AOP-89

SOLAR THERMAL TECHNOLOGY PROGRAM

FY89 Annual Operating Plan

November, 1988

Submitted By

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Albuquerque, New Mexico

and

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PREFACE

This Annual Operating Plan (AOP) provides detailed plans for the fiscal year 1989 (FY89) research and development (R&D) activities of the Department of Energy's (DOE's) Solar Thermal Technology Program (STTP). 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) is in preparation. This AOP is consistent with the structure, strategy, and goals of the draft new program plan.

Beginning in FY89, a single AOP which integrates the work of both of the major field laboratories, Sandia National Laboratories (SNL) and the Solar Energy Research Institute (SERI), has been prepared. This differs from past years in which each organization, including the involved DOE Operations Offices, prepared their individual planning documents. A single AOP is consistent with the structure and implementation strategy of the new program plan which consists of interrelated missions and supporting core R&D requiring close coordination of the field laboratory activities.

SECTION I

PROGRAM OVERVIEW

PROGRAM PLAN:

A new Multi-Year Program Plan which reflects the new program structure and strategy is currently in preparation and will serve to guide the course of the program for the next several years. Meantime, the program summary below outlines the major features of the new program plan. The Appendix provides detailed descriptive material for the draft long range program plan and includes a summary of overall mission, rationale and benefits, implementation plan, task structure, and task descriptions for each program activity. This background material establishes the basis for the specific FY89-90 activities described in Sections II and III, respectively.

PROGRAM GOAL:

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 enhance international competitiveness.

PROGRAM OBJECTIVES:

- DEVELOP HIGH-PERFORMANCE AND RELIABLE SOLAR THERMAL SYSTEMS AND COMPONENTS THAT WILL BE COMPETITIVE FOR ELECTRIC AND PROCESS HEAT APPLICATIONS.
- DEVELOP TECHNOLOGY FOR USING HIGHLY CONCENTRATED SUNLIGHT FOR CHEMICAL AND MATERIALS PROCESSES.
- ENHANCE U.S. INDUSTRIAL CAPABILITY TO INTRODUCE SOLAR THERMAL TECHNOLOGY INTO THE MARKETPLACE.

PROGRAM STRATEGY:

- PROVIDE ASSISTANCE TO INDUSTRIES FOR NEAR-TERM MARKET PENETRATION EFFORTS THROUGH REFINEMENT OF PROVEN TECHNOLOGY OPTIONS.
- MAINTAIN SOLAR THERMAL ELECTRIC TECHNOLOGY DEVELOPMENT PROGRAM FOR ACHIEVEMENT OF LONG-TERM GOALS IN THE LATE 1990'S.

- EMPHASIZE THE VERSATILITY AND UNIQUE ATTRIBUTES OF CONCENTRATED SOLAR ENERGY TO DEVELOP SPIN-OFF MARKETS THAT FOSTER THE U.S. SOLAR THERMAL INDUSTRY AND CONTRIBUTE TO ACHIEVEMENT OF THE LONG-TERM GOALS.

- DEVELOP NEW CONSTITUENT BASES IN THE USER/SUPPLIER INDUSTRIES AND ENCOURAGE TECHNOLOGY EXCHANGE AMONG UNIVERSITIES, FEDERAL LABORATORIES, AND THE PRIVATE SECTOR..

- STRENGTHEN THE SCIENTIFIC BASE OF THE PROGRAM IN AREAS SUCH AS ADVANCED OPTICS, CONVERSION PROCESSES, AND PHOTON-MATTER INTERACTIONS.

PROGRAM STRUCTURE:

The Solar Thermal Technology Program has recently been restructured to better focus on a number of near-term commercialization opportunities for the technology created by the changing national energy environment, while maintaining a research and development core which is essential to achieving the long term technology goals[1].

Previously, the program structure consisted of eleven technology oriented tasks[2]. The current program structure consists of three core R&D activities and three mission activities as shown in Figure I-1.

FIGURE I-1. SOLAR THERMAL TECHNOLOGY PROGRAM STRUCTURE

CORE RESEARCH AND DEVELOPMENT

C1. EXPLORATORY RESEARCH
C2. CONCENTRATOR DEVELOPMENT
C3. SOLAR-ELECTRIC TECHNOLOGY READINESS

MISSIONS

M1. NEXT-GENERATION USER SYSTEMS
M2. PHOTOCHEMICAL SYSTEMS
M3. ADVANCED ELECTRIC TECHNOLOGY

1. "Bringing Solar Thermal Technology to the Marketplace", U.S. DOE Report to Congress, CE-0233, Aug 1988.
2. "National Solar Thermal Technology Program: Five-Year Research and Development Plan, 1986-1990," DOE/ 0160, U.S. DOE

ACTIVITY SUMMARY:

The long term objectives and key milestones for the Solar Thermal Technology Program are listed below for each program activity.

CORE RESEARCH AND DEVELOPMENT

C1. EXPLORATORY RESEARCH

Objective: Develop and maintain the scientific and theoretical base of Solar Thermal Technology and conduct fundamental studies on advanced concepts and applications including solar chemistry/materials processing.

Key Milestones:

- o Scientific understanding of photochemical effects by concentrated solar flux.
- o Examine performance and potential of concentrated flux for materials processing.

C2. CONCENTRATOR DEVELOPMENT

Objective: Develop optics, optical materials and cost effective concentrators to support the overall program.

Key Milestones:

- o Stretched-membrane heliostat commercial readiness - FY93.
- o Stretched-membrane dish commercial readiness - FY95.

C3. SOLAR-ELECTRIC TECHNOLOGY READINESS

Objective: Continue the development of the crucial components and systems needed to establish technical readiness of electric power production applications for major domestic markets by the late 1990's.

Key Milestones:

- o Performance and readiness of central receiver advanced receivers verified by solar tests.
- o Performance and readiness of reflux receivers and Stirling engines verified by solar tests.

MISSIONS

M1. NEXT-GENERATION USER SYSTEMS

Objective: Achieve at least 30% reduction in the cost of electricity from commercially available solar thermal systems through collaborative cost-shared R&D with an industrial partner to serve markets in the early 1990's.

Key Milestones:

- o Verification of approaches through pilot field tests - FY90.
- o Commercial implementation of verified approaches - FY92.

M2. PHOTOCHEMICAL SYSTEMS

Objective: Develop the technology required to field a project demonstrating solar-driven chemical processes with an emphasis on the detoxification of hazardous wastes.

Key Milestones:

- o Build and test a pilot scale plant for detoxifying dilute aqueous waste - FY90.
- o Build and test a pilot plant for high temperature decomposition of hazardous chemicals - FY93.

M3. ADVANCED ELECTRIC TECHNOLOGY

Objective: In cooperation with industry, select and apply a single preferred next-generation electric technology to achieve competitive cost of electrical energy in the mid 1990's.

Key Milestones:

- o Decision on technology option and system experiment - FY91.
- o Initiate operation of system experiment - FY93.

PROGRAM TASK STRUCTURE:

Each program activity consists of a number of tasks which comprise the Work Breakdown Structure (WBS) of the program. Figure I-2 illustrates the program WBS at the task detail level.

FIGURE I-2. SOLAR THERMAL TECHNOLOGY PROGRAM WORK BREAKDOWN STRUCTURE

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

SECTION II

FY 1989 TASK DETAIL

1. CORE 1 - EXPLORATORY RESEARCH

Task 1. Photon Interaction with Materials and Chemicals

Objectives: Carry out research to develop the knowledge base in photochemistry necessary to optimize the benefits of photon enhancement in both high and low temperature processes for the synthesis and dissociation of chemical compounds, and to characterize the interaction of concentrated solar flux with the surfaces of metals and ceramics.

Rationale: In order to develop the technology for application of solar energy to the destruction of hazardous chemicals and/or contaminated water supplies it is necessary to develop a base of fundamental information on the photo and thermal chemistry and spectroscopic properties of various types of hazardous compounds and wastes. Such data is necessary for engineers to develop operating systems for decomposition of waste streams containing mixtures of chemicals. Fundamental understanding of the processes involved in forming coatings on material surfaces in high solar fluxes, and their durability under operating environments is necessary to establish the value of solar processing of materials surfaces. Comparisons with laser treatments are necessary to evaluate the relative advantages and disadvantages of solar processing.

FY 1989 Task Description: Work will focus on experiments to measure absorption characteristics under destruction conditions (both low and high temperature as appropriate to the substances), to study the mechanisms of breakdown of different classes of compounds, to identify of reaction intermediates and products of incomplete reaction, and to obtain quantum yield and reaction kinetic data. Through the use of tunable lasers and/or filtered solar simulators, photochemically active absorption bands will be identified. Classes of chemical compounds will be chosen based on prior work at the University of Dayton, SERI, and Sandia for these laboratory experiments. The information will provide a basis for the design of reactors, evaluation of feasibility, and definition of classes of compounds that are susceptible to solar thermal detoxification processes. Supported by subcontracted effort, theoretical approaches to the prediction of susceptibility to solar treatment for classes of compounds will be initiated.

Some catalytic chemical reactions are enhanced by the presence of concentrated solar energy. Experiments have confirmed such behavior in some chemical reactions and with some catalysts. Also, chemical reactions can provide different products and increased yields in the presence of high solar flux. Analytical and laboratory techniques will be used to understand the mechanisms and predict such effects to develop the basis for future applications. The synergism of thermal and photolytic effects will be examined. Chemical processes, which in the long term could lead to fuels, will be examined in the laboratory and those that show the highest promise will be pursued.

In the area of high flux effects on materials, work will focus on determining the optimum exposure conditions for processes, the mechanism for absorption of broad band radiation, the depth profile and the material structural changes as a function of operating conditions and sample preparation, and rates of diffusion and heat penetration. Materials with desired properties, improved performance, and reduction in reliance on strategic materials could thus be obtained. Analytical models based on experimental data to predict the materials behavior and extend the performance to other materials will begin.

FY 1988 Accomplishments: Most of the effort in FY 1988 was on empirical experiments to show solar flux induced effects on materials and chemicals. Such data was helpful in establishing the presence and influence of solar flux on chemical and materials processing. This task is designed to develop the knowledge base for future solar system applications.

Resources:

	Baseline	Enhanced
In-House:	750K	750K
Subcontracts:	550K	800K
Total:	1300K	1550K

Major Milestones:

Dec. 1988	Initiate contract with National Academy of Sciences (NAS) to assess the role of concentrated solar flux in chemistry and materials treatment.
May 1989	Obtain results from laboratory experiments to explain the role of UV and visible radiation (wavelength) in decomposition of toxic chemicals.
Sept. 1989	Results of a working microscopic model to explain and predict the performance of TiO_2 catalyst in an aqueous contaminated solution.

Task 2. New Optical Capability

Objectives: Achieve a possible unique source of tailored frequency from the solar flux and explore optical techniques to control, concentrate and use the flux beneficially.

Rationale: Concentration of solar energy forms the foundation of solar thermal systems. Concepts from very low to very high concentration have been developed over the past 15 years and some of these have been implemented at a commercial scale. Higher concentration of above 30,000 suns reaches the practical threshold for pumping of lasers and through optical techniques of frequency shifting can result in achieving a unique source of high energy photons. In order to fully utilize the capability of the solar flux, new optical approaches for tailoring the spectral distribution and techniques for control and articulation of concentrated solar beam are needed.

FY 1989 Task Description: Optical techniques for frequency doubling in lasers would allow the development of a new source of high frequency photons, important in the long term for general solar chemistry applications and possibly in the Photochemical Systems mission. Presently, the source of high frequency photons are ultraviolet (UV) lamps using electricity. These are very inefficient and short bulb lifetime adds to the cost of obtaining this high quality photon energy. Techniques for directly converting the broad band of solar spectrum to a high value source would increase the usefulness of solar energy as a source. Furthermore, techniques for splitting wavelength bands for special applications would be explored.

New concepts for very high concentration over 60,000 suns have been proposed and demonstrated. Ways of achieving these levels of concentration or higher will be investigated. The innovative optical approaches involved in these high concentrations as well as for lower concentrations where tracking requirements for dish concentrators may be relaxed will be further investigated. Based on this increased understanding of the high concentration approaches, the use of solar energy in pumping lasers will be evaluated compared to use of electricity for laser pumping. Merits of scaling up the laser equipment will be evaluated.

Innovative optical techniques for solar processing applications, solar concentration for specialized needs, and control and articulation of uniformly concentrated solar beams are some of the areas included for investigation. Such capability is needed for uniformly treating large materials surfaces and for new applications.

FY 1988 Accomplishments: A new technique for very high concentration was developed and demonstrated. High concentration of 60,000 suns was reached and its applications were investigated.

Resources:		Baseline	Enhanced
	In-House:	150K	150K
	Subcontracts:	200K	350K
	Total:	350K	500K

Major Milestones:

Jan. 1989 Conduct solar pumped laser experiment with very high solar concentrations.

May 1989 Assess merit of scaling up laser experiments and optical concepts for achieving a source of lower wavelength laser beam.

Task 3. Materials Processing

Objectives: The objectives of this project are to develop and demonstrate, in cooperation with industry, new processes for the industrial application of materials processing using concentrated solar radiation. Surface processing of metals or bulk processing of composites or ceramics is the area of primary focus in the near term.

Rationale: Solar treatment of materials offers an opportunity for early implementation by industry. Rapid thermal processing for broad classes of materials is receiving increased emphasis in the materials community because it can reduce processing time, treat special shapes while producing improved material properties such as an increase in hardness, and corrosion and wear resistance. Solar treatment of materials surfaces using high solar flux can offer the above advantages and also treat large surface areas. In addition, for rapid thermal processing, lower quantities of strategic materials may be required (since the high performance material is present in a thin layer on the surface) and new kind of materials may be produced. Conventional means of rapid thermal processing involve scanning or pulsing lasers, using arc lamps, infrared heaters, induction furnaces, ion or electron beams or flame heating. Each method has advantages and disadvantages, but all are relatively energy inefficient consuming large amounts of energy for processing relatively small amounts of materials and some (nonoptical methods) do not allow adequate control of the depth of penetration of the heat affected zone into the material. The synthesis of high performance ceramic fibers, whiskers and powders for composite materials and other uses also has a number of distinct potential advantages compared to conventional processing methods and will be studied.

FY 1989 Task Description: At SERI, the focus will be on surface transformation hardening of alloys and process development for treatment and preparation of surfaces and methods of application of desired coatings. Small-scale experiments with solar furnaces to prove concepts and to determine sensitivity to parameters such as flux, exposure time, and atmosphere will be conducted. The industrial applications of solar surface processing by developing advanced surface modification solar processes leading to wear resistant, corrosion resistant, and tribological coatings will be expanded. Laboratory research will be conducted to identify potential coating/substrate materials for development of processes for cladding of alloy materials to substrates. Coatings with desired properties will be obtained and best materials and candidate processes will be established through market and systems analysis. New applications for high solar flux processing will be investigated as appropriate. The surface and bulk treatment of carbon fiber, composite materials and ceramics will be conducted, and one of the processes will be picked for future demonstration of the feasibility of solar treatment at the Solar Thermal Test Facility. An industrial partner will assist in analysis of experiments.

At Sandia, focus will be on the preparation of the testing capability for treatment of materials and facility modifications for experiments on components provided by partner(s) will be a significant effort. A beam redirection and sample translation stage that allow the handling of horizontal samples will be designed and constructed. The most promising advanced systems for study and demonstration in cooperation with industry will be picked and a candidate process pilot demonstration will be planned with an industrial partner.

FY 1988 Accomplishments: During FY 1988, experiments were conducted to evaluate the solar flux processing of coatings on metal surfaces, and also the solar effects on carbon fibers. Specific coatings, such as nickel aluminide, titanium carbide, and boron nitride on steel, were identified as most promising for solar applications. Techniques for applying these coatings were investigated. For the carbon fiber, improved resistance to oxidation was observed with solar treated fibers. Effect on the bulk composition, changes in structure and fiber strength were under evaluation.

Resources:

	Baseline	Enhanced
In-House:	600K	600K
Subcontracts:		100K
Total:	600K	700K

Major Milestones:

Mar. 1989 — Determine if the solar treating of metals and/or ceramics can result in desired properties (e.g., hardness) with reduced reliance on strategic materials.

May 1989 — Convene an advisory group to evaluate progress and promise of carbon fiber treatment with concentrated solar flux, based on work at GTRI.

Task 4. Advanced Concepts and Systems Evaluation

Objectives: This task provides the analysis required to evaluate new and advanced solar thermal system concepts for both electric and non-electric applications and recommend areas that deserve enhanced research and development.

Rationale: New concepts must be evaluated in a system context to qualify their value and potential. The systems analysis must be done in an application context since applications require specific performance characteristics. The on-going analysis of the results of research and of existing projects is important to providing direction to the overall program. Particular attention will be given to assessment of the ultra-high flux concentrator and the solar processing of materials. Advanced electrical concepts will be evaluated.

FY89 Task Description: Sandia and SERI will focus their analytical efforts in the following areas:

1) Performance modeling and conceptual systems for treating hazardous chemicals.

2) Assessment of the system aspects and potential impact of new ideas and processes developed in the Photon Interactions with Materials and Chemicals task and the Materials Processing task.

3) Assessment of the need and value of new optical capabilities for the long-range program.

4) Evaluation of work funded through the FY89 SBIR program.

5) Performance modeling of advanced electricity generating solar thermal systems and improvement of system models as needed.

