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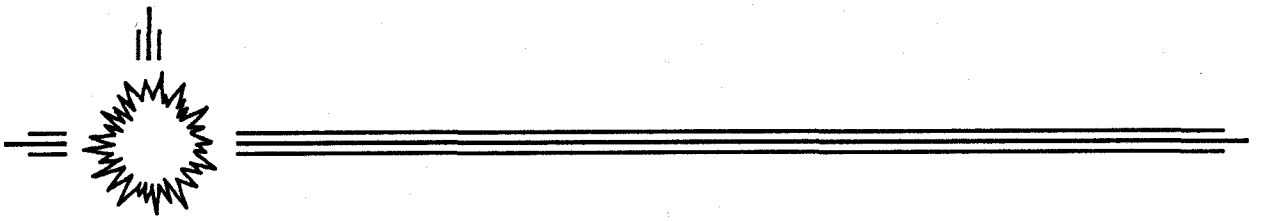

Quarterly Progress Report:

FIRST QUARTER FISCAL YEAR 1990

DOE SOLAR THERMAL TECHNOLOGY PROGRAM

Submitted By:

Solar Energy Research Institute
Golden, Colorado

Sandia National Laboratories
Albuquerque, New Mexico

Issued January 1990

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FOREWORD

The research and development described in this document were conducted within the U.S. Department of Energy's (DOE) Solar Thermal Technology Program. The overall goal of the Solar Thermal Technology Program is the utilization of concentrated solar energy to provide an economical, environmentally sound renewable energy supply to ensure energy security and to enhance international competitiveness.

A major restructuring of the Solar Thermal Technology Program was completed by the field laboratories and the DOE Solar Thermal Technology Division. The structure, strategy, and goals of the new program plan are reflected in the FY 1990 Annual Operating Plan (AOP). This document reports progress and status in relation to the AOP.

Beginning in FY 1989, a single Quarterly Progress Report which integrates the work of both of the major field laboratories, Sandia National Laboratories (SNL) and the Solar Energy Research Institute (SERI), was inaugurated. This reporting, continuing in FY 1990, differs from past years in which each organization prepared its individual progress reports, and is consistent with the structure and implementation strategy of the new program plan which consists of interrelated R&D projects requiring close coordination of the field laboratory activities.

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 program 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 R&D
     - 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

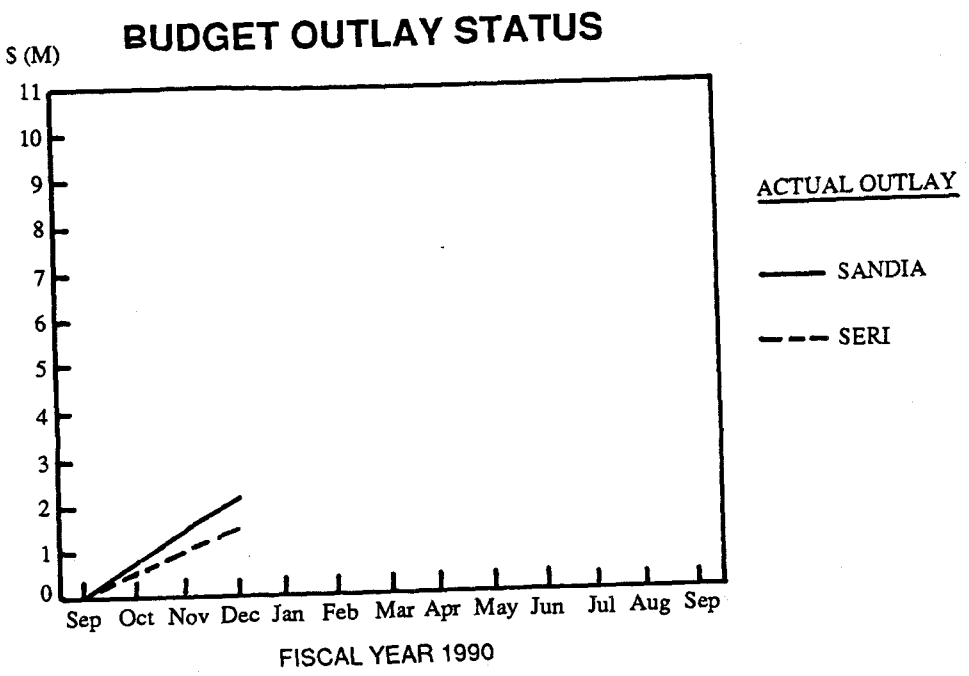
Specific implementation of the Solar Thermal Technology Program is assigned to two field laboratories, the Solar Energy Research Institute in Golden, Colorado, and Sandia National Laboratories in Albuquerque, New Mexico. Together, these two field laboratories are responsible for implementation of the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

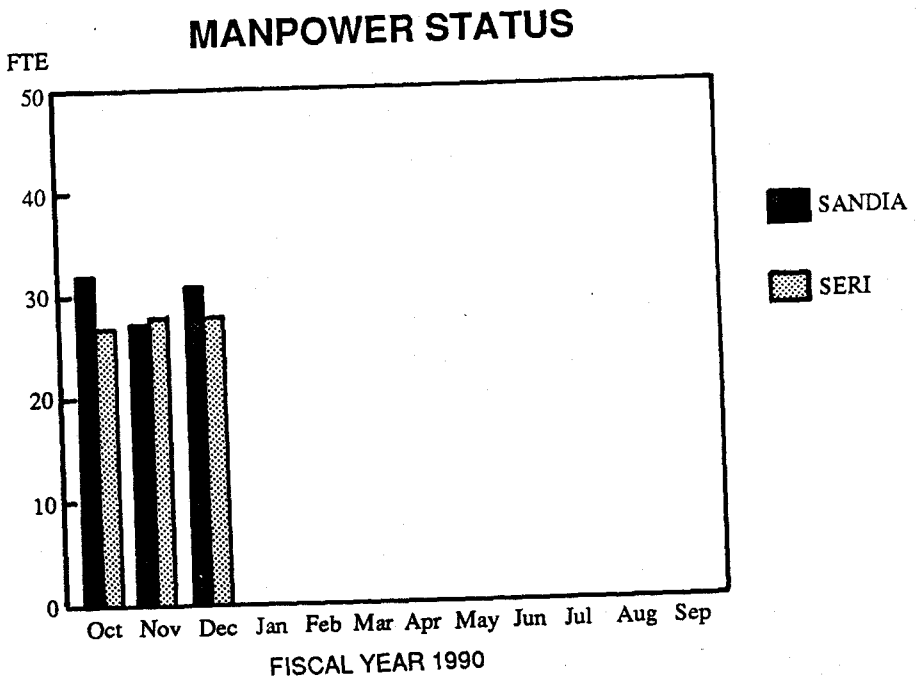
A field Laboratory Management Council (LMC) provides the focus for interaction with the DOE program management and for planning and coordination of the field activities. The LMC is co-chaired by a senior management representative from each laboratory. In order to provide a clear delineation of management 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	D. Blake, SERI
A. Photon Interaction with Materials and Chemicals	
B. High Flux Optics	
C. Materials	
D. Receiver/Reactor Modeling	
2. CONCENTRATOR DEVELOPMENT	C. Tyner, SNL
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 1989 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.	RFP	Univs.	SERI	$300	$300	--	Open	TBD	TBD	D. Blake
Exp. Res.	Solar Incineration of Hazardous Waste	Univ. of Dayton	SERI	$140	--	$140	04/89 - 03/90	Univ.	--	G. Glatmeier
Exp. Res.	Photochemical Metals Removal from Water	TBD	SERI	$25	$25	--	Open	Univ.	--	D. Blake
Exp. Res.	Chemical Research	University of Houston	SERI X07028-01	$200	--	$186	04/89 - 03/90	Univ.	Topical Report	G. Nix
Con. Dev.	Membrane Heliostat Dev.	Solar Kinetics Inc.	SNL33-1227	$704	$512	$192	04/87 - 12/89	Small	SAND89-7023	D. Alpert
Con. Dev.	Replaceable Membrane	TBD	SNL42-9690	$50	--	$50	11/89 - 06/90	TBD	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 1989 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	$430	$450	04/89 - 04/92	TBD	--	K. Boldt
Con. Dev.	Collector Support Struc. & Pedestal	TBD	SNL42-9813	$900 (est.)	--	$400	09/89 - 06/91 (est.)	TBD	--	T. Mancini
Con. Dev.	Faceted Dish Development	TBD	SNL42-9814	$1,200 (est.)	--	$200	09/89 - 06/91 (est.)	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	$900	$500	04/88 - 12/89	Small Bus.	SAND88-7035	T. Mancini
Con. Dev.	Solar Collector Pedestal Fabrication	TIW Fab. & Mach.	SNL57-4436	$57	$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 1989 Funds ($K)	Period of Performance	Contract Type	Major Reports	Project Monitor
Elec Tech	Reflux Heat-Pipe Receiver	Stirling Thermal Motor	SNL33-3036	$225	$124	$101	04/87 - 2/90	Small	--	R. Diver
Elec Tech	Technician Support	Kirk-Mayer	SNL01-9646	$110	$110	0	10/86 - 10/89	Small	--	R. Diver
Elec Tech	DAR Design Studies	Foster Wheeler	SNL06-0312	$136.9	$125.9	10	6/87 - 9/89 (Extended to 06/90)	Large	SAND88-7038	J. Chavez
Elec Tech	Molten Salt Subsytem/ Component Test Experiment	B&W	SNL91-4687	$7,884	$7,854	30	03/84 - 09/89 (Extended to 06/90)	Large	SAND87-2290	J. Chavez
Elec Tech	PRE Panel/ Manifold	Hufman, Inc.	SNL70-8957	$20	--	$20	10/89	Small	--	J. Chavez
Elec Tech	STM4-120	Stirling Thermal Motors	SNL53-8452	$300	--	$15	07/86 - 12/89	Small	--	K. Linker
Elec Tech	Solar Receiver	Stirling Thermal Motors	SNL33-3036	$155	--	--	Active	--	--	R. Diver
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 1989 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	--	--	Active	--	--	R. Diver
Elec Tech	Technician Support	Kirk-Mayer	SNL01-9646	$85	--	--	Active	--	--	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	$100	$10	02/87 - 12/89	Large Bus	--	C. Cameron
Elec Tech	Solar Receiver Heat Loss Testing	California Polytech	SNL02-5759	$105	$75	$30	09/86 - 02/90	Univ.	ASME and ISES papers	A. Heckes
Elec Tech	STEP Test Program	Georgia Power	SNL42-4859	$42	0	$42	06/89 - 03/90	Large	Final Test Report	A. Heckes
Photo Sys.	Catalyst Development and Reactor Modeling	University of Houston	SNL55-4032	$149	--	--	01/88 - 10/89	--	--	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 1989 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	$56	$191	04/89 - 03/90	Univ.	--	G. Glatzmaier
Photo Sys.	Chemical Analysis	Multiple		$50	--	$50	Open	TBD	--	J. Anderson

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	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 vs. 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 1 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 SDW system.
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 UV component of global normal and diffuse radiation at the Golden, Colo., 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 UV-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.

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.
	C2-2 (January, 1990)	Decision Point--Begin commercial scale design or refine seven-meter optical element design to improve performance.
	C2-4 (January, 1990)	Topical report on innovative heliostat drive system performance.
	C3-1 (January, 1990)	Initiate six-meter DAR salt flow testing.
	C2-2 (February, 1990)	Deliver seven-meter-diameter aluminum membrane dish optical element for testing at the STTF.
	C1-1 (March, 1990)	Obtain results from laboratory experiments to explain the role of UV 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.
	C2-3 (June, 1990)	Document cost potential of silvered metal structural mirrors.

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			
High-Flux Photon Processes			
o ASSESS MERIT OF SCALING UP LASER EXPERIMENTS AND OPTICAL CONCEPTS FOR ACHIEVING A SOURCE OF LOWER WAVELENGTH LASER BEAM - This milestone was completed as rescheduled.	(C1-2)	05/89 (12/89)*	12/89
o CONVENE AN ADVISORY GROUP TO EVALUATE PROGRESS AND PROMISE OF CARBON FIBER TREATMENT WITH CONCENTRATED SOLAR FLUX, BASED ON WORK AT GTRI - This milestone was completed as rescheduled.	(C1-3)	05/89 (11/89)*	11/89
Concentrator Development			
o REPORT ON EVALUATION OF LaJET INNOVATIVE DISH PERFORMANCE	(C2-2)	04/89 (12/89)*	
Next-Generation Commercial Systems			
o COMPLETE CONTRACT NEGOTIATIONS AND AWARD CONTRACT	(M1-1)	06/89 (TBD)*	
o COMPLETE AN R&D PLAN AND INITIATE R&D ACTIVITIES	(M1-2)	07/89 (TBD)*	
Photochemical Systems			
o COMPLETE CAESAR EXPERIMENT	(M2-3)	06/89 (TBD)*	
FY 1990			
I. High Flux Photon Processes			
o COMPLETE CAESAR EXPERIMENTS USING A NONUNIFORM ABSORBER - This milestone was completed on schedule.	SN (1A-3)	12/89	12/89
o HIGH FLUX SOLAR FURNACE OPERATIONAL - This milestone was completed on schedule. The Furnace was operated at full concentration on December 29, 1989.	SE (1B)	12/89	12/89

MAJOR MILESTONE		PLANNED	ACTUAL
2. Concentrator Development			
o INITIATE FABRICATION OF FIRST PROTOTYPE OF SAIC'S 100 m^2 MARKET-READY HELIOSTAT - The negotiations on the contract were underway during the latter part of the First Quarter.	SN (2A)	11/89 (01/90)	
3. Electric Systems Development			
o COMPLETE INSTALLATION OF THE PRE - This milestone was rescheduled to January, 1990.	SN (3A)	11/89	1/90*
o COMPLETE BENCH TESTS OF HEAT-PIPE RECEIVERS - This milestone was completed.	SN (3B)	10/89	10/89
o COMPLETE ON-SUN TESTING OF A REFLUX POOL BOILER AT THE STTF - This milestone was completed.	SN (3B)	11/89	11/89
4. Technology Development			
o AWARD MULTI-YEAR R&D SYSTEM IMPROVEMENT CONTRACTS WITH ONE OR MORE INDUSTRIAL PARTNERS - Four companies responded with proposals to a Request for Quotation (RFQ) issued in April, 1989, to 16 potential candidates. Two companies were selected as qualified joint-venture partners for the Next-Generation User System Program. Contract negotiations were underway during the first quarter of FY 1990 to obtain scopes of work of interest to Sandia and the DOE at affordable prices.	SN (4A-1)	12/89	TBD
o RESPONSES TO THE REQUEST FOR INFORMATION WILL BE EVALUATED - This milestone was completed.	SN (4C-1)	11/89	11/89

*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 coordination and planning meeting on resource assessment was held at SERI.

The SERI and Sandia team met to coordinate plans for measurement of available near-ultraviolet (NUV) radiation, 250-400 nm, in the terrestrial solar spectrum. Measurements will be made at Golden and Albuquerque. Data collected will include: latitude; longitude; time of day; day of year; broadband direct normal and broadband global horizontal radiation; direct normal and global horizontal NUV; and atmospheric moisture content. The best available models, LOWTRAN and SPCTRAL2, will be used to identify the significant factors which influence the NUV resource. Instrumentation will be calibrated against NIST standards recently obtained at SERI.

o The Spectroradiometer for measurement of ultraviolet flux from 1 to 30 suns is operational.

During this reporting period, the integrating sphere foreoptics for SERI's Licor and Instruments, SA (ISA) spectroradiometers were received. These foreoptics will enable calibration of SERI's solar simulators and ultraviolet light sources, as well as measurement of global and direct normal outdoor ultraviolet irradiance. The spectroradiometers and foreoptics are now being calibrated against NIST standard tungsten and argon-arc ultraviolet light sources. Also, SERI has streamlined the HP/85-based operating software for the ISA spectroradiometer, and has written an operating manual for the software. These new capabilities are important in view of the urgent need for assessment of the near-ultraviolet resource available for solar detoxification of hazardous wastes and the importance of quantitative calibration of solar simulators for laboratory experiments.

