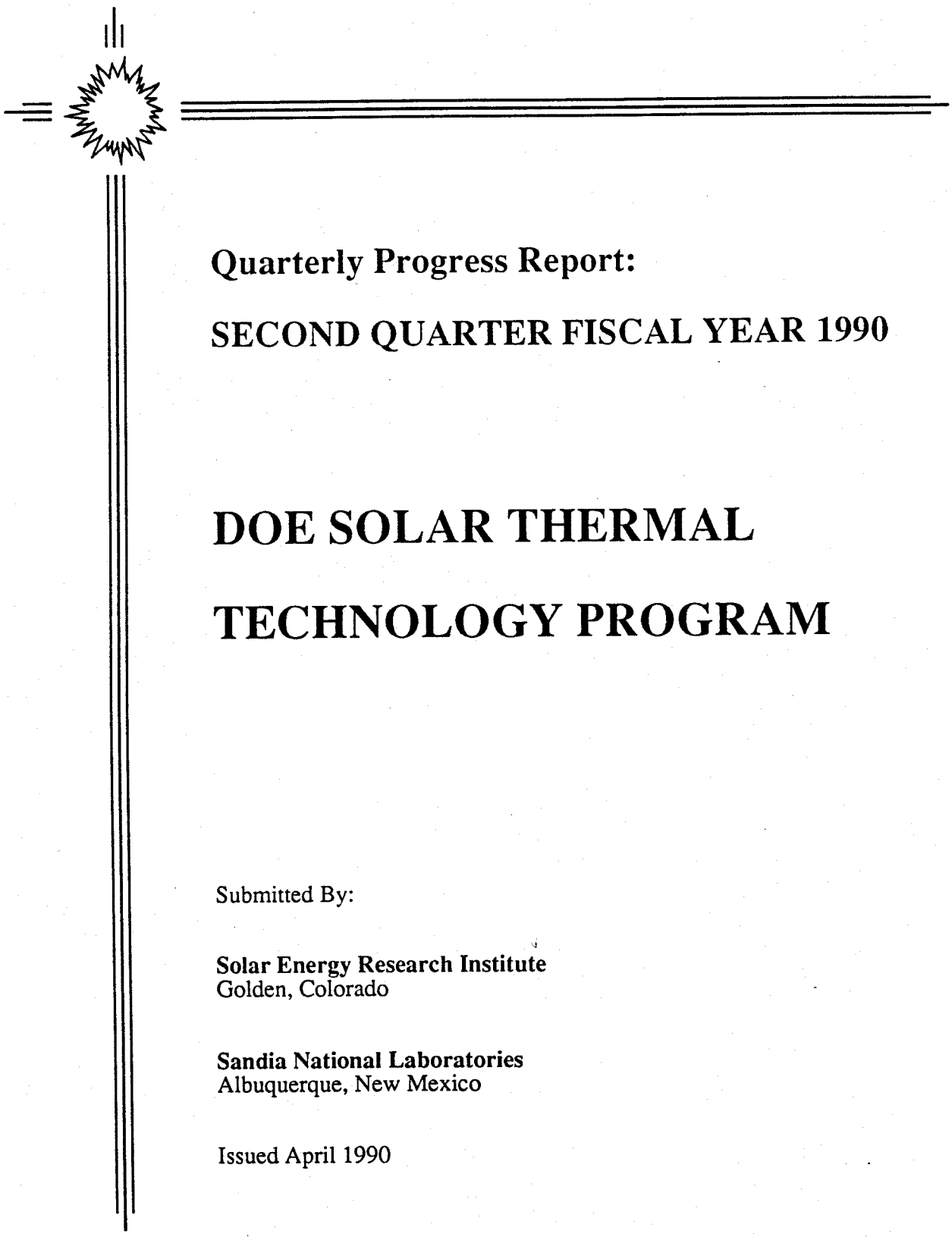

Quarterly Progress Report:

SECOND QUARTER FISCAL YEAR 1990

DOE SOLAR THERMAL TECHNOLOGY PROGRAM

Submitted By:

Solar Energy Research Institute
Golden, Colorado

Sandia National Laboratories
Albuquerque, New Mexico

Issued April 1990

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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 Technology Program. This single document is prepared jointly and reports the work of both major field laboratories, Sandia National Laboratories (SNL) and the Solar Energy Research Institute (SERI), and their contractors.

The Solar Thermal Technology Program includes both the Electric and Solar Detoxification Applications and related research and development. With the recent reorganization within the Department of Energy's Office of the Assistant Secretary for Conservation and Renewable Energy, the Solar Thermal Technology Program has been split into two separate efforts. One is aimed at solar thermal electric application and the other focuses on solar detoxification application.

Section 2 describes the work directly related to the solar thermal electric program. Section 1 describes the work included in the solar detoxification program. Beginning with the next quarterly report, the two areas of work will be organized in a way that the reader can more easily follow them as individual packages. The laboratories intend to maintain a joint SERI/SNL report for each of the two program areas.

MANAGEMENT STATUS REPORT

Structure of the Solar Thermal Technology Program

The Solar Thermal Technology Program is structured to focus on a number of commercialization opportunities for the technology while maintaining a baseline of research and development which is essential to achieving the long-term technological goals. The programmatic structure consists of four major activities, each having several associated tasks, as shown below.

1. HIGH-FLUX PHOTON PROCESSES
   - Task A. Photon Interaction with Materials and Chemicals
     - Subtask A-1. Solar Photochemical Destruction of Hazardous Contaminants in Water
     - Subtask A-2. Improved Catalysts for Photochemical Removal of Hazardous Contaminants from Water
     - Subtask A-3. High-Temperature Photo/Thermal Chemistry
   - Task B. High-Flux Optics
   - Task C. Materials
   - Task D. Receiver/Reactor Modeling

2. CONCENTRATOR DEVELOPMENT
   - Task A. Heliostats
   - Task B. Parabolic Dishes
   - Task C. Optical Materials
   - Task D. Structural Dynamics

3. ELECTRIC SYSTEMS DEVELOPMENT
   - Task A. Central Receiver Technology
   - Task B. Distributed Receiver Technology
   - Task C. Conversion Technology

4. TECHNOLOGY DEVELOPMENT
   - Task A. Next-Generation Commercial Systems
     - Subtask A-1. Project Development
     - Subtask A-2. Partner-Driven Research and Development
     - Subtask A-3. Design Assistance and CORECT Support
   - Task B. Photochemical Systems
     - Subtask B-1. Identification of Application Opportunities
     - Subtask B-2. Solar Processing of Dilute Aqueous Organic Chemicals
     - Subtask B-3. High-Temperature Solar Destruction of Toxic Chemicals
   - Task C. Advanced Electric Technology
     - Subtask C-1. Technology Identification
     - Subtask C-2. Joint-Venture Consortia
     - Subtask C-3. Development Requirements
     - Subtask C-4. System Experiments

Field Management—Structure and Responsibilities

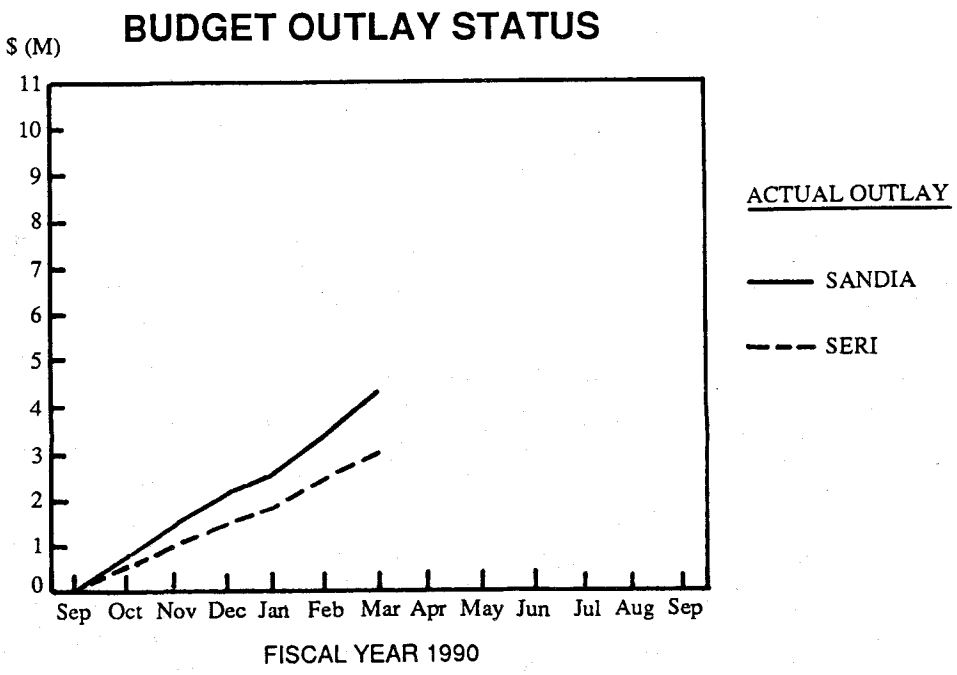
Specific implementation of the Solar Thermal Technology Program is assigned to two field laboratories, the Solar Energy Research Institute in Golden, Colorado, and Sandia National Laboratories in Albuquerque, New Mexico. Together, these two field laboratories are responsible for implementation of the research and development 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.

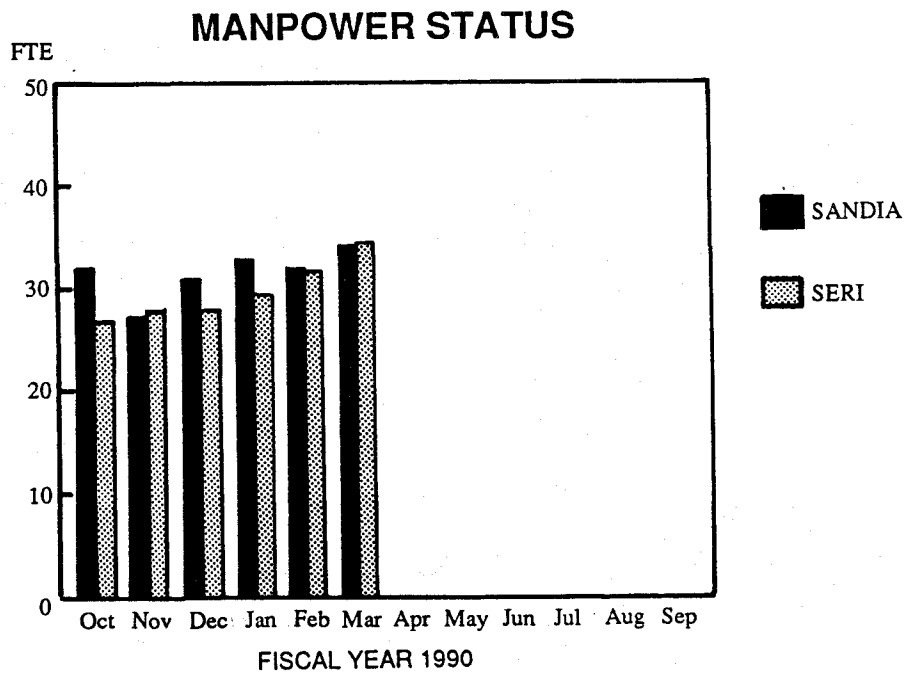
A field Laboratory Management Council (LMC) provides the focus for interaction with the DOE program management and for planning and coordination of the field activities. The LMC is co-chaired by a senior management representative from each laboratory. In order to provide a clear delineation of management responsibilities for each program activity, a lead responsibility is assigned by laboratory for each of the current program activities.

SOLAR THERMAL TECHNOLOGY PROGRAM WORK BREAKDOWN SCHEDULE

PROGRAM ACTIVITY	LEADER (Individual)
1. HIGH-FLUX PHOTON PROCESSES	J. Anderson, SERI M. Carasso, SERI
A. Photon Interaction with Materials and Chemicals	
B. High-Flux Optics	
C. Materials	
D. Receiver/Reactor Modeling	
2. CONCENTRATOR DEVELOPMENT	C. Tyner, SNL M. Carasso, SERI
A. Heliostats	
B. Parabolic Dishes	
C. Optical Materials	
D. Structural Dynamics	
3. ELECTRIC SYSTEMS DEVELOPMENT	P. Klimas, SNL
A. Central Receiver Technology	
B. Dish Receiver Technology	
C. Conversion Devices	
4. TECHNOLOGY DEVELOPMENT	
A. Next-Generation Commercial Systems	J. Holmes, SNL
B. Photochemical Processing	J. Anderson, SERI
C. Advanced Electric Technology	P. Klimas, SNL

Resource Summary





SOLAR THERMAL SUBCONTRACTS
PROCUREMENT PLAN AND STATUS SUMMARY

Task	Specific Contract Subject	Contractor	Lab Contract Number	Present Contract Value ($K)	Prior Year Funds ($K)	FY 1990 Funds ($K)	Period of Performance	Contract Type	Major Reports	Project Monitor
Exp. Res.	Evaluation of Solar Flux Application	National Academy of Science	SERI X-19012-01	$278	$135		07/89 - 02/91	Other Govt.	TBD	B. Gupta
Exp. Res.	High Solar Flux Concentration	Univ. of Chicago	SERI X-06019-02	$100	$100		10/89 - 10/90	Univ.	TBD	B. Gupta
Exp. Res.	Chemical Research	University of Houston	SERI X07028-01	$200	$186		04/89 - 03/90	Univ.	Topical Report	G. Glatzmaier
Exp. Res.	Solar Detox.	University of Arizona	SERI 10035-01	$27	$27		12/89 -	Univ.	TBD	R. Hewett
Exp. Res.	Carbon Fibers	Georgia Tech	SNL40-2672	$260	$260		6/89 - 5/91	Univ.	TBD	G. Kolb
Con. Dev.	Membrane Heliostat Dev.	Solar Kinetics Inc.	SNL33-1227	$704	$192		04/87 - 12/89	Small	SAND89-7028	D. Alpert
Con. Dev.	Replaceable Membrane	IST	SNL42-9690	$50	$50		11/89 - 06/90	Small	TBD	D. Alpert

SOLAR THERMAL SUBCONTRACTS
PROCUREMENT PLAN AND STATUS SUMMARY

Task	Specific Contract Subject	Contractor	Lab Contract Number	Present Contract Value ($K)	Prior Year Funds ($K)	FY 1990 Funds ($K)	Period of Performance	Contract Type	Major Reports	Project Monitor
Con. Dev.	Heliostat Integration	Solar Kinetics Inc.	SNL42-9691	$100	$100		10/89 - 04/90	Small	TBD	D. Alpert
Con. Dev.	STTF Technician Services	Ewing Technical Design	SNL63-5487	$1,350	$450		04/89 - 04/92	TBD	--	E. Rush
Con. Dev.	Collector Support Struc. & Pedestal	TWGAssociates	SNL42-9813	$900 (est.)	$400		09/89 - 06/91 (est.)	TBD	--	T. Mancini
Con. Dev.	Faceted Dish Development	SKI SAIC	SNL42-9814	$1,200 (est.)	$200		09/89 - 06/91 (est.)	Large Business	TBD	T. Mancini
Con. Dev.	Low-Cost Drive	Peerless-Winsmith	SNL90-5753	$487	--	--	Active	--	--	J. Grossman
Con. Dev.	Stretched-Membrane Dish Development	Solar Kinetics, Inc.	SNL55-2495	$1,730	$500		04/88 - 12/89	Small Bus.	SAND88-7035	T. Mancini
Con. Dev.	Solar Collector Pedestal Fabrication	TIW Fab. & Mach.	SNL57-4436	$57	--	--	12/87 - 12/89	Large Bus.	--	T. Mancini

SOLAR THERMAL SUBCONTRACTS
PROCUREMENT PLAN AND STATUS SUMMARY

Task	Specific Contract Subject	Contractor	Lab Contract Number	Present Contract Value ($K)	Prior Year Funds ($K)	FY 1990 Funds ($K)	Period of Performance	Contract Type	Major Reports	Project Monitor
Elec Tech	Reflux Heat-Pipe Receiver	Stirling Thermal Motor	SNL33-3036	$225	$101		04/87 - 6/90	Small	--	R. Diver
Elec Tech	Technician Support	Kirk-Mayer	SNL01-9646	$110	--	--	Closed	Small	--	R. Diver
Elec Tech	DAR Design Studies	Foster Wheeler	SNL06-0312	$136.9	10		6/87 - 9/89 (Extended to 09/90)	Large	SAND88-7038	J. Chavez
Elec Tech	Molten Salt Subsytem/ Component Test Experiment	B&W	SNL91-4687	$7,884	30		03/84 - 09/89 (Extended to 06/90)	Large	SAND87-2290	J. Chavez
Elec Tech	Volumetric Receiver Furnace Test	NMSU	SNL66-9967	$30	-0-		01/90 - 08/90	Univ.	--	J. Chavez
Elec Tech	PRE Panel/ Manifold	Hufman, Inc.	SNL70-8957	$20	$20		Closed	Small	--	J. Chavez
Elec Tech	STM4-120	Stirling Thermal Motors	SNL53-8452	$300	$15		07/86 - 12/89	Small	--	K. Linker
Elec Tech	2ndSTM4-120	Stirling Thermal Motors	SNL75-8851	$360	--	--	04/89 - 06/90	Small	--	K. Linker

SOLAR THERMAL SUBCONTRACTS
PROCUREMENT PLAN AND STATUS SUMMARY

Task	Specific Contract Subject	Contractor	Lab Contract Number	Present Contract Value ($K)	Prior Year Funds ($K)	FY 1990 Funds ($K)	Period of Performance	Contract Type	Major Reports	Project Monitor
Elec Tech	ASCS Design	NASA LeRC	DOE Inter-agency	$750	--	--	01/89 - 01/93	Govt.	--	K. Linker
Elec Tech	Tech Support Services	Tech Reps	SNL01-2370	$100	--	--	Closed	--	--	R. Diver
Elec. Tech.	Solar Test Support	EG&G	SNL05-4912	$150	$150		12/88 - 10/93	Large Bus.	--	C. Cameron
Elec Tech	Electrical Support Service	J & S Electric Co., Inc.	SNL75-7415	$120	$60		02/89 - 02/92	Serv. Support	--	J. Stomp, Jr.
Elec Tech	Engineering Services	Black & Veatch	SNL33-1900	$110	$10		02/87 - 12/89	Large Bus	--	C. Cameron
Elec Tech	Solar Receiver Heat Loss Testing	California Polytech	SNL02-5759	$105	$30		09/86 - 02/90	Univ.	ASME and ISES papers	A. Heckes
Elec Tech	STEP Test Program	Georgia Power	SNL42-4859	$42	$42		06/89 - 03/90	Large	Final Test Report	A. Heckes
Photo Sys.	Catalyst Development and Reactor Modeling	University of Houston	SNL55-4032	$225	--	$75	01/88 - 09/90	--	--	J. Sprung

SOLAR THERMAL SUBCONTRACTS
PROCUREMENT PLAN AND STATUS SUMMARY

Task	Specific Contract Subject	Contractor	Lab Contract Number	Present Contract Value ($K)	Prior Year Funds ($K)	FY 1990 Funds ($K)	Period of Performance	Contract Type	Major Reports	Project Monitor
Photo Sys.	Solar Incineration of Hazardous Waste	University of Dayton	SERI X-06082-1	$140	$191		04/89 - 03/90	Univ.	--	G. Glatzmaier

KEY
Exp. Res. = Exploratory Research
Con. Dev. = Concentrator Development
Elec. Tech. = Solar Electric Technology
Photo. Sys. = Photochemical Systems

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

Major Milestone Schedule

The major milestones for each program task are summarized below in chronological order and by task reference. This set of major 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.