6) Management of the RTEC joint effort between SERI and Hughes on the advanced conversion concept to complete feasibility experiments.

Resources:

	Baseline	Enhanced
In-House:	450K	450K
Subcontracts:		
Total:	450K	450K

Major Milestones:

July 1989 Establish economic potential of materials treatment with solar compared to other technologies.

July 1989 Initiate laboratory tests on closed loop 10W RTEC system.

2. CORE 2 - CONCENTRATOR DEVELOPMENT

Task 1. Heliostats

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

Rationale: The heliostat is the component of the central receiver system that collects and concentrates sunlight by tracking the sun. The heliostat comprises the largest cost element and has a direct effect on the overall performance of the central receiver system. Therefore, it is essential to minimize the capital, operating, and maintenance costs without significantly sacrificing performance. The stretched membrane heliostat has gone through research and two stages of development and appears capable of meeting program needs. This is because of the simplicity and light weight of the stretched-membrane technology. Membrane concentrators promise to cost significantly less than concentrators that use glass mirrors. Current estimates show for large quantity builds, heliostats have the potential to be reduced to approximately $\$50/m^2$. This cost would allow a dramatic step towards attractive, competitive system costs.

Commercial readiness is the time when sufficient industrial manufacturing and in-field operating experience exists so industry can confidently respond to market opportunities without government support. Our goal is to accomplish that in FY93. That event will have been preceded by the evaluation of two 50 m^2 prototype mirror modules (FY89) and the design, fabrication, and evaluation of commercial scale prototype stretched-membranes heliostats that incorporate new and optimized pedestal, structure and tracking. Testing of a cost-shared small build (5 to 10) of the commercial heliostat will establish their commercial readiness. If, during the testing of prototype membrane heliostats, we reach insurmountable problems, we will redirect the program to assure the commercial readiness of glass/metal heliostat designs.

FY89 Task Description: Upon completion of the fabrication and initial characterization of the second SKI and SAIC prototype membrane mirror modules, one or two industrial contracts will be issued for the design integration of drive and mirror module and for the cost analysis of an integrated commercial-scale heliostat. Evaluation of the 50 m^2 prototypes will be completed in FY89 and will have a large influence on the integrated commercial-scale design. The basis for cost and performance comparison will be the 150 m^2 pedestal mount design developed in the FY88 design improvement studies.

Pending a successful design and cost analysis for an integrated commercial heliostat, one or two industrial contracts will be issued for the fabrication of a prototype commercial membrane heliostat. This heliostat will be evaluated and characterized at the Solar Thermal Test Facility. This evaluation will be completed in mid-FY91. The technical support will be provided by both Sandia and SERI.

FY88 Accomplishments: The fabrication of the second SAIC 50m^2 prototype stretched-membrane mirror module was completed and evaluation was started. Fabrication of the second SKI mirror module was started. Both contractors based their prototype mirror modules on second generation, 150m^2, pedestal mount commercial designs. Optical and environmental performance evaluations will be completed in FY89.

Resources:

	Baseline	Enhanced
In-House:	450K	450K
Subcontracts:	775K	875K
Total:	1225K	1325K

Major Milestones:

Nov. 1988 — SAIC contrator report on the design and prototype fabrication for the improved stainless steel membrane heliostat.

Mar. 1989 — SKI contractor report on the design and prototype fabrication for the improved aluminum membrane heliostat.

June 1989 — SAIC contrator report on the design of a commercial, integrated stainless steel membrane heliostat based on test results for the improved 50 m^2 mirror module.

Aug. 1989 — Initiate contract to build prototype stainless steel integrated heliostat.

Sep. 1989 — SKI contractor report on the design of a commercial, integrated aluminum membrane heliostat based on test results for the improved 50 m^2 mirror module.

Sep. 1989 — Topical report on SANDIA's optical and environmental evaluation of SAIC and SKI improved 50 m^2 membrane mirror modules.

Task 2. Parabolic Dishes

Objective: Establish the commercial readiness of the parabolic dish solar collector for distributed receiver solar thermal electric applications.

Rationale: The parabolic dish is the component of the distributed receiver system that collects and concentrates sunlight by tracking the sun. It is the largest single cost element of a distributed solar thermal electric system and has a direct effect on the overall system performance. Therefore, it is essential to minimize the cost of dishes without sacrificing performance.

The stretched membrane parabolic dish is considerably lighter and potentially more cost effective ($120/m^2 versus over $200/m^2) than conventional silvered glass facet dishes, while potentially achieving comparable performance.

Commercial readiness for the stretched membrane parabolic dish is not expected until FY95. This is the time when sufficient industrial manufacturing and in-field operating experience will exist so industry can confidently respond to market opportunities without government support. This will be preceded by build/evaluation of a small optical element assembly, a commercial-scale dish, and a small-build (5 to 10) of commercial dishes.

FY 1989 Task Description: The LaJet innovative dish has 95 reflective membrane facets. Structural weaknesses discovered in FY88 will be corrected and the performance will be characterized by mid FY89.

The fabrication and evaluation of the 7-meter diameter stretched membrane optical element assembly will be completed in FY89. Upon the successful performance of the optical element, a 100 m^2 stretched-membrane dish will be designed, fabricated, and evaluated by FY91. Sandia will manage the industrial contracts. Sandia and SERI will assist industry in the design, modifications, analyses, and evaluations of stretched-membrane dishes that have the potential of performance and/or cost improvements. Laboratory assistance is provided through the development of analytical capabilities to model the optical and structural features of stretched-membrane dishes and measurement of their performance.

Early in FY89 Sandia and SERI will complete a trade-off study of potential dish technologies. A decision will be made on whether or not to initiate another industrial design, build and evaluation program that would complement and provide an alternative to the current membrane dish development program.

SERI will utilize its optical tests capabilities to assist in the assessment and evaluation of the performance of dish concentrators. The Scanning Hartmann Optical Test (SHOT) instrument is suitable for laboratory characterization of large reflective surfaces. SHOT will initially be used to evaluate the 3m composite dish optical element provided by SAIC.

FY 1988 Accomplishments: A multifaceted, membrane-reflector innovative dish was provided for evaluation by LaJet under prior year funding. Serious structural weaknesses prevented optical performance evaluation in FY88.

Two membrane fabrication fixtures, 1.4-m and 3.7-m in diameter, were used at SKI to evaluate the proposed free-form yield fabrication process for aluminum membrane dishes. The results indicated that the free-form yielding of aluminum produced repeatable and accurate parabolic dishes.

SERI developed the Scanning Hartmann Optical Test (SHOT) instrument for characterizing the surface contour errors of large concentrators. SAIC designed and fabricated a 3m composite (glass fiber reinforced epoxy) prototype parabolic dish optical element for evaluation using the SHOT apparatus.

SERI has developed computer codes from nonaxisymmetric nonlinear analytical models for the structural and optical response of a stretched membrane dish as a function of ring deformation and loadings. Copies of the design code and documentation were distributed to potential industrial manufacturers of stretched membrane dishes.

Resources:

	Baseline	Enhanced
In-House:	600K	600K
Subcontracts:	800K	1300K
Total:	1400K	1900K

Major Milestones:

Jan. 1989	Contractor report on aluminum membrane dish fabrication issues.
April 1989	Report on evaluation of LaJet innovative dish performance.
April 1989	Decision Point - Start second dish design, prototype fabrication, and test program based on SANDIA/SERI tradeoff studies and DOE budget constraints.
Aug 1989	Deliver 7m diameter aluminum membrane dish optical element, for testing at the STTF.
Sept 1989	Decision Point - Begin commercial scale design or refine 7m optical element design to improve performance.

Task 3. Optical Materials and Procedures

Objectives: Research and develop optical materials that provide higher performance, lower cost, increased longevity, or satisfy new requirements for both heliostats and dishes.

Rationale: Lightweight, durable and efficient optical reflectors are required to achieve the cost and performance goals for advanced heliostats and parabolic dishes.

FY 1989 Task Description: SERI, supported by Sandia, will perform research on silvered polymer film reflectors that will emphasize studies on three major unresolved issues. First, the primary factors leading to the corrosion of silver will be delineated. Laboratory experiments, already designed, will isolate the importance of the polymer composition, the silver, the adhesive, the substrate, and environmental factors (UV, temperature, gases) for the improved formulations that were defined in FY88. One approach to inhibiting silver corrosion, is to use thin, metal interlayers either in front or behind the silver to further block light, or to passivate the silver, or to isolate corrosive components from the silver. Further, Sandia will expose these new films at a variety of field sites to verify their performance.

A second area of increased effort will be to identify means for correcting the delamination problem that has been observed when the silvered polymer is applied to large structures and exposed to the environment, especially moisture. The adhesion between silver and polymer is weak and is decreased with moisture (this process is reversible). Three general approaches to effect improvement have been identified; two approaches involve improvement of the intrinsic adhesion by means of inorganic or organic interlayers.

In a third area, we will initiate the investigation of alternate means of application of the film to the membrane and of special adhesives that may allow easy in-field film replacement.

The testing of surface coats, that can provide soil resistance, moisture barriers, and abrasion resistance will continue for films that are already developed.

Sandia, supported by SERI, will perform silvered metal (sol-gel) reflector research directed at the development of a protective overcoat for the silver and verification of its protection lifetime by accelerated and outdoor environmental testing. Mechanical testing, bending, stretching, and welding will be started in FY90. An analysis of the potential cost effectiveness of silver metal versus silvered polymer and other reflectors will be completed.

The Large Aperture, Near Specular Imaging Reflectometer, LANSIR, and other optical instruments will be used by SERI to evaluate optical materials developed in this program. These instruments can measure spectral reflectivity and specularity as a function of direction, sample size, and membrane tension.

FY 1988 Accomplishments: Considerable progress was made to decrease the UV degradation of mechanism of silvered polymers. Polymer mirrors have failed in Arizona and other sites from one to two years of outdoor exposure. Other outdoor tests up to seven years on PMMA films supplied by the 3M Company show the good performance of the unsilvered polymer. Similar test results identified that the corrosion problem occurs at the silver/polymer interface. Detailed mechanistic studies that led to a better understanding of the cause of degradation at the silver interface have resulted in two modifications (altered PMMA and ultrathin metal interfacial barriers) both of which are showing improved corrosion resistance in accelerated tests.

Cleaning activities were initiated. Abrasion resistant hardcoats on silver polymer reflectors have shown improvements in cleaning and have indicated some reduction in environmental degradation during accelerated tests. Good abrasion resistance and weatherability for temperature cured hardcoats were demonstrated. For ultraviolet (UV) cured hardcoats, abrasion resistance was good but the weatherability needs improvement.

Silvered metal (sol-gel) research activities included the evaluation of various sol-gel concentrations, process temperatures, and solution parameters aimed at producing a protective overcoat. Initial coupon results showed good optical characteristics and properties for a short period in accelerated weathering. Moisture penetration resulted in failure of the overcoat.

Resources:

	Baseline	Enhanced
In-House:	825K	1125K
Subcontracts:	150K	200K
Total:	975K	1325K

Major Milestones:

April 1989 Interim report on polymer film-to-silver adhesion.

July 1989	Define protective overcoat for silvered metal reflectors.
Aug 1989	Document cost potential of silvered metal structural mirrors.
Sep. 1989	Interim report on corrosion inhibition using altered polymers and metal interlayers.

Task 4. Structural Analysis

Objectives: Develop analytical and experimental data which will allow concentrator weight and cost to be minimized while maximizing structural integrity and performance.

Rationale: Considerable cost saving can be achieved by reducing a concentrator's weight. Currently, concentrators are over-designed due to lack of understanding of how wind loads interact with concentrators. However, to maintain or to improve the optical performance, it is necessary to make a rigid light weight structure that survives static and dynamic wind loading. This is particularly true for stretched membrane concentrators. This task will develop the tools and the data base to allow thorough analysis and understanding of the structural dynamics associated with wind and other loads and their effect on the design of solar concentrators.

FY 1989 Task Description: There are three areas of emphasis in this task: 1) analysis of effects due to wind and weight induced loadings and geometric imperfections on the design and performance of concentrators, 2) experimental evaluation of the response of concentrators to wind loads, and 3) the evaluation of innovative concentrator drive systems on overall system cost and performance.

The structural analysis will extend the current capabilities that exist to predict the detailed response of membrane concentrators to various design and operating parameters. Experimental models will be developed for current stretched membrane configurations. The structural and optical models developed in FY88 will be used to predict the structural response and optical/thermal performance of stretched membrane designs as a function of both static and dynamic loads. The interactions between the support ring, overall structure and the membrane will be investigated in greater detail to provide additional understanding of the response and performance of an integrated structural system.

The wind load experiments will be used to continue the refinement and understanding of the wind-induced loads imposed on the concentrators. Wind tunnel experiments will be continued on both heliostat and dish configurations to include a more detailed evaluation of dynamic response. In order to more accurately assess the dynamic effects of winds on concentrators, more detailed scale models will be tested which are a better representation of specific design concepts under current consideration. A field testing program will be initiated to verify the wind tunnel results and to develop data for the specific design concepts chosen for less costly wind tunnel tests.

New drive concepts are being developed in other areas of the program for heliostats which address either cost reduction potential or innovative design or both. The performance of these drive concepts will be evaluated in the field as they are developed. Results from these tests will be used to assess the potential impact on both the structural response and optical performance of the heliostat concepts for which they were designed.

FY 1988 Accomplishments: A sophisticated analytical model of dish membrane response to non-axisymmetric boundary conditions was developed and validated. This model includes an integrated capability to predict the membrane shape in response to the imposed loading and support conditions and to generate both optical and thermal performance predictions for that shape. It also has the capability to interface with external, finite element programs which can include the effects of specific structural design concepts and then predict the membrane interactions with the structure. This analytical model represents a significant predictive capability which allows the use of inexpensive micro-computers to perform functions typically conducted on large, expensive, mainframes.

Wind load experiments were conducted at Colorado State University in their boundary layer tunnel to measure the mean and peak loads on both heliostats and dishes. This work has served to define the expected wind loadings on generic designs and to distinguish, for the first time, the specific wind load components which affect heliostats and dishes in fundamentally different ways. Experiments have also measured the wind loads on both isolated and in-field concentrators. Wind load data on dishes were obtained in a wind tunnel to define the major load components and compare them with loads on heliostats.

A new pedestal-type, low-cost drive system developed for heliostats has the potential to reduce the cost of this component for either traditional glass/metal or stretched membrane designs. In addition, under a DOE SBIR project, an innovative drive and tracking system is being developed specifically for the stretched membrane heliostat which takes advantage of the increased structural efficiency and allows loads to be distributed more uniformly back to the foundation. It also provides for face-down stow to reduce soiling.

Resources:		Baseline	Enhanced
	In-House:	375K	375K
	Subcontracts:	100K	150K
	Total:	475K	525K

Major Milestones:

Feb. 1989	Define wind load field test program.
June 1989	Topical report on structural/optical analysis of membrane dish prototype.
Sep. 1989	Topical report on innovative heliostat drive system performance.

3. CORE 3 - SOLAR-ELECTRIC TECHNOLOGY READINESS

Task 1. Central Receiver Technology

Objectives: Continue to develop a basic analytical and experimental understanding of the thermal, fluid dynamics, and materials issues of the direct absorption and other receivers and to demonstrate the long-range operation of scaled molten salt pump and valve components.

Rationale: The current development path is intended to achieve a long-term goal of cutting receiver costs by 50% while increasing annual performance by 15%. This could reduce the cost of produced energy from central receiver systems by up to 20%. To achieve this goal, current efforts are centered on development of receivers to eliminate the need for tubes. The principal concept being investigated is the falling-salt-film direct absorption receiver (DAR). In a DAR, the heat absorbing fluid (potentially a blackened molten nitrate salt) flows in a thin film down a basically flat, near-vertical panel (rather than through tubes) and absorbs the concentrated solar flux directly. Potential advantages of the DAR include a significantly simplified design, improved thermal performance, increased reliability and operating life, and reduced capital and operating costs. Before the technology can be implemented, however, we need a better understanding of DAR flow and energy transfer phenomena, materials issues, and system factors. An alternative concept is the Internal Film Receiver (IFR) which retains some of the film heat transfer advantages without the salt being exposed to the environment.

In addition to advanced receivers, central receiver program needs include demonstration of the long-term functionality of molten salt components (including large-scale pumps and valves) and development of improved working fluids.

FY89 Task Description: Work will continue to develop a basic analytical and experimental understanding of the thermal, fluid dynamics, and materials issues of the direct absorption and other receivers and to demonstrate the long-range operation of scaled molten salt pump and valve components. At Sandia, the following activities are planned:

- Continue the analytical, design, and testing activities on the salt film DAR, including scale model tests of water and molten salt flow, thermal and structural analysis, performance calculations, and system integration trade-off studies.
- Continue the intermediate-scale model pump and valve testing that was initiated in FY88 and continue performance evaluation.
- Continue low-level interactions with the IEA/SSPS Volumetric Receiver Program and the planned Spanish IFR concept experiment.
- Provide SSTF support to the testing activities associated with DAR.

At SERI the following activities are planned:

- o Continue the laboratory tests of heated falling salt films. Droplet ejection from a flowing film of molten draw salt will be investigated with emphasis on understanding the basic mechanisms. Additional efforts will be made to understand the breakdown of films subjected to intense radiation. Both the droplet ejection and the film breakdown problems will be approached from experimental and theoretical directions, with the goals of defining operational regimes and means to prevent or mitigate the problems. Researchers will also perform experiments to determine the effect of film waviness on heat transfer rate.