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

Accomplishments

o Proposed mechanism for actions of TiO_2 as a photocatalyst can reconcile conflicting results reported in the literature.

The mechanism for actions of TiO_2 as a photocatalyst is shown in Figure 1.A.2.1 and can explain several discrepancies that appear in the literature on use of TiO_2 particles

Formation of the Effeotive Eleotron-Hole Pair [TiO_2^--OH·]:

$TiO_2 \xrightarrow{h\nu} TiO_2^- + OH$ [1]

Oxidation of TiO_2^-:

$H^+ + TiO_2^- \rightarrow TiO_2 + 1/2\ H_2$ [2]
$H^+ + TiO_2^- + H_2O_2 \rightarrow TiO_2 + H_2O + OH$ [3]
$H^+ + TiO_2^- + O_2 \rightarrow TiO_2 + HO_2$ [4]

Nonproduotive Reaotions:

$H^+ + TiO_2^- + OH \rightarrow TiO_2 + H_2O$ [5]
$2\ OH \rightarrow H_2O_2$ [6]
$2\ HO_2 \rightarrow H_2O_2 + O_2$ [7]
$HO_2 + OH \rightarrow H_2O + O_2$ [8]
$H_2O_2 + OH \rightarrow H_2O + HO_2$ [9]

Pollutant Oxidations:

$4\ OH + TCE \rightarrow 2\ CO_2 + 3\ HCl + H_2$ [10]
$2\ OH + CH_2Cl_2 \rightarrow CO_2 + 2\ HCl + H_2$ [11]
$OH + HCOOH \rightarrow CO_2 + H_2O + 1/2\ H_2$ [12]

Figure 1.A.2.1

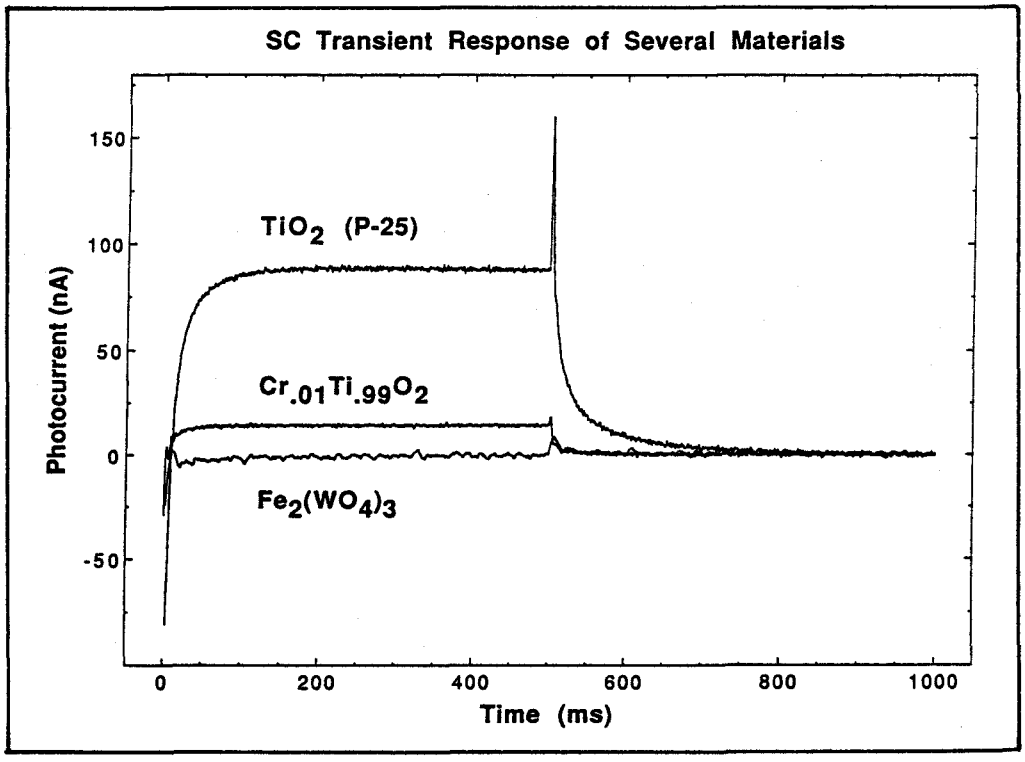


Figure 1.A.2.2

as a photooxidation catalyst. Conflicting results have been published on the effects of pH and the addition of H_2O_2 on the rates of photoinduced oxidative reactions on TiO_2 particles. Several authors have reported a square root dependence of the rate of photooxidation on light intensity and attributed it to semiconductor kinetics despite their use of different types of TiO_2. Also some have contended that O_2 is required for the photodetoxification process. The proposed mechanism, based on the hydroxide radical as the primary route for transferring photoinduced hole to the pollutant, can reconcile these results and can assist in establishing the role of O_2 in the photodecomposition process.

It is seen that many of the reactions in Figure 1.A.2.1 are pH and material dependent; hence, one material might favor a high pH for the photodetoxification process while another might not. Under the conditions depicted in Figure 1.A.2.1, the rate of decomposition is controlled by the relative trapping rates of the OH• by TiO_2-, O_2- (as HO_2 species), H_2O_2, and the pollutant. Reactions 8 and 9 depend on both (OH•) and (H_2O_2) concentration. As a result, addition of too much H_2O_2 will result in quenching of the beneficial oxidation reactions of OH• (reactions 10 to 12); optimal amounts of H_2O_2 will result in an enhancement via reaction 3. This then leads to an important limitation on the system, which is that there is a maximum, optimum steady-state (OH•) concentration obtainable due to the reactions 5 to 9.

Researchers have decomposed TCE, dichloromethane, and formic acid in the slurry cell in the absence of O_2 (using the Pt electrode as the electron sink); this implies reactions similar to Eq. 10-12 are active and potentially significant. Thus, other species besides O_2 may serve as an electron sink.

Finally since reaction 6 must be included at a rate of 6×10^9 M^{-1} sec^{-1}, it is apparent that the OH• concentration (barring any beneficial radical chain reactions) will vary as the square root of the light intensity, and hence the pseudo first order rate of reaction with the pollutant will vary similarly. This is a general result that is independent of the nature of the TiO_2 being used. In summary, researchers have unequivocally demonstrated the importance of the hydroxide radical and the corresponding limitations for the photodetoxification process.

- **New materials for photodetoxification are being explored.**

Researchers have begun applying the slurry cell technique to the search for potentially more efficient new materials that are photoactive in the visible region of the spectrum. Chromium (Cr) doped TiO_2 has been prepared and studied. While Cr doping leads to a defect level at 500 nm, it was found that the material is only very weakly active at 450 nm and is significantly less efficient than Degussa P-25 in the ultraviolet (Figure 1.A.2.2). This is attributed to formation of surface states that lead to more efficient electron-hole recombination. Fe_2O_3 and $Fe_2(WO_4)_3$ have been studied and found to be virtually inactive when compared to the Degussa P-25 (Figure 1.A.2.2). All evidence here leads to the conclusion that the charged particles have very long lifetimes (i.e., they are not efficient at reducing O_2 or H_2O_2) and hence yield low OH• concentrations.

Planned Activities for Next Quarter

- A comprehensive list of potential new semiconductors for use in the photodetoxification scheme is being compiled.

- Two new analytical techniques will be brought up for characterization of the optical properties of new semiconducting materials: (1) diffuse reflectance and (2) photo-modulated transmission spectroscopy.

- Based on theoretical consideration and the mechanism in Figure 1.A.2.1, researchers will determine maximum rates obtainable in an OH• driven system for comparison with current experimental values.

- Efforts will be made to improve the quantum yield of photodetoxification with anatase TiO_2.

- Ground water from a contaminated site will be tested in the laboratory.

Subtask A-3. High Temperature Photo/Thermal Chemistry

Accomplishments

- **Significant photolytic enhancement of dichloromethane destruction in the presence of excess chlorine was observed by University of Dayton workers.**

  Addition of substances such as chlorine which absorb the solar spectrum has the possibility of enhancing the destruction of compounds which do not themselves absorb. Greater than 99.9 percent destruction of CH_2Cl_2 was observed in mixtures of 1:3 CH_2Cl_2/Cl_2 at temperatures as low as 300°C under irradiation with the solar simulator.

- **Formation of Cl_2 was observed in the homogeneous thermal oxidation of dichloromethane.**

  One of the questions yet to be answered in the purely photo/thermal approach to the destruction of hazardous waste compounds is the breadth of applicability of the method, particularly for molecules with poor adsorption in the near-ultraviolet, for mixtures of absorbers and non-absorbers, and for wastes sensitized by good absorbers.

  Recently, SERI reported field tests in which about 3-nines destruction was observed for poor near-ultraviolet absorbers like methylene chloride (CH_2Cl_2). Researchers have postulated that free chlorine might be released in early stages of thermal/photo treatment and that the chlorine would then photodissociate to chlorine atoms (radicals) which could initiate chain reactions, destroying the CH_2Cl_2.

  An exploratory experiment was carried out on the MBMS with purely thermal treatment of CH_2Cl_2 (about 2 percent concentration) in air at 700°C and about 1 second residence time. Figure 1.A.3.1 shows the spectrum of products when CH_2Cl_2 (m/z = 84) was continuously injected in 21 percent O_2/78 percent He. Note the significant production of Cl_2 (m/z = 70) (an absorber in the near-ultraviolet) as well as HCl (m/z = 96). The DE was about 99.9 percent.

- **Steam reforming effectively destroyed a nitrogen-containing compound, but the rhodium catalyst was deactivated reversibly by a sulfur-containing compound.**

  Tests were made with a rhodium-on-alumina catalyst to measure its utility in steam reforming mixtures, nitrogen-containing compounds and sulfur-containing compounds. Acetonitrile is steam-reformed to CO, CO_2, H_2, and N_2; sulfur compounds seem to

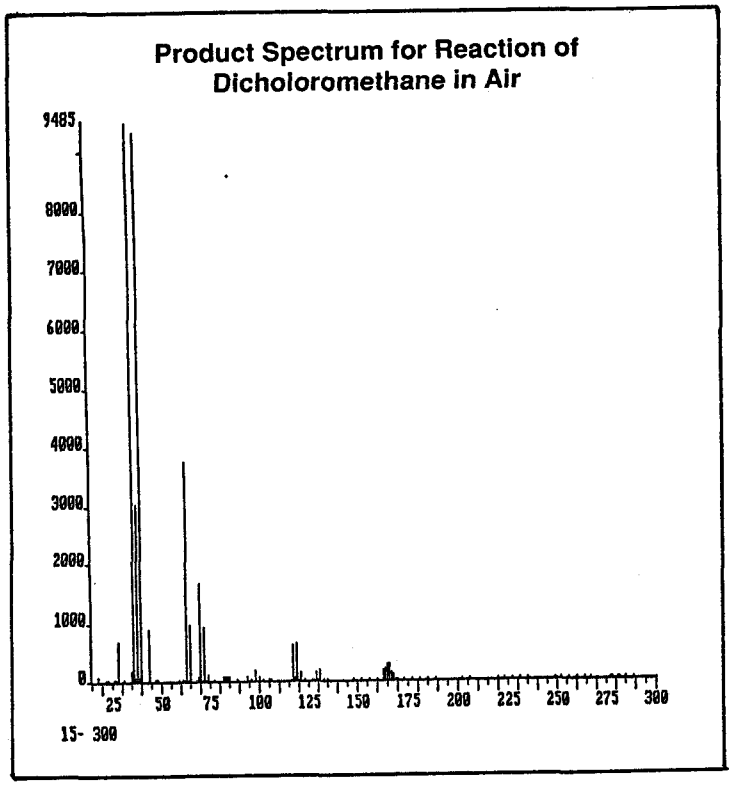


Figure 1.A.3.1

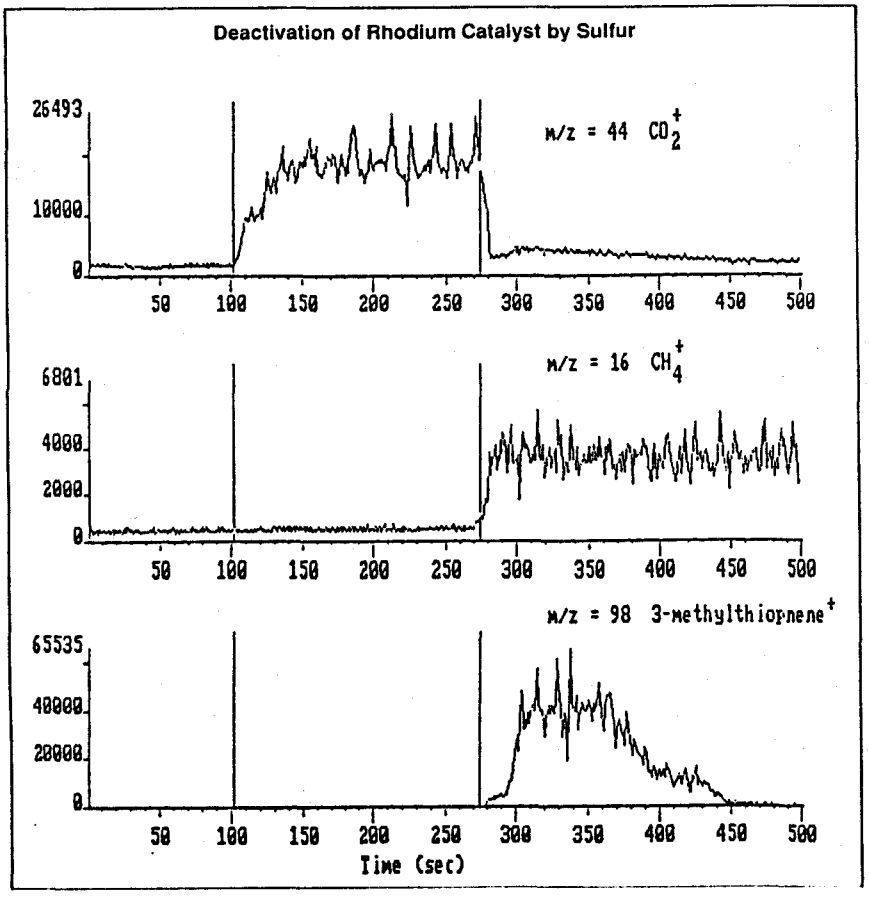


Figure 1.A.3.2

reversibly deactivate the catalyst. Figure 1.A.3.2 is a plot showing this deactivation. 3-Methylthiophene ($m/z = 96^+$) was injected during a steam-reforming run of methane ($m/z = 16^+$). As the figure shows, the signal for methane increased and the signal for the product (CO_2: $m/z = 44^+$) decreased when the 3-methylthiophene was injected. The catalyst could be rejuvenated, however, with O_2 in steam at 800°C.

o **An argon ion laser was installed in the MBMS laboratory.**

A new argon ion laser (Inova 200 - Coherent) was received, installed, and tested in December. The laser was obtained with SERI-GPE funds supplementing the program funds. This laser was rated at 2.5 watts output in the near-ultraviolet region (300 nm to 340 nm). With this output defocused to a diameter of one inch, the power is greater than the equivalent of 1000 suns. Researchers have set up the MBMS apparatus to monitor the light absorbed (as well as the product slate) as a function of time. This real-time monitoring of absorption will allow a determination of quantum yields. Figure 1.A.3.3 is a schematic of the MBMS/laser destruction apparatus.

o **A literature review of high-temperature photocatalysis was begun.**

A review of literature dealing with heterogeneous gas phase photocatalysis was begun. This will provide a basis for selection of catalysts for initial study.

o **The SOLTOX reactor is operational, and thermal characterization was begun.**

The SOLTOX reactor was returned to operation. After recalibration of supporting instrumentation (flow meters, IR analyzer) and installation of new bourdon tube pressure gauges, thermal characterization tests were begun by using carbon dioxide as the test gas. Examination of the initial data from these steady-state tests showed that thermal equilibrium (constant temperatures) is attained much more slowly in the exit gases than in the porous ceramic absorber (the catalyst support), because the alumina insulation that lines the DCAR reactor has a substantial thermal mass which significantly affects exit gas temperatures until the insulation reaches thermal equilibrium with the aluminum reactor shell and with the exit gases. Once thermal equilibrium is attained, model predictions of frit temperatures agree well with measurements, when estimated frit properties and measured values of peak solar flux, flux distribution, and gas flow rate are used as input to the calculation.

o **CAESAR tests with radially nonuniform absorber were successfully completed.**

The Catalytically Enhanced Solar Absorption Receiver (CAESAR), mounted on DLR's seventeen-meter dish at the PAN facility near Lampoldshausen, Federal Republic of Germany, was fitted with a radially nonuniform, rhodium catalyzed, porous ceramic absorber that was tailored to force a greater mass flow through regions of greater incident solar flux (absorber center). Thermal and chemical (reforming) tests were conducted successfully during October and November. Preliminary results indicate that the radially nonuniform absorber, exposed to the peaked solar flux from the uncovered dish, did indeed cause greater gas flow through the center section and resulted in generally more uniform radial temperature variations and improved methane conversion. Analysis of the data from these tests has been initiated.

