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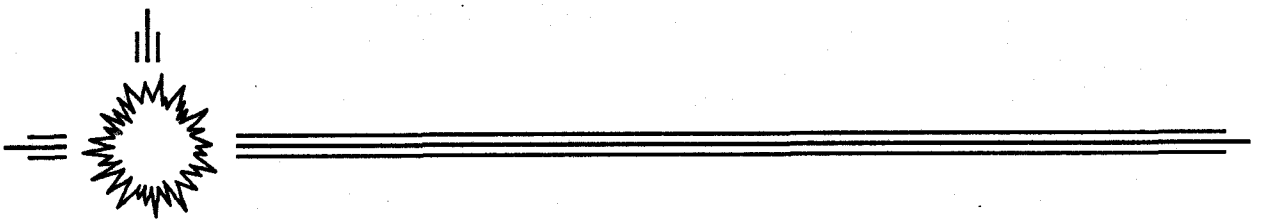

Quarterly Progress Report:

FOURTH QUARTER FISCAL YEAR 1989

DOE SOLAR THERMAL TECHNOLOGY PROGRAM

Submitted By:

Solar Energy Research Institute
Golden, Colorado

Sandia National Laboratories
Albuquerque, New Mexico

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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 has been largely completed by the field laboratories and the DOE Solar Thermal Technology Division, and a new Multi-Year Program Plan (MYPP) was completed. The structure, strategy, and goals of the new program plan are reflected in the FY 1989 Annual Operating Plan (AOP). This document reports progress and status relative 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), has been inaugurated. This reporting differs from past years in which each organization prepared its individual progress reports, and is consistent with the structure and implementating 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 near-term commercialization opportunities (missions) for the technology while maintaining a baseline of research and development (core) which is essential to achieving the long-term technological goals. The program structure consists of three core R&D activities and three mission activities, each having several associated tasks, as shown below.

CORE RESEARCH AND DEVELOPMENT

C1. EXPLORATORY RESEARCH
1. Photon Interaction with Materials and Chemicals
2. New Optical Capability
3. Materials Processing
4. Advanced Concepts and Systems Evaluation

C2. CONCENTRATOR DEVELOPMENT
1. Heliostats
2. Parabolic Dishes
3. Optical Materials and Procedures
4. Structural Analysis

C3. SOLAR-ELECTRIC TECHNOLOGY READINESS
1. Central Receiver Technology
2. Distributed Receiver Technology
3. Conversion Devices

MISSIONS

M1. NEXT-GENERATION USER SYSTEMS
1. Project Development
2. Partner-Driven R&D
3. Design Assistance and CORECT Support

M2. PHOTOCHEMICAL SYSTEMS
1. Identification of Application Opportunities
2. Solar Processing of Dilute Aqueous Chemical Wastes
3. High-Temperature Solar Destruction of Hazardous Wastes

M3. ADVANCED ELECTRIC TECHNOLOGY
1. Technology Identification
2. Joint Venture Consortium
3. Development Requirements
4. System Experiment

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 core research and development activities and the specific missions 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.

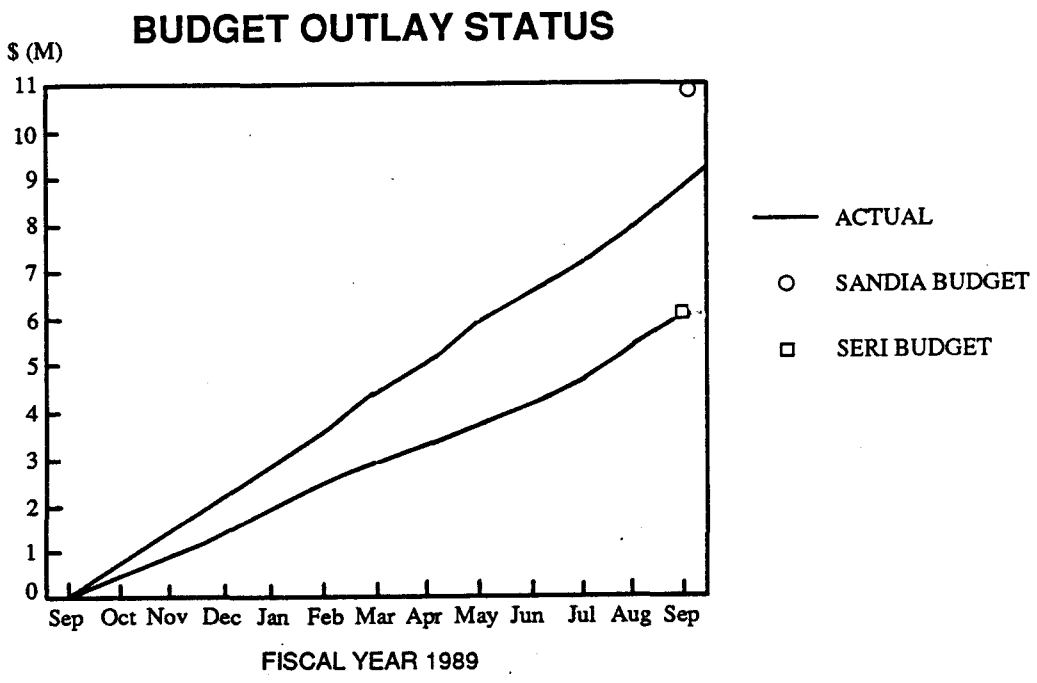
A field Laboratory Management Council (LMC) provides the focus for interaction with the DOE program management and for planning and coordination of the field activities. The LMC is co-chaired by a senior management representative from each laboratory and is composed of the field Activity Leaders and Activity Coordinators.

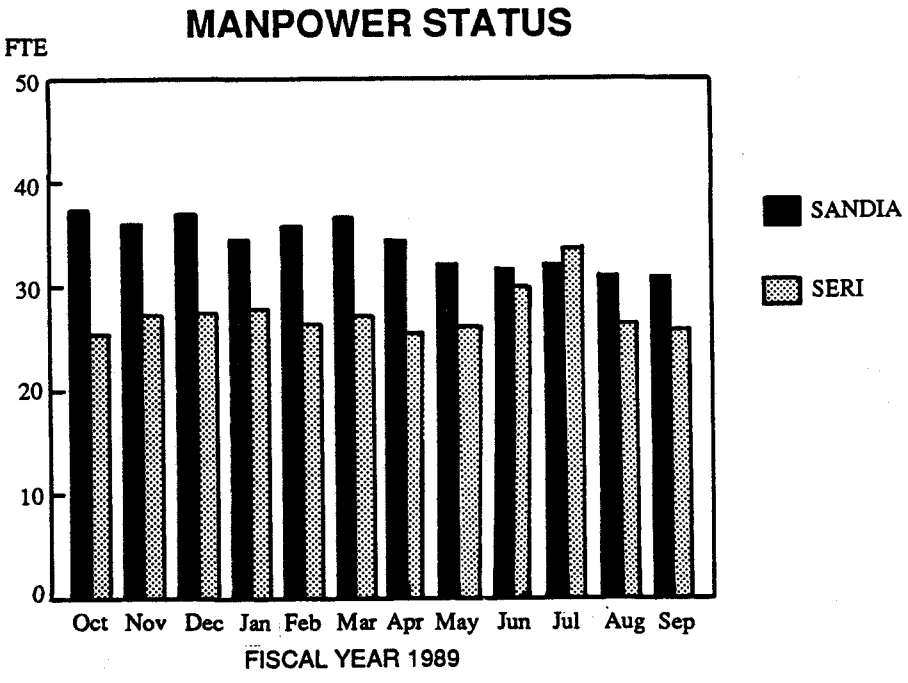
In order to provide a clear delineation of management responsibilities for each program activity, a lead responsibility and a coordination responsibility are assigned by laboratory for each of the six current program activities. In each case, the activity coordination responsibility will reside at the laboratory which does not have the activity leader responsibility. The cognizant laboratory is responsible for designating the specific individual for each function. Field activity management responsibilities for FY 1989 are shown below. The Activity Leaders are responsible for preparing reports on program activity for this Quarterly Progress Report.

FY 1989 PROGRAM ACTIVITY FIELD MANAGEMENT RESPONSIBILITIES

PROGRAM ACTIVITY	LEADER/COORDINATOR (Laboratory)	(Individual)
CORE R&D		
C1. Exploratory Research	SERI/SNL	Blake/Klimas
C2. Concentrator Development	SNL/SERI	Tyner/Carasso
C3. Electric Technology Readiness	SNL/SERI	Klimas/Carasso
MISSIONS		
M1. Next-Generation User Systems	SNL/SERI	Holmes/Gupta
M2. Photochemical Systems	SERI/SNL	Anderson/Tyner
M3. Advanced Electric Technology	SNL/SERI	Klimas/Gupta

Resource Summary





FY 1989 SOLAR THERMAL SUBCONTRACTS
PROCUREMENT PLAN AND STATUS SUMMARY

Task	Specific Contract Subject	Contractor	Lab Contract Number	Present Contract Value ($K)	Prior Year Funds ($K)	Current Year Funds ($K)	Period of Performance	Contract Type	Major Reports	Project Monitor
C1	Evaluation of Solar Flux Application	National Academy of Science	SERI X-19012-01	$278	--	$135	07/89 - 02/91	Other Govt.	TBD	B. Gupta
C1	High Solar Flux Concentration	Univ. of Chicago	SERI X-06019-02	$100	--	$100	10/89 - 10/90	Univ.	TBD	B. Gupta
C1	RFP	Univs.	SERI	$300	$300	--	Open	TBD	TBD	D. Blake
C1	Solar Incineration of Hazardous Waste	Univ. of Dayton	SERI	$150	--	$150	04/89 - 03/90	Univ.	--	G. Glatzmeier
C1	Photochemical Metals Removal from Water	TBD	SERI	$25	$25	--	Open	Univ.	--	D. Blake
C1	Chemical Research	University of Houston	SERI X07028-01	$200	--	$186	04/89 - 03/90	Univ.	Topical Report	G. Nix
C2	Membrane Heliostat Dev.	Solar Kinetics Inc.	SNL33-1227	$704	$512	$192	04/87 - 12/89	Small	SAND89-7028	D. Alpert
C2	Heliostat Integration	Science Applications	SNL05-7867	$169	$144	$25	10/88 - 09/89	Large	TBD	D. Alpert

FY 1989 SOLAR THERMAL SUBCONTRACTS
PROCUREMENT PLAN AND STATUS SUMMARY

Task	Specific Contract Subject	Contractor	Lab Contract Number	Present Contract Value ($K)	Prior Year Funds ($K)	Current Year Funds ($K)	Period of Performance	Contract Type	Major Reports	Project Monitor
C2	Membrane Heliostat	Science Applications	SNL33-1226	$503	$498	$5	04/87 - 08/89	Large	SAND89-7027	D. Alpert
C2	Replaceable Membrane	TBD	SNL42-9690	$50	--	$50	11/89 - 06/90	TBD	TBD	D. Alpert
C2	Heliostat Integration	Solar Kinetics Inc.	SNL42-9691	$100	--	$100	10/89 - 04/90	Small	TBD	D. Alpert
C2	Struct. Eng. Services	WG Associates	SNL33-1510	$145	$120	$25	03/87 - 08/89	Small Bus.	--	C. Cameron
C2/C3	STTF Technician Services	Ewing Technical Design	SNL63-5487	$1,350	$430	$450	04/89 - 04/92	TBD	--	K. Boldt
C2	Collector Support Struc. & Pedestal	TBD	SNL42-9813	$900 (est.)	--	$400	09/89 - 06/91 (est.)	TBD	--	T. Mancini
C2	Faceted Dish Development	TBD	SNL42-9814	$1,200 (est.)	--	$200	09/89 - 06/91 (est.)	TBD	--	T. Mancini
C2	Low-Cost Drive	Peerless-Winsmith	SNL90-5753	$487	--	--	Active	--	--	J. Grossman
C2	Stretched-Membrane Dish Development	Solar Kinetics, Inc.	SNL55-2495	$1,730	$900	$500	04/88 - 12/80	Small Bus.	SAND88-7035	T. Mancini
C2	Solar Collector Pedestal Fabrication	TIW Fab. & Mach.	SNL57-4436	$57	$57	--	12/87 - 12/89	Large Bus.	--	T. Mancini

FY 1989 SOLAR THERMAL SUBCONTRACTS
PROCUREMENT PLAN AND STATUS SUMMARY

Task	Specific Contract Subject	Contractor	Lab Contract Number	Present Contract Value ($K)	Prior Year Funds ($K)	Current Year Funds ($K)	Period of Performance	Contract Type	Major Reports	Project Monitor
C2	Wind Load Reduction Research	Colorado State University	SERIH-6-06034-1	$45	--	$45	06/88 - 12/89	Univ.	--	A. Lewandowski
C3	Reflux Heat-Pipe Receiver	Stirling Thermal Motor	SNL33-3036	$225	$124	$101	04/87 - 2/90	Small	--	R. Diver
C3	Technician Support	Kirk-Mayer	SNL01-9646	$110	$110	0	10/86 - 10/89	Small	--	R. Diver
C3	DAR Panel Module Design	B&W	SNL63-6991	$60.6	$52.6	0	12/87 - 12/88 (Task 1) 01/89 - 09/89 (Task 2)	Large (Cancelled)	--	J. Chavez
C3	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
C3	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
C3	DAR Salt Flow Loop	Advanced Thermal Systems	SNL55-9510	$63.5	$49.0	$14.5	11/87 - 09/89	Small	--	J. Chavez

FY 1989 SOLAR THERMAL SUBCONTRACTS
PROCUREMENT PLAN AND STATUS SUMMARY

Task	Specific Contract Subject	Contractor	Lab Contract Number	Present Contract Value ($K)	Prior Year Funds ($K)	Current Year Funds ($K)	Period of Performance	Contract Type	Major Reports	Project Monitor
C3	PRE Panel/ Manifold	Hufman, Inc.	SNL70-8957	$20	--	$20	10/89	Small	--	J. Chavez
C3	STM4-120	Stirling Thermal Motors	SNL53-8452	$315	--	$15	07/86 - 12/89	Small	--	K. Linker
C3	Solar Receiver	Stirling Thermal Motors	SNL33-3036	$155	--	--	Active	--	--	R. Diver
C3	2ndSTM4-120	Stirling Thermal Motors	SNL75-8851	$366	--	--	04/89 - 06/90	Small	--	K. Linker
C3	ASCS Design	NASA LeRC	DOE Inter-agency	$1200	--	--	01/89 - 01/93	Govt.	--	K. Linker
C3	Technical Programmer	Technadyne	SNL06-5409	$81	--	--	Completed	--	--	M. Fewell
C3	Tech Support Services	Tech Reps	SNL01-2370	$100	--	--	Active	--	--	R. Diver
C3	Technician Support	Kirk-Mayer	SNL01-9646	$85	--	--	Active	--	--	R. Diver
C3	Solar Test Support	EG&G	SNL52-5653	$590	$590	--	07/83 - 11/86	Large Bus.	--	C. Cameron
C3	Solar Test Support	EG&G	SNL05-4912	$150	--	$150	12/88 - 10/93	Large Bus.	--	C. Cameron

FY 1989 SOLAR THERMAL SUBCONTRACTS
PROCUREMENT PLAN AND STATUS SUMMARY

Task	Specific Contract Subject	Contractor	Lab Contract Number	Present Contract Value ($K)	Prior Year Funds ($K)	Current Year Funds ($K)	Period of Performance	Contract Type	Major Reports	Project Monitor
C3	Electrical Support Service	J & S Electric Co., Inc.	SNL75-7415	$120	--	$60	02/89 - 02/92	Serv. Support	--	J. Stomp, Jr.
C3	Engineering Services	Black & Veatch	SNL33-1900	$110	$100	$10	02/87 - 12/89	Large Bus	--	C. Cameron
C3	Solar Receiver Heat Loss Testing	California Polytech	SNL02-5759	$105	$75	$30	09/86 - 09/89	Univ.	ASME and ISES papers	A. Heckes
C3	STEP Test Program	Georgia Power	SNL42-4859	$42	0	$42	06/89 - 10/89	Large	TBD	A. Heckes
M2	Catalyst Development and Reactor Modeling	University of Houston	SNL55-4032	$149	--	--	01/88 - 10/89	--	--	J. Sprung
M2	Chemical Analyses and Analyses System Conceptual Design	Delphi Research, Inc.	SNL75-6779	$50	--	--	10/88 - 09/89	--	--	J. Sprung

FY 1989 SOLAR THERMAL SUBCONTRACTS
PROCUREMENT PLAN AND STATUS SUMMARY

Task	Specific Contract Subject	Contractor	Lab Contract Number	Present Contract Value ($K)	Prior Year Funds ($K)	Current Year Funds ($K)	Period of Performance	Contract Type	Major Reports	Project Monitor
M2	Solar Incineration of Hazardous Waste	University of Dayton	SERI X-06082-1	$140	$56	$191	04/89 - 03/90	Univ.	--	G. Glatzmaier
M2	Chemical Analysis	Multiple		$50	--	$50	Open	TBD	--	J. Anderson

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 and list other significant technical accomplishments in the SIGNIFICANT ACCOMPLISHMENTS SUMMARY.