- o Continue analytical and design support to DAR development.

- o Investigate the potential of the IFR concept.

FY 1988 Accomplishments: Researchers performed tests which resulted in good estimates of the convective heat transfer coefficient within the film. The high values of the heat transfer coefficient suggest that a salt film darkener probably will not be required. Researchers identified the ejection of salt droplets from the turbulent film as a potentially significant issue, and they performed experiments to define the extent of the problem and the efficacy of potential operating and design fixes. The experiments provided an understanding of salt film behavior. Accurate measurements of instantaneous film thickness for a vertical water film were completed and provide new insight into falling film behavior. These data will aid in the development of hydrodynamic models of falling liquid films. Specific accomplishments include:

- o Fabricated 5-m long DAR lab model and initiated hot salt flow tests. Identified initial droplet formation at 5 meters.

- o Investigated DAR material compatibility and dopants. Found no corrosion problems for temperatures being considered and a requirement for little or no dopant.

- o Performed 10-m water flow tests on a 2 meter diameter cylinder to simulate DAR. Found significant water droplet formation at velocities of 1/4th of the commercial system velocities.

- o Performed design and structural analysis of external DAR. Established base system design and cost comparisons.

- o Designed and initiated fabrication of DAR salt flow loop and 10 meter molten salt flow test panel.

- o Pump and Valve - Completed fabrication and installation of pumps and valves in loop. Initiated water and salt tests. Found operational problems with cold and hot pumps and flanges.

		Baseline	Enhanced
Resources:	In-House:	1125K	1125K
	Subcontracts:	475K	475K
	Total:	1600K	1600K

Major Milestones:

October 1988 Complete DAR blackener evaluation

March 1989 Complete pump & valve scale test performance evaluation

April 1989 Initiate 6m DAR salt flow testing

Task 2. Distributed Receiver Technology

Objective: To continue development of the sodium reflux receiver through analytical, design, and experimental activities

Rationale: Stirling dish-electric systems have been identified as having potential for meeting the Department of Energy (DOE) long-term energy cost goals. Dish-electric systems based on Stirling engine technology were successfully demonstrated by Advanco Corp. and McDonnell Douglas Corp. and showed the potential for high efficiency. To reach the ultimate potential for dish electric systems, a high efficiency, low maintenance, and low cost receiver is required. The current development thrust is to improve the longevity and reduce the O&M costs of these systems, as well as to improve performance.

The reflux heat-pipe receiver coupled with the Stirling engine has the potential to be an optimum match for the Stirling engine's capability and requirements. In addition, the reflux heat-pipe receiver may be readily applied to other solar thermal applications, with significant life and performance advantages over conventional tube receivers.

FY89 Task Description: Work will continue to develop the sodium reflux receiver through analytical, design, and experimental activities. At Sandia the following activities are planned:

- o Continue the analytical and design activities on the sodium reflux receiver, including bench tests and the initiation of on-sun tests of receivers at the STTF and system integration trade-off studies.
- o Provide STTF support and facility upgrade for the testing activities associated with the sodium reflux receiver.
- o Integrate the STM heat pipe receiver with the STM4-120 kinematic Stirling engine and controls, and initiate a hybridization study for the STM system.

- o Initiate a materials compatibility activity to evaluate the long-term effects of liquid metals and the thermal cycling environment. The emphasis in FY89 will be to identify the key issues and review the applicability of the prior work.

- o Perform system analyses as output from the developmental activities becomes available.

FY88 Accomplishments:

- o Expanded CIRCE computer codes to support development of dish Stirling systems.

- o Investigated pool boiler and wicked receivers for FPSE.

- o Completed first on-sun test of a reflux heat-pipe solar receiver in Israel for thermochemical transport application.

Resources:

	Baseline	Enhanced
In-House:	900K	900K
Subcontracts:	225K	325K
Total:	1125K	1225K

Major Milestones:

Nov. 1988	Complete first bench tests of a reflux pool boiler at the STTF.
Feb. 1989	Complete first bench tests of wicked receivers.
April 1989	Complete fabrication and checkout and initiate on-sun testing of the first reflux heat-pipe solar receiver at the STTF.
Sep. 1989	Decision on heat pipe vs. pool boiler receivers for further development.

Task 3. Conversion Technology

Objective: To test and evaluate the performance of the STM kinematic Stirling engine on-sun and complete the preliminary design of a free-piston Stirling engine (FPSE).

Rationale: Stirling engines have been identified as the most efficient power conversion unit for solar-electric systems (with a net efficiency of 29%, a dish concentrator/Stirling engine system currently holds the world record for solar-to-electric power conversion). These engines are available in a range of sizes, 3 to 50 kW_e, that is suitable for small-modular solar system, and they produce AC electric power that can be connected directly to utility grids. In addition, Stirling engines can be hybridized to run on both solar energy and natural gas, so the systems can produce power during low insolation periods.

Utility companies have exhibited a strong interest in purchasing Stirling electric systems, and several U.S. manufacturers have been active in developing and producing the engines. Alternate uses of the engines (heat pumps, mobile power systems, etc.) will increase production quantities and lower the unit cost. Development costs for Stirling engines is financed primarily by non-solar electric applications, but some additional development is needed to insure that the engines will be suitable for solar electric systems.

FY89 Task Description: Efforts to test and evaluate the performance of the STM kinematic Stirling engine on-sun and to complete the preliminary design of a free-piston Stirling engine (FPSE) will continue. At SANDIA the following activities are planned:

- Test the STM4-120 engine in the SSTF Engine Test Facility and on-sun. Complete the design and fabricate the control system for on-sun testing.
- Initiate the procurement of an upgraded kinematic Stirling engine.
- Provide project management and technical support to the FPSE preliminary design activities initiated in FY88; complete two preliminary design contracts in FY89.
- Provide STTF support to the testing activities associated with the Stirling engines.

FY88 Accomplishments:

- Received kinematic Stirling engine (STM4-120) for bench testing at SANDIA.
- Released RFP for FPSE preliminary designs. Performed heat engine analysis to predict STM engine performance.
- STTF Support - CIRCE performance computer code compared to test results. Facility upgraded to support tests. Tested Barber-Nichols Organic Rankine Engine.
- Completed central engine system study. Initiated feasibility and conceptual designs for dishes.
- Accelerate the pace of FPSE development by initiating two detailed designs in FY89 (with prior year funds).
- Completed the FY88 commitment to NASA Lewis for joint funding of the FPSE preliminary design contracts. Proposals for these contracts are under final evaluation (with prior year funds).

	Baseline	Enhanced
Resources: In-House FTE:	450K	450K
Subcontracts:	575K	975K
Total:	1025K	1425K

Major Milestones:

Jan 1989 Initiate Preliminary Design of FPSE.

Aug 1989 Initiate STM4-120 tests on-sun

4. MISSION 1 - NEXT-GENERATION USER SYSTEMS

Objectives: 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 1990's through collaborative, cost-shared, near state-of-art R&D with an industrial partner.

Key Milestones:

- o Verification of approaches through pilot field tests - FY90.
- o Commercial implementation of verified approaches - FY92.

Rationale: A basic assumption is that in-place commercial solar electric technology can be improved to maintain market competitiveness even after tax credits and current favorable long-term utility power purchase agreements terminate. The achievement of this goal requires a significant reduction in the cost of electricity produced in order to remain competitive. This task will provide the R&D support for the required improvements.

Task 1. Project Development

FY89 Task Description: A Commerce Business Daily announcement will be used to obtain expressions of interest in the project. This expression of interest will be used to develop a qualified source list for a future Request for Quotation related to the R&D program. The final selection of the partner will be made competitively, based on the proposals received. The selection criteria are as follows:

1) The solar system must be currently available.

2) The ability of the proposed approach to achieve electrical energy costs that are competitive in a U.S. market with less attractive electricity purchase agreements than those currently in place and without the benefit of tax credits.

3) The ability and commitment of the industrial partner to achieve commercial implementation of a verified approach in FY92.

4) The ability and commitment of the industrial partner to contribute at least 50 percent of the project cost.

Resources:

	Baseline	Enhanced
In-House:	225K	225K
Subcontracts:	0	0
Total:	225K	225K

Major Milestones:

Nov. 1988 — Prepare and release CBD notice, with proposals due Feb. 15, 1989.

Apr. 1989 — Select joint-venture partner for fielding improvements to a commercial solar thermal electric system.

June 1989 — Complete contract negotiations and award contract.

Task 2. Partner-Driven R&D

Objectives: This task will provide the required R&D necessary to improve the selected system.

Rationale: State-of-art technology will be used as much as possible to improve the system. In order to reduce the risk of the changes some R&D may be required to refine and demonstrate the new features prior to incorporating them into the system. Commercial solar thermal electric systems that are now in operation use parabolic dish or trough solar collectors. The work to be performed under the cost-shared agreements will be divided into phases. Authorization to proceed into each phase will be dependent on availability of funds and the acceptability of prior phase results. It is emphasized that funding of each phase will be subject to careful review and if a viable approach is not perceived the agreement will not proceed.

FY89 Task Description: This task will not start until the private sector partner is selected through the CBD Notice process and the necessary R&D has been identified. This task will provide the required R&D necessary to improve the selected system. FY89 efforts will be to identify and plan the needed work and where it is best accomplished. Subcontracts will be used when appropriate to assist conduction of the work.

Resources:

	Baseline	Enhanced
In-House:	225K	225K
Subcontracts:	165K	165K
Total:	390K	390K

Major Milestones:

July 1989 — Complete an R&D plan and initiate R&D activities.

Task 3. Design Assistance and CORECT Support

Objectives: The objectives of this task are to accelerate the use of solar thermal systems through cooperative efforts with private industry, to assist and educate potential users, and to support industry and users in the selection, design, characterization, and demonstration of promising solar thermal systems.

Rationale: In order to be effective, the solar thermal program requires a continual flow of information between the program and industry and users. The program's dissemination of R&D results to industry, and the reciprocal communication of industry's needs to the program, are necessary to keep the R&D relevant and to ensure developments are rapidly implemented by industry. This task fosters this flow of information by providing direct technical assistance to industry as well as through conferences, workshops, and publications. This task also provides an interface among CORECT, the solar thermal program and industry to foster near-term applications of solar thermal systems.

FY89 Task Description: Sandia as mission leader will receive requests and coordinate their efforts with those of SERI to provide information and fulfill industry requests for technology evaluation, application screening, data, and design evaluation to assist industry and users in implementing the solar thermal option within CORECT initiatives and other commercial initiatives. Existing analysis tools and data will be used to provide this assistance and additional industry needs for improved techniques will be considered and acted upon. The primary focus of workshops and meetings is SOLTECH 89 where sessions will be conducted jointly with industry for specific federal, state and local agency audiences. An Annual Program Technical Review meeting is planned in conjunction with SOLTECH 89.

Resources:

	Baseline	Enhanced
In-House:	75K	75K
Subcontracts:	10K	10K
Total:	85K	85K

Milestones:

March 1989 Participate in the SOLTECH 89 joint meeting.

5. MISSION 2 - PHOTOCHEMICAL SYSTEMS

Task 1. Identification of Application Opportunities

Objectives: Identify opportunities for applying solar thermal technologies to the destruction of toxic chemicals and perform systems analyses to define cost and performance goals.

Rationale: Two types of solar-driven chemical processes are being investigated for the decomposition of organic chemical wastes. The first is a solar photocatalytic treatment of dilute aqueous wastes such as mill effluents and contaminated groundwater. Organic wastes are usually found in concentrations of parts per million and must be reduced to meet EPA standards, which are often in the few parts per billion level.

The second process utilizes highly concentrated solar fluxes (300 suns to 1500 suns) to photolytically or photocatalytically decompose or reform concentrated waste streams at high temperatures (approximately 700°C to 1000°C).

While both processes can be generically applied across a wide range of wastes, they are most effective when directed toward specific waste streams. This task is oriented towards selecting and characterizing real-world opportunities toward which these processes can be developed. Pilot- scale and field experiments can be designed and constructed that will address the needs of these specific opportunities.

FY 1989 Task Description: Market analyses will be performed by a Sandia/SERI team to identify specific opportunities. Opportunities in solar photocatalytic water detoxification will be identified and evaluated by review of the state and federal agency needs, and industry needs, aimed toward the eventual selection of a specific opportunity for a field-scale experiment in 1993. Cost goals will be established, based upon competition with the advanced conventional technologies that will be necessary to meet future environmental regulations.

Similarly, opportunities in high flux solar detoxification of chemical wastes will be identified and evaluated. The current need for high-temperature destruction capacity will be assessed to determine where solar thermal can provide the greatest contribution. The added value of producing fuel from toxic waste by thermal catalytic reforming will also be assessed.

The SERI/Sandia team will establish contacts with the waste management industry (including EPA, HAZWRAP, and industry representatives) to form an advisory committee that will provide background for this activity.

FY 1988 Accomplishments: Preliminary investigations have been performed at both SERI and Sandia. A survey of water detoxification opportunities in the Southwest has been completed by the University of Arizona. Fifty specific sites were catalogued and described, forming the basis for the eventual selection of a site for a field experiment.

Resources:		Baseline	Enhanced
	In-House:	150K	150K
	Subcontracts:		50K
	Total:	150K	200K

Major Milestones:

Feb. 1989	Preliminary cost comparison of solar photocatalytic water detoxification with conventional technologies.
March 1989	Analysis of opportunities for field experiments.
Sept. 1989	Preliminary cost comparison of high-temperature solar detoxification with conventional technologies.

Task 2. Solar Processing of Dilute Aqueous Organic Chemicals

Objectives: The objective is to build and test a pilot scale experiment by mid-1990, followed by a larger, on-site system experiment near a commercial site by 1992.

Rationale: The photocatalytic destruction of organic chemicals, particularly chlorinated hydrocarbons, in water has been demonstrated in small scale under both artificial ultraviolet (UV) sources and natural sunlight under one-sun conditions.

The largest remaining research issue is that of quantifying the effects of solar flux concentration (up to more than 100 suns) and other variables, such as pH, on process efficiency and reaction rate. Process characterization will be performed at laboratory scales for a variety of chemicals. Pilot-scale experiments, using an existing solar test system, will allow many engineering issues to be addressed. These include confirmation of the effect of varying solar concentration on the reaction rate and process efficiency, the effect of contaminants other than the target chemical on the process, methods of recycling or immobilizing the catalyst to simplify the process, and investigating different reactor configurations. Industrial observers will be involved at this stage to ensure that the needs of this market sector are addressed.

The final step will test the photocatalytic process in a real-world situation, operating at or near a contaminated water source. Industrial observers will be involved at this stage to help assess the performance and cost effectiveness of the solar detoxification process compared with more conventional alternatives.

FY 1989 Task Description: SERI researchers will conduct laboratory experiments and provide data to Sandia on the effect of varying solar concentration and other variables on the decomposition process, on the chemical reactions and by-products expected with the target chemical contaminants and on the amount of energy available in the range of solar wavelengths from 400 nm down to 300 nm. They will also establish the expected quantum efficiency of the process.

Sandia will hold the major responsibility for the design and construction of a pilot-scale experiment, adapted to existing facilities. Process characterization data, generated by SERI in the laboratory, will be used as the basis for these designs. An organic chemical, representative of those commonly found in water will be selected. Various reactor configurations, that are irradiated with concentrated solar flux by multiple heliostats or by a series of parabolic troughs, will be evaluated and tested in combination with catalysts to determine the most appropriate design for the pilot-scale experiment. Chemical analysis techniques and procedures will be determined for the pilot-scale experiment.

FY 1988 Accomplishments: Accomplishments in FY88 include the characterization of the solar photolytic process on dilute solutions of one or more chlorinated hydrocarbons, e.g., TCE or TCA, the successful destruction of a limited range of organic pollutants under both artificial ultraviolet and natural sunlight (SERI) and thermal performance measurements with falling film reactors at the STTF (Sandia).

		Baseline	Enhanced
Resources:	In-House:	750K	750K
	Subcontracts:	150K	375K
	Total:	900K	1125K

Major Milestones:

Oct. 1988	Working group meeting to define R&D issues and approaches for FY89.
April 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.
Sept. 1989	Completion of the preliminary testing of the pilot-scale experiment. Brief advisory group on the results and implement recommendations towards further experimentation or modification of activity priorities.

Task 3. High-Temperature Solar Destruction of Toxic Chemicals

Objectives: Construct and test a pilot-scale plant in a commercial situation by 1992.

Rationale: High-temperature photolytic and photocatalytic decomposition or reforming of organic compounds under artificial light has been demonstrated in the laboratories at the University of Dayton and SERI for a limited number of compounds. Field testing using solar furnaces at Sandia and White Sands is now being conducted to confirm the photolytic and photocatalytic effects under natural sunlight conditions. Experiments and calculations have demonstrated that the solar unique ability to heat reaction sites directly can lead to compact, efficient, and extremely effective chemical reactors.

A substantial number of research issues remain to be answered before industry can be induced to apply these technologies in a commercial situation. First, sufficient laboratory testing must be completed to differentiate between the thermal, photo and catalytic effects on decomposition and to characterize the relative performance and cost effectiveness of each effect at laboratory, pilot-plant, and commercial scales.

Both research and engineering issues, such as scaleability, process characterization, and design of reactors and the potential annual system performance, also need to be addressed both analytically and experimentally. The solar furnace at Sandia provides a pilot-scale test bed in which many of these R&D issues can be determined.