Planned Activities for Next Quarter

o SOLTOX reactor testing will continue with testing of a range of organic materials. Thermal and flux characterization testing will be completed.

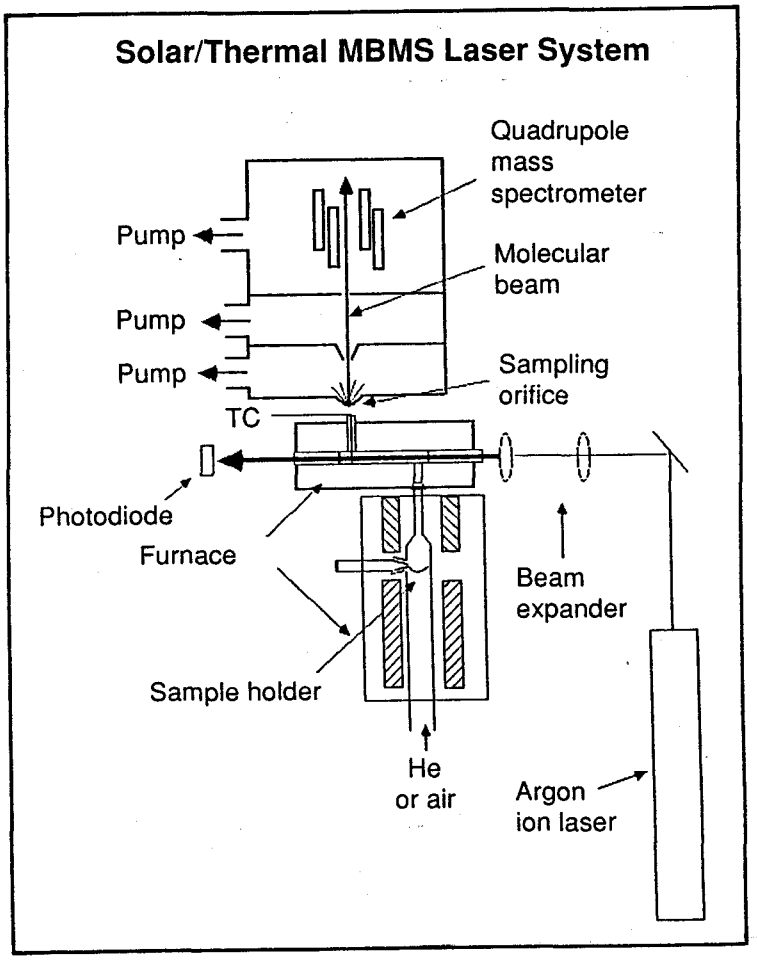

Solar/Thermal MBMS Laser System
Quadrupole mass spectrometer
Pump
Molecular beam
Pump
Pump
Sampling orifice
TC
Photodiode
Furnace
Beam expander
Sample holder
He or air
Argon ion laser

Figure 1.A.3.3

- o CAESAR activities during the next quarter will focus on analysis of the test data and performing incident solar flux characterization measurements at the absorber location on the dish. The latter are essential for proper analysis of the data and model predictions.

- o Identification of PIRs in the photo/thermal reactions of organics will be the focus of experiments in the laboratory.

- o A photocatalytic reactor will be assembled, and testing of heterogeneous photocatalysts will begin.

TASK B. HIGH FLUX OPTICS

Accomplishments

- **The University of Chicago successfully tested solid dielectric secondary concentrators.**

  Solid secondary concentrators made from YAG and sapphire (dielectric constant = 1.78) were successfully tested on sun. Preliminary results indicate that flux levels exceeded those obtained with liquid-filled secondaries.

- **The subcontract for site development and construction for the SERI High-Flux Solar Furnace has been completed.**

  The subcontract for site development and construction with Hughes-Groesch Constructors of Arvada, Colorado, was completed in October. SERI staff occupied the site beginning in October and began installation of furnace systems and components within the Control Building.

- **The primary concentrator has been installed and aligned at the SERI High-Flux Solar Furnace.**

  The support structure for the primary concentrator facet array, built by Dan-Ka Products, was moved to the furnace site and was installed within its protective building. All 23 mirror facets have been mounted on the structure and have been aligned. Initial alignment was based on an analytical prediction of facet-pointing angles. Final alignment was on-sun by using the center facet as a reference. The flux mapping system provided real-time data to maximize the peak flux from the superimposed images from the reference facet and the facet being aligned.

- **The heliostat system has been installed and aligned at the SERI High-Flux Solar Furnace and is fully operational.**

  Modified heliostat reflector panels and a modified support structure, both built by Dan-Ka Products, have been fabricated for the heliostat at the furnace. The modified structure was initially bolted to a spare drive unit fixed to the ground. The reflector panels then were mounted to the structure and were adjusted to form a flat surface. Bracing was added to the structure and the torque tube to minimize both gravity and wind-induced deflections. The entire assembled structure then was hoisted to the top of the pedestal/drive unit (previously installed) and was fixed in place. In a near-operational position, the panels then were realigned by using a near-observer technique.

  The PC-based control system for the heliostat, built by Solar Power Engineering Company (SPECO), was installed at the site and has demonstrated accurate tracking of the heliostat. Both limit switches and encoders were adjusted and set. The precise geometrical relationship of the optical components was established at the site by a survey. The data from the survey were entered into the control software. The orientation of the heliostat reflective surface to the drive unit also was established, and the data were entered into the control software. Tracking under calm wind conditions is excellent. In gusty wind conditions, there is some motion about the azimuth axis. This will be minimized with the addition of a spring-loaded tether to the structure.

- **Design and fabrication of major components for the SERI High-Flux Solar Furnace have been completed.**

  An air-actuated shutter has been designed, built, installed, and tested at the furnace. This system, built in-house, is capable of opening or closing in approximately 0.5 seconds. It has been interfaced with the DACS and can be independently controlled with a manual controller. This shutter has been mounted on a temporary positioning table until final installation of the more sophisticated positioning system is completed. The temporary table also supports the flux mapping/calorimeter plate used to provide detailed measurement of flux profiles in the target plane.

  The delivery of the positioning system, purchased from SCANEX, Inc., Boulder, Colorado, has been delayed. Initial delivery of the table was expected in December. Discussions to establish a new delivery schedule are ongoing. Some modifications to the temporary table are planned. These modifications will provide additional capability to support some of the initial experiments planned for the furnace.

  Design and fabrication of an attenuator have been completed by Advanced Thermal Systems, Inc. The unit has been assembled at the furnace and has been bench-tested successfully. Work remaining includes erection of the attenuator, connection to the DACS, and operational checks.

- **With the SERI High-Flux Solar Furnace operational, a major milestone was met.**

  A major milestone "High-Flux Solar Furnace operational" (FY 1990 AOP, Milestone 1B) was met in December, 1989. With final alignment of the heliostat and primary concentrator, installation of the heliostat control system and operation of the DACS to control furnace systems and acquire data, the furnace was operated at full concentration for the first time on December 29, 1989. All 23 facets were focused onto the cooled flux mapper/calorimeter plate. Initial measurements using the calorimeters are very encouraging when compared with analytical predictions. Flux maps also were captured and stored for later analysis. More extensive characterizations of the flux capabilities of the system are planned for January.

- **The University of Chicago is providing design and fabrication support for an initial secondary concentrator to be used in the furnace.**

  The University of Chicago has developed an initial version of a ray-trace analysis code for reflective-type secondary concentrators. This code interfaces directly with the SERI furnace code (SULFUR) to provide an explicit analysis of secondary concentrator performance in the furnace configuration. The code allows for specification of an axisymmetric reflective secondary of arbitrary shape and size. The target plane can be moved along the optical axis to determine the flux behind the exit plane of the secondary. Modifications and enhancements to the model are currently in progress and will allow analysis of high-index secondaries. Use of the code for parametric studies to provide design guidance for the initial secondary concentrator is planned for January.

Planned Activities for Next Quarter

- Safety and operational checks of the furnace systems will continue.

- Flux-characterization experiments also will continue.

- The attenuator will be installed, and the checkout tests will be completed.
- Researchers will conduct initial experiments in detoxification and materials-processing.
- Design and fabrication of the reflective secondary will be completed at the University of Chicago.

TASK C. MATERIALS

Accomplishments

- **Experiments were conducted by SERI at the Sandia Solar Furnace during the week of October 16.**

  Alloy samples obtained from B. Wellman were exposed in the solar beam in an inert gas purge. Rapid heat treatment was used to anneal hardened samples, to harden annealed samples, and to redissolve an unwanted surface phase with limited success. Additional work is required in order to control the thermal gradient to the degree of producing interesting surface phases. Separate experiments were carried out to investigate the possibility of cladding from various powders that were predeposited on 1040 steel substrates. Successful clads were obtained by using Ni-Cr compound, Cr-oxide, stainless steel, and WC powders.

  Analytical work on these samples, including microscopy, x-ray diffraction, and hardness testing was performed. The cladding material exhibits good interfacial quality. The Cu-Be alloys were all annealed, but surface selectivity in these experiments was poor. Further experimentation is required.

- **A review meeting was organized by SERI and held on November 16 to 17.**

  Five distinguished panelists were invited to attend the two-day meeting and heard presentations on the work at SERI on surface modification and the work at Georgia Tech Research Institute on the rapid thermal processing of carbon fiber tows. Their task was to critique the work and to provide information to the program on future work. The results of their considerations were provided orally at the end of the meeting. The formal recommendations have not been received. The preliminary recommendations have been used as a guide for planning.

- **A new target-assembly vacuum system and mass-flow system for film-growth experiments have been completed.**

  The new vacuum system includes a turbomolecular pump for evacuating the system to 10^{-8} torr, a residual gas analyzer for leak-testing and process-monitoring; an independent roughing system capable of handling hazardous/corrosive or abrasive gases; and dynamic control of the chamber pressure. The mass flow system provides automated control of up to four gases, including provisions for one liquid vapor source. The gases can be proportioned continuously over a wide range of flow conditions. The system has been leak-tested, operationally checked, and is ready for transport to the furnace.

- **Georgia Tech Research Institute (GTRI) is prepared for carbon-fiber testing.**

  Carbon-carbon composites are a high-tech material containing many ideal properties whose primary market is aerospace. These composites, however, do suffer one major disadvantage--when exposed to an oxygen environment and to temperatures greater than 400°C, carbon readily oxidizes to form gaseous carbon oxides. Intensive research is currently being performed in the Western World to improve the oxidation resistance of carbon-carbon composites. Under contract to Sandia, GTRI is conducting research to improve the oxidation resistance of the reinforcing fibers by treating them within a solar furnace.

During the present quarter, the following five activities were performed by GTRI and Sandia.

1. GTRI continued to change the design of the equipment that supports the fiber during the treatment process in its solar furnace. This will allow GTRI more easily to treat large quantities of fiber.

2. A technique for mounting the carbon fiber tow in the tensile-test machine was developed at GTRI.

3. Results of work to date were presented at a materials processing review meeting held at SERI. This work included carbon fiber research at GTRI and systems analysis at Sandia. The conclusion of the review committee was that the work at GTRI to improve oxidation resistance of carbon fibers is potentially very important and should be continued. The review committee recommended that GTRI strive to determine whether the improved oxidation-resistance that GTRI has observed is due to a solar effect or a thermal effect.

4. A high-temperature convection oven was loaned to GTRI from Sandia. This oven will facilitate oxidation-resistance testing of the carbon fiber tows.

5. In response to the review committee's suggestion, plans were made to perform some simple tests to determine if solar treatment improves oxidation resistance beyond that achieved with thermal treatment. Researchers are in the process of obtaining the most oxidation-resistant fiber that the Hercules Company manufactures. Hercules improves oxidation resistance by using a thermal treatment. The Hercules fiber will be placed beside the solar-treated fiber in the convection oven, and it will be exposed to the same temperature history. The weights of the samples will be compared at various times to determine if the solar treatment improves the oxidation resistance beyond the thermal treatment.

Planned Activities for Next Quarter

- GTRI will complete modifications to its furnace and will treat a large quantity of carbon fibers. The oxidation resistance of these fibers will be compared with thermally treated fibers available from industry.

- Tensile and modulus tests of the treated fiber will begin.

- Sandia will aid GTRI in performing TEM analysis of the treated fiber.

- The new target assembly will be installed at the SERI furnace on South Table Mountain.

- Preparations will be made for experiments on growing carbon films from CH_4 and H_2.

- Preparations will be made during this period to allow for experiments in growing films from other precursors at SERI.

TASK D. RECEIVER/REACTOR MODELING

Accomplishments

- **An ASME paper describing a comparison of receiver/reactor models was completed.**

  A paper entitled "Radiative Transport Models for Solar Thermal Receiver/Reactors" has been accepted for presentation at the Solar Energy Conference scheduled for April 1 to 4 in Miami, Florida. The American Society of Mechanical Engineers (ASME) is sponsoring the conference. This paper describes in detail a comparison of three methods for calculating the volumetric absorption of solar energy in a receiver/reactor and is based on work performed at SERI during FY 1989.

- **Conduction heat transfer was added to the high-flux receiver/reactor model, and the complete model for TCE oxidation was run successfully.**

  SERI has expanded the high-flux receiver/reactor model to include the effect of axial conduction. This effect could be important for monolithic absorbers such as the reticulated alumina foams. As it stands now, the model accounts for (1) local absorption of solar energy; (2) radiative transport in the infrared band; (3) convection between the absorber and the gas; (4) axial conduction in the absorber; (5) axial pressure drop in the gas stream; and (6) conservation of species and chemical reaction rate. The full model has been successfully run for the case of thermocatalytic decomposition of trichloroethylene in air.

- **DCAR reactor modeling was conducted.**

  Destruction of trichloroethane (TCA) in a DCAR reactor like the one at the SOLTOX facility was modeled at Sandia by using a kinetic expression for TCA destruction by steam reforming determined experimentally at the University of Houston. The calculations assumed a solar flux of 80 kW per square meter, a Rh loading of 0.2 percent, and a TCA flowrate of 1.7 kg per hour. These conditions produced a TCA residence time in the catalyst coated absorber of 0.23 seconds and an absorber temperature of 680°C once the absorber and the gas mixture (TCA, steam, carbon dioxide) had attained thermal equilibrium. For these conditions, the DCAR model predicted a TCA destruction efficiency of 99.9997 percent. Since higher temperatures are easily attainable, a destruction efficiency of six 9s (99.9999 percent) should be easily achieved.

