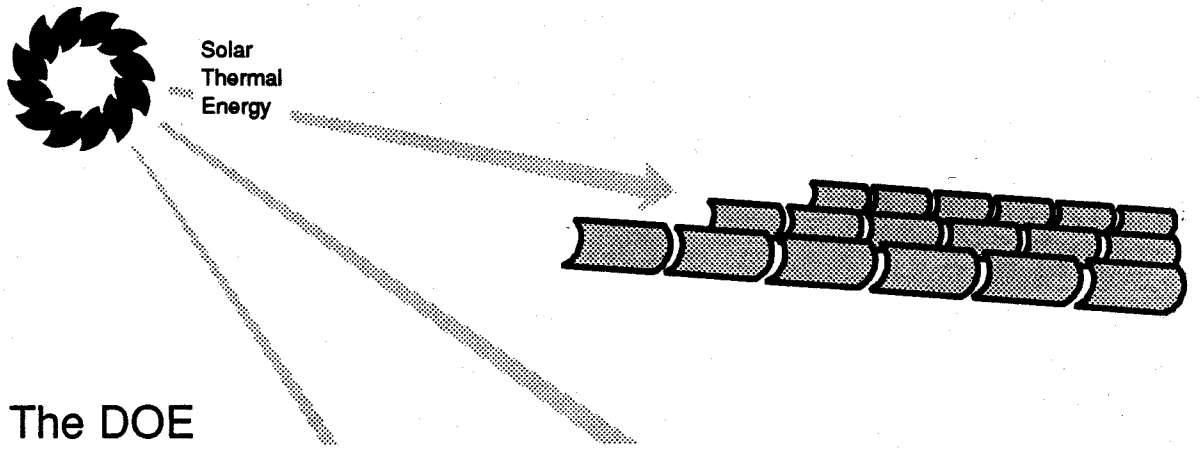
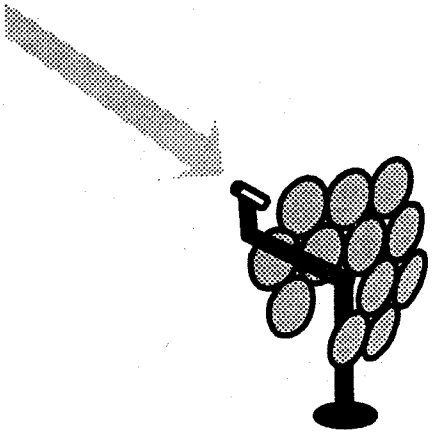


The DOE

Solar Thermal Electric Program

Quarterly Progress Report
First Quarter, Fiscal Year 1992

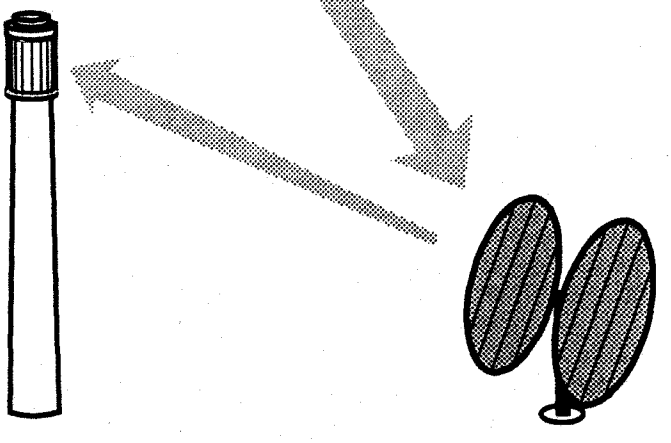


Submitted by:

Sandia National Laboratories
Albuquerque, New Mexico

National Renewable Energy Laboratory
Golden, Colorado

January, 1992



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FOREWORD

The research and development described in this report were conducted within the U.S. Department of Energy's (DOE) Solar Thermal Electric Technology Program. This document is prepared jointly and reports the work of both major field laboratories, Sandia National Laboratories (SNL) and the National Renewable Energy Laboratory (NREL), and their contractors.

This quarterly progress report is written to the Solar Thermal Electric Technology Program's draft Annual Operating Plan (AOP) of January 21, 1992.

MANAGEMENT STATUS REPORT

Structure of the Solar Thermal Electric Technology Program

The Solar Thermal Electric Technology Program is a market-oriented, industry-driven set of cooperative activities with heavy private sector involvement in both planning and execution. It has taken this approach in order to accelerate the commercialization of solar thermal electric technology. By closely linking the program to private sector needs, specific activities support early market penetration of the technology, and program resources are more highly leveraged. Government/industry partnerships produce teams uniquely qualified to accomplish this. The partnerships combine the manufacturing, marketing, and management skills of industry with the solar-specific experience base and analytical and experimental capabilities of the laboratories.

Under this scenario, the program is divided into two main categories: Commercial Applications and Technology Development. Commercial Application activities determine the overall direction of the program. Technology Development efforts in the concentrator and power conversion tasks support the Commercial Applications task. This is the second fiscal year that the program has had this orientation. Relative to fiscal years prior to FY91, technology development milestones focus on nearer timeframes, and far-term research plays a reduced, but continuing, role. The FY92 structure of the program is outlined as follows:

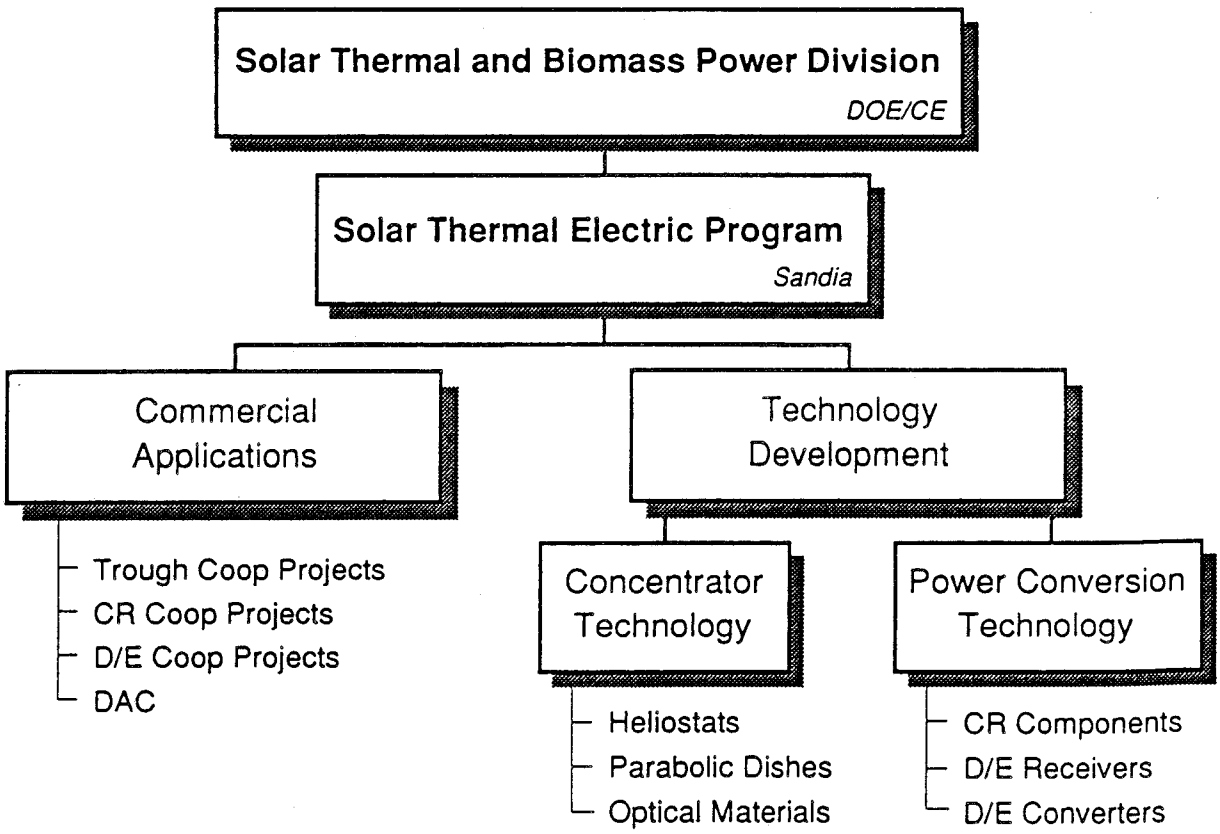
FY92 SOLAR THERMAL ELECTRIC PROGRAM

I COMMERCIAL APPLICATIONS
- A. Central Receiver Cooperative Projects
- B. Dish/Engine Cooperative Projects
- C. Parabolic Trough Cooperative Projects
- D. Design Assistance

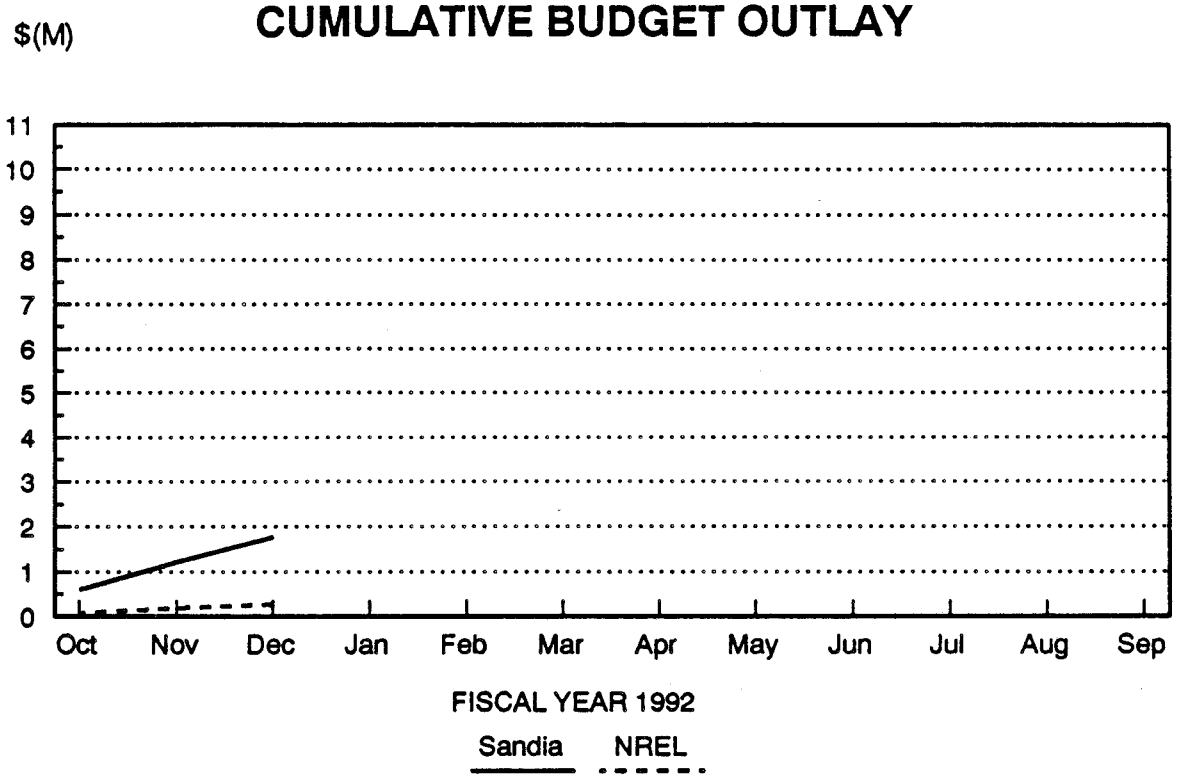
II TECHNOLOGY DEVELOPMENT
- A. Concentrators
  1. Heliostats
  2. Parabolic Dishes
  3. Optical Materials
- B. Power Conversion
  1. Central Receivers
  2. Dish Receivers
  3. Dish Converter Solarization

Field Management - Structure and Responsibilities

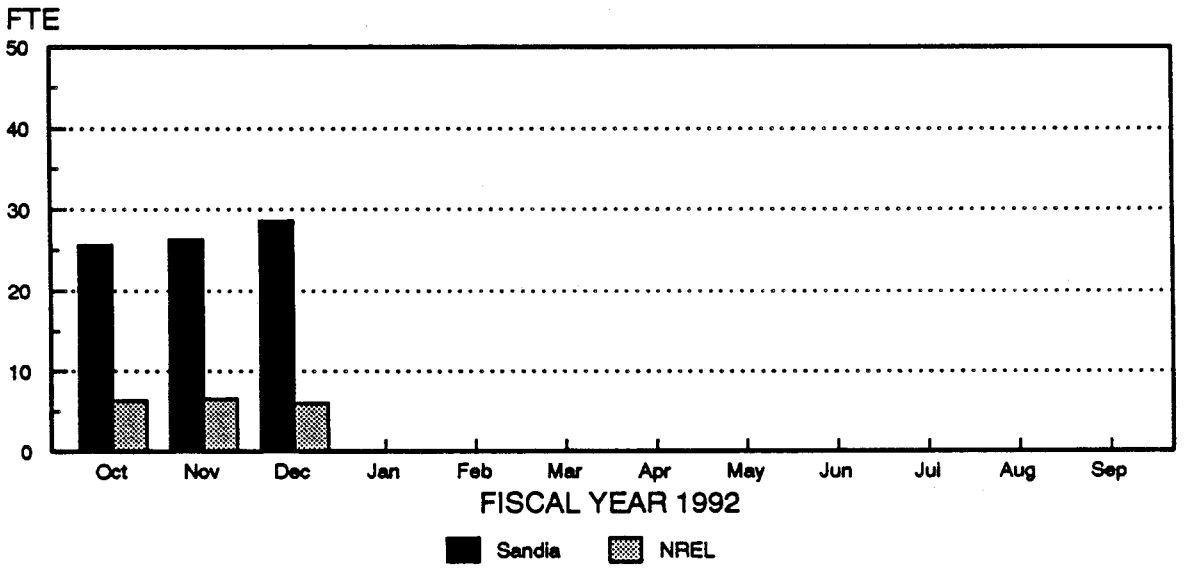
Specific implementation of the Solar Thermal Electric Technology Program is assigned to two field laboratories, Sandia National Laboratories in Albuquerque, New Mexico, and the National Renewable Energy Laboratory in Golden, Colorado. Sandia National Laboratories is the Program's lead laboratory. Together,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