FY 1989 Task Description: SERI will complete its testing of the White Sands solar furnace and analyze the results to demonstrate at least "six nines" destruction efficiency has been achieved and to determine the products of incomplete combustion (PICs) that remain. SERI will then characterize the process, isolating the effects of thermal, photo and catalytic action on the process.

Sandia will also complete their experiment on the solar driven catalytic reforming of concentrated solvents at their solar furnace facility with the intention of characterizing the process and isolating the effects of thermal, photo and catalytic action on the process.

When both teams have generated sufficient data, a working meeting will be held to compare the results of each process, to identify remaining research issues and to recommend future research directions. A target chemical or group of chemicals will be selected at this time and a test protocol will be devised to clarify any remaining research issues and facilitate the selection of the major thrust. Both Sandia and SERI researchers will be assigned specific R&D tasks in support of the major thrust.

FY 1988 Accomplishments: Preliminary evaluation of the SERI and Sandia processes are underway in the solar furnace at White Sands and STTF, respectively. Sufficient data have been taken to confirm that further investigation of these solar-driven processes is warranted. Testing is currently being performed to further characterize both processes, particularly in terms of destruction efficiency. The CAESAR experiment has been designed and fabrication initiated.

Resources:

	Baseline	Enhanced
In-House:	600K	600K
Subcontracts:	125K	250K
Total:	725K	850K

Major Milestones:

Oct. 1988	Working Group Meeting at SERI to define R&D issues and approaches for FY 1989
April 1989	Complete experiments demonstrating "six nines" destruction of dioxin and decomposition of concentrated solvents to EPA standards.

April 1989	Avisory Group meeting to review results of SERI and Sandia tests and advise regarding future directions for R&D.
June 1989	Complete CAESAR experiment.

6. MISSION 3 - ADVANCED ELECTRIC TECHNOLOGY

Task 1. Technology Identification

Objective: To identify and evaluate potential advanced solar thermal electric technologies, which can provide a cost-attractive option for specific applications within the next five years.

Rationale: Dish and central receiver technologies have been studied for the past ten years and are nearly ready for implementation in certain applications. It is believed that there is considerable private sector interest to apply these basic technologies in specific markets. However, to initiate the application of these technologies, some DOE assistance may be required.

FY89 Task Description: A promising solar electric technology will be identified through the use of formal procurement processes currently available within the DOE/SANDIA/SERI structure. Through this procurement process, the national solar thermal community will be asked to identify opportunities for an advanced solar thermal electric system that can be cost competitive in United States and international markets. The potential value and cost-effectiveness of each of the proposed systems will be evaluated primarily by a team of SANDIA/SERI personnel using established system study tools and information provided by the industrial participants. Additional evaluation for applications aimed at specific international and Department of Defense (DOD) markets will be obtained through CORECT and DOD initiatives, respectively.

Based on the evaluations, market/technology combinations will be characterized in FY89 as those most likely to be cost-effective for specific applications.

FY88 Accomplishments: This is a new mission for FY89

Resources:

	Baseline	Enhanced
In-House:	190K	190K
Subcontracts:	0K	0K
Total:	190K	190K

Major Milestones:

Sep. 1989 Several attractive market/technology combinations will be characterized.

Task 2. Joint Venture Consortia

Objective: To issue a request for proposal which will result in the formation of industry, user, government consortia that will provide the necessary resources to field a competitive, next generation solar thermal electric system experiment within five years.

Rationale: Joint-venture consortia are required to field a system experiment based on the technology application identified in Task 1. A joint venture involving technical and financial resources will be required to reduce the risk to the organizational participants.

FY89 Task Description: Based on the results of Task 1, a request for proposal (RFP) will be issued. Contract award is expected to lead toward the organization of industry, user, and/or government consortia that will provide the necessary resources to field a competitive, solar thermal electric system experiment within five years. Joint-venture consortia are required to field a system experiment based on the technology application identified in Task 1. A joint venture involving technical and financial resources will be required to reduce the risk to the organizational participants.

FY88 Accomplishments: This is a new mission for the national solar thermal program. Private U.S. industry has shown interest in a solar central receiver system experiment. Other consortia are possible.

Resources:

	Baseline	Enhanced
In-House:	130K	130K
Subcontracts:		
Total:	130K	130K

Major Milestones:

July 1989 Begin preparation of RFP for system experiment.

Task 3. Development Requirements

Objective: This activity will identify development work which will have to be performed in order to reduce the risk of fielding a joint-venture system experiment.

Rationale: In order to reduce the risk of fielding a cost-effective system experiment, some component-level development may be required.

FY89 Task Description: Advanced technology solar thermal electric systems may be cost effective in some electric markets, but at unacceptable risks to the joint-venture partners. A joint Sandia-SERI team will work with the consortia members to identify where component-level development and reliability data will be required to reduce the financial and performance risk to an acceptable level. The conclusions of this study will be used to prioritize work in the core development programs, and could result in the development of some components required for meeting critical schedules.

FY88 Accomplishments: This is a new mission in FY89.

Resources:

	Baseline	Enhanced
In-House:	130K	130K
Subcontracts:	50K	50K
Total:	180K	180K

Major Milestones:

Sep 1989 — Initial identification of development requirements for advanced electric technology.

Task 4. System Experiment

Objective: This activity will field a cost-effective system experiment within the next five years.

Rationale: The importance of this mission lies in the need for the near-term development of low-cost critical components (e.g., concentrators, receivers, and conversion devices) for solar thermal energy systems. This need can best be met by developing a near-term, joint-venture project that involves the installation and operation of a solar electric system that uses a significant number of the solar unique components. Solar systems must be fielded so that volume production will eventually allow components to be produced within the solar thermal program's cost and reliability goals.

The power ratings, costs, and performance of the near-term plant must be acceptable to the joint venture investors. In particular, near-term plants must produce energy cost effectively in the selected market place. The near-term collaborative project will establish an industrial base, provide valuable system performance data, and will reduce the risk for private ventures that will follow.

FY89 Task Description: This task will not start until FY91.

SECTION III

FY 1990 PLANS

1. EXPLORATORY RESEARCH

FY90 Activity Description: Research data and analytical basis will be developed to understand the mechanisms and impact of flux concentration on the enhancement of photocatalytic and photochemical processes. Surface treatment of materials will be enhanced to bring industrial parts for solar testing. New optical capabilities will be enhanced to result in a unique source.

Total Funding: $4300K

Major Milestones:

Q4 FY90	Obtain chemical reaction kinetics and quantum yield data for single and multiple component mixtures.
Q4 FY90	Solar system experiments on material surfaces treatment of industrial parts.

2. CONCENTRATOR DEVELOPMENT

FY90 Activity Description: Stretched-membrane heliostats and parabolic dishes will continue development, fabrication, and evaluation in pursuit of the commercial readiness goals.

Research and development of optical materials will continue in an effort to conclude with viable polymer film, silvered metal, or other materials.

The wind loading program will continue with in-field and wind tunnel tests.

Total Funding: $5000K

Major Milestones:

Q1 FY90	Initiate a contract for design and fabrication of a commercial scale, integrated aluminum membrane parabolic dish.
Q1 FY90	Topical report on Sandia's optical and environmental evaluation of 7m aluminum dish optical element.

Q1 FY90	SKI contractor report on membrane dish design and fabrication of 7m optical element.
Q1 FY90	Initiate contract to build prototype aluminum integrated heliostat.
Q3 FY90	Deliver integrated stainless steel membrane heliostat for testing at the STTF.
Q4 FY90	Deliver commercial scale, integrated aluminum membrane dish for testing at the STTF.
Q4 FY90	Deliver integrated aluminum membrane heliostat for testing at the STTF.

3. SOLAR-ELECTRIC TECHNOLOGY READINESS

FY90 Description: Continue to investigate basic DAR design, fluid dynamics, and material issues. Initiate DAR on-sun salt panel flow testing at the STTF. Complete a reevaluation of the DAR concept and initiate a second generation DAR design. Continue participation with the IEA/SSPS project Task III on receivers.

Continue the evaluation of the sodium reflux receiver. Complete the first phase of reflux receiver on-sun testing. Integrate and test interface (receiver/Stirling engine) controls. Complete Phase I of a reflux receiver hybrid design study.

Continue the on-sun evaluation of the kinematic Stirling engine. Initiate the design/procurement of a second generation or updated kinematic Stirling engine. Complete the detailed design(s) of the FPSE that was started late in FY89.

The joint SERI-Hughes RTEC effort on the 10W closed loop experiments will be completed and evaluation of the concept potential based on the test results will be carried out.

Total Funding: $5,000K

Major Milestones:

Q2 FY90	Initiate DAR solar test
Q2 FY90	Complete hybrid reflux receiver design study
Q2 FY90	Complete 10W experiment for closed loop RTEC system.
Q3 FY90	Initiate advanced DAR design study
Q3 FY90	Initiate second generation reflux receiver tests at STTF

Q3 FY90 Complete STM4-120 tests on-sun

Q4 FY90 Update DAR evaluation

4. NEXT-GENERATION USER SYSTEMS

FY90 Activity Description: Initiate an R&D program with the selected joint venture partner to develop component or system modifications that will enhance the future competitiveness of the subject solar thermal system.

Total Funding: $1500K

Major Milestones:

Milestones for this activity will depend on the specific system and joint venture partner selected in FY89.

5. PHOTOCHEMICAL SYSTEMS

FY 1990 Activity Description: A pilot-scale reclamation experiment will be built and tested using an existing facility at the STTF. Depending on the outcome of FY 1989 research, particularly with respect to the effect of higher flux concentrations on the photocatalytic process, either a MISR experiment would be modified or a pilot-scale experiment constructed to fit within one of the bays of the STTF.

With respect to the high-temperature solar decomposition process, major effort will be directed towards the understanding and characterization of the selected process and target organic waste. A pilot-scale experiment will be operated.

Both advisory reviews and technical support from industry and universities will be utilized during FY 1990 to ensure that the R&D is technically correct and addresses the needs of the private sector.

Total Funding: $3000K

Milestones:

Q3 FY90 Build and operate a pilot scale plant for detoxifying dilute acqeous waste. Report results of pilot scale testing and plans for an on-site field experiment.

Q4 FY90	Select the process for high flux decomposition of hazardous chemicals.

6. ADVANCED ELECTRIC TECHNOLOGY

FY90 Task Description: Work will continue to establish a single consortium that has interest in pursuing the selected market and technology combination. The design of the system experiment will be started. Component-level development efforts, if any, will be started this FY. Contracts will be initiated to evaluate potential sites for the system experiment.

Total Funding: $1200K

Major Milestones:

Q2 FY90	Report on consortium development and technology development needs for the system experiment.
Q2 FY90	Issue RFP for system experiment.

SECTION IV

FY 1989 RESOURCE SUMMARY

Total program resources available in FY89 consist of $15.0M in new budget authority (including $300K in capital equipment funds) plus prior years unobligated budget authority in the amount of $2.959M. Table IV-1 shows allocation of these resources by program activity and organization. All necessary solar test facility support and maintenance is included in the appropriate task budget.

TABLE IV-1. FY89 SOLAR THERMAL PROGRAM BUDGET SUMMARY

($ in Thousands)

PROGRAM ACTIVITY	LABS TOTAL(1)	DOE/HQ	ACTIVITY TOTAL	FY89 FUNDS
CORE RESEARCH AND DEVELOPMENT				
C1. EXPLORATORY RESEARCH	3240	250	3490	2990
C2. CONCENTRATOR DEVELOPMENT	5115	100	5215	4215
C3. SOLAR-ELECTRIC TECHNOLOGY	4290	669	4959	3900
MISSIONS				
M1. NEXT-GENERATION USER SYSTEMS	740	100	840	840
M2. PHOTOCHEMICAL SYSTEMS	2215	100	2315	1915
M3. ADVANCED ELECTRIC TECHNOLOGY	540	300	840	840
SUBTOTALS:	16140	1519	17659	14700
CAPITAL EQUIPMENT	300		300	300
TOTALS:	16440	1519	17959	15000

(1) Includes $40K in each Core & Mission Activity for Laboratory Management Council

TABLE IV-2. FY89 SOLAR THERMAL PROGRAM FIELD LABORATORY BUDGET DETAIL

($ in Thousands)

PROGRAM ACTIVITY	SANDIA FTE	SANDIA In-House	SANDIA Contract	SANDIA Total	SERI FTE	SERI In-House	SERI Contract	SERI Total	Laboratory Total
CORE RESEARCH AND DEVELOPMENT									
C1. EXPLORATORY RESEARCH	3.0	450	260	710	10.0	1500	490 **990**	1990 **2490**	2700 **3200**
C2. CONCENTRATOR DEVELOPMENT	8.5 **9.5**	1275 **1425**	1700 **2350**	2975 **3775**	6.5 **7.5**	975 **1125**	125 **175**	1100 **1300**	4075 **5075**
C3. SOLAR-ELECTRIC TECHNOLOGY	15.5	2325	1275 **1775**	3600 **4100**	1.0	150	–	150	3750 **4250**
MISSIONS									
M1. NEXT-GENERATION USER SYSTEMS	2.0	300	175	475	1.5	225	—	225	700
M2. PHOTOCHEMICAL SYSTEMS	5.0	750	150 **450**	900 **1200**	5.0	750	125 **225**	875 **975**	1775 **2175**
M3. ADVANCED ELECTRIC TECHNOLOGY	2.0	300	50	350	1.0	150	—	150	500
SUBTOTALS:	36.0 **37.0**	5400 **5550**	3610 **5060**	9010 **10610**	25.0 **26.0**	3750 **3900**	740 **1390**	4490 **5290**	13500 **15900**
LABORATORY MANAGEMENT COUNCIL	0.8	120		120	0.8	120		120	240
CAPITAL EQUIPMENT			150	150			150	150	300
TOTALS:	36.8 **37.8**	5520 **5670**	3760 **5210**	9280 **10880**	25.8 **26.8**	3870 **4020**	890 **1540**	4760 **5560**	14040 **16440**

Normal Values = $15.M Baseline Budget Level
Bold Values = $17.959 Enhanced Budget Level

FIGURE IV-3. FY89-90 BUDGET BY TASK FOR CORE R&D ACTIVITIES

	FY89 FTE	FY89 In-House	FY89 Contract	FY89 Total	FY90 Estimate
C1. EXPLORATORY RESEARCH					
1. Photon Interaction with Materials and Chemicals	5.0	750K	550K	1300K	
			800K	**1550K**	
2. New Optical Capability	1.0	150K	200K	350K	
			350K	**500K**	
3. Materials Processing	4.0	600K		600K	
			100K	**700K**	
4. Advanced Concepts and Systems Evaluation	3.0	450K		450K	
	13.0	1950K	750	2700	4300K
			1250K	**3200K**	
C2. CONCENTRATOR DEVELOPMENT					
1. Heliostat Stretched Membrane	3.0	450K	775K	1225K	
			875K	**1325K**	
2. Parabolic Dish Stretched Membrane	4.0	600K	800K	1400K	
			1300K	**1900K**	
3. Optical Materials and Procedures	5.5	825K	150K	975K	
	7.5	**1125K**	**200K**	**1325K**	
4. Structural Analysis	2.5	375K	100K	475K	
			150K	**525K**	
	15.0	2250K	1825K	4075K	5000K
	17.0	**2550K**	**2525K**	**5075K**	
C3. SOLAR-ELECTRIC TECHNOLOGY READINESS					
1. Central Receiver	7.5	1125K	475K	1600K	
2. Distributed Receiver	6.0	900K	225K	1125K	
			325K	**1225K**	
3. Conversion Devices	3.0	450K	575K	1025K	
			975K	**1425K**	
	16.5	2475K	1275K	3750K	5000K
			1775K	**4250K**	

Normal Values = $15.M Baseline Budget Level
Bold Values = $17.959 Enhanced Budget Level

FIGURE IV-4. FY89-90 BUDGET BY TASK FOR MISSION ACTIVITIES

	FY89 FTE	FY89 In-House	FY89 Contract	FY89 Total	FY90 Estimate
M1. NEXT-GENERATION USER SYSTEMS					
1. Project Development	1.5	225K		225K	
2. Partner-Driven R&D	1.5	225K	165K	390K	
3. Design Assistance and CORECT Support	0.5	75K	10K	85K	
	3.5	525K	175K	700K	1500K
M2. PHOTOCHEMICAL SYSTEMS					
1. Identification of Application Opportunities	1.0	150K		150K	
			50K	**200K**	
2. Solar Processing of Dilute Aqueous Chemicals	5.0	750K	150K	900K	
			375K	**1125K**	
3. High-Temperature Solar Processing of Chemicals	4.0	600K	125K	725K	
			250K	**850K**	
	10.0	1500K	275K	1775K	3000K
			675K	**2175K**	
M3. ADVANCED ELECTRIC TECHNOLOGY					
1. Technology Identification	1.2	190K		190K	
2. Joint Venture Consortium	0.9	130K		130K	
3. Development Requirements	0.9	130K	50K	180K	
	3.0	450K	50K	500K	1200K

Normal Values = $15.M Baseline Budget Level
Bold Values = $17.959 Enhanced Budget Level

SECTION V

MAJOR MILESTONE SUMMARY

The major milestones for each program task are summarized below in chronological order and by activity-task reference. This set of major milestones forms the basis for progress reporting and tracking in the FY89 Quarterly Progress Reports.