Planned Activities for Next Quarter

- The major effort at SERI in the second quarter will focus on methods for determining radiative properties of various absorber materials which are compatible with the computation methods chosen for the receiver/reactor model.

2. Concentrator Development

Objectives

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

o Testing of second-generation stretched-membrane mirror modules was completed.

Sandia completed the evaluation of the optical performance of the two second-generation stretched-membrane mirror modules. Because of their simple design and light weight, heliostats using membrane reflectors have the potential to cost significantly less than familiar glass-mirror designs. The second-generation mirror modules were built by Science Applications International Corporation and by Solar Kinetics, Inc. Sandia's evaluation indicates that the quality of the reflected beams is as good as that from current glass-mirror heliostats. The observed beam shapes are indicative of reflectors with nearly ideal parabolic contours. Researchers estimate the total mirror-normal errors to be about 1.3 and 1.5 mrad for SKI's and SAIC's mirror modules, respectively. Measurements of the mirrors' optical performance on windy days indicate that the additional, wind-induced slope error is less than 1 mrad--well within Sandia's specifications and a significant improvement over the first-generation designs. Cleaning of a membrane mirror was also demonstrated for the first time. The mirrors could be returned to nearly 95 percent of the clean reflectance with a simple high-pressure spray. The reflective surfaces are still in good condition; the solar averaged reflectances are about 90 percent. A report documenting all aspects of Sandia's testing will be completed next quarter.

If manpower is available, Sandia will continue to operate the two mirror modules on a daily basis to determine long-term operation and maintenance costs, and to assess the durability of the silvered-acrylic reflective surfaces.

o Solar Kinetics, Inc., began the design of a market-ready, stretched-membrane heliostat.

Sandia placed a contract with Solar Kinetics, Inc., for the design of a fully integrated, stretched-membrane heliostat. Until now, Sandia's efforts have focused on the heliostat's mirror module because its technical issues seemed the most challenging. Under the present contract, SKI will integrate its existing design for a membrane mirror module into the design of a fully integrated heliostat. Key elements of the current design include the heliostat's drive, pedestal, foundation, and control system. SKI has selected a heliostat size of 50 m^2 as best for today's commercial markets. To protect the reflective surface of the single-module heliostat, the heliostat will be stowed vertically except in high winds. The design will be completed in six months, at which time a prototype will be fabricated for Sandia's evaluation.

- **Fabrication of first prototype of Science Applications International Corporation's 100 m^2 market-ready heliostats is being negotiated.**

  Science Applications International Corporation's (SAIC) design uses two 50 m^2 mirror modules on a single pedestal. Though not necessarily the optimal heliostat for large power plants, this design was selected because it will provide a near-term commercial product. Two key advantages of this design are the use of an existing drive system and the ability to stow the mirror module face down. In addition, very few modifications would be required to build 50-m^2 heliostats for use at smaller power plants. Contract negotiations between Sandia and SAIC were still underway at the end of the quarter and should be completed in January. Installation of the prototype at the NSTTF is scheduled for July, 1990.

- **Static load testing of the drive from Solar Power Engineering Company's heliostat was delayed until next quarter.**

  The drive for Solar Power Engineering Company's 200 m^2 heliostat was scheduled for static load testing this quarter; however, Sandia's static testing facility was not available for use, and the testing has been rescheduled for early next quarter.

- **Alpha-Solarco installed a photovoltaic array on a prototype of the low-cost heliostat drive.**

  Alpha-Solarco completed the installation of a 125 m^2 concentrating photovoltaic array at its test facility in Pahrump, Nevada. The system uses one of the low-cost heliostat drives developed for Sandia by the Peerless-Winsmith Company. The drive was loaned to Alpha-Solarco by Sandia.

  A second prototype of the low-cost drive has been loaned to the Electric Power Research Institute for a similar application. This unit has been returned to Peerless-Winsmith to be fitted with a new adapter.

Planned Activities for Next Quarter

- The drive from Solar Power Engineering Company's 200 m^2 heliostat will be statically load-tested to ensure that it meets specifications. It if passes the test, it will be reinstalled on the heliostat, and testing of the optical performance will commence.

- The final report from Science Applications International Corporation on the design of a market-ready heliostat will be published.

- The final report from Solar Kinetics, Inc., on its improved design for a stretched-membrane heliostat will be published.

- Sandia's final report on the testing of the two improved stretched-membrane mirror modules will be completed.

TASK B. PARABOLIC DISHES

Accomplishments

- **A seven-meter-diameter, stretched-membrane dish was formed and measured.**

During the month of December, Solar Kinetics, Inc. (SKI), of Dallas, Texas, formed and measured the slope error of a seven-meter-diameter, stretched-membrane dish (f/D = 0.6). The dish membrane is made from 12 overlapping strips of 4 mil thick 304 stainless steel welded together. The metal membrane is attached to the concentrator ring, and the two are mounted in a fixture designed specifically to form the dish.

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. Four separate cycles of vacuum and water forming were used to shape the current membrane. After each forming step, the slopes at four points and the center displacement of the membrane were measured. These measurements then were used to determine how the membrane would be loaded next--that is, whether vacuum or hydroforming would be used to further shape the membrane. The last step in the forming process, referred to as tuning, involves additional forming of the membrane by using only uniform vacuum loading.

Errors in membrane slope are measured by using a laser, a pentaprism mounted on rails along a dish radius, and a target located 4.2 meters from the vertex of the dish at the focal point. The laser beam illuminates the prism in the plane of the dish ring where it is directed paraxially onto the dish surface. (A pentaprism has the property that the exiting laser beam is directed at a 90R angle to the incident beam.) A small mirror placed on the dish surface reflects the beam to the focal plane of the dish. The local error is determined by comparing the position of the laser beam on the target plane with the location where a perfect parabola would reflect the beam. Measurements are made along the dish radius, and the data are combined to determine the standard deviation of the measured shape from a perfect parabola. The measured slope errors are shown below for the dish immediately after forming and after five consecutive tuning steps.

Initial shape	7.94 mr (1σ)
Tuning Step 1	8.35 mr (1σ)
Tuning Step 2	6.92 mr (1σ)
Tuning Step 3	5.84 mr (1σ)
Tuning Step 4	4.00 mr (1σ)
Tuning Step 5	3.40 mr (1σ)

These measurements were made along a radius parallel to the membrane seams. Slope error measurements across the seams tend to be from 0.5 to 1.0 mr larger. These numbers do not include the outer 3 percent of the dish area, a convention adopted during Phase I of the project because of the boundary effects near the membrane attachment point at the dish rim where the slope error tends to be large.

The objective of the seven-meter-diameter testing is to determine the accuracy of SKI's forming process. Researchers would have considered the tests to be successful if the slope error had been 5.0 mr. The 3.40 mr slope error achieved on the first seven-meter diameter, stretched-membrane dish is an outstanding accomplishment.

SKI researchers are proceeding to roll the membrane onto a contoured mandrel; then they will install it on the dish again and will measure its optical performance. From these experiments, researchers will be able to determine how much handling the membrane will affect the accuracy of the dish. If the parabolically contoured membrane can be rolled, the dish can be made at the factory and can be assembled at the site--thereby eliminating costly site fabrication.

SKI will fabricate two more parabolic membranes and optically will characterize the best one by using its Laser Ray Trace instrumentation. After the seven-meter-diameter optical element has been fully characterized, SKI will assemble and install it at Sandia for on-sun testing. The current schedule has the optical element being delivered to Sandia during March, 1990.

- **Initial thermal and optical evaluation of faceted dishes was completed.**

Sandia and SERI completed an initial evaluation of the effects of the geometric arrangement of the facets and the facet support-structure contour on the performance of a solar concentrator comprising 12 stretched-membrane facets, each 3.5 meters in diameter.

The dish concentrator computer codes CIRCE and ODMF were used to model the optical performance of the dish; and a thermal model, which includes conduction, convection, and radiation heat transfer, was used to calculate the thermal losses from a cavity receiver. The solar collector efficiency, defined as the product of the optical efficiency of the collector and the thermal efficiency of the receiver, was optimized for comparing 10 possible combinations of facet arrangement and support structure contour.

Preliminary results show that the astigmatic effect of the off-axis facets dominates the performance of the solar collector. If the dish focal length is allowed to increase slightly (accommodating the geometric spreading of the facets for various facet arrangements) to maintain the dish focal-length-to-diameter ratio at about 0.6, the optimal collector efficiency for most of the cases studied is constant at 0.77 for a receiver aperture diameter of 0.42 meters. This suggests that other factors, such as the fabrication of identical parts, the simplicity of the facet support structure design, and the cost of manufacturing the dish, may be more important than the facet arrangement or the support structure contour for defining the collector design. Further analysis addressing the following questions is underway and will be completed in January.

- How does the performance of the dish vary with different facet f/Ds, dish focal length, and two facet arrangements (2TOP and 4INLINE) and for a spherical facet support structure?

- Does a parabolic facet support structure with facets having a variable f/D offer improvements on the above configurations?

The results from this analysis will be combined with preliminary structural design analysis to define the configuration of the faceted stretched-membrane dish in late January.

- **Contracts were placed, and an initial meeting was held for the project on faceted stretched-membrane dishes.**

The initial meeting for the Faceted Dish Development Project was held on Tuesday, December 19, 1989, at Sandia in Albuquerque, New Mexico. The meeting was attended by representatives of the contractors: 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. In the morning, presentations were made by SKI and SAIC about their respective development of stretched-membrane facets and by WGA on facet support structure and pedestal design concepts. A working meeting was held in the afternoon to discuss the interfaces between the facets and the support structure.

Phase 1 of the project is the development and testing of facets fabricated by SKI and SAIC and the development of facet support structure and pedestal designs by WGA. Solar Kinetics proposes to develop stretched-membrane facets (3.5 meters in diameter) involving the plastic forming techniques that it has successfully demonstrated for the seven-meter dish. SAIC will elastically form facets similar in construction to those developed for the stretched-membrane heliostats. If the evaluation of cost and performance of the faceted dish shows it to be the best near-term concentrator, then Phase 2 of the project (the transfer of the facet support structure and pedestal designs from WGA to SKI and SAIC and the fabrication of the faceted dishes) will proceed.

At the afternoon meeting, several issues related to the design of the faceted dish and the interfaces between the facets and the facet support structure were resolved. It was agreed:

- That the facet support structure will have compound curvature (this adds little to the cost of the dish);
- That the facets will be arranged in either a modified hexagonal-close-packed array or in four lines of three facets each, and will be defined by a final optical and structural analysis;
- That the attachment points for the facets to the facet support structure will be at a radius of 1.75 meters from the center of the facet and at 120R spacing around the perimeter of the rim ±1.25 cm;
- That the facet-facet support structure envelope is a cylinder 3.5 meters in diameter and 30.5 cm high;
- That the dish-stow position will be a semi-inverted, downward looking orientation;
- And that dish control system will be a simple PC controller.

Eleven action items were identified at the meeting and were assigned to team members. The project schedule was revised to show the first facets delivered to SERI for testing in April, 1990; the facet support structure and pedestal designs completed in July, 1990; the second set of facets delivered to SERI in August, 1990; and the Decision Point Design Review conducted in October, 1990.

Two major developmental issues and an approach for their resolution were identified at the meeting. First, it is clear from the discussions at the meeting that the development of the stretched-membrane facets is substantially more complex than was originally anticipated. The elastic-facet-fabrication approach requires that the stainless steel membranes be operated at very high levels of stress with very low factors of safety. The plastic-membrane-fabrication approach will require several different facets to span the range of facet f/D. Secondly, the ECP 305 polymer film from the 3M Company will be laminated to the metal membranes of the required focal lengths. The elastic facets and the film will be focussed and unfocussed over the course of a day's cycle. In both facet approaches, the film will be operated at an initial strain that is much greater than has ever been experienced on the stretched-membrane heliostats. The average heliostat strain is about 0.05 percent and the average strains in the faceted stretched-membrane dish range from about 0.14 percent to 0.33 percent.

To address these two issues, researchers are proceeding to evaluate increasing the dish focal length, thereby allowing work at the upper end of the facet f/D range, defined for the project, and spherically contouring the facet support structure, to further limit the range of facet f/D. If researchers are able to work at larger facet f/D without greatly compromising the performance of the dish, then the operating membrane stresses will be reduced in the elastic approach as well as the strain in the polymer films in both facet-fabrication approaches. The use of a spherically contoured facet support structure will limit the range of facet f/D required and should reduce the number of facet shapes required for the plastic fabrication approach.

- **SERI measured the optical performance of a small dish concentrator (PV application) from Science Applications International Corporation (SAIC) by using SHOT.**

The dish was delivered to SERI for characterization of its optical performance by SAIC. It has a diameter of 59.5 inches and an f/D of .4. It is a fiberglass molded dish designed by SAIC for photovoltaic applications. Measurement results will be sent to SAIC.

- **SERI extended the measurement capability of SHOT.**

Modifications have been made to the beam scanning system of the SHOT instrument and extend the upper end of the dish f/D testing range from 1.0 to 3.0. This was done in anticipation of testing needs for dish facets to be produced by SKI and SAIC. A new baseplate has been fabricated and installed to allow a new beam-scanning configuration in addition to the standard one. The standard configuration uses a lens to achieve a scanning solid angle of approximately 23 degrees. This allows testing of f/Ds between 0.5 and 1.0. This lens now can be easily removed, and the scanning unit can be moved into a repeatable position on the same baseplate. This new configuration results in an included scanning angle of approximately 18 degrees and extends the maximum dish f/D, which can be tested to 3.0.

- **SERI used SUPERSAP, a finite element structural code, to analyze deflections of support structures for faceted dishes.**

SERI researchers are currently using SUPERSAP, a finite element structural analysis code, to model support structures for faceted-dish concentrators. This code, together with SERI's concentrator optical/thermal analysis code ODMF, will be used to analyze the effects which support-structure loads have on the optical/thermal performance of

the concentrator as a whole. An interface is being planned to allow displacement output from the finite element code to be input directly to ODMF for performance analysis.

SERI researchers will verify the approach by structurally modeling an existing concentrator, one whose deflections can be measured. The heliostat subsystem of SERI's High-Flux Solar Furnace has been chosen for this purpose. A finite element model currently is being developed to be used to predict displacements due to prescribed static loads on the heliostat structure. These loads can be applied to the real structure, and displacements can be measured to corroborate the model. In this way, researchers plan to verify the modeling approach.

- **Optical evaluation of the LaJet 460B solar concentrator was performed.**

At the request of the Cummins Engine Company and the LaJet Energy Company, a test team from Sandia Laboratories went to Abilene, Texas, in November to evaluate the optical performance of the LaJet Energy Company's 460B solar concentrator. The LEC 460B is a revised version of the LEC 460 solar concentrator of which 700 are installed at SOLARPLANT1 in Warner Springs, California. The LEC 460B has 24 aluminized polyester facets, 1.5 meters in diameter and produces about 32 kWT. Modifications to the LEC 460 reflect corrections to problems experienced with the diurnal drive on the LaJet Innovative Concentrator during testing at Sandia. Sandia redesigned the diurnal drive on the Innovative Concentrator, and LaJet has incorporated these changes into the LEC 460B. The LEC 460B is the concentrator being used for the dish-Stirling project sponsored by the Cummins Engine Company and involving LaJet, Sunpower, and Thermacore. During a test of the dish-Stirling system Project, engineers were concerned that the flux distribution produced by the LEC 460B may have caused the failure.

Sandia engineers and technicians took the Video-Flux-Mapping System to LaJet and measured the flux-density distributions in three planes: the receiver aperture plane, and 12.7 and 16.5 centimeters behind the aperture plane. Flux-density distributions were measured with all of the mirror facets on the target and with the mirror facets brought into focus on the target one-at-a-time--corresponding to the sequence used during the test on October 25, 1989.