	Date	Activity-Task Reference	Descriptive Title
Fiscal Year 1990			
First Quarter, FY 1990			
SN	October, 1989	3B	Complete bench tests of heat-pipe receivers.
SN	November, 1989	2A	Initiate fabrication of first prototype of SAIC's 100-m^2 market-ready heliostat.
SN	November, 1989	3A	Complete installation of the PRE.
SN	November, 1989	3B	Complete on-sun testing of a reflux pool boiler at the STTF.
SN	November, 1989	4C-1	The responses to the Request for Information will be evaluated.
SN	December, 1989	1A-3	Complete CAESAR experiments using a non-uniform absorber.
SE	December, 1989	1B	High-Flux Solar Furnace operational.
SN	December, 1989	4A-1	Award multi-year R&D system improvement contracts with one or more industrial partners.
Second Quarter, FY 1990			
SN	January, 1990	2A	Complete testing and documentation of two improved prototype stretched-membrane mirror modules.
SN	January, 1990	2D	Complete documentation of initial wind load studies.
SN	January, 1990	3A	Initiate the salt flow testing on the PRE.

	Laboratory—Date	Activity-Task Reference	Descriptive Title
SE	February, 1990	1A-2	Identify potential photocatalysts that will extend the active region toward the visible in the solar spectrum and assess the potential for improving the efficiency water treatment.
SN	February, 1990	2B	Complete fabrication of the seven-meter single element module.
SN	February, 1990 (April, 1990)	3C	Initiate final design of Advanced Stirling Conversion System.
SE	March, 1990	1A-3	Compare PIRs in photo, catalytic and thermal processes in order to show the benefits of the solar process.
SN/ SE	March, 1990	4A-3	Participate in the SOLTECH90 joint meeting.
SN/ SE	March, 1990	4B-1	Conduct a workshop for industrial participants at SOLTECH90 to encourage industrial involvement in photochemical systems.

Third Quarter, FY 1990

SN	April, 1990	2A	Complete testing and documentation of the low-cost drive.
SN	April, 1990	1A-3	Complete draft final report documenting the CAESAR experiments.
SN	May, 1990	1C	Review and evaluate merits of carbon fiber treatment with high solar flux.
SE	May, 1990	2B	Complete validation of SHOT.
SN	May, 1990	2B	Complete on-sun testing of the seven-meter single element module.
SN	May, 1990	3A	Complete the comparative study of salt and air receivers.
SN	May, 1990	3B	Decision on heat-pipe versus pool-boiler receivers for further development.
SE	June, 1990	1B	Identify optical components for a wavelength shifting system and document expected efficiencies in solar applications.

Laboratory--Date	Activity-Task Reference	Descriptive Title
SN June, 1990	2A	Complete design of SKI's market-ready prototype heliostat.
SE June, 1990	2B	Complete computer model of the faceted dish support structure.
SN June, 1990	2B	Complete optical testing of the facets for the faceted dish.
SN June, 1990	3A	Complete the Phase I solar testing of the PRE.
SN June, 1990	3A	Complete 4000 hours of operation on the molten salt pump and valve hot loop; complete 2000 hours of operation on the cold loop.
SE June, 1990	4B-2	Complete tests on multiple compound mixtures that model those found in real sites under consideration for system experiment.
Fourth Quarter, FY 1990		
SE July, 1990	1C	Evaluate the benefits of solar surface treatment of metals for specific applications.
SN July, 1990	2A	Complete fabrication of SAIC's prototype of 100-m^2 market-ready heliostat.
SN July, 1990	2B	Program decision point: Dish designs to fabricate and test.
SN July, 1990	2C	Complete the Sol-Gel mirror production cost study.
SN July, 1990	2C	Complete and document replaceable film study.
SN July, 1990	3B	Complete preliminary design of a hybrid reflux receiver.
SE August, 1990	2B	Complete validation of OPTDISH and ODMF optical codes using the data from SHOT.
SN August, 1990	3A	Complete testing of an optimized volumetric receiver absorber.

	Laboratory--Date	Activity-Task Reference	Descriptive Title
SN	August, 1990	4B-1	Complete a conceptual design of a commercial-scale system for solar detoxification of water.
SE	August, 1990	4B-2	Select a preferred catalyst immobilization scheme for use in the first system experiment.
SE	August, 1990	4B-3	Identify the most promising applications of the solar detoxification of hazardous waste processes, develop a conceptual configuration, and compare the system performance and cost with conventional alternatives.
SE	September, 1990	1A-1	Assess the availability of near ultraviolet component of global normal and diffuse radiation at the Golden, Colorado, site and document a model that will allow predictions to be made at other sites.
SE	September, 1990	1A-3	Determine quantum yields for destruction of representative hazardous organic compounds in a high-flux system.
SN	September, 1990	1A-3	Complete initial phase survey of steam reforming of representative toxic organic solvents.
SN	September, 1990	2A	Initiate fabrication of first prototype of SKI's market-ready heliostat.
SN	September, 1990	2A	Complete testing and documentation of two large-area glass-mirror heliostats.
SE	September, 1990	2C	Complete and document preliminary evaluation of ultraviolet-enhanced mirrors for photochemical applications.
SE	September, 1990	2C	Document studies of polymer film-to-silver adhesion.
SN	September, 1990	3C	Initiate on-sun testing of the STM 4-120 Stirling.
SE	September, 1990	4B-1	Complete site selection process for the first system experiment.
SN	September, 1990	3A	Complete a draft report describing U.S./F.R.G. collaborative study of second-generation central receiver technology.

Laboratory—Date	Activity-Task Reference	Descriptive Title
Fiscal Year 1989		
	C1-3 (November, 1989)	Convene an advisory group to evaluate progress and promise of carbon fiber treatment with concentrated solar flux, based on work at GTRI.
	C2-2 (December, 1989)	Report on evaluation of LaJet innovative dish performance.
	C1-2 (December, 1989)	Assess merit of scaling up laser experiments and optical concepts for achieving a source of lower wavelength laser beam.
	C2-1 (January, 1990)	Topical report on Sandia's optical and environmental evaluation of SAIC and SKI improved 50 m^2 membrane mirror modules.
	C3-1 (January, 1990)	Initiate six-meter DAR salt flow testing.
	C1-1 (March, 1990)	Obtain results from laboratory experiments to explain the role of ultraviolet radiation (wavelength) in decomposition of toxic chemicals.
	C2-1 (April, 1990)	SKI contractor report on the design of a market-ready integrated aluminum membrane heliostat based on test results for the improved 50 m^2 mirror module.
	C2-2 (May, 1990)	Deliver seven-meter-diameter aluminum membrane dish optical element for testing at the STTF.
	C2-3 (June, 1990)	Document cost potential of silvered metal structural mirrors.
	C2-2 (July, 1990)	Decision point--begin commercial scale design or refine seven-meter optical element design to improve performance.
	C2-4 (September, 1990)	Topical report on innovative heliostat drive system performance.

Laboratory--Date	Activity-Task Reference	Descriptive Title
	M1-1 (TBD)	Complete contract negotiations and award contract.
	M2-3 (TBD)	Complete CAESAR experiment.
	M1-2 (TBD)	Complete an R&D plan and initiate R&D activities.

NOTE: Dates that are in parenthesis indicate a rescheduling.

SIGNIFICANT ACCOMPLISHMENTS SUMMARY

MAJOR MILESTONE	PLANNED	ACTUAL
FY 1989		
Core 1. Exploratory Research		
o Obtain results from laboratory experiments to explain the role of ultraviolet radiation (wavelength) in decomposition of toxic chemicals. (C1-1)	03/90*	03/90
This milestone was completed as rescheduled.		
Core 2. Concentrator Development		
o Topical report on Sandia's optical and environmental evaluation of SAIC and SKI improved 50 m^2 membrane mirror modules. (C2-1)	01/90*	02/90
Core 3. Electric Systems Development		
o Initiate six-meter DAR salt flow testing. (C3-1)	01/90*	
FY 1990		
1. High-Flux Photon Processes		
o Identify potential photocatalysts that will extend the active region toward the visible in the solar spectrum and assess the potential for improving the efficiency water treatment. SE (1A-2)	02/90	02/90
- This milestone was completed as scheduled.		
o Compare PIRs in photo, catalytic, and thermal processes in order to show the benefits of the solar process. SE (1A-3)	03/90	03/90
- This milestone was completed as scheduled.		

*Rescheduled to this date.

MAJOR MILESTONE		PLANNED	ACTUAL
2. Concentrator Development			
o Complete testing and documentation of two improved prototype stretched-membrane mirror modules.	SN (2A)	01/90	01/90
o Complete fabrication of the seven-meter single element module.	SN (2B)	02/90	02/90
o Complete documentation of initial wind load studies.	SN (2D)	01/90	01/90
3. Electric Systems Development			
o Complete installation of the PRE.	SN (3A)	11/89	03/90
- This milestone had been rescheduled and has been completed.			
o Initiate the salt flow testing on the PRE.	SN (3A)	01/90	
o Initiate final design of Advanced Stirling Conversion System.	SN (3C)	2/90 (04/90)*	
- Sandia and NASA/LeRC were scheduled to award contracts for the final design of the Advanced Stirling Conversion System (ASCS). Due to a delay in funding, this contract was not placed.			
4. Technology Development			
o Participate in the SOLTECH90 joint meeting.	SN/SE (4A-3)	03/90	03/90
- This milestone was completed on schedule.			
o Conduct a workshop for industrial participants at SOLTECH90 to encourage industrial involvement in photochemical systems.	SN/SE (4B-1)	03/90	03/90
- This milestone was completed on schedule.			

*Rescheduled to this date.

TECHNICAL STATUS REPORT

1. HIGH-FLUX PHOTON PROCESSES

Objectives

The objectives of work on High-Flux Photon Processes are to develop and to maintain the scientific and theoretical base for solar thermal technology and to conduct fundamental studies on advanced concepts and applications, including solar chemistry and materials processing.

TASK A. PHOTON INTERACTIONS WITH MATERIALS AND CHEMICALS

Subtask A-1. Solar Photochemical Destruction of Hazardous Contaminants in Water

Accomplishments

o A new laboratory loop for catalyst testing has been assembled and checked.

A new photocatalytic reactor system, which uses a high-flux solar simulator as a light source, was fabricated, assembled, and checked for leaks. This system will be primarily used for photocatalyst testing. This system is able to contain solutions of volatile compounds in water and is impervious to chlorinated solvents, because it is constructed entirely of Pyrex, quartz, Viton, and Teflon components. This system also contains a variable path-length photoreactor, which can accommodate solid catalysts from 0.25 inches to 1.0 inches in length and up to 2.0 inches in diameter. A 12-L mixing vessel was plumbed into the reactor system and will provide TCE solutions of constant concentration. The increased flux input from the simulator will facilitate rapid testing for catalyst activity. Use of this concentrated radiation also will allow a wider portion of the relationship between flux and destruction rates to be defined. (SERI)

o A spectral radiometer has been adapted to high fluxes and measures simulator output.

A spectral radiometer has been adapted with innovative foreoptics to create an instrument that can measure the spectral content of concentrated light sources. The first task for this instrument has been to measure the number of near-ultraviolet photons put out from the laboratory simulators used on experiments under solar detoxification of water (SDW). The data from these measurements are shown below.

LIGHT SOURCE	POWER, W/m^2 250-400 nm	FLUX, quanta/ $sec\text{-}m^2$ 250-400 nm	Suns (Flux)
Sun, D.N., AM 1.5*	2.20 x 101	4.64 x 1019	1.00
1 kW Xe lamp (old)	2.24 x 103	2.01 x 1021	43.3
1 kW Xe lamp (new)	5.98 x 103	5.34 x 1021	115
1.6 kW Hg-Xe lamp (new)	4.93 x 104	4.33 x 1022	933

*Direct normal solar radiation, Air Mass 1.5, BRITE model (R. Hulstrom, et al, Solar Cells 15 [1985], 371).

It is clear from the data in the table that the high-flux ultraviolet light source will be very useful in accelerated testing of the lifetime of photocatalysts, as well as in determining wavelength dependence of reaction rates. The figures given last year to describe the output of the solar simulator probably correspond to power and flux levels somewhere between the values reported in the table for the "old" and "new" Xe lamps. These data are very important in judging the quantum efficiency of the process of solar detoxification of water, and in comparing the results from one experiment to those from another. (SERI)

- **Important new analytical procedures have been established.**

  Analytical procedures for acetonitrile, sodium formate, and parts-per-billion (ppb) solutions of TCE in water have been developed. These procedures consist of total-organic-carbon (TOC) analysis performed on subcontract, and improved in-house GC headspace methodology. The order for a TOC analyzer for the laboratory has been placed. This will add capability for detecting nonvolatile organics and carbonate ion, and will allow better monitoring of material balances in the destruction experiments. (SERI)

- **Formate ion will be used as a model compound for tests of the process of solar detoxification of water.**

  Experiments to test formate ion as a convenient model compound for photodestruction conditions were initiated. Formate is a nonvolatile compound that consumes only one hydroxyl radical per molecule destroyed. Blank runs established that leaks were negligible and that the TOC analyses were accurate and reproducible. Tests are underway to establish if the phosphate buffer is competing with the formate for hydroxyl radical. (SERI)

- **Hazardous compounds are to be categorized for ranking according to treatability.**

  A compilation of the compounds on the priority lists of the Environmental Protection Agency (EPA) has been assembled in a format that will be useful for categorizing compounds by structural type, demonstrated treatability, or likely treatability by the process of solar detoxification of water. This will be a more useful guide to the market assessment and research than the lists in the form published by EPA. (SERI)

- **Ultraviolet lamps have been characterized for comparison to photons from the process of solar detoxification of water.**

  To facilitate comparison of low-temperature solar detoxification systems to similar photo-oxidation systems driven by electric lamps, the efficiencies of various types of ultraviolet-emitting lamps have been estimated. Typical values for mercury and xenon arc sources are 1 to 2 ultraviolet watts (250 nm to 400 nm) available per 100 watts input (1 percent to 2 percent). Fluorescent blacklight-blue bulbs are substantially more efficient, with approximately 15 percent of the input power emitted in the ultraviolet. Because of the relatively low cost and high efficiency of fluorescent sources, they may represent competition to solar photons in advanced photo-oxidation systems. (SERI)

Planned Activities for Next Quarter

- Evolution of the effects of various process parameters using formate as the target compound will continue.
- Researchers will continue testing samples from contaminated sites.

Subtask A-2. Improved Catalysts for Photochemical Removal of Hazardous Contaminants from Water

Accomplishments

- o A list of potential catalyst materials for solar detoxification of water will satisfy a milestone.

  Researchers have completed a list of potential semi-conductors that might improve the system performance of solar detoxification of water and possible criteria for selecting the best candidates. These materials will be investigated as improvements of the TiO_2 catalyst currently being used. The materials on this list offer the potential for either a higher quantum efficiency (more effective use of the photons), or a broader action spectrum (using more of the photons available in the solar spectrum). This list will fulfill a milestone of the Solar Thermal Program. (SERI)

Planned Activities for Next Quarter

- o Scientists will test commercial, fixed catalysts.
- o New treatments of the TiO_2 catalyst that are expected to improve performance will be tested.
- o Researchers will begin tests of new catalyst materials to characterize improvements in performance.

Subtask A-3. High-Temperature Photo/Thermal Chemistry

Accomplishments

- **A high-temperature reactor model/design tool has been completed for TCE.**

  A model of the gas-phase (high-temperature) receiver/reactor for oxidation of TCE has been developed. Researchers have integrated equations describing the thermocatalytic decomposition of trichloroethylene in air into the radiation model, and have tested them successfully. This model will be essential in designing both laboratory and field-test equipment for the high-temperature processes. As show in the accompanying figure (Figure 1.A.3.1) it will allow researchers to predict in advance both the penetration of sunlight into the porous frit used in the reactors, and the degree of reaction at various stages of the frit. This capability will be critical in designing and evaluating new reactor designs. (SERI)

- **A software package for chemical thermodynamics was installed.**

  A software package for chemical thermodynamics was installed and is being used to calculate equilibrium compositions for a number of reaction systems relevant to solar detoxification. The software can calculate equilibrium data for various types of reactions as well as predicting compositions of reaction mixtures. In addition, it can be used to predict the stability of materials in contact with potentially corrosive reactants or products in detoxification systems. This capability is important for designing effective detoxification experiments and systems. (SERI)

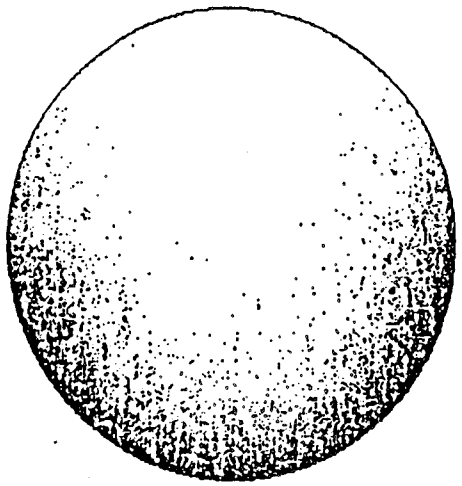
- **Radiative properties of reticulated ceramic foams have been characterized.**

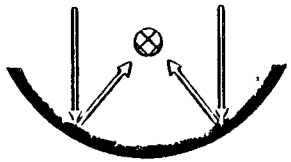
  Researchers have developed a technique for characterizing the radiative properties of reticulated alumina foams. In order to model these materials, radiative properties such as the extinction cross section and albedo are required for each wavelength band of interest. Reticulated foams have a highly irregular structure, and determination of these radiative properties would seem difficult. The method that has been developed allows one easily to characterize the foams with only a small amount of experimental data. This is significant because the ceramic foam materials are planned for the absorber section of a number of receiver/reactor concepts, and radiative modeling of them is critical to good designs. (SERI)

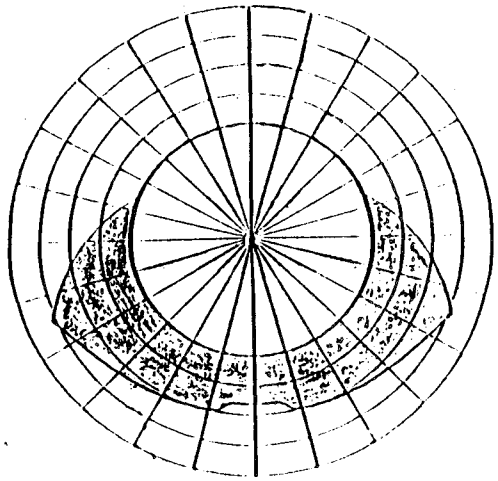
- **Photo-oxidation experiments were conducted on the Molecular Beam Mass Spectrometer.**

  A recently installed ultraviolet laser (Argon Ion) has been used photochemically to destroy 1-chloronaphthalene. These experiments were conducted by using the Molecular Beam Mass Spectrometer which allows real-time monitoring of species in high-temperature reactors. In the experiments with 1-chloronaphthalene, the sample was carried through a heated quartz photo-reactor by a synthetic air (20 percent O_2, 80 percent He) mixture, and products were measured by the spectrometer. These experiments were conducted with an average light intensity equivalent to approximately 680 suns and with a residence time equal to 10 seconds. The ultraviolet light causes significant enhancement in the destruction of the chloronaphthalene. The spectrometer also allows measurement of all products that produced high-temperature reactions, and it appears that at higher temperatures there are substantially fewer products of incomplete combustion produced by ultraviolet photodecomposition. (SERI)

VOLUMETRIC ABSORPTION OF SOLAR UV RADIATION







Distribution of Absorbed Radiation
Inside Receiver/Reactor Tube (MONTE 3)

Flux Distribution Incident
On Tube Surface

Figure 1.A.3.1

- **Response surface methodology was used to interpret results from photo-oxidation experiments.**

  Statistical methods are being used to design optimal experiments and to analyze the photodestruction data that are being collected with the Molecular Beam Mass Spectrometer. By using this strategy, the data obtained for 1-chloronaphthalene have been used to calculate response surfaces for destruction efficiency and production of products of incomplete combustion as a function of chloronaphthalene concentration, reactor-residence time, and ultraviolet light intensity. This technique will allow data from the spectrometer to be used to identify optimal operating conditions for photodestruction. (SERI)

- **Measurement of products of incomplete combustion and products of incomplete reaction from thermal, thermal/catalytic and photolytic processes met a milestone.**

  Data from the Molecular Beam Mass Spectrometer were used to satisfy the detoxification milestone for solar to measure and to characterize products from photo/thermal/catalytic processes. Pyrolysis of a number of organic species was studied in pure helium where an extensive number of products were produced that were often more hazardous and more thermally stable than the starting material. This is in contrast to the solar processes, where only innocuous products were seen. The products are being characterized as a function of temperature, concentration, light intensity, and residence time. (SERI)

- **CAESAR measurements of solar-flux and analysis of test data were initiated.**

  The Catalytically Enhanced Solar Absorption Receiver (CAESAR), mounted on the seventeen-meter dish at the PAN facility near Lampoldshausen, Germany, was tested with both a uniform absorber and a radially nonuniform absorber during 1989. Examination of the data from these tests identified eight as having data that are worth analyzing in depth. Proper analysis of the data, however, including comparisons with model predictions, requires an accurate knowledge of the distributions of incident solar flux over the front surface of the absorbers. To this end, characterization measurements of incident solar flux at the absorber location on the dish were begun in late March. It is anticipated that these will take approximately two months to complete. (SNL)

- **Reforming studies at the University of Houston were conducted.**

  Studies at the University of Houston on coke formation during reforming experiments showed that coke formation ceases when operating temperatures exceed 800°C. The bench-scale reforming apparatus used to measure reforming kinetics was modified by changing the heater configuration so that wall heating in front of the catalyst support was minimized. This change essentially eliminated coke formation ahead of the catalyst support--a problem that had complicated determination of mass balances and rate equations.