Date	Activity-Task Reference	Descriptive Title
First Quarter, FY89		
Oct. 1988	C3-1	Complete DAR blackener evaluation
	M2-2	Working group meeting to define R&D issues and approaches for FY89.
	M2-3	Working Group Meeting at SERI to define R&D issues and approaches for FY 1989
Nov. 1988	C2-1	SAIC contrator 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.
Dec. 1988	C1-1	Initiate contract with National Academy of Sciences (NAS) to assess the role of concentrated solar flux in chemistry and materials treatment.
Second Quarter, FY89		
Jan. 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.

Feb. 1989	C2-4	Define wind load field test program.
	C3-2	Complete first bench tests of wicked receivers.
	M2-1	Preliminary cost comparison of solar photocatalytic water detoxification with conventional technologies.
Mar. 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	SKI contractor report on the design and prototype fabrication for the improved aluminum membrane heliostat.
	C3-1	Complete pump & valve scale test performance evaluation
	M1-3	Participate in the SOLTECH 89 joint meeting.
	M2-1	Analysis of opportunities for field experiments.

<u>Third Quarter, FY89</u>

April 1989	C2-2	Report on evaluation of LaJet innovative dish performance.
	C2-2	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	Initiate 6m DAR salt flow testing.
	C3-2	Complete fabrication and checkout and initiate on-sun testing of the first reflux heat-pipe solar receiver at the STTF.
	M1-1	Select joint-venture partner for fielding improvements to a commercial solar thermal electric system.
	M2-2	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	Avisory Group meeting to review results of SERI and Sandia tests and advise regarding future directions for R&D.
May 1989	C1-1	Obtain results from laboratory experiments to explain the role of UV radiation (wavelength) in decomposition of toxic chemicals.
	C1-2	Assess merit of scaling up laser experiments and optical concepts for achieving a source of lower wavelength laser beam.
	C1-3	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	SAIC contrator 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	Topical report on structural/optical analysis of membrane dish prototype.
	M1-1	Complete contract negotiations and award contract.
	M2-3	Complete CAESAR experiment.

Fourth Quarter, FY89

July 1989	C1-4	Establish economic potential of materials treatment with solar compared to other technologies.
	C1-4	Initiate laboratory tests on closed loop 10W RTEC system.
	C2-3	Define protective overcoat for silvered metal reflectors.
	M1-2	Complete an R&D plan and initiate R&D activities.
	M3-2	Begin preparation of RFP for system experiment.
Aug. 1989	C2-1	Initiate contract to build prototype stainless steel integrated heliostat.
	C2-2	Deliver 7m diameter aluminum membrane dish optical element, for testing at the STTF.
	C2-3	Document cost potential of silvered metal structural mirrors.
	C3-3	Initiate STM4-120 tests on-sun

Sept. 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	SKI contractor report on the design of a commercial, integrated aluminum membrane heliostat based on test results for the improved 50 m^2 mirror module.
	C2-1	Topical report on SANDIA's optical and environmental evaluation of SAIC and SKI improved 50 m^2 membrane mirror modules.
	C2-2	Decision Point - Begin commercial scale design or refine 7m optical element design to improve performance.
	C2-3	Interim report on corrosion inhibition using altered polymers and metal interlayers.
	C2-4	Topical report on innovative heliostat drive system performance.
	C3-2	Decision on heat pipe vs. 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 towards 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.

First Quarter, FY90

C2	Initiate a contract for design and fabrication of a commercial scale, integrated aluminum membrane parabolic dish.
C2	Topical report on Sandia's optical and environmental evaluation of 7m aluminum dish optical element.
C2	SKI contractor report on membrane dish design and fabrication of 7m optical element.
C2	Initiate contract to build prototype aluminum integrated heliostat.

Second Quarter, FY90

C3	Initiate DAR solar test
C3	Complete hybrid reflux receiver design study
C3	Complete 10W experiment for closed loop RTEC system.
M3	Report on consortium development and technology development needs for the system experiment.
M3	Issue RFP for system experiment.

Third Quarter, FY90

C2	Deliver integrated stainless steel membrane heliostat for testing at the STTF.
C2	Initiate advanced DAR design study
C2	Initiate second generation reflux receiver tests at STTF
C2	Complete STM4-120 tests on-sun
M2	Build and operate a pilot scale plant for detoxifying dilute acqeous waste. Report results of pilot scale testing and plans for an on-site field experiment.

Fourth Quarter, FY90

C1	Obtain chemical reaction kinetics and quantum yield data for single and multiple component mixtures.
C1	Solar system experiments on material surfaces treatment of industrial parts.
C2	Deliver commercial scale, integrated aluminum membrane dish for testing at the STTF.
C2	Deliver integrated aluminum membrane heliostat for testing at the STTF.
C3	Update DAR evaluation
M2	Select the process for high flux decomposition of hazardous chemicals.

SECTION VI

MANAGEMENT AND IMPLEMENTATION PLAN

1. PROGRAM MANAGEMENT

The management and direction of the Solar Thermal Technology Program is structured to be responsive to national energy policy. That policy is provided by the Secretary of the Department of Energy and incorporates recommendations from the Executive Office, the Congress, national energy advisory boards, other government agencies, industry, universities and others. Sound management of the program is essential to ensure that the overall goals of the Solar Thermal Technology Program are appropriate and are met and that the activities leading to those goals proceed in an orderly, cost-effective manner.

Implementation of the Solar Thermal Technology Program, as defined by the Multi-Year Program Plan, legislative requirements, resource availability, and the Annual Operating Plan, requires careful tracking of research and development activities to assure satisfactory progress toward the overall program goals. Milestones and decision points are established for each program task and are used to determine the necessity for redirecting activities in view of program priorities and available program resources.

Solar Thermal Program Management and Organization

The DOE Division of Solar Thermal Technology is one of two divisions reporting to the Office of Solar Heat Technologies under the Deputy Assistant Secretary for Renewable Energy. The Division is responsible for managing and reporting the status and progress of the Solar Thermal Technology Program. Policy formulation, planning, resource allocation, and evaluation activities are performed by the Division of Solar Thermal Technology. DOE operations offices and field laboratories have been assigned responsibility for implementing the program.

Field Laboratory Management and Organization

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. Functions of the LMC include:

- Program planning and strategic development as requested by DOE program management.
- Field management coordination and program integration including development of an Annual Operating Plan, periodic progress reports, and interaction with DOE program management.

- Division of responsibilities and budgets between the two field laboratories in accordance with interest, capability, staff resources, and availability of supporting technical facilities.

- Conduction of special studies and assessments which assist in the overall program planning, justification, priorities, and strategic development.

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. Assignment of activity leader responsibility by laboratory will be reviewed by the Laboratory Management Council annually to ensure appropriate representation of capabilities, efficient management, and orderly technical progress. Also, it is expected that the mission structure of the program will change as ongoing missions are completed and new ones are defined. The cognizant laboratory is responsible for designating the specific individual for each function. Field activity management responsibilities for FY89 are listed in Table V-1.

The Activity Leader is responsible for:

- Planning and scheduling, with the Activity Coordinator, the specific research and development activities to meet the objectives and goals of the program activity.

- Serving as the point of contact for interaction with the cognizant DOE Solar Thermal Division Program Manager.

- Representing the program activity as a member of the Laboratory Management Council.

- Maintaining activity resource expenditures within the level established in the Annual Operating Plan. This includes the SNL/SERI split and the subcontract activities.

- Summary and reporting of the program activity budget information.

- Preparing program activity input for Quarterly Status Reports, Annual Technical Report, and other such documents as needed.

- Working with the Activity Coordinator in defining and coordinating specific support from each field laboratory.

The Activity Coordinator is responsible for:

- Executing the responsibilities of the Activity Leader in the absence of or at the request of the Activity Leader.

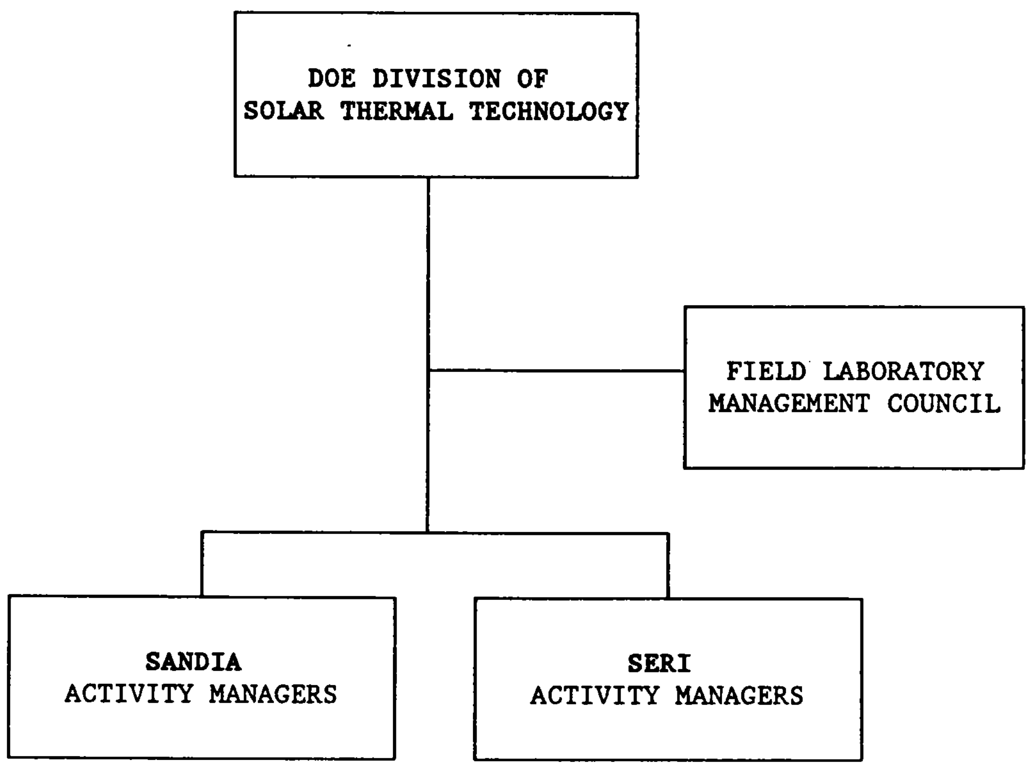
- Obtaining and coordinating specific support from project managers within his laboratory.

TABLE V-1. FY89 PROGRAM ACTIVITY FIELD MANAGEMENT RESPONSIBILITIES

PROGRAM ACTIVITY	LEADER/COORDINATOR
CORE R&D	
C1. Exploratory Research	SERI/SNL
C2. Concentrator Development	SNL/SERI
C3. Electric Technology Readiness	SNL/SERI
MISSIONS:	
M1. Next-Generation User Systems	SNL/SERI
M2. Photochemical Systems	SERI/SNL
M3. Advanced Electric Technology	SNL/SERI

The Solar Thermal Program field management organization, illustrating the coordinating function of the LMC is shown in Figure V-1.

FIGURE V-1. SOLAR THERMAL PROGRAM MANAGEMENT ORGANIZATION



2. REPORTING

The DOE Solar Thermal Technology Program management is kept informed of program progress and management issues on a continuing basis through a variety of formal and informal means such as site visits, frequent telephone communication, weekly highlights, quarterly reports, periodic program reviews, and other topical meetings. The Quarterly Status Report is the primary formal mechanism for documentation of program progress, current planning, budget status, and other relevant management information. Beginning in FY89, a joint, program-level quarterly report will be published by the field laboratories.

3. DISSEMINATION OF RESEARCH & DEVELOPMENT RESULTS

The objective of information dissemination efforts is to make the technology base and specific R&D results developed through the DOE Solar Thermal Program readily available to all. In-house and subcontracted R&D results are documented in written technical reports and are also presented in the form of papers at program reviews, professional society conferences, industry association meetings, workshops, and seminars.

Press releases and periodic laboratory publications such as SERI's newsletter "In Review" and Sandia's "Science News" and "Sandia Technology" are used to highlight technical achievements and important new results.

Technical reports published by the laboratories are submitted to the DOE Technical Information Center (TIC) at Oak Ridge, Tennessee for entry into the national data base on energy technology, and for sale by the National Technical Information Service (NTIS). SERI and Sandia also make limited immediate distribution of technical reports to targeted industry, laboratory, and university representatives.

4. TECHNOLOGY TRANSFER

The Solar Thermal Technology Program supports a number of technology transfer related activities to insure the prompt, accurate, and continuous flow of significant research and technology development information to industry and other users.

Topical reports/publications are periodically prepared and distributed to indicate the status of the solar thermal technologies and projects. Technical reports and papers on all aspects of the program's R&D are published and widely distributed. Each year, several meetings/workshops are conducted to bring interested organizations, as well as researchers, scientists, engineers, and users together in a technical forum to exchange technical and programmatic information. DOE also participates in International Energy Agency (IEA) meetings and workshops. Industrial and end user representative and foreign and domestic researchers/scientists/engineers are encouraged to visit the field laboratories, solar thermal project sites, and test facilities to exchange information and ideas.

Sandia and SERI use several additional mechanisms for technology transfer. Continuing academic and industry involvement through postdoctoral, sabbatical, visiting scientist, summer faculty, and student programs afford the opportunity for first-hand interactions with laboratory staff and facilities. Direct involvement in conducting significant portions of the R&D work through subcontracts to universities and industry offers a direct avenue for technology transfer and participation with the solar thermal community.

APPENDIX

DRAFT PROGRAM PLAN

CORE RESEARCH AND DEVELOPMENT

CORE 1: EXPLORATORY RESEARCH

GOALS The goals are 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 demonstrate, in cooperation with industry, a capability for the industrial application of materials processing using concentrated solar radiation.

RATIONALE AND BENEFITS Major attributes of concentrated solar energy are high temperatures, high concentration, high heating rates, and wide spectral distribution. The high temperature attribute has been explored in the past to capture the heat and convert it into electricity through rotating machinery. The value of the other three attributes has been shown by early experiments which suggest that these can be used for effective destruction of toxic chemicals, processing and synthesis of high value materials, and development of a unique source of high frequency photons. In addition to supplying the necessary energy more effectively into the materials and chemicals, these solar attributes have shown in many cases to improve the properties of materials and/or produce higher yields through different chemical pathways. To more fully utilize these attributes in high value applications, a better understanding is needed of how the concentrated solar flux interacts with chemicals and materials.

Solar processing of materials offers an opportunity for early implementation in industry. Rapid thermal processing for broad classes of materials is receiving increased emphasis in the materials community because it can be used to conserve energy and reduce processing time while producing improved material properties such as an increase in hardness, and corrosion and wear resistance. Rapid thermal processing of surfaces with high solar flux can produce even greater energy savings and can be used to treat large surface areas. In addition, lower quantities of strategic materials may be required (since the high performance material is present in a thin layer on the surface) and new kinds of materials may be produced. Conventional means of rapid thermal processing involve scanning or pulsing lasers, using arc lamps, infrared heaters, induction furnaces, ion or electron beams or flame heating. Each method has advantages and disadvantages, material and some (nonoptical methods) do not allow adequate control of the depth of penetration of the heat affected zone into the material. While solar materials processing has been shown to be feasible and offers advantages over lasers, further data is needed to establish the operating parameters for different materials.

The bulk processing of high performance ceramic fibers, whiskers and powders for composite materials and other uses also has a number of distinct potential advantages compared to conventional processing methods and will be studied.

IMPLEMENTATION STRATEGY Initial analysis and laboratory experiments in photochemistry, materials surface treatments and combined photon and thermal driven chemical processes have offered sufficient clues for new application areas of solar thermal systems. More detailed understanding of the phenomena for more effective use of special attributes of concentrated solar energy will be developed to provide a sound scientific and technical base.

In the materials processing area, a broad range of materials processing applications in a sequenced priority designed to gain the attention of industry as quickly as possible. To attain initial credibility and visibility with potential industry partners, the early emphasis will be on the transformation hardening of metals. This application should foster early industry interest since industry is currently using lasers in this application and some experimental work has been done in this area both internationally and at SERI. As the mission progresses, the early work in transformation hardening will be broadened to include other solar surface applications selected to enhance and expand industry interest. Early investigation of solar processing to improve the bulk properties of materials will be exploratory in nature. Once substantial materials experience has been gained through our investigation of solar surface processing, promising bulk material processing applications will be identified in conjunction with industry and a pilot process developed.

New approaches will be evaluated through systems analysis and applications analysis and experiments will be conducted to verify their potential. Participation of laboratories, universities and industry will be sought as appropriate to fully utilize existing capabilities. Criteria for selection of new topics will be developed to assure that selected research projects will either extend the flux, temperature or spectral capability of solar resource or improve the performance, life, reliability, or application potential of components and solar thermal systems.

An important element will be to keep abreast of international activities in this area and coordination with those activities through the IEA/SSPS tasks.

TASK DESCRIPTIONS

Task 1: Photon Interaction with Materials and Chemicals

This task will focus on increasing the understanding of how solar photons impart their energy to chemicals, materials and small particles. In order to develop the technology for application of solar energy to the destruction of hazardous chemicals and/or contaminated water supplies it is necessary to understand the chemistry and spectroscopic properties of typical types of compounds and actual wastes. Such information is also needed for situations containing mixtures of chemicals. Fundamental understanding of the depth of penetration of coatings on base material surfaces and their durability under operating environment is necessary to establish the value of solar processing of materials surfaces. Comparisons with laser treatments are necessary to evaluate the relative advantages and disadvantages of solar processing.

