes, Bill	DOE/AL
Jenkin, Brown	SNL
Keane, Colleen	Tech Reps
Knorousky, Gerald	SNL
Lambert, Ken	PAL Engineering Services, Inc.
Leigh, Jerry	NMERI
Lewis, Abbey	Consultant
Luton, Wayne	Daggett Leasing Corp
Manakee, Ken	NM Ext. Service
McInteer, Bob	SNL/Video
Merritt, Ron	State of NM
Miller, Jamie	Gambrills, MD
Mooney, Dave	NREL
Nagar, Anna	Thermosol Equipments
O'Brien, Phil	Consultant
O'Chesky, Fred	State Senate
Otts, John	SNL/TT
Parker, Terry	Consultant
Peacock, Gary	Charlotte, NC
Riley, Ann	State Senator
Risser, Vern	Daystar
Roybal, Roderick	SNL
Rucker, Keith	Consultant
Selber, Jennifer	EPA
Sheinkopt, Ken	SEIA
Sherwood, Larry	ASES
Shsh, Amit N.	American Credit Corporation, Ltd.
Silver, Frank	Consultant
Stafford, Byron	NREL
Straubach Robert	Consultant
Tewnor, Bill	Jordon Energy
Tucker, Lesley	Consultant
Turton, Mike	Japan Economic Review
Watley, Roger	SNL
Wynn, Richard	Consultant
Yellowhorse, Larry	6612
Young, William E.	Merrit Island, FL

INDUSTRIAL PROCESS HEAT

Allegro, Joe	Inner Solar Roofing
Batalia, Tony	Army Corp of Engr.
Bergquam, Jim	Bergquam Energy System
Blummer, Robert	General Services Admin.
Brooks, Bobby	Sun Utility
Cordova, Adrian	Plains Electric
Edrol, Steve	Santa Fe A&E
Foltz, Ross	Foltz Engineering
Franey, Harry	CDC
Frasier, Hilda	Florida Energy Office
Gee, Randy	IST
Gregory, Diana	Florida Dept of Comm. Affair
Hamasaki, Les	Sun Utility Network
Harmon, Bob	Corps of Engineers
Harrison, John	FSEC
Hoshidi, Bob	Rockwell ETEC
Jane Hale, Mary	NREL
Kulkarni, Promod	CEC
Ortiz, Nestor	SNL
Palmer, Sharon	Seed International
Peebles, Craig	A&T
Proulx, Andrew	Consultant
Schuller, Phil	Pennsylvania Energy Office
Spearing, Pat	Thermo Max
Stein, Bill	Ft. Huarachua
Thomas, Susie	VA Energy Office
Thompson, Charlie	Thompson Assoc.
Welch, Julie	Arkansas Sci & Tech Authority
Wildin, Maurice	Analysis

INSOLATION

Bahm, Ray	Ray Bahm & Assoc
Bolluk, Phil	Ascencion Technology
Polanski, Ann	SEIA
Renae, Dave	NREL
Sockwell, Jimmy	U of Chicago

MODELING

Dunlop, John	SRRC
Fairchild, Chris	NMSEIA
Habert, Joja	Consultant
Klein, Sandy	U. of Wisconsin

SOLAR ABSORPTION COOLING

Erickson, Don	Energy Concepts
Gonzales, Jorge	U of Puerto Rico
Kakow, Burton	U of S. Florida
Kaylor, Bud	McDill AFB

SOLAR EDUCATION

Appenzeller, Michelle	Middleburg, Florida
Beck, Chirsteen	SNL/Educ
Benolt, D.	Barre, Vermont
Cooley, A.	Barre, Vermont
Gilbertson, Neil	SNL
Holley, Ken	SNL
Johnson, L.	Barre, Vermont
Ladas, Linda	SEIA
Milligan, B.	McIntosh Middle School Sarasota, Florida
Smith, Jeremy	High school student, Sevierville, Tennessee
Olsen, Kurt	SNL

SOLAR FURNACE

Chris Olson	SNL

SOLAR THERMAL SYSTEMS

Beer, Gino	Consultant
Bullock, Don	Texas Energy Office
Cabanillas, Rafael	U of Sonora
Cable, Bob	Kramer Junction Co.
Cohen, Gilbert	KJC
Cole, Howard	Porous Metal Prod.
Dawson, Dan	SNL/CA
Dutler, Derrick	Peco Gen
Fossum, Donna	CTI
Foster, Robert	NMSU
Frier, Scott	KJC
Gee, Randy	IST
Hertweek, Roy	SNL
Johnson, Brian	State of NM
Jurman, Ken	State of Virginia
Kanelloponlos, Sia	Full Circle
Kearney, Dave	KJC
Korpelus, Eric	Full Circle
Lawson, Steward	KJC
Lespron, Tony	Consultant
Machuca, Edwardo	CIEDAC
Markem, Chuck	AAA Solar
Mathis, Dianne	Harper Lake
McCracken, Horace	McCracken Solar
Mørner, Svein O.	Consultant
Pearlson, Richard	Consultant
Plympton, Patricia	EPA
Rodosovitch, Carol	PNM
Sivapalan, N., Dr.	Consultant
Wirdzek, Phil	EPA

SOLAR THERMAL TESTING

Beckman, Bill	U of Wisconsin
Delaplain, Gilbert	SNL
Drabka, Bob	MDAC
Edgin, Robert	Solar Ovens Inc.
Emmrich, Carol	FSEC
Fassino, Guido	Consultant
Gevnais, Bob	MDAC
Johnson, Dave	Antenna Engineering
Johonnson, Stefan	STM
Karnowski, Peter	SNL
Morgan, Phyllis	Redi Communication
Paridis, Leo	Raytheon Company
Thomas, Gary	Consultant

UTILITIES

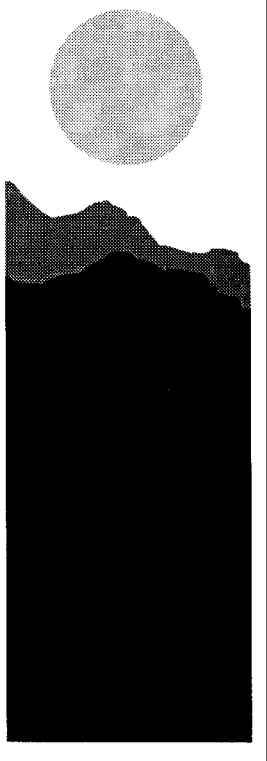
Bennett, Mark	Consultant
Fox, Lucien	Ogden Power
Harlon, Mark	PNM
McCononey, John	KJC
Montoya, Ben	PNM
Pinkston, Diana	APS

Major Milestones

Milestone	Planned	Actual
Participate in Soltech '94.	Feb 94	Feb 94
Document FY93 STDAC activities (SAND94-0257).	Mar 94	Mar 94

Resources

($k)	Sandia	NREL	DOE	Total
FTE Costs	582	35	0	617
Contracts	153	0	100	253
Total	735	35	100	870



E. SOLAR MANUFACTURING INITIATIVE

The objective of the Solar Manufacturing Initiative is to develop manufacturing technology and processes that will permit cost-effective deployments of solar thermal systems in low-volume, early commercial applications; to reduce uncertainty in the cost and reliability of key solar components in order to improve financing of early commercial systems and reduce the risk of performance warranties; to promote the development of system-level business plans and industrial partnerships linking manufacturing scenarios to commercial sales prospects; and to establish the manufacturing basis for achieving the substantial cost reductions possible through higher volume production.

The Solar Thermal Manufacturing Technology (SolMat) initiative is aimed at reducing the cost of solar thermal technologies in an environment of uncertain future sales and modest initial production volumes. In this way, SolMat will fill a critical need for allowing solar thermal manufacturers to produce cost-effective products even before market demand will support high volume production.

Accomplishments

NREL staff completed a solicitation package for "Heliostat Manufacturing for Near-Term Markets." This solicitation is the first under the new SolMat (Solar Manufacturing Technology) initiative. The intention of work to be performed under this solicitation is to develop heliostat production scenarios, heliostat costs, and market strategies consistent with near-term markets. The solicitation, which developed close coordination with the DOE/HQ and Sandia, was sent to NREL Subcontracts and should result in the release of Request for Proposal before May. A notice of the program in Commerce Business Daily in January resulted in letters of interest from approximately 20 companies.

Major Milestones

Milestone	Planned	Actual
Award contract on heliostat solicitation.	Aug 94	
Award contract on manufacturing improvement studies.	Sep 94	

Resources

($k)	Sandia	NREL	DOE	Total
FTE Costs	100	180	0	280
Contracts	0	1720	0	1720
Total	100	1900	0	2000

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.

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 and cost-efficient concentrator designs, optical materials development is also an important part of concentrator development.

1. HELIOSTATS

Accomplishments

Heliostat development activities are primarily associated with support of the Solar Two Project.