  A gas chromatograph was added to the analytical train of the reforming apparatus. Steam reforming of trichloroethane (TCA) over pelleted rhodium with direct determination of H_2, CO, CO_2, CH_4, and TCA by gas chromatography and of HCl by titration then confirmed the rate expressions developed previously in experiments where only HCl formation was measured. Researchers began experiments that compare TCA destruction over rhodium supported on reticulated alumina to the results obtained with pelleted rhodium. TCE experiments also are planned. (SNL)

- **Pilot-scale experiments were begun at the SOLTOX facility.**

  Studies of reforming organic compounds at the SOLTOX facility were initiated. A preliminary experiment on reforming methane/carbon dioxide at 1100°C, a total system pressure of 600 mm, and flow rates of 0.25 and 0.5 moles per minute of CH_4 and CO_2, yielded 85 percent conversion of methane to products.

  Visual inspection of the rhodium-coated, reticulated-catalyst supports used in the CAESAR and SOLTOX experiments showed that rhodium deposition was much greater near the surface of the support than in its interior regions. If this is caused by wicked transport from cooler interior regions to hotter surface regions during evaporation of water during the deposition of rhodium nitrate, then more uniform deposition can be obtained by removing water by convective heating, microwave heating, or freeze drying. (SNL)

- **Discussions were initiated for study of high-flux solar photon processes.**

  Discussions have been held with SRI International and the MIT Energy Laboratory to initiate independent studies aimed at identifying high-flux solar photon processes with potentially beneficial applications in the national interest. The studies have an identical title and similar scope: "High-Flux Solar Photon Processes--The Potential for Applications."

  To cover the breadth of specialized knowledge called for in each of these studies, and to avoid the danger of partial and perhaps biased views, it is essential that the study be performed by a number of professionals who can become familiar with the solar resource, but can represent the breadth of knowledge necessary to span current knowledge of photolytic and photocatalytic research, including that of high-flux, monochromatic, coherent sources. Each of the two studies will conclude with recommendations of research that will have the potential to lead to beneficial applications of the solar resource. The output of these studies will be used to begin research into promising processes and possible applications. (SERI)

Planned Activities for Next Quarter

- Researchers will expand the range of chemicals tested in photo-oxidation experiments with the Molecular Beam Mass Spectrometer.

- Researchers will characterize optimum conditions for destruction of target chemicals and minimization of formation of products of incomplete reaction.

- CAESAR activities will focus on completing the measurements of the incident solar flux characterization and on utilizing the results in analyzing the test data and performing calculations with the absorber computer model.

- The studies by SRI International and the MIT Laboratory probably will begin.

TASK B. HIGH-FLUX OPTICS

Accomplishments

- **Characterization testing has yielded flux measurements exceeding performance predictions.**

  Peak flux measurements of nearly 2,500 suns have been routinely measured over the last quarter by using the colorimeters and flux-mapping system at SERI's High-Flux Solar Furnace. The full 9.7 kW of power is fully contained within a twelve-centimeter-diameter circle at the target plane. Ninety-four percent of the full power is contained within a ten-centimeter-diameter circle. The flux profile is somewhat flatter than a gausian curve and indicates (as expected) that the optics are highly accurate. (SERI)

- **Design, fabrication, and installation of the major components for SERI's High-Flux Solar Furnace were completed.**

  A unique, two-plate attenuator has been designed, fabricated, installed and tested at SERI's High-Flux Solar Furnace. This device is located between the primary concentrator and the target and does not block the incoming concentrated beam when fully open. The two plates block the beam from above and below when attenuation is desired. When the attenuator is fully closed, the measured plate temperatures have not exceeded 80°C, and the attenuator, therefore, requires no active cooling. Tests indicate that the intensity of the incoming flux is attenuated linearly with plate position. The attenuator can be controlled either manually or through the central control and data-acquisition system.

  Delivery of the experiment positioning system purchased from SCANEX, Inc., of Boulder, Colorado, has been delayed. The x and y axis positioners of the system have been assembled and tested, and the z axis position is now being fabricated. All components for the control system are on hand and will be assembled after completion of the z axis positioner. (SERI)

- **Several experiments have been performed by SERI researchers at the High-Flux Solar Furnace.**

  The first set of experiments at SERI's High-Flux Solar Furnace have been completed. These experiments were designed to demonstrate the feasibility of producing high-value silicon carbide powders (a ceramic) by using concentrated solar energy. The process combines silica (SiO_2) and carbon (C) in a high-temperature reaction to form silicon carbide (SiC) and carbon monoxide (CO). Researchers performed a number of tests in which the product was formed inside a graphite receiver/reactor. Solar flux to the receiver was estimated at 160 W/cm^2 to 190 W/cm^2. Internal cavity temperatures of 1750°C to 1800°C were measured with a tungsten/rhenium thermocouple. The particle-size distribution of the powders is estimated to be from 10 to 50 microns in diameter. Samples have been sent to an outside laboratory for chemical analysis to determine purity. Future research will determine additional reaction parameters and data on reactor design to assess fully the potential of the process. (SERI)

- **The University of Chicago is nearing completion of the design and fabrication of a reflective secondary concentrator for the High-Flux Solar Furnace.**

  Researchers at the University of Chicago have designed a reflective, compound parabolic secondary concentrator for SERI's High-Flux Furnace to achieve average flux concentrations at its exit aperture of over 20,000 suns. The device will be water-cooled with a protected silver reflective surface. Fabrication of the secondary is nearly complete. A flow-through colorimeter also has been designed and fabricated to measure the power at the exit aperture of the secondary. (SERI)

Planned Activities for Next Quarter

- Installation and checkout of the positioning system from SCANEX will occur.
- Researchers will continue experiments on materials processing.
- Experiments on detoxification will commence.
- The secondary concentrator will be installed, and its performance will be measured.
- SERI will initiate a subcontract to fabricate a turning mirror.
- A video-tape will be produced to describe the High-Flux Solar Furnace and its capabilities.
- The High-Flux Solar Furnace will be inaugurated.

TASK C. MATERIALS

Accomplishments

o Experiments on surface modification have begun at SERI's High-Flux Solar Furnace.

In the normal manufacturing process of CuBe alloys anomalous conditions occasionally result in an upper layer overly rich in Beryllium. This layer has to be removed before the alloy can be marketed. An experiment of SERI's High-Flux Solar Furnace was designed to study the possibility of changing this condition to a normal alloy composition. To accomplish this the sample was overcoated with a thin (2 micron) layer of copper. These materials were irradiated in pure N_2 atmosphere to approximately 850°C in an attempt to induce diffusion of Be from the beta-phase layer into the Cu on either side. It was found that the atmospheric control was adequate, but the control of temperature of the substrate was poor due to variations in the thermal distribution over the surface of the target and unreliable thermocouple measurements. Metallographic analysis of the target materials revealed some interesting redistributions of a second-phase material in the subsurface zone beneath the beta-phase material and near the back surface of the Cu plate. However, there appeared to be little observable change in the inverse beta-phase layer as a result of the thermal treatment. Additional experiments were carried out and involved the cladding of 1040 steel substrates with 316 stainless steel. Successful clads were obtained with both materials, but difficulties surfaced again in controlling the temperature and in measuring the temperature of the near-surface region. The difficulties point out the need for a reliable means of temperature measurement as a part of the furnace facility. (SERI)

o Analytical work on cladded materials revealed good metallurgical bonding.

Optical evaluation of the microstructural features of 316 stainless steel, NiCr, Cr_2O_3, and NiAl clads on 1040 steel showed good metallurgical bonding and completely dense coatings, and indicated that the solar furnace techniques researchers are developing are at least as good as those in current use. Techniques of X-ray diffraction were used to identify the phases present: for Cr_2O_3 there were Cr_2O_3 lines and bcc Fe; and for 316 stainless steel there was a mix of bcc Fe and fcc FeNiCr (with the primary phase being FeNiCr). Work is continuing on the NiCr cladding materials with additives to improve the interfacial hardness. (SERI)

o Preparations have been made to perform experiments in the growth of thin films.

A vacuum chamber with a high transmission window and a mass flow control system was transported to SERI's High-Flux Solar Furnace and was assembled for experiments in film growth. The system has been leak-tested, and a Safe Operating Procedure has been written to describe its operation at the Solar Furnace. The first planned experiments will investigate the growth of carbon films from methane and hydrogen mixtures by rapid, thermal, chemical vapor deposition. (SERI)

o Georgia Tech Research Institute and Sandia Laboratories continued to analyze and to test the oxidation resistance of solar-treated carbon fibers.

Carbon-carbon composites are a high-tech material containing many desirable properties whose primary market is aerospace. Sandia and Georgia Tech Research Institute (GTRI) are conducting research to improve the oxidation resistance of the reinforcing fibers by treating them within a solar furnace.

During the present quarter, measurements of the oxidation resistance of solar-treated carbon fibers were performed. In addition, both organizations conducted experiments and analysis in order to understand the underlying phenomena. Final technical data were collected in anticipation of the final project review scheduled for early May at GTRI. A major U.S. supplier of carbon fiber was briefed on the status of the project in an attempt to obtain financial support for further research.

GTRI completed modifications to its solar furnace and treated a large quantity of IM-6 carbon fiber. Because of the improvements in the design of the fiber-handling apparatus, GTRI was able to treat more carbon fiber in a few days than the total amount treated in all previous years. During two of these days, Sandia installed a photometric system and measured the temperature of the fiber during the test. These temperatures were collected in order to understand whether the oxidation improvement is due to a solar photon effect or a temperature effect.

Sandia performed TEM and elemental analyses, and GTRI performed x-ray diffraction analyses of treated and untreated fiber in an attempt to understand the effect that solar treatment has on the morphology and chemical makeup of the fiber. GTRI performed several oxidation tests to obtain a good statistical estimate of the magnitude of improvements in oxidation resistance.

Results to date suggest that solar-treated carbon fibers have a new combination of material properties beyond what is commercially available. Unlike other commercially available fibers that are heat-treated to improve oxidation resistance, the solar-treated fibers maintain the same modulus of elasticity and tensile strength as the untreated fiber. The final assessment of this tentative conclusion will be made at the review to be held in May. (SNL)

Planned Activities for Next Quarter

- The growth of thin films on substrates heated in a reactive gas atmosphere will be studied at SERI. The solar beam will be used to heat the substrate and to drive the reaction, and the resulting film growth will be screened for photolytic effects. The experiments this quarter will center on growing carbon coatings (hard carbon, diamond-like carbon, and diamond) on various substrate materials. These materials exhibit tribological, optical, electronic, and protective properties that are of great industrial interest. Reports of progress will be made at the Eighth International Conference on Thin Films, in San Diego, California, in April, 1990, and at the Sixteenth DOE Surface Studies Conference in Golden, Colorado, in June, 1990.

- The final report for GTRI's project on carbon fiber will be written. In addition, the final review of all technical work performed by GTRI and Sandia will be held during May, 1990. A decision regarding whether or not this research will continue will be made at that time.

TASK D. RECEIVER/REACTOR MODELING

Accomplishments

- **Results from the numerical model developed for DCAR reactors were compared with preliminary data on reforming methane.**

  Results from the numerical model developed for DCAR reactors and applied to the SOLTOX and CAESAR experiments were compared with preliminary data obtained at the Sandia furnace for both carbon-dioxide heating and carbon-dioxide reforming of methane. The temperature response of thermocouples located in the absorber was determined by using model predictions of the thermal environment in the absorber. In general, these temperatures and predictions of the species concentrations exiting the reactor compared well with the measured data. This result suggests that the thermal and chemical environment in the absorber is being realistically modeled. More detailed model validations are planned.

  A three-flux radiation approach is being implemented into the model for the solar-band radiative transfer. This will provide a capability to account directly for collimated or conical solar incidence. Once solar flux distributions for the new heliostat just installed at Sandia's furnace are measured, the model will be used to provide guidance for the design of the next generation DCAR absorber. (SNL)

- **A paper on a direct catalytic absorption reactor for destruction of hazardous waste was named the test paper at a solar conference.**

  The paper entitled "Investigation of a Direct Catalytic Absorption Reactor for Hazardous Water Destruction" by R.D. Skocypec and R.E. Hogan was named the best paper of the American Society of Mechanical Engineers (ASME) in solar thermal at the 1990 International Solar Energy Conference. (SNL)

Planned Activities for Next Quarter

- CAESAR activities during the next quarter will focus on completing the characterization on measurements of incident solar flux and will utilize the results in analyzing the test data and performing calculations with the absorber computer model.

2. CONCENTRATOR DEVELOPMENT

Objective

The objective for Concentrator Development is to develop cost-effective concentrators and optical materials to support the variety of solar thermal applications.

TASK A. HELIOSTATS

Accomplishments

- **The drive from a heliostat (200 m^2) of the Solar Power Engineering Company passed Sandia's qualification testing.**

  The elevation drive from a heliostat (200 m^2) of the Solar Power Engineering Company passed Sandia's static load testing without any problems. After the drive failed last year under static testing, Sandia's Applied Mechanics Division suggested several improvements that were incorporated into the design by the drive's manufacturer. Sandia's suggested improvements were apparently instrumental in increasing the strength and durability of the drive. The testing was performed in Sandia's Statics Laboratory, a unique facility designed for load-testing large pieces of equipment, such as heliostat drives. The drive will be reinstalled at the National Solar Thermal Test Facility, and the 72 mirrors will be aligned when manpower is available. Sandia's evaluation of the heliostat then will commence. Key issues to be addressed in the evaluation include the heliostat's optical quality, tracking accuracy, and stability in windy conditions.

- **The initial meeting was held with Science Applications International Corporation for fabrication of a market-ready heliostat of 100 m^2.**

  Sandia held an initial meeting with Science Applications International Corporation (SAIC) for the new contract to build the first prototype of a market-ready heliostat. The heliostat will use two stretched-membrane mirror modules (50 m^2) on a single pedestal (Figure 2.A.1). SAIC plans to begin assembling the heliostat at Sandia in August; installation of the heliostat at the National Solar Thermal Test Facility for Sandia's evaluation should be completed by the middle of September.

- **Sandia completed a report on the testing of the two improved stretched-membrane mirror modules.**

  Sandia completed a report summarizing the results of its assessment of the two improved stretched-membrane mirror modules. Sandia concluded that the new mirror modules were significant improvements over the first-generation models. An invited paper summarizing the results of Sandia's assessment also has been prepared for the *Journal of Solar Energy Materials*.

- **The final report from Science Applications International Corporation (SAIC) was published by Sandia.**

  The final report from Science Applications International Corporation on the design of a market-ready heliostat was published. The report titled "Selection and Design of a Stretched-Membrane Heliostat for Today's Markets" (SAND89-7040), is the final deliverable on SAIC's previous contract with Sandia.

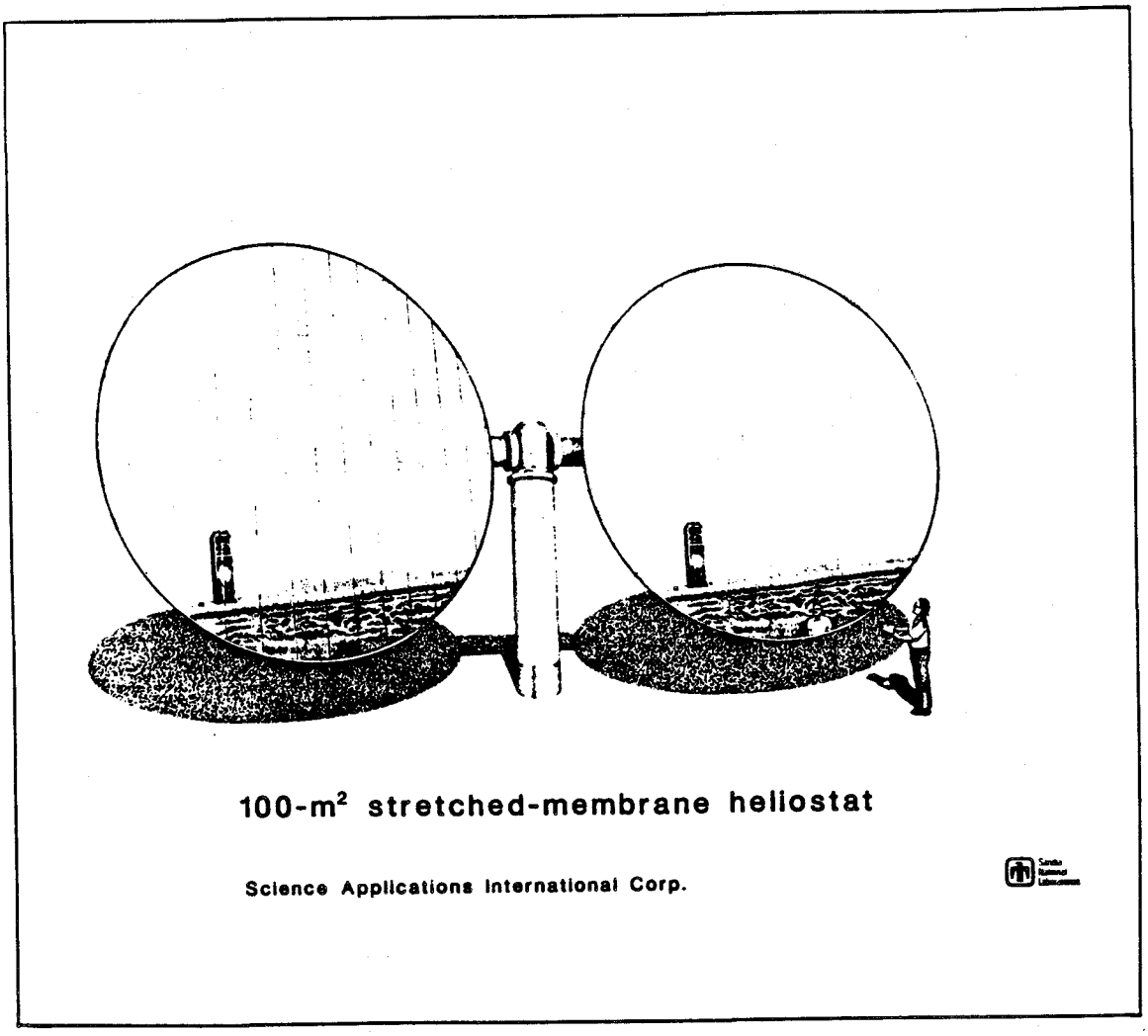


Figure 2.A.1

Artist's conception of SAIC's 100 m² stretched-membrane heliostat. Drawing by Gene Clardy of Sandia.