Materials Effects The basic resource of concentrated solar energy is photons over a wide frequency range. The high heating rates on large surface areas of materials and surfaces of particles are expected to create better properties in materials and higher chemical yields. Surface and bulk effects, as well as the synergistic effects of photon and thermal energy will be investigated by teams of researchers through analytical and laboratory experimental techniques. Experiments will use concentrated solar energy from solar furnaces where appropriate. Early experiments have shown such effects on metals and carbon fibers. These effects need to be better understood to establish a more sound basis for future applications of concentrated solar flux.

Thermal and Photon Induced The high frequency photons are particularly suitable to provide the energy necessary to trigger a chemical reaction pathway which otherwise would require large quantities of thermal energy and the path may still not be achieved. Catalytic reactions are enhanced by the presence of concentrated solar energy. Laboratory experiments have confirmed such behavior in chemical reactions and with some catalysts. Also, chemical reactions provide different products and better yieLds in the presence of high solar flux. Analytical and laboratory techniques will be used to understand the mechanisms and predict such effects to develop the basis for future applications. Combined and synergistic effects of thermal and photon effects will be examined.

Task 2: New Optical Capability

Concentration of solar energy forms the foundation of Solar Thermal systems. Concepts from very low to very high concentration have been developed over the past 15 years and some of these have been implemented at a commercial scale. Higher concentration of above 30,000 suns allows to reach the threshold for pumping of lasers and through optical techniques of frequency shifting can result in achieving a unique source of high frequency photons. In order to fully utilize the capability of the solar flux, new optical approaches for tailoring the spectral distribution and techniques for control and articulation of concentrated solar beam are needed.

Very High Concentration New concepts for very high concentration over 60,000 suns have been proposed and demonstrated. Ways of achieving these levels of concentration, the innovative optical approaches involved in these high concentrations as well as for lower concentrations where tracking requirements may be relaxed are some of the areas included for further investigation. Increased understanding in these areas will allow the program to explore the use of solar energy in pumping lasers which otherwise requires 600 times more energy in the form of electricity. Other potential applications and effects of every high concentration will be explored.

Innovative Optics Innovative optical techniques for solar processing applications, solar concentration for specialized needs, and control and articulation of uniformly concentrated solar beam are some of the areas included for investigation. Such capability is needed for uniformly treating large materials surfaces and for new applications. Increased understanding and integration of these innovative optical approaches into solar thermal systems could lead to improved and more cost-effective solar thermal systems.

Tailored Frequency Optical techniques for frequency doubling in lasers would allow the development of a unique source of high frequency photons, important in the long term for general solar chemistry applications and the Photochemical Systems mission. Presently, the source of high frequency photons are UV lamps using electricity. These are very inefficient and their short bulb lifetime adds to the cost of obtaining this high quality photon energy. Techniques for converting the broad band of solar spectrum to a high value source would increase the usefulness of solar energy as a source. Furthermore, techniques for splitting wavelength bands for special applications would be explored.

Task 3: Materials Processing

This task will focus on encouraging early industry interest and participation in developing solar materials processing approaches. Surface processing of metals (hardened or wear resistant surfaces) or bulk processing of composites or ceramics are the areas of primary focus in the near term.

Rapid thermal processing for broad classes of materials is receiving increased emphasis in the materials community because it can reduce processing time, treat special shapes while producing improved material properties such as an increase in hardness, and corrosion and wear resistance. Solar treatment of materials surfaces using high solar flux can offer the above advantages and also treat large surface areas. In addition, lower quantities of strategic materials may be required (since the high performance material is present in a thin layer on the surface) and new kinds of materials may be produced. Conventional means of rapid thermal processing involve scanning or pulsing lasers, using arc lamps, infrared heaters, induction furnaces, ion or electron beams or flame heating. Each method has advantages and disadvantages, but all are energy inefficient consuming large amounts of energy for processing relatively small amounts of materials and some (nonoptical methods) do not allow adequate control of the depth of penetration of the heat affected zone into the material. The synthesis of high performance ceramic fibers, whiskers and powders for composite materials and other uses also has a number of distinct potential advantages compared to conventional processing methods and will be studied.

Surface Transformation Hardening of Alloys Develop solar transformation hardening and demonstrate it in a major application as soon as possible to quickly attain credibility and visibility with potential industry partners. Conduct small-scale experiments with solar furnaces to prove concepts and to determine sensitivity to parameters such as flux, exposure time, and atmosphere. Identify best materials and candidate process through market and systems analysis. Develop industrial partnership to assist in analysis and planning of experiments. Carry candidate process through pilot demonstration with industrial partner.

Advanced Surface Processes Expand the industrial applications of solar surface processing by developing advanced surface modification solar processes leading to wear resistant, corrosion resistant, and tribological coatings. Conduct basic laboratory research in order to identify potential coating/substrate materials for development. Work on gas phase reaction processes and cladding of alloy materials to substrates in order to produce coatings with desired properties. Conduct small-scale experiments at solar furnaces to prove concepts. Design and construct beam redirection and sample translation stage that allow the handling of horizontal samples. Identify best candidate coating/substrate combinations for process development through market and systems analysis. Select most promising advanced systems for study and demonstration in cooperation with industry.

Bulk Materials, Composites, and Ceramics Identify and develop processes that could use highly concentrated solar radiation to improve the bulk properties of high performance materials. Identify and study the mechanisms involved in inducing bulk material improvements. Through small-scale laboratory and field experiments select a candidate process and optimize the process parameters as required for scale up to a pilot process with industrial participation. The phasing of this task will be such that exploratory research will be performed in the early years of the mission with scale-up to occur after Tasks 1 and 2 are completed. Through market and systems analysis assess the benefits of solar processing of bulk materials. With industry collaboration select appropriate bulk material processes for demonstration and pilot plant scale up.

Task 4: Advanced Concepts and Systems Evaluation

New concepts must be evaluated in a system context to quantify their value and potential. This system analysis must be done in an application context, since certain applications require specific performance characteristics. Both system and applications analysis will be conducted at various stages of research to continue evaluation and assessment of the merits of continuing research on the concept, and to establish the performance requirements for new concepts at an early stage. Scientific advancements in conversion approaches offer the possibility of using efficient thermal driven conversion approaches which do not involve moving parts. Evaluation of these approaches in a system should point out any new opportunities for further evaluation.

CORE 2: CONCENTRATOR DEVELOPMENT

GOALS 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 FY93 and FY95, respectively.

RATIONALE AND BENEFITS Concentrators are the components of solar thermal systems that track the sun and reflect radiation to the receiver or chemical reactor. The concentrator for a line-focus system is a parabolic trough; for a point-focus system it is a parabolic dish; and that for a central receiver system it is a heliostat. Since concentrators are typically the largest cost element of a solar thermal system, it is therefore essential to minimize costs without sacrificing performance.

Troughs have been considered "commercially ready" for the past five years. Trough technology is commercialized with more than 100,000 m^2 in operation, producing in excess of 170 MWe. Cost, performance, and longevity continue to be of major importance and will be addressed by industry either independently or through collaboration with DOE on a cost-share basis (refer to Mission 1 - "Next Generation User Systems.")

Today, glass/metal concentrators are a mature but not optimized technology. Structural and functional integrity have been demonstrated, but cost and longevity remain of concern. For example, the large-area, glass/metal heliostat is estimated to cost approximately $\$150/m^2$ based on the assumption of large quantity, mass production. The faceted, multi-membrane parabolic dish is estimated to cost $\$200/m^2$ under the same assumptions. Further cost reduction requires the development of concentrators using innovative designs, such as large stretched membranes.

For heliostats, the stretched-membrane concept consists of two thin metal membranes stretched over both sides of a large diameter metal ring. The reflective surface is a directly silvered metal, silvered-polymer film or micro-thin glass glued to the front membrane. A vacuum in the space between the two membranes is actively controlled to provide a concave, focused contour to the reflector. Further, the space between the two membranes can be quickly pressurized to force the reflective surface into a convex, defocused contour.

The application of stretched-membrane technology to dish collectors is a logical step in their design, as well. Initial analysis and experiments have indicted that, although the forming process is more complex for dishes since the membrane must undergo plastic deformation to achieve the required contour, accurate dishes can be formed using the stretched membrane process. The application of stretched-membrane technology to dish collectors is currently several years behind heliostat development.

Because of the simplicity and light weight, concentrators using the stretched-membrane technology have the potential to cost significantly less than the current concentrators. Current estimates show the heliostats and dishes have the potential to be reduced to approximately $\$50/m^2$ and $\$120/m^2$, respectively. Achieving these costs will allow a dramatic step towards competitive solar thermal system costs.

Ongoing research, development, analysis and testing are essential to a successful concentrator program. Materials research will be directed at developing optical materials that are integral to membrane heliostats and dishes including: reflectivity, cost, durability, adhesion, surface hardness, UV enhancement and weight. Soiling and cleaning of polymer and glass reflectors will also be addressed.

The structural analysis activities will involve in-field and wind tunnel wind load studies, support to the stretched-membrane technology development, and support to advanced/innovative concentrator design.

Test, evaluation and measurement activities are ongoing in support of all activities related to concentrator development. The facilities that support this activity consist of heliostat, dish and trough test fields, beam characterization systems and a trough turn table.

<u>**IMPLEMENTATION STRATEGY**</u> The concentrator development program is structured to achieve commercial readiness of stretched-membrane heliostats and parabolic dishes by FY93 and FY95, respectively. Commercial readiness for the collectors is the time when sufficient industrial manufacturing and in-field operating experience exists so industry can confidently respond to market opportunities without government support. Simultaneously, materials R&D, structural dynamics, and test/evaluation activities will support current and innovative concentrator concepts. As relates to the stretched-membrane concentrators, simultaneous development programs are underway for the heliostat and the parabolic dish. Sandia and SERI scientists and engineers will work closely with industry in the design, construction and evaluation of the stretched-membrane concentrators.

Activities on stretched-membrane heliostats have passed through the development of two first generation, scaled, prototype mirror module designs and is currently into a program for two second generation prototypes mirror modules that have improved significantly from the previous designs. The second generation program will complete test and evaluation in FY89. One or two industrial participants will perform a design and cost analysis on commercial, full-scale heliostats that incorporate new and optimized pedestal, structure and tracking. These will be built and evaluated in FY9O and 91. Several commercial heliostats will then be built and evaluated by mid-FY92. Commercial readiness will be established and commercial support made available during FY93.

The stretched-membrane parabolic dish program will follow a strategy similar to the heliostat program, only lag by approximately two years. Stretched-membrane dish development has just passed the initial, small-scale verification phase, and is beginning to design first generation prototype hardware. The problems associated with this technology are more complex than the stereteched-membrane heliostat because the membrane must be plastically formed into the shape of a paraboloid having a focal length to diameter ratio (F/D) of approximately 0.6 (heliostat f/D is 20-200). Therefore, commercial readiness and commercial scale is not anticipated until FY95.

Reflector material research and development is a key task for achieving the cost and performance goals for solar concentrators. Because polymer films may have useful lifetimes less than that of the structural components in-field replacement will be considered in the development of the reflective material and in the design of the concentrators. Inorganic alternates to silvered polymers will also be sought that promise longer life.

Development of commercial-scale heliostats and dishes will be performed by private industry so as to maximize technology transfer.

TASK DESCRIPTIONS

Task 1: Heliostats

The objectives of this task are to establish commercial readiness of the stretched-membrane heliostat through the following steps:

<u>Commercial Design Optimization and Cost Analysis</u> Upon completion of the fabrication of the second SKI and SAIC scale prototype SM mirror modules in FY88, one or two industrial contracts will be issued for the final design, optimization, and cost analysis of an integrated full-commercial-scale heliostat. Evaluation of the two 50 m^2 prototype mirror

modules will be completed in FY89 and will have a large influence on the final commercial-scale design.

Build and Evaluate Commercial Scale SM Heliostat Pending a successful design and cost analysis, one or two industrial contracts will be issued for the fabrication of a full commercial scale SM heliostat. This heliostat will then be evaluated and characterized at the Solar Thermal Test Facility. This evaluation will be completed in mid-FY9l.

Commercial Scale Production Program Pending satisfactory results from full scale prototypes, one or two industries contracts will be negotiated for the building of several commercial-scale heliostats. These will be placed into operation for a long-term evaluation to be completed in FY93.

Commercial Readiness and Support Sandia and SERI will assist industry in modifications, improvements, analyses and evaluations which have the potential of performance and/or cost improvements beginning in FY93.

Task 2: Parabolic Dish

Commercial readiness of the parabolic dish will proceed through the following major phases:

First Prototype Membrane Parabolic Dish A scaled, 7m prototype optical element will be designed by SKI during FY89. An integrated, commercial-scale dish will be designed in FY90, built and evaluated by FY91. At the end of the performance testing this dish will be for a solar test of a Stirling engine available from the Core 3 activity.

Commercial Dish Cost Analysis An industrial contract will be issued for the cost analysis of an integrated, commercial-scale membrane parabolic dish. This analysis will be completed in FY91.

Build and Evaluate A Second Generation, Stretched Membrane Parabolic Dish Pending the successful design, testing, and cost analysis, an industrial contract will be issued for the design, fabrication, and evaluation of a second generation membrane parabolic dish. This program is scheduled for completion in FY93.

Commercial Scale Production Program Pending satisfactory results with the first and second generation stretched membrane dish prototypes(s), an industrial contract will be negotiated in FY93 for a build of several commercial scale parabolic dishes to be placed in the field for long-term evaluation. This activity will be integrated with the Stirling engine development program in Core 3.

Commercial Readiness and Commercial Support Sandia and SERI engineers and scientists will assist industry in modifications, improvements, analyses and evaluations that have the potential of performance and/or cost improvements to the small-build design starting in FY95.

Pending a decision in FY89, an alternate dish concept or second membrane dish development program may be initiated. This program will initially lag the on-going membrane dish development but will have the same FY94 commercial readiness goal.

Task 3: Optical Materials and Procedures

Research and develop optical techniques and materials that could allow higher performance, lower cost, increased longevity or satisfy new requirements for both heliostats and dishes.

Reflective Materials This ongoing research and development effort would be related to materials and coatings for reflectors that have improved reflectivity, lighter weight, increased life, moisture resistance, and special characteristics such as enhancement of the UV component of the reflected beam as needed for the Photochemical Systems activity. Both polymer and inorganic reflectors will be considered.

Soiling and Cleaning Engineering efforts on cleaning methods are not affordable until FY90 or later. The activity involves materials research and development leading to reflector surfaces that prevent the attachment of permanent soil layers. A cleaning program will be established to develop non-contact cleaning techniques, equipment and fluids.

Task 4: Structural Analysis

The objective of this task is to develop analytical and experimental data that will allow concentrator weight and cost to be minimized while maximizing structural integrity and performance. Considerable cost saving can be achieved by making concentrators that are lighter in weight than silvered glass concentrators. However, to maintain or to improve the optical performance, it is necessary to make a rigid, lightweight structure that is unaffected by dynamic wind loading. This is particularly true for stretched membrane concentrators. This task will develop the tools and the data base to allow thorough analysis and understanding of the structural dynamics of solar concentrators.

Structural Analysis Maintain ongoing expertise for structural analysis of current designs such as stretched-membrane concentrators or other innovative concentrator configurations.

Wind Loading Program It is essential to the performance and cost improvement of concentrators that wind loading be better understood and predictable. The dynamic response of concentrators will be studied by instrumenting field concentrators and monitoring under real conditions. The in-field studies will be supported by analyses and wind tunnel tests.

CORE 3: SOLAR-ELECTRIC TECHNOLOGY READINESS

GOALS Continue the thrust of the Solar Thermal Program to develop the components and systems needed 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 mission is to achieve technical readiness and be economically cost competitive in major domestic markets by the late 1990s.

RATIONALE AND BENEFITS The overall mission of the Solar Thermal Program is to develop a renewable energy supply option to reduce fossil fuel usage and to enhance national energy security. The three major energy consumption sectors in the U.S. are process heat (including heating and cooling), transportable fuels, and electric power production. The theme of the Solar Thermal Program is development of a grid-connected solar thermal electric power capability. Interim goals are to bring the technologies to a condition of technical readiness which would permit sales to remote and export markets. Currently, electrical power applications have made encouraging progress toward technical readiness. Projections of major utility needs for capacity increases--mid to late 1990s--and the current pace of central and distributed receiver development are reasonably well aligned. In the case of distributed receivers, dish-electric systems are thought to be strong candidates for mid-term export and domestic remote markets as soon as reliable and moderate performing systems are available. Interim high-value markets such as these are essential for all solar technologies so that the cycle of ever increasing production volume and ever improving performance and costs can be initiated.

The Solar Thermal Program has progressed through a great variety of technical approaches to solar electric power production over the life of the program. Activities have ranged through feasibility studies, component and system development, and large-scale field experiments.

Central Receivers In a solar central receiver system, the receiver converts heliostat concentrated solar radiation into thermal energy. Receivers have been designed, built and tested using water/steam, molten nitrate salt, liquid sodium, and air as heat transfer fluids. Present liquid receivers operate at temperatures near 600°C with efficiencies between 75% and 90%. Over the past 10 years, extensive development has been done on moderate temperature receivers. This work continues to be the principle focus of receiver development in the program since these receivers enable electricity production through coupling with Rankine-cycle steam turbines and intermediate temperature industrial process heat generation. Emphasis is on improving the reliability and efficiency and decreasing the capital cost of this type of receiver. Our development path is intended to achieve a long term goal of cutting receiver costs by 50% while increasing annual performance by 15%. This could reduce the cost of produced energy from central receiver systems by up to 20%. To achieve this goal, our current effort is centered on development of the falling-salt-film direct absorption receiver (DAR).