CUMULATIVE BUDGET OUTLAY



MONTHLY MANPOWER LEVEL



Procurement Summary

SOLAR THERMAL ELECTRIC SUBCONTRACTS

Task	Specific Contract Subject	Contractor	Lab Contract Number	Present Contract Value ($K)	Prior Year Funds ($K)	FY 1992 Funds ($K)	Period of Performance	Contractor Type	Major Reports	Project Monitor
IA	Molten Salt System Study	Bechtel	SNL87-5142	$217	0	0	01/92-06/92	Large	TBD	J. Chavez
IIA1	Replaceable Membrane	IST	SNL42-9690	$50	$50	--	11/89 - 2/91	Small	91-7006	D. Alpert
IIA1	Heliostat Integration	Solar Kinetics, Inc.	SNL42-9691	$100	$100	--	10/89 - 1/91	Small	90-7038	D. Alpert
IIA1	Heliostat Fabrication	SAIC	SNL54-5780	$540	$400	$140	01/90 - 4/91	--	None	D. Alpert
IIA1	NSTTF Technician Services	Ewing Technical Design	SNL63-5487	$1,350	$450		04/89 - 04/92	--	TBD	E. Rush
IIA1	Coll. Supp. Struc.& Ped.	WGAssoc	SNL42-9815	$242 (est.)	--	$242	09/89 - 4/91	--	TBD	T. Mancini
IIA1	Faceted Dish Development	SKI SAIC	SNL42-9814B SNL42-9814A	$209 $238	-- --	$209 $238	09/89 - 4/91 (4/91)	Large	TBD	T. Mancini
IIA1	Stretched-Membrane Dish Dev.	Solar Kinetics, Inc.	SNL55-2495	$1,656	$500	--	04/88 - 12/91	Small	88-7035	T. Mancini
IIB1	Volm.Rec. Furnace Test	NMSU	SNL66-9967	$45	$30	0	01/90-12/90 (Extended to 12/91) Contract completed 12/91	Univ. Paper	1992 ASME	J. Chavez
IIB2	Reflux Heat-Pipe Rec.	Stirling Ther. Motor	SNL33-3036	$245	$225	$20	04/87 - 7/91	Small	--	T. Moss
IIB3	2ndSTM4-120	Stirling Ther. Motor	SNL75-8851	$265	$265	--	04/89 - 06/90	Small	--	M. Powell

Procurement Summary (continued)

Task	Specific Contract Subject	Contractor	Lab Contract Number	Present Contract Value ($K)	Prior Year Funds ($K)	FY 1992 Funds ($K)	Period of Performance	Contractor Type	Major Reports	Project Monitor
IIB3	ASCS Design	NASA LeRC	DOE Inter-agency	$6169	1035	1800	01/89 - 01/93	Govt--		M. Powell
IB	Dis JVP	Cummins	SNL69-7763	$7000	$1750	0	06/91-12/93	Large		R. Diver
II	Solar Test Support	EG&G	SNL05-4912	$150	$150		12/88 - 10/93	Large	--	C. Cameron
II	Electrical Support Service	J & S Electric Co., Inc.	SNL75-7415	$120	$60		02/89 - 02/92	Serv. Support	--	J. Stomp, Jr.
IIB3	Heater Heads	Stirling Therm Mtrs	SNL78-8095	$ 46	46		10/1 -12/31/90	Small	--	K. Rawlinson
IIB2	Solar Rec. Heat Loss Testing	California Polytech	SNL02-5759	$105	$30		09/86 - 09/92	Univ.	ASME and ISES papers	A. Heckes
IIB2	Heat-Pipe	Cummins	NREL11160-01	$75			07/91	Large	--	M. Bohn
IC	O&M cost Reduction	LUZ Engineering Corp.	SNL12-3117	$234	234		05/91-06/92	Large	Three Reports	G. Kolb
IID	Tech Trans Documentation	Solar Energy Inds. Assoc.	SNL42-5186	$327	$187		03/90-02/92	Non-profit	Three TT Rpts.	D. Menicucci

NOTE - This list contains subcontracts exceeding $25,000.

Major Milestone Schedule

For reference, milestones identified in the FY 1992 Annual Operating Plan (AOP) for each program task are given below. This set of milestones forms the basis for progress reporting and tracking in this Quarterly Progress Report. Quarterly reports focus on the status of each milestone for the current quarter in the "Significant Accomplishments Summary."

Fiscal Year 1992

Lab	Date	Activity-Task Reference	Descriptive Title
First Quarter, FY 1992			
SN	October 1991	IIA2	Place contracts for two facet sets for the Faceted Stretched Membrane Dish.
SN	November, 1991	IA	Complete summary of commercialization regulatory barriers.
SN	November, 1991	IB	Draft utility-scale dish/engine joint venture RFP.
SN	November 1991	IIB3	Support the DOE Modular Power Generation Workshop.
SN	December 1991	IC	SEGS O&M reduction R&D plan documented.
SN	December 1991	IIB2	Complete pool-boiler materials and methods bench tests.
SN	December 1991	IIB2	Test thermal imagery system for reflux receivers.
Second Quarter, FY 1992			
SN	January 1992	IA	Support utility consortium's development of a proposal to the California Energy Commission for Solar Two financial support.
SN	February 1992	ID	Participate in the SOLTECH 92 joint meeting.
SN	February 1992	IIA2	Place pedestal fabrication contract for Faceted Stretched Membrane Dish.
RE	February 1992	IIA3	Contract award for alternative optical reflective material development.
RE	February 1992	IIB2	Define approach and roles for collaborative industry/laboratory investigation of non-reflux receiver development.

RE	March 1992	IIA3	Second contract award for alternative optical reflective material development.
RE	March 1992	IIB2	Award contracts for hybrid receiver development.
SN	March 1992	IIB2	Complete testing and evaluation of the Dynatherm heat-pipe receiver.
RE	March 1992	IIB2	Complete Cummins/Thermacore heat-pipe fabrication and ground test of the durability receiver.

Third quarter, FY 1992

SN	April 1992	IA	Initiate detailed design efforts for the Solar Two project, pending an agreement between DOE and the utility consortium.
SN	April 1992	IB	Release utility scale dish/engine joint venture RFP.
SN	April 1992	IC	Report issued that describes initial R&D work to reduce O&M costs.
SN	April 1992	IC	Contract established with Kramer Jct. Company to implement full multi-year R&D plan.
NE	April 1992	IIA3	Select sites and document test plan for optical materials outdoor testing.
SN	May 1992	IIA2	Complete design of the 60 kW_t Single-Element, Stretched Membrane Dish.
SN	May 1992	IIB1	Complete the study of thermal storage and steam generator issues in support of Solar Two.
SN	June 1992	IIA1	Document test results on the two large-area glass heliostats and the low-cost drive.
SN	June 1992	IIB1	Complete final report on the joint USA/German Second Generation central receiver status assessment.

Fourth Quarter, FY 1992

SN	July 1992	IB	Deliver a CPG dish/Stirling system to the Pennsylvania Energy office Thermacore test site.
SN	July 1992	IIA2	Install drive pedestal for the Faceted Stretched-Membrane Dish at the NSTTF.
SN	August 1992	IIA2	Place contracts for the fabrication of the 60 kW_t, Single-element, Stretched-Membrane Dish.

SN	August 1992	IIA2	Install first set of facets on the drive pedestal at the NSTTF.
RE	August 1992	IIA3	Document alternative reflector materials R&D progress and suggested activity.
SN	September 1992	IB	Deliver a CPG dish/Stirling system to the SCAQMD test site.
SN	September 1992	IC	Issue report that describes interim R&D work to reduce O&M costs.
SN	September 1992	IIB1	Complete study of the internal film receiver concept.
SN	September 1992	IIB2	Complete validation of advanced molten salt instrumentation and salt freeze phenomena, testing.
SN	September 1992	IIB2	Complete setup and begin 10,000-hour pool-boiler bench test.
SN	September 1992	IIB2	Complete second generation on-sun pool-boiler receiver fabrication and begin testing.
SN	September 1992	IIB3	Complete Fabrication of the Detroit Diesel, 25kW power conversion system.
SN	September 1992	IIB3	Conclude test-cell evaluation of the STM4-120 engine.
SN	September 1992	IIB3	Complete final designs of ASCS selected to be commercialized.

SIGNIFICANT ACCOMPLISHMENTS SUMMARY

MAJOR MILESTONES	Planned	Actual
FY 1992		
TASK I		
• Complete summary of commercialization regulatory barriers.	11/91	11/91
• Draft utility-scale dish/engine joint venture RFP.	11/91	11/91
• SEGS O&M reduction R&D plan documented.	12/91	12/91
• Support utility consortium's development of a proposal to the California Energy Commission for Solar Two financial support.	01/92	
• Participate in the SOLTECH'92 joint meeting.	02/92	
• Initiate detailed design efforts for the Solar Two project, pending an agreement between DOE and the utility consortium.	04/92	
• Release utility scale dish/engine joint venture RFP.	04/92	
• Report issued that describes initial R&D work to reduce O&M costs.	04/92	
• Contract established with Kramer Jct. Company to implement full multi-year R&D plan.	04/92	
• Deliver a CPG dish/Stirling system to the Pennsylvania Energy office Thermacore test site.	07/92	
• Deliver a CPG dish/Stirling system to the SCAQMD test site.	09/92	
• Issue report that describes interim R&D work to reduce O&M costs.	09/92	
TASK II		
• Place contracts for two facet sets for the Faceted Stretched Membrane Dish.	10/91	10/91
• Support the DOE Modular Power Generation Workshop.	11/91	11/91
• Complete pool-boiler materials and methods bench tests.	12/91	12/91
• Test thermal imagery system for reflux receivers.	12/91	12/91
• Place pedestal fabrication contract for Faceted Stretched Membrane Dish.	02/92	
• Contract award for alternative optical reflective material development.	02/92	
• Define approach and roles for collaborative industry/laboratory investigation of non-reflux receiver development.	02/92	

SIGNIFICANT ACCOMPLISHMENTS SUMMARY (cont'd)

MAJOR MILESTONES	Planned	Actual
FY 1992		
• Award contracts for hybrid receiver development.	03/92	
• Complete testing and evaluation of the Dynatherm heat-pipe receiver.	03/92	
• Complete Cummins/Thermacore heat-pipe fabrication and ground test of the durability receiver.	03/92	
• Second contract award for alternative optical reflective material development.	03/92	
• Select sites and document test plan for optical materials outdoor testing.	04/92	
• Complete the study of thermal storage and steam generator issues in support of Solar Two.	05/92	
• Complete design of the 60 kW_t Single-Element, Stretched Membrane Dish.	05/92	
• Document test results on the two large-area glass heliostats and the low-cost drive.	06/92	
• Complete final report on the joint USA/German Second Generation central receiver status assessment.	06/92	
• Install drive pedestal for the Faceted Stretched-Membrane Dish at the NSTTF.	07/92	
• Place contracts for the fabrication of the 60 kW_t, Single-element, Stretched-Membrane Dish.	08/92	
• Install first set of facets on the drive pedestal at the NSTTF.	08/92	
• Document alternative reflector materials R&D progress and suggested activity.	08/92	
• Complete study of the internal film receiver concept.	09/92	
• Complete validation of advanced molten salt instrumentation and salt freeze phenomena, testing.	09/92 09/92	
• Complete setup and begin 10,000-hour pool-boiler bench test.	09/92	
• Complete second generation on-sun pool-boiler receiver fabrication and begin testing.	09/92	
• Complete Fabrication of the Detroit Diesel, 25kW power conversion system.	09/92	
• Conclude test-cell evaluation of the STM4-120 engine.	09/92	
• Complete final designs of ASCS selected to be commercialized.	09/92	

TECHNICAL STATUS REPORT

I COMMERCIAL APPLICATIONS

A. Central Receiver Cooperative Projects

Objective: Develop and support an implementation plan for a utility-scale solar central receiver electricity generating facility.

Accomplishments

Solar Two consortium.

Southern California Edison, with support from Sandia and Bechtel, solicited utilities, state agencies, and industry for participation in the Solar Two project. To date, SCE has received commitments for $13.5M towards the $19.5M required for the 50% cost-share with DOE (Figure 1). Eight utilities with service territories in five states are represented in the consortium, including Edison, LADWP, SMUD, PG&E, Idaho Power, PacifiCorp (owner of Utah Power and Pacific Power), APS, and SRP. A portion of a number of the utilities' contribution to the project will be made up with funds from EPRI's Tailored Collaboration Program. California Governor Wilson's FY92-93 budget requests $500,000 from the state's PVEA account for Solar Two. The Governor's legislation would also request $500,000 in FY93-94, with a provision for additional funding based on performance and need. In addition, SCE is currently evaluating proposals from several architect/engineers that should add an additional $1-2M to the total. A consortium of California's municipal utilities is also expected to participate in the project. Sandia and Edison are continuing their efforts to interest utilties in Texas and Nevada in Solar Two.

Solar Two consortium's application to DOE for cost sharing.

SCE has completed a draft of its application to DOE for cost sharing the Solar Two project and will likely submit it early next quarter. SCE's management needs to be convinced that it will not be held liable if the project is started and commitments for the full $39M are not obtained.

On December 16, Sandia's Craig Tyner met with Paul Kearns and his staff at DOE's NREL-area office to brief them on the Solar Two project and to reveiw requirements for the consortium's application to DOE for cost sharing. Kearns identified several important activities that should be started as soon as possible so that the project can get under way as planned in mid-FY92. These key

activities include a government audit and meeting the requirements of NEPA and equal employment opportunity rules. SCE staff are working directly with DOE's area office to ensure all these requirements are met in a timely manner.

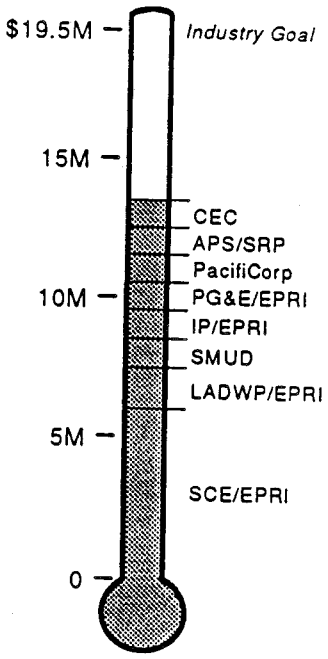


Figure 1.

Report on barriers to commercialization published.

Under contract to Sandia, Michael Lotker, LUZ Development Corporation's former VP of Business Development, prepared a short report summarizing his experience with marketing a solar thermal technology. The title of the report is "Barriers to Commercialization of Large-Scale Solar Electricity: Lessons Learned from the LUZ Experience." The report focuses on the barriers to commercialization, including such topics as energy pricing policy, PURPA regulations, tax policy and frequent expiration of tax credits, property taxes, the lack of incentives to utilities (both IOU and municipal), and state regulation of utilities, including the impact of environmental adders. Lotker's experience provides unique insights that will be useful in the future marketing of commercial solar power plants, both solar thermal and PV. Copies of the final report were distributed to many state utility regulatory agencies and energy offices.

New power tower brochure.

A new brochure on solar power towers was completed. The brochure, "Today's Solar Power Towers," (SAND91-2018) lists the advantages of power towers, describes the components that would be used in a commercial system, and summarizes the development and testing of each component that has brought the technology to the brink of commercialization. The brochure is targeted for technical staff members of utilities and state regulatory and energy offices. Copies of the brochure will be distributed at SOLTECH 92.

Planned activities for next quarter

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

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

- Secretary Watkins and Mr. Davis have scheduled a visit to Southern California Edison Company on January 2 and 3 to discuss, among other things, the Solar Two project. Charles Imbrecht, Chairman of the California Energy Commission, also plans to attend.

B. Dish/Engine Cooperative Projects

Objective: Form industry, user and government consortia which will field economically competitive prototype dish/engine solar electric systems for remote and grid-connected markets.

Press conference held for 5kW$_e$ Dish/Stirling Joint Venture Program.