Date	Activity-Task Reference	Descriptive Title
First Quarter, FY 1989		
October, 1988	C3-1	Complete DAR blackener evaluation.
	M2-2	Working group meeting to define R&D issues and approaches for FY 1989.
	M2-3	Working Group Meeting at SERI to define R&D issues and approaches for FY 1989.
November, 1988	C2-1	SAIC contractor report on the design and prototype fabrication for the improved stainless steel membrane heliostat.
	C3-2	Complete first bench tests of a reflux pool boiler at the STTF.
	M1-1	Prepare and release CBD notice, with proposals due Feb. 15, 1989.
December, 1988	C1-1 (June, 1989)	Initiate contract with National Academy of Sciences (NAS) to assess the role of concentrated solar flux in chemistry and materials treatment.
Second Quarter, FY 1989		
January, 1989	C1-2	Conduct solar pumped laser experiment with very high solar concentrations.
	C2-2	Contractor report on aluminum membrane dish fabrication issues.
	C3-3	Initiate Preliminary Design of FPSE.
February, 1989	C2-4	Define wind load field test program.
	C3-2 (July, 1989)	Complete first bench tests of wicked receivers.

	C3-3	Kickoff meetings held for Advanced Stirling Conversion Systems.
	M2-1 (April, 1989)	Preliminary cost comparison of solar photolytic water detoxification with conventional technologies.
March, 1989	C1-3	Determine if the solar treating of metals and/or ceramics can result in desired properties (e.g., hardness) with reduced reliance on strategic materials.
	C2-1 (July, 1989)	SKI contractor report on the design and prototype fabrication for the improved aluminum membrane heliostat.
	C3-1 (June, 1990)	Initiate pump and valve scale test per formance evaluation.
	C3-3	Demonstration of Stirling Thermal Motors' KSE at ETF.
	M1-3	Participate in the SOLTECH89 joint meeting.
	M2-1 (April, 1989)	Analysis of opportunities for field experiments.

Third Quarter, FY 1989

April, 1989	C2-2 (December, 1989)	Report on evaluation of LaJet innovative dish performance.
	C2-2 (June, 1989)	Decision Point - Start second dish design, prototype fabrication, and test program based on SANDIA/SERI tradeoff studies and DOE budget constraints.
	C2-3	Interim report on polymer film-to-silver adhesion.
	C3-1 (January, 1990)	Initiate six-meter DAR salt flow testing.
	C3-2 (August, 1989)	Complete fabrication and checkout and initiate on-sun testing of the first reflux heat-pipe solar receiver at the STTF.
	C3-3	Negotiate contract for second Stirling Thermal Motors' KSE.
	M1-1 (September, 1989)	Select joint-venture partner for fielding improvements to a commercial solar thermal electric system.

	M2-2 (September, 1989)	Review by external advisory group of analyses and experiments characterizing the effect of solar concentration and other process variables on the mineralization of chemical contaminants. Revision of R&D priorities as necessary.
	M2-3	Complete experiments demonstrating "six nines" destruction of dioxin and decomposition of concentrated solvents to EPA standards.
	M2-3 (September, 1989)	Advisory Group meeting to review results of SERI and Sandia tests and advise regarding future directions for R&D.
May, 1989	C1-1 (March, 1990)	Obtain results from laboratory experiments to explain the role of UV radiation (wavelength) in decomposition of toxic chemicals.
	C1-2 (December, 1989)	Assess merit of scaling up laser experiments and optical concepts for achieving a source of lower wavelength laser beam.
	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.
June, 1989	C2-1 (September, 1989)	SAIC contractor report on the design of a commercial, integrated stainless steel membrane heliostat based on test results for the improved 50 m^2 mirror module.
	C2-4 (July, 1989)	Topical report on structural/optical analysis of membrane dish prototype.
	C3-3 (March, 1989)	25 kWe bench testing Stirling Thermal Motors' KSE at ETF.
	M1-1 (TBD)	Complete contract negotiations and award contract.
	M2-3 (TBD)	Complete CAESAR experiment.
	M3-1	Mission 3 Request for Information released.

Fourth Quarter, FY 1989

July, 1989	C1-4	Establish economic potential of materials treatment with solar compared to other technologies.
	C1-4	Initiate laboratory tests on closed loop 10 W RTEC system.
	C2-3	Define protective overcoat for silvered metal reflectors.
	M1-2 (TBD)	Complete an R&D plan and initiate R&D activities.
	M3-2 (September, 1989)	Begin preparation of RFP for system experiment.
August, 1989	C2-1 (September, 1989)	Initiate contract to build prototype stainless steel integrated heliostat.
	C2-2 (February, 1990)	Deliver seven-meter-diameter aluminum membrane dish optical element for testing at the STTF.
	C2-3 (June, 1990)	Document cost potential of silvered metal structural mirrors.
September, 1989	C1-1	Results of a working microscopic model to explain and predict the performance of TiO_2 catalyst in an aqueous contaminated solution.
	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.
	C2-1 (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.

C2-3	Interim report on corrosion inhibition using altered polymers and metal interlayers.
C2-4 (January, 1990)	Topical report on innovative heliostat drive system performance.
C3-2	Decision on heat pipe versus pool boiler receivers for further development.
M2-1	Preliminary cost comparison of high-temperature solar detoxification with conventional technologies.
M2-2	Completion of the preliminary testing of the pilot-scale experiment. Brief advisory group on the results and implement recommendations toward further experimentation or modification of activity priorities.
M3-1	Several attractive market/technology combinations will be characterized.
M3-3	Initial identification of development requirements for advanced electric technology.

NOTE: Dates that are in parenthesis indicate a rescheduling.

SIGNIFICANT ACCOMPLISHMENTS SUMMARY

MAJOR MILESTONE	PLANNED	ACTUAL
Core 1. Exploratory Research		
o RESULTS OF A WORKING MICROSCOPIC MODEL TO EXPLAIN AND PREDICT THE PERFORMANCE OF TiO_2 CATALYST IN AN AQUEOUS CONTAMINATED SOLUTION (C1-1)	Sept.	Sept.
- This milestone was completed.		
o ESTABLISH ECONOMIC POTENTIAL OF MATERIALS TREATMENT WITH SOLAR COMPARED TO OTHER TECHNOLOGIES (C1-4)	July	July
- This milestone was completed as scheduled.		
o INITIATE LABORATORY TESTS ON CLOSED LOOP 10W RTEC SYSTEM (C1-4)	July	July
- This milestone was completed as scheduled.		
Core 2. Concentrator Development		
o SKI CONTRACTOR REPORT ON THE DESIGN AND PROTOTYPE FABRICATION FOR THE IMPROVED ALUMINUM MEMBRANE HELIOSTAT (C2-1)	March	July
- This milestone was completed.		
o TOPICAL REPORT ON SANDIA'S OPTICAL AND ENVIRONMENTAL EVALUATION OF SAIC AND SKI IMPROVED 50 m^2 MEMBRANE MIRROR MODULES (C2-1)	Sept.	Jan. 1990
- This milestone has been rescheduled.		
o SAIC CONTRACTOR REPORT ON THE DESIGN OF A COMMERCIAL, INTEGRATED STAINLESS STEEL MEMBRANE HELIOSTAT BASED ON TEST RESULTS FOR THE IMPROVED 50 m^2 MIRROR MODULE (C2-1)	June	Sept.
- This milestone was completed as rescheduled.		
o INITIATE CONTRACT TO BUILD PROTOTYPE STAINLESS STEEL INTEGRATED HELIOSTAT (C2-1)	Aug.	Sept.
o 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 (C2-1)	Sept.	April 1990
- This milestone has been rescheduled.		

MAJOR MILESTONE	PLANNED	ACTUAL
o DECISION POINT—BEGIN COMMERCIAL SCALE DESIGN OR REFINE SEVEN-METER OPTICAL ELEMENT DESIGN TO IMPROVE PERFORMANCE (C2-2)	Sept.	Jan. 1990
- This milestone has been rescheduled.		
o REPORT ON EVALUATION OF LAJET INNOVATIVE DISH PERFORMANCE (C2-2)	April	Dec.
- The evaluation was completed; the report is to be available in December, 1989.		
o DELIVER SEVEN-METER-DIAMETER ALUMINUM MEMBRANE DISH OPTICAL ELEMENT FOR TESTING AT THE STTF (C2-2)	Aug.	Feb. 1990
- This milestone has been rescheduled.		
o INTERIM REPORT ON CORROSION INHIBITION USING ALTERED POLYMERS AND METAL INTERLAYERS (C2-3)	Sept.	Sept.
- This milestone was completed as scheduled.		
o DEFINE PROTECTIVE OVERCOAT FOR SILVERED METAL REFLECTORS (C2-3)	July	Sept.
- This milestone was completed.		
o DOCUMENT COST POTENTIAL OF SIVEREDd METAL-STRUCTURAL MIRRORS (C2-3)	Aug.	July 1990
- This milestone has been rescheduled.		
o TOPICAL REPORT ON STRUCTURAL/OPTICAL ANALYSIS OF MEMBRANE DISH PROTOTYPE (C2-4)	June	July
- This milestone was completed as rescheduled.		
o TOPICAL REPORT ON INNOVATIVE HELIOSTAT DRIVE SYSTEM PERFORMANCE (C2-4)	Sept.	Jan. 1990
- This milestone has been rescheduled.		
Core 3. Solar-Electric Technology Readiness		
o COMPLETE FIRST BENCH TESTS OF WICKED RECEIVERS (C3-2)	Feb.	July
- This milestone was completed as rescheduled.		

MAJOR MILESTONE	PLANNED	ACTUAL
o COMPLETE FABRICATION AND CHECKOUT AND INITIATE ON-SUN TESTING OF THE FIRST REFLUX HEAT-PIPE SOLAR RECEIVER AT THE STTF (C3-2)	April	Aug.
- This milestone was completed as rescheduled.		
o DECISION ON HEAT PIPE VS. POOL BOILER RECEIVERS FOR FURTHER DEVELOPMENT (C3-2)	Sept.	May, 1990
- The decision to select either pool-boiler or heat-pipe reflux solar receivers for further development has been postponed until May, 1990. Although there has been a significant amount of progress recently in the advancement of both concepts, more information will be required before this important decision can be responsibly made.		
Mission 1. Next-Generation User Systems		
o SELECT JOINT-VENTURE PARTNER FOR FIELDING IMPROVEMENTS TO A COMMERCIAL SOLAR THERMAL ELECTRIC SYSTEM (M1-1)	April	Oct.
- Four companies responded with proposals to a Request for Quotation (RFQ) issued in April to sixteen potential candidates. Two companies were selected as qualified joint-venture partners for the Next-Generation User Systems Program, and contract discussions were underway during the second quarter.		
o COMPLETE CONTRACT NEGOTIATIONS AND AWARD CONTRACT (M1-1)	June	TBD
- Discussions and clarification began late in September to establish the scope of work and to determine the costs involved.		
o COMPLETE AN R&D PLAN AND INITIATE R&D ACTIVITIES (M1-2)	July	TBD
- This milestone was scheduled for completion in July, but the final date will be determined.		
Mission 2. Photochemical Systems		
o PRELIMINARY COST COMPARISON OF HIGH-TEMPERATURE SOLAR DETOXIFICATION WITH CONVENTIONAL TECHNOLOGIES (M2-1)	Sept.	Sept.
- This milestone was completed as scheduled.		

MAJOR MILESTONE	PLANNED	ACTUAL
o REVIEW BY EXTERNAL ADVISORY GROUP OF ANALYSES AND EXPERIMENTS CHARACTERIZING THE EFFECT OF SOLAR CONCENTRATION AND OTHER PROCESS VARIABLES ON THE MINERALIZATION OF CHEMICAL CONTAMINANTS. REVISION OF R&D PRIORITIES AS NECESSARY (M2-2)	April	Sept.
- This milestone was completed as rescheduled.		
o COMPLETION OF THE PRELIMINARY TESTING OF THE PILOT-SCALE EXPERIMENT. BRIEF ADVISORY GROUP ON THE RESULTS AND IMPLEMENT RECOMMENDATIONS TOWARD FURTHER EXPERIMENTATION OR MODIFICATION OF ACTIVITY PRIORITIES (M2-2)	Sept.	Sept.
- This milestone was completed as scheduled.		
o ADVISORY GROUP MEETING TO REVIEW RESULTS OF SERI AND SANDIA TESTS AND ADVISE REGARDING FUTURE DIRECTIONS FOR R&D (M2-3)	April	Sept.
- This milestone was completed as rescheduled.		
Mission 3. Advanced Electric Technology		
o SEVERAL ATTRACTIVE MARKET/TECHNOLOGY COMBINATIONS WILL BE CHARACTERIZED (M3-1)	Sept.	Sept.
- This milestone was completed as scheduled.		
o BEGIN PREPARATION OF RFP FOR SYSTEM EXPERIMENT (M3-2)	July	Sept.
- This milestone was completed as rescheduled.		
o INITIAL IDENTIFICATION OF DEVELOPMENT REQUIREMENTS FOR ADVANCED ELECTRIC TECHNOLOGY (M3-3)	Sept.	Sept.
- This milestone was completed as scheduled.		

TECHNICAL STATUS REPORT

Core 1. Exploratory Research

Objectives

To establish the scientific base and to understand the phenomena involved in effective use of the unique attributes of concentrated solar energy, to develop and to demonstrate, in cooperation with industry, a capability for the industrial application of materials processing using concentrated solar radiation.

TASK 1. PHOTON INTERACTION WITH MATERIALS AND CHEMICALS

Accomplishments

- **Mechanism for the action of solar irradiated TiO_2 in destruction of organic compounds in water was constructed from laboratory data.**

  A photoelectrochemical slurry cell has been successfully developed at SERI to permit detailed investigations of the photodecomposition of pollutant species at semiconductor photocatalytic particles. This cell also allows for rapid screening of new photocatalysts and for general photocatalytic efficacy as a function of wavelength, pH, temperature, specific pollutant identity, particle size, etc. For photooxidation processes at TiO_2 particles, a mechanism of the chemical kinetics at the particle surface has been successfully established. The analysis is based on the detailed nature of the transient photocurrent response of the slurry cell in the millisecond time regime. The analysis shows that the photooxidation process proceeds through the initial formation of OH-radicals, rather than by direct transfer of positive holes from the TiO_2. The corresponding reduction process involves electron capture by O_2. However, it is shown that the resulting O_2 can react with OH to short-circuit the desired reaction. The addition of H_2O_2 was found to prevent this short-circuit and to produce additional OH which would enhance the rate of photooxidation. This confirms the beneficial effects of H_2O_2 found in other direct laboratory studies of the oxidation kinetics. Figure 1.1.1 shows the block diagram of the slurry cell apparatus and Figure 1.1.2 shows the mechanism which has been proposed to account for the function of TiO_2.

- **Destruction efficiencies for twelve compounds by the steam-reforming process was studied in the molecular beam mass spectrometer system.**

  Experiments were conducted at SERI to test steam reforming as a method of destroying hazardous waste. The catalyst used in these studies was rhodium (0.5%) on a reticulated alumina support. In earlier tests, this catalyst showed deactivation by coking at 700°C, and tests were conducted at 800°C to ascertain if deactivation could be prevented. It was hoped that at this elevated temperature, the coke would be steam-gasified. Twelve compounds were tested and destroyed over the catalyst. They included:

1,1,1-trichloroethane	($C_2H_3Cl_3$)	hexane	(C_6H_{14})
1,1,2-trichloroethane	($C_2H_3Cl_3$)	benzene	(C_6H_6)
trichloroethylene	(C_2HCl_3)	toluene	(C_7H_8)
dichloromethane	(CH_2CL_2)	chlorobenzene	(C_6H_5Cl)
chloroform	($CHCl_3$)	methanol	(CH_3OH)
carbon tetrachloride	(CCl_4)	acetone	(C_3H_6O)

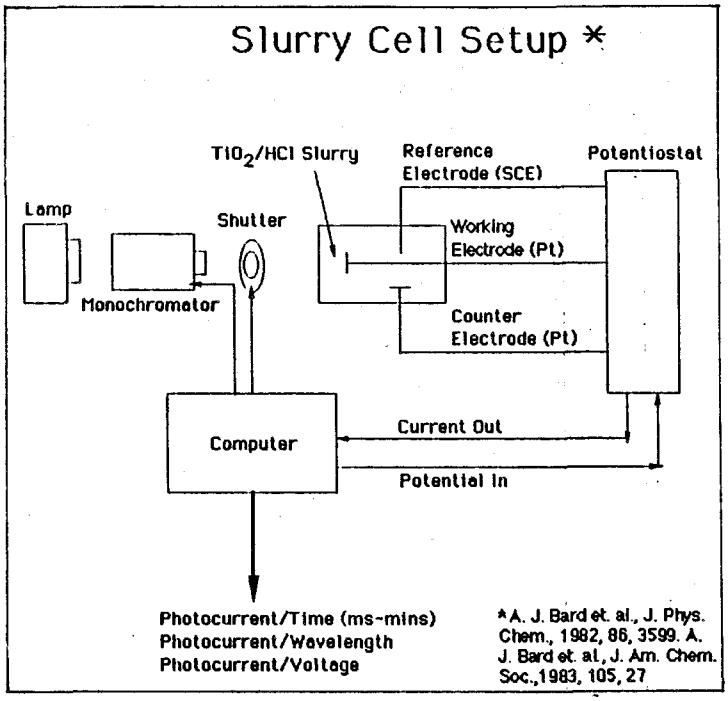


FIGURE 1.1.1.