Top-level survey of the Solar Two heliostat field

Top-level survey results were reported for the Solar Two field. Sandia transmitted to Bechtel a letter report detailing the results of the top-level survey of the Solar Two heliostat field, as well as a copy of the survey database. Of the 21,816 facets in the original Solar One field, 1265 will require replacement because of missing facets, excessive corrosion, or severe cracking. A total of 523 motor leaks were identified, and 139 of the 1818 heliostats exhibited communication problems. In addition, many of the heliostats would not respond (i.e., would not drive) upon receipt of a command to do so. This occurred for a total of 421 azimuth drives and 428 elevation drives in the field. The survey results have proven valuable to Bechtel in estimating field repair costs.

Solar Two's field operational survey

Support was provided for an operational survey of the Solar Two field. Sandia provided on-site support for an operational survey of the Solar Two field, during which six heliostat strings were exercised for varying periods over a three week interval. Based on this field experience, it was determined that many of the drive problems identified during the top-level survey are because of the encoders. Of the encoder problems, roughly 65% were cleared up by simply cleaning and exercising the encoder connectors. The operational survey provided Bechtel important information with which to refine their estimates of field repair costs. The survey was also valuable in exercising new field heliostat controllers, or stimulators, being developed by Sandia for Solar Two. Numerous desirable enhancements and modifications to the current stimulators were identified.

Stimulator development

Requirements were identified for further stimulator development. Following the operational survey of the Solar Two field, a series of meetings and discussions were held between Sandia, Bechtel, SCE, and Advanced Thermal Systems, Inc. (ATS), the stimulator developer. The meetings were used to arrive at a project consensus on the final attributes desired for the new Solar Two heliostat field controllers (stimulators). A detailed statement of work based on the overall consensus was transmitted to Sandia purchasing for final negotiations with ATS. Work will commence during the next quarter.

Replacement glass facets tested at NSTTF

Replacement glass facets were tested on the Solar One heliostat at the National Solar Thermal Test facility (NSTTF). Two flat-glass facets from Carissa Plains were modified and then mounted adjacent to one another using progressively adaptable brackets on the NSTTF Solar One heliostat. The objective of the exercise was to demonstrate a reasonable approach for the replacement of missing Solar One facets, and to evaluate the resultant beam quality of the heliostat. Numerous assembly issues and recommendations were identified and transmitted to Bechtel. An internal Sandia

memo written by the testing organization described the beam quality of the following: (1) the unmodified heliostat (both before and after improved canting); (2) the heliostat following replacement of a single facet with flat glass; and, (3) the heliostat following replacement of two facets. This information will be transmitted to Bechtel in April.

Solar Two 95-m^2 heliostat tested at NSTTF

A LUGO-like heliostat with flat Carissa Plains glass was assembled and tested at NSTTF. Sandia has assembled and tested the beam quality of a LUGO-like heliostat tracker with 16 flat glass mirror modules from Carissa Plains. The heliostat was assembled with the individual modules in a horizontal orientation. Various assembly issues identified during the exercise were transmitted to Bechtel, along with a conceptual design of an assembly with the modules in a vertical orientation. Bechtel evaluated the information Sandia had provided, and determined that a vertical orientation for the modules would likely prove more economical for assembly at Solar Two. Preliminary beam quality evaluations indicate an acceptable performance for the heliostat in the horizontal configuration. Performance in a vertical configuration is expected to be equal or superior to the horizontal configuration. An internal Sandia memo describing the observed beam quality has been written by the testing organization. This information will be transmitted to Bechtel in April.

Temperature-curvature effect evaluated

The temperature-curvature effect for the flat Carrizo Solar glass has been evaluated. A draft memo describing the temperature-curvature relationship for two Carissa Plains glass facets (measured in an environmental chamber) is in progress, and will be released in April.

Planned Activities for Next Quarter

- Complete and release letter report describing the beam quality observed in the NSTTF Solar One heliostat with flat glass replacement modules.
- Complete and release letter report describing the beam quality observed in the LUGO-like heliostat with horizontally-configured Carissa Plains flat glass mirror modules.
- Complete and release memo on the temperature-curvature data for the Carissa Plains flat glass facets.
- Provide recommendations for Solar Two beam characterization system to Bechtel.
- Determine appropriate canting procedures for Solar Two heliostats, both existing and added.
- Conceptualize advanced heliostat RFP.

Major Milestones

Milestone	Planned	Actual
Complete report on the dual-module, stretched-membrane heliostat.	Dec 93	Dec 93
Complete evaluation of facet replacement for Solar Two using flat Carrizo Solar glass. (Final report in progress.)	Jan 94	Mar 94
Complete evaluation of a LUGO heliostat with flat Carrizo Solar glass. (Final report in progress.)	Mar 94	Mar 94
Release RFP for advanced heliostats.	Aug 94	

Resources

($k)	Sandia	NREL	DOE	Total
FTE Costs	234	0	0	234
Contracts	250	0	0	250
Total	484	0	0	484

2. PARABOLIC DISHES

Accomplishments

Dish development activities were greatly reduced this quarter because it was necessary to reassign concentrator resources to higher-priority heliostat activities in support of the Solar Two project. To a certain extent, this situation will continue for the coming quarter as well.

SAIC faceted stretched- membrane dish

The facets on the faceted stretched-membrane dish have been realigned to a focal length of 9.9 meters from their original, design focal length of 9.0 meters to accommodate a design revision incorporated by SAIC into their concentrator for use in the Utility-Scale Joint-Venture Program. The solar concentrator will be tested during the next quarter.

Single-element dish design to be evaluated

Initial discussions have started with Solar Kinetics (SKI) to determine an appropriate, mutually-acceptable statement of work for follow-on activities for the single-element, stretched-membrane dish project. A Request for Quotation (RFQ) for this activity should be released to SKI during the next quarter.

Planned Activities for Next Quarter

- Perform calorimetry and flux mapping of the SAIC facets at the longer focal length.
- Install elastically-formed, SKI facets on the faceted stretched-membrane dish, align facets, and begin flux mapping and calorimetric testing.

Major Milestones

Milestone	Planned	Actual
Complete testing of the faceted stretched-membrane dish with plastically-formed facets (delayed due to Solar Two heliostat testing).	Mar 94	
Place a contract to further evaluate and analyze the single-element, stretched-membrane dish.	Apr 94	
Place several small contracts to evaluate advanced dish concentrator concepts.	Jun 94	

Resources

($k)	Sandia	NREL	DOE	Total
FTE Costs	324	0	0	324
Contracts	180	0	0	180
Total	504	0	0	504

3. OPTICAL MATERIALS

Accomplishments

Optical materials commercialization support role

Under a collaborative cost-shared subcontract between the National Renewable Energy Laboratory (NREL) and the 3M Company, a commercial version of ECP-305+ is being developed. During accelerated exposure testing, ECP-305+ has demonstrated dramatically improved resistance to corrosion and delamination failures compared to other silvered polymers. Based on results of accelerated weathering tests, NREL believes the ECP-305+ could have an effective lifetime of 10 years or more in good environments.

Although this new material is promising, commercial deployment is risky for the solar industry because of the uncertainties involved in accelerated testing. To overcome these problems, NREL has initiated two new activities to accelerate commercialization. The first activity is demonstrating manufacturability of new materials. The goal of this activity is to develop and demonstrate commercial production processes for new materials, and then rapidly gain field experience with the materials. In the first experience of this type, NREL has contracted with 3M to produce a commercial run of ECP-305+. The film is then provided at no cost to solar companies for demonstration and testing purposes at different sites. In this way, the solar industry can gain experience with the film with minimal risk.

The second planned commercial support activity is a limited 50/50 cost share offer for solar companies who want to use new optical materials in commercial projects. The offer will be applicable to modest size projects to reduce the risks of early commercial deployments, and will assist companies in gaining experience with the materials in commercial project environments. The Solar Industrial program plans to provide a similar offer to manufacturers of solar heat concentrators.

ECP-305+ test deployments

Under subcontract with 3M, the first commercial production of ECP-305+ will be demonstrated. NREL expects delivery of roughly 2250 m^2 of this product by mid-April 1994. NREL has agreed to provide the following quantities of ECP-305+ to interested solar manufacturers for field deployment/demonstration purposes:

Quantity of ECP-305+

Company	Project	(m^2)	Time Frame
Cummins Power Generation JVP	Dish/Stirling USJVP	720	Spring 1994
Industrial Solar Technology	Brighton, Colorado, Refurbish-ment	540	Summer 1994
Science Applications International Corporation	Solar Two; USJVP	90-180	1995
United Solar Technology	California Energy Commission	18-27	Spring 1994

These cooperative efforts dramatically demonstrate an effective interaction (aimed at commercialization of solar thermal electric systems) between NREL, the solar manufacturing community, and the polymer film/metallization industry (3M).