In a DAR, the heat absorbing fluid (a blackened molten nitrate salt) flows in a thin film down a basically flat, near-vertical panel (rather than through tubes) and absorbs the concentrated solar flux directly. Potential advantages of the DAR include a significantly simplified design, improved thermal performance, increased reliability and operating life, and reduced capital and operating costs.

In addition to the DAR, central receiver program needs include demonstration of the long-term functionality of molten salt components (including large-scale pumps and valves) and development of improved heat transfer fluids. As the technology progresses toward technology readiness, further development and refinement of thermal storage technology, steam generation, and control systems will be required. Longer term efforts to enhance technology competitiveness should include further evaluation of advanced receiver/heat transfer systems such as the hot air/steam volumetric receiver being studied in Europe.

Distributed Receivers Stirling dish-electric systems have been identified as having potential for meeting the Department of Energy (DOE) long-term levelized energy cost goals. Dish-electric systems based on Stirling engine technology were successfully demonstrated by Advanco Corp. and McDonnell Douglas Corp. and showed the potential for high efficiency. A shortcoming of the Advanco and McDonnell Douglas modules (both used United Stirling Engines) was the directly illuminated tube receiver. Because of the inherent nonuniformities of concentrated sunlight, the directly illuminated Stirling engine heater tubes experience temperature gradients that degrade performance and limit life. The calculated life of the United Stirling Advanco tube receiver was approximately 16,000 hrs @ 720°C. In addition, directly heated tube receivers require highly accurate concentrators to produce reasonably uniform incident solar flux distributions, and even with good flux distributions the tubes must be spread out and enlarged to the extent that engine performance is compromised.

Although receiver efficiency was demonstrated to be good, it was probably not optimum since receiver size was dictated by tube flux limitations and engine performance considerations. Also, receiver performance was degraded because of openings between tubes (to improve tube circumferential flux distributions) and because of a ceramic plug in the center of the receiver, which resulted in reduced effective receiver absorptance and in an effectively higher receiver temperature. Another shortcoming of the Stirling tube receiver is that it cannot be readily hybridized with fossil fuels.

The reflux heat-pipe receiver represents the next step in the evolution of Stirling receiver technology and has the potential to address all of the tube receiver shortcomings outlined above. In addition, the reflux heat-pipe receiver may be readily applied to other solar thermal applications, with similar life and performance advantages over conventional tube receivers.

In the reflux heat-pipe solar receiver, sodium and/or potassium is used as an intermediate heat transfer fluid between a solar receiver/absorber and the heater tubes of a Stirling engine. The liquid metal is evaporated from the backside of the solar absorber (the evaporator) and flows to the Stirling engine's heater where it condenses (condenser). The liquid is passively returned to and distributed over the evaporator by gravity (refluxing), capillary forces in a wick, or by a combination of the two effects.

The liquid metal intermediate heat transfer fluid permits, to a large extent, the independent optimization of the solar receiver and the Stirling engine's heater tubes. In addition, the high heat transfer and isothermal nature of evaporating and condensing metals is ideally suited to the thermodynamic requirements of Stirling engines and to the design of solar receivers. Isothermal operation has the important advantage of reducing thermal stresses and therefore increasing the potential for long life. Furthermore, fossil-fuel-fired heat pipes can in principle be readily combined with a reflux heat-pipe solar receiver to utilize solar and fossil fuel in any proportion (hybridization).

Conversion Devices Stirling engines have been identified as the most efficient power conversion unit for solar-electric systems (with an efficiency of 29%, a dish concentrator/Stirling engine system currently holds the world record for solar-to-electric power conversion). These engines are available in a range of sizes, 10 to 50 kWe, that is suitable for small-modular solar system, and they produce ac electric power that can be attached directly to utility grids. In addition, Stirling engines can be hybridized to run on both solar energy and natural gas, so the systems can produce power during low insolation periods.

Utility companies have exhibited a strong interest in purchasing Stirling electric systems, and U.S. manufacturers have shown an interest in producing the engines. Alternate uses of the engines (heat pumps, mobile power systems, etc.) will increase production quantities and lower the per unit cost. Development costs for Stirling engines is financed primarily by non-solar electric applications, but some additional development is needed to insure that the engines will be suitable for solar electric systems.

IMPLEMENTATION STRATEGY Continued development of central receiver technology utilizing molten salt working fluids requires advances in several areas: receivers (including improved performance, decreased costs, and improved lifetimes), materials studies, salt component scale-up (including pumps and valves), and development of advanced working fluids (with reduced costs and lower melting points). Continued monitoring and evaluation of advanced receiver programs, such as volumetric hot air, is also required to assure optimal program direction.

Because of budget limitations, our receiver development efforts are focussing on one area, the falling-salt-film DAR, which has the potential for meeting all program objectives in this area. Work is progressing to demonstrate the engineering feasibility of this concept by addressing all aspects of the technology in a coordinated Sandia/SERI program. Supporting materials work is in progress to investigate DAR dopant requirements and assess optical properties and long-term durability issues of DAR components. To address the issues of scale-up of salt system pumps and valves, we are currently testing components sized for use in a small CR plant. Upon conclusion of this accelerated lifetime testing and component demonstration, further testing of even larger components will be required to reduce risks associated with commercial plants. Finally, to reduce problems associated with the potential freezing of the working fluid (including heat trace requirements), we are investigating advanced molten salt working fluids which offer the potential of both reduced cost and lower freezing points.

DOE has begun a development effort for reflux receivers for dish electric systems. The objective of the reflux heat-pipe receiver task is to develop the tools and expertise to design and build long-lived, reliable, cost-effective receivers. An essential part of this effort is the development of reflux heat-pipe receiver technology. Specific objectives are listed below:

- Demonstrate the feasibility of reflux heat-pipe receiver technology by successfully testing at least one reflux heat-pipe receiver on a Test Bed Concentrator (TBC).
- Identify the best receiver design approach, e.g., wicked heat pipe vs. reflux pool boiler, wire screens vs. sintered powder wicks.
- Develop generic low-cost, high-efficiency, reliable reflux heat-pipe receiver technology for advanced Stirling solar conversion systems and other applications.
- Develop the technology to hybridize reflux heat-pipe receivers.

The reflux heat-pipe solar receiver program will be conducted in two phases. Three projects are anticipated in Phase I: (1) STM Receiver, (2) Reflux Pool Boiler Receiver, and (3) Alternative Wicked Heat Pipe Receiver. In the design, development, and testing of these three different approaches, it is anticipated that the first three objectives will be met. Each project will involve the testing of one or more receivers on a TBC.

In Phase II, a "best" receiver design will be identified, hybridized, and constructed, and made available for long-term testing. This will become the baseline receiver design that will be used in advanced dish-electric systems of the future.

Parallel materials studies to consider 20-year life in a sodium environment with thermal cycling will have to be deferred along with other long-term issues such as oxidation resistant and optical coatings, and gas diffusion through the receiver walls. Materials issues will be addressed by assessing the degradation of prototype receivers after testing and by derating receiver operating temperature.

Conversion Device development has, in the past, investigated virtually every noninternal combustion heat engine ever conceived. These have included steam turbines, piston steam engines, Brayton cycle turbines in many versions and sizes, organic Rankine cycle turbines, thermoelectric converters, sodium heat engines, thermionic converters, MHD, liquid metal thermal electric converters, regenerative thermal electric converters, and kinematic and free-piston Stirling engines. The key attributes for cost effective solar thermal conversion devices have been shown to be high performance at relatively low temperatures, durability and reliability with low maintenance, low production cost, and the prospect for ready availability from suppliers not completely dependent on solar thermal applications for sales.

Central receiver power plants will be based on large steam turbines of the type used in conventional steam power plants. Steam-injected gas Brayton systems are also attracting interest in the central receiver and convention power plant communities. Only minor special modifications are required for implementation and no R&D is judged to be necessary.

The Stirling engine has been singled out by distributed receiver developers for dish-electric systems. Stirling engines are the highest efficiency engines available for dish-electric applications. Cycle efficiencies can range to almost 50 percent. Only very large steam turbines can achieve similar efficiencies, and no other small engine can come close. Advanced engines now in development by the federal and private sectors are being designed for long life at very low O&M costs.

"Direct" converters such as RTEC and LMTEC operate with virtually no moving parts and offer the long-term prospects of being inherently maintenance free while still providing good performance.

The implementation strategy for dish-electric conversion is to pursue the engineering development needed to adapt Stirling engines being developed by non-DOE sources to solar thermal requirements. This approach is judged to provide the only possibility of technical readiness by the late 1990s. Two or three "generations" of Stirling engines will be built and tested, upgraded, and reevaluated. A series of about six field evaluation experiments is planned for initiation in FY93. These field experiments would probably be located at power utility companies' sites so that the Program can benefit from their perceptions on dish-electric power systems and also so that these institutions can become comfortable with solar thermal power. Several utilities have already expressed a willingness to participate.

The RTEC and LMTEC concepts, if exploratory development budgets permit research at the fundamental processes and device level, are hoped to be ready for engineering development in the FY92-93 time frame.

Operating and maintenance costs are two of the biggest uncertainties in the use of Stirling engines. To establish user confidence in the technology, the current program will purchase and operate existing kinematic Stirling engines. These engines will be adapted to solar collector systems and work will be conducted to improve overall system reliability and performance. The national labs in conjunction with NASA will also participate in the development of free-piston Stirling engines. The potential for lower maintenance and production costs makes free-piston engines an attractive option for future commercialization, but free-piston engines are in a much earlier stage of development and several uncertainties exist in increasing their performance. Manufacturers and utilities are participating in the development of both free-piston and kinematic Stirling engines.

TASK DESCRIPTIONS

The primary activities to be conducted within this mission include the direct absorption receiver for central receiver applications and the reflux receiver and a focal mounted conversion system for distributed receiver applications. Backing these up in later years, should the high-promise, high-risk developments prove over ambitious, would be alternative receivers such as a salt-in-tube receiver for central receivers or a conventional heat-pipe or gas-in-tube receiver for dish collectors. Out-year activities in a more optimistic vein include work on advanced receiver concepts.

Other key activities included in this mission include materials compatibility and materials properties support work; system integration support to properly interface receivers with concentrators, with conversion systems, and with balance of plant components; and the necessary STTF test and evaluation activities. This mission does not include the development of concentrators. These are developed as an across-the-board activity since concentrators are required for all Solar Thermal missions.

Task 1: Central Receiver Technology

Direct Absorption Receivers A number of technological uncertainties affecting DAR feasibility require resolution before the concept can be considered a commercial alternative. To address these uncertainties, a joint Sandia/SERI research and development program to determine DAR feasibility is currently under way. Current elements of this plan include materials compatibility and small-scale water and salt flow tests at SERI; large-scale water flow tests at Sandia; and design and fabrication of a large-scale salt flow and solar test at the STTF. These programs are part of a coordinated plan targeted to address all major uncertainties of the DAR (including flow stability, receiver design issues, and solar performance), and thus establish its engineering feasibility, by FY9O. Under the reduced target budgets of the MYPP, these goals will be delayed by up to 1 to 2 years. Once engineering feasibility has been demonstrated, scale-up testing to demonstrate commercial feasibility such as a full receiver test at Solar One) will be addressed.

Materials Compatibility A number of materials research issues need to be resolved as part of the DAR program. Ongoing work at SERI is addressing a number of these issues, including film absorptance and emittance (with and without dopant) and dopant properties (including interactions with salt, agglomeration, and preparation). Except for new issues, this work will be concluded in early FY89. Ongoing work will address dopant and salt chemistry issues unique to the DAR (including dopant corrosion, erosion, and lifetime and salt degradation in contact with air, carbon dioxide, and water vapor) on a larger scale and for an extended period of time (1-2 yrs). This extended flow loop testing will be conducted at the STTF.

System Integration The analytical and systems engineering work needed to properly interface the receiver with the tower, the storage subsystem, the controls and instrumentation, and with the balance of the piping system are included in this subtask. The activity will increase throughout the period covered by this MYPP as larger and more sophisticated experiments are undertaken. As technology readiness approaches, further development and refinement of critical balance-of-system components such as thermal storage systems, steam generators, and control systems will be needed.

Alternate/Advanced Receivers Fall-back positions such as salt-in-tube or internal film receivers may be necessary if the promise of the DAR concept is not fulfilled. Conversely, if budgets permit advanced concepts to be considered, an advanced gas receiver, as an example, or an as-yet unidentified concept could further improve the state of the art.

Pump and Valve Tests The current series of pump and valve tests are identifying many key technical challenges that must be resolved if salt is to become a viable heat transfer fluid for central receiver systems. These tests will be completed over the next 3 years, and a series of full-scale tests will be initiated in FY9l.

Advanced Heat Transfer Fluids A high-temperature heat transfer fluid with a lower freezing point than the current nitrate salts would greatly benefit the cost effectiveness of central receiver systems. Preliminary work has identified Hitec or calcium- or lithium-based ternary nitrate salts as potential candidates. Further experimental and systems work to investigate corrosion, fluid properties, and system compatibility issues will be required.

CRTF Support The STTF support needed to conduct all the experimental work outlined above is included in this subtask.

Task 2: Distributed Receiver Technology

Reflux Receiver The reflux heat-pipe receiver represents the next step in the evolution of Stirling receiver technology and has the potential to be an optimum match for the Stirling engine's capability and requirements. In addition, the reflux heat-pipe receiver may be readily applied to other solar thermal applications, with significant life and performance advantages over conventional tube receivers. In the reflux heat-pipe solar receiver, sodium and/or potassium is used as an intermediate heat transfer fluid between a solar receiver/absorber and the heater tubes of a Stirling engine. The liquid metal is evaporated from the solar absorber (the evaporator) and flows to the Stirling engine's heater where it condenses (condenser). The liquid is passively returned to and distributed over the evaporator by gravity (refluxing), capillary forces in a wick, or by a combination of the two effects.

Material Compatibility This work is a bare-bones effort to understand the materials issues in the reflux receiver.

Systems Integration The objective is to insure adequate matches with the concentrator and engine and involves development of control strategies and interface requirements. Performance assessment and providing fundamental information to systems analysis and optimization tasks (not included here) is also an objective of this task.

Alternate/Advanced Concepts In FY91-93, this work will develop either an advanced reflux receiver for a dish Stirling system, or an alternative receiver concept if for some reason reflux receivers prove not to be viable. The advanced reflux receiver would be a hybridized version of a second generation reflux receiver. It may also incorporate thermal energy storage if systems analysis indicates an advantage.

DRTF Support This activity provides test support to the previously outlined work, primarily the reflux receiver development.

Task 3: Conversion Devices

Stirling Engines In FY88 a Kinematic Stirling engine (STM4- 120) from Stirling Thermal Motors will be delivered to Sandia for bench testing (Milestone A). Through FY88 and FY89 the engine will be operated to gain experience and test control systems. In FY89 the STM4-I2O will be mated with a reflux solar receiver and tested on the TBC at Sandia (Milestones B, C, and D). In FY89 and beyond, the STM4-I2O could be tested with a parabolic concentrator developed within the program. Also, a second engine would be purchased and tested that will have upgraded technology.

Beginning in FY89 the preliminary design(s) of one or more Free-Piston Stirling Engines (FPSE) will start (Milestone A). This design will be carried through FY90 when the detailed design(s) of one or more FPSE will begin (Milestone B). In out years the fabrication and delivery of a FPSE to Sandia could be achieved.

System Integration In support of testing the kinematic Stirling engine at Sandia, control systems and integration with other components will be required. Prior to the delivery of the STM4-I2O, a control system developed by Sandia will be tested at Stirling Thermal Motors (Milestone A). During FY88 and FY89, the controls will be tested with the engine on the test bench and the TBC (Milestone B and C).

DRTF Support This task provides support for testing of the receiver and Stirling Engines and also for the integrated receiver engine combination.

MISSIONS

MISSION 1: NEXT-GENERATION USER SYSTEMS

GOALS 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 1990's through collaborative, cost-shared, near state-of-art R&D with an industrial partner.

Key Milestones:

- o Verification of approaches through pilot field tests - FY90.
- o Commercial implementatio of verified approaches - FY92.

RATIONALE AND BENEFITS Several private sector companies have succeeded in commercial deployment of solar thermal technology for the generation of electricity for sale to utilities. More than 140 MWe of capacity has already been deployed in California; an additional 440 MWe is under construction or being planned.

These companies have made great strides in improving the performance and reliability and in reducing the cost of the systems. Collector costs alone have decreased by factors of 5 to 10. Mass production, quality control during manufacturing and advanced control technology have also contributed to the success.

The success of future solar thermal electric generating plants will depend upon further significant gains in cost effectiveness to be competitive without the benefit of tax credits and with less attractive electricity purchase agreements than those currently in place. Furthermore, to benefit the commercial marketplace in the near future, the mission goals must be achieved by 1992.

IMPLEMENTATION This mission is structured about one or more collaborative R&D projects towards which the private sector partner(s) contribute at least 50% of the project cost. The majority of the contributions by the DOE will be spent in supporting an integrated R&D team consisting of staff from the SERI and Sandia. The private sector partners matching funds will be directed towards additional supporting R&D and/or development of a suitably-sized test section near a commercial plant. The mission will consist of two major tasks, as follows:

Effective technology transfer of the most up-to-date developments to the private sector will occur directly in this mission. Because of the substantial matching of R&D funds to be required, the partner(s) will be in the best position to utilize solar thermal technology in a commercial plant. Proprietary rights of the partner(s) will be respected; however, the resutls of any federally-funded R&D performed by Sandia of SERI in support of the partner(s) will be generally available to all interested parties.