The results of flux-mapping tests indicate that the images of the fifth and twentieth facets brought into focus on the target were superimposed on the back of the receiver--substantially increasing the flux density near the location of the failure. It also appears that the facets were focussed beyond the aperture plane and that their alignment was not as well controlled as expected.

Planned Activities for Next Quarter

- The performance of dishes using different facet f/Ds, facet arrangements and support structure curvatures will be compared by using CIRCE and ODMF.

- SERI plans to validate SUPERSAP by conducting measurements of static load deflection on SERI's heliostat and comparing them to predictions.

- Solar Kinetics, Inc., will deliver the seven-meter-diameter, stretched-membrane optical element to Sandia for testing in March, 1990.

- A meeting of the Design Team for the Faceted Stretched-Membrane Dish Development Project will be held in January.
- Sandia will measure SAIC's concentrator performance on-sun.

TASK C. OPTICAL MATERIALS

Accomplishments

o Tunneling prevention experiments show promise.

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 initiate at mirror edges or at interior points that are subjected to excessive stress. Moisture weakens the silver/PMMA adhesion and speeds tunneling. Large mirrors stowed face up have collected puddles of rain water that induced tunneling. A simple laboratory simulation is to immerse samples in water for extended periods.

Several approaches to mitigate tunneling are in progress and three procedures have apparently eliminated tunneling on laboratory-scale samples (5 inches by 8 inches or 18 inches by 20 inches) during extended water immersion. The three procedures are:

1. Mechanically clamping the mirror edges to an aluminum substrate;
2. Embedding the silver in a symmetrical structure (the pieces of film bonded back to back) presumably to avoid differential thermal or hygroscopic expansion; and
3. Using glass substrates, or aluminum substrates, that are coated with a baked paint.

At the same time, similar experiments with bare aluminum or stainless steel substrates have performed very poorly. These results, though very encouraging, are to be interpreted as preliminary indications of research in progress.

o The new ECP-305 continues to show its improved performance.

Outdoor and accelerated laboratory tests both by the 3M Company and SERI continues to show the improved durability of ECP-305 when compared to the previous production material ECP-300A.

o An outdoor test plan is being developed jointly between Sandia and SERI.

Sandia and SERI researchers met to discuss and to develop an outdoor testing plan for polymer mirror coupons. Fourteen accessible sites were selected and typified into one or more of three categories depending on how extensive the testing at the site could be; how many coupons were possible; what kind and what sizes will be placed there; and how frequently coupons will be evaluated.

o The contract on the replaceable membrane was placed.

Sandia placed a contract with Industrial Solar Technology of Denver 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, ECP-305 from the 3M Company, is bonded very tightly to the metal substrate, which makes replacement difficult. To facilitate replacement, the reflective film must be bonded to a separate substrate that would be clamped or lightly glued to the metal substrate. 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 multi-faceted

stretched-membrane dishes. The first demonstration of a replaceable reflective film using one of the existing stretched-membrane mirror modules is planned at the DOE Solar Thermal Test Facility in the middle of 1990.

- **Bidders for the cost study of sol-gel mirrors were identified.**

  Potential bidders for a study to determine the cost to fabricate sol-gel planarized, stainless steel mirrors have been identified. The study, that will establish the relative costs of producing ECP silvered polymer films and front-surface, sol-gel mirrors, has been delayed.

Planned Activities for Next Quarter

- Experiments to avoid tunneling will be extended to include sputtered, inorganic adhesive layers between the silver and PMMA. In parallel, weathering experiments on a variety of silver/polymer/adhesive/substrate materials also will continue.

- A meeting with Industrial Solar Technology will be held in Denver, Colorado, to begin the selection of materials to be evaluated as part of Sandia's contract to develop a replaceable reflective film for membrane heliostats.

- A Request for Quotation will be issued, and a contract will be placed for the Sol-Gel Mirror Cost Study.

TASK D. STRUCTURAL DYNAMICS

Accomplishments

- **Colorado State University (CSU) recommended reducing the wind-load design guidelines.**

  Prof. J. A. Peterka, et al., have completed their latest wind-tunnel tests on parabolic dish concentrators and submitted a drafted report on this work to SERI.

  Building on previous studies, they have been able to advance the state-of-the-art in design guidelines for both heliostats and parabolic dishes and concluded that:

  1. Experimental difficulties may have caused an overestimate in peak azimuthal moments by up to 12 percent;

  2. A re-evaluation of the reference velocity employed in calculating the force and azimuthal moment coefficients in previous studies of parabolic dish collectors indicate that the coefficients could be reduced by about 10 percent to 14 percent for the in-field cases.

  The report and these conclusions are currently undergoing SERI's technical peer review.

- **The wind-load, field-test program has been cancelled.**

  Considerations under the FY 1990 budget forced cancellation of the wind-load, field-test program. Some measurements of strain for low-level winds have been completed. Analysis indicated drift in the null offset measurements prevented accurate calculation of loads. Changes to the strain gauges to reduce drift were being contemplated, although no further measurements are planned at this time.

Planned Activities for Next Quarter

- A memorandum will be prepared to summarize the work performed on wind-load measurements.

- Sandia is producing a design guide (for dishes and heliostats) based on the wind tunnel testing at Colorado State University.

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 solar thermal electric power production applications to penetrate major national and international markets by the late 1990s.

TASK A. CENTRAL RECEIVER TECHNOLOGY

Accomplishments

- **Fabrication and assembly of the 3 MWt Panel Research Experiment is 95 percent complete.**

  The fabrication of all components for the Panel Research Experiment (PRE) has been completed. The panel/frame assembly has been mounted on the PRE base structure inside the tower at the Central Receiver Test Facility (CRTF) and the stainless steel piping installation was completed. The PRE is an experiment of 3 MW_t designed to evaluate the Direct Absorption Receiver (DAR). This experiment was designed, built, and assembled at the CRTF. The PRE will allow flow testing with water and molten salt and will provide a test bed for DAR testing with actual solar heating.

  With the installation of the panel/frame assembly on the PRE base structure and the completion of the inlet and outlet piping, the construction of the PRE is approximately 95 percent complete. A significant amount of work on the heat trace, insulation, and electrical connections has been completed. After it was installed, the panel was tilted back to 5 degrees, the angle at which testing will start. Work that remains to be done before water-flow checkout and testing can be initiated is completion of heat trace installation; electrical connection of the valves and instrumentation; and supply air for the valves and tensioning system.

  The plan for testing the PRE has been completed; however, the test plan is being modified (i.e., the flow testing has been cut back) in order to meet the program's goals of achieving solar testing with the PRE. Researchers expect to begin water flow testing early next quarter.

- **The molten-salt pump and the cold-loop motor are being repaired.**

  The molten-salt pump and the valve hot loop operated for 2400 hours before the shaft on the hot pump motor was damaged. This test successfully demonstrated the maintenance and life of some components of the pump and valve loops. The pump and valve testing consists of two pumped loops, one to simulate the hot side of the receiver (565°C) and one for the cold side (285°C). Each loop contains a pump and six representative valves scaled for a 60-MWe commercial solar power plant. The molten salt pump and valve loop are intended to demonstrate the effectiveness of full-scale hot and cold salt pumps.

  The cantilevered pump that is used in the hot loop had been operating without problems. However, after achieving the milestone of 2400 hours of operation, the pump shaft developed a deflection. This was most likely caused by the shaft stress relieving

in the high-temperature salt. This quarter the pump was pulled for inspection and disassembly, and a new shaft and bearings were ordered from the manufacturer. Because this test is not operated as a plant operation, no spare parts were readily available. The pump is being reassembled and will be ready for operation early next quarter.

Researchers have experienced a significant number of problems with the cold-loop pump and motor, since the initiation of the experiment on the pump and valve. These problems have been caused by manufacturing and design errors. In September, 1989, the stator windings burned out (the cause is unknown). During past quarter the motor was repaired by the manufacturer at no charge to Sandia (approximate repair cost was $25,000). The cold-pump motor currently is being reassembled, and the cold loop operation will begin again early next quarter.

The interim report on the operation and testing of the pump and valve loop has been finalized and was sent to the DOE and industry. The interim report covered the the operation, experiences, and lessons learned primarily from the hot side of the pump and valve loop.

- **The study to compare molten-salt and volumetric-air central receiver technologies was initiated this quarter.**

The study to compare the cost and performance of molten salt and volumetric-air central receiver power plants was initiated. This study entitled "Second Generation Central Receiver Technology" is a joint effort of the United States and the Federal Republic of Germany (FRG) under the Small Solar Power Systems (SSPS) Subtask III, and is intended to provide guidance in directing future U.S. and German governmental programs to develop solar-thermal-electric technology. The study is scheduled to conclude in the summer of 1990.

An initial meeting was held in Cologne, West Germany, on December 12 to 14, 1989, for the purpose of setting goals, establishing guidelines, and adopting methodologies to be used in the study. The meeting was attended by two individuals from Sandia and several study participants from the West German organizations Interatom and Deutsche Forschungs-und Versuchsanstalt fur Luftund Raumfahrt (DLR). During the meeting, consensus was reached on the three items listed above. Some of the more important agreements made at the meeting are listed below.

1. The study will focus on two different plant sizes;
   a. 30 MW in solar and hybrid modes with a nominal solar multiple of 1.2.; and
   b. 100 MW in solar only mode with a nominal solar multiple of 1.8.

2. Three basic technologies will be considered
   a. Salt-in-tube;
   b. Volumetric air; and
   c. Direct-absorption salt.

3. Heliostat sizes will be 150 m^2, with construction of
   a. Glass/metal for 30 MW size;
   b. Stretched-membrane for 100 MW size.

4. The SOLERGY computer code will be used to calculate annual energy.

5. Primary responsibilities for analysis of technology/size are:
   a. 30 MW-- air technology to FRG, salt technology to the U.S. with limited help from FRG;
   b. 100 MW--all salt technologies to the U.S., joint responsibility for air system.

6. The U.S. will perform reliability analyses of both air and salt technologies.

o **A final report was begun on testing the porous ceramic volumetric receiver absorber test in Spain.**

A final Sandia report on the testing of the Sandia volumetric receiver absorber was begun this quarter. Over ninety tests were conducted on the Sandia volumetric receiver absorber, which was tested on the 200-kWt volumetric receiver test bed at the Plataforma Solar de Almeria. The purpose of this testing was to investigate the feasibility of using the porous ceramic material for the absorber in a volumetric air receiver. The ceramic material is of interest because of its structural properties and its high temperature capabilities. A report on the test results prepared by the test conductor at the Plataforma was received by Sandia last quarter. This report will be used in the final Sandia report on the porous ceramic absorber.

o **A contract was initiated for the furnace testing of the volumetric receiver absorbers.**

As part of the U.S. participation in the IEA/SSPS Task III, researchers have designed and built a test apparatus for testing volumetric receiver absorber material in a solar furnace. In order to expedite the testing, a contract has been initiated with New Mexico State University to test the absorber samples in the test apparatus at their solar furnace in Las Cruces, New Mexico.

The apparatus consists of a glass housing formed to hold a three-inch sample of a volumetric receiver, with a fan blowing air (which can be heated) through the absorber. A glass housing is used so that the inlet air flow rate can be measured accurately. The incident solar flux will be characterized, and the absorber sample will be instrumented with thermocouples. The testing will provide information on absorber temperature limitations, efficiency, and heat-transfer coefficients. The results of these tests will be used for validating a computer model of volumetric receiver absorbers. The contract with New Mexico State University will begin in January, 1990.

o **Optical characterization of oxidized wire volumetric receiver absorber samples was completed.**

Volumetric receiver absorber materials are being characterized optically as part of the U.S. participation in the IEA/SSPS Task III. This quarter, six samples of a crimped and uncrimped inconel knit wire mesh (rolled, with flux parallel to the mesh as proposed for the PHOEBUS receiver absorber) have been tested optically. Analysis has shown transmission of approximately 4 percent on a sample (8 mm thick) and negligible transmission on a sample (12 mm), with reflectance values of 4.5 percent for both samples. Consequently, more than 90 percent of the energy is being absorbed within the first 8 mm of the sample. These measurements indicate that the knit wire mesh absorber prepared in this manner will be too optically dense. In addition, the samples have severe radial nonuniformities which will affect the performance of the absorber. In addition, optical characterization of six samples of a pyromark-coated ceramic matrix (similar to that tested in Almeria) material was begun this quarter.

Planned Activities for Next Quarter

- The flow-testing of the PRE will begin next quarter. Water flow checkout and testing will be initiated early in the quarter. After the insulation and electrical connection is completed and the salt is loaded into the sump, the salt-flow testing will begin.

- The next meeting on the salt-air receiver comparison study will be held during March 26 to 30, 1990, in Albuquerque, New Mexico. Preliminary cost and performance analyses of all technologies will be performed by Sandia, Interatom, and DLR during the quarter in preparation for this meeting. Reliability and uncertainty analyses will be performed after the meeting in March.

- Both the hot and cold loop on the pump and valve loop test will be put back in operation after the pumps and motors are reinstalled early in the quarter. Researchers expect that the hot loop will return to continuous operation. However, the cold loop will be operated manually in the start-up mode.

- The furnace testing of the volumetric-receiver-absorber samples will begin at New Mexico State University.

- The optical characterization of the volumetric-receiver-absorber materials will continue next quarter.

TASK B. DISTRIBUTED RECEIVER TECHNOLOGY

Accomplishments

o Tests were completed on a bench-scale, heat-pipe solar receiver.

Liquid metal heat pipes are currently being developed to transfer energy from the focal point of a parabolic solar concentrator to the heater tubes of one or more Stirling engines. Potentially, heat pipes can provide an efficient and passive means for transferring the concentrated solar energy; however, there are practical limits on the capabilities of heat pipe systems. The major restraints are imposed by the wick in the heat pipe that is required to distribute the liquid metal working fluid across the heated surface. Gravity loads and boiling are the primary factors that can interfere with the wick's operation.

To determine the operating limits on a heat-pipe solar receiver, a bench-scale liquid-metal heat pipe was constructed and tested. The system for testing the bench-scale heat pipe is shown schematically in Figure 3.B.1. Quartz halogen lamps are used to apply heat fluxes up to 80 W/cm^2 to a section (3 by 10 cm) of the heat pipe. A stainless-steel screen wick transfers liquid sodium from a pool at the bottom of the heat pipe to the heated surface. The liquid sodium was forced to flow further through the wick and to travel a greater distance against gravity by moving the lamps up the test vessel. To simulate a full-scale heat pipe's operating characteristics under startup conditions, gutters were placed in the heat pipe to prevent the condensed sodium from flowing to the top of the wick-covered surface. In a full-scale 75-kW receiver, the wick will be required to lift liquid sodium approximately 40 cm against gravity.

The heat pipe's operation was flawless at a lamp position of 25 cm above the sodium pool. Internal temperatures were isothermal, and power transients did not complicate the system's operation, regardless of the vapor temperature, power level, or transient duration. At a lamp position of 33 cm, however, the heat pipe's absorber surface temperature was much higher than the vapor temperature, even at partial power. An analysis of the results indicates that boiling occurred and the wick became filled with vapor. (Raising the lamps actually increases the effective superheat in the liquid sodium because of the increased pressure drop in the wick.) Vapor was trapped in the wick by the fine cover layers of screen that were provided to enhance the wick's capillary pumping capabilities. The excessive temperature drop between the absorber surface and the vapor space makes it impractical to use this particular wick structure in a full-scale heat-pipe solar receiver.

The wick structure in the bench-scale heat pipe was based on a design that was proposed by Stirling Thermal Motors (STM). Coarse layers were placed next to the wall to allow liquid sodium to flow freely, and fine screens were placed on top to increase the capillary pumping capabilities. Sandia is now working with STM to develop a wick that allows vapor to escape from the wick structure. In the redesigned system, fine screens alone will distribute sodium over small areas of the heated surface, and arteries will carry the bulk of liquid sodium over long distances. Innovative methods have been developed for forming and joining the arteries. A second bench-scale heat-pipe is currently being assembled to test the operation of the redesigned wick structure. Testing on the second bench-scale heat pipe will begin in the second quarter of FY 1990.