Commercial deployment of ECP-305+

Industrial Solar Technology (IST) has announced plans for a commercial solar heat project using ECP-305+ as the reflective surface for a parabolic trough. The project would deploy approximately 630-m^2 of troughs to provide hot water for a Colorado prison. The project is currently being reviewed by the prison decision makers and is seeking financing from investors. If the project proceeds, it will mark the first commercial deployment of ECP-305+.

Advanced solar reflector concepts

Eight proposals for "Advanced Reflector Materials Research and Development" were received in response to a request for proposals (RFP) whose scope of interest included cost-shared, collaborative development of advanced reflector materials themselves; improved cleaning techniques and anti-soiling strategies for such material systems; and development of general methods for accurate service

life prediction of solar reflectors. On the basis of technical merit and cost, two of the eight proposals will be funded. One proposal deals with deposition of a wear-resistant protective layer onto silvered PET (polyethylene terepthalate) film. The second proposal extends previous efforts at developing a silvered fluoropolymer mirror. The RFP was intended to capture new opportunities and innovative concepts, and to fill in gaps in the technology that are believed to be critical to the ultimate success of competitive commercial reflector products.

Coating for solar reflector materials

Samples of polyester films having several formulations of an innovative top UV-protective coating were received from Monsanto Co. of St. Louis, Missouri. Metallized polymer film solar reflectors must incorporate some form of protection against terrestrial solar UV radiation to allow optical durability in outdoor service conditions. Typically, UV absorbers are incorporated into the bulk polymer film to provide stability, but this approach does not work with all polymers. Monsanto's technology uses a thin (0.5-2 micron) UV-absorbing, visibly clear top coating (tradenamed Sorbalite) to protect the film. Such a coating could allow the use of less expensive polymer films (such as polyester) for solar reflector applications. NREL has deposited a silver reflective layer on the back side of these materials, performed initial optical characterization of the resulting mirrors, and has begun accelerated exposure testing of these samples. Unweathered solar-weighted hemispherical reflectance measurements of some samples exceeded 90%.

Outdoor testing

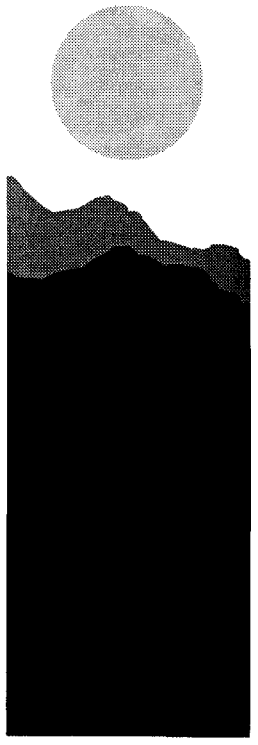
A DOE Solar Thermal Electric Program milestone titled "Initiation of Outdoor Materials Testing at Fourth Site" was successfully completed. This milestone was scheduled for completion in March 1994. Meteorological monitoring equipment was installed and activated, and candidate reflector material samples were deployed, at an outdoor exposure test site in Abilene, Texas. Operation of this site is a cooperative effort between Cummins Power Generation (CPG) and NREL. The staff at CPG have demonstrated a keen interest in this project and worked hard in assisting NREL to meet this milestone.

Industrial Contacts

CONTACT	ORG.	COMMENTS
B. Benson	3M	Alternate reflectors
C. Bernetevich	Foster-Wheeler	Conductive polymers
B. Butler	SAIC	Alternate reflectors
D. Dahlen	3M	Alternate reflectors
M. Featherby	SAIC	Alternate reflectors
R. Gee	IST	Alternate reflectors
W. Horne	EDTEK	Reflector materials
D. Keenan	Sheldahl	Alternate reflectors
P. Kelly	UST	Reflector materials
K. May	IST	Selective absorbers
K. Mohror	AZ CEC	Reflector materials
H. Razavi	Monsanto Co.	UV absorbing coatings
W. Schrenk	Dow Chemical	Alternate reflectors
P. Soliday	CPG	Alternate reflectors

Planned Activities for Next Quarter

- Negotiations will begin with two industrial partners who have proposed cost-shared development of advanced solar reflectors.
- A fifth outdoor test site will be activated at Barstow, California.
- 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.



Major Milestones

Milestone	Planned	Actual
Issue Request for Proposal (RFP) for additional alternative reflector R&D.	Feb 94	Nov 93
Activate fourth outdoor test site (Abilene, Texas).	Mar 94	Mar 94
Activate fifth outdoor test site (Barstow, California).	May 94	
Document status of outdoor testing activities.	Jun 94	
Document alternative reflector materials R&D progress.	Aug 94	

Resources

($k)	Sandia	NREL	DOE	Total
FTE Costs	0	890	0	890
Contracts	0	500	0	500
Total	0	1390	0	1390

B. POWER CONVERSION

Power conversion development efforts synchronize R&D activities with the needs of users, expanding the availability of resource data and improving system performance. Power conversion systems for both dish/engine systems and power tower systems are tested at Sandia's National Solar Thermal Test Facility (NSTTF). 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 the Central Receiver Technology program is to advance the development and commercialization of central receiver technologies. This work will mitigate risk of central receiver systems, support industry and utility concerns by conducting research on new concepts, and perform testing and analysis of components and procedures. The following are key tasks within this activity: (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 quarter include continued testing of molten-salt freeze/thaw panel tests, photometer transient experiments for feed-forward control of the receiver, continuation of the thermal shock tests, and completion of the molten-salt thermal cycling corrosion tests.

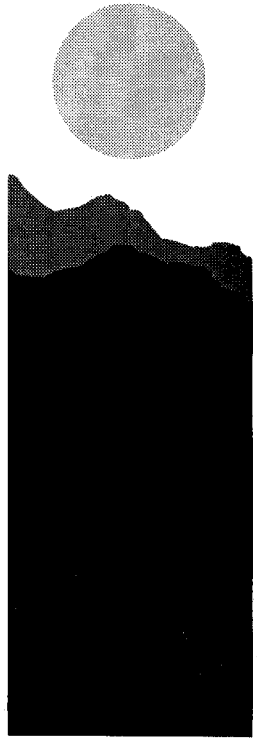
Freeze/thaw panel experiments

Experiments were conducted to measure the effects of thawing a panel that was frozen full of nitrate salt. In a molten-salt central receiver, a panel can become frozen with salt if a drain valve fails to open during the nightly shut down. The 60%-sodium/40%-potassium nitrate salt has a freezing point of approximately 430°F and expands about 4.6% by volume upon melting. A major concern with thawing a panel is when the panel is heated in the center with frozen plugs on each end, the salt will expand in the heated zone causing yielding of the receiver tubes.

We have conducted two freeze/thaw cycles on the panels installed in Sandia's molten-salt loop. In each case the panels were filled with molten salt and allowed to freeze. The heat trace on the headers and jumper tubes kept them above the freezing point. It took approximately 25 minutes to freeze the salt in the panel and cool its temperature to below 200°F. After the drain valve was opened to allow liquid salt out of the headers and jumper, heliostats were used to melt the salt by heating the panel from the bottom where we believed there was an air/salt interface. After freezing and thawing the panel twice, we measured the tube diameters and compared them to the pretest values. Every tube experienced some yielding, which resulted in a permanent strain from 1% to 4%. In the design of commercial central receivers, permanent deformation due to thawing should be accounted in the life time prediction.

Analysis of freezing in piping

"Cold filling" of piping refers to starting flow of a liquid through piping that is below the freezing point of the liquid. In a molten-salt central receiver plant, considerable electricity could be consumed if all the lines have to be kept above the salt freezing point with heat trace, especially during extended shut downs. If the lines could be filled while they are cold, the parasitic electrical load could be reduced and the plant start-up times could be cut considerably. Two concerns with cold filling the piping are (1) how far the salt can flow before freezing the line shut (penetration depth), and (2) the piping stresses induced during this thermal shock.



Some analysis has been done to address the first concern using an empirically based correlation from the literature. For large diameter piping, such as used with the riser or downcomer of Solar Two, we could theoretically flow through thousands of feet of piping at full flow. In a commercial-scale plant, we may be able to flow

through *miles* of cold riser or downcomer piping. See Table 1.

To determine if this correlation is consistent with experience we have had in molten-salt systems, we compared results of the analysis to those obtained from our recent panel experiments and those from the Molten-Salt Electric Experiment (MSEE). In our recent molten-salt panel experiments, we were able to flow through all four passes of the panels that were at ambient temperature with the salt flowing at 0.6 m/s. The total length of piping is about 18.3 meters. The correlation predicts the fluid should freeze in about 15.24 meters. This means we were probably on the border of freezing.

In one of the reports on MSEE, experiments were described where the receiver was started cold (below the salt freezing point). In two cases, the panel was successfully filled, but in one case it was partly frozen. The correlation predicted that salt would have barely made it through (freezes in 4.27 meters, whereas the panel height is about 3.66 meters), which is consistent with the results of the test. For the Rockwell receiver, the correlation predicts the receiver should be above 200°F to flood fill the receiver at the design flow. We plan to validate this correlation through further experiments with our panel next quarter.