A press conference announcing the Cummins/DOE/Sandia Dish-Stirling Joint Venture Program (JVP) was held in the office of Congressman Phil Sharp on Wednesday, October 16, 1991. The joint venture program's objective is to commercialize dish/Stirling systems for remote application.Congressman Sharp represents Columbus, Indiana, the world headquarters for Cummins Engine Company, and is the chairman of the House Energy and Power subcommittee. Remarks were made by Congressman Phil Sharp, DOE Assistant Secretary Mike Davis, Cummins Vice President George Fauerbach, and Sandia Advanced Energy Technology Director Bill Marshall. The DOE and Sandia each released written announcements to the press. The dish-Stirling JVP was covered by Indianapolis (Indiana), Abilene (Texas), Lancaster, (Pennsylvania) and Columbus (Ohio) newspapers.

Kick-off meeting held for the Dish-Stirling Joint Venture Program.

The kick-off meeting for the Dish-Stirling Joint Venture Program (JVP) was held at the Cummins Engine Company's world headquarters in Columbus, Indiana on Thursday, Ocotober 24, 1991. The primary focus of the meeting was to discuss the JVP work plan and to review technical status.

The Cummins work plan was completed and accepted by Sandia in November. It calls for an extremely aggressive schedule with the first module scheduled for delivery to the Pennsylvania Energy Office (PEO) test site at the Thermacore facility at Lancaster (Pennsylvania) in July 1992. The second field installation is to go to the California Polytechnic University (Cal Poly) (Pamona) test site in September 1992. Funding for the second unit is being provided by California's South Coast Air Quality Management District. The delivery schedule for Cal Poly and the PEO was reversed due to funding constraints by the PEO.

Sunpower demonstrates full power on the Joint Venture free-piston Stirling engine.

Sunpower, Inc. demonstrated 6 kW_e gross output for a total of eight hours on their free-piston Stirling engine. The engine was recently modified to incorporate gas bearings. The cost of implementing this life-extending modification was entirely supported by Sunpower. The engine is required to demonstrate 100 hours of operation before systems integration testing -- currently scheduled for March 1992 at the Abilene, Texas test site.

Following completion of the 8-hour run, the engine's displacer gas spring was moved from the back-end of the machine to inside the linear alternator to significantly reduce the overall length of the machine. Another 8-hour run was then completed on November 25, 1991. No visible signs of wear were apparent following the runs.

Thermacore completes wall-to-wick bond tests and starts heat-pipe receiver durability testing.

Thermacore completed a series of tests involving the bond strength of the sintered nickel-powder wick to the Haynes 230 hemispherical absorber. Previous Thermacore heat-pipe receivers have failed or had limited operation due to a poor wick-to-absorber bond. Delamination at this interface has caused absorber hot spots and eventual failure of the receiver.

Thermacore previously determined that the poor bonding was due to lack of quality control in the application of nickel plating. Evidence suggested that the on-sun absorbers had insufficient plating thicknesses. The plating serves as a

high temperature braze during the sintering process. Thermacore has worked with the plating vendor to develop control procedures.

The Thermacore tests show that for plating thicknesses greater than 1 mil (0.001 inch), the wall-to-wick bond is stronger than the wick. (Failure occurs in the wick.) Failure in the bulk wick occurs at approximately 1500 psi. Plating thicknesses of 1.5 mils will therefore be specified on subsequent receivers and strict quality-control procedures will be utilized. Following these tests Thermacore assembled a trial dome/wick structure and performed wick bond tests on samples cut from the dome. The results, however, still indicated insufficient bond strength. The problem was attributed to the relative heating rates of the absorber and wick. Thermal analysis indicated that for the samples the wick heats-up before the substrate, whereas for the domes, the opposite is true. The sintering fixture was then modified and heavily instrumented and another trial dome/wick structure was processed. Bond tests from this run were successful -- strengths exceeded even those from the coupon tests were measured and failures always occurred in the wick itself. In early December, the second durability heat-pipe receiver was fabricated, processed, tested on quartz lamps, and shipped to Abilene, Texas. It was then installed on a CPG-460 concentrator and testing was initiated on December 17, 1991. As of January 3, 1992, approximately 30 hours at temperature had been accumulated. Testing was conducted on Christmas day and New Year's day. Financial support of this development effort was shared by NREL. On-sun testing is being conducted as part of the JVP.

Cummins and CFIC complete a Licence and Development agreement for an alternative 5-kW$_e$ Stirling engine.

Because of the importance of the Stirling engine to the Joint Venture program, Clever Fellows Innovation Consortium (CFIC) was included as a parallel Stirling engine developer. In November, CPG and CFIC reached agreement on licensing and royalties for the CFIC engine. The CFIC engine technology, which utilizes flexures, virtually eliminates wear and makes possible extremely long-life engines. CFIC is confident enough in the technology that they were willing to accept a fixed-price contract (totally borne by CPG) for a firm-date delivery of an engine that meets the CPG specifications. CPG will select either the Sunpower or CFIC engine for further development in Phase 2 of the JVP. CFIC provides additional Stirling engine expertise and technology to CPG.

Cummins moves into a new facility in Abilene, Texas.

Through a industrial development program sponsored by the city of Abilene, Texas, CPG has signed a one-year lease on a facility in Abilene, Texas. The approximately 5000 square foot office/shop facility was purchased by the city at an extremely low cost. The city has brought the facility into code compliance

and has made a number of Cummins specified improvements to the property. Improvements include concentrator foundations, wiring, fencing, site preparations, and plumbing. The monthly cost of this facility to CPG, which will eventually support engine testing and concentrator manufacturing, is approximately $1000.

Concentrator mirror development continued at the CPG-South facility.

CPG, South, staffed by former LaJet personnel, continued development of concentrator mirrors. The mirror rim design was finalized after extensive testing of actual-size machined samples. The effective diameter of the rim remains at 60 inches. A sample rim extrusion has been received and an order was placed for 138 rims. An order was also placed for a roll of ICI-453 7-mil film (65 inches wide). The film production run, originally scheduled for early-December, has been postponed for late January 1992. The film will then be shipped to Vacuum Depositing, Inc. in Louisville, Kentucky for metallizing. An off-the-shelf clamp and membrane tensioning air cylinder have been purchased for prototype development purposes. The mirror tensioning fixture uses a pneumatically actuated clamp to significantly speed up mirror production.

Cummins Electronics continues concentrator/engine controls integration.

During this reporting period Cummins Electronics (CEL) significantly increased their staff and efforts to design the water pumping application control system and to integrate the concentrator and engine controls. All controls and sensors used in the system are now the responsibility of CEL and will be implemented utilizing the same demanding total quality management principles used in state-of-the-art diesel-engine electronic-control systems. Drafts of the System/Segment Specification and System/Segment Design documents were completed in December. A system preliminary design review was held at the CEL facilities on December 20, 1991.

2nd Dish/Stirling JVP team meeting held at Sunpower.

The second Dish/Stirling Joint Venture Program (JVP) team meeting was held at the Sunpower, Inc. facilities in Athens, Ohio on December 11. The meeting's primary objective was to review the status of the Sunpower 5 kW_e (net) free-piston Stirling engine. The cooling and control systems designs along with packaging concepts and integration issues were also presented and discussed.

Sunpower demonstrated the 5-kW_e engine in their test cell. Heat input to the engine is provided by a Thermacore, Inc. electric heat-pipe, which has proven to be extremely reliable and which has permitted Sunpower to concentrate on engine development. A life-test electric heat-pipe of the same design has accumulated about 12,000 hours of operation at full power. The recently

implemented gas bearings were also demonstrated. The gas bearings apparently have virtually eliminated wear in the engine, and have significantly reduced friction loss, which has proven to be more than expected. Although engine/alternator efficiency is currently less than expected (20% vs. 30%), the performance is adequate for a 5 kW_e (net) system output. The plan is to freeze the design and to be well into a 100-hour durability demonstration by Christmas. Design improvements to increase engine/alternator efficiency to approximately 32% at 675°C will be implemented in Phase 2.

Cummins Electronics evaluates the Solartrac Solar Array Tracking Controller for the Dish-Stirling Joint Venture Program.

A meeting to discuss lessons learned in the development of the Solartrac Solar Array Tracking Controller was held at the Cummins Engine Company's world headquarters in Columbus, Indiana on November 12, 1991. The Solartrac controller was developed at Sandia for tracking photovoltaic concentrator systems in the DOE photovoltaic program. Alex Maish of Sandia's Photovoltaic Technology Research Division 6224 presented the Solartrac design. The tracking controller design specifications for the Cummins 5-kW_e system was presented by Cummins Electronics personnel. It appears that the dish-Stirling's requirements are different enough from those of concentrating photovoltaics that the Solartrac system can not be utilized directly. The Cummins requirements for field diagnostics and support also tend to drive the controller design. However, it appears that many of the lessons learned with limit switches and other sensors are in good agreement with Cummins' experiences. In addition, many of the open loop control algorithms developed at Sandia will be of direct benefit to the Joint Venture Program. Collaboration, particularly in the areas of surge protection, power management, and wind sensors, will continue between Sandia's photovoltaics group and the Joint Venture Program.

Cummins Power Generation finalizes drive geometrical design for the Dish-Stirling Joint Venture Program.

A design review meeting for the diurnal and declination concentrator drives to be used in the Cummins Power Generation (CPG) dish-Stirling Joint Venture Program was held at the Peerless Winsmith representative's office in Carrollton, Texas on November 21, 1991. The diurnal drive is based on the low-cost azimuth drive concept developed under the heliostat program. The drive design for the CPG-460 concentrator presented by Winsmith is smaller than the original heliostat design and incorporates a 3-inch hole through the center to accommodate cables. Castings for the nodular-iron drive housing appears to be the critical path activity for the first system delivery, currently scheduled for July, 1992. The drive designs were finalized in mid-December, 1991, and casting vendors have been contacted. If normal processes are allowed to prevail, the first gear box will not be available until May or June, 1992. Winsmith has

indicated that this process can be expedited by carefully tracking the bidding, prototyping, and production schedules for the casting. Expediting fees for the pattern makers and founders will be considered if the schedule dictates. CPG plans to purchase four drives in Phase 1 of the JVP. CPG is interested in having one of the first drives evaluated by Sandia.

Program provides equipment for the Dish-Stirling Joint Venture Program.

As a consequence of the elimination of LaJet Energy Company as a subcontractor in the JVP (a business decision by CPG) many of the solar specific assets owned by LaJet are no longer available. Consequently, the program loaned a LEC-460 solar concentrator to CPG, South. The program has also loaned a calibrated Epply direct normal insolation pyrheliometer and tracker. Excess IBM personnel computers which will be used for data acquisition at the Abilene test site have also been provided.

Rod Mahoney of Sandia's Electronic Materials Applications Division 6221 has developed a fixture for the Device & Services portable specular reflectometer to better measure reflectivity on the CPG stretched membrane facets. The calibrated reflectometer and prototype fixture have been provided to CPG. CPG personnel are delighted with the modification since it greatly reduces the effort associated with and improves the reliability of reflectivity measurements.

Program provides technical support for the Dish-Stirling Joint Venture Program.

Sandia provided to CPG recommended design modifications to the Thermacore receiver geometry that will significantly reduce peak flux intensities on the heat-pipe absorber. The flux intensities and performance implications of the modifications were quantified with the receiver analysis models, CIRCE2 and AEETES. CPG implemented the modifications. Also provided were calculated optimum locations of thermocouples on the Thermacore heat-pipe receiver. 24 thermocouples located at the center-of-aim of each of the 24 facets are being used in the durability heat-pipe tests to detect hot spots.

Sandia initiates development of a "2F" mirror quality assurance technique to support mirror manufacturing QA by Cummins.

Development of a technique to evaluate the optical quality of stretched membrane facets was initiated. The approach uses the same hardware and software used in the Sandia Beam Characterization System (BCS). In this technique, a specially designed target is placed at the radius of curvature of the mirror (two focal lengths). It is therefore called the "2F" technique and is capable of providing rapid measurement of mirror quality. The Beamcode software is

capable of providing the necessary data reduction of the vast amount of video based data. The objective is to provide the equipment, techniques, and training to support mirror production at CPG, South scheduled for March 1992. A mirror facet developed under the DOE Innovative Concentrator Program is being used for the development process. The technique will also be provided to SKI and SAIC to support mirror development in the DOE Faceted Dish Program.

Draft Request for Proposal (RFP) package for a utility-scale dish-electric joint venture program completed (Major Milestone completion).

A draft RFP package for a utility-scale dish-electric joint venture program was completed and submitted for review by personnel at NREL, Sandia, and DOE. Reviews received thus far have been very constructive. The results of the Modular Power Generation Workshop held in San Francisco, California, on November 7-8, 1991, will also be utilized to improve the next version. Release of the RFP is anticipated for early third quarter, FY92.

Planned activities for next quarter

- The JVP team meeting number 3 will be held in Abilene, TX on January 22, 1992. Concentrator and receiver subsystems will be the focus of the meeting.

- CPG, South will continue durability heat-pipe receiver testing. A CPG-460 solar concentrator will be used for concentrator controls development testing. Systems integration testing in Abilene, TX will be started near the end of the quarter.

- The program will provide technical support to the JVP in the following areas: loan of additional calibrated reflectometers, loan of a video flux mapper system, loan of another surplus computer for engine data acquisition. Sandia personnel and training, will also be provided as necessary.

- Development of the 2F mirror quality assurance technique will continue transfer of the technology to CPG, South will begin.

- Sunpower will demonstrate 100 hours at full power output on their prototype solar engine.

- A DOE peer review of the Dish-Stirling Joint Venture Program will be conducted in Albuquerque, New Mexico, on March 11-13, 1992.

- Presentations on the Cummins Dish-Stirling Development Programs and the DOE Joint Venture Programs will be made by Jerome Davis, President

of CPG, and Rich Diver, Technical Manager of Joint Venture Programs at Sandia, respectively, at SOLTECH 92 in Albuquerque, New Mexico, on February 17-19, 1992.

C. Parabolic Trough Cooperative Projects

Objective: Work closely with industry to reduce costs associated with operating and maintaining parabolic trough-based, solar electric generating plants through research and development based on the extensive operating experience of LUZ Engineering Corporation and its derivatives..

Accomplishments

Report completed which defines the strategy to reduce operating and maintenance costs.

Despite the bankruptcies filed by LUZ International in November 1991, DOE its Sandia is continuing our contract with LUZ Engineering Corporation (LEC) to reduce the operating and maintenance costs at SEGS plants. Since LEC, a subsidiary of LUZ International, is paid by revenue sales from the plants, this company and its derivative Kramer Junction Company will continue to operate and maintain the SEGS plants.

The costs associated with O&M have a significant influence on the economic viability of the SEGS technology. Currently, O&M costs account for approximately 20% of the plant electricity costs. Reductions in O&M costs (expressed in cents/kW-hr) would enhance the profitability of the SEGS plants, as well as the marketability of other solar power technologies currently being developed by the Program. An example of a DOE technology that would benefit is solar central receivers. Central receiver power plants have many of the same subsystems contained within a SEGS power plant and the O&M of these subsystems would be similar.

This work will be performed in two phases, each governed by a separate contract:

1. A study of the historical O&M costs at the LUZ plants is conducted and these costs are categorized. This information is used to develop a multi-year strategy address the most costly O&M categories. Upon completion of the strategy, research and development (R&D) is begun to reduce the cost of one or more of the important O&M categories.