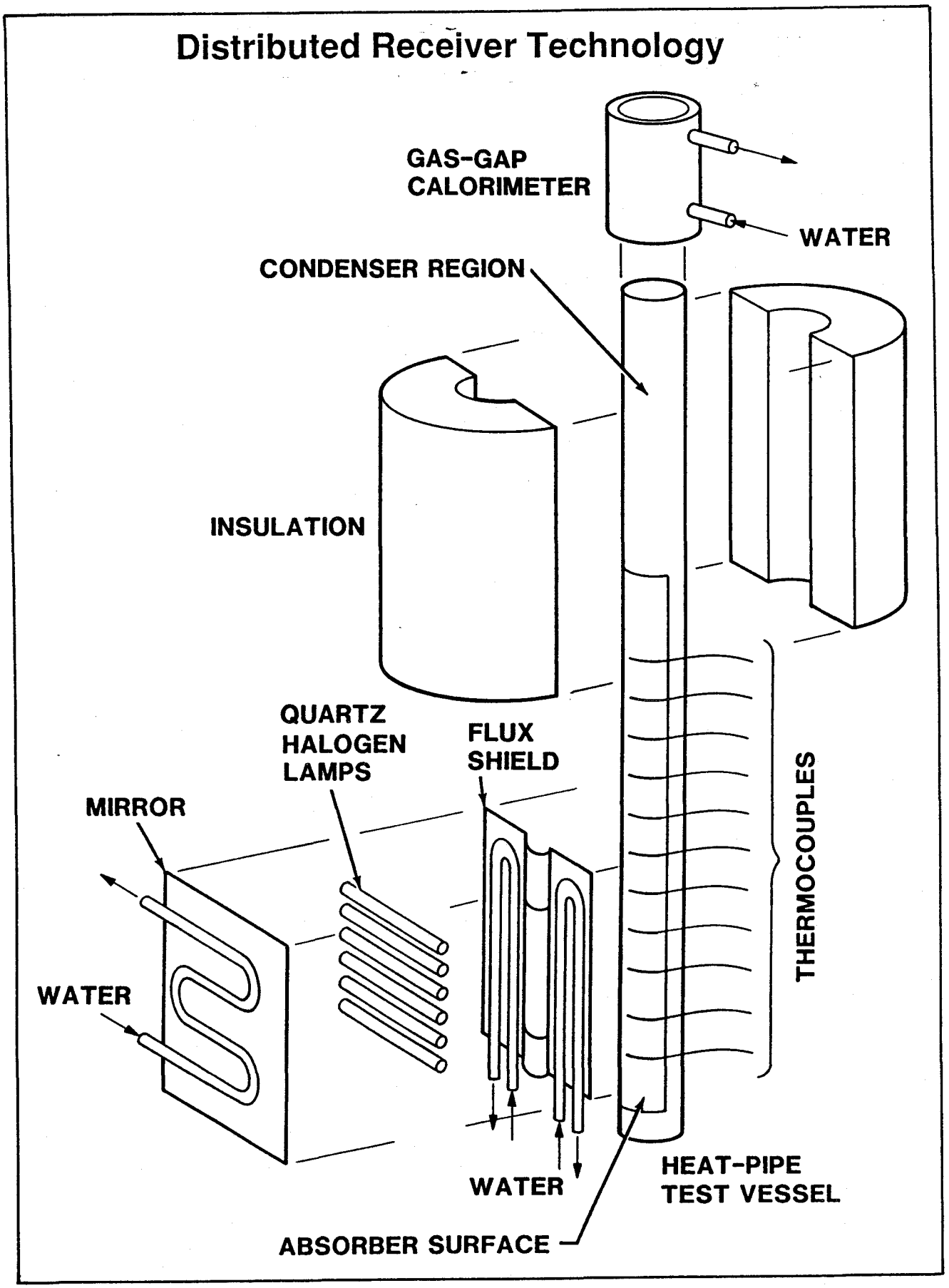

Distributed Receiver Technology
GAS-GAP
CALORIMETER
WATER
CONDENSER REGION
INSULATION
QUARTZ
HALOGEN
LAMPS
FLUX
SHIELD
MIRROR
THERMOCOUPLES
WATER
WATER
HEAT-PIPE
TEST VESSEL
ABSORBER SURFACE

Figure 3.B.1

- **The problem of the hot restart associated with the first reflux pool-boiler receiver using a passive technique was resolved.**

  Over 80 hot restarts were run. Repeatable conditions for failure to resume boiling (the "hot-restart problem") were established. The problem of hot restart was suppressed by the addition of approximately 5 standard cc of xenon to the boiler vapor space.

- **The initial all-day test of the first reflux pool-boiler receiver was completed successfully at the Solar Thermal Test Facility (STTF).**

  The first all-day test was run on a clear day with over 10 hours of continuous operation at a sodium-vapor temperature of 800°C. Daily receiver efficiency was approximately 89 percent, as determined from the total energy input to the receiver and the total energy extracted by the calorimeter.

- **The X-ray cinematography of the reflux pool-boiler receiver was begun.**

  Researchers are using X-ray cinematography to attempt to determine void fraction, adequacy of vapor-flow-passage dimensions, and distribution of nucleation sites in the pool boiler. Fixturing for a view normal to the absorber symmetry axis has been completed, and first images during boiling have been obtained.

- **Candidate materials and improvements in methods were identified for the next-generation reflux pool-boiler receiver; and screening tests were designed.**

  Three candidate materials for the next-generation reflux pool boiler have been identified and ranked with regard to eleven criteria. Improvements also have been identified--including boiler-gas additions and alternatives to electric-discharge-machined artificial nucleation sites. Screening tests for improvements in the materials and methods have been designed; they will use the same bench-scale approach used for the first receiver.

- **A group was organized to study lifetime issues for reflux receivers; a long-term bench-test design was started.**

  An organizational meeting was held to initiate in-depth consideration of issues about reflux-receiver lifetime. This effort will involve solar engineers, stress analysts, and materials specialists in both analysis and testing. One test already in design will use the bench-scale approach to assess the effect of long-term, liquid-metal boiling on the heated surface, as well as the long-term stability of the boiling itself.

- **A study group to compare pool-boiler and heat-pipe receivers was organized.**

  An organizational meeting was held to initiate comparison of the pool-boiler and heat-pipe receivers. A list of attributes and associated weighting factors was drawn up and discussed. It was concluded that the weighting factors require refining. The help of a systems analyst will be sought. A zeroth-order estimate of manufacturing costs has been made and will be critiqued at the next meeting, to be held in early January.

- **A design was initiated for the on-sun pool-boiler for STM engine tests.**

  A preliminary layout design for integrating the STM 4-120 engine to a pool-boiler receiver has begun. The receiver/engine unit requires a new mounting system. A one-

thousand-hour oven test of the 316L materials on-hand has been initiated. The materials will be evaluated for suitability for up to 1000 hours of on-sun testing of the STM engine.

Planned Activities for Next Quarter

- Additional full-day tests to further characterize performance of the reflux pool-boiler receiver will be completed. Researchers will continue X-ray cinematography, and infrared thermography to map the absorber surface temperature will be initiated.

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

- The one-thousand-hour bake of coupons at 800°C will be completed. The coupons are cut from the materials and weldments of a mockup of the first reflux pool-boiler receiver. Baked and unbaked parts will be pull-tested to failure to compare force-displacement characteristics. The information will be used to determine if a backup for the STM receiver will be built from on-hand parts identical to those used in the mockup and first on-sun test.

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

- The bench-test, lamp-array heater will be redesigned to provide longer bulb life, easier bulb replacement, and lower cooling requirements. The lamp array will be used for the screening tests and the long-term bench test. A minimum of 100 hours for bulb life is desired.

TASK C. CONVERSION TECHNOLOGY

Accomplishments

o A review of the final preliminary design of the Advanced Stirling Conversion System (ASCS) was held.

Stirling Technology Company (STC) held the final design review of its Advanced Stirling Conversion System (ASCS) at NASA/Lewis Research Center. STC's design includes a free-piston Stirling engine coupled with a hydraulic pump and conventional hydraulic rotary generator (Figure 3.C.1). Because of the concern for long-life and reliability, STC has proposed the use of NaK liquid metal pool boiler solar receiver. This receiver concept would provide NaK vapor at 700°C to the heater head of the Stirling engine. Based on STC's design the annual electrical output to the utility grid could be 57,100 kWh with a net system efficiency of 29.8 percent. In addition to the system design, STC has been testing, through its subcontractor Thermacore, small bench-scale NaK pool boilers. Thermacore has been successful in demonstrating its pool boiler. Coupled with the idea of a pool boiler comes the issue of the materials at 700°C and in a NaK environment. STC has been conducting life tests of the proposed heater head material, receiver material and certain braze joints. STC will be testing these material samples for up to 10,000 hours. These data should provide required information regarding life and material issues. To support the preliminary design, General Engineering, Inc., and Westinghouse Electric Corporation conducted cost-to-manufacture and FMEA (Failure Modes and Effects Analysis) of their design. The intent of the ASCS is to develop a system which is reliable and can be manufactured. This design review concludes STC's deliverables for this phase of the contract.

Cummins Engine Company (CEC) also held its final preliminary design review of its Advanced Stirling Conversion System (ASCS) at NASA/Lewis Research Center. CEC's design includes a free-piston Stirling engine coupled with a linear alternator and sodium heat pipe solar receiver (Figure 3.C.2). This receiver concept would provide sodium vapor at 700°C to the heater head of the Stirling engine. Based on CECs sub-contractor, Sunpower, the annual electrical output to the utility grid could be 65,953 kWh with a net system efficiency of 34.9 percent. To support its preliminary design, CEC conducted a cost-to-manufacture and FMEA (Failure Modes and Effects Analysis) of its design. The cost projections presented indicated that the CEC design would be approximately double the cost of the DOE goals. This difference will be reviewed by Sandia and NASA. This design review concludes CEC's deliverables for this phase of the contract.

o Testing of the STM4-120 continued at Sandia's Engine Test Facility.

The Stirling Thermal Motors kinematic Stirling engine, STM4-120, achieved an additional 40 hours of power production during the quarter. These additional hours double the amount of power-production time previously recorded. During this period the engine operated at a heater head temperature of 780°C and cycle pressures of 4 MPa (588 psig) and 5 MPa (735 psig). Under these conditions the engine shaft power was measured at 7.0 kW and 9.0 kW, respectively (Figure 3.C.3). The corresponding cycle efficiency for the engine was 31 percent and 34 percent. The efficiency is based on output shaft power relative to energy delivered to the engine's heater heads. The predicted power and efficiency at these cycle pressures are:

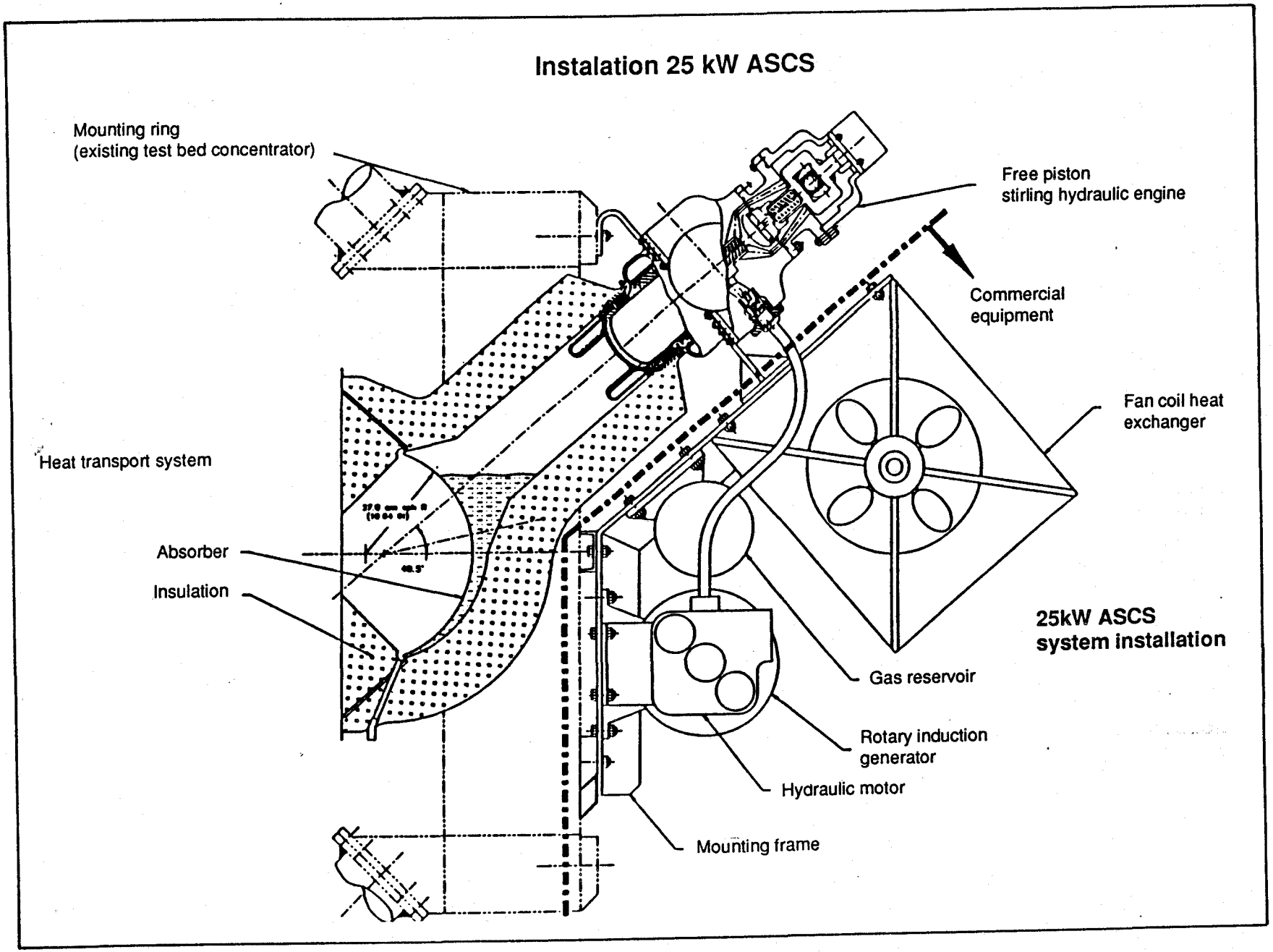

Instalation 25 kW ASCS
Mounting ring
(existing test bed concentrator)
Free piston
stirling hydraulic engine
Commercial
equipment
Fan coil heat
exchanger
Heat transport system
Absorber
Insulation
25kW ASCS
system installation
Gas reservoir
Rotary induction
generator
Hydraulic motor
Mounting frame