Mechanistic Aspects of the TiO_2 Slurry Photoresponse

Photoexcitation:

$$TiO_2 \rightarrow TiO_2^* \qquad I_o$$

$$TiO_2^* \rightarrow TiO_2 \quad \text{all forms of relaxation} \qquad k_{-1}$$

$$TiO_2^* \rightarrow TiO_2^- + OH^\cdot \qquad k_r = k'_r[H_2O]$$

$$\Phi = k_r/(k_r + k_{-1})$$

Photoproduct Reactions:

$$TiO_2^- + OH^\cdot \rightarrow TiO_2 + OH^- \qquad k_{rc}$$

$$2\,OH^\cdot \rightarrow H_2O_2 \qquad k_t$$

$$TiO_2^- + H_2O_2 \rightarrow TiO_2 + OH^- + OH^\cdot \qquad k_{tp}$$

$$TiO_2^- + H^+ \rightarrow TiO_2 + 1/2\,H_2 \qquad k_{rh}$$

Reactions At the Working Electrode:

$$TiO_2^- \rightarrow TiO_2 + e^- \qquad k_{et}$$

$$OH^\cdot \rightarrow OH^- + h^+ \qquad k_{ht}$$

$$H_2O_2 \rightarrow 2\,H^+ + O_2 + 2\,e^- \qquad k_{pet}$$

$$J = TiO_2^- \times k_{et} + 2 \times H_2O_2 \times k_{pet} - OH^\cdot \times k_{ht}$$

FIGURE 1.1.2.

Of these compounds, the aromatics seemed to have a lower level of destruction. Using the new GC injection system, researchers were able to introduce these species (at about 1 percent to 2 percent) at a constant rate for about 10 minutes. During that time, researchers saw no evidence of deactivation. In addition, the only products seen were CO, CO_2, HCl, and Cl_2. Figure 1.1.3 shows the destruction efficiency for the compounds. For non-aromatics, the amount of material remaining was below the detection limit as is indicated on the plot. However, at 700°C with 1,1,1-trichloroethane, some dichloroethylene was formed.

During the month of September the high-temperature photoreactor was assembled and tested. Figure 1.1.4 is a schematic representation of this set-up. The output of a 1 kW solar simulator was focused into a 10 cm heated quartz reactor, and products were sampled with the MBMS. The focus of the lamp was not optimum, but enough output was obtained for a preliminary study. In addition, the output of the simulator has not yet been measured.

Preliminary tests using this SERI setup were conducted at low temperatures (where no significant thermal decomposition occurred) with xanthone, 1-chloronaphthalene and hexachlorobenzene in air, as model hazardous waste compounds. Researchers saw enhanced destruction of xanthone and 1-chloronaphthalene with the simulator on, as compared to that with the simulator off. Figure 1.1.5 shows this photoeffect for xanthone. This figure displays the ion intensity in the mass spectra for three species as a function of scan number (each scan = 1.2 second). During this experiment the solar simulator was off initially and was turned on at scan 235. Note the marked decrease in the signal for xanthone (M/Z = 196). Also, note the increase in the signal for M/Z = 180 and 118. These unidentified species are PICs whose production was enhanced by the light. At scan 380, a cut-off filter was placed in the light beam. This filter cuts off all light below 300 nm, and with this filter the simulator probably more accurately approximates solar radiation. With the filter (scan 380 to 450) the destruction of xanthone is scarcely affected. However, the production of PICs seems to be decreased. At 570 the simulator was turned off, and at 690 it was turned on again. The cut-off filter was placed in the beam from 800 to 910. This shows the reproducibility of these results.

Figure 1.1.6 shows the experimental results for 1-chloronaphthalene. The plot of the top of this figure is a plot of the intensity of the 1-chloronaphthalene (M/Z = 162) as a function of time (1 scan = 1.2 seconds). From 300 to 400 the solar simulator was on; while from 400 to 500, it was off. This figure shows a decrease in the 1-chloronaphthalene signal due to photolysis. At the bottom of this figure is a plot of the mass spectrum which is obtained when the signal with the light off is subtracted from the signal with the light on. This spectrum shows species that are produced as a result of photochemistry. As the spectrum shows, the most intense peak is due to CO_2 (M/Z = 44). However, there are a number of other peaks seen in the spectrum which indicate that a number of PICs are produced photochemically under these very mild destruction conditions. Interestingly, the cut-off filter had no pronounced effect upon production of PICs or destruction of 1-chloronaphthalene. At thermal/photolytic conditions where the hazardous waste destruction is significant, it is anticipated, based on Dellinger's results, that ultraviolet might lower the level of PICs.

No photo effect was seen with hexachlorobenzene. This was undoubtedly due to the fact that this molecule is a poor absorber and the light source was not optimized through the reaction cell.

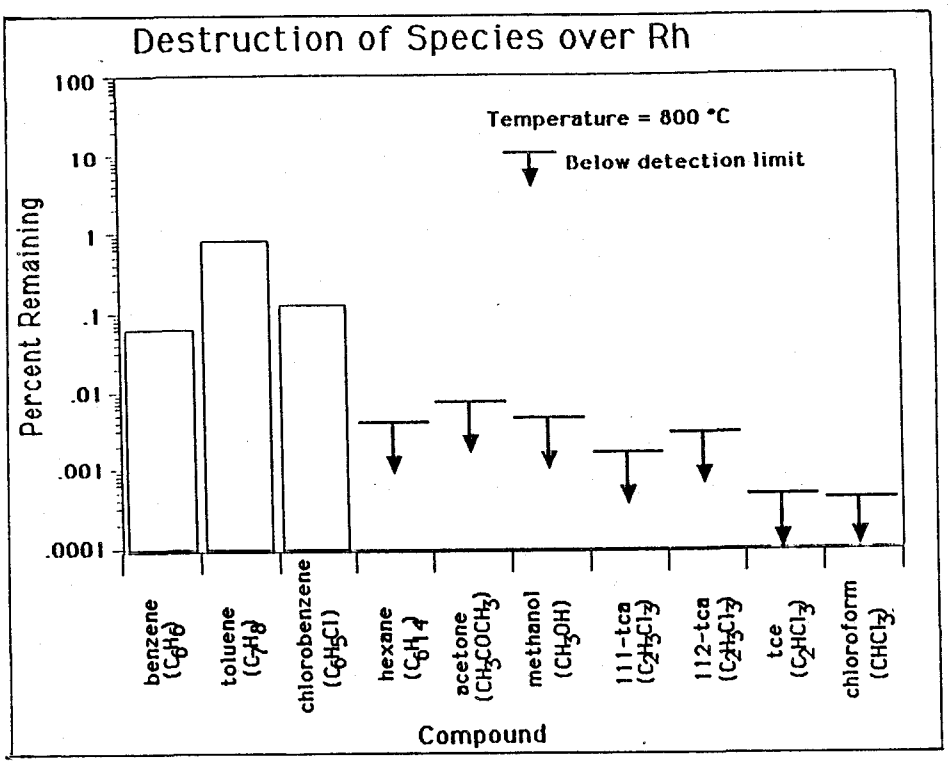


FIGURE 1.1.3.

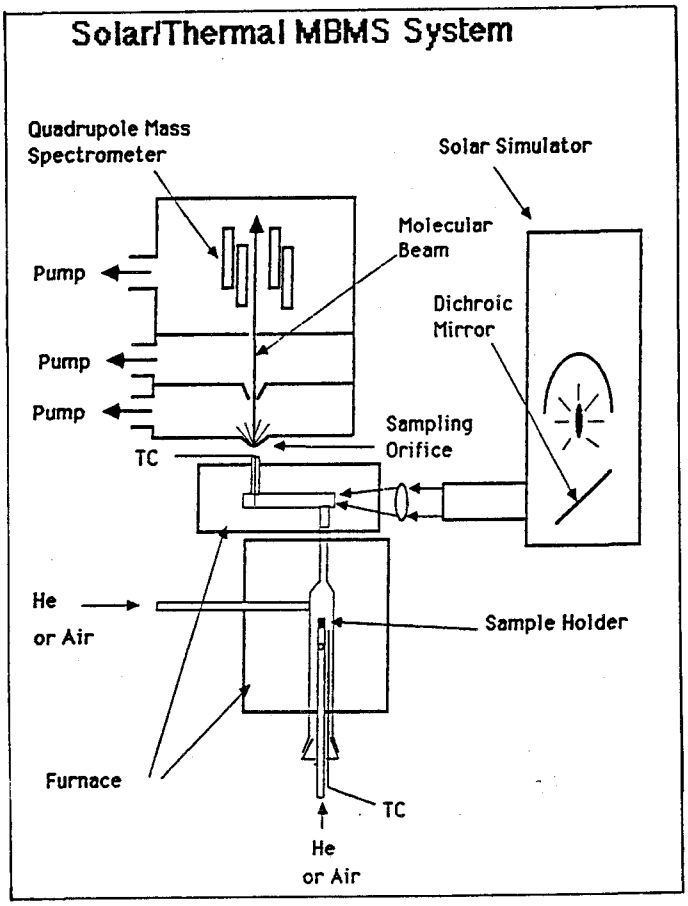


FIGURE 1.1.4.

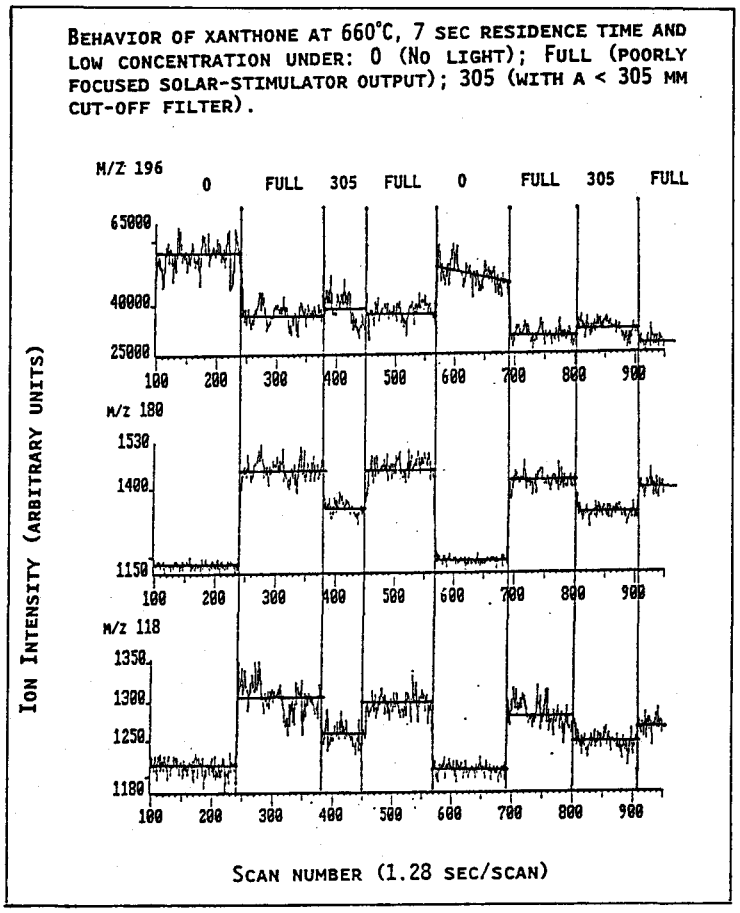


FIGURE 1.1.5.

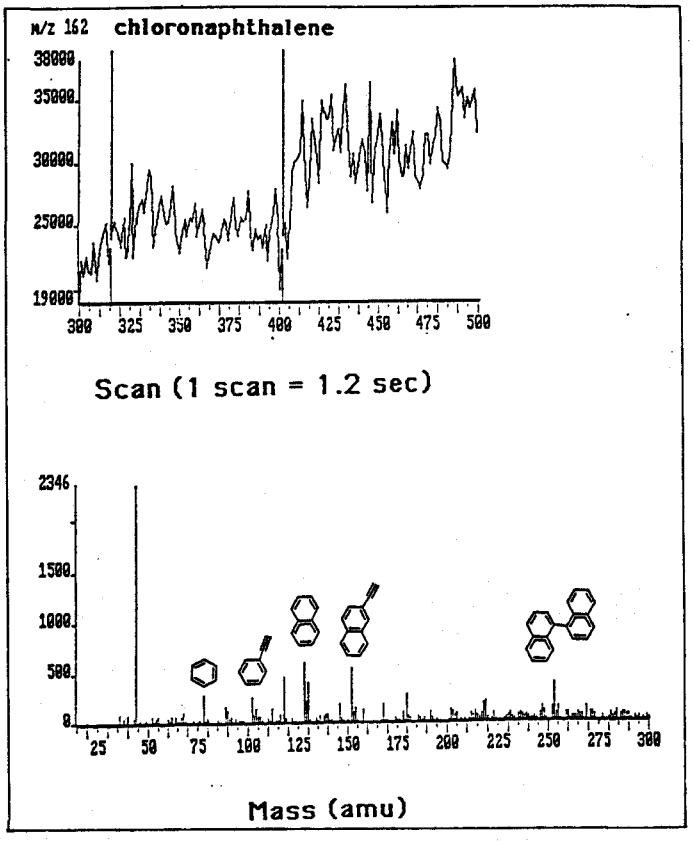


FIGURE 1.1.6

- **Research performed under SERI subcontract at the University of Houston is directed toward definitive experiments to determine the extent of solar enhancements for chemical synthesis reactions and to identify practical applications.**

SERI researchers reviewed the subcontracted research at the University of Houston (UH). The thrust of the UH research is to use direct-concentrated sunlight to drive chemical synthesis reactions. The Houston researchers are emphasizing heterogeneous catalytic reactions of gaseous or vapor species. The rationale is that the portion of the spectrum which is energetically suitable will activate catalytic sites or adsorbed molecules on the surface of the solid catalyst particles. The less energetic portion of the solar spectrum will be absorbed as heat on the surface of the catalyst, to be used as heat to drive the endothermic reactions. Expected solar benefits are higher yields and greater selectivity to desired products.

The UH research is centered about the experimental efforts of Professor W. Wentworth of the Chemistry Department, supported by the research of Professor A. Ignatiev of the Physics Department and Professor W. Prengle of the Chemical Engineering Department. Professor W. Prengle has performed thermodynamic and engineering analyses to guide the experimental research. The chosen system involves the production of cresols and xylenols from feedstocks such as normal hexane, methanol and water; or phenol and methanol. Professor Prengle's assessment shows that, given appropriate solar performance, a solar-based process has the potential to be cost-effective when compared to currently practiced conventional thermal synthesis technology.

Professor Wentworth has conflicting data on solar reaction performance. Earlier experiments with propanol decomposition reactions showed definite solar photenhancements. Experiments with the cresol synthesis have resulted in spurious results, typically with low yield of the desired products. Careful analysis of the experimental apparatus indicates that cold reactor walls exist and may be removing most of the high-boiling products from the effluent stream. This would account for the sporadic appearance of these products in the effluent. The experimental apparatus is being modified to provide adequate heating of the cold walls, after which the experiments will be repeated.

This series of experiments is very important to determine the viability of the concept. The generality of Professor Prengle's analysis implies that a number of systems exist for which solar may have advantage relative to conventional thermal technology. The key is to generate the data to validate the basis of the systems analysis. The experimental effort will be closely scrutinized to ensure a fair and unbiased evaluation of the concept.

- **The contract with the National Academy of Engineering (NAE) was started.**

The SERI contract with NAE began. Under this work the NAE will review the science and application potential of photon interaction with chemicals, paticularly to identify the potential of concentrated solar energy in photochemical application and to recommend the necessary research. A committee will be formed during the next period. Names of potential committee members are being sought from various sources.

Planned Activities for Next Quarter

- Alternative semiconductor catalysts will be identified with the potential for improved performance in a solar system.
- Laboratory testing will begin on new semiconductors and doped TiO_2.
- The new auger ion laser will be installed for use in photo destruction studies.
- The optics on the solar simulator will be improved.
- Screening compounds for solar-enhanced destruction will continue, and products of incomplete reaction will be identified.
- A literature search will be carried out to determine the state of the art in heterogeneous photocatalysts for gas-phase reactions of organic compounds.

TASK 2. NEW OPTICAL CAPABILITY

Accomplishments

- **The subcontract for site development and construction for the High-Flux Solar Furnace is nearing completion.**

  The subcontract for site development and construction with Hughes-Groesch Constructors of Arvada, Colorado, is expected to be complete by October 20. The only remaining activities are the final electrical and mechanical details within the Control Building. Access to the site and within the site has been improved significantly with the completion of asphalt paving.

- **Fabrication of the dish facet and structure for the dish support have been completed for the High-Flux Solar Furnace.**

  Dan-Ka Products, under contract to SERI, has completed the fabrication of the support structure for the dish mirror facets. The structure was shipped to SERI and was set up in the Field Test Laboratory Building to evaluate facet mounting and alignment procedures. The structure has been moved to the site and awaits placement within its protective building.

- **Heliostat structural hardware and software control systems have been developed for the High-Flux Solar Furnace.**

  Dan-Ka Products, under subcontract to SERI, is fabricating modified heliostat reflector panels for the Solar-Furnace heliostat. Modifications are required to accommodate a flat reflector surface rather than the curved mirror panels of the original design. A modified panel arrangement has been designed to allow for almost one-hundred percent fill of the aperture plane with reflector surface. This design negates the possibility of a face-down stow position, but provides for much higher performance of the system. A front-surface, enhanced-aluminum mirror on a ground glass substrate has been obtained from Optical Coating Laboratory Inc. Dan-Ka Products currently is assembling the modified panel structure and is bonding the glass to the structure by using an optically flat table as a fabrication jig.

  Solar Power Engineering Company (SPECO), under subcontract to SERI, has developed a PC-based control system for the heliostat. The control system consists of a software package which provides for all the operational functions necessary for the heliostat, a software-hardware interface board, and positioning/motor controller electronics package. The system was delivered to SERI and was tested in the laboratory by using the heliostat drive mounted on a temporary, short pedestal. Modified, limit-switch brackets were installed, adjusted and tested as well. The heliostat's pedestal and drive unit were installed at the site and successfully were tested by using a manual controller.