2. The full multi-year strategy developed in Phase 1 is implemented. Work will be performed to complete the R&D begun in Phase 1 and on the remaining important O&M categories.

The Phase 1 contract is under way and the work scheduled over a 6-month period. This work is entirely funded by DOE.

Phase 2 is to last several years and the cost share between LUZ (or its derivatives)and DOE is 50% by each organization. Sandia has begun negotiating this new contract and it should be in place in the 3rd quarter of FY92.

Because of distractions caused by LUZ's financial dilemma, our contract with LEC to reduce O&M costs is approximately 3 months behind our original schedule for Phase 1. During the quarter, LEC wrote a report which details the O&M cost reduction strategy to be implemented in Phase 2. Nine cost reduction categories were identified. A review of these categories indicated that most are directly applicable to central receiver technology.

1. **Automated Control** - Upgrade control system automation and operation in order to improve reliability and lifetimes and to optimize performance, particularly during daily transients and hybrid operation. Additionally, develop plant simulation models for integration into control room use to improve operation and training.

2. **Performance Monitoring** - Improve plant operation by upgrading selected instruments related to performance monitoring, refining plant performance models and upgrading plant test loops to better quantify solar field performance factors.

3. **Maintenance Planning** - Optimize maintenance strategies in the power block, solar field and BOP by upgrading the ability to select trade-offs between performance, reliability and maintenance, and improving the utilization of manpower and spare parts.

4. **Cyclic and Transient Operation** - Evaluate the effects of frequent plant cycling on critical components which have shown reduced lifetimes to date, particularly remotely operated control and shutoff valves. Further, upgrade the ability to control and optimize transient operation by improving plant instrumentation for selected equipment and subsystems.

5. **Water Use** - Reduce O&M costs for water purchase and treatment by reducing makeup water requirements and refining makeup water treatment methods, as well as improving waste water recovery through improved processing techniques.

6. **Heat Collection Elements** - Reduce heat collection element maintenance costs through improvement of maintenance strategies based on a better understanding of heat losses and actual field conditions, on-site repair of

damaged units, and the development of less expensive replacement alternatives.

7. Mirrors - Improve the average reflectivity of the solar field mirrors at reduced costs through an evaluation of mirror washing methods, potential anti-soiling treatments, and better reflectivity measurement techniques.

8. Solar Collector Assembly Interconnection - Reduce lost performance and maintenance costs due to flexible hose failures via the design and test of rotating ball joints as an alternative.

9. Solar Field Control/Electronics - Improve the solar field performance at SEGS III-VII by upgrading the Field Supervisory Controller with newer technology and by enhancing the localized controller hardware and software design.

The entire cost-reduction strategy will take approximately three years to implement and the cost of it will depend in great part on the willingness of the SEGS owners to cost share the project. Initial indications are that the SEGS owners are very interested in participating.

Planned activities for next quarter

- Phase 1 activities will be completed by performing initial work on items 4 and 6 described above. In particular,

- Methods for improving the reliability of valves contained within the turbine-bypass system at SEGS VI and VII will be investigated.

- A LUZ trough and heat-collection element will be installed at the National Solar Thermal Test Facility in Albuquerque. Heat loss measurements will commence and an analytical model for the test will be developed.

D. Design Assistance

Objective: 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.

Support: The Design Assistance Center activities reported here are generally supported by (1) the Solar Thermal Electric Program, (2) the Solar Thermal Industrial Program, or (3) both programs. They are reported together for

completeness and in recognition of the fact that boundaries are often not distinct within each activity.

Accomplishments

Program continues support to Gould Incorporated, Foil Division.

Gould is in the process of upgrading its 60,000 square foot solar system that is used to produce hot water for a copper foil manufacturing process. The upgrade should be completed within a year or two and, when completed, is expected to produce electricity savings of at least $120,000 per year. Sandia will continue to provide technical consulting throughout the course of the project.

Technical consulting for the California Energy Commission (CEC).

The DOE's representatives at Sandia Labs are involved in a number of CEC activities. The first involves the proposed solar project at the prison in San Luis Obispo. Program engineers were called to assist in measuring the hot water load at the prison as a prelude to the California Department of Corrections (CDC) signing a contact with Besi Corp to install a third-party financed solar system. The measurements were used to resolve a dispute between Besi and CDC. With the dispute now resolved, the two parties are moving to enter the contract.

Efforts are currently underway to assist in issuing a Request for Proposals for a solar system at another CDC prison. Sandia will provide engineering support on this project.

SMUD, State of California, and DOE agree to develop a Solar Absorption Cooling Project in a state building.

The Sacramento Municipal Utility District (SMUD), the California Energy Commission (CEC), the California Department of Corrections (CDC), and DOE (Sandia) have agreed to develop a pilot solar absorption air conditioning and heating project at a CDC training facility near Sacramento. The objective of the project is to establish the technology for utility demand side management and to verify its benefits and performance. The agreement specifies that all of the parties will cooperate and co-fund an effort to install a 100 ton air conditioning system. The project will begin during the next quarter.

SMUD is also interested in working on a longer term effort to develop resources to more effectively use solar thermal technology for other utility demand side management efforts.

Technical Support for the New Mexico State Energy and Minerals Department (NMEMD).

Sandia is continuing to work with the NMEMD to provide technical assistance and consulting regarding the use of solar thermal technology in the state of New Mexico. Technical consulting regarding the development of the State's comprehensive energy policy was provided.

A new effort has recently begun in which program engineers will help train State of New Mexico engineers on the methodology to identify and refurbish non-operating solar thermal systems within state institutions. The first refurbishment project involves a community college in northern New Mexico. Sandia will assist the State on the techniques to bring the existing non-operational system into production.

Support provided for Sandia's technology transfer programs.

Sandia's Solar Thermal Program is consulting to Sandia's Technology Transfer Program about the application of solar thermal technology. Currently, engineering support is provided on several projects: a) The development, test, and evaluation of a solar powered ice melting system for cow-watering troughs, b) the use of solar energy for drying pumice at a processing plant, c) providing UV data for use in a private solar detox development effort, and d) helping to develop a solar ORC engine. These efforts are supported outside of the DOE Solar Thermal Industrial and Electric Programs.

Technical Assistance provided to the State of Arizona.

DOE has been asked to provide engineering consulting to the Arizona Department of Commerce concerning the refurbishment of an existing, non-operational solar trough system at a school. The system was built in the early 80's and was never used. It is currently being considered for heating the building space and indoor pool. Sandia will be assisting a local A&E firm that has been hired to design the modifications, which are expected to be relatively straight forward.

Solar thermal technology applied at Kirtland Air Force Base.

Sandia, a tennant of Kirtland Air Force Base, is continuing to work with base officials to provide engineering consulting to an Architect & Engineering (A&E) Company that was hired to renovate over 100 of the base houses. It is proposed that several services will be provided to the A&E firm including: 1) training regarding solar water heating technology, 2) develop and help apply a procedure that allows the architects to identify those houses that are best suited for solar water heating, 3) assistance in writing the RFP package to procure the contractors

for installing the solar systems, and 4) technical consulting during the installation and initial operation of the systems. This effort is expected to start in 1992 and will continue for about six months.

Refurbishment of solar system at the VA Hospital continues.

DOE/Sandia is assisting engineers at the Veterans Administration Hospital in Albuquerque, NM to renovate and to return an existing solar system into service. This system, which was installed in 1985, has been shut down since 1986 because it produced excessively hot water and caused pressure/temperature relief valves to open. Last year, Sandia began working with VA engineers to restart the system. One-half of the system and is now under automatic operation. Discussions are now under way about modifying the hot water system to use the remainder of the solar system. After it is 100% operational, the system could save about $12,000 per year in gas usage.

Consulting to Solar Uno in Santo Domingo.

Sandia is consulting with Solar Uno about the use of solar thermal electric technology for Santo Domingo in the Dominican Republic. Currently there are severe electricity shortages on the island and solar is a candidate technology for additional generation. Solar absorption air conditioning is being considered for utility demand side management. The consulting will continue throughout the year.

Consulting to the Government of Mexico.

Sandia's Photovoltaic Systems Research Division is coordinating a technical consulting effort to help the Mexican government apply renewable technologies in Mexico. As part of the effort, the solar thermal program is providing consulting about solar thermal technologies. Currently, Sandia is assisting in the design of a walk-in, fish storage bin that will be cooled with ice from and Energy Concepts ice maker. Another effort involves the development of a 50kW solar thermal electric project in Puertos Lobos. A used ORC engine coupled with IST troughs is being considered for this demonstration project, which will be managed by a consortium of Mexican government and university engineers.

Testing of the Energy Concepts ice maker.

The DOE, as represented by Sandia engineers, is continuing to work with Energy Concepts to test the Mini- and Full-Isaac solar ice makers. The testing has followed a plan that was jointly developed by DOE and Energy Concepts. The results of the tests are being used by Energy Concepts to improve the design of their systems. Additional tests may be conducted on the Double-Isaac, a larger

version of the Full-Isaac, six of which are scheduled to be sold to the Mexican government.

Testing of the first BSAR solar water heater/distiller concluded.

Sandia has been testing the residential solar water heater/distiller developed by BSAR. The testing is based on a plan that was jointly developed by DOE and BSAR. The test results will be used by BSAR to improve the design of the system. Tests of the first BSAR model are complete and suggested design changes have been implemented by the manufacturer. A new model is currently being assembled for testing next quarter, which is expected to continue through spring of 1992.

Solar message is presented.

Representatives of DOE at Sandia have presented various solar talks or participated in various civic activities. These are outlined below:

a) City of Albuquerque Energy Forum. Sandia engineers participated in a City of Albuquerque workshop entitled "Creating a Sustainable Energy Future." The workshop was developed by six city departments, along with a city Energy Conservation Council, to prepare a plan to reduce the city's conventional fuel use by 10% by 1995 using renewable technologies and conservation.

Dave Menicucci was an organizer and coordinator in the Energy Education breakout session, which developed a plan to educate energy users about alternatives and energy conservation. Dan Alpert participated in the Land Use breakout session, which addressed land use issues related to energy use and renewable energy production.

b) Solar energy talk presented to Albuquerque/Las Cruces NM Electricity Task Force. A talk about solar energy technology was presented to the Albuquerque/Las Cruces NM SENSE task force. This task force is a coalition of city councilors from the two cities. The purpose of the task force is to explore alternative energy sources that can be used by municipal utilities.

Sandia was invited to this meeting to discuss the current state of solar technology and some issues relating to electricity generation. The presentation included an overview about all solar technologies along with a discussion about the pros and cons of tax credits. Special emphasis was placed on the efforts in California and Nevada to incorporate long-term pollution costs in the estimates for new electric generating plants. With the addition of these environmental costs, solar

plants (like central receivers) are among the most cost effective generating systems.

c. **Solar energy talk presented at the Annual New Mexico Science Teachers Conference.** An invited address about solar energy technology was presented at the Annual Conference of the New Mexico Science Teachers Association. Members of this association include most of the science teachers in the state of New Mexico. This conference, attracted about 100 attendees and one of its focuses was on renewable energy.

The 45-minute talk was very well received and there was considerable follow-up discussion during and after the session. Several teachers asked for additional information regarding solar energy for use in their courses. There was special interest in obtaining a copy of the solar education package that was jointly developed by Dave Menicucci and Sandia's education outreach program.

Miscellaneous Consulting Efforts

Other on-going technical assistance projects include:

- LBJ Hospital in Samoa
- New Mexico Solar Energy Industries Association
- Solar Weatherization Assistance Program
- Utah Parks and Recreation Department
- Pennsylvania Energy Office

On-going test and evaluation projects include:

- Pegasus
- IST

Progress on these activities will be reported next quarter as appropriate.

Planned activities for next quarter

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

TECHNOLOGY/SUBJECT	REQUESTER	AFFILIATION
Central Receiver Tech	Russell Garnsworthy	CRA, LTD., Australia
Dish/Stirling	Errique Barnes	Premezclados Panama
	Fred Lundgren	Individual
	Art Seki	Hawaiian Electric Co.
	Mike Snyder	Sunstrandt Corp.
	Ray Dunlop	New England Electric
	Khalry Agha	Individual
	Bob Rodgers	PKI
	John M. Lyons	Applied Science Lab
General Information	Carlo LaPorto	United Solar Technology
	Curt Rossey	Ariz. Dept. of Commerce
	Ellis Perez	Santo Domingo
	George Nichol	Army Corp of Engineers
	Jeff Webb	Santa Fe
	Hugh Edmonds	Louisville, KY
	Ebert	Ariz. Public Service
	Linda Stewart	Albuquerque City Council
	Britt Reed	Utah Division of Energy
	Brad Rose	Solar Works
	Marty Emowitz	Re: San Luis Obipso & PV
	Frank Clements	Nevada Nuclear Waste Task Force
	Larry Maltese	Calif. Department of Re: California SWAP
	Dave Reinhart	SMUD
	Kelly Beninga	SAIC
	Curt Hensen	Rio Grande
	Bruce French	Florida
	Bruce Vincent	SMUD
	Mr. Constantio	Consultant
	Dave Knipfer	Gould
	R. Gee	Video on Brighton "Beta"
	Eric Brus	Individual
	Bengt Thoren	Lund Institute of Tech. Lund, Sweden
	Ethan Owens	Student
	Penelope Fitzgerald	Univ. of New So. Wales, Australia
	Tom Chapman	Univ. of New So. Wales, Australia

Ted Godett	Stirling Thermal Motors
Matt McKelvie	University of South Florida
Hugh Edmunds	Individual
Len Oyenque	American Pumice
Pat Skerrett	Union of Concerned Science
Hugh B. Edmonds	Individual
Jim Besquorn	Individual
Bruce Vincent	SMUD
Jurg Bieri	Individual
Jeff Beamon	Idaho Power
Jeff Kline	New Mexico State Land
JoAnn Emmel	New Mexico State University
John Mall	Northrop
Bob Curcio	BDM
George Mosinskis	Southern California
Carol Streher	Lovington
Walt Gerlach	Arizona Public Service Co.
Chuck Markam	AAA Solar
John Tidd	RTT
Mark Finley	RTT
Ted Petersen	RTT
Thomas Pylkkaney	Atlantic Energy Ltd.
Don Pope	VA Hospital, Albuquerque
Paul Jorgensen	Energy Concepts
Jim Self	Individual
Amy L. Sickler	Nippon Steel U.S.A., Inc.
Randall L. Clark	Advent International Corporation
Mark L. Radtke	Advent International Corporation
Yasushi Aoki	Nippon Steel U.S.A., Inc.
Frank Reid	Western Mining Corporation Limited
Jeffrey Nathanson	N.M. Business Innovation Cent
Shinobu Umino	NTT America
Michael Moloney	BHP
Eiichi Fukushima	Lovelace Medical Foundation
Bill Sha	Argonne National Lab

	Dave Schinalzer	Argonne National Lab
Instrumentation	Jim Thacker	Automated Measurement
Integrated Resource Planning	Bud Wilden	State of New Mexico
Passive Solar Design	Steve Slater	Grande Hogar de Los Niños
PVCR	Robert Wills	Solar Design Associates
	Schavale Vasel	PV Forum
	Shephali Patel	deLucia and Associates, Inc.
	Craig C. Clifton	Quality Repair & Service Tech
	Andy Walker	State of Colorado
	Chuck Whiticher	Individual
Soldering Application	Mike Hosking	Sandia
Solar Education	Cliff Holt	University of New Mexico
	Vern Risser	Lesson plan for PV school staff
	John Erden	University of New Mexico
	Dan Morley	Individual
	Lawrence Haywood	Arizona State University
	Barbara Rogers	Hawthorne Elementary
ST Concentrators	Maroon Abraham	Sigma Design Company
Solar Thermal Systems	Todd S. Kelly	Individual
	Charles Bensigner	PKI
	Ray Dunlop	New England Electric
	Carlo LaPorta	UST

Stretched-Membrane Dish	Hisashi Yasumori	Kawasaki Steel, Tokoyo
Tech Transfer Contacts	Randy Gee	Industrial Solar Technology
	Tom Volek	NM Solar Energy Industries Assn.
	Britt Reed	Utah Division of Energy
	Mary Mercado	Washington Middle School
	Fred Grissom	Consultants
	Don Barrlet	Plains Electric
	Ed Saunders	Ruth Fisher School, Phoenix
	Dave Knipfer	Gould Electronics
	Lori Cameron	SW Energy Council
	Jeff Webb/Jim Baca	New Mexico Land Office
	Harold Trujillo	N.M. Energy Minerals Dept.
	Bill Lawrence	VA Hospital, Albuquerque
	Jerry Trojan	City of Las Cruces
	Susie Thomas	Virginia Division of Energy
Trough Design	John Reardon	University of New Mexico

NREL Industrial Contacts

Industrial Contacts on Optical Materials

CONTACT	ORGANIZATION	COMMENTS
G. Shier and W. Schrenk	Dow Chemical	Alternate reflector materials
F. Wilkinson	Integrity Systems	Aluminum reflectors
D. Dahlen	3M Companuy	Optical measurements of outdoor samples from Phoenix and Miami
K. May and R. Gee	IST	Alternate reflector materials
K. Beninga	SAIC	Alternate reflector materials
J. Hanoka	Mobile Solar	PMMA films
B. Klein and D. Nick	Business Factors, Inc.	Alternate reflector materials

II. TECHNOLOGY DEVELOPMENT

A. Concentrator Technology

1. Heliostats

Objective: Establish commercial readiness of the heliostats for central receiver solar thermal electric applications.