Figure 3.C.1

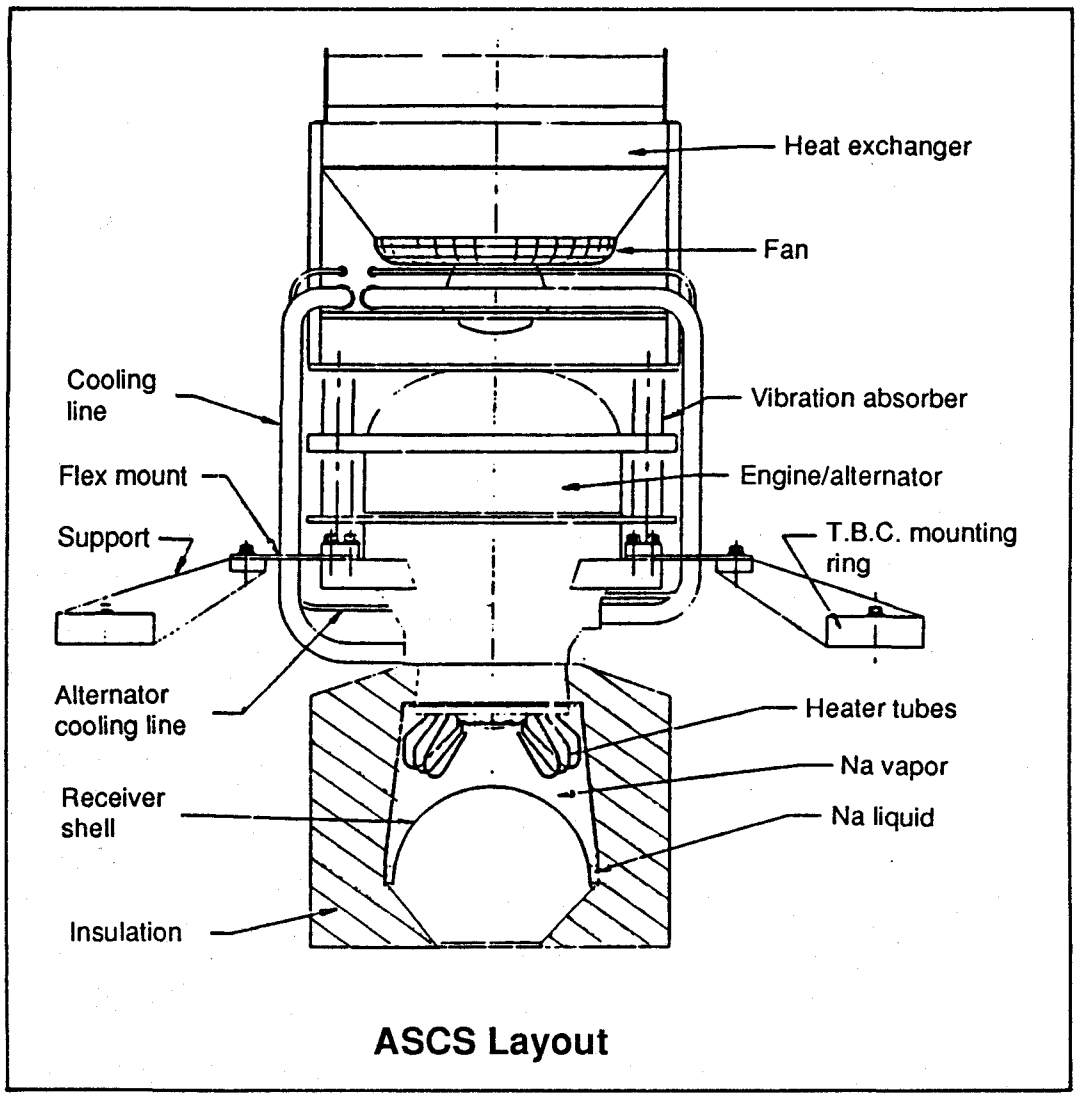
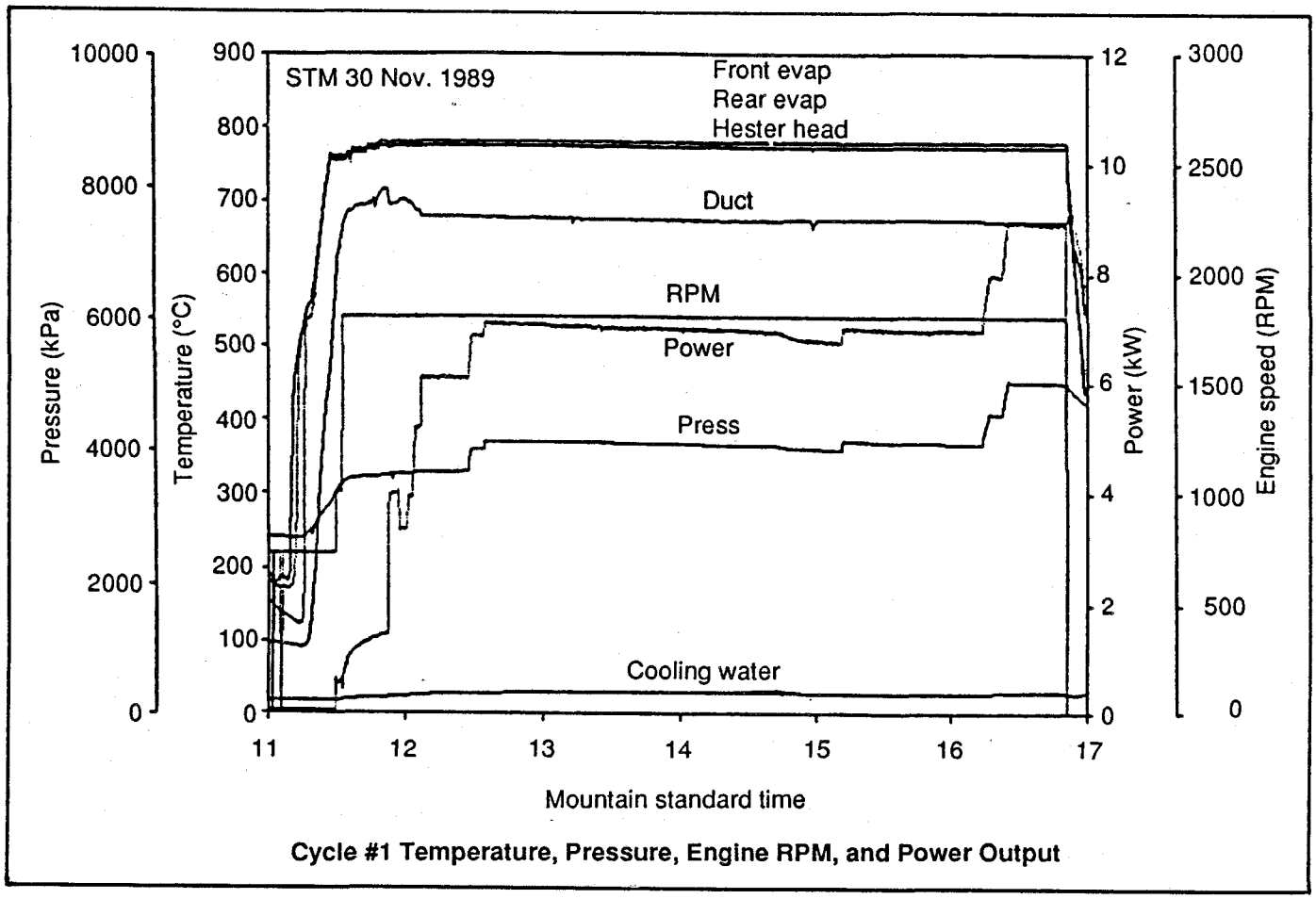

Heat exchanger
Fan
Cooling line
Vibration absorber
Flex mount
Engine/alternator
Support
T.B.C. mounting ring
Alternator cooling line
Heater tubes
Na vapor
Receiver shell
Na liquid
Insulation
ASCS Layout

Figure 3.C.2



Cycle #1 Temperature, Pressure, Engine RPM, and Power Output

Figure 3.C.3

	Predicted		Actual	
Pressure, MPa	4	5	4	5
Power, kW	7.2	9.50	7.0	9.0
Efficiency, Percentage	32.0	34.5	31.0	34.0

The actual performance is in close agreement with the predicted values. This is a good indication that the engine will meet its design point power of 25 kW at an efficiency of 40 percent to 45 percent and a cycle pressure of 12 MPa (1760 psig).

- **SERI and Hughes Aircraft conducted a successful combined regenerator/condenser test.**

A combined regenerator/condenser test at Hughes Aircraft was successful. This was the first test of this subassembly and is an essential step toward the ten-watt, closed-loop for Regenerative Thermoelectrochemical Conversion (RTEC) tests. Previous successful tests performed separately on the regenerator and the condenser led the way for this test. The test consisted of using an acid mixture simulating the depleted acid stream exiting the RTEC cell (mixture 6H) and regenerating it through the regenerator, and using a base mixture simulating that exiting the RTEC cell on the base side. This base stream was combined with the gas stream of H_2O and NH_3 exiting the regenerator in a water-jacket-cooled shell and tube heat exchanger packed with a high surface-area packing. Success of the test was evident when the pressure in the condenser did not rise--indicating complete condensation (recombination). Titration and weight change of the base solution were used to calculate the amount of ammonia and water vapor produced during regeneration.

- **Hughes is continuing RTEC research for automotive applications by using funds from the Office of Transportation Systems.**

SERI has been informed by Hughes Aircraft that the DOE Office of Transportation Systems (Conservation) has entered into a five-year development program for an application of RTEC in a configuration using identical operating temperatures and working fluid to that developed by the joint work of Hughes and SERI for automotive propulsion. Following is an excerpt from Hughes' drafted letter to SERI.

> The advances we have made on the SERI program recently gained the attention of the Department of Energy (DOE) Office of Transportation Systems: they now view thermoelectrochemical technology as a promising approach to electric vehicle propulsion. In a cost-sharing arrangement with Delco Remy Division of General Motors, DOE recently initiated a 5-year program to explore this approach. Work during the first two years will be done at Hughes Aircraft, after which Delco Remy will perform the scale-up and vehicle integration tasks. A key milestone after two years will be a bench-scale model of the system. . .
>
> The conversion efficiency and power density achieved with RTEC are already close to the performance needed for transportation applications. The main challenge facing us in the next two years will be to show that similar performance can be achieved using low-cost membranes and electrode catalysts.

The work supported by the Solar Thermal Program on the joint Hughes-SERI research should see industrial application through the Office of Transportation Systems'

support. Additional research may be necessary to overcome the combined issues of materials and heat transfer associated with regeneration of the RTEC corrosive fluid in an automotive combustor, as well as the recuperation subsystem. SERI researchers are currently discussing these issues with Hughes and are guiding its approach on this new contract.

Planned Activities for Next Quarter

- Operation of the Stirling Thermal Motors' STM4-120 kinematic Stirling engine will continue at Sandia's Engine Test Facility. Monitoring the power, efficiency, and reliability will be the main thrust of the testing program while increasing the engine's cycle pressure.

- After review of the final 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 Advanced Stirling Conversion System. The final design(s) should begin in February and continue through the year.

- Sandia will be negotiating a contract 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. In tandem, CEC will use a similar control system developed under this contract for its commercial kW system.

- Hughes will conduct RTEC closed-loop experiments using the SERI-developed regenerator and a bipolar cell capable of producing 10 W.

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 selected, and contract discussions are underway for Next-Generation User Systems.**

  Four companies submitted proposals in response to a Request for Quotation issued April, 1989, on the request from the Next-Generation Commercial Systems Program for cost-shared improvements in the cost of electricity produced by existing commercial facilities. Technical and cost evaluations of the proposals were conducted during June, 1989. Technical considerations caused one proposer to be rejected, immediately. Upon further review, another proposer, meeting most of the technical requirements, was rejected because that company did not have a solar thermal plant close to the size and type of the one proposed.

  The status of the Next-Generation Commercial Systems Program was reviewed by DOE Headquarters and Sandia's management in early October, 1989. It was decided that Sandia would enter contract discussions with the two proposers in order to establish the areas of common interest, to set the terms and conditions, and to obtain affordable cost proposals. The two potential contractors were notified, late in October, on the portions of their proposals that are of interest to Sandia and the DOE. Both proposers immediately indicated an interest in pursuing the reduced programs. Replies were due by December 15, 1989. One company responded. The other requested a time extension, to early January, 1990. The current respondent, however, does not have all of the other contractual agreements in place, (i.e., a customer for the electricity produced and authorization to purchase the plant from its present owners) so that further discussions are pending successful resolution of these issues. The second potential contractor's response will be evaluated when received.

Planned Activities for Next Quarter

- Planned future activities include completion of contract negotiations for the Next-Generation Commercial Systems. With DOE Headquarters' approval, one or two contracts will be awarded in March, 1990 (Milestone 4A-1). Completion of the R&D plans and initiation of R&D activities are currently scheduled for the third quarter of FY 1990.

Subtask A-3. Design Assistance and CORECT Support

Accomplishments

o Design assistance included a number of activities during the quarter.

SERI and Sandia have continued the planning of the SOLTECH 90 meeting to be held in Austin, Texas, in March, 1990. The solar thermal portion of the meeting will contain four symposia sessions, a set of technical displays, and an exhibit. The symposia will contain 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 will consist of professionally constructed backboards containing pictures and summary information to augment the symposia topics. The display will be placed near the technical meeting rooms. An exhibit booth also will be constructed. This booth will feature some working models of solar thermal systems, and some promotional brochures and handouts.

Sandia staff has continued assisting Cummins Engine Company and its contractors in their effort to demonstrate a free-piston dish Stirling system. Sandia engineers assisted in determining the cause of the leak that developed in the absorber surface during on-sun testing of the dish/Stirling system in Abilene, Texas, in October, 1989. The post-test analysis focused on three major areas: (1) materials, (2) heat pipe design and analysis, and (3) dish-receiver interface. Sandia's X-ray and ultrasonic analysis and Thermacore's metallographic showed no material flaws in the absorber. Sandia also analyzed the wick design and its properties. As a result, some suggestions were forwarded to improve the redundancy of the radial arteries.

Sandia engineers analyzed the LEC 460B concentrator with the Video-Flux-Mapping system and the CIRCE2 model. The analysis suggests that the concentrator may have created a "hot spot" on the receiver that may have caused the absorber failure. Based on this analysis, Cummins has begun to fabricate an improved receiver. Sandia will present a final assessment of the dish-receiver interface and will recommend new techniques for focus and alignment to prevent hot spots. Guidance about how to detect and respond to this problem also will be presented. Sandia will continue its involvement in the project through this year.

Sandia staff members continued to interact with officials of Science Applications International Corporation (SAIC), Camp Pendelton (Marine Base), and Roan Corporation regarding the planned renovation of SOLARPLANT 1. Sandia technical staff has reviewed the proposed changes for the plant as well as the projections for plant performance. Several technical suggestions were forwarded to SAIC. Sandia's participation on the project as a technical advisor is expected to continue through this fiscal year.

During this quarter, Sandia learned that American Energy Technologies (AET) of Green Grove Springs, Florida, has signed a protocol agreement to build nine flat- plate collector factories in the U.S.S.R. The first will be built in Armenia. The goal of the effort is to produce a total of six million square meters of solar collectors per year for ten years. These collectors will produce domestic hot water.

Review of Russian literature also shows that the Soviets are interested in central receivers. They plan to build a 300 MWe central receiver power plant near Ashkabad.

Sandia informed SAIC, SKI, and Bechtel of AET's plans and recommended that they also contact the Soviets about possible joint ventures. One idea Sandia suggested was for the American firms to build the heliostat factories in the U.S.S.R. for the central receiver project. The companies are following this lead.

Industrial Solar Technology and United Solar Technologies are in the process of finalizing an agreement to install a solar-thermal, industrial-process heat system at the California State Women's Prison at Tehachapi, California. The trough system will use the IST troughs and will supply steam and hot water for the prison. The Solar Thermal Design Assistance Center (STDAC) has agreed to assist in designing and installing a performance monitoring system for the new plant. Sandia staff also will be involved with analyzing and reporting results of the system performance. The work is currently in progress and will continue through this year.

Representatives of Mexico's Social Security Institute (IMSS) visited Sandia during the quarter. These individuals are responsible for a program to reduce energy usage in approximately 6,000 hospitals and clinics throughout Mexico. The purpose of the visit was to identify energy conservation and renewable energy technologies that may be applicable to their needs.

The visit included technical discussions about applying low-temperature and medium-temperature solar thermal, stand-alone photovoltaics, commercial wind power, and the basics about building energy conservation. There was much interest in the simplest and most easily applied solar systems such as the BDM trough systems and the PKI dish/steam engine. The Mexicans think that these technologies can be applied cost-effectively throughout Mexico now.