Tests with photometers

Experiments with photometers continued this quarter to measure the transient response of photometers relative to flux gages. These tests are being conducted to determine if photometers can be used to measure flux on a central receiver to provide feed-forward control of the molten-salt flow. The impetus for this investigation is to determine if there are more reliable, lower cost alternatives to flux gages that are easier to maintain. Photometers should cost less to maintain and should be more reliable. Experiments were conducted with a glycol-cooled panel mounted on the solar tower of the National Solar Thermal Test Facility.

Results showed the photometers responded as fast or faster than flux gages, which are more than adequate for receiver application. There are a few issues that should be addressed before photometers can be relied upon for receiver control. Results for our photometer experiments were presented at the 1994 American Society of Mechanical Engineering (ASME) International Solar Energy Conference and the Solar Two receiver kickoff meeting. Rockwell, the receiver vender for Solar Two, was enthusiastic about these results and is very interested in integrating photometers into the receiver control system.

Table 1. Penetration depths for molten salt for various pipe diameters, velocities, and salt inlet temperatures for a wall temperature T_W = 20°C.

Diameter (in.)	Flow Velocity (m/s)	Salt Inlet Temperature	Penetration Depth
0.75	3	288°C (550°F)	39 m (129 ft)
0.75	1	288°C (550°F)	17 m (57 ft)
0.75	1	371°C (700°F)	27 m (87 ft)
1.5	3	288°C (550°F)	132 m (435 ft)
1.5	1	288°C (550°F)	58 m (191 ft)
1.5	1	371°C (700°F)	90 m (294 ft)
6	3	288°C (550°F)	1498 m (4920 ft)
6	1	288°C (550°F)	657 m (2160 ft)
16	3	288°C (550°F)	8340 m (27400 ft)
16	1	288°C (550°F)	3660 m (12000 ft)

Component thermal shock tests

Hardware such as flanges and check valves proposed for implementation into the Solar Two molten-salt system is being tested in a molten-salt loop at the National Solar Thermal Test Facility to verify the use and reliability of these components. We have conducted 25 thermal shocks of four types of flanges by flowing 550 °F salt through them while they were at approximately 300 °F and 25 shocks with the components at 100 °F. In addition, a total of 280 slow thermal cycles (typical of overnight shut down and cooling) has been completed by the end of this quarter. The flanges have neither experienced leaking nor have they failed.

Corrosion tests

Tests to determine if thermal cycling exacerbates the corrosion of 304 and 316 stainless steels in molten-nitrate salt at 560 °C have been successfully completed. The tests demonstrated that thermal cycling is not a factor even for the most impure grades of salt. As a result of the test, we identified corrosion allowances and specifications for the concentrations of impurities in the salt. We were able to relax the constraints on salt impurity levels to the point where the Solar Two project should realize substantial savings in the purchase of salt. We presented these findings at the recent International ASME Solar Energy Conference.

The isothermal experiments to determine corrosion rates on chromium-molybdenum containment alloys for the steam generator are continuing. Three different materials have been exposed to three different salt mixtures at 454 °C for 3700 hr, which corresponds to about 1.5 yr of operation of Solar Two. The materials tested are 9-Cr, 1-Mo and 2¼-Cr, 1-Mo steel alloys. The 9-Cr, 1-Mo is being tested at two silicon levels. Corrosion is very slow for all materials in each salt mixture except 2¼-Cr, 1-Mo. This alloy is severely corroded in a salt mixture that has a high chloride concentration. Also, silicon seems to inhibit corrosion. Our preliminary conclusion is that corrosion will not be an issue on the salt side of the steam generator if it is made of the 9-Cr, 1-Mo alloy. These tests will continue.

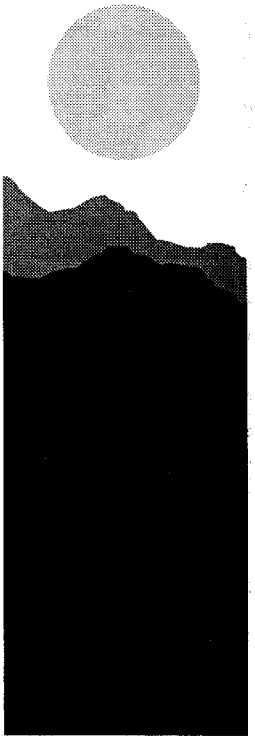
1994 ASME International Solar Energy Conference

The 1994 American Society of Mechanical Engineering International Solar Energy Conference was held concurrently with the Industrial Power Conference March 28-30 in San Francisco, California. The Solar Energy Conference consisted of 83 papers presented in 21 sessions including two sessions on central receivers. All the Solar Thermal Power sessions were well attended, attracting many more new attendees (particularly from the Industrial Power Conference) relative to previous years. James Pacheco, James Chavez, Gregory Kolb, and Michael Prairie from Sandia each presented a paper in the Central Receiver sessions.

One paper in particular, *Value of Solar Thermal and Photovoltaic Power Plants to Arizona Public Service (APS) Company,* by Paul Smith of APS was of interest to central receiver technology because it described the value of load-following to meet actual utility electricity demand profiles.

Planned Activities for Next Quarter

- Complete the isothermal corrosion test on the steam generator materials.
- Begin documentation of photometer and flux mapping tests.
- Conduct further molten-salt loop panel and component tests.
- Complete the final report on the testing of the volumetric receiver absorber at NMSU.
- Prepare a final test report for the Sandia/Bechtel absorber test.
- Continue the installation of the RAS (internal film receiver) at the Plataforma Solar de Almeria.



Major Milestones

Milestone	Planned	Actual
Complete testing of the Bechtel volumetric air receiver at the Plataforma Solar (FY93 carryover milestone).	Jun 93	Oct 93
Publish a report on the testing of the Bechtel volumetric air receiver.	Nov 93	Nov 93
Complete the planned thermal cycling corrosion testing of Stainless Steels and 4000-hr static molten-salt corrosion tests of Cr-Mo materials.	Mar 94	Mar 94
Complete planned tests of the molten-salt components and of the receiver panel on the molten-salt loop.	Apr 94	
Initiate testing of 500-kW_t RAS molten-salt internal film receiver at the Platforma Solar de Almeria.	Apr 94	
Complete the planned testing of photometers for measuring global flux on receivers.	Sep 94	

Resources

($k)	Sandia	NREL	DOE	Total
FTE Costs	540	0	0	540
Contracts	489	0	0	489
Total	1029	0	0	1029

2. DISH RECEIVER TECHNOLOGY—

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

Accomplishments

Two promising advanced wick structures are under development and test for application to future heat pipe receivers, particularly in support of the joint venture programs. Sandia's improved receiver wick modeling capabilities were used to evaluate options for Cummins. Additional limit testing of the Cummins 36-kW_t receiver was performed on Sandia's Test Bed Concentrator. The next-generation Thermacore 75-kW_t heat pipe fabrication is on hold until wick properties are improved. The pool boiler on-sun testing final report was completed and is in review. Post-test analysis of the bench-scale durability pool boiler is underway. Sandia is assisting Science Applications International Corporation in the design of a pool boiler for application to the joint venture program.

Metal felt wick materials

Felt metals are now being explored as a potential wick structure for a solar receiver. Felt metals are typically made with fine fibers (≈10μm) that are loosely laid down to form a mat with a high porosity. Felt metals are commonly used in filtration applications. In an unsintered state, felt metals are extremely pliable so they can easily conform to the shape of a receiver dome.

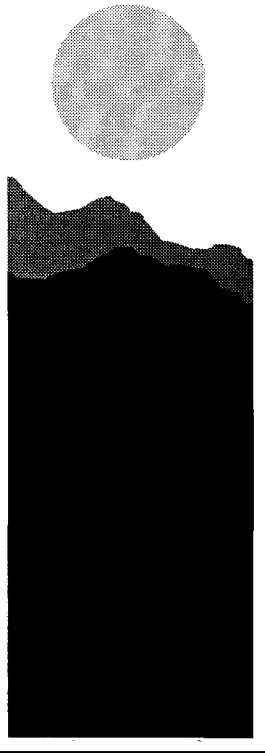
Preliminary tests were performed on samples from Bekaert Fibre Technologies to determine the metal felt's permeability and effective pore size. The material can be compacted to alter the pore radius and permeability. Figure 2 shows the range of properties that can be obtained by selectively compacting the felt metal material. Tests on the Bekaert samples indicate that the wick properties of these metal felts could be several times better that any of the wick materials that have been tested to date. For comparison, a standard metal powder frit, such as the one used in Cummins' current receivers, the permeability is on the order of 20 microns^2 and the pore radius is about 60 microns. (To improve a wick design, the permeability must increase and the pore radius must decrease.)

Several felts metal samples have been sintered in Sandia's hydrogen oven. After sintering, the felts were found to form a good bond with stainless steel and Haynes 230 substrate materials. The felts tend to stiffen on sintering making them more durable, and they also shrink somewhat, which could aid in pressing the material to the convex surface of a receiver dome to improve bonding.