- **Design and fabrication of several major furnace components have been initiated.**

  An experiment-positioning system has been purchased from SCANEX, Inc., Boulder, Colorado. This system consists of a modified standard material handler and software control system. Modifications include the addition of a third axis and expansion of the travel range in the two horizontal axes. The software allows for the definition of a number of motion/trigger sequences which can include input and output of digital data from other hardware or software, and the downloading and initiation of the sequences

through an EPROM. Delivery of this system is expected in the first week of December. SERI has built a temporary system for experiment-positioning to allow initial furnace operations to take place prior to arrival and installation of the SCANEX system.

A Basic Order Agreement has been placed with Advanced Thermal Systems, Inc., Englewood, Colorado, to provide design and fabrication of additional components for the furnace. Initial work has begun on the design of an attenuator. A unique design concept has been developed to place the attenuator between the concentrator and the experiment. This results in a significant decrease in size of the hardware when compared with the venetian blind designs at the Sandia and Whites Sands Furnaces. Detailed design of this concept is currently underway with fabrication expected to begin at the end of October.

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

A modification on a subcontract has been placed with the University of Chicago's Solar Energy Group, led by Drs. R. Winston and J. O'Gallagher to provide ray-trace analysis tools for various high-flux secondary concentrators and to fabricate a cooled, CPC reflective secondary for initial high-flux experiments at the furnace. The analytical capabilities will be interfaced with the SERI-developed SOLFUR model, which provides for an explicit analysis of the furnace's configuration.

- **The high-flux optical system is being prepared for a laser-pumping experiment.**

Work at the University of Chicago has focused on the preparation of a new laser pumping experiment with a CrNdGSGG cylindrical laser that is expected to be more efficient in coupling to the solar spectrum. The heliostat used in the high-flux system is being modified to continuously track the sun. Stannous chloride dissolved in ethylene glycol is being investigated as a high-refractive index liquid to optically couple with the secondary concentrators to more closely match the refractive index of the solid secondary. Experiments with the YAG solid secondary have shown that with some secondaries there may be inhomogeneities in the material that result in hot spots, which lead to fracture of the piece.

Planned Activities for Next Quarter

- Site construction is to be completed.
- The dish structure will be installed at the site, and the mirror facets will be mounted and aligned.
- The modified heliostat structure will be installed at the site, and the mirror panels will be aligned.
- The attenuator, shutter and experiment-positioning components will be installed at the test site.
- The data acquisition, control system, and instrumentation also will be installed at the test site.
- Initial safety and operational checks will be conducted on the furnace systems.

- Initial experiments will be conducted in detoxification and materials processing.
- The design and fabrication of the CPC secondary are to be completed at the University of Chicago.
- Development of the solid, high-refractive index secondaries will continue.
- The solar-laser-pumping experiment with the CrNdGSGG cylindrical laser will be conducted.

TASK 3. MATERIALS PROCESSING

Accomplishments

- **Experiments using vanadium and manganese powders, mixed with hard-facing alloy powders, have yielded claddings with improved interfacial properties.**

  Vanadium and manganese powders were obtained, and researchers have learned how to mix these with a NiCr alloy powder and to disperse the mixtures on the surface of steel samples. The samples were processed in high solar fluxes (in the range of 200 W/cm^2 to 220 W/cm^2) at the Sandia Solar Furnace. The additive powders did not interfere with the melting or bonding of the alloy to the substrate. Microhardness measurements showed substantial improvements in the interfacial and coating hardness over experiments using the NiCr alloy without additives. Scanning electron microscopy and energy dispersive X-ray techniques revealed the changes in chemistry in the alloy, at the interface, and in the substrate. The changes account for the improvement in hardness.

- **Exposure of substrates with predeposited plasma-sprayed coatings to high solar flux resulted in reactions of the overlayer and substrate materials to form new alloy phases.**

  A series of experiments was carried out on Fe, Ni, and Ti substrate materials with plasma-sprayed Al on one surface. The coatings were exposed to high solar flux (200 W/cm^2) at the Sandia Solar Furnace. In all cases, as the surface temperature approached the melting point of Al (933 K), reaction of the Al with the substrate material was induced. Various alloy phases were created as a function of exposure time and temperature of the target material. After reaction, the surface coating remained somewhat porous, as was the starting coating material. The samples have been sent to Armco R&D, Middletown, Ohio, for complete evaluation.

- **A meeting with the manufacturer of high intensity arc lamps revealed significant areas of mutual interest.**

  G. Kolb of Sandia arranged a visit to the furnace facility and a meeting with representatives of Vortek, a manufacturer of high-intensity arc lamps. Vortek makes solar simulators with high-pressure arc lamps that operate with electrical input ranging from 50 kW to 300 kW. During the last few years, the company has developed concentrating optics that allow delivery of white light to targets in the range of 0.5 to 3.0 kW/cm^2. Vortek successfully developed rapid thermal annealing for the electronics industry and now is involved in developing some metallurgical applications for lamps. The company presented work on the phase transformation hardening of steel that was most impressive, and confirmed SERI researchers' conclusions that this application is most interesting for fluxes in the range of 1 kW/cm^2. The company seemed most interested in SERI's work involving cladding of materials from powder melt and photon-enhanced chemical vapor deposition. There would appear to be a strong basis for interaction in the future with their researchers.

- **Researchers in industry and government reviewed the economic study comparing solar and non-solar material-processing techniques.**

  Researchers last quarter reported the results of a study that compared the economics of solar and non-solar technologies in material processing. In that study, the cost/performance of treating materials with a solar furnace was compared to similar

treatment with high-intensity electric-arc lamps. The economic results indicated that the solar furnace can perform better than the lamp by as much as a factor of three under certain operating scenarios. In other scenarios, the lamp is more cost-effective. The scenario that appears most promising for the furnace is batch-processing that employs flux levels near 5000 suns or greater.

During the present quarter, a meeting was held to review the technical merit of the study. Individuals from Sandia, SERI, and Vortek Industries (the arc-lamp manufacturer) provided technical comments. Comments were relatively minor and did not change the conclusions of the study.

Market potential for high-intensity white light was discussed with Vortek. Vortek stated that the market for its arc lamps is growing because arc lamps can perform many of the same functions that lasers can and are more cost-effective. The company representatives also stated that most of their arc-lamp customers use the lamp in a batch-processing mode. This latter point, in conjunction with the results of the systems study, suggests that a market may currently exist for materials processing with existing solar furnace technology.

- **Georgia Tech Research Institute (GTRI) redesigned equipment that supports the carbon fiber during the solar-treatment process.**

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.

GTRI is conducting research to improve the oxidation resistance of the reinforcing fibers by treating them within a solar furnace. During the present quarter, GTRI decided to change the design of the equipment that supports the fiber during the treatment process in its solar furnace. In the new design, the fiber will be supported between supply and take-up spools and will be contained within a chamber that protects it from the environment. The spool arrangement will allow GTRI to treat much larger quantities of fiber, and the chamber should prevent fiber breakage and other deleterious effects on the fiber from the environment.

Planned Activities for Next Quarter

- Experiments will be performed at the Solar Furnace in cladding and rapid thermal annealing.
- A task review meeting will be hosted at SERI on November 16 to 17, 1989.
- Results will be presented at the annual symposium of the American Vacuum Society in Boston, Massachusetts, on October 2 to 6, 1989.
- Experimentation will begin on the SERI Solar Furnace with carbon film growth.

- A meeting will be held at SERI to review the status of the surface treatment, carbon fiber, and systems analysis conducted at SERI, GTRI, and Sandia. Several experts from the materials-processing community will be invited.

- Research at GTRI will continue. In particular, the new equipment for handling carbon fiber will be installed at GTRI's furnace, and the possibility of testing the oxidation resistance of the treated fibers to atomic oxygen will be explored.

TASK 4. ADVANCED CONCEPTS AND SYSTEMS EVALUATION

Accomplishments

- **Hughes conducted successful regenerator experiments using the regenerator developed by SERI.**

A number of successful regenerator tests for Regenerative Thermoelectrochemical Conversion (RTEC) have been performed at Hughes Aircraft Company by researchers there. The most promising test has yielded 27 mole % of ammonia, and had a ratio of 2.82 H_2O/NH_3. These results were in good agreement with previous SERI tests under similar conditions. Furthermore, the H_2NH_3 ratio is approaching the ratio required for optimal system efficiency. The viscosity of the regenerated acid was moderately high, but manageable, and was free of particulate matter (which was found in early shakedown tests). The operating conditions were as follows: flow rate: 1 ml/second; furnace temperature: 700°C; fluid pressure: 20 psi. Two mirror leaks developed during this test sequence. Both are in joint seals and should be easily repairable. The regenerator tube is performing without problems of any kind.

These tests are an important prerequisite to accomplish the project objective of demonstrating a 10 W closed-loop operation. The demonstration of technical feasibility of the RTEC concept will take place at Hughes Aircraft Company in El Segundo, California, in March, 1990, and will consist of operating a closed-loop system producing 10 W of electric power.

In the joint effort that constitutes the RTEC Project between SERI and Hughes, the fabrication of a regenerator assembly involving an electric heater has been a responsibility for SERI. That is because in a solar RTEC system, the thermal regeneration of the spent working fluid exiting the RTEC cell will occur in the solar receiver.

The design of a regenerator was a particularly challenging task due primarily to the extreme corrosiveness of the working fluid at the high-regeneration temperatures. A secondary difficulty stemmed from the fact that very little was known about the thermophysical characteristics of the fluid.

A persistent effort by a multidisciplinary team consisting of SERI and Hughes researchers, as well as specialized suppliers, finally resulted in the design and fabrication of a regenerator heater section that has proved successful. It consists of a tubular section made of a special grade of graphite (Stackpole 2300). The internal surface was vitrified by a proprietary process by Vitre-Graf Corporation in Gardena, California, and all surfaces then were coated with a layer of silicon carbide by chemical vapor deposition by Midland Materials Research Corporation, in Midland, Michigan.

A special graphite/metal joint seal was developed by SERI which enabled a leak-tight connection between the "cold-end" of the heater section (below 300°C) and the metallic (Carpenter 20) plumbing to the pump outlet. At the "hot-end" of the regenerator, an all-graphite expansion chamber was fabricated and included a metered expansion valve. This valve enables the heater section to contain the working fluid in its liquid state and controls the adiabatic expansion of the fluid in the expansion chamber. This chamber, in turn, enables the separation of the gaseous phase of the resultant dissociation from the remaining liquid.

Shakedown runs of this assembly, first tested at SERI and then reproduced at Hughes as part of the 10 W closed-loop system, were performed successfully on July 27, 1989, at Hughes. In the facsimile transmission to SERI at the conclusion of this shakedown test Hughes researchers stated: "Results of the shakedown test indicate that the regeneration apparatus functions as desired, and further tests can be conducted without difficulty. The (regeneration) system is, hence, deemed operational."

This accomplishment signifies the overcoming of a major challenge to the technical feasibility of the RTEC concept. As such, it enables the progression to a closed-loop operation of the whole RTEC system and subsequently to further research and development leading to a solar RTEC system.

- **A detailed comparison was completed on three methods for calculating solar absorption in receiver reactors.**

  Researchers completed a detailed comparison of the two-flux, discrete ordinate, and Monte Carlo methods for computing absorption of solar energy in a dish-mounted receiver/reactor absorber. This comparison shows that the two-flux method over-predicts the absorption by about 60 percent near the front of the absorber. The reason for this behavior is that the two-flux method treats the radiation as if it were isotropic while in fact, the input beam from a dish is highly anisotropic (it is confined to a cone of 45° half angle). The discrete ordinate and Monte Carlo methods treat this highly directional radiation in detail and, therefore, yield comparable results. Over-predicting solar absorption near the front of the absorber means that absorber and gas temperatures will be over-predicted significantly and that chemical reaction rates will also be over-predicted significantly. This effect will probably be even more pronounced in photolytic reactors. Results of the comparison showed that for more nearly isotropoic radiation, the two-flux model gave a good comparison with the other two methods and, therefore, can be recommended for predicting infrared transport in the absorber if the geometry of the absorber allows. A paper has been submitted for presentation describing the above results at the Solar Energy Division Conference of the American Society of Mechanical Engineers (ASME) in April, 1990.

- **A code was developed to solve solar absorption, infrared transport, and convective heat transfer in a typical receiver/reactor absorber.**

  Researchers developed a code which utilizes the Monte Carlo method for predicting the local volumetric absorption of solar energy in an absorber, the two-flux method for calculating infrared transport in the absorber, and a convective heat transfer model for predicting heat transfer from the absorber to a gas flowing through the absorber. The Monte Carlo solution of solar absorption is relatively slow but only needs to be calculated once when the geometry and properties of the absorber and the characteristics of the input beam are provided. An iteration is required between the infrared solution and the energy-conservation equation so that the two-flux method can greatly speed up the calculation relative to the use of Monte Carlo method for the infrared solution. Thus, this hybrid model takes advantage of the accuracy of the Monte Carlo method for the solar solution and the speed of the two-flux method for the infrared solution.

- **Researchers have made substantial progress in developing the capability to accurately model parabolic-trough reactor-receivers used in solar water detoxification.**

  Researchers have converted an existing Monte Carlo ray-trace code for application to the line-focusing parabolic geometry used in the outdoor photocatalytic decomposition

experiment. Results from the code, which is called OPTTRF, include the radial and axial flux distribution and angle of incidence along the surface of the receiver/reactor tube. This information is important when attempting to characterize the concentration of ultraviolet radiation on the receiver for comparison to bench-scale experiments being performed at SERI and for use as a boundary condition for models describing the absorption of ultraviolet photons in the receiver volume.

A radiative transfer model has been developed, utilizes the data generated from output of the code OPTTRF, and is capable of predicting the absorption and scattering of ultraviolet radiation within the receiver of parabolic trough receiver/reactor geometry. The model employs a Monte-Carlo ray-trace technique for predicting the distribution of absorbed ultraviolet energy inside the reactor tube. The model will allow researchers to study the effect of receiver and collector geometry, catalyst properties and loading and incident flux on the destruction of toxic wastes in a parabolic trough photodecomposition process.

Researchers also have developed a radiative transport model based on the two-flux method. The purpose of this work is to allow an objective comparison with more detailed codes such as discrete ordinates and Monte Carlo to determine under what conditions the two-flux method will give acceptable results. Presently, the two-flux code is being compared with results published by other users of this method to ensure that it functions correctly. Then, detailed comparisons with the more detailed codes can begin.

An instrument has been identified for measuring the absorption and scattering coefficients as well as scattering phase function for TiO_2 catalyst in suspended or fixed geometries. The apparatus relies on a collimated beam originating from a Xenon arc lamp or He-Ne laser to illuminate a sample. A detector is designed to pivot 180° around the sample in order to measure the intensity of scattered radiation. Use of the instrument will allow future measurement of properties necessary for predicting the radiative characteristics of receiver/reactors in the analytical model.

- **Power Kinetics, Incorporated, is interested in capabilities in radiative transport modeling.**

Power Kinetics, Incorporated (PKI), of Troy, New York, has expressed interest in SERI's capabilities in radiative transport modeling. PKI is developing a receiver/reactor under a DOE SBIR contract which will involve detailed modeling of the receiver. SERI is assisting in the technical monitoring. Progress made at SERI in the last several months on radiative transfer modeling could potentially save PKI much work in model development. With that in mind, SERI researchers are providing technical assistance to PKI by providing detailed descriptions of the Monte Carlo code recently completed and validated by SERI. SERI researchers have compared several methods of radiative transfer modeling. Although these comparisons are continuing, at this time it appears that the Monte Carlo method has the most to offer in terms of ease of use, reliability, and accuracy. PKI plans eventually to validate the code with experimental data, and this activity is consistent with SERI's objectives for activities in receiver/reactor modeling and the program objectives of technology transfer and design assistance to industry.

Planned Activities for Next Quarter

- Planned activities for the next quarter include primarily the assembly and testing of two bipolar cells at Hughes Aircraft Company--both using the DOW Chemical, hydrogen bypass electrode/membranes. An initial bipolar cell having a size of two inches by two inches will be tested, and then one that is six inches by six inches will be tested. Work will continue on assembly of the closed-loop system, and on defining an envelope of feasible operating parameters for the regenerator.

- The existing convection code will be modified so that it will predict the behavior of a simple reacting system. Most likely, steam reforming of methane will be chosen.

Core 2. Concentrator Development

Objectives

To develop cost-effective concentrators in support of the National Solar Thermal Program. The major goal of the Concentrator Development Activity is to establish the commercial readiness of the heliostats and parabolic dishes by FY 1993 and FY 1995, respectively.

TASK 1. HELIOSTATS

Accomplishments

- **The final meeting was held with Science Applications International Corporation on its design for a market-ready stretched-membrane heliostat.**

  Science Applications International Corporation (SAIC) presented its design for a market-ready stretched-membrane heliostat at a final review meeting at Sandia's Central Receiver Test Facility (CRTF) on September 6, 1989. The 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 exiting 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. SAIC has completed detailed design drawings of the heliostat, cost estimates, and two scale models.

- **Science Applications International Corporation completed the draft of a report on the design for market-ready heliostats.**

  Science Applications International Corporation (SAIC) completed a drafted final report on the design of a market-ready stretched-membrane heliostat. This milestone is the final task in SAIC's contract with Sandia to evaluate alternative concepts for supporting a membrane heliostat, and to select a design best suited for near-term commercial markets. SAIC's preferred design uses two 50-m^2 mirror modules on a single pedestal; detailed design drawings and two scale models also were prepared. A contract for the installation of a prototype of the market-ready heliostat (also a milestone for Core 2) is currently under negotiation.