Accomplishments

There were no significant accomplishments in the area of heliostat development this quarter.

Planned activities next quarter

- Testing and evaluation of SPECO's 200 m^2 heliostat, STS's 150-m^2 heliostat, and Winsmith's low-cost heliostat drive will continue.
- Testing and evaluation of SAIC's 100-m^2 stretched-membrane heliostat will continue.

2. Parabolic Dishes

Objective: To bring parabolic dish concentrator technology to technical readiness for use in dish/Stirling electric systems.

Accomplishments

Contracts for the fabrication of facets for the Faceted Stretched-Membrane Dish placed.

The contracts for fabrication of the facets for the Faceted Stretched-Membrane Dish were placed with Science Applications International Corporation (SAIC) of San Diego, California, and with Solar Kinetics Incorporated (SKI) of Dallas, Texas, in October. In Phase 2 of the project, these two contractors will each fabricate twelve facets for installation on the drive pedestal/support structure that will also be fabricated in Phase 2 of the project.

In addition to the twelve facets, SKI and SAIC will provide the facet focus and control systems for the dish. Both contractors will be using the designs that they developed during Phase 1 of the project: SAIC will make elastic facets, which are similar to the stretched-membrane heliostats, with a membrane position-sensing focus control; and SKI will pre-form their facets and focus them by controlling

the vacuum level. SAIC plans to deliver facets to Sandia in early June 1992, and SKI intends to deliver their twelve facets in late July 1992.

When delivered to Sandia, all or some of the facets will be tested to verify their performance and correct operation. Tests will be performed to verify that: the facets were not damaged in shipping; the dimensional specifications of the facet and the mounting-bolt holes are correct; the facets demonstrate slope errors similar to those measured in Phase 1 of the project; the focus system dead band is correct; vacuum and focus control systems take the facet from a no-focus to a fully-focused position in less than 5 minutes; and the vacuum and focus control systems hold the focal point of the facet within ± 10 cm for 8 hours on two consecutive days. Sandia is responsible for completing the acceptance tests within two months of the facet delivery.

In addition to the facets, SKI and SAIC will also deliver: Facet and Control System Installation Plans, Facet and Facet Control System Operating Procedures, and Maintenance Manuals; two complete sets of as-built 35mm aperture cards for the facet vacuum and facet control systems; and a Final Report.

The design of the drive pedestal and support structure for the Faceted Stretched-Membrane Dish was completed.

WG Associates of Dallas, Texas, completed the scaled-down design of the pedestal and the facet support structure for the Faceted Stretched-Membrane Dish. The design modifications were made to accommodate *downsizing* of the facet diameters from 3.5 to 3.0 meters. We used the redesign phase as an opportunity to improve on a number of design issues including: reevaluation of the elevation drive, simplification of the transition section design, and redesign of the facet mounts on the support structure. None of these changes alters the concepts developed as part of the Phase 1 dish design, but they do simplify the fabrication and reduce the cost of the structure. Engineering drawings have been delivered to Sandia for distribution to the other project participants.

Kickoff Meeting Conducted for Phase 2 of the Faceted Stretched-Membrane Dish Project.

On Thursday, November 14, 1991, the Phase 2 Kickoff Meeting was held for the Faceted Stretched-Membrane Dish Development Project. The meeting was attended by the two contractors who will fabricate facets for the dish, Solar Kinetics, Inc. (SKI) of Dallas, Texas, and Science Applications International Corp. (SAIC) of San Diego, California, WG Associates, the structure designer, and staff from Sandia and the NREL. The morning session of the meeting comprised presentations by SAIC and SKI on their facet fabrication plans and schedules, and a presentation by WG Associates on the structural design modifications. In the afternoon session of the meeting, we discussed the installation of the dish at

the NSTTF and the alignment and focusing of the facets. Two staff members from one of Sandia's safety groups were present to serve as consultants on pertinent issues.

Request for Quotation for fabrication of the drive pedestal and support structure for the Faceted Stretched-Membrane Dish released.

The Request for Quotation for fabrication of the drive pedestal and facet support structure for the Faceted Stretched-Membrane Dish has been released. The response to the RFQ is due back at Sandia by January 30, 1992.

Planned activities for next quarter:

- Place contract for fabrication of the drive pedestal and support structure for the Faceted Stretched-Membrane Dish.
- Review replacement of the optical film on the 7-meter diameter optical element.
- Modify the NASA tracking structure to accommodate testing of facets for the Faceted Stretched-Membrane Dish.

3. Optical Materials

Objective: Perform appropriate R&D to obtain materials for concentrators which have improved duratilbiy and performance, increased service lifetimes, and decreased cost.

Accomplishments

Progress was made on research and development proposed and cost-shared by industry on collaborative alternate reflector materials.

Technical reviews and cost analyses were performed for eleven industrial responses to a NREL solicitation for a Letter of Interest for research and development on alternate reflector materials. Based upon these reviews, a source selection committee determined that four proposals were technically acceptable and that three of these were within the budgetary guidelines. Clarification of technical and cost issues were obtained from the three proposers within the competitive range. Technical, quantitative, and qualitative reviews were performed and documented for these three proposals. All three proposals were found to be solid and acceptable. Recommendations for negotiations were provided, and a high priority for placement of these subcontracts was urged.

Negotiations were initiated with the three companies determined to be within the competitive range. The three concepts which will be investigated are a directly deposited reflective surface, an all-polymeric solar reflector material, and a metallized Teflon polymer reflector. Statements of work were written for each of these proposals and were delivered to the responsible subcontract administrator for further action. It is anticipated that one subcontract will be awarded in late January 1992, and the other two during February 1992.

An analysis of costs for material and processing of metallized polymer reflectors, carried out under a consultant agreement by Business Factors, Inc., is nearly completed.

The purpose of this activity is to determine if other metallized polymer mirror configurations, which have potential for meeting the optical and durability goals, can be fabricated for significantly less cost then ECP-305, the present state-of-the-art polymer reflector.

Several teleconferences were held between NREL personnel and Business Factors, Inc. (BFI), to track their progress. BFI researchers indicate that they have uncovered a number of interesting insights that will be documented in their final report. A drafted report of their findings and results was delivered to NREL in December. This report is being reviewed by NREL and Sandia staff, who will attend a presentation by BFI at NREL in early January, 1992.

Preliminary results are available for a set of silvered fluoropolymer film reflectors exposed in the solar-simulator accelerated weathering chamber at 60°C and in an Atlas Weather-Ometer (WOM.)

Although the cloudy appearance of such films causes concern with regard to specularity, unmetallized films have demonstrated excellent weathering characteristics. Cost estimates suggest that certain fluoropolymer films could provide an attractive alternative to the current material of choice (acrylic) used in polymer reflectors.

Teflon FEP and Tefzel (a modified TFE polymer) films were provided by DuPont. Silver deposition was performed at NREL by using a sputtering apparatus. The sample set consisted of: (1)silvered Tefzel; (2) silvered Teflon; (3) silvered Teflon having a protective coating between the polymer film and the metal layer; and (4) silvered Teflon having a protective coating behind the silver. A sheet adhesive was used to bond the reflector materials to bare aluminum substrates.

All samples exhibited very high initial (unweathered) values (95 percent to 96 percent) for solar-weighted hemispherical reflectance. After one week of exposure in the solar simulator chamber, the first three samples previously

mentioned had all visibly tarnished and experienced over 10 percent loss in reflectance. The silvered Teflon sample with the protective back coating, however, had not degraded. After four weeks of exposure, the reflectance of this promising sample had dropped to 84 percent. These results are in agreement with two-month test results for exposure in the Weather-Ometer.

Progress has been made on a site selection and test plans for an expanded outdoor test program for optical materials.

Sandia staff members have provided the names and contacts of various utility companies which have expressed interest in actively supporting solar thermal electric technology, in particular, by financial investment in Solar Two. These companies will be contacted to discuss NREL's plans to activate several outdoor test sites to demonstrate the real-world durability of candidate optical materials. Utilities will be encouraged to contribute to the effort by providing land at the proposed test sites, maintenance staff, and/or weather data.

A survey was begun on the availability of insolation and measurement of atmospheric data near potential outdoor test sites of interest. Environmental information of interest includes global and direct normal insolation (total solar and ultraviolet light), humidity, temperature, wind speed, wind direction, precipitation, and ambient pollutants such as nitrous oxides, SO_2, etc. The names of several people and organizations who are currently involved with these types of measurements and who might be of some help in the outdoor testing project have been identified during discussions with resource-assessment personnel at NREL. The subject of ultraviolet measurements also was discussed, and additional information was obtained on how these measurements are made and on what instrumentation is available.

Results of outdoor and accelerated weathering for a variety of materials related to ECP-305 provided an updated indication of the optical durability of this class of metallized polymer reflectors.

Samples of ECP-305 which have experienced two years of outdoor weathering in Arizona and in Florida have been made available by the 3M Company to NREL for optical measurements. Previously reported results for the experimental precursor to ECP-305 (designated 719-37-G) indicated significant degradation by 24 months of outdoor exposure at these sites. The current data confirm this result for ECP-305 mounted on bare aluminum (Al) substrates. However, ECP-305 mounted on painted (coil-coated) A1 (PAl) substrates continues to exhibit good optical durability. Outdoor test results for various sample constructions and exposure sites are shown in Figure 2.

After two years exposure in Arizona the average reflectance of four samples of ECP-305 mounted on painted A1 is 90.8 percent. In accelerated exposure tests in

an Atlas Weather-Ometer (WOM), ECP-305 is found to degrade to 90.8 percent in approximately 5.5 months. Thus, an acceleration factor of approximately 4.4X is found between the WOM and outdoor exposure in Arizona. Extrapolating outdoor life based upon WOM results (90 percent reflectance in 8 months) predicts that degradation to 90 percent reflectance in Arizona will occur after approximately 3 years (rather than 5 years, which is the present program's goal).

Assuming the acceleration factor remains 4.4 under all circumstances (i.e., is linear with time and does not vary from one material to other similar materials), then an increase of 2X to 3X in WOM durability is required to project an outdoor life for the ECP-305 material of 5 to 10 years. Two types of mirrors mounted on coil-coated A1 have maintained reflectance above 90 percent for more than 24 months in the WOM. 3M mirror type 719-37-K (Rohm and Haas polymer with no ultraviolet stabilizer added) has a reflectance of 91.5 percent at 28 months (Figure 3). 3M-mirror type 719-37-F (Continental polymer with no ultraviolet stabilizer added) has a reflectance of 90 percent at 26 months. The reflectance of both types, K and F, is beginning to decrease significantly at these respective exposure times. One concern with regard to these materials is their visual loss of specularity long before it is exhibited by analogous materials having ultraviolet additives (types L and G, respectively).

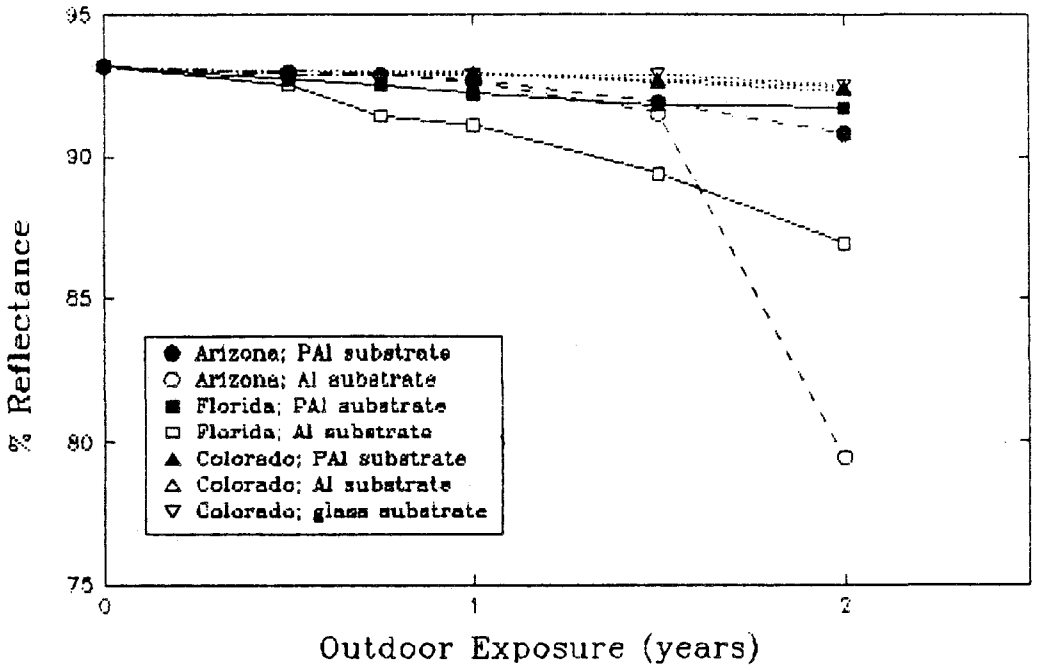


Figure 2. Solar-weighted hemispherical reflectance of ECP-305 as a function of substrate and outdoor exposure.