A contract has been placed with Howard M. Cole Porous Metal Products (PMP) in Jacksboro, Texas, to develop a receiver with a felt metal wick. PMP has received domes for the construction of the receivers; they have also made several sintering runs to develop the techniques for bonding the felt metals to substrate materials. Sandia met with Howard Cole to kick off a development program for the felt metal wick structure. Pete Dussinger of Thermacore Inc. also attended. Porous Metal Products will develop a wick structure on a dome for delivery to Sandia and Thermacore.

Friction Coating Inc. brazed powder wick

Sandia models of potential wick designs were used to select the most promising wick structure from samples provided by Friction Coatings Inc. last quarter. Friction Coatings Inc. demonstrated the application of the selected wick structure to a small (5-inch diameter) sample dome. After the application process was fully developed, Sandia delivered several full-size Cummins-style domes to Friction Coatings Inc. Friction Coatings Inc. is currently awaiting the manufacture of an assembly mandrel for the full-scale domes. Development of the appli-



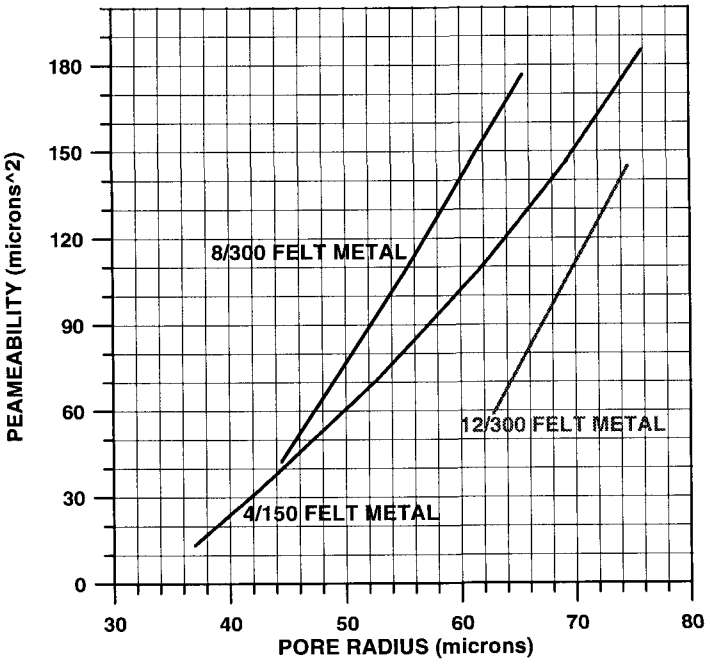


Figure 2. Wick properties available from felt metal materials. (As the materials are compacted, the permeability and pore radius decrease. The material designator, 8/300, refers to a material that has a 8-micron wire diameter and a felt weight of 300 grams per square meter.)

cation process took longer than expected. A completed dome is expected to be delivered to Sandia in May.

Cummins 36-kW$_t$ heat-pipe receiver successfully limit-tested at Sandia

The Cummins 36-kWt heat pipe receiver was tested for 3 additional days on Sandia's Test Bed Concentrator (TBC-1). The purpose of the test was twofold. First, the limit test would increase confidence in the Cummins design. In addition, the results could be directly compared to the Sandia/Thermacore wick model for model calibration. The same receiver was previously limit tested at Sandia with limited success in December. The difficulties in December were traced to a de-primed artery, caused by harsh test procedures.

The receiver power input and throughput was ramped up over the three-day test to find the throughput limit of the current receiver. On the third test day, the receiver was subjected to the full TBC-1 dish power from sunrise, using the natural insolation ramp to increase power. The receiver demonstrated successful operation at 56-kW$_t$ throughput with 67-kW thermal input from the dish. **This is a new record for on-sun heat-pipe receiver throughput**. The thermal losses were high because a wide open aperture was used, allowing receiver protection with an infrared (IR) camera. The throughput was limited by the dish power and the calorimeter capabilities, both of which reached their limits while the receiver continued to operate.

Sandia's model predicts that the receiver throughput at steady state should be 63 kW$_t$. This power could not be reached with the current equipment. Cummins and Thermacore attended the testing, and were quite pleased with the results and Sandia's responsiveness. The receiver was delivered to Sandia late on February 7, and was on sun by February 9 to coincide with the USJVP kickoff meeting.

The receiver exhibited some difficulties during startups on the first two days of testing. These difficulties appear similar in nature to those seen on the 75-kW$_t$ heat pipe. Thermacore saw similar problems with this receiver on their lamp-fired test. Sandia has proposed that hydrogen, generated from residual water in and on the surface, combines to form sodium hydrides at low temperature. As the temperature is increased during startup, the hydrides, now present in the wick, rapidly release the hydrogen, causing local dryouts. The decomposition pressures of the hydrides are significant at the heat-pipe operating temperatures. The free hydrogen is swept to the condenser section during heat pipe operation, where it does not have opportunity to re-combine with the sodium pool. Upon cooling down and freezing, the hydrogen readily re-forms the hydrides in the pool and wick. Sandia backed up this theory with data from other unrelated tests and literature.

Sandia has reviewed Thermacore's filling and processing procedures, and have advised Cummins to change the procedure to eliminate trace water in the system. Cummins has acquired a turbo-molecular vacuum pump and Residual Gas Analyzer, and will use them to develop a new processing procedure at Thermacore. This procedure will likely involve a high-temperature bakeout of the completed receiver prior to the introduction of sodium. Sandia will retest the 36-kW$_t$ heat pipe after Thermacore operates it for at least 500 hours. This time-at-temperature will tend to drive the hydrogen out of the system, as seen on the artery-free device.

Artery-free receiver

On-sun operation of the Cummins/Thermacore artery-free receiver continued on a regular basis throughout the quarter. **Cummins has accumulated 1000 hour operation on-sun with this receiver**. The receiver continues to operated without difficulties or maintenance. Operation will continue based upon dish availability. Thermacore developed an artery-free receiver design for application to the Dish/Stirling Joint Venture Program (DSJVP) project. This has the potential of reducing the receiver costs significantly.

Cummins 75-kW_t heat-pipe receiver

Cummins is developing a 75-kW_t heat-pipe receiver under contract with Sandia. The receiver will be applied to the STM engine package after direct-illumination testing is completed. The receiver is based upon existing wick technology used on the 36-kW_t receiver. All of the receiver parts are available awaiting final assembly. Final assembly is awaiting demonstrated improvements in the wick permeability. The limited permeability has been blamed on differential thermal expansion between the absorber and the sintering mandrel, and has been seen on the 36-kW_t receiver as well. New mandrels have been fabricated for both receivers, and a practice sinter has been performed with the 36-kW_t dome. The resulting wick was being prepared for permeability analysis at the end of the quarter. When good permeability is demonstrated, the receiver will be completed and delivered for test.

Nickel wick mechanical properties

An effort is underway to determine the strength requirements of a Thermacore-type thick nickel wick. This is in support of (1) Sandia's collaboration with Thermacore to develop a 75-kW_t heat-pipe receiver and (2) the Dish/Stirling Joint Venture Program. In the present period, mechanical properties of a representative wick have been measured, finite-element stress analysis has been performed, and a contract for creep characterization has been issued.

The room-temperature-wick yield strength, ultimate tensile strength, fracture strain, and elastic modulus are all on the order of 10% to 20% of wrought-nickel values. We have scaled accordingly the temperature-dependent wrought-nickel elastic modulus in our finite-element stress analysis. Predicted stresses in the wick of a prototype heat-pipe receiver are near the measured value for yield at room temperature. While they are compressive, reversal probably will occur as a result of creep. Repeated tensile cycling of this magnitude could lead to early fatigue failure. To address this scenario, a contract has been issued to creep-test nickel-wick samples at elevated temperature, and a total of 18 samples have been wire-EDM cut from the first Sandia/Thermacore 75-kW_t heat-pipe receiver.

Bench-scale pool-boiler receiver durability test

The durability bench-scale pool boiler developed a very small leak at a condenser thermowell after **about 7500 hours total lamp-on time**. The recorded behavior was normal until the last 12 hours of operation. The leak symptoms were (1) decreased boiler thermal-power throughput and (2) a single lower-than-normal indicated temperature. The internal pressure was near-normal, indicating that very little air leaked into the boiler. The test was operator-terminated, the test vessel was drained, and the residual liquid metal was distilled out under vacuum. The vessel was sectioned and metallurgical examination has started.