- **Sandia published the final report from Solar Kinetics, Inc.**

  The final report from Solar Kinetics, Inc. (SKI), on its improved design of a stretched-membrane heliostat was published. The report, titled "Design and Demonstration of an Improved Stretched-Membrane Heliostat" (SAND89-7028), is the final deliverable on SKI's previous contract with Sandia. Currently, under a new contract to Sandia, SKI is designing a fully integrated, market-ready heliostat. The design will be completed in June, 1990, and the first prototype then will be fabricated.

- **The Electric Power Research Institute (EPRI) installed a photovoltaic array on a prototype of Sandia's low-cost heliostat drive.**

  The Electric Power Research Institute (EPRI) completed the installation of a concentrating photovoltaic array at the PVUSA site in Davis, California. The system uses one of the low-cost heliostat drives developed for Sandia by the Peerless-Winsmith Company. Sandia loaned the drive to EPRI.

Planned Activities for Next Quarter

- The heliostat (200 m^2) from the Solar Power Engineering Company will be reinstalled at the Solar Thermal Test Facility, and Sandia's evaluation will begin.

- Sandia's testing of the low-cost drive and ATS's heliostat (150 m^2) will continue. Testing and documentation of the results are planned to be completed in September.

TASK B. PARABOLIC DISHES

Accomplishments

- **Two additional seven-meter, single-element membranes were formed and measured by Solar Kinetics, Inc.**

  Solar Kinetics, Inc. (SKI), has formed and measured the slope C errors of the second and third seven-meter membranes (f/D = 0.6) for the seven-meter-diameter optical element. The membranes are formed in a fixture that holds the concentrator ring and is designed to sustain the pressures of the plastic-forming process. The dish-forming process is an iterative one in which uniform and nonuniform loads, vacuum and hydroforming with water, respectively, are alternately applied to plastically form the metal membrane into a parabolic shape. Several cycles of vacuum and water forming are used to shape the membrane and, after each cycle, the slopes are measured to determine the next step in the process. The radial slope error is determined by comparing the measured radial slope distribution of the formed membrane with the radial slope distribution of a perfect parabola. Three seven-meter membranes have been formed, and each has demonstrated an improved radial slope error over previous ones. The measured slope errors are shown below.

Membrane	Slope Error (1σ)
First Membrane	3.40 mr
Second Membrane	3.30 mr
Third Membrane	3.10 mr

These measurements have exceeded expectations, and if the circumferential errors for the seven-meter-diameter membranes are similar to those for the 3.7-meter membranes, the total slope error for the optical element will be between 4.0 mr and 5.0 mr.

SKI rolled the membranes onto a contoured mandrel, reinstalled them on the ring, and measured their performance. Within measurement uncertainty, the measured slope errors were the same after they were rolled and mounted on the ring as they were before. This means that a single-element, stretched-membrane dish can be fabricated at the factory and can be assembled at the site. Previously, researchers thought that the membrane could not be rolled and that much of the dish fabrication would have to be completed on-site. Therefore, the single element, stretched-membrane dish will be much less expensive to fabricate and to install than had been previously thought. Researchers also decided to fabricate a second mandrel to mitigate the risk associated with storing and shipping the formed membranes on a single mandrel. This has resulted in about a three-week slip in the schedule.

SKI has completed the assembly of the optical element in Dallas. This involved cutting a circular hole at the center of the optical membrane, installing the central hub and supporting spokes, and installing the rear membrane. SKI and Sandia engineers are currently measuring the strains associated with the weight of the dish and simulated receiver loads. Once these tests have been completed, the optical element will be raised so that the optical axis is horizontal for optical measurement with the laser-ray-trace instrument.

After testing has been completed in Dallas, the optical element will be disassembled and shipped to Sandia for on-sun measurements. The test fixture for tracking the seven-meter optical element has been designed and is currently being fabricated at the Solar Thermal Test Facility. The optical element is currently scheduled for delivery to Sandia in late May, 1990.

o **Design of the faceted stretched-membrane dish continued.**

The team working on the Faceted Dish Development Project Design met at Sandia on January 24, 1990. The meeting was attended by the project participants: Solar Kinetics, Inc. (SKI), of Dallas, Texas; Science Applications International Corporation (SAIC) of San Diego, California; WGAssociates (WGA) of Dallas, Texas; and staff from SERI and Sandia.

Phase 1 of the project is the development and testing of facets fabricated by SKI and SAIC and the development of support structure for facet and pedestal designs by WGA. Solar Kinetics is developing stretched-membrane facets (3.6 meters in diameter) by using the plastic-forming techniques that the company has successfully demonstrated for the seven-meter dish. SAIC is fabricating elastically formed facets similar in construction to those developed for the stretched-membrane heliostats. WGA is designing the facet-support structure and pedestal for the twelve-facet dish.

The following decisions on design were reached at the meeting on Design Review.

- The facets for the Faceted Stretched-Membrane Dish will be arranged in a 2TOP configuration. This facet arrangement is the best thermal/optical arrangement and also has structural advantages for the pedestal, allows for convenient attachment of the facets to the facet support structure, and accommodates a high-efficiency connection between the facet-support structure and the power-conversion assembly.

- The dish's focal length was established at 10.5 meters. That focal length results in a high thermal optical performance and carries no structural penalties within the range of dish focal lengths (7.7 to 10.5 meters) that were considered. Attempts to increase the dish's focal length further will result in only marginal increases in optical/thermal performance and could carry large penalties in relation to the cost of the structure.

- The facet f/D range was established in the range of about 2.8 to 3.0. The range will be set by the final contour of the facet's support structure. Elastic facets should readily adapt to the facet's f/D range of about 2.8 to 3.0, and since the facet f/D is relatively large, the facets will operate at much reduced stresses. A single plastically formed facet also may adapt to this facet f/D range. At the most, two plastic facet f/Ds will be required. Stresses in the polymer film also are much reduced at the longer facet f/Ds. SKI and SAIC both think that they can make better optical facets in the longer facet f/D.

- A compromise contour, between parabolic and spherical, has been selected for the supporting structure of the facet. The outermost facets of the dish will be located on a spherical contour of radius 10.5 meters, and the innermost facets will be compromised by locating them at a slightly shorter facet f/D. This contour will best accommodate ease of fabrication and thermal/optical performance of the dish.

- An articulated support structure for the power-conversion assembly was selected to allow researchers to get the power-conversion assembly from the reflected solar flux quickly. If the elevation drive were used to off-track the concentrator, it would have to be substantially oversized and thus would increase its cost for very limited duty. By articulating the support structure of the power-conversion assembly, researchers can get the power-conversion assembly off-sun quickly and can add little to the cost of the dish. This option provides excellent protection for the power-conversion assembly, especially during initial on-sun testing of the integrated dish-Stirling system. If an articulated support is not required on production units, it can easily be eliminated from the design with only minor modifications to the structure.

- Two stow orientations will be used for the faceted stretched-membrane dish. Stow position 1 will be the normal stow position with the dish facing or slightly below the horizon. This orientation for the dish should prolong the life of the polymer film. Stow position 2 will be the high-wind stow position. At a prescribed wind velocity, the dish will automatically track to stow 2, and will face the zenith, to reduce wind loads on the structure. Once the wind has subsided, the dish either will resume operation or will return to the stow position 1.

- SERI has initiated testing at Houser Laboratories to evaluate the stresses in the polymer of the laminated, reflective steel membranes.

o **Validation of the Scanning Hartmann Optical Test (SHOT) is nearing completion at SERI.**

Researchers at SERI are completing a series of tests designed to validate and to characterize the Scanning Hartmann Optical Test instrument (SHOT). The test specimen being used for these tests is a three-meter membrane dish with f/D of 0.67. The repeatability of the instrument is being assessed by performing three tests in succession without disturbing the dish or the instrument. The effect of the number of data points, as well as the accuracy of the best-fit surface predicted by the SHOT, is being assessed by performing tests using 1000, 2000, and 4000 data points, by moving the dish off center a known amount, and by comparing this shift with that predicted by the "displaced" measurements obtained from the SHOT. Also, the effects of several instrumentation variables are being investigated--including the location of the spot tracking system (STS) relative to the beam scanning system (BSS) as well as the location of the test specimen relative to the instrument as a whole. If the STS can be moved to one side without significantly affecting the accuracy, then the amount of obstructed data can be minimized. The data for most of these tests have been acquired and will be reduced to quantitatively determine SHOT characteristics.

o **SERI acquired capability to analyze deflections and stresses in the support structure for stretched-membrane faceted dishes.**

SERI has acquired an extensive capability to analyze the deflections in support structures for stretched-membrane faceted dishes. This capability includes Algor finite element software modules now implemented on a 386-processor and personnel trained in their use.

The first application of these analytical tools is in calculating the deflections of the WG Associates' design of the support structure for the stretched-membrane facets from Science Applications International Corporation (SAIC) and Solar Kinetics, Inc. (SKI). The results of this analysis, together with measurements of the optical

performance of these facets to be performed at SERI beginning in April, will enable a prediction of the performance of the dish as a whole.

This capability also will extend SERI's capability to perform complex transient thermal analyses required for prediction of the behavior of materials with complex configurations undergoing surface treatment involving concentrated flux.

- **The National Aeronautics and Space Administration (NASA) explored use of silver polymer mirrors on lunar surface stations.**

  Dr. Ted Mroz, Manager of the Solar Dynamic and Thermal Systems Branch, NASA Lewis Research Center (LRC), visited SERI to explore the possibility of using polymer mirrors or a stretched membrane concentrator in NASA's new lunar surface station. After the LRC concept was discussed, he elaborated on the Pathfinder Surface Power Project, whose objective is to develop solar-based power technology to a level of readiness sufficient to enable extraterrestrial surface missions in the twenty-first century.

  A three-month assessment of feasibility is about to begin at LRC on the lunar surface mission. SERI can support that study with concepts by using polymer mirror reflectors (25 KW_e); defining required research to extend technology on solar thermal concentrators and optical materials to lunar-surface applications; structural and optical analysis of proposed concepts; and performing required testing of prototypes.

Planned Activities for Next Quarter

- Solar Kinetics will complete testing the seven-meter optical element in Dallas, Texas, in April, 1990.
- Solar Kinetics, Inc., will deliver the seven-meter-diameter, stretched-membrane optical element to Sandia for testing in May, 1990.
- The validation of SHOT will be completed.
- SKI and SAIC will deliver their prototype facets to SERI for evaluation by using the SHOT system in April.

TASK C. OPTICAL MATERIALS

Accomplishments

- **SERI began experiments to identify causes and to develop techniques to prevent tunneling.**

  Delamination at the interface between silver and PMMA has been in a failure mode in the form of "tunnels" on heliostats, troughs, and dishes. Tunnels usually begin at mirror edges or at interior points that are subjected to excessive stress. Moisture weakens the silver/PMMA adhesion and speeds tunneling. A simple, but extreme, laboratory simulation is to immerse samples in water for extended periods. A more sophisticated test is being completed. This test will include statistically large sample sets that are cycled in exposure to temperature and moisture. A number of promising sample kinds, including edge constraints and chemical bonding of adjoining films will be tested.

  Guided by prior laboratory experiments, a series of samples (18 inches by 24 inches) was prepared by using the current procedures of choice--including machine lamination of ECP-305 to aluminum substrates that are coated with a baked paint. Excellent resistance to tunneling was expected while, in fact, these samples failed quickly in a particular way. During the machine lamination at Industrial Solar Technology (IST), the rolls of silvered polymer (150 feet by 2 feet) were fed from the laminator to the substrates and were then trimmed with a razor-cut across the two-foot width of swath. All the observed tunnel failures initiated from the razor-cut edges and not from the edges corresponding to the one-hundred-fifty-foot lengths that were already formed during the slitting operation at the 3M Company. Presumably, razor-cuts produce flaws in the brittle polymer that become sites that initiate tunneling. These observations can explain much of the tunneling problems experienced by IST at its parabolic trough installations near Denver. In other experiments, heat-sealing the polymer edges has been shown to slow tunneling. Hot cutting procedures are being investigated in place of razor cutting as a means to anneal the polymer edge as it is being cut.

  Other means to mitigate tunneling are being explored. Optically transparent inorganic layers between the silver and PMMA act as adhesive layers, and such samples have resisted tunneling. Because tunneling experiments are statistically quite variable, researchers are using a latin-square statistical test design to optimize experiments.

- **A SERI-prepared, altered-mirror construction showed excellent performance.**

  Accelerated weathering tests in the Weather-Ometer indicated that there is a synergism between ultraviolet light, metal substrates, and the adhesive used with polymer mirrors, such that elimination of any one of the variables slows corrosion of the silver. This has led at SERI to a new construction of silvered-polymer mirror samples that have been subjected to accelerated weathering in the solar-simulator exposure chamber. Samples which have been mounted with and without adhesive to both bare aluminum and coil-coated aluminum substrates have been subjected to over 1000 hours of exposure. All combinations of adhesive and substrate material demonstrate excellent optical durability (a loss of less than 2 percent in reflectance). The durability of these samples exceeds that of any other material run in the solar simulator.

- **Sandia identified possible contamination in equipment from the 3M Company when producing the silvered-acrylic film, ECP-305.**

  At SERI's request, Sandia's R. Mahoney analyzed a sample of new silvered-acrylic film ECP-305 from the 3M Company, to identify causes of silver corrosion. An analysis also was performed on a prototype of the film that is thought to be identical except that the acrylic had been extruded on 3M's pilot-scale equipment. Both materials had been weathered in SERI's solar simulator. After 700 hours in this very severe environment, the ECP-305 had substantial corrosion, but the prototype material had almost none. (The ECP-305 is still a significant improvement over the older film, ECP-300A). Sandia's surface analysis with scanning Auger microscopy found a number of small crystals on the surface of the ECP-305; the constituents of these crystals included silver, sulfur, oxygen, silicon, and sodium. Similar crystals, though much less abundant, also were found on the prototype material. The constituents of the crystals, as well as their increased abundance in the ECP-305, indicates there may be processing contamination that will shorten the expected life of ECP-305. Moreover, the apparent durability of the prototype material demonstrates that, if produced in the right conditions, it is possible to make a silvered-acrylic film that is very resistant to corrosion. The results of Sandia's analysis were reviewed with SERI researchers at a meeting on February 1 and have been forwarded to the 3M Company.

- **Sandia held an initial meeting on its contract with Industrial Solar Technology on replaceable reflective films.**

  Sandia held an initial meeting on its new contract with Industrial Solar Technology (IST) to develop a method of replacing the reflective film on a stretched-membrane heliostat. The film is expected to be replaced several times during a heliostat's thirty-year life; however, the best film currently available, 3M's ECP-305, is bonded very tightly to the metal substrate, which makes replacement difficult. IST will evaluate alternative materials for the substrate and methods of attaching it to the heliostat. The selected method is likely to be applicable to both parabolic troughs and multifaceted stretched-membrane dishes. The first demonstration of a replaceable reflective film involving one of the existing stretched-membrane mirror modules is planned at the National Solar Thermal Test Facility in the middle of 1990.

- **A Request for Quotation was issued for a cost study of solar reflectors.**

  A Request for Quotation was issued for a cost study of solar reflectors to develop estimates on production cost for sol-gel mirrors on stainless steel and silver acrylic polymer film laminated to thin stainless steel. The study will develop cost estimates for three production levels: 60,000 m^2 per year; 600,000 m^2 per year; and 6,000,000 m^2 per year. This corresponds to power production levels of 10,100, and 1000 M_e per year.

- **Evaluation of ultraviolet reflectors is in progress.**

  A literature search of ultraviolet reflector materials has been completed. Appropriate articles and other sources of information related to enhanced concentration of ultraviolet radiation are being reviewed. Much research has been done in reflector materials for specific ultraviolet laser lines. Much of this work has resulted in rather narrow band reflectors tailored to the laser wavelength of interest; broadband ultraviolet reflectance has not been adequately addressed. The most frequent concept contemplated for achieving high reflectance in the ultraviolet has been multi-layer dielectric interference coatings. Ten-to-fifty-layer coatings are not unusual. Technical concerns involve controlling the thickness of each layer within 1 percent to

5 percent, as well as stress development between adjoining layers. Although such technical obstacles can be overcome (for small areas), the resulting process is extremely expensive. In addition, durability is a critical issue. Little attention has been paid to real world conditions expected to be experienced in solar applications.

Planned Activities for Next Quarter

- Quotations on the Request for Quotation (on the Solar Reflector Cost Study) will be received at Sandia by April 25, 1990. Proposals will be reviewed, and recommendations will be made to Sandia's Purchasing Department in May. A contract will be placed in June, 1990.

- Experiments to avoid tunneling in parallel with weathering experiments on a variety of silver-polymer adhesive substrate materials and edge and joining configurations will continue.

- Mechanical tests will be conducted to determine the effects of cyclic stresses on the optical performance of ECP-305 that is mounted on stainless steel of 0.003 inches.

TASK D. STRUCTURAL DYNAMICS

Accomplishments

- **The close-out of the wind-load, field-test program has been completed.**

  A memorandum summarizing the wind-load program was completed and distributed. The computer and associated data-acquisition equipment from this program are being integrated into other programs at the National Solar Thermal Test Facility. All work on the field-test program has been completed.

- **Colorado State University (CSU) is preparing a wind-load design guide.**

  Sandia has contracted with Prof. J. A. Peterka to finalize the drafted design guide and included the latest test results for both dishes and heliostats. Funding also has been included to allow Colorado State University to determine the level of effort required to determine off-peak loading on collectors (an area of interest to the designers).

Planned Activities for Next Quarter

- A drafted version of the design guide is expected for review by Sandia and SERI. Sandia also will evaluate the estimate of effort required to include off-peak loading in the design guide.

3. ELECTRIC SYSTEMS DEVELOPMENT

Objectives

Objectives for work on Electric Systems Development involve continuing the development of the components and systems required to establish technical readiness of applications of solar thermal electric power production to penetrate major national and international markets by the late 1990s.

TASK A. CENTRAL RECEIVER TECHNOLOGY

Accomplishments

o Water-flow testing of the Panel Research Experiment (PRE) was initiated.

Water-flow testing of the Panel Research Experiment (PRE) at Sandia was initiated. Flow-testing was initiated while the fabrication of the PRE was being completed in order to expedite testing. PRE fabrication has been completed, and the system (pumps, valves, and instrumentation) is being operated from the process-control computer in the control room. The PRE is an experiment of 3 MWt, designed to evaluate the Direct Absorption Receiver (DAR). In this experiment, designed, built, and assembled at the Central Receiver Test Facility (CRTF), flow-testing with water and molten salt will be demonstrated. The fluid flows down the panel (1 meter wide by 6 meters long), which is tilted back 10°. After the flow-testing has demonstrated the concept, the PRE will be raised to the top of the CRTF tower for solar testing.