- **Advanced Thermal Systems' 150-m^2 heliostat was reinstalled at the Central Receiver Test Facility**

  Advanced Thermal Systems' large-area heliostat was reinstalled on August 3, 1989. The 150-m^2 glass-mirror heliostat was removed last January when the low-cost drive was damaged by water that accumulated inside the azimuth drive's housing and froze. Four of the heliostat's 20 mirror modules were damaged severely when the drive failed; these were replaced with spare modules. In addition, a small part of the rear structure was replaced. All 20 of the mirror modules were re-aligned to compensate for gravity-induced sagging and to provide optimal performance on an annual basis. Evaluation and testing of both the quality of the reflected beam from the heliostat and of the performance of the low-cost drive will be resumed.

- **The drive from Solar Power Engineering Company's 200-m^2 heliostat was repaired by Hub City.**

  Hub City completed the repair of the drive used on Solar Power Engineering Company's 200-m^2 heliostat. The drive's worm gear was redesigned to increase its strength, and a tougher alloy was used. The repaired drive was shipped to Sandia at the end of September, and it will be retested statically to assure that it meets specifications. After successfully passing the static testing, it will be reinstalled on SPECO's heliostat for operational testing and evaluation of the heliostats optical performance.

- **The third unit of the low-cost drive will be loaned to the Electric Power Research Institute (EPRI) for use on a photovoltaic tracker.**

  So far, only three units of Peerless-Winsmith's low-cost drive have been built. One is currently being used on Advanced Thermal Systems' 150-m^2 heliostat, and one has been loaned to Alpha-Solarco for use on a prototype photovoltaic array tracker in Pahrump, Nevada. Sandia had originally planned to use the third unit for environmental testing. However, researchers have decided for the present to forgo environmental testing in favor of obtaining additional operational experience, and will loan the third unit to EPRI for use on a photovoltaic array tracker that is part of DOE's PVUSA project in Davis, California. The third unit currently, is being repaired by Peerless-Winsmith. Engineers at Peerless-Winsmith suggested that they might be willing to fabricate a few additional prototypes for use in the environmental testing program.

- **Completion of testing of the prototype membrane heliostats has been delayed.**

  A milestone for the completion of testing the two improved stretched-membrane mirror modules has been delayed; researchers now anticipate completing the testing in January, 1990. Three aspects of the planned testing program remain: (1) a demonstration of the cleaning of the silver-acrylic film is required; (2) additional measurements of the reflected beams are needed; and (3) the defocusing systems have not been evaluated.

Planned Activities for Next Quarter

- The drive from Solar Power Engineering Company's 200-m^2 heliostat will be load-tested statically to ensure that it meets specifications. If it passes the test, the drive 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.

- Performance testing of the two prototype stretched-membrane mirror modules will conclude.

- Operational testing of the low-cost drive mounted on a 150-m^2 heliostat will continue.

TASK 2. PARABOLIC DISHES

Accomplishments

- **On-sun testing of the LaJet Innovative Concentrator was completed.**

The LaJet Energy Company's innovative concentrator comprises 94 stretched-membrane facets made with silver polymer film and attached to a light-weight, space-frame structure. The drives are a polar-mounted configuration, tilted at the local latitude angle, to allow for a constant tracking speed in a single axis. Following initial testing of the concentrator, it was determined that the support and drive structures were too soft -- they were redesigned and stiffened by Sandia. The collector has since been aligned on-sun and has been tested at the Sandia Solar Thermal Test Facility.

The first on-sun test of LaJet's innovative concentrator was the measurement of the total power through the receiver aperture made with a cold-water-cavity calorimeter. The calorimeter is designed to operate near ambient temperature--thereby minimizing thermal losses. It was mounted at the focal plane of the dish with an equivalent receiver aperture of 0.5 meters diameter. The first measurements made with the calorimeter showed 95 kW_t removed through the receiver aperture at an insolation level of about 1000 w/m^2. This is about 25 percent less than the 130 kW_t that was expected at this insolation level.

Two reasons for the low power measurement were identified and corrected. First, the silver-polymer facets were very dirty; they were cleaned. Secondly, the alignment of the facets, performed by using a distant-light-source technique, was not very good; the facets were realigned on-sun. After these two conditions were corrected, the total power measured through the receiver aperture was 128 kW_t, corresponding to a collector efficiency of 85 percent, at an insolation of 1000 W/m^2. The maximum power, 133 kW_t, was measured at solar noon on June 24. Total power measurements also were made early in the morning and during windy and cloudy conditions. The time of day did not affect the total power measurement much, but winds greater than about 15 mph did reduce the total power through the receiver aperture.

The flux-density distribution in the receiver plane also was measured by using a video-flux mapping technique. Maps of the flux reflected onto a lambertian target located in the receiver aperture plane were taken for five hours before and after solar noon. A video camera mounted on the dish was used to record the intensity distributions at the receiver plane, and a computer-based video processing system was used to analyze the data. Flux gages, located in the target plane, provide an absolute flux-density calibration for the video maps. Test results show that the flux-density distributions did not vary much for the four hours on either side of solar noon--indicating that there was not a large shifting of the structure during this period. Peak fluxes measured during the flux-mapping tests were about 2800 suns.

The purpose of these tests was to evaluate the optical performance of the LaJet Innovative Concentrator. It was not the intention to evaluate the tracking system or the long-term performance of the dish. It is clear that: (1) the alignment and focus of the facets is very good, much better than initially expected; and (2) the stiffening of the LaJet structure was successful in reducing flux variations over the course of the day.

- **Solar Kinetics' design of a seven-meter-diameter, stretched-membrane optical element was reviewed and evaluated.**

  Solar Kinetics is designing a seven-meter-diameter optical element for testing at Sandia. The design utilizes a fixture to support the ring during fabrication of the membranes; a mechanical attachment between the stainless steel membrane and a carbon steel ring; and a polymer membrane that is initially conical in shape to reduce the stress levels in the laminated film.

  During the months of August and September, two design reviews were held in Dallas, Texas, to evaluate the hardware and the procedures that will be used to fabricate the seven-meter optical element. Current plans are for SKI to fabricate at least one seven-meter optical element at the company's shop during late November. It then will come to Sandia during December to fabricate and to assemble the optical element for testing.

- **The Requests for Quotations to develop a multi-faceted stretched-membrane dish were released in August.**

  Requests for Quotation for the Faceted SM Dish and Pedestal were released in August, and the proposals were received at Sandia during the first week in September. The Technical Review Committee met during the week of September 18. The cost proposals have been evaluated, and recommendations have been made to Sandia's Purchasing organization. Contracts for facet development and facet support structure and pedestal design are currently being negotiated. Awards should be announced during October.

  Researchers are seeking to develop a near-term dish concentrator that builds on the successful stretched-membrane heliostats developed by the Solar Thermal Program. This concentrator will be integrated with an advanced solar receiver and a Stirling engine/generator in a modular 25 kW_e power production unit. The Dish Development Project comprises two phases and is expected to produce a fully integrated faceted concentrator for testing at Sandia's Solar Thermal Test Facility (STTF) in 21 months.

  In Phase 1 of the project, one or more contractors will develop large stretched-membrane facets for optical evaluation at the Solar Energy Research Institute (SERI). Concurrent with the facet development, another contractor, working with the facet contractor(s), will design the facet support structure and the concentrator drive pedestal. The facet support structure and drive pedestal are required to meet specific criteria, such as providing ground-level accessibility to the receiver/engine, inverted or vertical concentrator stow, and low cost. The end of Phase 1 is a major point for project decisions. A technical review will be conducted to evaluate the optical facet designs; facet support structure and pedestal designs; facet focus and control systems; and results of performance and cost analysis performed at Sandia and SERI. Phase 1 is expected to require six months to complete. At the end of Phase 1, a decision will be made on whether or not to proceed with Phase 2 of the project, the final design and fabrication of the solar concentrator.

Planned Activities for Next Quarter

- Contracts will be placed in October for the facet development and the facet support structure and pedestal designs for the Multi-Faceted Stretched-Membrane Dish Development Project.

- In November, Solar Kinetics will demonstrate the fabrication of a seven-meter-diameter, stretched membrane optical element at the company's shop in Dallas, Texas.
- Solar Kinetics will arrive at Sandia during December to start fabrication of the seven-meter-diameter, optical element that will be tested on sun.

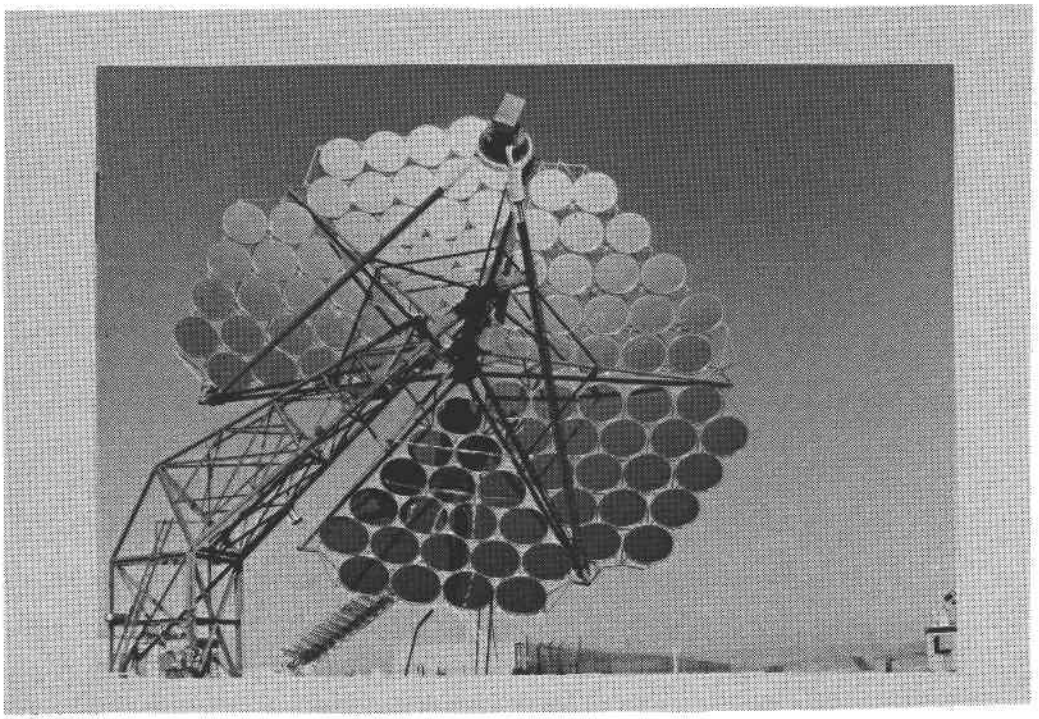


Figure 2.2.1. LaJet innovative concentrator in test

TASK 3. OPTICAL MATERIALS AND PROCESSES

Accomplishments

- **A major improvement in the lifetime of silver polymer mirrors has been achieved with the new ECP-305 material.**

  All accelerated weathering tests with the new production material from the 3M Company under a variety of weather and solar simulation mechanisms indicate radically improved weathering by ECP 305, as compared to ECP 300A.

  While the final test of this new mirror remains for outdoor performance in field installations, researchers think that its performance in simulated, accelerated weathering devices indicates that with this mirror the program degradation targets will be met and perhaps exceeded.

  Continuing accelerated experiments in the Solar Simulator after 700 hours of exposure continue to show ECP-305 is far superior, with a hemispherical reflectance of 80 percent, while the ECP-300A has lost most of its reflectance in the same environment after 300 hours. Moreover, one of the experimental precursors to ECP-305, labelled Type G, is showing a remarkable resistance to degradation--losing less than 5 percent of its initial reflectance during the same period, and in the identical environment. Current degradation research is targeted at continuing experimental exposure of ECP-305 and Type G to accelerated weathering and development of hypotheses about the reasons for this excellent performance. Close coordination between SERI and 3M researchers in this area continues.

- **Work has begun on the problem of delamination.**

  A significant effort will be directed in FY 1990 toward the issue of delamination at the silver-polymer interface. The extent of the delamination problem is hard to quantify; most of the results from the field tend to be anecdotal in nature, and it is difficult to replicate failure modes with laboratory-sized samples. Consequently, very little is known about the tunneling mechanism. Three broad categories are currently being considered for their potential to mitigate delamination effects. These include: improving adhesion via (1) organic and/or (2) inorganic interlayers (treatment of the silver), and (3) prevention of tunnel initiation and propagation by mechanical means.

- **Preliminary evaluation of hardcoats on front-surface silvered mirrors was completed.**

  The motivation for this project is to produce a structural optical element. Unlike glass facets that must be externally supported and provide no load bearing function whatsoever for the structure, a thin glass mirror on sheet steel could serve as a structural element as well as the optical surface. This could result in much simplified, low weight, and lower cost solar concentrators. Since the resulting mirrors are a thin glass, they should demonstrate the lifetimes and desirable characteristics of glass mirrors and also greater flexibility. The first applications of structural mirrors would probably be for stretched-membrane heliostats and faceted stretched-membrane dishes.

  Researchers have completed the preliminary evaluation of the protection afforded by hardcoats on top of front-surface silvered mirrors provided by GM Vacuum of Newport Beach, California, and Denton Vacuum of Cherry Hill, New Jersey. The

mirror "stack" comprises a 5-mil stainless steel substrate, a 3000 Angstrom dielectric/planarizing layer of sol-gel glass over the steel, a silver layer 1500 Angstroms thick applied on top of the sol-gel, and a proprietary protective layer on the silver. GM Vacuum's process involves a single overcoat of Al_2O_3 and results in samples having total hemispherical reflectance values of about 95 percent and 15mr specular values of 93 percent. The Denton Vacuum process involves two protective overcoats--one of which is Al_2O_3. Both of these coating processes meet the performance specifications of MIL-M-13508C for adhesion of the protective overcoat. Initial results have shown that pinholes in the single-layer overcoats do not protect the silver layer. Multiple overcoats should provide protection, however.

In addition to the ability to protect the silver layer, other questions about the structural mirror remain to be answered. Some of the unresolved issues are: the cost of the structural mirrors; the mechanical properties of the sol-gel mirror "stack"; and alternative methods of applying the sol-gel.

- **Structural sol-gel mirror coupons were sent to SERI for evaluation.**

  Samples of the GM Vacuum and Denton Vacuum mirrors were sent to SERI for testing in the Weather-Ometer in May. They are currently being tested, and initial results should be available during October.

- **A cost study was delayed on sol-gel mirrors.**

  A study to establish the relative costs of producing ECP silvered polymer films and front-surface, sol-gel mirrors has been delayed. Since the sol-gel mirror development has been cancelled, researchers recommend that the proposed cost study not be undertaken.

Planned Activities for Next Quarter

- Experiments will begin to test preliminary hypotheses causing the delamination effect. In parallel, weathering experiments on a variety of silver/polymer/adhesive/substrate materials also will continue.

TASK 4. STRUCTURAL ANALYSIS

Accomplishments

- **A comparison on costs for glass and multi-faceted stretched membrane dishes shows good potential for stretched membrane dishes.**

  SERI researchers completed a comparison of the performance and economics of a multi-faceted membrane dish with a glass-metal dish for the generation of electricity with a Stirling engine. Between the two, the faceted membrane dish will have a lower optical efficiency due to the void spaces between facets, the fact that the facet surfaces do not coincide with a parabolic surface, and the difference in optical characteristics of the glass-metal and membrane/film reflectors. However, the analysis shows that the membrane dish can produce energy for the same cost as a state-of-the-art glass-metal dish patterned after the MacDac dish, if the cost per unit area of the faceted dish concentrator is no more than 88 percent of the cost of the MacDac concentrator, or only $\$185/m^2$. (As defined here, the concentrator cost includes the cost of facets, support structure, drive, pedestal, installation, and, if necessary, the present value of film replacement costs. It excludes the receiver, engine, and balance of system costs.) Although the design and cost of a membrane dish are the subject of current study, this break-even cost is potentially achievable. This potential recommends continued research and development on the membrane dish concept for electric power generation.

- **Several enhancements were made to the stretched-membrane, faceted-dish computer codes.**

  A computer program which processes data generated by the dish concentrator ray trace programs OPTDSH and ODMF was developed to provide tabulated information on the directional distribution of radiative intensity in the receiver target plane. This type of information is required for modeling receivers and reactors. This initial research marks the beginning of a larger effort aimed at establishing continuity between concentrator optics and receiver/reactor performance.

  SERI researchers have developed a modified version of the dish concentrator optical analysis code OPTDSH which can model off-axis elliptical sections of paraboloidal surfaces of revolution. The light source for ray tracing has been changed to be a point source at an arbitrary user-specified location. In addition, the target plane location and orientation have been made completely arbitrary as well. This new tool is necessary for designing instruments like the SHOT (Scanning Hartmann Optical Test) for more complex, off-axis, concentrator geometries. This modified version is currently being tested.

- **Much interest has been expressed by industrial users of SERI's codes ODMF and OPTDSH.**

  In response to a request, the multi-faceted dish ray trace code ODMF has been supplied to Science Applications International (SAIC). The company is interested in using the code in research and development on multi-faceted dishes. In the process, a first-draft documentation for the code was completed and provided along with the program.

Interest has been expressed to SERI also by L'Garde, which is interested in off-axis inflatable optical elements and Rockwell International for the Solar Dynamic NASA space station.

- **SHOT capability to measure optical performance of stretched membrane optical elements was extended.**

  SERI is preparing for the optical testing of small dishes with shorter focal lengths expected to be used in Mission 3. To accomplish this a modification to SHOT to allow testing of dishes with f/Ds in the range of 1.0 to 3.0 is now complete. The Beam Scanning System (BSS) was redesigned to enable testing of dishes with f/D ratios in this range. Testing of the new configuration of the instrument is now in progress. Also being explored are concepts for testing off-axis optical elements of various configurations. Work will begin to adapt existing structural analysis codes for the analysis of faceted dish support structures. The structural analysis of the support structure is essential for estimating optical and thermal efficiency of faceted dishes. In addition, work will continue to enhance ODMF and OPTDSH code capability.