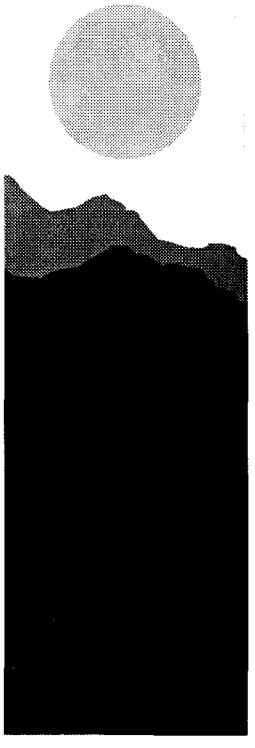
Initial results of the metallurgical examination are encouraging, although it must be kept in mind they are tentative. As suspected, the leak is in a material and in a boiler feature (the IN600 thermowell) that would not be part of a commercial receiver. Equally important, the condition of the Haynes Alloy 230 and the heated-surface powder-metal coating appear to be good. Some surface recession and grain-boundary grooving of the Haynes Alloy 230 are apparent, but appear to be slight. Better characterization will be possible after completion of cross-sections and analysis of NaK for Haynes Alloy constituents. It is expected that sufficient information will be available by the end of April for completion of a paper on this subject to be presented at the Intersociety Energy Conversion Engineering Conference this summer.

TBC controls and safety upgrades

The specification for the control system upgrade for the Test Bed Concentrators (TBCs) has been finalized. The Request for Quotation (RFQ) will be published in the Commerce Business Daily early in the next quarter.

Hybrid receivers

Stirling Technology Company (STC) of Richland, Washington, has been under subcontract to NREL since April 1992 in a two-phase program to demonstrate the



feasibility of a 10-kW_{th} hybrid liquid-metal pool-boiler receiver for dish/Stirling application. During burner testing on January 22, a problem with the burner resulted in burn through of the porous metal burner surface and significant damage to the burner subsystem. STC performed a detailed investigation and concluded that the most likely failure mode was an elongated screw hole in the porous burner matrix. The screw hole was one of several used to hold the burner matrix in place. The small opening (about 1 mm in diameter) created by elongation of one of the screw holes, allowed the flame to propagate backwards to the upstream side of the matrix and into the recuperator where temperatures in the range of 1000 °C to 1300 °C resulted. This severely damaged the burner outer shell, parts of the burner matrix, and part of the recupertor. Temperatures on the boiler side of the matrix actually dropped from about 775 °C to about 650 °C as the flame moved upstream; for this reason, there was no damage to the boiler. The investigation has shown that the burner design is fundamentally sound, although most of the burner must be rebuilt. Work is underway to make these repairs and the boiler should be back in operation by April. On-sun testing has now been set for late June.

Cummins Power Generation (CPG) has resumed work on their hybrid heat-pipe subcontract and has brought their contract up to date by submitting past-due monthly reports. CPG has assigned a new project manager to their hybrid work who should be able to facilitate CPG's efforts in the future. CPG is planning to start on-sun testing in July.

Planned Activities for Next Quarter

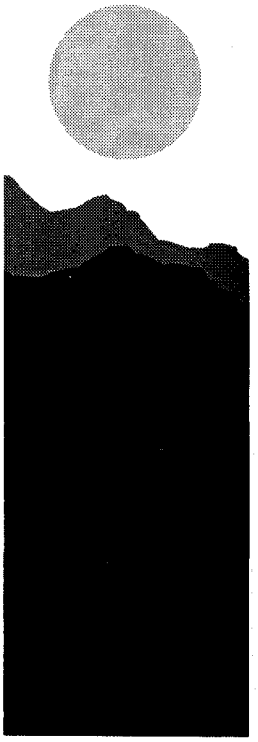
- The metallurgical examination of the durability bench-scale pool boiler will continue. Most of the results are expected early in the quarter, and the findings will be presented at the IECEC this summer.
- The creep characterization for the Thermacore thick nickel wick will be completed.
- A bench-scale receiver is being constructed to determine the performance of the Porous Metal Products felt-metal material in a sodium heat pipe. Test results from the bench-scale system should be available in the 3rd quarter of FY94.
- Friction Coatings Inc. and Porous Metal Products are both expected to deliver domes in the next quarter. Both of these domes will be sized for incorporation into a Cummins 36-kW_t heat-pipe receiver. Sandia will measure the as-fabricated wick properties. Any dome suitable for incorporation into a receiver will be delivered to Thermacore if so requested by Cummins.
- 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 STM heater heads. Sandia will complete the interface design and prepare the heater heads and fixture for attachment to the receiver.
- Cummins will continue to test the artery-free heat-pipe receiver in Abilene, Texas, as dish availability permits. In addition, operation of complete systems in Abilene and Lancaster, Pennsylvania, will continue to accrue hours on full-scale heat-pipe receivers. Cummins will also return the 36-kW_t heat-pipe receiver to Sandia for further limit testing on the Test Bed Concentrator.
- Sandia will continue supporting receiver development for the joint venture programs. This includes product improvement for the DSJVP with Cummins, advanced heat-pipe design for the Cummins USJVP, and pool-boiler design support for the SAIC USJVP. The pool-boiler support will include additional testing of the second-generation pool boiler near the summer solstice.
- A contract will be awarded for the TBC controls upgrades.

Major Milestones

Milestone	Planned	Actual
Complete 500 hours testing on CPG artery-free heat pipe.	Oct 93	Oct 93
Complete evaluation of relustered TBC-2.	Dec 93	Dec 93
Complete 1000 hrs testing on CPG artery-free heat pipe.	Feb 94	Mar 94
Complete fabrication of Friction Coatings wick on a dome suitable for incorporation in a heat-pipe receiver.	Mar 94	
Complete durability bench scale reflux receiver test.	Apr 94	Jan 94
Begin on-sun testing of STC hybrid pool-boiler receiver.	Apr 94	
Complete planned on-sun testing of Cummins/Thermacore second-generation 75-kWt heat-pipe receiver.	May 94	
Begin on-sun testing of Cummins/Thermacore hybrid heat-pipe receiver.	Sep 94	
Complete controls and safety upgrades on Sandia's TBCs.	Sep 94	
Complete on-sun testing of a Sandia-designed heat-pipe receiver.	Sep 94	
Develop statement of work for a 2nd-generation hybrid receiver.	Sep 94	

Resources

($k)	Sandia	NREL	DOE	Total
FTE Costs	827	175	0	1002
Contracts	862	250	0	1112
Total	1689	425	0	2114



3. DISH CONVERTER SOLARIZATION—

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 system

A project is currently underway with Northern Research and Engineering Corporation (NREC) to solarize and test a Brayton cycle PCS. (See Figure 3.) 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 Aerospace Research Establishment (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 system's 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 a 30-kWe Brayton PCS. The result will be a fully evaluated Brayton system that could potentially be used in the Utility Scale Joint Venture Program (USJVP).

Phase 1 of the NREC project is proceeding on schedule. The economic model being developed at Sandia with input from NREC, DLR, and WG Associates has been completed. Further, the preliminary economic analysis has been performed. This analysis indicates that a dish/Brayton power system is very cost-competitive with a dish/Stirling power system. This analysis will be finalized early next quarter.

Based on the presentation that NREC gave Cummins Power Generation, Inc. (CPG) last quarter on the applicability of their 30-kWe engine to the Utility Scale Joint Venture Program (USJVP), CPG has decided to include the engine as back-up to their baseline Stirling engine/heat pipe receiver.

Stirling cycle power conversion system

Phase 1 of a cost-shared project with Detroit Diesel (DDC) and its sub-contractor, Stirling Thermal Motors (STM), is complete. This project (see Figure 4) 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).

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 1 consists of system checkout and debugging. Power and temperature levels started out relatively low (600 °C). Two of the specific objectives of this phase are 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 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 reinstalled and the engine will be operated at full input power.