Water-flow testing has been used to evaluate the performance of inlet and collection manifolds, and to test, to calibrate, and to check the pump, valves and instrumentation. The tensioning system, air cooler, and heat trace also have been checked. All start-up problems have been repaired.

Water flow on the panel, tilted 10° back, is very good. Droplet formation has been observed at 4 to 5 meters, as in other tests, down the panel. However, in the absence of wind, there is little or no droplet ejection. Water-flow testing will continue until late May (to continue to check the system and to characterize the flow). Sandia will then begin salt melt in the system. The safety and operating procedures are currently being prepared for this test.

o The molten-salt pump and valves, both hot and cold, are operational.

Both the hot and cold loop of the molten-salt pump and valve tests, at Sandia, were restarted this quarter. The hot loop operated for 1400 hours this quarter, and has a total of 3800 hours of operation. The cold loop operated for 500 hours this quarter; that time is its total hours of operation. The molten-salt pump and valve tests consist of two pumped loops, each with one pump and five valves. One side simulates the hot side of the receiver (565°C), and the other simulates the cold side of the receiver (285°C). The pumps and valves are designed for a molten-salt central receiver power plant of 30 MWe. This test was designed to demonstrate a commercial-scale salt transport system.

The hot loop was restarted after a new pump shaft was installed. The rebuilt pump is working well. Valve packing material currently being used is a fiberglass core with Inconel wire-wrapped packing used with teflon rings. These materials work very well and have operated in valves with only minor flaking for up to 3000 hours. Sandia currently is testing the limitation of the packing material to determine how many hours the material can last between repackings. The loop continues to operate in the unattended auto-sequence mode.

The cold loop also was restarted this past quarter after the motor was repaired. Initially, the cold loop operated intermittently due to "start-up" problems (e.g., instrumentation drifting, control-algorithm bugs, etc). However, the loop is now operating in the unattended auto-sequence mode. The vertical turbine pump appears to be working satisfactorily. The valves in this loop use the original graphite-fiber packing; and thus far, there have been no catastrophic failures of the packing material. However, the valve packing will be replaced with the proven, less-expensive fiberglass with Inconel packing used on the hot loop.

The interim report on the pump and valve test prepared last quarter is being published as a Sandia report. Also during the past quarter, Babcock & Wilcox (prime contractor on the pump and valve test) subcontracted with Science Applications International Corporation (SAIC) to conduct the data evaluation of the pump and valve loops. SAIC is providing monthly reports on the evaluation of the data to Sandia.

- **New Mexico State University's Solar Furnace will be used to test volumetric receiver materials.**

Sandia initiated a contract with New Mexico State University for the testing of volumetric receiver absorber materials at the University's Solar Furnace. Testing these materials is required to assist in characterizing the heat-transfer coefficients, temperature limitations, and efficiency of various porous heat transfer materials (e.g., ceramic foams, knit wire mesh, etc). The test results will be used to select optimum materials and to validate computer models of volumetric air receivers to use in Sandia's tests. In a volumetric air receiver, concentrated solar energy is absorbed by a porous absorber. Air flows through the absorber and convectively transfers energy from the absorber to the air.

Six volumetric air-receiver absorbers have been tested at the Plataforma Solar de Almeria in Spain. However, due to size and instrumentation limitations, quantitative measurements to characterize the absorbers have not been possible. The tests in the furnace at New Mexico State University will utilize absorber samples (7 centimeters in diameter) which are heavily instrumented so that the performance of the absorber material can be characterized. Absorber materials to be tested include porous ceramic Inconel wire mesh and stainless-steel foils. Testing will begin after the test apparatus has been installed and instrumented.

- **A drafted report entitled "Solar Central Receiver Performance Evaluation Standards" was completed.**

After two years of effort by an international team of experts in the evaluation of the performance of solar receivers, SERI has published a first-edited draft of this report. This effort is a part of the International Energy Agency, Small Solar Power Systems (IEA-SSPS) Task III. Authors from the Federal Republic of Germany, Spain, Switzerland, and the United States made contributions to this effort.

- **Analysis of reliability of a salt-in-tube central receiver power plant was completed.**

Sandia recently completed a reliability analysis for a solar-central receiver power plant that employs a salt-in-tube receiver. Because reliability data for a number of critical plant components have only recently been collected, researchers think that this is the first time such an analysis can be defended with a high degree of credibility. The design of the power plant that was analyzed was similar to the 100 MWe plant defined by Pacific Gas and Electric for the United States' utility study of central receiver concepts. The analysis predicted a forced outage rate of 5.7 percent and an overall plant availability, including scheduled outages, of 90 percent.

The calculation of availability was performed with the UNIRAM computer code. This code was developed in the 1980s by the Electric Power Research Institute and is becoming widely used within the utility industry of the United States. To run the code, the analyst must provide a logic model and reliability data for the power plant's components and/or subsystems, that is, the mean time between failures and mean down times. This type of data was collected initially for the Solar One power plant, and the code was run to ascertain if it could predict the actual availability achieved at the plant over a three-year period. The code predicted the actual availability within 1 percent.

With confidence in the code, researchers then proceeded to collect data applicable to the molten salt plant. These data sources were: (1) the commercial-scale molten-salt pump and valve tests currently being conducted at Sandia; (2) salt receiver tests conducted in France and the United States; (3) heat-trace data from the United States' Molten Salt Electric Experiment; (4) data on power block and steam generation from the LUZ solar plants and the United States' utility industry; and (5) control system and other applicable data from Solar One. The logic model for the plant was expressed in terms of a reliability block diagram. The diagram relates the series-parallel arrangement of the plant's components and subsystems.

As mentioned previously, the forced outage rate predicted by UNIRAM was 5.7 percent. The code identified the most important contributors to the plant's unavailability. Failures in the control system were identified as the most important cause of forced outages. Receiver problems were rated second with turbine outages a close third. The overall plant availability of 90 percent meets the goal identified by the United States' utility study.

- **An interim meeting was held on the Second Generation Central Receiver Study.**

The purpose of the "Second Generation Central Receiver Study" is to compare the cost and performance of molten salt and volumetric-air, central-receiver power plants. The study is a joint effort of the United States and Germany and was initiated in the fall of 1989. The study is intended to provide guidance in directing future United States' and German programs to develop solar-thermal electric technology. The study will focus on 30 MW and 100 MW plants with capacity factors in the 40 percent to 50 percent range.

A meeting to discuss interim results was held at the Solar Thermal Test Facility during the week of March 26. Five individuals representing the German organization's DLR and Interatom were in attendance, as were three researchers from Sandia. Results from analyses of the 30 MWe and 100 MWe molten salt plants were presented by

Sandia. These results were compared with more preliminary analyses of the 30 MWe air plant by Interatom. Interatom had not analyzed the 100 MWe air plant prior to the meeting, and much attention was devoted to defining this analysis during the meeting. To date, it appears that the salt plants will have a lower levelized energy cost primarily due to the expensive thermal storage system required by the air system. However, Interatom and DLR informed Sandia that the storage system is being redesigned as part of the PHOEBUS consortium and that the cost may be reduced.

Many agreements regarding details of the analysis were made during the meeting to ensure that future comparisons will be on a common basis. Sandia presented the results of a reliability analysis of the 100 MWe salt plant analyzed in the United States' utility study. Interatom will perform a similar analysis of the air plant prior to the next meeting held in June, 1990.

- **Problems with mirrors at Solar One have been analyzed.**

During January, 1990, Sandia conducted a detailed survey of problems with mirrors at Solar One. This survey was done because several Sandia researchers noted (during a brief visit to the site during the fall of 1989) that greater than 100 mirror facets had either fallen to the ground or were broken. All of these failures have occurred following final shutdown of the plant in September, 1988. The purpose of the more recent survey was to assess more accurately the magnitude and possible causes of the fallen and broken mirrors as well as to measure reflective surface losses due to random corrosion throughout the field. The last corrosion survey was conducted by Southern California Edison and Sandia, Livermore, in July, 1986.

Four types of problems with mirrors have occurred at the plant.

1. Sixty-eight entire facet pans have fallen to the ground due to failure of the glue bond at the mounting bracket for the facet. The glass was destroyed upon impact with the ground. Reflective surface lost by the mechanism is 2380 square feet.

2. The glass on forty-three facets has corroded very badly and is broken. The glass pulled away from the honeycomb structure within the pan and fell to the ground. The facet pan remained attached to the heliostat structure. Reflective surface lost by this mechanism is 1505 square feet.

3. Forty facets have small cracks. Researchers assume that the glass on these facets is not usable because either (a) they will soon corrode and fall, or (b) the surface is distorted enough to prohibit interception of reflected beams by the receiver. Reflective surface lost by this mechanism is 1400 square feet.

4. Approximately half of the 21,816 facets in the field has some amount of random mirror corrosion. Total random corrosion is approximately 760 square feet.

The reflective surface area lost due to these four problems is approximately 6050 square feet. This represents 0.78 percent of the total field area of 765,600 square feet.

When the survey was conducted in 1986, only the fourth problem was occurring. That survey predicted that between 600 and 850 square feet should be lost due to random corrosion in 1990. The recent measurement of 760 square feet confirms that prediction.

An analysis of the failure modes revealed that facet venting appears to solve most of the problems. Researchers vented approximately one-half of the facets in 1984. Based on updated price quotes from the vendors who performed the work previously, researchers estimate it will cost approximately $120,000 to vent the remainder of the heliostat field.

Since the total reflective area lost to date is less than 1 percent, researchers think that nothing should be done to remedy the problems during the next year. In January, 1991, staff should conduct another field survey. This survey will require one man-day. If problems continue to escalate at an unacceptable rate, researchers should install vents in the remainder of the field.

Planned Activities for Next Quarter

- Water-flow testing of the PRE will be completed next quarter. Researchers will initiate salt-flow testing of the PRE.

- Testing will continue on both loops. Staff will replace the valve packings in the cold loop, and researchers will hold a meeting to discuss the future and potential modifications to the loops.

- Low-power (<500 kW per square meter) low-temperature (600°C) tests will be completed on the volumetric-air absorber tests at New Mexico State University.

- The first drafted review of the standards document will be completed, and an authors' meeting for review will be held in June, 1990.

- The next Second Generation Central Receiver Study Group will be held during the second week of June, 1990, in Cologne, West Germany. Sandia will revise analyses of cost and performance for the salt plant. The revisions will be based on comments received at the March meeting. Sandia also will perform uncertainty analyses and will present these results during the June meeting.

TASK B. DISTRIBUTED RECEIVER TECHNOLOGY

Accomplishments

- **Sandia engineers initiated designs for gas-fired hybrid receivers.**

  Sandia engineers have initiated studies on design of gas-fired heat pipes and are designing a wick-type evaporator that will be incorporated into a sodium-filled heat pipe. Eventual applications for Sandia's evaporator design include gas-fired sodium heat pipes as well as hybridization of solar receivers.

  The evaporator under design at Sandia's Solar Thermal Test Facility (STTF), located just west of the Sandia mountains, is of a tube-and-shell type of heat exchanger. Heat transfer and stress calculations are being performed. Considerations in design include heat-transfer efficiency, thermal stress, pressure drop, reliability, and ease of fabrication. The Sandia design will be compact and more rugged than previous gas-fired evaporators. Following design, the evaporator will be fabricated in Sandia's shops, and then it will be calorimetry-tested at Sandia's Engine Test Facility at the STTF.

  The design tools used for the Sandia tube-and-shell evaporator, which will initially be applied to ground-testing the STM4-120 Stirling engine, will eventually be applied to gas-fired heat-pipe and/or pool-boilers to be integrated with Sandia-developed reflux receivers.

- **The full-scale pool-boiler spare parts were qualified for one-thousand-hour tests.**

  A one-thousand-hour bake at 800°C of coupons cut from the materials and weldments of a mockup of the first Sandia reflux pool-boiler receiver was completed. Baked and unbaked parts were pull-tested to failure to compare force-displacement characteristics. Except for one filler-metal weldment that is very lightly loaded in service, no significant change in characteristics was noted. Thus, from a thermal-aging standpoint, the full-scale pool boiler spare parts that are on hand are suitable for construction of a backup for the STM receiver for on-sun testing.

- **Diagnostics by x-ray on Sandia's reflux pool-boiler receiver continued.**

  Analysis has been completed on the first real-time X-ray images of the pool boiler. They were taken during full-power operation on test-bed concentrator number 1 at Sandia. The main objective was to determine void fraction in the boiler. The imaged area was near the pool surface. The quality of the data has been less than expected. A 30 percent void fraction was indicated in one part of the imaged area; a void fraction as negative as -10 percent was indicated in another. A different method of detection is being installed to improve the quality of data. The new method also will permit greater latitude in image-area location.

- **Preparations are underway for pool-boiler materials and methods tests at Sandia.**

  Haynes 230 structural elements, instrumentations, and NaK have been acquired for short-term screening tests of Sandia's pool-boiler materials and methods. Development of alternatives to electric-discharge-machined cavities for boiling stabilization has begun. This development includes laser drilling and metal-powder sintering tests. Alternative quartz-lamp holders have been located for testing. If

these holders function well in the short-term tests, they will be considered for use in the follow-on, long-term tests.

- **Studies on lifetime issues have begun.**

  Sandia engineers have ordered samples of Haynes 230 material for tests on short-term creep and creep-fatigue interaction. Stress analyses that will be coordinated with the material characterizations have begun.

- **Comparisons of pool-boilers and heat-pipe receivers were initiated at Sandia.**

  Sandia engineers have developed evaluation criteria for dish-Stirling receivers that will be used: (1) to compare reflux heat-pipe and pool-boiler receiver concepts with each other and other receiver concepts; (2) to help make design decisions; and (3) to guide resources for research and development. The starting point in the process is the estimation of manufacturing cost. A zeroth-order estimate of manufacturing costs has been completed for a pool-boiler receiver with laser-drilled artificial nucleation sites, a pool-boiler receiver with sintered-powder nucleation sites, a heat-pipe receiver with a screen wick, and a receiver mount and housing. No optimizations for cost were made. The results are $1965, $2057, $2486 and $1474.

- **Sandia researchers completed fabrication of the second bench-scale, heat-pipe receiver.**

  A new bench-scale, heat-pipe receiver has been constructed and filled with sodium, and it is now ready for high-flux testing. An earlier bench-scale receiver revealed that vapor could be trapped in the heat-pipe's wick structure and could block the flow of heat from the absorber surface to the vapor space. The latest bench-scale, heat-pipe has a wick structure that is capable of venting vapor and thereby preventing overheat conditions on the absorber surface. An electromagnetic (EM) pump is also provided on the surface. An EM pump is also provided on the second heat pipe to boost the system's pumping capability if the losses in flow are found to be excessive in the new wick structure.

  The new heat pipe is installed in the test system, and a preliminary check on instrumentation and the EM pump has been completed. Testing the system with high-flux power input from quartz halogen lamps will begin in the next quarter.

Planned Activities for Next Quarter

- Additional full-day tests to further characterize performance of the reflux pool-boiler receiver will be completed at Sandia. Diagnostics by x-ray will be continued, and infrared thermography to map the absorber temperature will be initiated.

- Bench-scale test vessels will be built to screen improvements in candidate materials and methods for the next-generation of Sandia's reflux pool-boiler receiver.

- Design will continue on a long-term test of bench-scale reflux pool-boiler receivers. This test will determine the long-term effects of boiling on the heated-surface material and the long-term stability of the boiling itself.

TASK C. CONVERSION TECHNOLOGY

Accomplishments

o Testing of the STM4-120 continued at Sandia's engine test facility.

The Stirling Thermal Motors' kinematic Stirling engine, STM4-120, has obtained a total of 132 hours of operation. During this quarter the engine's operating pressure was increased to 6.5 MPa (955 psi). With an evaporator temperature of 780°C, cooling water of 23°C, an engine speed of 1800 rpm, and full piston stroke of 48.5 mm, the engine produced 12.3 kW of shaft power at an efficiency of 35 percent. Figure 3.C.1 shows how the output performance of the engine's power compares to the predicted output level. Because the measured performance is following the predicted level, this indicates that the 25 kW level should be obtained at a cycle pressure of 12 MPa.

During this quarter of testing, several areas required correction in the heat pipes used to power the Stirling engine. Power levels beyond 12.3 kW were not achieved because one of the heat pipes was experiencing a sodium dryout in its evaporator. This resulted in overheating of the heat pipe. Two areas are possible in causing this problem. These include an incorrectly attached baffle in the heat pipe or a lack of sodium inventory overlooked during fabrication. Sandia and Stirling Thermal Motors are currently investigating this matter further. In addition, three heater head bellows have failed. The bellows allow deflection that naturally occurs within the heater head. These failed bellows were analyzed by Sandia's materials group. Results indicate that the failures were a result of external oxidation of the bellows. The outer layer of the bellows surface (321 SS) is oxidized more rapidly at elevated operating temperatures. During shutdown, the bellows return to their initial condition and crack the outer oxidized layer of the material, which flakes off and exposes new, unprotected metal. This process continues during each thermal cycle until a failure occurs. Figure 3.C.2 shows various areas of the bellows. The dark side of each section shows the oxidation. The curved sections of the bellows show how the cracks propagate through the material thickness, and eventually fail. To prevent future failures, all of the bellows made from 321 SS will be replaced with Inconel 625. Inconel 625 was recommended by Sandia's materials group as a metal which does not exhibit the rapid oxidation as 321 SS does. In addition, the 625 provides a fatigue failure of two-million cycles. This compares with 321 SS, which has a lifetime in fatigue failure of 1000 cycles. After replacing the bellows, the engine pressure will be increased, and charterizing the engine will continue.

o SERI's closed-loop Regenerative Thermoelectrochemical Conversion (RTEC) experiments have begun at Hughes Aircraft Corporation.

During this quarter, the first test of the closed-loop RTEC system was completed. The test sequence was as follows. First, freshly prepared acid and base solutions were loaded into the cell storage tanks. A cell test then was conducted. A peak power of 12.3 watts was attained. Performance started to decline after 40 minutes of operation as the acid fluid was nearing depletion. The spent acid solution then was cycled into the thermal regenerator. Regeneration was accomplished at 700°C, over a span of 35 minutes. The regenerated acid and base then were recycled back into the cell's storage tanks. A second cell run then was conducted. A peak power of 7.5 watts was attained. The cell performance dropped off rapidly once consumption of base solution had lowered its level to below the minimum required for proper base circulation.