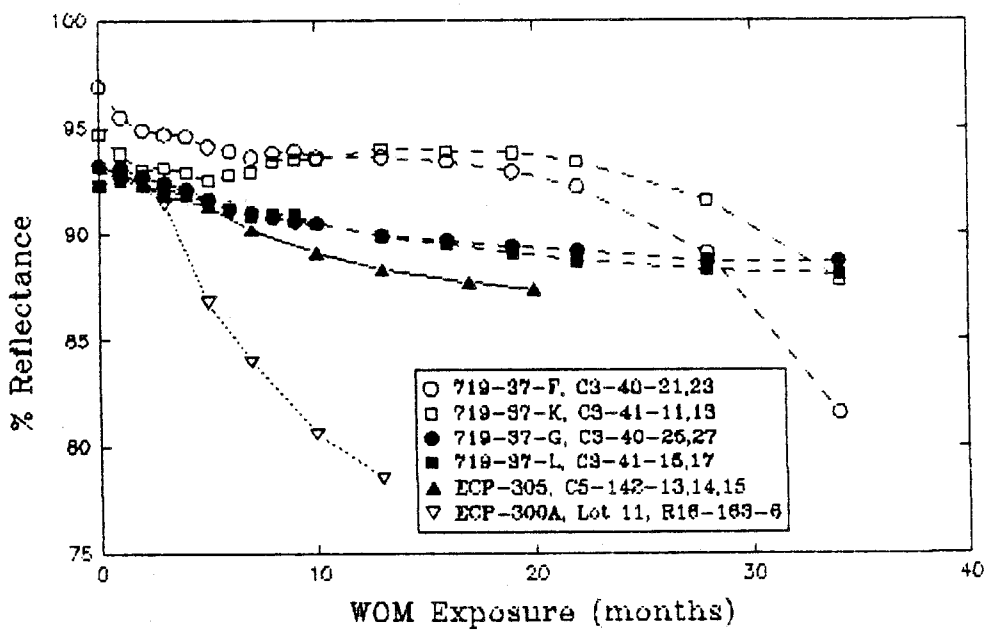


Figure 3. Solar-weighted hemispherical reflectance of silvered polymer reflectors on PA1 substrates as a function of WOM exposure.

Accelerated tunnel tests conducted at NREL suggest that thermal treatment of ECP-305 is effective at preventing delamination failures even for samples bent to realistic curvatures after substrate lamination and heat treatment in a flat configuration.

Several sets of curved samples (18 inches by 24 inches) have been in the static water bath tunneling test for up to three months. All samples were ECP-305 cut with a razor blade and mounted without edge tape onto aluminum substrates. Nineteen mounted samples were bent to approximately a fourteen-inch radius of curvature (single axis) and then were thermally treated at 80°C for 65 hours. None of the samples that were thermally treated after bending tunneled for up to three months in water. Twelve samples were thermally treated (80°C, 65 hours) after mounting and then were curved to a fourteen-inch radius. By one month, 10 of the 12 samples had tunneled. Eleven additional samples were thermally treated (80°C, 65 hours) after mounting and then curved to a seventy-inch radius. None of the eleven samples tunneled after 3 months in water. In summary, samples which are thermally treated after bending do not tunnel and samples that are bent to a radius between 70" and 00 do not tunnel even when curved after thermal treatment.

Several important instruments recently have been repaired or upgraded.

The magnetron sputter deposition system has been unavailable for two months due to a vacuum leak which could not be isolated by a helium leak detector because the existing sorption pump could not pump helium. A mechanical roughing pump, which is capable of pumping helium, was installed in parallel with the sorption pump. Under normal operation this pump will allow more rapid evacuation of the deposition chamber without the expense associated with using liquid nitrogen. Subsequent to installation of the new roughing pump, leak checking was carried out, and the vacuum leak was found to have been repaired. The magnetron unit will be used to prepare samples of alternate reflector materials designed by NREL researchers.

An Instron mechanical test instrument has been set up at NREL and is now operational. Air lines have been run to allow operation of the pneumatically actuated grip system. A Safe Operating Procedure previously had been written and approved for this equipment. This apparatus will be used to perform tensile testing of candidate superstrate materials for polymer films as well as adhesion measurements of various interfaces comprising metallized polymer reflectors.

The data acquisition and control software for the Reflectometer II (which allows measurement of specular reflectance as a function of collection aperture at specific wavelengths) has been re-written to allow this instrument to be interfaced with an IBM compatible computer. Previously, an HP-85 computer was used and exhibited problems in reliability and inflexibility in terms of data

reduction and archiving. The new system will greatly facilitate the accumulation of optical measurements directly into a data-base system. Routine ease of generating reports and graphical display also will be allowed.

Planned activities for next quarter

- Initiatives for subcontracted research and development on alternate reflectors will begin.
- Parallel and complementary work at NREL on alternate reflector materials will continue; candidate constructions will be prepared, optically characterized, and subjected to accelerated and real-time durability testing.
- Outdoor exposure test sites will be identified, and plans for expanded outdoor exposure testing of materials will be documented.

B. Power Conversion

1. Central Receiver Technology

Objective: Develop central receiver technology in direct support of the central receiver commercial applications programs.

Accomplishments

Molten salt Pump and Valve Test final report completed.

Final approval of the molten salt pump and valve test report has been obtained. The report will be published in January.

Bechtel selected for the thermal storage and steam generator study contract.

A contract has been placed with Bechtel to evaluate design, cost, and warranty issues associated with molten salt thermal storage and steam generator designs. In order to select a design for the Solar Two project (a retrofit of the Solar One pilot plant with molten salt technology), an optimal design for a 100 MW_e plant needs to defined. The Utility Studies, completed in 1988, proposed a baseline design for all the major subsystems in a central receiver power plant. However, the thermal storage and steam generator are two subsystems in which a number of design issues have been raised. The design, cost, and warranty of these two systems need further definition.

A review of design and construction experience of existing large hot tank systems will be conducted. Bechtel will solicit information from contractors on the designs for hot tanks. Bechtel will conduct an evaluation which will consider the feasibility of the design, capital costs, operation and maintenance procedures and costs, and the availability of warranties. A report will be written documenting the information and the results of the comparison.

A review of design and construction experience of large steam generator systems will be conducted. The review will include the Utility Studies, the B&W steam generator report, and the SEGS experience with kettle boilers. Bechtel will solicit information from manufacturers on the design, fabrication, cost, and warranty of the U-tube/U-shell steam generator system, the straight-tube/ straight-shell steam generator designs, and on the kettle boiler evaporator design. Using the information provided, along with information from the initial review, a comparison of the three different approaches will be conducted. As in the case of the storage study, the evaluation will consider the feasibility of the design, capital costs, performance, operation and maintenance procedures and costs, and the availability of warranties. A report will be written documenting the information and the results of the comparison.

This study will help define the commercial system and the selection of the Solar Two subsystems. The study is expected to be completed in six months.

SPECO to prepare design specifications for Central Receiver Power Plants.

Southern California Edison (SCE) has established a contract with Solar Power Engineering Company (SPECO) to prepare design standards for central receiver power plants. The document and its contents will be the basis for the design of the Solar Two plant and for future molten salt central receiver systems and component design.

SPECO will prepare an outline for design standards for the entire central receiver molten salt plant. The current scope of work calls for detailed design standards to be established for molten salt components only (e.g., pumps, valves, heat trace, etc.);, other systems will be detailed later.

Sandia is supporting SCE in their contract with SPECO. The detailed design standards on the molten salt components are to be completed in six months, in time to support the initial design of Solar Two.

Sandia plans molten salt corrosion tests.

Sandia, at the request of SCE, is planning experiments to determine the suitability of molten nitrate salts, with chloride levels between 0.2% and 0.7% by

weight, for use in central receiver power plants. The motivation for these experiments is the interest in Chilean nitrate salts, which may be significantly cheaper (by as much as 40%) than the current salt source, but which have relatively high levels of chlorides. Experimental results will show effects on material corrosion and the long-term stability of the salt.

This issue was addressed earlier, but with the specific mixture "Solar Salt" with less than 1% total impurities (by weight). The composition of "Solar Salt" was defined by Olin Chemical Corp. in 1980. The Olin composition of "Solar Salt" consists of high purity 60% sodium nitrate and 40% potassium nitrate, by weight. The impurity level for sodium chlorides (NaCl) in solar salt is 0.3 % by weight. Numerous tests were conducted in the early 80's to understand the effects of nitrate salts on material corrosion. However, almost all the tests were conduced with very pure nitrate salts.

The objectives of these experiments are:

1. Evaluate the effects of chloride levels of up to 0.7 %, by weight, on the corrosion characteristics of carbon and stainless steels.

2. Evaluate the suitability of Chilean nitrate salts (three different grades) for use in molten salt central receiver solar plants.

3. Evaluate the decomposition, if any, of the nitrate salts during long-term testing.

These tests will be conducted at the Solar Thermal Test Facility. There will be two vessels with five to ten kilograms of salt for each of six different salts. Each salt will be tested in a carbon steel vessel at 400^{o}C and a stainless steel vessel at 600^{o}C. The vessels will contain metal coupons which will be examined periodically to determine corrosion effects during the 4000-hour test period.

The experiment assembly will begin early next quarter and testing will begin late next quarter.

Review of the second generation central receiver study completed.

The second generation central receiver study was sent out for review last quarter. This joint US/German effort to compare the cost and performance of molten salt and volumetric-air central receiver power plants was initiated in the fall of 1989. The study was reviewed by experts in the US and Europe. The Sandia and DLR study participants are currently determining how to resolve the reviewer comments.

Volumetric air receiver testing completed at New Mexico State University.

The contract with New Mexico State University to test volumetric air receiver absorber materials was completed last quarter. The contract with Bechtel to design and fabricate a volumetric receiver absorber, to be tested at the Plataforma Solar, is on hold pending US approval for involvement in the IEA and the IEA's agreement to test the absorber. No work has been initiated on the modeling of volumetric receivers until US involvement in the IEA is defined.

Planned activities for next quarter

- A meeting will be held to review the progress on the thermal storage and steam generator study.
- A meeting will be held in January at the to provide input to SPECO on the molten salt central receiver design standards.
- The test apparatus design, test plans, safe operating procedures, and preliminary hazardous assessment will be initiated for the molten salt corrosion tests. Fabrication of the test apparatus will begin next quarter.
- Reviewer comments on the Second Generation Central Receiver study will be resolved and final report will be prepared for publication.

2. Dish Receiver Technology

Objective: Develop liquid metal reflux receiver technology in direct support of industry-led commerical programs and investigate advanced concept for long-term reliable and low-cost receivers.

Accomplishments

Completed scheduled tests of bench-scale NaK boilers (Dec'91 milestone).

Sandia engineers have completed scheduled tests on four bench-scale pool boilers. The tests are part of an effort to evaluate materials and methods for the next-generation liquid-metal reflux-pool-boiler receiver. The materials and methods that are under consideration have been selected based on their potential for long life and economical operation. The selected materials are Haynes Alloy 230 for the vacuum envelope and NaK-78 for the heat-transfer fluid. The methods under consideration are laser-drilled holes and various sintered-powder-metal coatings to stabilize boiling. Also studied was the effect

on boiling behavior of gas additions to the boiler vapor space and heated-surface orientation. The bench-scale boilers were cylinders 1.75" in diameter and 36" long, heated using a quartz-lamp array. The tests were run on 16 separate days over a period of 16 weeks. The major conclusions are: (1) none of the bench test pool boilers met the requirements for stable boiling, (2) inert-gas addition and test-vessel tilting reduced but did not eliminate boiling instability. A detailed report on these results has been distributed to Sandia's counterparts in the solar pool-boiler community.

Based on the test results, construction of four more bench-scale boilers has been initiated. Tests of a number of additional boiling-stabilization candidates are planned, including electric-discharge-machined holes, a Thermacore-fabricated sintered-powder surface, several Friction-Coatings-fabricated sintered-powder surfaces, and a screen overlay of one of the previously-tested powder coatings.

Cummins durability heat-pipe fabrication completed and testing started.

The Thermacore heat-pipe receiver is a key element in the Cummins 5-kW dish-Stirling system. Previous receivers have shown significant progress, but continued difficulties have centered around the absorber wall-wick bond. Thermacore appears to have solved the problem, and Cummins has begun testing the next Durability Heat Pipe on schedule. Cummins has a very aggressive schedule to deliver complete systems this summer.

CPG and Thermacore completed fabrication and ground-testing of the durability heat pipe Number 2 and shipped it to the CPG facility in Abilene, Texas, for on-sun testing. Mark Bohn (NREL) met with CPG and Thermacore on December 10 to observe the last part of the ground-testing and to discuss results and future plans. This receiver incorporates the optimized nickel-plating thickness that resulted from the detailed investigation of the reasons for the formation of hot spots on the absorber dome of the first durability receiver. In addition, the heat pipe wick was sintered to the absorber dome by a new technique that significantly improves the absorber and wick bond. Details are presented in the Joint Venture Program description in section I.B. of this quarterly. The ground test, which is performed with radiant heat lamps, was completed without any problems. The heat pipe was received in Abilene on Monday, December 16, and began a five-hundred-hour durability test the next day. Chuck Andraka, Rich Diver, and Mark Powell (Sandia) attended the first on-sun test, and discussed test plans and goals. Although formal NREL involvement is complete (the final report on the project is due in January), CPG offered to send NREL continuing monthly reports. The durability testing phase is funded by Sandia through the dish-Stirling Joint Venture Program.

Dynatherm heat-pipe receiver tested.

The Dynatherm receiver has begun testing at Sandia, and has set a new record for thermal energy throughput for an on-sun heat-pipe receiver.

The Dynatherm heat pipe receiver was funded by Cummins for possible application to the 5 kW dish-Stirling system. The receiver uses Sandia-provided 316L stainless steel domes and a screen wick assembly. Cummins specification was for 30kW throughput, and the Dynatherm design point is nearly 40 kW throughput.

Initial tests of the receiver were performed on Friday December 6, 1991. The receiver reached 450°C before the sun got too low to continue testing. After modifications to the infrared (IR) camera, the receiver was again tested on Friday December 13, 1991. The receiver was tested on the Sandia 60kW solar furnace. After a slow ramp up in power, the receiver reached a peak throughput power of 27 kW, with a furnace solar input of about 47 kW. This is a new record for thermal energy throughput, and would be sufficient to operate the Cummins 5kW net engine. The high losses (20 kW) are due to the lack of an aperture on the receiver. Losses would be about 5-6 kW with a proper aperture.

The aperture was omitted for these tests in order to view the entire absorber surface with the IR camera, providing early detection of possible wick dryout. The solar input was limited to 47 kW due to poor solar conditions caused by volcanic ash and excess moisture. Fifty-four kW solar input can be expected on a dryer day, but 60 kW input will have to wait until the ash settles out of the upper atmosphere. The dish in tracking mode should be able to deliver about 65 kW under current conditions.

The operation of the Dynatherm receiver demonstrated the flexibility of Sandia's new 60 kW solar furnace. The input to the receiver could be carefully controlled during early stages of testing, and different solar conditions can be simulated. After limits are established, tracking-mode testing can proceed without the need to re-install the receiver. In fact, the furnace will be used to melt the sodium prior to tracking mode testing. The receiver is mounted horizontally in the furnace, which is the most demanding orientation for a heat-pipe receiver. Limits established by the furnace-mode testing should therefore be absolute.