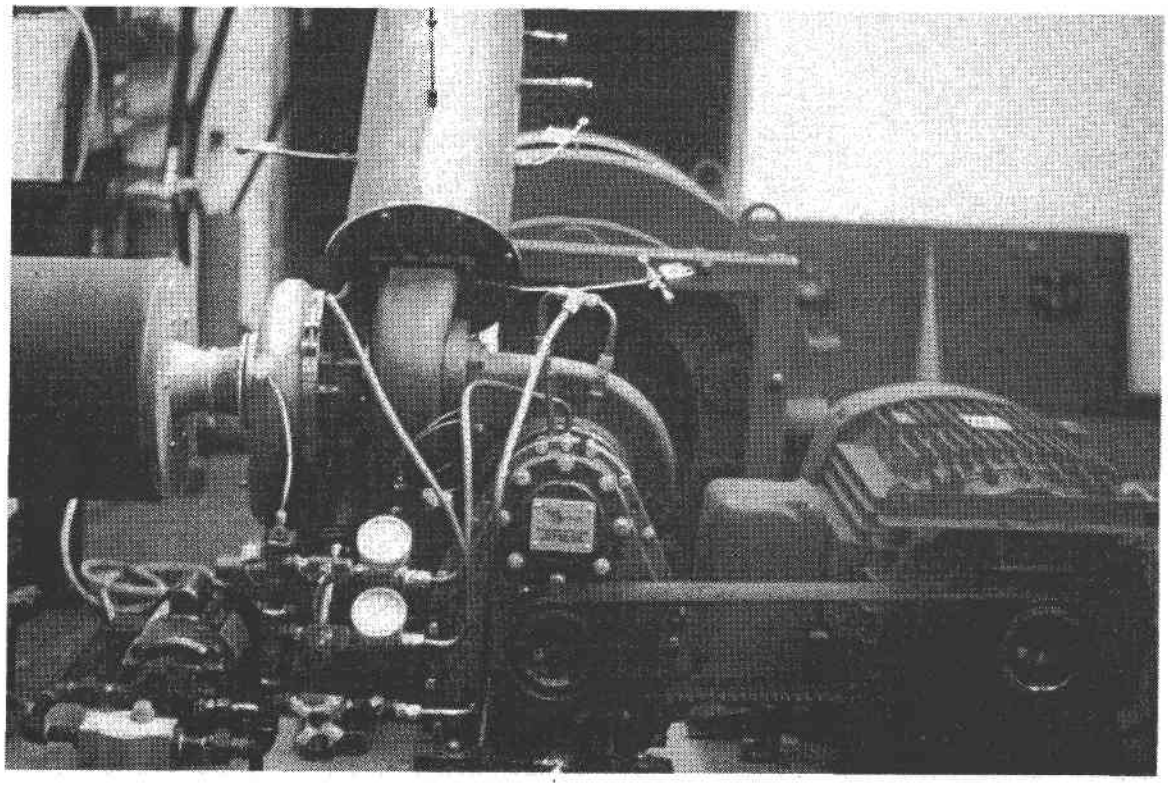


Figure 3: NREC's Brayton engine developed for the Gas Research Institute.

Phase 2 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 3 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.

Phase 2 of the project, which consists of performance mapping of the STM engine, was initiated in January. Several difficulties occurred during this testing. First, the maximum power that could be achieved from the engine was 16.5 kW_e. This power level was achieved under conditions where the expected power level was 22 kW_e. It is currently believed that this reduced power level is the result of a faulty set of piston rings in one of the engines four cylinders. All of the piston rings will be replaced to determine if this is the actual cause of the reduced power level.

A second difficulty arose during an test sequence in early March. During start-up, the engine controller "locked up" before the alternator was hooked up to the grid. As a result, the engine heater head was over-heated. The front side of the heater head tubes went to at least 1025 °C; the pressure in the engine working fluid was at 6 MPa. The heater head ruptured in four locations, one associated with each of the four quadrants in the heater head. The engine was removed from the Test Bed Concentrator for examination and repair. STM is currently producing another four heater heads to replace the ones that failed. Also, this opportunity will be used to replace the piston rings to determine if they are the cause of the reduced power level.

Planned Activities for Next Quarter

- Continue on-sun testing of the STM4-120 PCS with a DIR.
- Complete the dish/Brayton economic analysis.
- Initiate Phase 2 of the NREC/DLR Brayton system project
- Complete final report on the DDC/STM PCS development, design, fabrication, and bench-testing.

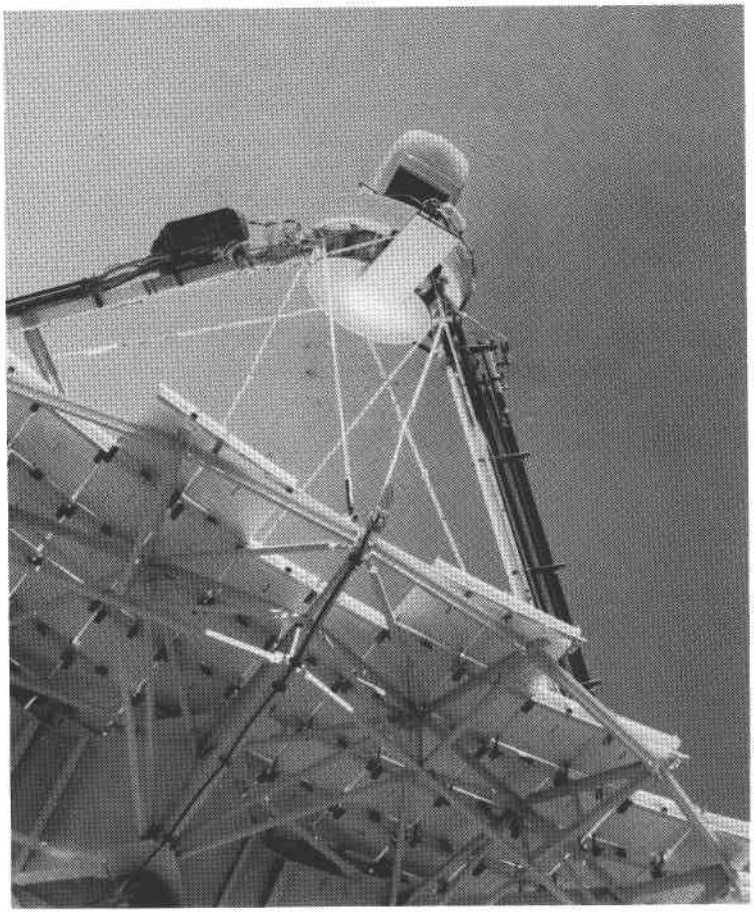


Figure 4: STM/DDC PCS testing at Sandia's NSTTF.

Major Milestones

Milestone	Planned	Actual
Complete check-out of the Stirling PCS based on the STM4-120 with DIR.	Jan 94	Dec 93
Complete on-sun testing of the Stirling PCS based on the STM4-120 with a DIR.	Mar 94	May 94 (estimated)
Complete preliminary design and cost analyses of dish/Brayton power systems.	Mar 94	Mar 94
Integrate the Stirling PCS with an alkali metal solar receiver.	Apr 94	
Begin construction of a solarized Brayton PCS.	Apr 94	
Complete on-sun testing of the Stirling PCS with an alkali metal receiver.	Aug 94	

Resources

($k)	Sandia	NREL	DOE	Total
FTE Costs	324	0	0	324
Contracts	625	0	0	625
Total	949	0	0	949

III. REIMBURSABLES

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. Reimbursable programs were a significant portion of the activities at the NSTTF in FY91-92, but have been very limited since the beginning of FY93. These activities currently are limited to answering inquiries, and planning and preparing for tests scheduled early in FY95. This decrease reflects a decline in activity among our customers, particularly those in the defense sector. However, a significant increase in solar thermal electric activities at the facility has more than filled the gap.

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

Funds-in process established for user facilities

Sandia's Technology Transfer Center has established a process for bringing funds directly into Sandia for activities at Sandia's User Facilities and Technology Deployment Centers, such as the National Solar Thermal Test Facility and Design Assistance Center. Using recently-approved procedures, it is estimated that requests for services can be processed in two weeks or less. One of the initial requests to be processed will be before hail impact testing of greenhouse glazing for 3M. This test will be performed with a specially-designed test apparatus that is used to test hail impact on solar mirrors and photovoltaic cells. Until now, the Photovoltaic Systems Evaluation Laboratory has been unable to accommodate 3M's test request because, while within our capability, it was outside our mission. Furthermore, the effort was too small to be a Work-For-Others program, and there was no other funding mechanism available.

Large-scale test of volumetric air receiver

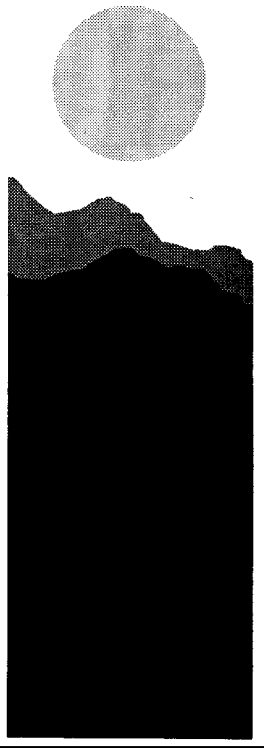
Testing of a Large Scale Test of Atlantis Energie Ltd.'s Volumetric Air Receiver at the National Solar Thermal Test Facility (NSTTF) is still expected to occur early in FY95, but there has been no activity in the past quarter.

Major Milestones

No program milestones. Individual reimbursable projects have milestones for their customer.

Resources

No Solar Thermal Electric Program resources are used to support reimbursable testing.