TASK DESCRIPTIONS

Task 1: Project Development

Selection of Collaborative R&D Partner(s) A solicitation will be released to attract potential private sector partners. Responses will be evaluated both on technical merits and on the ability of a potential partner to meet the terms of the cost-sharing arrangement and to provide an appropriate site for the test section. One or more partners may be selected.

Review and Reporting Reporting requirements and reviews are as specified by the Uniform Reporting System (DOE 1332.1A) and Scientific and Technical Information Program (DOE 1430.2A) documents, per the Reporting Requirements Checklist (DOE F1332.1).

Task 2: Partner-Driver R&D

Tightly-focused R&D programs will be formulated to meet the specific needs of the partner(s). These needs will be addressed in a classical engineering approach, starting with preproduction development of components and proceeding logically through prototype manufacture and test.

Development and Design of Prototypes Achievement of the goals by 1992 will require new research directions. Multiple research and development directions will be required if a single approach is incapable of producing the degree of improvement needed.

Field Testing in a Power Plant Environment Initial testing at the component level having taken place in Subtask 2.1, more extensive testing will be conducted in a power plant environment. The test program will include investigation of component, subsystem and system performance, checkout of direct steam generation stability and control, investigation of automatic collector field control and determination of performance reliability and operational characteristics.

Final Design Based upon the results of the field testing, final prototype design will be conducted. A key element of this subtask will be the specification of manufacturing methods which will ensure cost-effective mass production.

Perform Large-ScaLe Reliability Testing The final configuration of the commercialized technology will undergo field testing for operation, performance and reliability at a power plant. If possible, this test system will be installed as a portion of an operating facility in order to function in an actual commercial environment. It is envisioned that this installation will be part of a commercial power plant. This large-scale test would consist of a subsystem which is sufficiently large for test purposes but would still comprise only a small percentage of the field of a full-scale commercial solar power plant.

Task 3. Design Assistance and CORECT Support

The objectives of this task are to accelerate the use of solar thermal systems through cooperative efforts with private industry, to assist and educate potential users, and to support industry and users in the selection, design, characterization, and demonstration of promising solar thermal systems. In order to be effective, the solar thermal program requires a continual flow of information between the program and industry and users. The program's dissemination of R&D results to industry, and the reciprocal communication of industry's needs to the program, are necessary to keep the R&D relevant and to ensure developments are rapidly implemented by industry. The design assistance task fosters this flow of information by providing direct technical assistance to industry as well as through conferences, workshops, and publications. The design assistance task provides an interface among CORECT, the solar thermal program and industry to foster near-term applications of solar thermal systems.

Technical Assistance A vital element of industrial assistance efforts is to work directly with industry by providing consultation on technology status, application screening, component and system performance predictions and design tools and handbooks. Utilizing the experience base of personnel and facilities at the federal laboratories, components and systems can be evaluated. Independent evaluation establishes user confidence and provides feedback to R&D. Industry recently requested such support in assessing new storage materials and approaches and their integration into higher temperature trough systems. Another industrial request was to make available the optical and structural analysis techniques and computer programs developed by federal laboratory personnel for solar concentrators. These and other broader based activities designed to assist industry by providing consultation on technology status, application screening, and component and system performance predictions will be provided on request and should enhance U.S. industry's ability to bring improvements of existing systems to the marketplace with higher confidence of success and better expectations of meeting the challenge of international competition.

Committee on Renewable Energy Commerce Trade (CORECT) CORECT represents a specific mechanism for supporting the solar thermal industry. A multiagency working group to support U.S. industry in facilitating the use of U.S. renewable energy technology in worldwide applications is already in place. Created by Congress in the Renewable Energy Industries Development Act of 1983, CORECT has focused primarily on export markets to make available to U.S. industry information and technical assistance directed toward potential users. Through this program, important information on export markets and domestic opportunities for renewable technology allows U.S. industry to clearly assess the market potential and establish the relevance of their technology to the specific applications. CORECT-generated data will be used more fully to target specific solar thermal system applications and to assist U.S. industry in exploiting commercial opportunities. CORECT has proposed specific tasks to be accomplished by the DOE solar thermal program. CORECT activities have already identified potential niche markets for immediate applications of solar thermal systems.

MISSION 2: PHOTOCHEMICAL SYSTEMS

GOALS 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.

RATIONAL AND BENEFITS The 20th Century in America is characterized by the ever-increasing use of resources. As a result, vast amounts of hazardous chemicals are accumulating in the air, land, and water to the point where, in the words of Russell Train, former Administrator of the Environmental Protection Agency, "Ultimately, nothing short of a second chemical revolution will gain control over toxic chemicals."

Recent estimates are that between 330 and 570 million tons of hazardous materials were generated in the U.S. between 1900 and 1980. And in 1988, the U.S. produced 280 million tons, more than enough to fill the Superdome in New Orleans 1500 times over. This estimate does not include the 2.5 million tons of contaminated soil awaiting destruction. Once these hazardous materials are produced, society is faced with their collection and storage, recycling, or disposal. Considering that there are more than 200,000 producers of hazardous materials in the U.S., and that more than a ton is produced for every person in the nation each year, dealing with these materials is a monumental problem.

When economical, hazardous compounds are usually recycled. However, the Environmental Protection Agency (EPA) contends that of the 280 million tons of hazardous materials generated each year that are subject to regulation, only about 1 million tons - or less than one-half of one percent - is recycled. Another 3 million tons (or less than 2%) is incinerated. The remainder are disposed of by dumping or discharging directly into the biosphere. About 39 million tons (14%) of concentrates are injected into deep underground wells. Another 33 million tons (12%), mostly sludges, are dumped into landfills. The final 204 million tons or nearly 73%, consist of wastewater contaminated with solvents, corrosive acids, metals, and other toxic substances.

The number of sites considered to be potentially hazardous has greatly increased in the past few years. In 1980, when Superfund was created, it was estimated that the U.S. had roughly 9000 problem sites. Six years later, the number had increased to more the 25,000. A recent estimate by the General Accounting Office (GAO) of the U.S. Congress identified 5,400 sites on federal land alone. Cleanup will cost "tens of billions of dollars" per year according to the GAO.

The solar photons contained in the near-ultraviolet portion of the solar spectrum are known to destroy hazardous chemicals. The use of a catalyst or sensitizer activated by the photons enhances destruction even more. Two solar-driven processes will be considered.

The first process is for low concentrations of organic chemicals in water that works at near ambient temperatures. Photons activate a semiconductor catalyst. Free hydroxyl radicals are generated which are able to completely convert a large variety of organic molecules to carbon dioxide, water, and simple acids.

The second concept uses highly concentrated solar flux at temperatures of over 1000°K to decompose or reform concentrated hazardous chemicals. Substitution of solar photons for more conventional processes has the potential to greatly reduce the consumption of energy produced by fossil fuels. Although estimates vary widely, it is likely that at least one to two quads per year may be saved at a minimum. Even beyond the possibility of photon-enhanced destruction of hazardous chemicals, direct absorption of concentrated sunlight on a catalyst-loaded ceramic matrix offers a distinct advantage over externally heated reactors by avoiding heat transfer limitations and, thereby, making possible effective reaction temperatures well in excess of 1200 K. This process promises to be efficient, inexpensive and reliable. In addition to hazardous chemical destruction industrial processes of interest include methanol production from methane, ammonia synthesis, production of hydrogen for coal and oil refining, decomposition of hydrogen sulfide, and water splitting. Potential benefits of solar-driven destruction include (1) greater destruction and removal efficiencies (DREs) at lower temperatures, lower costs, and higher energy efficiencies than with existing techniques; (2) fewer, if any, toxic by-products; and (3) applicability to the destruction of some hazardous materials such as dioxins for which no suitable process exists today.

IMPLEMENTATION STRATEGY There are two major paths that will be followed during the course of the mission.

The first path investigates the feasibility of destroying diluted hazardous chemicals in water. Substantial data exists in the literature and as a result of SERI and Sandia tests indicating that the process is feasible.

The second path, conducted in parallel to the first, initially investigates and characterizes two high-temperature photolytic and photo-catalytic processes to a point where sufficient knowledge is available to select one process over another for development at a pilot-plant scale.

Each path will be initially investigated by an integrated team of SERI/Sandia scientists and engineers. A key to success will be the continual involvement in all tasks of representatives from the private sector. Systems engineering and analysis will be required throughout all phases of the program. Systems issues include modeling of the overall destruction and annual system performance, chemical handling system; instrumentation; and incorporation of the regulatory, environmental and political acceptability into the final design.

Participation of private sector representatives and government regulatory bodies in all tasks will ensure that the technology conforms to their needs. The final confirmation of commercialability for any solar detoxification process will be obtained by testing under actual field conditions.

TASK DESCRIPTIONS

Task 1: Identification of Application Opportunities

Market Analysis -The objectives are to identify opportunities for applying solar thermal technologies to the destruction of toxic chemicals and perform systems analyses to define cost and performance goals. This task is oriented towards selecting and characterizing real-world opportunities toward which these processes can be developed so that pilot- scale and field experiments can be designed and constructed that will address the needs of these specific opportunities. The first work is to examine the size and structure of the current hazardous chemical generation and management industry with the goal of identifying promising areas for application of solar technology to guide the R&D. The study will include:

- types and locations of hazardous sources,
- structure and technology of current management/disposal industry,
- trends and expectations of the current market, and estimations of impacts of future regulatory actions (e.g. landfill ban) on the current market.

This information will be sought both in the literature and by developing contacts with important participants. This activity will be tightly focused on identifying market sectors that might be accessible to solar technologies.

The second activity under this subtask will be to analyze the potential of various solar technologies to successfully compete in the market sectors identified above. Annual system performance prediction will be an important part of this analyses. These analyses should provide the information required for making choices between potential market sectors and between competing solar technologies.

Technology Transfer Involve industrial and regulatory entities in this mission early in the R&D process, with the goal of inspiring cooperative ventures at the earliest practical stage.

Establish and cultivate contacts and information exchange with both government agencies (e.g. EPA) and interested industrial parties, including both hazardous waste management firms, hazardous waste generators with disposal/management needs and parties with interest in energy-related financial ventures. In addition to on-going information exchange, sponsorship of several joint industry/ government workshops is anticipated.

Mission Management The SERI and Sandia activity leader and coordinator will facilitate the tasks and activities described in this plan, and to provide a single focus for program leadership. The management activities for this task are expected to present challenges beyond those normally expected because of the need to mold the individual efforts at the two labs into a single well-conceived and strategically sound program. It is expected that these individual efforts can be directed so as to become complementary and mutually supporting. However, this will require frequent and regular contacts between the personnel at the labs and the management teams.

Task 2: Solar Processing of Dilute Organic Chemicals in Water

The photocatalytic destruction of organic chemicals, particularly chlorinated hydrocarbons, in water has been demonstrated at laboratory scale under both artificial ultraviolet (UV) sources and natural sunlight. The chemistry of many of these decomposition processes has been sufficiently explored to where it is possible to extrapolate to larger scale. A pilot-scale experiment, using concentrated sunlight, will allow many engineering issues to be addressed. These include the effect of varying solar concentration on the reaction rate and process efficiency, the effect of contaminants on the process other than the target chemical, methods of recycling or immobilizing the catalyst to simplify the process, and investigating different reactor configurations. Industrial observers will be involved at the pilot-scale to ensure that the needs of this market sector are addressed.

The final step will test the photocatalytic process in a real-world situation, operating at or near a contaminated water source. Industrial observers will also be involved at this stage to help assess the performance and cost effectiveness of the solar detoxification process compared with more conventional alternatives. A site will be selected where a competitive technology is in use, to attain a one-to-one comparison.

The performance result and design data obtained from the pilot and field-scale experiments will be transferred to potential industrial users.

Task 3: High-Temperature Solar Processing of Hazardous Chemicals

The main objective of this task is to test a pilot-scale plant for destroying hazardous chemicals in a commercial situation by 1992. High-temperature photolytic and photocatalytic decomposition or reforming of organic compounds under artificial light has been demonstrated in the laboratories at Sandia and SERI for a limited number of compounds. Field testing using solar furnaces at Sandia and White Sands is now being conducted to confirm the photolytic and photocatalytic effects under natural sunlight conditions. Experiments and calculations conducted at Sandia have demonstrated that the solar unique ability to heat reaction sites directly can lead to compact, efficient, and extremely effective chemical reactors.

A substantial number of research issues remain to be answered before industry can be induced to apply these technologies in a commercial situation. First, sufficient testing must be completed to define solar enhancements and to characterize the relative performance, versatility, and cost effectiveness of each effect at pilot-plant and commercial scales.

Engineering issues, such as scaleability and design of reactors and the potential annual system performance, also need to be addressed both analytically and experimentally. The CAESAR experiment, a dish mounted 100kW solar driven reactor, will address many of these issues. The Sandia solar furnace will allow many of these issues to be addressed at a modest scale.

MISSION 3: ADVANCED ELECTRIC TECHNOLOGY

GOALS This mission will establish cooperative-venture 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 market place. This mission will thus establish the manufacturing infrastructure and 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.

RATIONALE AND BENEFITS The importance of this mission lies in the need for the near-term development and fielding of critical components (e.g. low-cost concentrators, receivers, and conversion devices) for solar thermal energy systems. This can best be accomplished by developing a near-term, joint-venture project that involves the installation and operation of a solar electric system that uses a significant number of the solar unique components. Solar systems must be fielded in order to enter the component manufacturing learning curve so that volume production will eventually reach the solar thermal program cost and reliability goals. The power rating, costs and performance of the near-term plant must be acceptable to the joint venture investors. The near-term collaborative project will establish an industrial base, provide valuable system performance data, and will reduce the risk for private ventures that will follow.

IMPLEMENTATION STRATEGY During the first year, Sandia and SERI will work closely with industry to identify solar electric systems that can compete in the near term (5 years). Following this effort, a request for proposal will be issued which is intended to result in the formation of joint venture consortia for the development and fielding of a system experiment.

The initial effort will identify a number of proposed system experiments and recommended development required to reduce the technical and economic risk. The proposed systems will be carefully scrutinized by Sandia, SERI, and contracted participants to ensure that all of the technologies are fairly compared. Based on this evaluation, a technological concept will be selected for the system experiment. The criteria used for selecting the concept for the system experiment will be:

- Ability of the technology to penetrate a significant size (multiple plants) market following a successful system experiment.
- Ability to perform cost-effectively in the selected marketplace.
- Ability of the private sector partner to make substantial financial and in-kind contributions.
- Extent and cost of the preliminary research and development, if any is required to reduce the risk of the proposed system experiment.
- Degree to which the candidate system will reduce the cost and advance the performance of the critical solar thermal components.

If none of the candidate systems and market scenarios meet these criteria, this near-term activity will end and resources will be redirected into one of the other missions or research tasks. However, if one of the proposals can meet these (and other) criteria, a major program will be undertaken to field the selected system and thus transfer the technology to the private sector. The success of this mission in engaging private sector partners will substantially influence priorities in the Core Research activities.

The Field Management Council will assess the technology selection process along with the commitment of the consortia. It will also review supporting Core activities on a regular basis, and will provide recommendations to Headquarters that support this mission.

Building, operating, and characterizing the system experiment will be the primary mechanism for technology transfer to the private sector. Capital and O&M costs and the reliability and performance data will be available to the public in DOE reports. The project will be a public show case for state-of-the-art solar thermal electric technology.

TASK DESCRIPTIONS

Task 1: Technology Identification

This will provide input to determine the necessary steps to be taken in order to field a near-term solar thermal electric system experiment. Potential solar electric applications will be identified and evaluated through the procurement processes presently established within the DOE/SNL/SERI complex. The identification criteria will include market potential, technology readiness, development requirements and the formation of joint-venture consortia. The task will lead to the selection of a technological concept for a system experiment.

Task 2: Joint Venture Consortia

This mission requires government and private resources for implementation. Based on the results of Task 1, potential consortia members will be encouraged to align themselves in order to field a high potential near-term solar thermal electric system experiment.

Task 3: Development Requirements

Developmental requirements will be established by the consortia members, and will be used to direct the core activities. These directed R&D activities in the core program will be aimed at removing the technical, reliability, or risk problem(s) identified by the consortia.

Task 4: System Experiment

This activity will field a cost-effective system experiment within the next five years. The importance of this mission lies in the need for the near-term development and fielding of critical components (e.g., low-cost concentrators, receivers, and conversion devices) for solar thermal energy systems. This can best be accomplished by developing a near-term, joint-venture project that involves the installation and operation of a solar electric system that uses a significant number of the solar unique components. Solar systems must be fielded in order to enter the component manufacturing learning curve so that volume production will eventually reach the solar thermal program cost and reliability goals. The power ratings, costs, and performance of the near-term plant must be acceptable to the joint venture investors. In particular, near-term plants must produce energy cost effectively in the selected market place. The near-term collaborative project will establish an industrial base, provide valuable system performance data, and will reduce the risk for later private ventures that will follow. Results from the previous tasks will be used by the consortia in FY91 to decide whether to proceed with the system experiment. The consortia will be responsible for the funding, design, construction and operation of the plant. DOE laboratories will provide design assistance and evaluation of performance throughout the experiment. These laboratories may also contribute specific components or subsystems.

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