During the next quarter, testing of the receiver will continue. Faster ramp rate starts are planned, as well as higher power tests. Tracking tests will confirm the operation of the receiver in all orientations. Cold start tests will complete the test matrix after additional hours are put on the receiver.

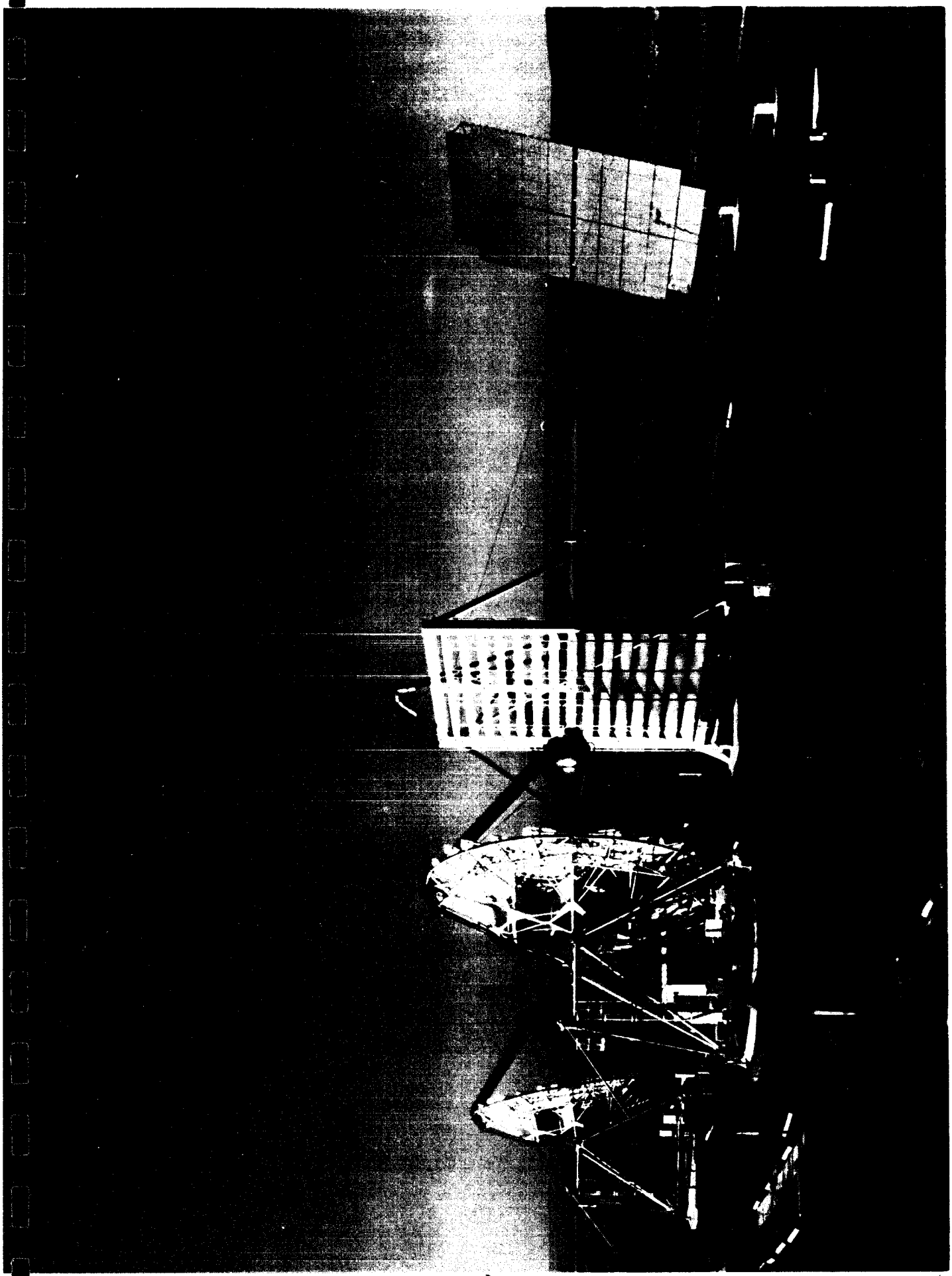


Figure 4. Dynatherm 30kW heat-pipe under test at the NSTTF.

Sandia solar-blind imaging radiometer assembled and tested.

Sandia has developed a new infrared (IR) solar-blind thermal imaging camera for use in testing reflux receivers. The camera views a narrow energy band around 1.85 microns, which is an atmospheric water absorption band. This allows mapping of the surface temperature in a non-intrusive manner (as opposed to many thermocouples).

The system consists of an uncooled lead sulphide (PbS) vidicon, a lens, a specially designed narrow-band transmission filter, and a remotely positioned filter wheel. The entire system is mounted in a weather-proof housing. The system is substantially less expensive than the commercially available Inframetrics system, has much better spatial and thermal resolution, and does not require liquid nitrogen cooling. The system also includes a recorder, a video analyzer, and a colorizer.

The new solar-blind IR camera was demonstrated during the initial Dynatherm receiver testing. The camera gives the ability to measure the temperature of the entire absorber surface on a pixel resolution. Equipment connected to the IR camera allowed the display of the peak temperature found on the surface, as well as automated shutdown on an overtemperature anywhere on the surface. This gives the capability of thousands of thermocouples scanned 30 times per second. No hotspots were detected during the day's testing. The excess sodium pool could be detected at the bottom of the absorber dome. The pool runs slightly hotter due to the longer thermal conduction path to the pool-vapor interface. This demonstrated the excellent thermal resolution of the camera.

Stirling Thermal Motors receiver development program updated.

Stirling Thermal Motors (STM) is continuing to develop a heat-pipe solar receiver with their own internal funds, and, to encourage this mutually beneficial program, Sandia is providing limited assistance to STM's effort. In the last quarter of FY91, a bench-scale receiver that was constructed by STM failed to operate properly when it was tested at Sandia. At the time of this test, it was suspected that a screen-bridge connecting the artery to the surface wick in the heat pipe was unable to transport an adequate supply of sodium to cool the heat pipe's absorber surface. Tests that were performed at Sandia on the bridge and artery system, however, showed that the flow capabilities of the bridge was more than adequate to meet the needs of the heat pipe system.

One of the few remaining explanations for the failure of STM's bench-scale receiver is that the artery deprimed at some point during the system's operation either at STM or Sandia. A residual gas analyzer scan of the heat pipe's vapor space indicated that air had leaked into the heat pipe. The presence of non-condensible gases in a heat pipe can cause arteries to deprime. A close

inspection of the heat pipe revealed a small pit near a weld that could have opened during high temperature testing. (As a heat pipe cools, sodium often plugs small leaks and makes it difficult to positively identify leaks until after the sodium is removed.) STM's bench-scale receiver has been moved to a glove box and the disassembly of the heat-pipe is currently under way.

To provide STM with additional assistance in their program, Sandia also modified its receiver wick code to predict the pressure distribution in a new wick system that STM is presently investigating. This new wick design will use a self-priming artery system that is made of a thick stack of sintered screens. The artery system will be configured in a radial and circumferential artery pattern, and then spot welded to the surface of a screen-covered dome that was developed in STM's earlier program with Sandia.

Sandia 75kW$_t$ heat-pipe receiver development initiated.

Sandia has renewed its efforts to internally design and construct a 75-kW (thermal) receiver for the dish/Stirling electric program. During the first quarter of FY92, plans were developed for a new wick system that is simple to construct and avoids the problems encountered in earlier designs. The new wick system will use arteries that are formed by rolling a thin strip of stainless steel into a loop and then sintering a few layers of screen into the open edge of the loop. The sintered-screens along the edge of the artery loop act as a bridge that can be connected to a screen covered evaporator surface. Several of these arteries will be mounted in a hub and spoke pattern over the evaporator surface of the heat pipe receiver to transport large quantities of liquid to the heated surface. Sandia's wick model has been used to predict the optimum arrangement for the wick system.

Sintered artery samples have been formed and they are now undergoing permeability and pore-structure tests. Construction has begun on a small bench-scale receiver to test the new wick concepts. An investigation is also under way to determine if a packed version of the new artery design can be used to form a completely self-priming artery system.

NREL Hybrid reflux receiver solicitation expanded.

The objective of this solicitation is to design, fabricate, ground-test, and field-test a 10 kW$_t$ reflux receiver capable of operation with concentrated solar flux or natural gas. Researchers anticipate that development of the receiver is critical to successful commercialization of the dish/Stirling concept by providing penetration to those markets where continuous power generation is required.

During this quarter the solicitation was expanded so that two awards could be made. Due to limited funding, however, only two design phases will be funded

in FY 1992, with the two fabrication and testing phases to be funded in FY 1993. Awards for the first phase should be made by March, 1992.

Southern California Gas Company committed to support the Hybrid Receiver Program.

Southern California Gas Company has stated in writing its intent to provide financial support to the Hybrid Receiver Program. The company committed "up to $150,000 over the 18 month period as contribution from the gas industry." Depending on which proposals are funded, this industrial contribution represents between 18 percent and 26 percent of the total project's cost. The Gas Company wants NREL to select the winning proposals, but wishes to review the winning proposals to determine appropriate contractual arrangements among all parties.

A Joint Work Statement was formulated to develop a non-reflux receiver for dish/Stirling applications.

Researchers prepared the draft of a Joint Work Statement for the Solid Receiver Task. In this task, NREL will collaborate via a Cooperative Research and Development Agreement with Cummins Power Generation (CPG) to develop a non-reflux receiver for dish/Stirling applications. The idea originally was submitted to NREL by CPG as an unsolicited proposal with the intent of developing an alternative to the heat-pipe receiver. Since the work plan involved a number of elements to which NREL could directly contribute, CPG and NREL agreed that a collaboration was a good approach.

A three-phase plan is envisioned. In the first phase, NREL will investigate several potential approaches. This investigation will involve literature searches, discussions with material suppliers, and thermal analyses. For the most promising candidates, materials testing will be performed in the laboratory and at the High Flux Solar Furnace to determine expected lifetime of the proposed materials of construction. If satisfactory, a preliminary technology assessment will be performed so that a fair comparison can be made with the heat pipe. Assuming a decision is made to proceed to Phase II, NREL will fund CPG to design, fabricate, and ground-test a full-scale receiver based on the concept. CPG then will perform on-sun testing at its facility to provide data on performance and durability. Based on these data, NREL will update the technology assessment to allow CPG to decide if the concept should be dropped or tested further, or if it is ready to be commercialized. Phase III would see CPG carrying out the steps necessary to place the concept in the field in commercial applications. The Joint Work Statement has been submitted to CPG for comments.

On-sun pool-boiler receiver documentation reviewed.

A final draft version of the full-scale pool-boiler's on-sun documentation has been reviewed by the authors, and all of the figures have been completed. Tech Reps, a Sandia contractor, is preparing the final form of the document for management review.

The documentation of the on-sun x-ray studies has also been completed and published.

Initiated design of 2nd-generation NaK steam-cleaning system.

Based on the successful demonstration of a prototype system for the reactive steam cleaning of NaK-contaminated hardware, design of a 2nd-generation system has been started. This system is being designed as a permanent installation that will be safer and much more convenient to use than was the prototype.

Planned activities for next quarter

- **Testing will be started on additional bench test pool boilers.**

The planned pool-boiler bench-test receivers tested this quarter led to the development of several new devices, which will be tested starting this next quarter. The tests will include the following boiling-stabilization candidates for the next-generation pool-boiler receiver: electric-discharge-machined holes, a Thermacore-fabricated sintered-powder surface, several Friction-Coatings-fabricated sintered-powder surfaces, and a screen-overlay of one of the previously-tested powder coatings. The long-term (10,000 hour) bench test implementation is on hold pending the results of these additional materials and methods bench tests.

- **Cummins durability heat-pipe receiver testing continued.**

Cummins will continue to test the new durability heat pipe in Abilene. After at least 100 hours at the 675°C operating temperature, Thermacore will begin fabrication of receivers for the first delivery systems. This should occur during the second quarter. The testing goal is 500 hours at 675°C, which is expected to be reached during the third quarter. The receiver testing is supported through the DOE Joint Venture Program.

- **Complete testing of Dynatherm heat pipe receiver.**

NSTTF's testing of the Dynatherm heat-pipe solar receive will be completed on the 60 kW solar furnace. Planned testing includes operation

to the limits of the receiver, and operation at all orientations in the tracking mode. Results of the testing will be provided to Dynatherm and Cummins.

- **Complete design and order next-generation pool-boiler receiver parts.**

A design review of the next-generation pool-boiler receiver will be completed, and a contract will be let for parts fabrication. A decision on the method of boiling stabilization will be deferred until the bench-scale tests have been fully evaluated. Implementation of the stabilization method and final assembly of the receiver will be done in house following the bench tests. Two receiver shells will be ordered. One shell will be complete with a condenser suitable for the gas-gap cold water calorimeter. The second receiver will only have the absorber end complete, allowing integration to the STM engine system. The absorber dome rim weld will be performed by Sandia after the application of the selected boiling initiation surface modification.

- **Requests for proposals/quotes for 75kW$_t$ heat-pipe receivers to be prepared.**

Based on success of the Thermacore and Dynatherm 30kW$_t$ receivers, a request for proposal or quote will be issued by Sandia to apply similar technology to a 75kW$_t$ heat-pipe receiver. The immediate goal is to provide a suitable receiver for the STM engine on-sun testing. The receiver also has application to ASCS engines and the second joint venture program.

- **Hybrid reflux receiver development awards anticipated.**

NREL expects awards for the first phase of the hybrid reflux receiver development contracts should be made by March.

- **X-ray testing evaluation to be studied.**

Sandia engineers will evaluate alternatives for continued x-ray studies for on-sun pool-boiler receiver testing. If new methods address the difficulties experienced during the on-sun testing, we will commit to developing those methods for the next-generation test. Otherwise, further x-ray studies will be discontinued.

- **Stirling Thermal Motors heat-pipe receiver development support to continue.**

A copy of Sandia's wick code that was modified to model STM's new wick arrangement will be delivered to STM. Sandia plans to also perform tests on a new bench-scale receiver that STM is fabricating. Testing in this

quarter, however, is contingent upon STM's timely delivery of the bench-scale system.

- **Sandia 75kW$_t$ receiver development to continue.**

Construction of a bench-scale receiver to test Sandia's new receiver design concepts will be completed, and samples of metal felts and wools will be obtained for permeability studies. Information on the permeability and capillary pumping capabilities on felts and wools will be used to assess the feasibility of constructing a completely self-priming artery system for heat-pipe solar receivers.

- **Steam cleaning design to be completed.**

The next-generation steam cleaner design will be completed and hardware implementation will begin.

- **Program will support DOE peer review.**

A significant effort will be expended on preparation for the presentation of the receiver projects for the DOE peer review scheduled for March.

3. Dish Converter Solarization

Objective: In cooperation with industry, test and evaluate conversion devices applicable to solar thermal electric technology and respond to solar-specific issues.

Accomplishments

Stirling Thermal Motors (STM) continues to accumulate STM4-120 operating hours.