PREDICTED vs MEASURED PERFORMANCE of the STIRLING THERMAL MOTORS, STM4-120

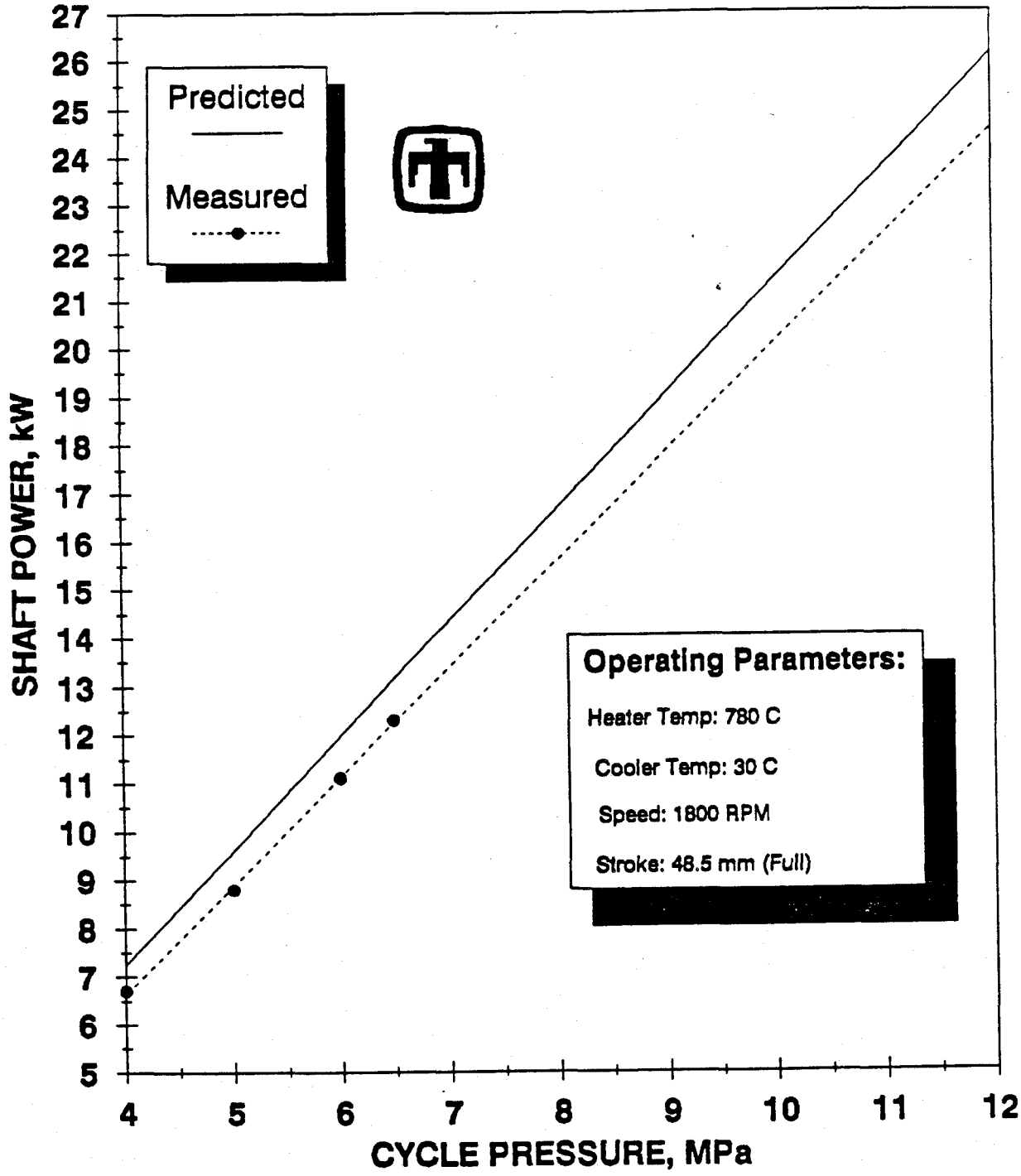
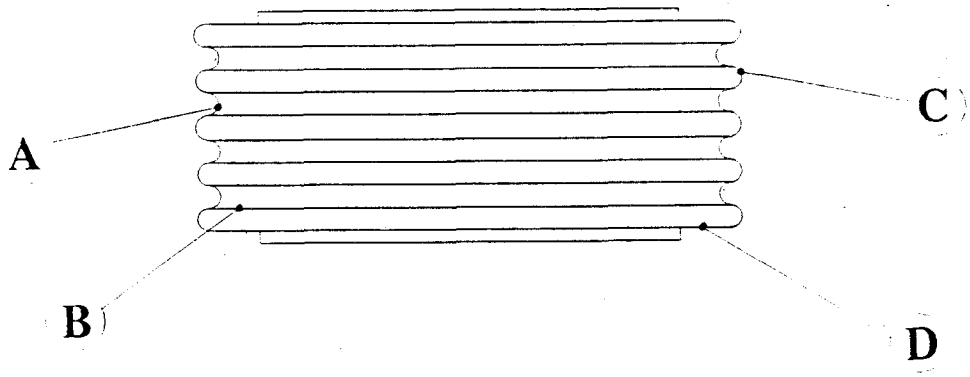
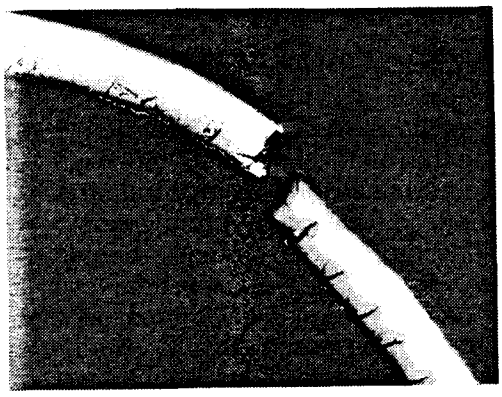


Figure 3.C.1

BELLOWS ANALYSIS
FOR
STIRLING ENGINE

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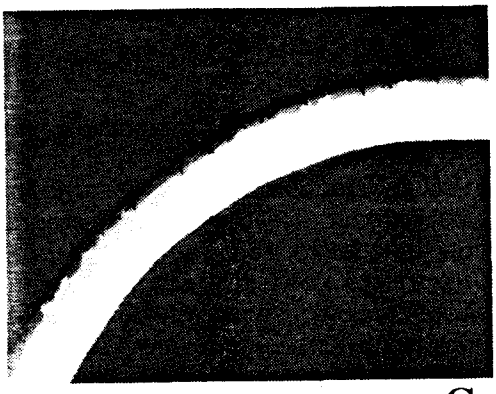
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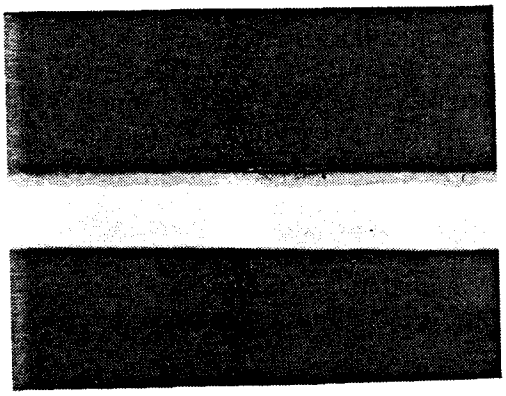
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D

Figure 3.C.2

This first test shows that the system can be operated in a closed-loop fashion. Preliminary estimates suggest that the composition of the acid is invariant from batch to batch. Analysis of the distillate (base solution) indicated that the composition was suitable for cell operation. Additional tests are planned.

This event is deemed to be significant, since it demonstrated that the operation of the RTEC cell, the thermal regeneration of the spent fluid, and the recombination of the regenerated effluents for recirculation through the cell are technically feasible. Moreover, the cell has operated at a power level exceeding the target requirement set more than two years ago at 10 W. However, this is the first operation of the closed-loop system. Therefore, it signals the beginning of a sequence of tests to be conducted and to serve for debuging the operation of the system and to enable a prolonged operation at a steady-state level.

Planned Activities for Next Quarter

- Operation of the Stirling Thermal Motors' STM4-120 kinematic Stirling engine will continue at Sandia's Engine Test Facility (ETF). Monitoring the power, efficiency, and reliability will continue during the quarter. With upgraded heat pipe parts, an increase in cycle pressure is scheduled to obtain higher power levels.

- After review of the final version of the preliminary designs of Stirling Technology Company (STC) and Cummins Engine Company (CEC), NASA/LeRC and Sandia will be awarding contract(s) for the final design of the ASCS. The final design(s) should begin in the next quarter and will continue through the year.

- Through NASA/LERC, Sandia will be negotiating with Cummins Engine Company for the development of a control system for the Stirling Thermal Motors', STM4-120, kinematic Stirling engine. This control system will be incorporated with the STM4-120 system to be installed on a test-bed concentrator for "on-sun" evaluation. Cummins will use a similar control system developed for its 4 kW system.

- Completion of RTEC closed-loop experiments is scheduled at Hughes Aircraft Corporation.

- A presentation will be made at DOE Headquarters on the RTEC work.

- Completion of the final draft of the report on the RTEC research is planned.

4. TECHNOLOGY DEVELOPMENT

Objectives

In collaboration with industrial partners the intent of this work is to develop systems that will result in (1) competitive solar thermal electric systems based on refinement and optimization of current commercially available systems; (2) systems for a solar-driven process that destroys toxic chemicals; and (3) advanced solar thermal electric systems that will improve performance and cost competitiveness in the middle of the 1990s.

TASK A. NEXT-GENERATION COMMERCIAL SYSTEMS

Subtask A-1. Project Development

Accomplishments

- **Qualified bidders were unable to proceed to the successful conclusion of contract discussions for the Next-Generation Commercial Systems.**

  Four companies responded with proposals to a Request for Quotation (RFQ) issued in April, 1989, to sixteen potential candidates. Two companies were selected as qualified joint-venture partners for the Next-Generation User Systems Program. Contract negotiations were underway with both companies during the first quarter of FY 1990. Early in the current quarter, researchers were notified by one of the respondents that the company was unable to participate at the reduced level of funding proposed by the government. The second respondent's proposal was contingent upon its having a contract for the sale of electricity. This contract was unable to be negotiated by the end of the current quarter. Consequently, all respondents were notified on March 30, 1990, that no contract award will be made on this Request for Quotation.

Subtask A-3. Design Assistance and CORECT Support

Accomplishments

- **Sandia and SERI worked as co-sponsors of SOLTECH 90.**

- The SOLTECH 90 meeting was held in Austin, Texas, on March 19 to 22, 1990. Sandia and SERI were co-sponsors of this national meeting. The solar thermal presence at the meeting consisted of four symposia sessions, a set of technical displays, and an exhibit. The symposia contained the following technical presentations: (1) an overview of the solar thermal program; (2) solar detoxification; and (3) case studies of the use of solar thermal technology for generating electricity and hot water. The technical displays were professionally constructed and contained pictures and summary information to augment the symposia topics. They were coordinated through the Solar Thermal Design Assistance Center (STDAC). The display was placed near the technical meeting rooms. An exhibit booth also was constructed and featured some working models of solar thermal systems, and some promotional brochures and handouts. Sandia and SERI personnel manned the exhibit.

  The solar thermal symposia were very well attended, and there was much interest in the materials shown at the display and backboard. In particular, Sandia's dish-Stirling model and SERI's detoxification system model attracted much attention. Also, as a result of the interaction with the participants, a number of new opportunities for the Design Assistance Center were identified. SERI and Sandia are preparing a final report (memorandum) about SOLTECH 90.

- **Sandia continued with assistance to Cummins Engine Company.**

  Sandia staff has continued assisting Cummins Engine Company. The analysis of the burnout of the commercial prototype dish/Stirling receiver (5 kWe) was completed. Attributable to improper focus of the LaJet 460B concentrator, recommendations were made which, if followed, should avoid similar problems in the future. Sandia staff helped formulate a comprehensive test plan for the system's proof of design and provided on-site support for the next phases of testing. A Sandia infrared camera also was loaned to Cummins to monitor distributions of receiver temperature. A second failure of the receiver was analyzed and found to be due to a change in fabrication techniques by Thermacore. The concentrator's focus remained as set according to Sandia's recommendations, and thereby eliminated that as a source of the problem.

- **Researchers are working on measuring the ultraviolet resource.**

  Sandia personnel are continuing to work with SERI's Solar Resource Assessment Office to measure or to estimate the ultraviolet resource in the radiation band of 250 nm to 400 nm. Both laboratories have agreed on a set of instruments, and a measurement program is underway. Sandia and SERI each will construct ultraviolet monitoring stations and will share the data. The goal of the project is to develop models that accurately can predict the ultraviolet resource as a function of total broad-band radiation and commonly measured weather variables. SERI currently retains ultraviolet instrumentation and has begun making measurements. Sandia is in the process of procuring instruments for its station, which is scheduled to begin operation during the next quarter. Completion of the whole project will require about one year.

- **An Industrial Process Heat System is scheduled for installation.**

  Industrial Solar Technology and United Solar Technologies are finalizing an agreement to install a solar-thermal Industrial Process Heat System at the California State Women's Prison at Tehachapi, California. The Design Assistance Center has agreed to assist in designing and installing a performance monitoring system for the new plant. Sandia staff are also involved as consultants on various aspects of the plant's engineering design--including the electrical control system, wind-loading analysis, and structural analysis. The work will continue through this year.

- **Engineers evaluated a solar system in American Samoa.**

  Sandia personnel conducted an on-site engineering evaluation of a solar absorption cooling system located at the LBJ Hospital in American Samoa. The flat-plate system has been inoperable for the last several years. It is now being considered for conversion to a hot-water heating system. The DOE Conservation Program is supporting the effort under its program for schools and hospitals. The DOE Solar Thermal Program has been requested to supply partial financial and technical assistance for the project. In response, DOE Headquarters asked the Design Assistance Center to inspect the system to determine the technical viability of the project.

  Based on the findings from the site visit, Sandia concluded the following. (1) There is a sufficient number of existing collectors that can be reused in the converted system (including an ample supply of spares). (2) The mounting structure should be rebuilt (currently in progress). (3) Sandia estimates that less than $20,000 is required to purchase the materials to upgrade the system to supply hot water for the hospital. The labor to perform the reconstruction of the system will be supplied by existing hospital and DOE contract personnel. (4) The Design Assistance Center will design the new system and will provide on-site consulting during the refurbishment. After the system is operating, the Design Assistance Center will provide engineering consulting regarding system performance for approximately a year or until the system is operating efficiently and reliably.

  The Solar Thermal Program has decided to provide partial support for the project. The project is currently underway and is expected to be completed within this fiscal year.

- **The chief of conservation services in Mexico asked for Sandia's assistance in reducing cooling loads in large buildings in Mexico City.**

  Sandia is coordinating the technical expertise for a project for A. Ecobedo, chief of conservation services in Mexico, by directing him to the appropriate resources at SERI, DOE Headquarters, or private industry. As an initial response, Sandia has provided information about SKI's building lighting retrofit kit, which is designed to reduce building lighting loads. Consulting by the Design Assistance Center is expected to be an ongoing activity.

- **Sandia and the California Energy Commission (CEC) are discussing how the two organizations can work together.**

  The initial meetings have been very productive, and a number of areas of collaboration have been identified--including planning, technical consulting, co-funded projects, and educational activities. A formal working agreement is expected to be finalized next quarter.

- **Sandia wrote a system simulator for a Fresnel lens solar thermal system proposed by the 3M Company to be used to generate process heat at an existing facility in Marshall, Minnesota.**

  The simulator was exercised at Sandia, the results were discussed with 3M, and the code was transferred to the 3M Optics Technology Development Program.

- **Energy Concepts Company (ECC) submitted a Statement of Work.**

  The Energy Concepts Company (ECC) has submitted a Statement of Work defining delivery, installation, and product support of an intermittent solar ammonia absorption cycle ice-maker. Sandia plans to site the unit at the Solar Thermal Test Facility.

- **Science Applications International Corporation (SAIC) has a dish concentrator at Sandia.**

  The scale-model, low-cost dish concentrator intended for photovoltaic applications began on-sun flux profile testing at Sandia. Early data are being reduced.

- **Solar Reactor Technologies (SRT) made a presentation on its research.**

  Solar Reactor Technologies (SRT) made presentations to Sandia's solar thermal staff relating to its HCl electrolysis project and its development of halogen volumetric receivers. As a result of discussions both during and following these presentations, Sandia was asked for proposals on assisting SRT with furthering these two efforts.

- **Representatives from Bechtel National and Pacific Gas and Electric (BN/PG&E) visited Sandia.**

  Representatives from Bechtel National and Pacific Gas and Electric visited Sandia in order to survey the latest developments in technology on molten-salt central receivers. Increased interest by the PHOEBUS consortium prompted the visit.

- **Solar energy technologists from Spain visited Sandia.**

  A delegation from Spain (Instituto de Energias Renovables and Plataforma Solar de Almeria) requested and were given briefings on Sandia's solar detoxification programs and details on solar-furnace design.

- **Alpha Solarco and the Electric Power Research Institute (EPRI) received long-term loans.**

  Long-term loans (greater than two years) of prototype low-cost drives have been made to Alpha Solarco and EPRI for use with photovoltaic arrays. This gives the solar thermal program the opportunity to collect long-term environmental test data to feed into the drive design.

- **Kirkland Enterprises consulted Sandia on steam-converter technology.**

  Representatives from Kirkland Enterprises, a Florida manufacturer of solar thermal systems, met with Sandia engineers to discuss technology in organic Rankine cycle and steam converters. Kirkland is interested in adding converters to an existing SOL THEM Fresnel lens trough system to run pumps at one of its solar thermal distillation plants.

- **Stirling Thermal Motors (STM) met with Sandia regarding heat pipes.**

  Sandia has been closely involved with Stirling Thermal Motors (STM) on improving the reliability of its gas-fired, sodium-filled heat pipes used to power the STM4-120 kinematic Stirling engine under ground test in Albuquerque. Design reviews at both Sandia and STM and information based on operating experience, residual gas analyses, metallurgical analyses, material considerations, and fabrication techniques have identified several factors which should lead to improved reliability for these devices.

Planned Activities For Next Quarter

- A number of computer models exist and predict solar thermal system performance. These models are useful in the design of new systems. However, there has been no comprehensive study of the accuracy of these models. Therefore, there is confusion in the community about their use. Sandia is planning to verify the accuracy of some of the most popular of these models by comparing predictions with actual system performance. This project for the Design Assistance Center will be initiated next quarter and will continue through this fiscal year.

- D. Knipfer, Senior Engineer with Gould Electronics, has asked for Sandia's assistance to improve the performance of Gould's IPH plant in Arizona. Originally designed and installed by SKI in 1982, this plant is continuing to operate, but has a number of engineering problems that must be corrected to achieve cost-effective operation. Knipfer asked for assistance in reducing flex-hose failures, measuring system performance, and estimating the remaining life of some critical system components. Sandia personnel are preparing an action plan to respond to the request. Work will begin on the project during the next quarter and will continue through this fiscal year.

- P. Schuller, Associate Director of the Pennsylvania Energy Office, asked for Sandia's assistance in developing a technical program in Pennsylvania to effectively use oil-overcharge money to promote renewable energy projects. Work on this project will begin next quarter.

- A. Bronstein, President of Sunsteam, has asked for Sandia's assistance regarding the licensing of his trough technology for overseas production. Assistance by the Design Assistance Center is being prepared through the CORECT activity, as well as through the Solar Energy Industries Association. This activity is expected to commence in the next quarter and will continue through this calendar year.

- P. Jaster of the 3M Company is developing a plan for a U.S. government-sponsored, low-interest loan program for solar-system manufacturers and installers. As currently conceived, the plan would provide construction and/or development loans for solar projects. An organization like Sandia would assist the lending agency in qualifying applicants. Jaster asked for the Design Assistance Center's critique of his plan before he presents it to Congress. A draft copy of the plan is expected to be sent to Sandia next quarter.

- B. LeBaron of Battelle and R. Perez of SUNY have developed a new, simplified insolation monitoring system. They asked Sandia to compare the performance of the new system with that of a traditional system. The request is currently being considered as a project for next year by the Design Assistance Center.

- o E. Carillo, general manager of ITE, a private solar energy system manufacturer and installer in Mexico, asked for Sandia's assistance in developing a solar thermal demonstration project in northern Mexico. The details of the project are being formulated. Work is expected to begin in the third or fourth quarters.