- **Wind-load, field-test program preparations were completed.**

  Installation of the equipment was completed and calibration tests have been successfully performed. Strains during low level winds (15 mph average) have been measured. A data base of no-wind-strain levels has been developed for null offsets.

Planned Activities for Next Quarter

- Data from the test performed will be examined by Sandia and Cermak Peterka Petersen, Inc. The analysis will help determine the adequacy of the system and possible modifications, if required, to the system for improved performance.

- Work will begin to adapt existing structural analysis codes for the analysis of faceted dish support structures. The structural analysis of this support structure is essential to the estimation of faceted dish optical and thermal efficiency. In addition, work will continue to enhance ODMF and OPTDSH code capability.

Core 3. Solar-Electric Technology Readiness

Objectives

To continue the thrust of the Solar Thermal Program to develop the components and systems required to establish technical readiness of electric power production applications for solar thermal central receiver and distributed receiver systems. Technical readiness is defined as the development of near-optimal performance in components and systems that also feature designs that are amenable to low-cost production at medium-to-high volume. The goal of the development activities in this Core is to achieve technical readiness and to be economically cost competitive in major domestic markets by the late 1990s.

TASK 1. CENTRAL RECEIVER TECHNOLOGY

Accomplishments

- **Fabrication of all components for the $3MW_t$ Panel Research Experiment was completed.**

  The fabrication of all the components was completed for the Panel Research Experiment (PRE) (i.e., the frame, panel, and manifolds). The PRE is an experiment for the $3MW_t$ Direct Absorption Receiver (DAR) that has been designed, has been built, and is being assembled at the Central Receiver Test Facility (CRTF). The PRE will allow flow testing with water and molten nitrate salt and will provide a test bed for DAR testing with actual solar heating.

  The basic PRE structure was completed last year. The piping installation, except for the inlet and outlet manifold, is complete. Installation of heat trace on the piping and heat exchanger is 90 percent complete. The tilt mechanism on the PRE structure also was tested this quarter. The frame structure, including air cylinders and insulation, has been assembled. The PRE absorber panel is at the CRTF and is currently being instrumented with over 60 thermocouples.

  After the panel instrumentation has been installed, the panel will be laid in the frame and will be attached to the air cylinders. Once the panel-frame assembly has been completed, the manifolds and shim-stock edge pieces will be attached. Then the whole panel-frame assembly will be mounted on the base structure.

  A drafted plan for the water flow, salt flow, and solar testing of the PRE has been prepared. Researchers plan on initiating water flow at the base of the tower in November, 1989. The test will start with a panel tilt of 5°.

- **Testing of the intermediate manifold was completed.**

  Testing of fluid flow for the Direct Absorption Receiver at both Sandia and SERI have shown that there is a potential for fluid loss-ejection for the falling fluid film after approximately four meters down the panel. The intermediate manifold (i.e., a collection-inlet distribution manifold) placed at four-meters down the panel was determined to be the most immediate feasible method of controlling the fluid loss. Consequently, researchers have been designing, building, and evaluating intermediate manifold designs during the last quarter.

A number of actively cooled (using the salt to cool the inlet manifold) and passively cooled intermediate manifold designs were tested. Both designs effectively collect and redistribute the fluid as demonstrated in the water flow testing. In addition, the test results and evaluations showed that, although the actively cooled manifold is feasible, it is very complicated and can affect the turn-down ratio of the Direct Absorption Receiver. The passively cooled manifold can be made simple and compact. However, researchers have not yet demonstrated the amount of flux that the passively cooled design can handle, nor the effect of the temperature and flux gradients. Designs of both the actively cooled and passively cooled intermediate manifold will be fabricated and tested (as needed) on the panel research experiment.

- **Thermocapillary breakdown measurements of the Direct Absorption Receiver are planned.**

  Thermocapillary breakdown is still a concern on the Direct Absorption Receiver. Testing has been conducted with water-flow tests. However, in order to accomplish the measurement of thermocapillary breakdown with molten salt in the most efficient manner, the existing test loop of the Direct Contact Heat Exchange at SERI is being modified. The modification involves installation of a heater rod (a vertical pipe with an internal heater). A molten salt film will be distributed on the outside surface of the heater rod, and sufficient power will be applied to cause the film to break down.

  Modifications to the test loop of the Direct Contract Heat Exchange have been delayed due to problems with production of the heater rods. These modifications will allow measurement of thermocapillary breakdown in a falling molten salt film. Two of the rods were received in September. Salt-flow-meter calibration has been completed.

- **A report on SERI's 1988 research on the Direct Absorption Receiver is in final review.**

  A report describing SERI's research on the Direct Absorption Receiver concept during 1988 (Direct Absorption Receiver -- Final Technical Report, SERI/TR-253-3438) has now received external peer review. The reviewers' comments have been incorporated into the report, and a final version, ready for publication, is under managerial review.

- **Cocurrent air-flow tests on the five-meter long water film apparatus have been completed.**

  Fluid flow testing of the Direct Absorption Receiver at both Sandia and SERI have shown that there is a potential for fluid loss/ejection for the falling fluid film after approximately four-meters down the panel. The objective of these tests was to determine if the shear induced by a co-current air flow near a falling liquid film could delay the growth of waves on the liquid film and ejection of liquid droplets from the film. These tests were identified at the review meeting on Direct Absorption Receivers last April. Two tests of the air-curtain experiment were completed. An air manifold was installed at the top of the five-meter-long water film apparatus. The manifold generated an air curtain around the periphery of the 75mm pipe for the two tests. The water film Reynolds number was approximately 30,000, and the air jet velocity was approximately 16m/s. Even with this relatively low air velocity, the jet seemed to greatly agitate the water film in the region close to the manifold and to tear significant quantities of water from the film. Based on these results, researchers have recommended no further work on this idea. However, it is still possible that an air current could be used further from the liquid film to contain droplets ejected from the film or to act as an aerodynamic curtain for a cavity receiver opening.

- **A system study of a quad-panel cavity Direct Absorption Receiver was performed.**

  Before commercial-scale designs of Direct Absorption Receivers can be realized, a method for controlling droplet ejection from the panel must be developed. In addition to testing, during the present quarter, researchers developed a conceptual design which has the potential to control these droplets.

  One concept that appears to be feasible is a receiver composed of four separate flat panels that are tilted back 5 to 10 degrees and are contained within a shallow cavity. The heliostats surround the receiver-tower, and each 90° sector is aimed at the facing receiver panel which is also spaced 90° apart. Wind spoilers protrude near the edges of each of the four panels and wind curtains are located within the spoiler structures. The wind curtains blow ambient air transverse to the direction of the salt flow. The spoiler structure is insulated to prevent solar-flux spillage from damaging it.

  Researchers studied the cost and performance of the quad-panel Direct Absorption Receiver power plant and then compared these results to a cylindrical Direct Absorption Receiver of the same size. This was done to determine if the quad approach could achieve the same LEC as the cylinder. The DELSOL3 code was used to size the Direct Absorption Receiver systems and the SOLERGY code was used to analyze annual performance. Researchers selected a commercial-sized plant with a receiver rated at 470 MW_t, a 200 MW_e turbine, and a solar multiple of 1.8. Selection of this size allowed use of much of the subsystem cost information presented in a recent utility study which investigated a salt-in-tube plant of the same size.

  The cost and performance of a quad-panel Direct Absorption Receiver is predicted to be similar to the cylindrical Direct Absorption Receiver concept. Disadvantages of the quad-panel concept due to lower receiver and field efficiencies are compensated by an improvement in receiver availability (i.e., the availability of the quad is higher because the receiver can operate with one of the panels down for maintenance; this is not possible with the cylindrical concept). The quad concept, therefore, should retain the same reduction, 15 percent to 20 percent, in LEC over the salt-in-tube receiver that was originally predicted for the cylindrical Direct Absorption Receiver. Experiments are needed to improve the understanding of wind spoiler and wind curtain performance as well as inlet manifold design and panel tensioning techniques. Some of these items will be addressed by the PRE. If results of these experiments are successful, the feasibility of a commercial-scale Direct Absorption Receiver design can be demonstrated.

- **Planning for the comparative study on the salt-air receiver was begun.**

  During this quarter, DOE and the European solar community proposed a new Small Solar Power Systems (SSPS) subtask (part of Task III) to perform a comparative study to evaluate the cost, performance, and maturity of central receiver technologies. This study would be a collaborative U.S. and European effort. Of primary interest is a comparison between systems that use molten-nitrate salt and those that use atmospheric air as the working fluid. This study will help chart the course of future technical development. An initial study outline and schedule were developed and submitted to the SSPS members for comment.

- **Researchers have completed 2400 hours of operation on the hot loop of the molten salt pump and valve.**

  The hot loop of the molten salt pump and valve has operated for 2400 hours. 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-MW_e 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 hot loop has been operating in automatic mode since January, 1989. The cantilevered pump that is used in the hot loop has been operating without problems. However, after achieving the milestone of 2400 hours of operation, the pump developed a vibration. The pump was pulled for inspection (this is a major task), and it was found that the lower wear ring was completely worn and that the shaft had a deflection of 0.060 inches. Researchers suspect that the shaft was stress-relieved. The pump and motor have experienced the equivalent of two years of start-ups.

  A new packing material, Inconel wire-reinforced braided jacket over an extended case used in conjunction with teflon washers, has proven thus far to be a suitable packing material. This packing material has been used for over 1500 hours as packing in a bellows valve (which had leaked) and for over 500 hours of operation in a control valve. This packing material will not blow out, and small leaks can be eliminated by tightening down the package. An interim report has been drafted on the operation, experiences, and lessons learned from the pump and valve loop.

- **The motor on the cold loop of the Molten Salt Pump and Valve Test is not operational.**

  As a result of manufacturing problems, researchers have accumulated only 14 hours of operation on the cold loop. The cold loop is not operating at the present time because of a non-salt specific component -- the motor.

  After a lengthy repair period, the pump and motor were returned by Byron Jackson in June. Since the initial start up in late June, the pump motor has experienced bearing failures and oil leaks. During the last quarter, the motor for the cold loop has been repaired and reinstalled three times. Most recently, the stator windings burned out; the cause is unknown. The motor is being repaired by the manufacturer at no charge to Sandia (approximate repair cost is $25,000). The motor should be repaired by December, 1989.

- **Testing of Sandia's porous ceramic absorber on the 200 kW volumetric receiver at the Plataforma Solar de Almeria has been completed.**

  Over ninety tests were conducted on Sandia's 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.

  The absorber was successfully tested and produced outlet air temperatures of 730°C. The efficiencies range from 78 percent at the lower temperatures to 57 percent at the higher temperatures. The receiver efficiencies of this absorber were expected to be in the range of 80 percent to 85 percent at 550°C. Subsequent to the design and

fabrication of this absorber, inspection of the absorber and a new calculation method showed that the ceramic foam used in this absorber design was not optimized. First of all, the Pyromark paint used to increase the absorber absorptivity is too thick, the paint blocks many of the pores and covers the micropores which increases the apparent optical density of the material. Secondly, the optical density of the material was too high to begin with, and the material is too thick. A variable density ceramic foam (with the less dense material at the front) would give a better volumetric absorption effect and have a better efficiency.

In spite of the lower-than-expected efficiencies, the absorber material performed extremely well, and there was no degradation of the ceramic material. At the beginning of the testing, there were concerns about thermal shocking of the ceramic material; however, there was not any cracking of the absorber pieces. Thermocouples installed in the absorber measured material temperatures of 1350°C. Transient testing of the absorber also was conducted. A test report is being prepared by the test personnel at the Plataforma. In addition, a Sandia report is being prepared.

- **The test apparatus for the furnace testing of the volumetric receiver absorbers was fabricated.**

  As part of the U.S. participation in the International Energy Agency/Small Solar Power Systems (IEA/SSPS) Task III, researchers have designed and built an apparatus for testing volumetric receiver absorber material at the Central Receiver Test Furnace. The apparatus consists of a glass housing formed to hold a three-inch-diameter sample of a volumetric receiver material, 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 accurately measured. 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.

- **Optical characterization testing was begun on the volumetric receiver absorber materials.**

  Volumetric receiver absorber materials are being characterized optically (for both solar and infrared) as part of the U.S. participation in the IEA/SSPS Task III. This work is being conducted by Division 6224. Thus far, six samples of a crimped and uncrimped Inconel knit wire mesh (rolled, with flux parallel the mesh) have been prepared for testing. Preliminary analysis has shown transmission of approximately 3 percent on a 6.4 mm thick sample. In addition, six samples of a Pyromark coated ceramic matrix (similar to that tested in Almeria) material have been prepared for measurement. Testing will continue.

Planned Activities for Next Quarter

- The assembly of the panel research experiment will be completed next quarter. After all the instrumentation and other electrical connections are made, the initial checkout and water flow tests will be conducted. This is anticipated to take place in November. Depending on the outcome of the water flow testing, the initial phase of the salt flow testing will begin at the end of the next quarter.

- A final schedule will be developed for the salt-air comparative study, and the study will begin.

- The motor for the cold pump will be repaired late in the quarter. After the cold-loop motor is repaired, it will be reinstalled, and testing will commence again. The failure to the hot pump has been evaluated, and a new shaft and bearing have been ordered. The motor will be quickly repaired, and operation will be resumed.

- Researchers will begin testing the three-inch-diameter absorber samples in the solar furnace. Testing will start with ceramic foam absorbers, and then wire mesh absorbers (similar to those to be used for Phoebus) will be tested.

- Optical characterization of volumetric receiver absorber materials will continue next quarter.

- Computer modeling of the volumetric receiver absorbers will resume next quarter.

TASK 2. DISTRIBUTED RECEIVER TECHNOLOGY

Accomplishments

- **Verification testing of CIRCE2 is nearly completed.**

  The CIRCE code is an adaptation of HELIOS for the optical analysis of point-focus solar concentrators. Previously, CIRCE gave the flux distribution and total incident power on flat targets if a continuous or multi-faceted axisymmetric concentrator dish was used. CIRCE2 has expanded capabilities which, among other features, allow the analysis of non-axisymmetric faceted concentrators and three-dimensional axisymmetric internal or external receivers.

  Extensive verification testing has been done to ensure that the code is robust and user-friendly. Future work will entail a final round of benchmarking before freezing the code and porting it to the PC. Efforts at documentation have begun.

- **Fabrication techniques for a full-scale screen wick reflux heat-pipe receiver are under development.**

  A full-scale reflux heat-pipe solar receiver is being assembled to develop fabrication techniques for heat-pipe receivers that use stainless-steel screens as wicks to pump liquid sodium over the surface of a spherical absorber. It will be used to study its effectiveness to transfer from the focal point of a solar concentrator to the heater tubes of a Stirling engine. Three layers of 55-mesh screen and two layers of 325-mesh screen have been stretched over an absorber dome. Although stretching the screens over the dome did generate some wrinkles and bubbles, all were easily removed. It is important that the screens be sealed to the front dome at the edges. The simplest method of sealing the screens to the front dome is to weld the screens with Tungsten Inert Gas (TIG) to the front dome and the front dome to the aft dome in one step. This process may, however, melt the screens rather than seal them to the front dome. To determine if the screens will melt or seal, two rectangular pieces of stainless steel (matching the thickness of the front and aft domes) sandwiching three layers of 55-mesh screen and two layers of 325-mesh screen were welded together with TIG. It is currently being sectioned to determine if the weld provided an effective seal for both the plates and the screens. Further assembly of the receiver will be delayed until the sample weld has been analyzed and the bench-scale, heat-pipe receiver tests have been completed.

- **Fabrication, checkout, and initiation of on-sun testing of the first reflux heat-pipe receiver were completed at the Solar Thermal Test Facility (STTF).**

  The first reflux receiver to be tested at the STTF was a reflux poolboiler receiver. The full-scale pool boiler receiver was successfully tested on-sun at one-half, three-quarters, and full power. Steady-state boiling was stable at all power levels and at temperatures from 700°C to 800°C. No problems were noted during startup. The receiver operated with about 4 kW to 5 kW heat loss at 800°C, with a heat output of 60 kW, resulting in efficiencies around 92 percent. The gas-gap calorimeter control system successfully maintained receiver temperature during changing insolation.