Publications

Chavez, J.M., R. Lessley, and J. Leon, **"Design, Fabrication, and Testing of a 250 KWt Knit-Wire Mesh Volumetric Air Receiver,"** *Proceedings of the 1994 American Society of Mechanical Engineers International Solar Energy Conference, March 27-30, 1994, San Francisco, California.*

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Kolb, G. J., J.M. Chavez, P.C. Klimas, W. Meinecke, M. Becker, and M. Kiera,. **"Evaluation of Second Generation Central Receiver Technologies,"** *Proceedings of the 1994 American Society of Mechanical Engineers International Solar Energy Conference, March 27-30, 1994, San Francisco, California.*

Pacheco, J.E., R.M. Houser, and A. Neumann, **"Concepts to Measure Flux and Temperature for External Central Receivers,"** SAND-93-2504C, *Proceedings of the 1994 American Society of Mechanical Engineers International Solar Energy Conference, March 27-30, 1994, San Francisco, California.*

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Wendelin, T., and G. Jorgensen, **"An Outdoor Exposure Testing Program for Optical Materials Used in Solar Thermal Electric Technologies,"** *Proceedings of the ASME International Solar Energy Conference in San Francisco, California, March 27-31, 1994.*

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Andraka, C.E., et al., **"Bench-Scale Durability Pool Boiler: Results and Analysis,"** *Proceedings of the 1994 Intersociety Energy Conversion Engineering Conference, August 8, 1994, Monteray, California.*

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Chavez, J.M., R. Lessley, and J. Leon, ***Design, Fabrication, and Testing of a 250 KWt Knit-Wire Mesh Volumetric Air Receiver,*** presented at the 1994 American Society of Mechanical Engineers International Solar Energy Conference, March 27-30, 1994, San Francisco, California.

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

Hellmuth. T.E., J.M. Chavez, L.K. Matthews, and C.A. Hale, ***Performance of a Wire Mesh Solar Volumetric Air Receiver,*** presented at the 1994 American Society of Mechanical Engineers International Solar Energy Conference, March 27-30, 1994, San Francisco, California.

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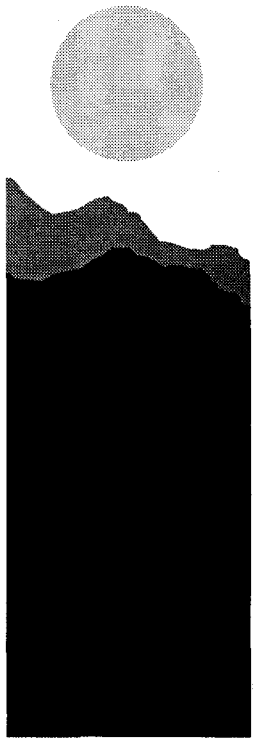
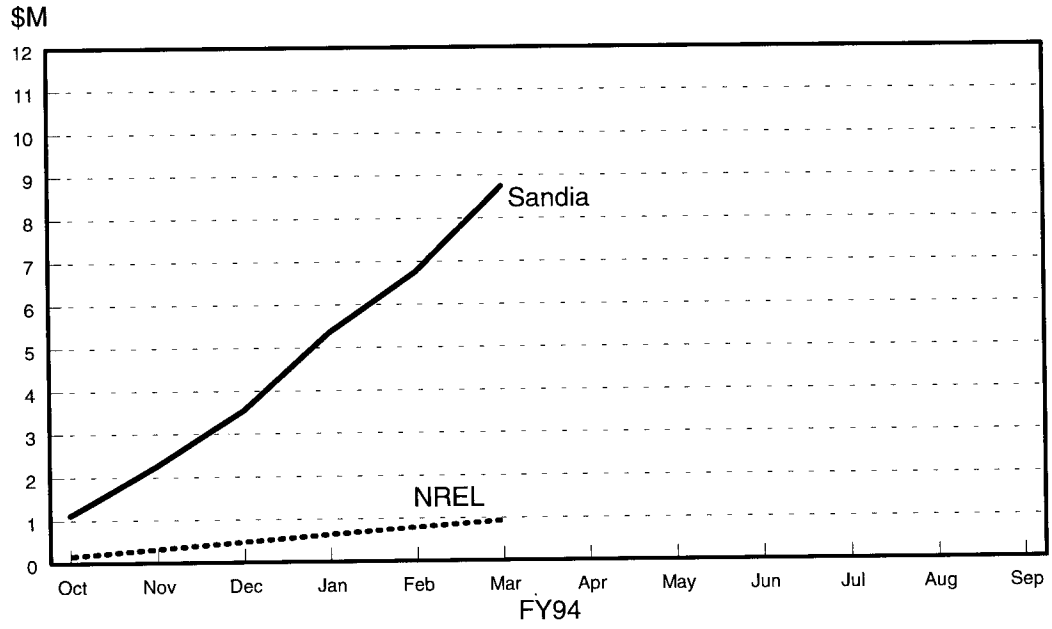
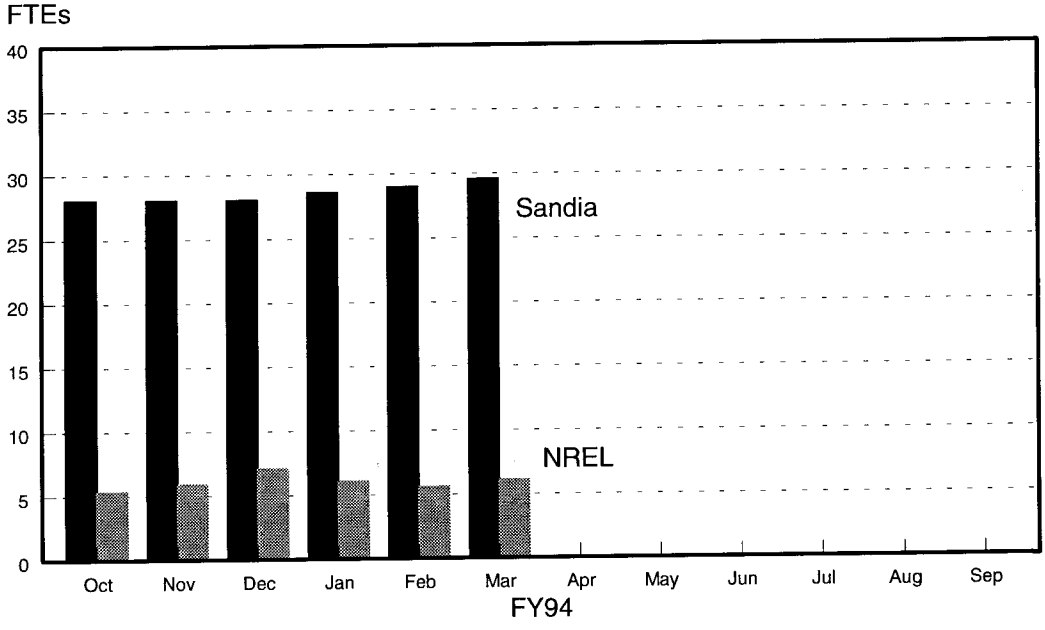


Cumulative Budget Outlay



Monthly Manpower Summary



Contracts over $100k

Task	Specific Contract Subject	Contractor	Lab Contract Number	Present Contract Value ($k)	Prior Year Funds ($k)	FY94 Funds ($k)	Total Costs to Date ($k)	Period of Performance	Contractor Type	Major Reports	Project Monitor
IB	DSJVP	Cummins	SNL 69-7763	6968	5045	1000	5568	06/91-09/95	Large	Phase	R. Diver
IB	USJVP	SAIC	SNL AB-8717A	8828	1656	1600	1072	12/93-09/98	Large	Phase	T. Mancini
IB	USJVP	Cummins	SNL AB-8717B	8989	1500	1600	877	01/94-09/98	Large	Phase	D. Gallup
IB	USJVP	Competitive	SNL AI-1530	10900	0	840	0	—	—	—	D. Gallup
IC	O&M cost reduction	KJC	SNL AB-0227	3154	1350	782	1261	07/92-09/95	Large	Phase	G. Kolb
ID	Commercial-ization Support	Meridian	SNL AF-4595	175	175	0	131	06/93-06/95	Large	Final	P. Klimas
II	Solar Test Support	EG&G	SNL AH-5081	495	99	0	41	10/93-10/94	Large	N/A	C. Cameron
II	Electrical Support Service	J&S Electric Co., Inc.	SNL 75-7415	351	351	0	343	02/89-02/94	Serv. Support	N/A	L. Gillette
IIA1	NSTTF Technicians	Ewing	SNL 63-5487	1947	1947	0	1743	04/89-04/94	Serv. Support	N/A	E. Rush
IIB2	Heat-pipe	Cummins	SNL AB-3348A	84	52	32	84	05/93-08/94	Large	Monthly	C. Andraka
IIB3	Dish/Stirling	Cal Poly Pomona	SNL 67-3678	146	146	0	131	11/91-05/94	Univ	Final	P. Klimas
IIB3	STM Engine	DDC	SNL AE-5963	132	132	0	124	03/93-03/94	Large	Final	S. Rawlinson
IIB3	Brayton Engine solarization	NREC	SNL AG-0408	153	153	0	153	08/93-02/94	Large	Phase	D. Gallup

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S. Gronich
R. Shivers
J. Kern
L. DiNunzio
M. Reed
F. Wilkins
C. Carwile

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G. Tennyson
N. Lackey

DOE/GO:

P. Kearns
R. Martin

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B. Marshall
S. Hauser
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D. Kumar

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