Follow-on discussions have centered on how the Solar Thermal Design Assistance Center (STDAC) can continue to help the Mexican government apply solar thermal technology. The Mexican officials are now assimilating the information that they received on this visit, and they will identify several specific solar thermal projects. At that time, they will request help from the STDAC in planning and executing those projects.

Planned Activities For Next Quarter

- STDAC personnel are preparing to assist in the evaluation of a solar thermal system in American Samoa. This system, which is currently installed at the LBJ Hospital, was designed for building cooling and has not operated for several years. Sandia is planning a trip to the site to inspect the system and to evaluate its performance. The main purpose of the trip is to determine if the system can be modified to supply domestic hot water. If it appears reasonable to convert the system to water heating, Sandia personnel will outline the best methods to bring it into full service. The DOE may supply funds to repair or to upgrade the system. A report of the evaluation and the STDAC recommendations will be complete next quarter.

- The STDAC is preparing a two-fold, color brochure on dish/Stirling technology. The brochure will highlight the potential of Stirling technology and will feature Sandia's Solar Thermal Test Facility, especially the engine test facility. It will be distributed at the SOLTECH meeting and also will be available for distribution to the public as required.

- The STDAC also is preparing a summary document that describes the success of the Solar One power plant. This four-color document will consist of approximately 10 pages and will review the history of the plant, its operational success, the lessons learned, and the future for central receiver technology. It is planned to be completed by the second quarter of FY 1990.

TASK B. PHOTOCHEMICAL SYSTEMS

Subtask B-1. Identification of Application Opportunities

Accomplishments

- **Industry workshops promoted technology transfer.**

  Industry workshops on the solar detoxification processes were held at SERI on October 24 to 25, 1989. These meetings drew about 30 participants, including a strong representation from various industrial groups such as NuTech, Groundwater Technologies, and Veda. The attendees also included a number of potential "users," such as Lawrence Livermore Laboratory and Rocky Flats. The presentations by the laboratories were well received, and the technical questions from the participants indicated that they appreciated the opportunity to gain information on these processes and considered the time well spent. The next workshop is scheduled to be held in March, 1990, as part of the SOLTECH90 program.

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

Accomplishments

- **The Solar Detoxification Test Facility (SDTF) was improved.**

  SERI engineers have designed and begun construction of glass reaction vessels for use at the Test Facility. The two vessels are designed for generating and containing real and simulated waste water. This waste water then can be transferred directly to a holding tank for solar decomposition in the parabolic trough reactor. In order to facilitate in the production handling of large volumes of simulated groundwater, a water deionizer has been included in the design. On-site production of simulated contaminated groundwater will greatly increase the ease and frequency of performing experiments at the test site.

- **Modeling results on a suspended catalyst are available.**

  Preliminary results from measurements on the extinction of ultraviolet radiation by Degussa TiO_2 indicate that nearly all incoming ultraviolet radiation is attenuated within a distance of one to two mm at the optimum catalyst loading of 0.1 wt percent. Due to the large optical thicknesses involved, these data are important when predicting and optimizing the performance of low-temperature aqueous receiver/reactors.

- **Laboratory data have been reanalyzed to improve laboratory test procedures.**

  A major data analysis effort has tied together all of the data collected in SERI's laboratories on Solar Detoxification of water in the past year. The results indicate the importance of several of the process parameters (such as insolation level and the addition of H_2O_2) to increasing process throughput. However, some of the most useful results from this analysis will be reflected in the methodology and techniques used in future experimental work. The results indicate that factors such as the time between the experiment and the solution analysis can have an important effect on the results. Leaks of the highly volatile solvents from the experimental apparatus also factored largely into the results. These conclusions have already had a major positive impact on the redesign of the laboratory apparatus.

- **Polar nephelometer measured the extinction coefficient of catalysts for solar detoxification of water.**

  SERI researchers are using a polar nephelometer to measure the absorption and scattering from a variety of catalyst configurations. The instrument measures scattered radiation as a function of angle through a 180° arc. It will also measure the extinction (scattering plus absorption) coefficient of any particular catalyst configuration. These measurements will be used as input for the radiation calculations in the collector/receiver model.

- **The radiation transport in a collector/reactor has been modeled.**

  A computer model of the radiation transport in a combined collector/reactor system has been developed. The model uses the available insolation and the scattering data collected on the polar nephelometer as input and calculates the distribution of that radiation through a reactor volume. Knowing this distribution of absorbed radiation will allow the calculation of volumetric photochemical reaction rates, and an accurate prediction of the overall system performance. The chemical reaction models have been tested independently in a photoelectric slurry cell, and are currently being added to the larger model.

- **The Ultraviolet Resource Assessment Program has been initiated.**

  A meeting was held between SERI and Sandia researchers to coordinate a campaign of measurement of the near-ultraviolet resource. Data will be collected on a continuous basis in both Golden, Colorado, and Albuquerque, New Mexico, by using instruments that are designed and calibrated to the same standards. Spectral data will be collected by SERI by using a new spectral radiometer that has optics capable of allowing measurements of concentrated ultraviolet light. This will allow direct measurement of not only the direct solar ultraviolet component, but also the effective ultraviolet reflectance of real concentrator systems. All of the data collected will be used to develop and validate atmospheric models being used by the Resource Assessment group at SERI. These models are expected to allow the prediction of near-ultraviolet solar energy from total spectrum measurements and other available atmospheric data.

- **Fixed ceramic supports coated with titanium dioxide are being tested at Sandia.**

  Alumina ceramic frits coated with titanium dioxide, manufactured by HiTech ceramics, are being tested under one sun exposure. The ceramics are being evaluated for use as a fixed catalyst support in the solar photocatalytic detoxification of water process. The titanium dioxide in the samples were fired at three different temperatures: 500°, 750°, and 1000°C to bond the catalyst. Other variables in the bonding process were weight percent of titanium dioxide in the wash coat and the percent of silicon dioxide used as binder. Data indicate that samples fired at 1000°C were deactivated and no reaction occurred. Samples fired at 750°C were also deactivated significantly, having only slight activity. The most successful samples were fired at 500°C. The amount of titanium dioxide in the wash coat did not appear to have a significant effect on the reaction rate. The effect of the bonding agent, silicon dioxide, is being evaluated.

- **Titanium dioxide catalyst enhanced with metal porphyrins was tested.**

  Titanium dioxide samples were enhanced at Sandia with three different metal porphyrins to photosensitize the catalyst--making it possible to absorb and to use a greater portion of the solar spectrum. Three samples were tested: one with a Zn porphyrin ring and two with Sn porphyrins, prepared under different conditions, attached to the titanium dioxide. The three samples were tested concurrently, along with an untreated sample of titanium dioxide, under one-sun exposure. The untreated sample of titanium dioxide yielded the highest reaction rate followed closely by the SnCl2 porphyrin sample. The other two samples, the Zn and Sn porphyrin rings on TiO_2, were less active. A possible reason the untreated TiO_2 yielded the highest reaction rate is that its density is much lower than the other samples and it has smaller particle sizes. Thus, it remained suspended quite easily--resulting in better mass transfer characteristics from the particle surfaces.

- **A potential field test for solar detoxification of water (SDW) was discussed with Lawrence Livermore Laboratory (LLNL).**

  Researchers met with representatives of Lawrence Livermore National Laboratory's (LLNL) Earth Sciences and Environmental Protection Departments to discuss the possibility of installing a field experiment of the SDW process at Livermore. A field experiment would provide valuable experience before the full demonstration for HAZWRAP in 1992. LLNL has in place a system that uses ultraviolet lamps to decontaminate ground water. Discussions centered around the possibility of installing a solar-driven system up-stream from the existing system. By using existing wells, pumps, monitors, controls, and permits, the field experiment could be completed quickly and at relatively low cost. LLNL seemed very interested in working together to further the technology, and it was agreed that the three laboratories (SERI, Sandia, and LLNL) would jointly pursue funding for the field experiment with HAZWRAP. LLNL personnel were also very interested in the high-temperature destruction processes being developed--they have several remediation sites that will produce gaseous waste streams.

- **Work continues on the technology transfer program for solar detoxification of water (SDW).**

  Sandia's Technology Transfer Department proactively seeks out opportunities to support commercially oriented industries in areas critical to solving problems of prime national importance. One aspect of this effort is the Technology Maturation Program (TMP), under which Sandia-developed technologies can further mature to the point where industry will be motivated to undertake the development of a marketable commercial product. The solar photocatalytic detoxification of water program has been selected to participate in Sandia's TMP. The objective of this effort will be to work closely with a partner in industry to develop the confidence required to fully commercialize the SDW technology. This internally funded effort will build directly on, and will closely coordinate with the progress in the Solar Thermal Program, but it will not utilize any funds from the Solar Thermal Program.

Planned Activities for Next Quarter

- The chemical reactions to the SDW system model will be included.

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

- o Side-by-side tests of the catalyst support system will begin.
- o A fixed catalyst system will be installed in the small-scale trough.
- o Tests of LLNL samples in the laboratory and the small-scale trough will occur.
- o Measurements will be made of concentrated near-ultraviolet light by a spectral radiometer.
- o Testing of fixed catalyst supports will continue. Engineering issues of a fixed catalyst support, such as geometric configurations, mass transfer limitations, and pressure losses, will be examined. Testing of trichloroethylene, multiple compounds, and synthetic ground water using Sandia's engineering scale trough system will continue.

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

Accomplishments

- o **Regeneration of activated carbon has been identified as a potential high-flux application.**

  SERI researchers are investigating applications for a process of high-temperature/high-flux solar destruction of hazardous waste. A number of possible applications involve the treatment of dilute chlorinated or nonchlorinated organics in air.

  One application deals with the treatment of exhaust or ventilation air from plants that use chlorinated or nonchlorinated solvents in their processes. In one year over 14 million pounds of organic solvents were released into the atmosphere in California alone. It is anticipated that release of these substances into the atmosphere will soon be restricted so that new technologies for removing them from exhaust air will be required.

  Another application that is being considered is the treatment of exhaust air from an "In Situ Vacuum Extraction Process." This new technology is being developed for the treatment of soils that are contaminated with volatile organics, such as chlorinated solvents or gasoline. This process removes the contaminants from the soil "in situ" without requiring the soil to be transferred to a processing facility. The process generates a stream of air with dilute concentrations of organics which must be removed and destroyed.

  Finally, a third technique uses low frequency radio waves to heat contaminated soil and groundwater to temperatures up to 250°C to drive the organics out as vapors. This process removes volatile as well as nonvolatile contaminants from the soil.

  In order to avoid air emissions, all of these processes currently require some technique such as a carbon adsorption/regeneration process to trap and then destroy the contaminants. In particular, a solar-based carbon regeneration and contaminant destruction process could serve as the final step for these processes. Consequently, an extensive review was performed to obtain literature to determine the economics of current carbon regeneration processes and the potential economics of a solar based process. Future work will focus on carbon regeneration because of its increasing importance in soil and groundwater cleanup efforts.

- **A new sampling and analytical system for SERI field tests is being designed.**

  Field test work was focused on developing a gas sampling and analysis capability at the SERI Solar furnace. Instrumentation that is being considered is based on Fourier Transform Infrared Spectroscopy (FTIR). SERI personnel met with representatives of Nicolet Corporation to determine the best instrument for the field-testing. Considerations include the type of chlorinated organics to be analyzed, their concentrations in the gas stream, and the temperature of the gas as it is sampled. FTIRs have the sensitivity and resolution to analyze complex mixtures of chlorinated organics at elevated temperatures (greater than 100°C). This capability will allow exit gas streams from the reactor to be analyzed directly on site at the time of the test. This method will be a significant improvement over earlier tests where analytical work was done off-site and required several weeks.

- **A new SERI subcontract is being finalized with the University of Dayton Research Institute.**

  A new subcontract with the University of Dayton Research Institute (UDRI) is being finalized. The subcontract will give UDRI additional support in the form of a post-doctoral individual for investigation of fundamental reaction mechanisms relating to high-temperature solar detoxification. A request for proposal for a modification to the existing UDRI research subcontract for additional research was sent to UDRI. SERI and the University of Dayton will be publishing a comprehensive paper on the results of the high-temperature/high-flux field testing program that occurred from June, 1989, to August, 1989.

- **A paper was presented by SERI at the Air and Waste Management Association Conference.**

  SERI personnel presented a paper at the International Specialty Conference that was hosted by the Air and Waste Management Association. The conference entitled "Thermal Treatment of Municipal, Industrial, and Hospital Wastes II" was held in Pittsburgh, Pennsylvania. The paper titled "Innovative Solar Technologies for Detoxification of Hazardous Wastes" included an overview of both the low-temperature water purification and high-temperature/high-flux processes. The talk was well attended with representatives from many private companies, and was well received. Participants raised numerous questions about both processes. This presentation is part of an effort to make members of the private business community aware of the solar-based detoxification technology that is currently being developed.

Planned Activities for Next Quarter

- Plans will be finalized for SERI field testing. Preliminary plans include field tests using a two-stage process in which contaminants vaporized from contaminated soil in the first stage are then destroyed in the second stage. Field tests are planned to investigate a variety of alternative conditions for the basic destruction process. These plans include the use of homogeneous initiators such as chlorine gas or heterogeneous catalysts such as titanium dioxide.

- SERI and the University of Dayton will be publishing a comprehensive paper on the results of the high-temperature/high-flux field testing program that occurred from June, 1988, to August, 1989. This paper will document the rationale for the field testing effort, the development of experimental hardware and procedures, the field test results along with discussion of their significance and implications, and plans for future testing.

TASK C. ADVANCED ELECTRIC TECHNOLOGY

Accomplishments

- **A Request for Information regarding potential program participants was released to the public.**

  In July, 1989, a Request for Information (RFI) regarding potential program participants was released to the public. The RFI requested information about solar thermal technologies that have potential to participate in this joint venture program.

  The Advanced Electric Technology Evaluation Team met during the quarter to discuss the 12 responses to the RFI. The purpose was to formalize the team's conclusions and to outline the request for quotation (RFQ). Prior to the meeting each evaluator completed an evaluation form for each responder. The form asked for qualitative verbal assessment and numeric scores for various categories. After carefully discussing each of the responses and associated scores and comments, the evaluation team formed a set of conclusions. An overview of these conclusions are presented below.

  1. The RFI evaluation process produced evidence that promising solar thermal technologies do exist and that this program can accelerate commercial application to the mid-1990s.

  2. The professionally prepared responses indicate that there is strong support for the Advanced Electric Technology Program. Further, the information contained in the RFI responses will be useful in preparing a higher quality RFQ than would have otherwise been possible.

  3. Many of the responders are experienced in various aspects of developing solar power plants, but none retains comfortable levels of all types of experience necessary to successfully complete the project. Thus, some potential for additional reconfiguration of consortia exists.

  4. Several of the responders discussed new or unique components that were not previously known to those in the Solar Thermal Program. These components will be referred to the appropriate programmatic areas for additional study and/or development.

  5. All of the responders will be debriefed about the results of evaluating the RFI response.

  6. Four of the responses were very credible and were rated substantially above the others. These included Cummins, Science Applications International Corporation (SAIC), Solar Kinetics Incorporated (SKI), and Bechtel. However, only the first three met the criteria (implied budget, schedule, market potential, etc.).

  7. All four of the top responses proposed hybrid (solar/fossil fuel) systems, and each required varying degrees of component development and system integration.

Following evaluation of the responses, the team developed an outline of the contents of the RFQ.

Planned Activities for Next Quarter

- The Request for Quotation (RFQ) will be ready for release possibly by March, 1990. Funding availability will determine the actual release date. The system experiment, which will operate for two or three years, is expected to be installed in 1993. The RFQ will request 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 show case 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.

TECHNOLOGY TRANSFER

Publications Completed in FY 1989

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