  During the first full-power tests, several hot restarts after cloud passage caused over-temperature alarms before boiling started again. The phenomenon was investigated during clear weather by using the shutter, and a simple control algorithm that virtually eliminates the problem was established. Very short clouds (10 seconds)

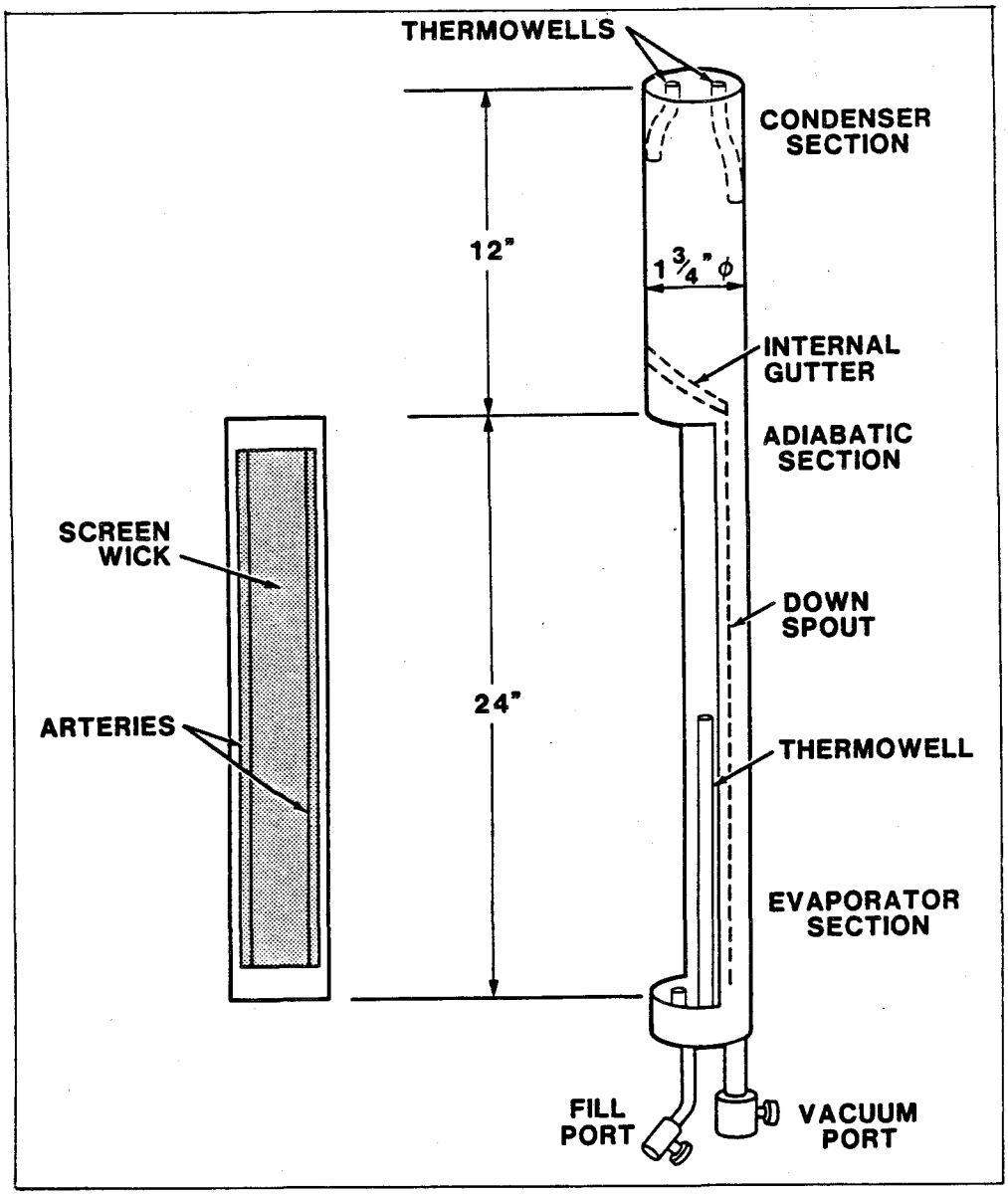

THERMOWELLS
CONDENSER SECTION
12"
1 3/4" ϕ
INTERNAL GUTTER
ADIABATIC SECTION
SCREEN WICK
DOWN SPOUT
24"
ARTERIES
THERMOWELL
EVAPORATOR SECTION
FILL PORT
VACUUM PORT

FIGURE 3.2.1.

that result in complete blockage of insolation can still cause the problem, but they may be unrealistic. Further extensive testing on partially cloudy days is planned. Also, the addition of small amounts of Xenon gas is planned to attempt to reduce the restart problem.

- **Techniques for fabricating the Stirling Thermal Motors' (STM) reflux heat-pipe solar receiver continue to be developed.**

Stirling Thermal Motors (STM) continues to investigate and to develop expertise in the fabrication of screen-wick, heat-pipe receivers on spherical absorbers. The approach involves sintering fine mesh screens on flat stainless steel sheet metal followed by hydroforming. STM has been empirically evaluating the sintering and hydroforming parameters in an attempt to reduce screen compression (and therefore maintain permeability) during fabrication.

To date, two samples (eight inches by eight inches) have been sintered to determine the best sintering parameters. The samples were constructed from a 321SS sheet (1.25 mm thick), five layers of coarse mesh, and three layers of fine mesh. The first sample was hydroformed to determine how much compression of the wick would occur. The preformed wick thickness was 1.25 mm, and the hydroformed wick thickness was 0.85 mm. Evaluation of the flow resistance using the STM computer code indicated that the flow resistance was acceptable; however, improvements are still desirable.

Fabrication of a sintering box for full-sized absorber blanks has begun and is expected to be completed in October. In order to reduce the forces required to hydroform the absorber, the blank will be fabricated from 1.0 mm material instead of 1.6 mm as was the original.

- **Tests began on the bench-scale heat pipe solar receiver.**

The operational lives of early Stirling dish-electric systems were limited by fatigue stresses in the engine's heater tubes. In these systems, nonuniform temperature distributions were caused by focusing concentrated solar directly on the engine's heater tubes. The temperature variations created high thermal stresses in the heater tubes which are already subjected to high mechanical stresses by the system's operating pressure (1500 psi and up). Stress problems will be reduced by the use of heat-pipe receivers that maintain isothermal conditions along the heater tubes.

A bench-scale, heat-pipe receiver has been constructed to explore fabrication techniques for heat pipe components and to determine operational limits of heat pipe systems. A schematic of the bench-scale heat-pipe is presented in Figure 3.2.1. In the test system, a one-inch by four-inch section of the heat pipe's wick is heated with quartz halogen lamps. Sodium in the heated section of wick evaporates and travels to the top of the heat pipe where it condenses. To duplicate operational difficulties that will be encountered in a full-scale heat-pipe solar receiver, a system of gutters is used to prevent condensed sodium from flowing back over the wick.

Testing of a bench-scale, heat-pipe receiver is now underway at the Solar Thermal Test Facility. The heat-pipe successfully operated at a vapor temperature of 750°C with the input heat flux from quartz halogen lamps of approximately 70 W/cm^2. The total power input to the heat pipe system is on the order of 2 kW of thermal. Tests have shown that if the sodium is allowed to freeze, the heat-pipe can be restarted easily, once the sodium in the wick is at least partly melted. Uniform internal

temperatures indicate that the system is operating properly, and system restarts from partially cooled conditions are smooth and steady.

Future tests will increase stress on the heat-pipe design by moving the quartz lamps vertically away from the supply of liquid sodium at the bottom of the heat-pipe. The operating limits on flux levels and receiver dimensions will be determined in tests that will be conducted in October. Start-up procedures also will be investigated in this sequence of tests. The successful completion of these bench-scale tests will clear the way for construction of a full-scale, 75-kW heat-pipe solar receiver for dish electric systems.

Planned Activities for Next Quarter

- The multi-layered screen mesh will be welded to the absorber dome, and the absorber dome will be welded to the aft dome. The welds will be tested to ensure that the screens are sealed to the absorber dome. The exact makeup of the multi-layered screen mesh and the method of welding will be based on the data collected from the weld sample and the bench-scale heat pipe receiver tests.

- Small amounts of Xenon gas will be added to the reflux pool-boiler receiver in increments in an attempt to reduce hot re-start superheats. Depending on the results, the sodium heat transfer fluid may be substituted with NaK.

- Reflux receiver performance will be evaluated over a wider range of conditions by operating the reflux pool-boiler receiver when weather and resources permit.

- Design and fabrication of bench tests to evaluate long-term boiling stability will be initiated.

- STM is expected to establish baseline fabrication parameters and to assemble the equipment to build a full-scale receiver. Shipment of the full-scale reflux heat-pipe receiver to Sandia is a possibility.

- A bench-scale apparatus will be used to determine operating limits on heat-pipe flux levels and receiver dimensions.

TASK 3. CONVERSION DEVICES

Accomplishments

- **Work continued on the preliminary design of the Advanced Stirling Conversion System (ASCS).**

  Stirling Technology Company (STC) and Cummins Engine Company (CEC) continued work on their preliminary designs of the Advanced Stirling Conversion System (ASCS). Cummins' concept (Figure 3.3.1) is a free-piston Stirling engine coupled with a linear alternator. Heat input is provided through a sodium heat-pipe reflux receiver operating at 700°C. The STC approach (Figure 3.3.2) uses a free-piston Stirling driving a hydraulic output to feed a conventional rotary generator. The heat input is provided to the engine via a sodium-potassium (NaK) pool boiler operating at 700°C. During the quarter, both contractors presented results of their Failure Modes, Effects and Criticality Analysis (FMECA). The FMECA was part of both contractors' statement of work. FMECA is a method used to identify weak links in the system design. The idea is to design an ASCS which is reliable and manufacturable. Both STC and CEC results indicated some minor design changes, but no "show-stopper."

  A joint meeting was held during the quarter on the heat-transport effort being conducted by both contractors. Thermacore, who is a subcontractor to both STC and CEC, is developing its heat-transport system. In addition to the design, Thermacore is conducting material tests to evaluate the sodium and NaK reactions at elevated temperatures.

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

  Testing continued on the Stirling Thermal Motors STM4-120 kinematic Stirling at Sandia's Engine Test Facility (ETF). The engine was operating routinely at low engine cycle pressure. A weld failure in a heat pipe caused by over thermal stressing shut down the system for approximately one month. The heat pipe and engine heater heads were returned to Stirling Thermal Motors for repair. During this period, Sandia continued readying the ETF for operating at full-cycle pressure in the engine. This involved reinforcing the test apparatus for safety. The heat-pipes and heater heads were returned to Sandia and were installed again on the engine. Low-power testing will begin again.

Planned Activities for Next Quarter

- The final review of the preliminary design for the Advanced Stirling Conversion System (ASCS) will be held at NASA/Lewis Research Center. Both Cummins Engine Company (CEC) and Stirling Technology Company (STC) will present their final preliminary designs. The Phase II of the ASCS will continue with final detailed design and hardware.

- Higher power testing of the Stirling Thermal Motors, STM4-120, kinematic Stirling engine will begin. The pressure will gradually be increased in the engine to increase the power output. Obtaining reliable operating hours will be the main goal during the next quarter.

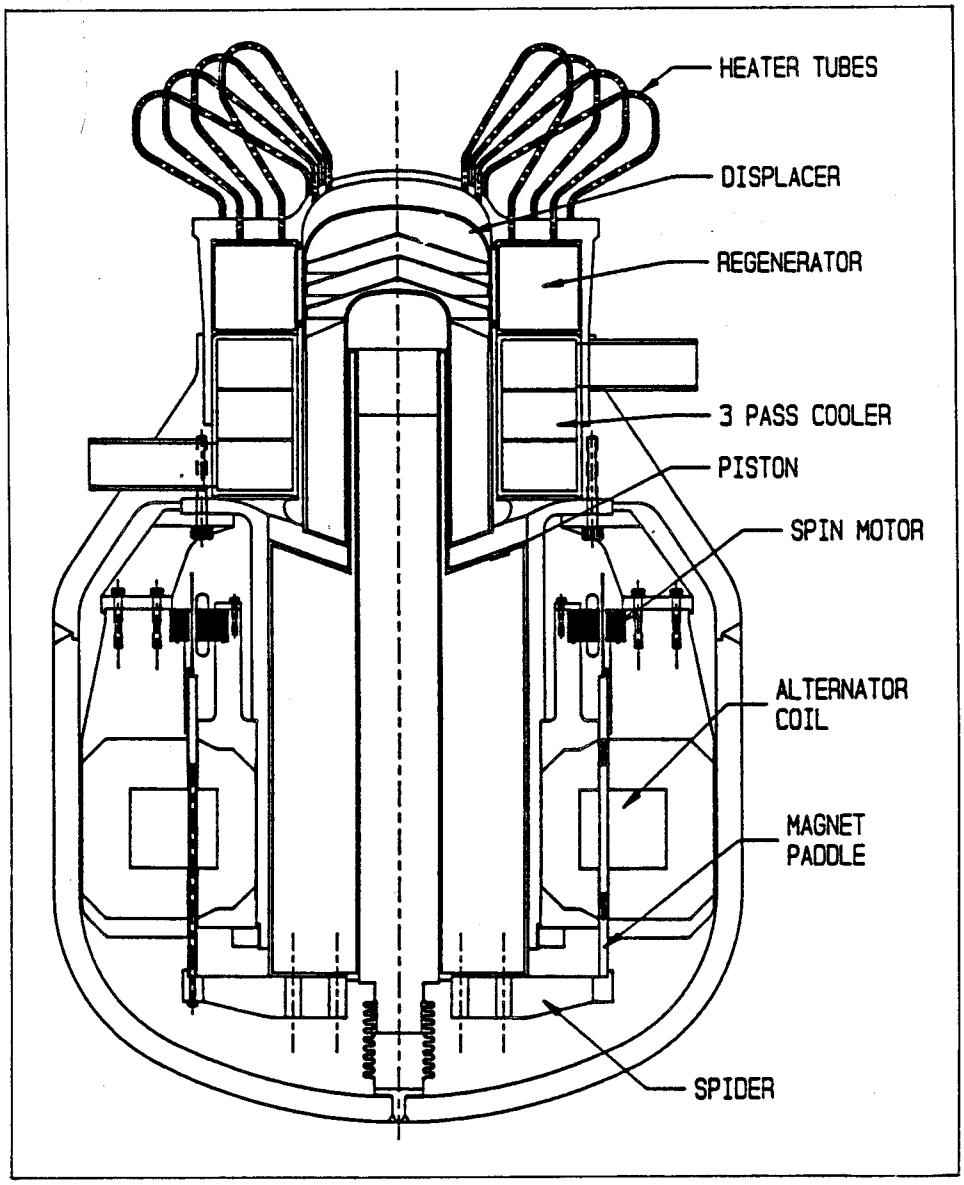

HEATER TUBES
DISPLACER
REGENERATOR
3 PASS COOLER
PISTON
SPIN MOTOR
ALTERNATOR COIL
MAGNET PADDLE
SPIDER

FIGURE 3.3.1.

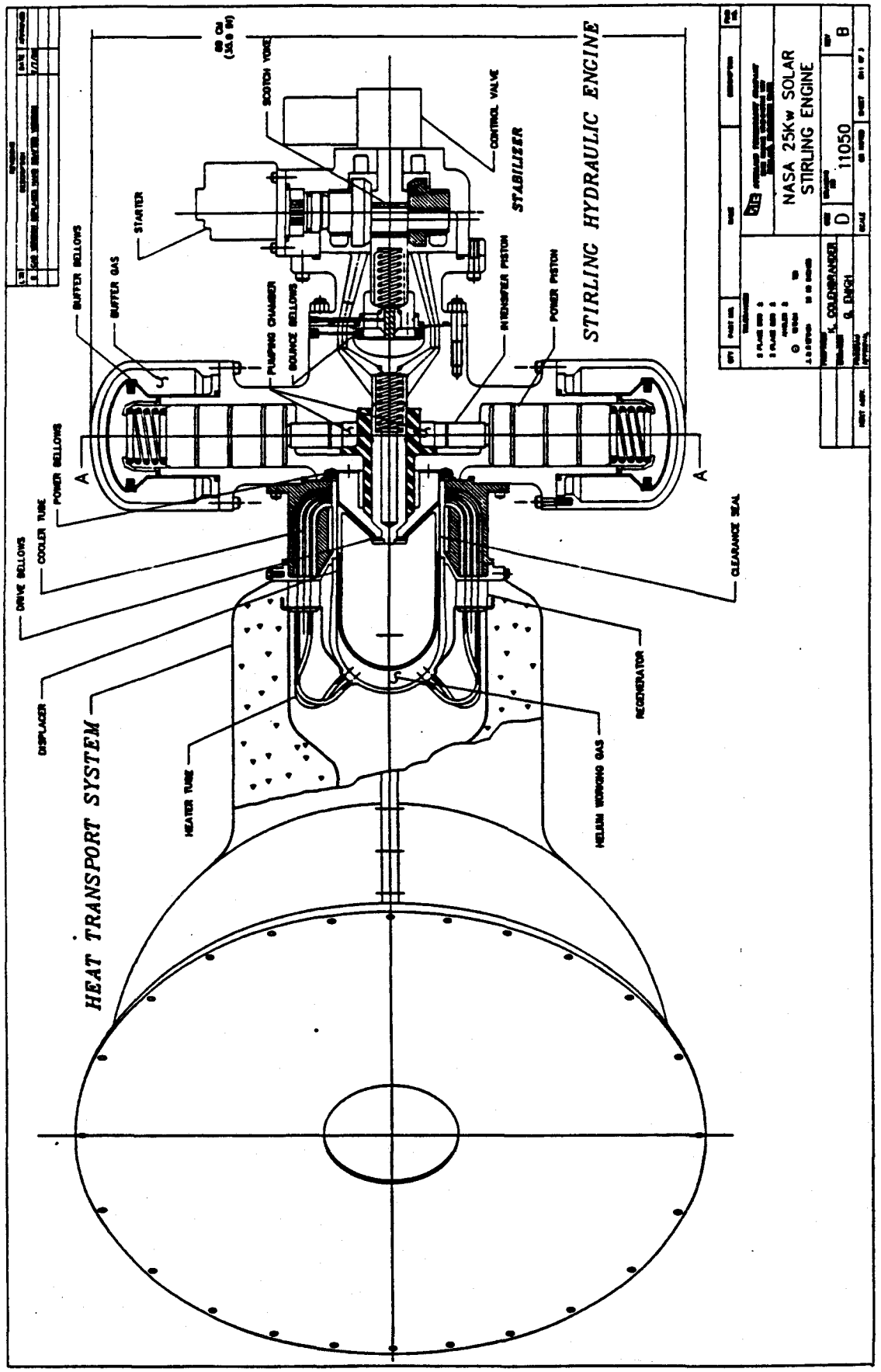

HEAT TRANSPORT SYSTEM
STIRLING HYDRAULIC ENGINE
NASA 25Kw SOLAR
STIRLING ENGINE
11050
DISPLACER
HEATER TUBE
REGENERATOR
HELIUM WORKING GAS
DRIVE BELLOWS
COOLER TUBE
POWER BELLOWS
BUFFER BELLOWS
BUFFER GAS
STARTER
PUMPING CHAMBER
BOUNCE BELLOWS
SCOTCH YOKE
CONTROL VALVE
STABILIZER
INTENSIFIER PISTON
POWER PISTON
CLEARANCE SEAL

FIGURE 3.3.2.