- o L. Garden, U.S. Department of Commerce, suggested that the Design Assistance Center be involved in a new CORECT initiative to introduce renewable energy technology in North Africa. He specifically suggested that Sandia plan some workshops. Activities by the Design Assistance Center on this project are scheduled to begin next quarter and will be coordinated through the Solar Energy Industries Association and CORECT.

- o During the SOLTECH symposiums on heat and electricity, numerous comments were made regarding the longevity of reflective films. It was noted that several new solar thermal projects are being planned, and there is controversy about using the films. There was overwhelming agreement that the status of existing films would be very useful, especially if it included some of the older projects that used these films. The Design Assistance Center is considering various approaches to provide this support.

TASK B. PHOTOCHEMICAL SYSTEMS

Subtask B-1. Identification of Application Opportunities

Accomplishments

- **Work in solar detoxification was well represented at SOLTECH 90.**

  The work on solar detoxification was well represented at the SOLTECH 90 conference held on March 19 to 22 in Austin, Texas. The conference was held in conjunction with the American Solar Energy Society's SOLAR 90. The solar detoxification activities were also presented to the Solar Thermal Committee of the Solar Energy Industries Association. This was an opportunity to interact directly with the solar industry members, and to inform them about the nature of the project and the wide array of opportunities for their participation in the activities. Members of the solar thermal industry indicated a high level of interest in the prospects for participation in the planned activities outlined as part of the proposed solar-detoxification initiative.

  A plenary address on the "Solar Detoxification of Water" by B. Gupta during the plenary session was very well attended, with approximately 200 people present. An overview of the work on detoxification was also presented in the review session on the Solar Thermal Technology Program. Finally, the Process of Solar Detoxification of Water was the topic of a two-hour symposium. This symposium also was well attended, with over 50 people present. Staff members were very successful in establishing and maintaining communications with a variety of people who have the potential to contribute to the activities of the solar detoxification program. (SERI/SNL)

- **A computer model was developed for system analysis of solar detoxification of water.**

  Researchers have improved the capability of a computer model that can be used to predict the performance of solar systems for detoxifying water. This model was first developed last year and was based on laboratory data generated at North Carolina State University. However, the university's data were obtained with ultraviolet lamps operating at significantly lower flux levels than would be typical for a solar system using parabolic troughs. The current model uses the latest laboratory data, which were generated at higher flux levels more typical of those expected in field systems.

  A second significant improvement made to the model was to characterize the solar resource as a function of latitude of the site, time of day, day of year, and cloudiness. This more detailed characterization captures the effect of atmospheric scattering, which is more important for ultraviolet than for the longer wavelength portions of the solar spectrum. It also permits quantification of the "cosine" effect (optical losses that occur in single-axis tracking systems such as parabolic troughs).

  These changes improve the ability to estimate the cost and performance of solar systems used for detoxifying water. They also help to identify the range of interest of parameters for investigation in the laboratory. (SERI)

- **Cost reductions were identified in the process of solar detoxification of water.**

  Investigations have indicated that the cost of the solar water detoxification system might be substantially reduced if new materials can be used for the reactor/receiver tube. Use of FEP fluorocarbon (Teflon) instead of quartz, for example, would reduce costs for receiver tubing by a factor of 20. Since capital costs are the principal

elements in the levelized processing cost of solar detoxification of water, reductions in these costs are an important factor in the development of this technology. (SERI)

- **Markets were identified for solar detoxification of water.**

  Researchers have begun to characterize the potential market for processes of solar water detoxification. Two market categories appear particularly attractive: groundwater remediation at hazardous waste sites and industrial wastewater discharge. Of the estimated 30,000 hazardous waste sites in the United States, the Environmental Protection Agency has listed 1,200 on the National Priority List (Superfund sites). At an estimated average cleanup cost of $25 million per site (GAO estimate), $30 billion will be spent on Superfund sites alone. Even if only a small percentage of these sites are assumed to be amenable to treatment with solar water detoxification, the potential market is large--perhaps about $2 billion. Researchers are pursuing a more quantified assessment of the potential market for solar detoxification systems; however, there exists significant uncertainty in both the base market and the potential market penetration for any remediation technology. This work helps to provide the rationale for continued support of research into solar detoxification systems. (SERI)

- **A Request for Quotation was issued for a conceptual design of a commercial-scale system for solar detoxification of water.**

  A Request for Quotation was issued in January for a conceptual design of a commercial-scale facility for solar detoxification of water. The conceptual design will support the planning for a full demonstration of the technology. Nine proposals were received and are currently being reviewed at Sandia and SERI. A contract should be placed early next quarter. (SNL)

Planned Activities for Next Quarter

- On-line monitoring of near-ultraviolet insolation will begin.

- Staff will refine cost and performance analysis of the process of solar detoxification of water.

Subtask B-2. Solar Processing of Dilute Aqueous Organic Chemicals

Accomplishments

- **Researchers from Sandia and SERI presented a joint paper at a conference on waste management.**

  A paper jointly coauthored by researchers from SERI, Sandia, and DOE Headquarters was presented at the Waste Management '90 Conference in Tucson, Arizona, on March 1. The paper provided a consolidated description of research results in photocatalytic decomposition of TCE in bench-scale and outdoor trough tests at SERI and Sandia. (SNL/SERI)

- **A catalyst laboratory testing loop was designed at SERI.**

  A third laboratory loop has been designed. The new system will be used for catalyst lifetime tests. A continuous one-pass mode will allow uninterrupted flow of contaminated water through the illuminated catalyst bed. Continuous flow will allow rapid accumulation on the catalyst bed of any ions or materials which might be present in groundwater. This design also requires reduced operator attention so that experiments can be run on a twenty-four-hour schedule. This system will provide important capability for rapid screening of water samples for possible catalyst poisoning or fouling. (SERI)

- **Performance characterization of a commercial TiO_2 catalyst material was begun.**

  Performance characterization has begun on a commercially available fixed TiO_2 catalyst. This material consists of TiO_2 supported on glass wool meshes of different weave sizes. Researchers measured the absorbance of the TiO_2 on the various meshes and observed that those meshes made from thicker strands lost more TiO_2 to the water. The two samples that were fabricated from thin strands did not slough off much TiO_2, and their peak absorbence was measured at 325 nm. The absorbance of the thicker strand materials ranged from 300 nm to 360 nm. Thus, relative to suspended TiO_2 solutions, the thin-strand materials fixation of the TiO_2 onto the glass mesh did not have appreciably different absorbance, but the absorbance range appeared to expand on the thicker strands. The performance of these catalysts will be tested with TCE to determine which material is most efficient and if the extended absorption range of the thicker materials is significant. The test is part of a series of tests of various catalyst-immobilization materials, as shown in the accompanying picture (Figure 4.B.2.1). (SERI)

- **A model of the process of solar detoxification of water combined radiative transfer and chemistry.**

  A model describing the generation of hydroxyl (OH) radicals inside a low-temperature aqueous receiver/reactor has been expanded to incorporate as input the photon flux originating from a typical parabolic trough concentrator. The model utilizes a kinetic formulation developed to describe the generation of OH radicals by TiO_2 particles illuminated by ultraviolet photons. The volumetric photon flux distribution is computed by using a Mie theory formulation combined with a Monte Carlo ray-trace code to describe the absorption and scattering inside the receiver/reactor. This model represents the first integration of all facets of the low-temperature aqueous receiver/reactor process. The model will play an important role in the design and characterization of efficient receiver/reactors. (SERI)

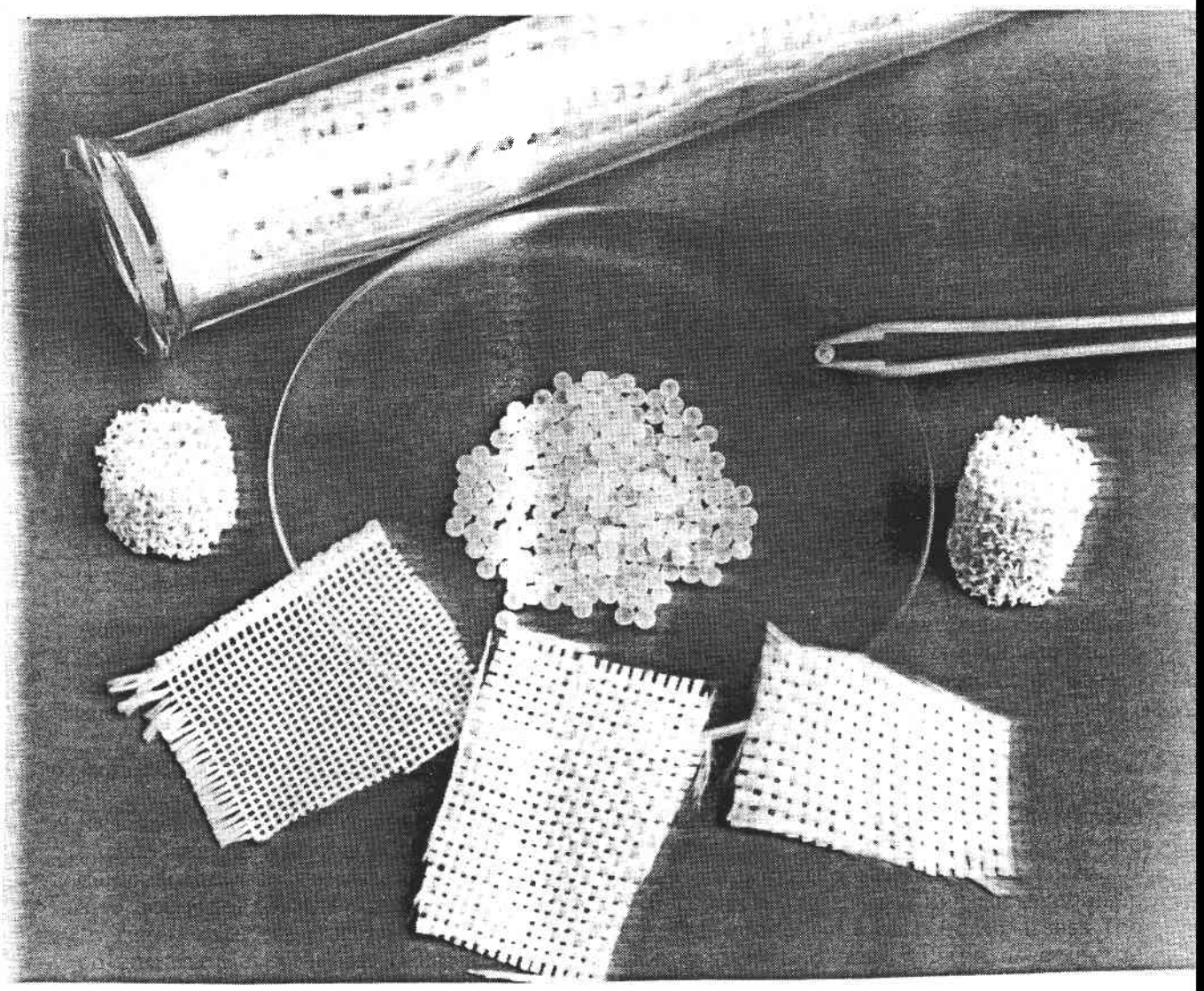


Figure 4.B.2.1 Various catalyst-immobilization materials being tested for solar detoxification of water

- **A fixed catalyst was mounted in the trough of the Solar Water Detoxification Test Facility.**

  Researchers have successfully mounted a TiO_2 impregnated fiberglass mesh inside a receiver/reactor located at the Hazardous Waste Detoxification Test Facility. The fiberglass mesh, a catalyst support manufactured by Nulite Inc., was suspended along the inside diameter of the receiver/reactor by using a series of Teflon spacers. The catalyst support was inspected at increasing flow rates in order to test its ability to withstand longer-term outdoor experiments. No adverse effects were apparent throughout the first series of tests. Outdoor photodecomposition experiments will begin upon completion of a series of leak tests. The successful support of the TiO_2 catalyst inside the receiver/reactor will allow researchers to test the photodecomposition process under conditions which will more closely approximate large-scale systems. (SERI)

- **Engineering-scale testing of solar water detoxification continued.**

  Tests of the solar water detoxification process continued in Sandia's parabolic trough facility (450 m^2). The goal of these efforts is to demonstrate the feasibility of solar-driven destruction of organic compounds at a scale large enough to be practical for industrial applications. Researchers are varying processing parameters, such as flow rate, initial contaminant concentration, and hydrogen peroxide concentration, to determine their impact on processing rates. For example, Figure 4.B.2.2 shows initial trichloroethylene concentrations ranging from 3500 ppb to 120 ppb being reduced to below the detection limit of 5 ppb at flow rates up to 23 gpm. In each case, the contaminant is completely destroyed before reaching the end of the trough system (720 feet long). The experiments were performed with a 0.1 weight percent suspension of TiO_2 and no hydrogen peroxide. The addition of hydrogen peroxide may further accelerate the destruction rate. (SNL)

- **The measurement of pressure drops for possible catalyst supports was initiated.**

  Researchers have built a small water-flow system for measuring the pressure drop of alternative catalyst supports as a function of water-flow rate. Pressure drop is an important concern in the development of a supported catalyst, and this information will be required for the design of an actual facility. The first material evaluated was reticulated alumina made by Hitech Ceramics. The material has a very high surface area, open pore structure, and (based on Sandia's and SERI's tests) high photocatalytic activity when coated with TiO_2. However, the measured pressure drop for this material is fairly high, and indicates that it may not be practical for use in parabolic troughs except at very low flow rates. Tests on Nulite's TiO_2-coated fiberglass cloth will be conducted next quarter. (SNL)

- **Additional catalyst development began at the University of New Mexico.**

  DOE's Waste Management Education and Research Center has funded a three-year collaborative effort between the University of New Mexico (UNM) and Sandia to enhance the solar photocatalytic detoxification process by developing sensitizers for the TiO_2 catalyst. Currently the process of solar detoxification of water uses only a small portion of the solar spectrum. The goal of this effort is to attach photo-sensitizers to TiO_2 to permit use of a larger portion of the sun's spectrum. This effort will be combined with the other catalyst-development efforts already underway. (SNL)

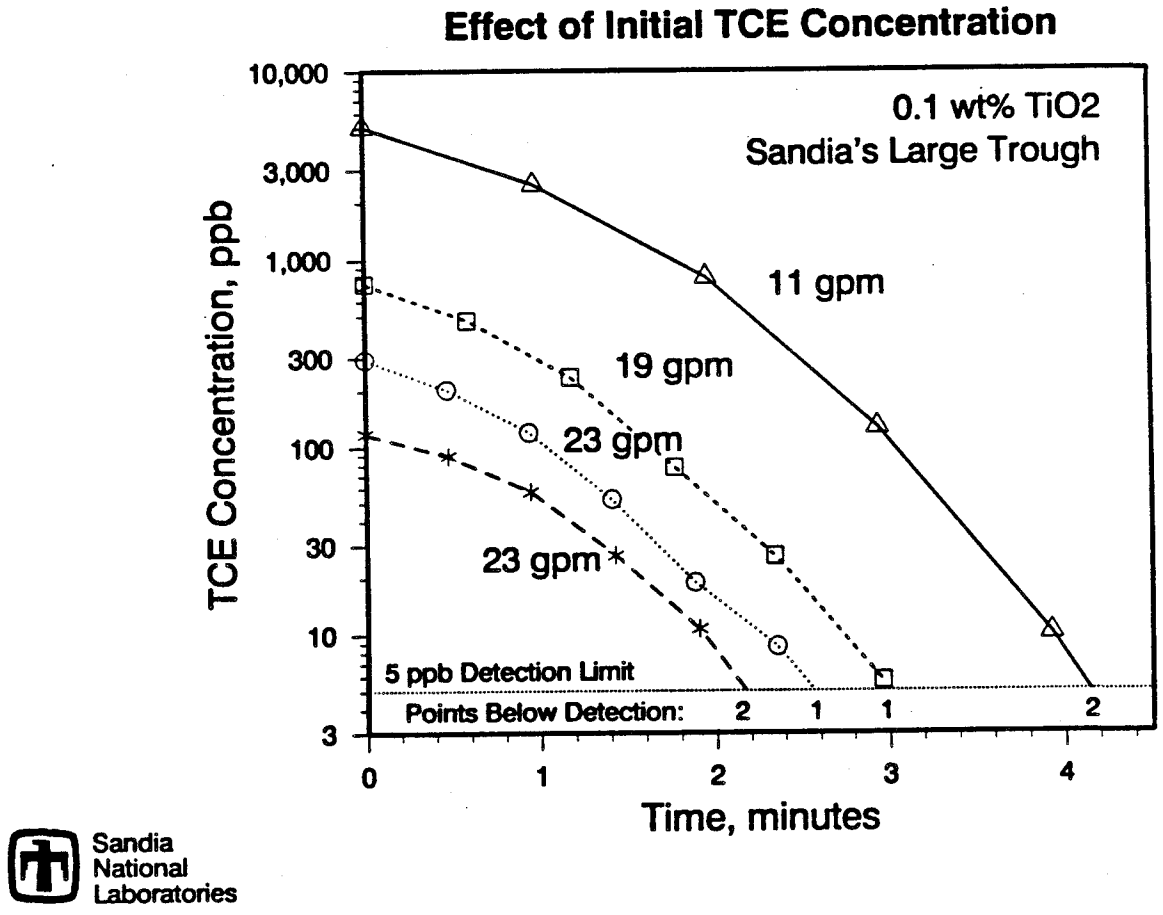


Figure 4.B.2.2

Results from Sandia's trough facility comparing the rates of destruction for 4 initial concentrations of trichloroethylene. Flow rates were as high as 23 gpm and no hydrogen peroxide was added. In each case, the contaminant was completely destroyed before reaching the end of the trough system.

Planned Activities for Next Quarter

- Laboratory and field tests of both commercial and innovative catalyst support systems will continue.
- Testing samples from field sites will continue.
- Engineering issues associated with fixed catalyst support, such as geometric configurations, mass transfer limitations and pressure losses, will be examined.
- Field tests of trichloroethylene, multiple compounds, and groundwater using the outdoor trough systems also will continue.

Subtask B-3. High-Temperature Solar Destruction of Toxic Chemicals

Accomplishments

- **Regeneration of activated carbon was identified as an application for high-temperature detoxification.**

  SERI systems analysis for high-temperature solar detoxification focused on evaluating technology in activated carbon regeneration. Activated carbon is used to purify gas streams from a variety of processes, including soil decontamination. Review of an EPA report entitled Superfund Innovation Technology Evaluation Technology Profile (November, 1989) indicated six new technologies for soil decontamination. The technologies all use carbon adsorption/regeneration in their processes. A survey of current literature shows that regeneration by thermal methods is the most common and is applicable when many substances, some of which may be unknown, must be removed from the carbon.

  Thermal treatments include air or steam regeneration. Regeneration typically occurs at 100°C to 200°C. A solar-based process could use air or steam as the regeneration gas and then could destroy the contaminant by photo/thermal oxidation or reforming, respectively.

  Adsorption data for many organic substances as a function of temperature and pressure have been obtained. These data will be used to obtain energy and cost estimates for a solar-based process that desorbs contaminants from carbon using either air or steam and then destroys them. (SERI)

- **A model of carbon regeneration has been developed.**

  Researchers have developed a model that will predict performance of a solar-based carbon regeneration and chemical destruction process. The model accounts for the composition, concentration, and flow rate of the contaminated gaseous feed stream. It also accounts for the adsorption capacity of the carbon and the cycling time required to regenerate the carbon using solar energy. This model will be used to assess the potential of a solar-based carbon regeneration system and also will be used in the design of carbon regeneration field tests. (SERI)

- **Staff attended a conference on treatment of contaminated soils.**

  Researchers attended an international symposium entitled "Hazardous Waste Treatment: Treatment of Contaminated Soils." The symposium was held in Cincinnati, Ohio, and was sponsored by the Air and Waste Management Association and the U.S. Environment Protection Agency's Risk Reduction Engineering Laboratory. Topics of the presentations focused on established and new technologies for soil decontamination. The technologies included thermal, chemical, biological, and physical extraction. Many of the thermal and extraction technologies use carbon adsorption to remove volatile contaminants from the process off-gas.