During 1991, STM has been cooperating with Detroit Diesel Corporation (DDC) to develop the STM4-120 kinematic Stirling engine for commercial applications, with production manufacturing, assembly and marketing by DDC. The commercialization efforts and application evaluations have been described in recently published papers co-authored by DDC and STM.

During 1991, STM began testing the first prototype of a direct-fired version of the STM4-120 Stirling engine. A total of 606 hours of operation were logged on two different engines, with 524 hours on Engine #1001 and 84 hours on Engine #1003. Furthermore, Engine #1001 operated 453 hours between 7-15 kW, and 24 hours

above 20 kW. Engine #1003 has operated nearly all of its hours between 7-15 kW.

These tests were part of a comprehensive engine development program and test plan being implemented at STM and includes an Incident Reporting and Corrective Action System (IRACAS), as well as increasing participation of DDC engineering and manufacturing personnel in reviewing the design of the STM engine.

The design of the reciprocating components in the engine has been under evaluation at DDC/STM to determine the manufacturing cost for production quantities greater than 5000 per year, and to compare the basic design parameters consistent with standards in the heavy duty engine industry. The design evaluation indicated that improvements in safety factors were needed to meet the heavy duty engine industry standards and several areas were reviewed and redesigned with feedback and finite element analyses (FEA) support from DDC. The revisions in the design of the reciprocating components in the STM4-120 are a result of this cooperative effort.

Several other improvements in the engine design have resulted from the cooperative effort with DDC and other outside experts, including alternative scraper designs which are significantly less costly to produce, sensor and wiring specifications best suited for the engine operating environment and alternatives for SAE standard power take-off designs. This phase of the cooperative effort is an initial stage of developing a "productionized" second generation design of the STM4-120, planned for 1992.

Design review for STM4-120 heater heads complete.

STM has been re-designing the heater heads for their 4-120 engine. This re-design eliminates the need for bellows, which have prone to failure. An explanation is as follows: The heater heads are composed of five main components -- the regenerator housing, the heater, the heater canister assembly, the cylinder, and the connecting duct. Thermal expansion between these components requires a flexible connection between them. To this point, this flexibility has been accomplished by bellows located in the heater canister assembly. Although the bellows have served their purpose with respect to flexibility, they have proven to be vulnerable. The main failure mode is due to severe oxidation of the thin material. Outer layers of material would oxidize at high temperature and flake off during the thermal cycling. Since then, the stainless steel bellows have been replaced by Inconel 625 bellows, a material much more resistant to oxidation.

Although the Inconel bellows are a step in the right direction, the bellows are still a weak link in the condenser section. The use of bellows results in more welds (some not inspectable), smaller vapor passages, and more complex vapor

ducting. The new design addresses these problems. Fewer welds result in a more reliable system. Larger vapor passages minimize the chances of sonic velocity limits and entrainment problems. The old design also requires the use of baffles to encourage the sodium vapor to flow in the proper directions. Small errors in placement can lead to entrainment problems.

For all of the reasons stated above, STM has redesigned the heater head with a flexible connecting duct. Each connecting duct is made from three tubes, oriented in a hairpin fashion, which are flexible enough to allow for thermal expansion, eliminating the need for the bellows. The new design also has the advantages of larger vapor flow areas and a more reliable liquid return system. With the new design, the heater canister has an diameter equal to the outer convolutions diameter of the previous bellows. The flow area in old design is limited by the diameter of the inner convolutions of the bellows. Larger flow areas result in lower vapor velocities and therefore lower the chances of liquid entrainment.

The design phase of the new heater heads is nearly complete. A design review was held at STM in November. Issues discussed included heater head life, the new liquid return system, stress analysis, and material issues. A bench-scale test is scheduled for late January. The test consists of coupling STM's 10-fin evaporator to the new heater head shell (without the regenerator housing or cylinder). Nitrogen or air will be forced through a tube bundle inside the heater head shell, absorbing the applied power. This test will simulate the sodium side of an actual heater head and demonstrate that the liquid return system is adequate. Fabrication of five new heater heads will start as soon as a successful bench test has been completed.

SNL gas-fired sodium evaporator tested.

As described in the FY91-3 report, the first full-scale evaporator testing was conducted from December, 1990 to February, 1991. Unstable operation was observed in this first unit. The unstable operation was attributed to high vapor velocities in the critical 450-600 C range preventing liquid sodium from returning to the lower manifold. Since the sodium was trapped in the upper manifold and the device contained no wick structure to allow the liquid sodium to wick downward, the tubes dried out and eventually overheated.

Also as described in the previous report, a wick "sampler" was fabricated and tested. This heat pipe consisted of four different wick designs in a single unit. The results indicated that extending the wicks into the upper manifold combined with a few tubes with liquid return lines would solve the problems encountered in the first full-scale evaporator. As a precautionary measure, we decided to increase the depth of the lower manifold, allowing a larger sodium inventory. A larger volume of sodium should ensure that no dryouts occur, especially in the

high vapor velocity range. Finally, the liquid return system was changed slightly. In the first full-scale unit, the condenser consisted of a 1-m x 50.8-mm (2") OD tube. Condensed sodium refluxed on the inner tube surface and was channeled into 9.5-mm (3/8") tube which opened above the upper manifold. The second evaporator would include a 25.4-mm (1") OD tube concentric with the 50.8-mm (2") condenser tube. With this design modification, vaporized sodium flows upward inside the 25.4-mm (1") tube and is deflected outward and then downward along the condenser tube. This change allows the vapor to assist the liquid sodium return system, further reducing the possibility of entrainment.

Fabrication was completed during November. The heat-pipe assembly was then filled with 370 grams of sodium. The inventory was determined by combining the amount needed to fill the lower pan plus the amount of sodium that "plates out" on all the inner surfaces. This plating thickness was determined by calculating the inventory lost (inventory that did not remain in the pool in the lower manifold) after running the first evaporator unit and the wick sampler heat pipe.

The second unit testing began in December. Unstable operation was observed in this unit also, although the apparent dryouts were not nearly as severe as the dryouts in the first unit. In addition, instrumentation indicated the sodium was returning to the lower manifold, demonstrating that our modifications discussed above solved the liquid return problem.

Upon further data reduction, some data indicated that the problem could have been due to boiling in the tubes -- i.e, too much sodium inventory. A method of determining the exact sodium level was needed. This was accomplished using a gamma ray source and detector system that can detect differences in density. The results confirmed that the sodium level was too high -- 46-mm above the lower manifold at operating temperature. Apparently, the plating thickness that was calculated on the previous units were more than on the second evaporator (the actual sodium volume measurement which had not plated out on this unit was more accurate, so future estimates should be more accurate).

Another problem was the collection of hydrogen in the heat pipe. Hydrogen, a combustion product, can diffuse through the evaporator surfaces at high temperature and collect in the heat pipe. Residual gas analysis of the heat pipe indicated high levels of hydrogen after less than an hour of operation. STM solved this problem with their heat pipes by installing hydrogen diffusors. It is possible that the problems we observed were a combination of boiling and hydrogen gas buildup. We elected to try removing the excess sodium first, then if necessary, install hydrogen diffusors. The reason for this sequence was that removing excess sodium is a low-risk operation, while installing a hydrogen diffusor is higher-risk, since opening the heat pipe is required (sodium contamination is a possibility).

In December, 112 grams of sodium were removed. This corresponded to the amount of sodium that remained in the tube bank at 800C. In an attempt to eliminate the need for a hydrogen diffusor, a heater was wrapped around the condenser end of the heat pipe. The heater increases the temperature at the top end slightly, allowing hydrogen to diffuse out of the heat pipe.

Testing after the sodium removal started in late December. The evaporator proved to be stable. At this point, we have achieved steady-state power levels of 14.5 kW and we have accumulated 16 hours of trouble-free operation. A plot of a typical run is shown in Figure 5. Plans include achieving power levels of 15^{+} kW (needed for full-power operation of the STM4-120), and 200 hours of operation. If the test is successful, at least four more units will be fabricated and integrated into the STM engine.

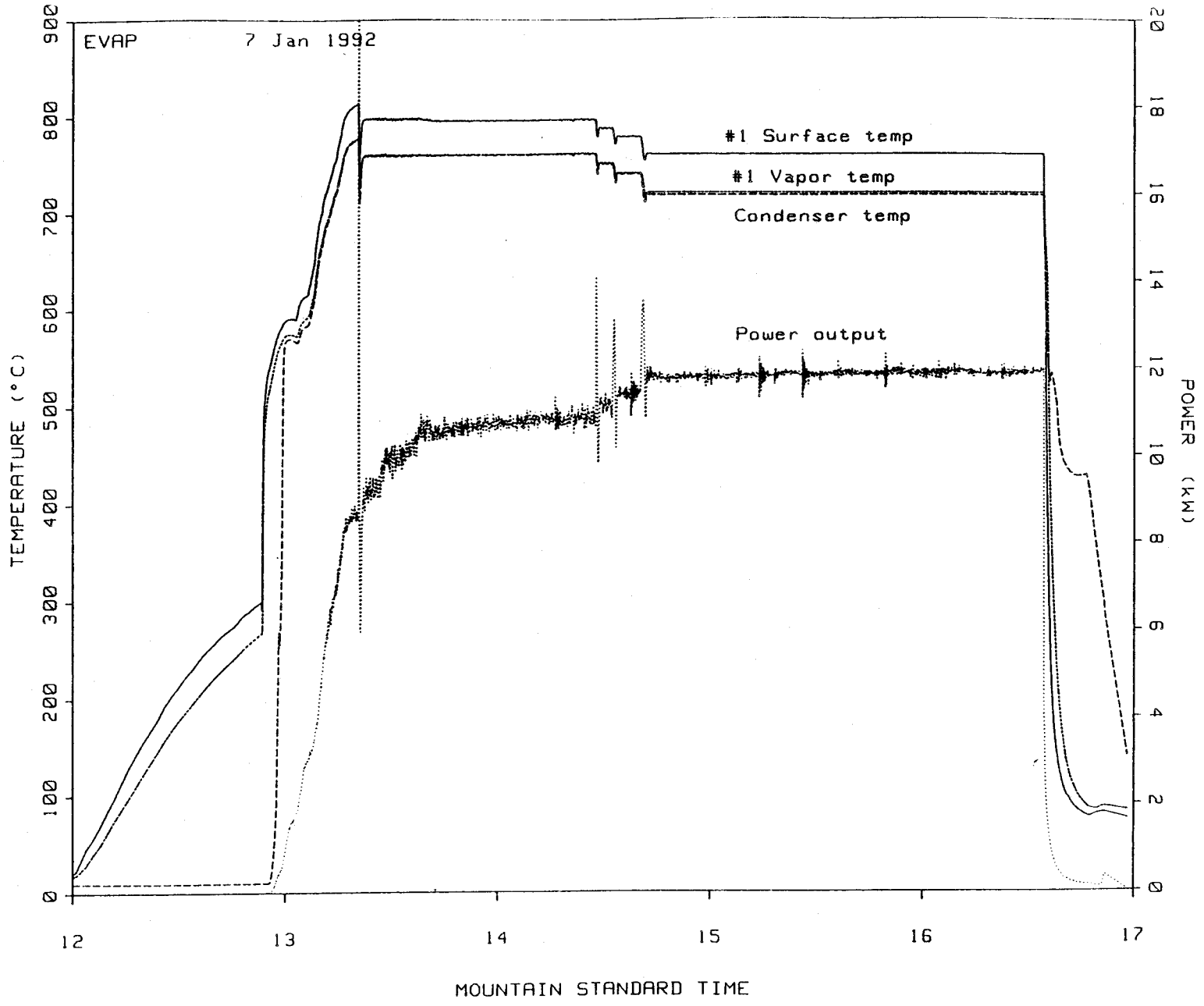


Figure 5. Gas-fired sodium evaporator operation.

Modular power generation workshop held.

On November 7-8, a workshop on modular power generation in the western and southwestern United States was held in San Francisco, California. Thirty-eight participants from DOE, the electric utility industry, regulatory agencies, the power systems manufacturing industry, and research and development organizations discussed current issues concerning develoment and deployment of modular power generation systems. The purposes of the workshop were to discuss candidate technologies for modular generation, identify obstacles to market growth for modular systems, and identify research needs to ensure system development and commercialization. The significant findings and recommended action items resulting from the workshop were compiled by the EA Mueller Energy Technologies Group. The findings will be presented to J. Michael Davis, Assistant Secretary of Conservation and Renewable Energy in the DOE.

The advantage of modular generation systems over central generation systems is the potential for lower transmission and distribution costs. Hower, before utilties can embrace the modular generation technology, questions concerning ownership of equipment, dispatchability of power, baseload competition, equipment operation and maintenance, regulation, and market definition must be answered. The participants recommended a collaborative effort between DOE, R&D Labs, utilities, regulators, manufacturers, and potential customers to address the outstanding issues identified in the workshop.

ASCS technology assessment review conducted.

On November 13, a technology assessment review of the Stirling Technology Company 25kW Advanced Stirling Conversion System (ASCS) was held at NASA, Lewis. The purpose of the review was to assess proposed changes to the STC ASCS. The changes address power output, system efficiency, and weight deficiencies identified in a Final Design Review held on February 23, 1991. STC proposed changing the mechanical to electric conversion system from a hydraulic motor/induction generator to a linear alternator. The Stirling engine would be significantly redesigned. The gas springs in the earlier design will be replaced by flexures; the piston seal will be a clearance seal; hydraulic pumping is eliminated; and the control systems are simplified. The proposed changes were approved and will be adopted in STC's final design configuration.

Planned activities next quarter

- Conduct 200-hour test on SNL gas-fired sodium evaporator
- Award cost-shared kinematic Stirling-based power conversion system contract to Detroit Diesel Corporation

III REIMBURSABLE PROGRAMS

National Solar Thermal Test Facility

Accomplishments

A fourth series of military aircraft material hardness tests for Northrop/U.S. Air Force were conducted.

Aircraft materials were installed in the windowed wind tunnel behind the high-speed shutter in the center test bay of the NSTTF solar power tower. Test samples were exposed to simulated nuclear thermal pulses. The test plan required that the peak flux be held within +/- 3.5% of the specified level. The highest solar insolation in November and December was typically less than 900 W/m^2. Usually the peak insolation would be around 1000 W/m^2 during this time. Because of the relatively low insolation and the tight tolerance required for the peak flux, Sandia and Northrop agreed to postpone part of the testing until Northrop returns in January.

Planned activities for next quarter

- **BDM International radome test.**

The BDM test scheduled to be conduct in November has been postponed until January. Most of the schedule slip was caused by low insolation which postponed the Northrop test series. A fiberglass radome will be exposed to several fluence levels simulating nuclear thermal pulses. Radar will be transmitted through the radome before, during, and after the test.

- **A fifth series of military aircraft material hardness test for Northrop/U.S. Air Force is scheduled to start in January, followed by a sixth series in June.**

These test series will complete testing of materials from the October/November test series as well as new test samples.

- **Atlantis Energy will return in March for a second test series on their Volumetric Air Receiver.**

The National Solar Thermal Test Facility will perform a test on a prototype volumetric central receiver in the 220 test bay of the solar tower under contract to private industry. The first test series was completed in May of 1990.

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"Facet Development for a Faceted Stretched-Membrane Dish by SAIC," SAND Contractor Rpt. 91-7008, Science Applications International Corporation, San Diego, California, 1991.

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