Mission 1. Next-Generation User Systems

Objectives

To achieve a significant reduction in the cost of electricity produced by currently available commercial solar thermal electric systems. The goal will be to enhance the marketplace competitiveness of these systems by the mid-1990s through collaborative, cost-shared, near state-of-the-art research and development with an industrial partner. Key milestones are verification of approaches through pilot field tests by FY 1990 and commercial implementation of verified approaches by FY 1992.

TASK 1. PROJECT DEVELOPMENT

Accomplishments

- **Qualified bidders were selected, and contracted discussions are underway for next-generation user systems (Milestone M1-1).**

  Four companies submitted proposals in response to a Request for Quotation issued April, 1989, on the request from the Next-Generation User 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 two remaining proposers were notified that Sandia wishes to enter contract discussions to establish the areas of common interest, to set the terms and conditions, and to determine the costs of involvement.

Planned Activities for Next Quarter

- Planned future activities include completion of the contract negotiations for the Next-Generation User Systems in October, 1989. With approval from DOE Headquarters, one or two contracts will be awarded in November, 1989 (Milestone M1-1). Completion of the R&D plans and initiation of R&D activities (Milestone M1-2) are currently scheduled for the second quarter of FY 1990.

TASK 3. DESIGN ASSISTANCE AND CORECT SUPPORT

Accomplishments

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

Sandia staff members continued to interact with officials from Scientific Applications International Corporation (SAIC), Camp Pendelton (U.S. Marine Corps Base), and Roan Corporation regarding the planned renovation of Solar Plant 1. The Camp Pendleton commander has approved an agreement to purchase the plant's solar electric power. It is understood that U.S. Navy officials are planning to publish a public notice of their intention to contract with SAIC and Roan. The notice is scheduled to appear in the CBD early in the next quarter. The SAIC and Roan team also is talking to San Diego Gas and Electric (SDGE) to try to agree on a contract to supply electrical power during peak periods. If this effort with SDGE succeeds, the plant will be immediately expanded by modifying the existing configuration of the solar portion and by adding an additional diesel generator. Sandia staff has reviewed some of the proposed plans for the immediate expansion. Several suggestions were forwarded to SAIC. Other assistance will be provided as needed.

SERI was contacted by Roan to seek assistance in developing the data to create a qualified facility to supply power to SDGE. SERI staff with utility and EPRI experience are providing assistance to Roan.

Roan Corporation, SAIC, California Energy Commission, and Bechtel National, Inc., are discussing the idea of retrofitting Solar 1 as a 10 MWe salt plant. Sandia staff was contacted about the possibility of providing technical support for the project under the Solar Thermal Design Assistance Center (STDAC). An agreement to support the effort will be arranged as the plans are implemented.

Sandia staff members are continuing to work with the Cummins Engine Company (CEC) team in its effort to demonstrate a free-piston dish-Stirling system by October, 1989. Despite the short development schedule and delays due to a corrected shortcoming in a critical engine-to-receiver interface, the project is expected to be completed on time. By the first week in October, the integration of the engine, receiver, and controls is expected to be completed at the Cummins test cell in Columbus, Indiana. The system will then be shipped to LaJet Energy Company in Abilene, Texas, for testing on the LEC-460B concentrator. Cold-water calorimetry indicates normalized power of approximately 30 kW to 32 kW through a seven-inch-diameter aperture. Comparisons with CIRCE indicate a gross slope error of 2.13 milliradians.

Ultraviolet (UV) solar radiation can be used to destroy some toxic wastes, and Sandia and SERI are developing systems to do so. A critical aspect of the development is assessing how much ultraviolet radiation is available. STDAC personnel are working with SERI's solar resource assessment office to measure or estimate this resource. However, UV radiation is difficult to measure and to model because it occurs in relatively small quantities as compared to the whole solar spectrum. STDAC personnel are reviewing the available instruments for measuring and modelling. It is anticipated that these tools may require some modification to make them applicable for use.

Sandia was asked by DOE to propose a methodology to measure more accurately global warming. The effort is being managed by Sandia's technology transfer directorate. STDAC personnel helped prepare the proposal by consulting on radiometer

instrumentation and techniques. The proposal was submitted on September 15, and response is expected in the next quarter. If Sandia is funded, STDAC personnel will continue consulting and will be involved in the data analysis.

The City of Albuquerque, New Mexico, is evaluating alternative methods to supply electrical energy for the future. One alternative is to create a city-owned utility, which would employ a mix of fossil fuel and renewable energy generators. STDAC personnel have been invited to provide technical guidance to the city in its evaluation effort, especially regarding the use of renewable energy technology. STDAC personnel met with city officials to discuss a working relationship. Another similar meeting is scheduled for the near future.

Planned Activities For 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 SOLTEC 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 about 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.

Mission 2. Photochemical Systems

Objectives

To develop the technology required to field a project demonstrating solar-driven chemical processes with an emphasis on the destruction of hazardous chemicals. At least one pilot-scale experiment representing a commercially replicable solar hazardous chemical destruction process will be tested in the field by 1994.

TASK 1. IDENTIFICATION OF APPLICATION OPPORTUNITIES

Accomplishments

o Review boards assisted in the detoxification mission.

Two review boards have been constituted to offer guidance and support to both the Solar Detoxification of Water and the Solar Destruction of Hazardous Waste technologies. The panels' meetings satisfy a Solar Thermal Program milestone. The first meeting of these boards was held in September, 1989. The review boards consisted of people from a broad spectrum of backgrounds, including photochemistry and combustion experts from academia, regulators and technology managers from several government agencies, and representatives of industrial firms involved in the design and installation of environmental control and remediation systems. The first day of the meetings consisted of technical briefings by the researchers involved in the mission activities. The second day had two sessions. The first was for reflection and discussion by the Review Board, and the second session was for the review board to present its recommendations to the researchers.

The recommendations of the Solar Detoxification of Water Review Board included placing more emphasis on both intermediate and final products (more detailed mass balances) and more emphasis on systems-level design and performance issues, including testing of more complex mixtures and actual groundwater samples. Another interesting suggestion was to mount a small system on semitrailers to be used as portable units for on-site studies in treatment. The individual board members also offered to assist the project in a number of ways, including passing along important information and helping to develop a profile of the needs and recommendations of potential users and developers in technology.

The Solar Destruction of Hazardous Waste Review Board noted that there needed to be better definition of the products of incomplete reaction from both of the processes. The board especially pointed out the required research and development to work toward more realistic mixtures of waste chemicals, and to start to account for specific system requirements imposed by various waste streams.

Both meetings were very successful; the technical briefings to the Review Board were well received, and the recommendations were thought-provoking and useful. Although a number of the recommendations had already been planned for future activities, it was useful to hear them in a more broad-based context. A number of on-going activities are planned to keep the Review Boards involved with, and informed about, the research until they meet again in the spring of 1990.

- **Researchers defined markets for solar destruction of hazardous waste.**

  Researchers have made a preliminary determination of the potential markets for the solar destruction of hazardous waste. These efforts fulfill the requirements of a FY 1989 milestone. Market contacts established, so far, include commercial incinerator firms, waste generators (many identified through a newly established EPA database), waste broker/recyclers, government agencies, and activated carbon suppliers.

  The potential markets appear to fall into three general categories; destruction of used solvents; steam-stripping of contaminated carbon from an activated carbon absorption system; and remediation of contaminated soils. There are over 100 Super-fund sites in the Southwestern United States, and many of them involve contaminated soils. However, although the amount of contaminated soils in the Southwestern United States is large, the contaminants run a broad spectrum of compounds, including chlorinated solvents, fuels, pesticides and heavy metals. In order to penetrate this market, the solar technology must be able to handle this variety of chemicals, and will probably be required to be transportable from site to site.

  The used-solvent market is also a large one in the Southwest, but interviews with both end-users and distributors indicate that most of these materials are recycled, usually by distillation. Thus, any solar process that will penetrate this market must be able to handle these still bottoms, which may contain very small amounts of solvent (e.g., 1%) mixed with a broad variety of other materials, including metals, waxes, oils, and grease.

  It seems likely that the current increases in the level of concern about air emissions will result in the installation of more carbon filtration systems. If this happens, then the market for regenerating activated carbon will almost certainly grow. Currently, however, there are only a few commercial carbon regeneration plants in the country, and they are not located in the Southwest.

TASK 2. SOLAR PROCESSING OF DILUTE AQUEOUS ORGANIC CHEMICAL WASTES

Accomplishments

- **Work on immobilized catalyst moved ahead.**

  SERI researchers have developed several new candidate materials to be tested as part of the in-house catalyst immobilization development. The materials under consideration include porous Vycor glass, Pyrex glass wool, and a glass-mat material. Tests have begun on the glass wool, which will be tested shortly. Additional efforts have begun to identify external companies that are already producing a similar product that can be adapted to a solar application.

- **An instrument is being developed to take outdoor ultraviolet measurements.**

  SERI researchers are developing an instrument for measuring direct normal ultraviolet solar radiation. This measurement is not typically taken by resource assessment groups; so some new methods will be required. The initial attempt involves adapting a total ultraviolet radiometer, which measures the global ultraviolet radiation, to work with a collimating tube. When this device is mounted on a tracking device, the tube will eliminate all of the sky radiation except that from the solar disk. These measurements are required to correlate the outdoor on-sun experiments with both laboratory work and to make predictions of system performance in other geographic regions or under other weather conditions.

- **Researchers reviewed the draft of a report of the Environmental Protection Agency on the ultraviolet-/ozone/ peroxidation system.**

  Researchers at SERI reviewed the draft of the Environmental Protection Agency's SITE program report entitled "Ultrox SITE Demonstration Draft Technology Evaluation Report." This report documented the use of a small Ultrox UV/oxone/H_2O_2 system (which uses lamps for a light source) for the remediation of a waste stream containing 13 chlorinated volatile organic chemicals. This process is somewhat similar to the Solar Detoxification of Water process, and is expected to be a direct competitor. Therefore, the limitations of this process, as outlined in this report, will be investigated carefully to ascertain how they apply to the solar process.

- **Proof-of-concept tests with salicylic acid were completed.**

  Experiments with salicylic acid using Sandia's engineering scale trough system were completed. Results demonstrate the photocatalytic process on a large scale. The effects of process variables such as catalyst loading and hydrogen peroxide have been quantified and are consistent with results found in the literature and from SERI's results.

- **Tests with trichloroethylene are in progress with Sandia's trough system.**

  Researchers are conducting a series of experiments with trichloroethylene. Sandia's engineering-scale trough system is being used. Data indicate high levels (<99%) of destruction of TCE occurs in one pass at 18 gpm by using titanium dioxide alone. Tests are underway to determine the enhancement of hydrogen peroxide on the reaction rates for this compound.

- **Fixed ceramic supports coated with titanium dioxide were received at Sandia.**

  Samples of alumina ceramic coated with titanium dioxide by various methods have arrived at Sandia and are being tested to determine their effectiveness as a fixed catalyst support. To bond the titanium dioxide, the samples were fired at three different temperatures: 500°C, 750°C, and 1000°C. Other variables in the bonding process were the percentage of weight of titanium dioxide in the wash coat and the percentage of a binder, silicon dioxide, that was used.

TASK 3. HIGH TEMPERATURE SOLAR DESTRUCTION OF HAZARDOUS WASTES

Accomplishments

- **Tests demonstrated the destruction of chlorinated solvents in oxidative environment.**

  The addition of a continuous-feed system to SERI's process equipment for Solar Destruction of Hazardous Waste permitted the process to be tested on several chlorinated solvents, methylene chloride (CH_2Cl_2) and trichloroethylene (C_2HCl_3). The solar process destroyed the solvents to below the detection limit of the analysis equipment, which represented a destruction efficiency greater than three-9s.

- **EPA-method analysis of tests confirmed six-9s destruction efficiency on dioxin.**

  Midwest Research Institute (MRI), under contract to SERI, conducted an analysis of the products from the Solar Destruction of Hazardous Waste process according to the EPA-Modified Method 5 protocol. MRI's results confirmed the six-9s destruction efficiency (DE) that had been measured earlier by the University of Dayton using a much-less-expensive analysis technique.

- **Reactor modeling of reforming processes continued at Sandia.**

  Values were estimated for unmeasured parameters used in the one-dimensional numerical model of the DCAR (Direct Catalytic Absorption Receiver) reactor, which treats absorption, emission, and scattering of solar radiation by gases and solids, solid phase conduction, convection between phases, and catalytic reactions on the surface of the solid phase. A series of sensitivity calculations then were performed by using the numerical model of the DCAR reactor.

  The sensitivity calculations showed: (1) that absorption of solar energy by the catalyst and its porous ceramic support is very efficient (little reradiation occurs); (2) that the flowing gases and the support rapidly reach temperature equilibrium (within about 1 cm from the front of the support); (3) that the solar energy absorbed by the catalyst and its support is efficiently used to drive the endothermic conversion of organic substrate to the products of reforming (hydrogen, carbon monoxide, and carbon dioxide for methane); (4) that conversion efficiency increases very rapidly with increasing temperature; and (5) that use of a three-layer support with porosity increasing from front to back lessens the steepness of temperature profiles within the support and causes gas and support temperatures to track each other more closely. The last conclusion suggests that by tailoring the axial and radial porosity of catalyst supports, relatively uniform temperatures can be obtained throughout the support, which will allow residence times in the reaction zone to be significantly increased and, thereby, assure very efficient destruction of the substrate.

- **CAESAR tests with radially uniform absorber successfully were completed.**

  The Catalytically Enhanced Solar Absorption Receiver (CAESAR) containing a radially uniform (i.e., uniform-flow), rhodium catalyzed, porous ceramic absorber was mounted on DLR's seventeen-meter dish at the PAN facility near Lampoidshausen, Germany. Thermal and chemical (reforming) tests were conducted throughout the report period. Preliminary results indicate that CAESAR performed satisfactorily over a range of operating conditions, steady-state and transient, in both thermal and reforming modes. The most severe limitation on performance appears to be the peaked solar flux distribution. Temperatures were highest (1150°C maximum) in the central portion of

the absorber and decreased by half toward the outer rim. Covers were placed the flux distribution more uniform. A maximum methane conversion of approximately 69 percent was achieved under these conditions.

Planned Activities For Next Quarter

- The output from data analysis on water detoxification tests performed so far will be used to identify optimum ranges for process parameters.
- Researchers will begin identifying candidate catalyst immobilization techniques for commercial systems.
- A laboratory testing program will be implemented for determining catalyst lifetime.
- The Solar Detoxification of Water testing program will include:
  - At laboratory scale, the initial testing of mixtures;
  - At small-scale, the on-sun tests of immobilized catalyst systems; and
  - At the engineering-scale, completion of TCE tests for comparison with laboratory results.
- The Solar Detoxification of Hazardous Wastes market assessment will be extended in soils, regeneration of activated carbon, and effluent solvent streams.
- CAESAR will be tested with a radially non-uniform absorber that is tailored to force a greater mass flow through regions of greater incident solar flux (absorber center).
- Experimentation on the SOLTOX process will be resumed to further quantify the proof-of-concept experiments recently completed.

Mission 3. Advanced Electric Technology

Objectives

This Mission will establish cooperative consortia, which will assess and field a next-generation solar thermal electric system experiment within the next five years. The system will be economically competitive in the electric marketplace. This Mission thus will establish the manufacturing infrastructure and will accelerate the cost and reliability learning curves for the unique solar thermal components critical to achieving the long-term performance and economic goals set for solar thermal systems.

TASK 1. TECHNOLOGY IDENTIFICATION

Accomplishments

- **The Mission 3 Request for Information was released.**

  In July, 1989, a Request for Information (RFI) regarding potential program participants was released to over 130 organizations who have been involved in solar energy projects. Additionally, the RFI was advertised in the Wall Street Journal to maximize the program's visibility. Ten companies have responded to the RFI with descriptions of a variety of solar thermal systems that are candidates for further development and field testing by around 1993. These responses will be used to develop a Request for Proposal (RFP), which will be sent to all of those who responded to the RFI. Evaluation of the RFI responses is scheduled to begin in early FY 1990.

Planned Activities for Next Quarter

- The Request for Proposal (RFP) is scheduled for release in FY 1990. The system experiment, which will operate for two or three years, is expected to be installed in 1993. The RFP 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 showcase for state-of-the-art solar thermal electric technology. Following the system experiment, the government's role will cease, and the industrial partner will market the solar electric technology.

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Anderson, J.V. and T. Bura, "Internal Film Receiver Design Study and Systems Assessment," ACCNR: 10568, ASME Winter Annual Meeting, Chicago, IL, December 1-2, 1988.

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Adkins, D.R., "Heat Pipe Solar Receivers for Stirling Engines."

Bohn, M., "Fluid and Thermal Behavior of the Direct Absorption Receiver."

Chavez, J.M., "An Overview of Advanced Central Receiver Concepts."

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Diver, R.B., "The reflux Heat-Pipe Solar Receiver Development Program."

Fish, J.D., "High-Temperature Solar Destruction of Hazardous Wastes."

Klimas, P.C., "Advanced Electric Generation Technology."

Linker, K.L. and K.S. Rawlinson, "Kinematic Stirling Engine Status for Solar Thermal Electric Systems."

Menicucci, D.F., J.M. Diggs, and W. Short, "The Advanced Electric Technology Cooperative Program."

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Third Quarter FY 1989

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