  Of particular interest is the vacuum extraction process for removing volatile organics from soils. In this process, a vacuum is drawn on vent holes that are drilled into the contaminated soil. The process has the advantage that volatile contaminants can be removed from the soil without excavation. A presentation on this process revealed that it is currently being used in seven pilot demonstrations and ten full-scale demonstrations with plans for many more demonstrations in the future. Both the pilot

and the full-scale demonstrations purify the process off-gas by using carbon adsorption.

Any soil-decontamination technology that uses carbon adsorption for purifying the process off-gas is of interest because the regeneration of the carbon and the destruction of the adsorbed contaminants currently is being considered as an application for the high-temperature solar destruction technology. (SERI)

- **Discussions were held with Lawrence Livermore Laboratories about technology experiments.**

SERI and Sandia researchers met with representatives from the Lawrence Livermore National Laboratory (LLNL) to discuss technologies in solar detoxification as possible methods for treating contaminated sites at LLNL. Among the sites discussed is a trichloroethylene (TCE) spill that caused underground contamination. The site is being treated by using vacuum extraction. The off-gas from this process is currently being exhausted to the atmosphere, but it is expected that it will have to be purified in the near future. Purifying this type of stream by using high-temperature solar detoxification has already been demonstrated in field tests. (SERI/SNL)

- **A spectrometer (FTIR) has been ordered for chemical analysis experiments in high-temperature detoxification.**

An order has been placed for a Fourier Transform Infrared (FTIR) Spectrometer. The FTIR has been chosen as the analytical method for the gas-phase photooxidation field tests. This method will be used for qualitative and quantitative analysis of field test gas streams that contain chlorinated and nonchlorinated organics. Substantial time was spent in talking with vendors to ensure that this instrumentation can perform the required analysis under rugged field-test conditions. These conditions include high-temperature gas streams that contain high concentrations of corrosive gases like hydrogen chloride (HCl). The high-flux solar detoxification field tests are scheduled to begin in May at SERI's High-Flux Furnace. These field tests are an ongoing effort and are expected to continue over the next several years. (SERI)

Planned Activities for Next Quarter

- A new reactor and analytical system for field-testing the photooxidation process will be developed.

TASK C. ADVANCED ELECTRIC TECHNOLOGY

Accomplishments

- **In July, 1989, a Request for Information (RFI) regarding potential program participants was released to the public.**

  The Request for Information (RFI) asked for information about solar thermal technologies that have potential to participate in this joint venture program. The Advanced Electric Technology evaluation team met in December, 1989, to discuss the twelve responses to the Request for Information (RFI). They concluded that there is evidence that promising solar thermal technologies do exist and that this program can accelerate commercial application to the middle of the 1990s. Following evaluation of the responses, the team developed an outline of the contents of the Request for Quotation (RFQ). Based on the outline, a complete RFQ package has been developed and is ready for release. The release of the RFQ is awaiting approval from DOE/ Headquarters.

Planned Activities for Next Quarter

- The Request for Quotation is ready for release but is being withheld pending approval from DOE/Headquarters. The system experiment, which will operate for two or three years, is expected to be installed in 1993. The request will ask for a detailed description of how the government and industry can work together to develop and field a solar thermal electric generating experiment. The fielded project will be a public showcase for state-of-the-art solar thermal electric technology. Following the system experiment, the government's role will cease, and the industrial partner will market the solar electric technology.

5. NATIONAL SOLAR THERMAL TEST FACILITY REIMBURSABLE PROGRAMS

Accomplishments

- **A windowed wind tunnel for testing nuclear hardness of samples of military aircraft material has been installed and is being used routinely in Sandia's solar power tower.**

  Under the sponsorship of the U.S. Air Force and in conjunction with Northrop Corporation, Sandia has constructed a windowed wind tunnel and has installed it in the center test bay of the National Solar Thermal Test Facility's (NSTTF) solar tower. The wind tunnel, shown in Figure 5.1, is used to expose military aircraft material samples to simulated nuclear thermal flash under simulated flight conditions. The simulated nuclear thermal flash provided by the heliostat field closely duplicates the requested "Glasstone" pulse shape as shown in Figure 5.2. The initial rise is provided by a high-speed shutter. The decay shape is achieved by alternately slewing and tracking groups of heliostats off the target at the 1.25-second interval of operation of the control system. The fluence (integrated flux) is also shown. The wind tunnel provides air flow at up to Mach 0.4; when boundary layer effects are considered, this simulates flight speeds of Mach 0.8. The wind tunnel can accommodate eight samples 4 inches by 4 inches or fewer larger samples. Sample exposures were conducted for both sets of small samples and single large (~144 square inches) samples which were also instrumented with thermocouples. Northrop was very pleased with both the pulse simulation and the flatness of the flux profile across the samples. During development, the flat profile was verified with the NSTTF's Beam Characterization System. Previously, these types of exposures have only been done on a much smaller scale at the White Sands Solar Furnace. Additional samples will be exposed in May.

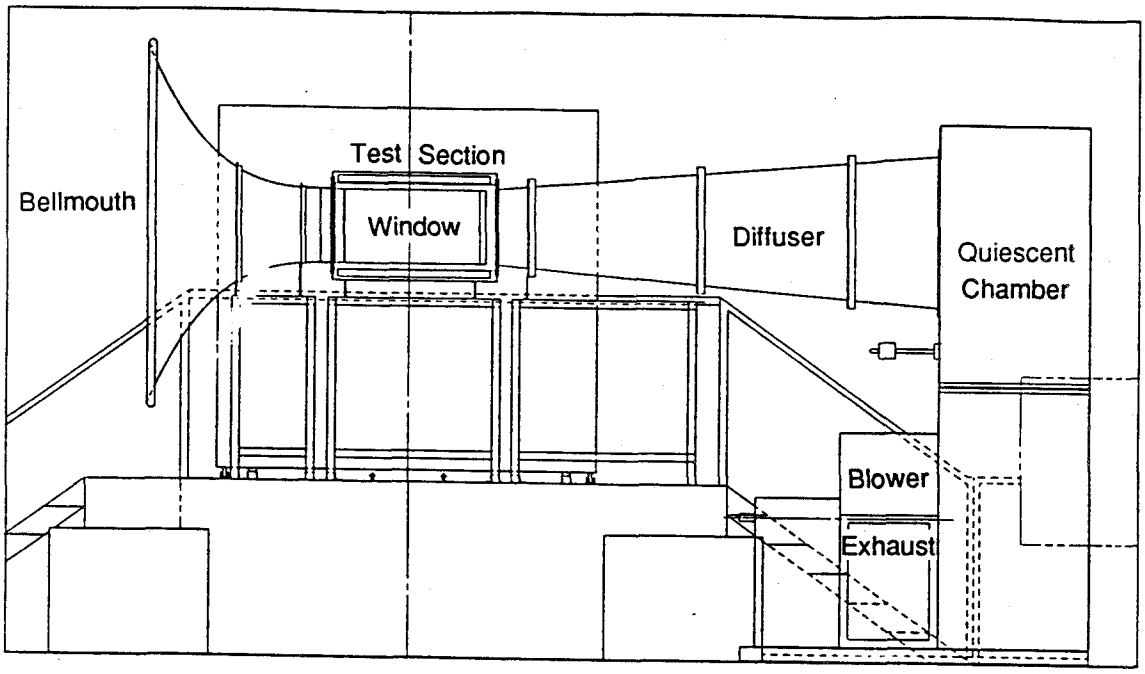
- **A volumetric receiver to be tested for private industry has been installed in Sandia's Solar Power Tower.**

  Sandia is under contract to private industry to conduct testing of a prototype volumetric central receiver in the test bay (36.6 meters in height) of the Solar Tower. The receiver, which was received in the middle of March, was lifted into the test bay, test stands were fabricated, and the blower and associated hardware have been installed. Following installation and checkout of instrumentation and cold flow characterization, testing is expected to begin in early April. The objectives of the tests are demonstration of feasibility and characterization of steady-state performance. If these tests are successful, a larger-scale test, including generation of steam, is anticipated. Details of the receiver design as well as progress of testing are sensitive and proprietary and will only be released after being cleared with the client.

- **A technique for characterizing a multiple heliostat beam has been developed.**

  Sandia's reimbursable programs, in addition to sharing the operating costs of the National Solar Thermal Test Facility, often have spin-off effects that benefit solar energy programs. As an example, validation of the Helios optical code by measurement of the flux produced by multiple heliostats has been a desire of researchers at the National Solar Thermal Test Facility (NSTTF), but has not been accomplished previously due to the lack of suitable targets and/or an applicable beam-characterization system. In conjunction with a reimbursable program for the U.S. Air Force, the capability to characterize beams from multiple heliostats has been demonstrated. The target used was high-temperature, AL-30 insulation board placed

USAF/NORTHROP CORPORATION - WIND TUNNEL



TEST SECTION: 48 CM H X 76 CM W X 9 CM D - 1 OR 8 SAMPLES

Figure 5.1

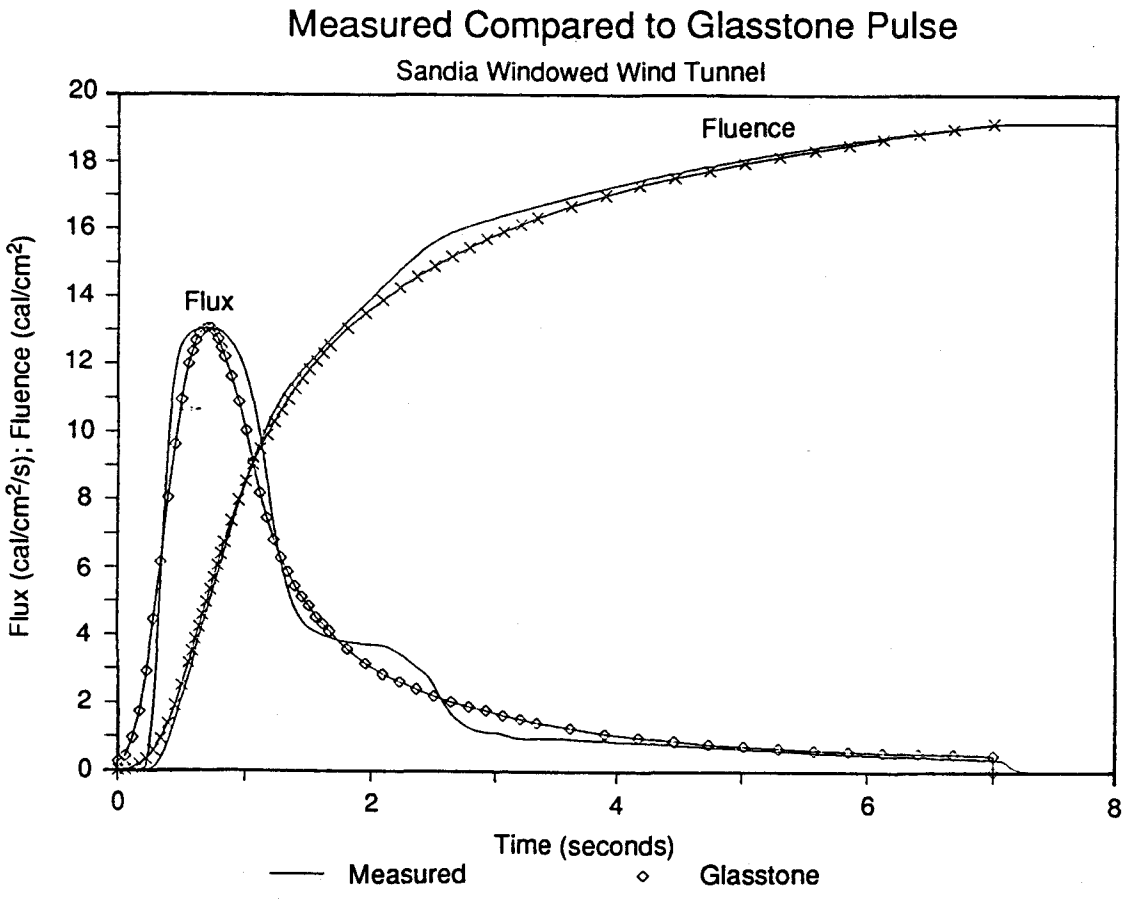


Figure 5.2

in the sample holder of the NSTTF windowed wind tunnel; the wind tunnel also provided air-cooling of the target. The NSTTF beam characterization system developed for evaluation of single heliostats was used. The system proved very useful for developing the flat flux profiles required for the reimbursable test program. Initial results indicate that Helios predicts the relative trends seen in the measured beam profiles. A large (2 meters by 3 meters) water-cooled white diffuse reflecting (lambertian) target has been installed for evaluation of flux patterns in support of reimbursable testing of a volumetric receiver. This target will permit validation of Helios over large areas and in absolute terms, since the target includes a Kendall radiometer. Researchers will use similar techniques to characterize the NSTTF beam for DAR and other future receiver test programs.

- **Sandia completed preparations for exposing a National Aerospace Plane antenna array to simulated aerodynamic heating at Sandia's National Solar Thermal Test Facility (NSTTF).**

  Under the sponsorship of the U.S. Air Force, Sandia has made preparations to test an antenna array for the National Aerospace Plane. The heliostat field is to be used to simulate aerodynamic heating experienced during reentry. General Dynamics, the manufacturer of the antenna, will operate the antenna during the simulated reentry. Helios runs to develop the required flux profiles have been completed, and a dummy antenna array has been received from General Dynamics. However, the actual test article was damaged by General Dynamics during assembly and cold testing, and the project is on an indefinite hold.

- **The Applied Physics Laboratory of Johns Hopkins University completed preparations for 25 days of hot boresight error measurements at the NSTTF.**

  For several years, Johns Hopkins University's Applied Physics Laboratory (APL), a U.S. Navy contractor, has evaluated radar systems while the radome is being exposed to simulated aerodynamic heating at the NSTTF. A water-cooled radome mount with rotational and slew capability was installed in the upper test bay (79.2 meters high) of the solar tower, and an antenna with rotational and translational capability was installed in a heliostat pedestal in the heliostat field. This system used to measure hot boresight error over a range of antenna to radome angles while the flux from the heliostat field is dynamically changed to maintain constant heating. APL personnel visited the NSTTF in March to perform cold radar scans in preparation for 25 days of hot tests to begin in April.

- **Cost estimates have been provided for nuclear hardness evaluation of aircraft canopies at the NSTTF.**

  Discussions are currently underway with the Defense Nuclear Agency (DNA) on using the heliostat field and highspeed shutter to evaluate the nuclear thermal hardness of two airplane canopies. DNA proposes to sponsor evaluation of an F-16 canopy for the U.S. as well as an entire canopy and cockpit for a British Buccaneer. PDA Engineering will assist in both of these tests. Previously, airplane canopies have been evaluated with Thermal Radiation Simulators (TRS) which burn aluminum powder in pure oxygen; however, TRS has a black body temperature of only about 4000 K. Solar radiation is much more closely matched to the 6000 K spectrum from a nuclear weapon and, thus, a much more realistic simulation can be achieved.

- **The NSTTF is being considered as a LIDAR research site.**

  In addition to having the capability to simulate various thermal effects, the solar concentrators at the NSTTF constitute large-scale optical systems with unique capabilities. In the past, these have been applied to astronomy and high-energy physics research. A new area of interest is the use of the point-focus dishes and the heliostat field as light collectors for LIDAR (laser radar). The Air Force is interested in using LIDAR for atmospheric sounding which is important to the understanding of the behavior of satellites in low earth orbit. A private company has contacted the NSTTF concerning the application of LIDAR to measurement of atmospheric pollution related to global warming. Discussion related to these potential projects is in the very early stages.

- **Sandia has received a request-for-cost estimate for development and testing of an industry-funded photochemical receiver.**

  Sandia has been requested to provide estimates for the design and testing of several novel wide spectrum, photochemical processes. Development of these systems is being done as a commercial venture by a company who needs to use the unique research and test capabilities at the NSTTF to demonstrate actual solar performance. Previous research has been performed at a small-scale in university laboratories sponsored by this company. Although the company is small, it has made established contacts with major commercial industries and utilities regarding commercialization of these processes. Discussions leading to definition of the scope of work are currently underway.

- **Scientists from the Jet Propulsion Laboratory (JPL) visited Sandia to discuss materials tests for a solar probe spacecraft.**

  A team of scientists from NASA's Jet Propulsion Laboratory visited Sandia to discuss materials testing in support of development of a thermal shield for a space craft which is to pass three solar radii above the surface of the sun. Trapezoidal carbon-carbon samples, each ~138 cm^2 and arranged in a pyramid, are to be exposed to a flux of 300 w/cm^2 to 400 w/cm^2 within a vacuum chamber. Sandia has performed preliminary analysis which indicates that these tests could be conducted on the new large solar furnace or on the solar tower. In designing the vacuum chamber, it appears that a spherical window of the type developed by Sandia for high-temperature solar detoxification receivers would significantly lower the cost relative to a thick, flat window as initially envisioned by JPL.

- **The heliostat for Sandia's 16 kW solar furnace has been upgraded.**

  The heliostat for Sandia's 16 kW Solar Furnace has been upgraded via replacement of the existing mirrors with flat, thin-glass laminate mirrors from Arco/Advanced Thermal Systems. Additional area was added as well as an extension of the operating hours at full power.

- **The heliostat for Sandia's 60 kW solar furnace was installed.**

  The heliostat for Sandia's 60 kW solar furnace has been installed. This heliostat is the Advanced Thermal Systems design and has been equipped with flat, thin-glass/glass laminate mirrors. Installation of controls for the heliostat is underway.

Planned Activities for Next Quarter

- The current series of hardness tests on military aircraft material for Northrop and the U.S. Air Force will be completed in early April. A second series of measurements will be conducted in May.

- Testing of the prototype volumetric central receiver in the test bay (36.6 meters high) of Sandia's Solar Tower will be completed. Testing will include demonstration of feasibility and characterization of steady-state performance. Test results will be released by the client after completion of testing.

- An extensive effort will be undertaken to validate the Helios code with data from Sandia's Beam Characterization System. A third-year participant in Sandia's Summer Teacher Enrichment Program will be conducting the work under the supervision of personnel from the NSTTF reimbursable programs.

- A series of hot boresight error measurements for radar systems undergoing simulated aerodynamic heating will be performed at the National Solar Thermal Test Facility. The test will begin in early April. Approximately 25 days of hot testing are estimated to be required.

- Evaluation of the nuclear hardness of a British Buccaneer canopy/cockpit system is tentatively scheduled to be performed at the National Solar Thermal Test Facility in June. These tests will be preceded by testing of a U.S. F-16 canopy.

- Sandia anticipates completing negotiations for development and test of proprietary photochemical receivers for private industry. The sponsor hopes to have an initial demonstration of feasibility during the third quarter.

- The new 60 kW solar furnace at the National Solar Thermal Test Facility will be brought to full operational status, and its performance will be characterized.

TECHNOLOGY TRANSFER

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The STDAC prepared a two-fold, color brochure on dish/Stirling technology. The brochure highlights the potential of Stirling technology and feature Sandia's solar thermal test facility, especially the engine test facility. It was distributed at the SOLTECH meeting and is available for distribution to the public as required.

Third Quarter FY 1990

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