Central Receiver Development Plan 1988-1989

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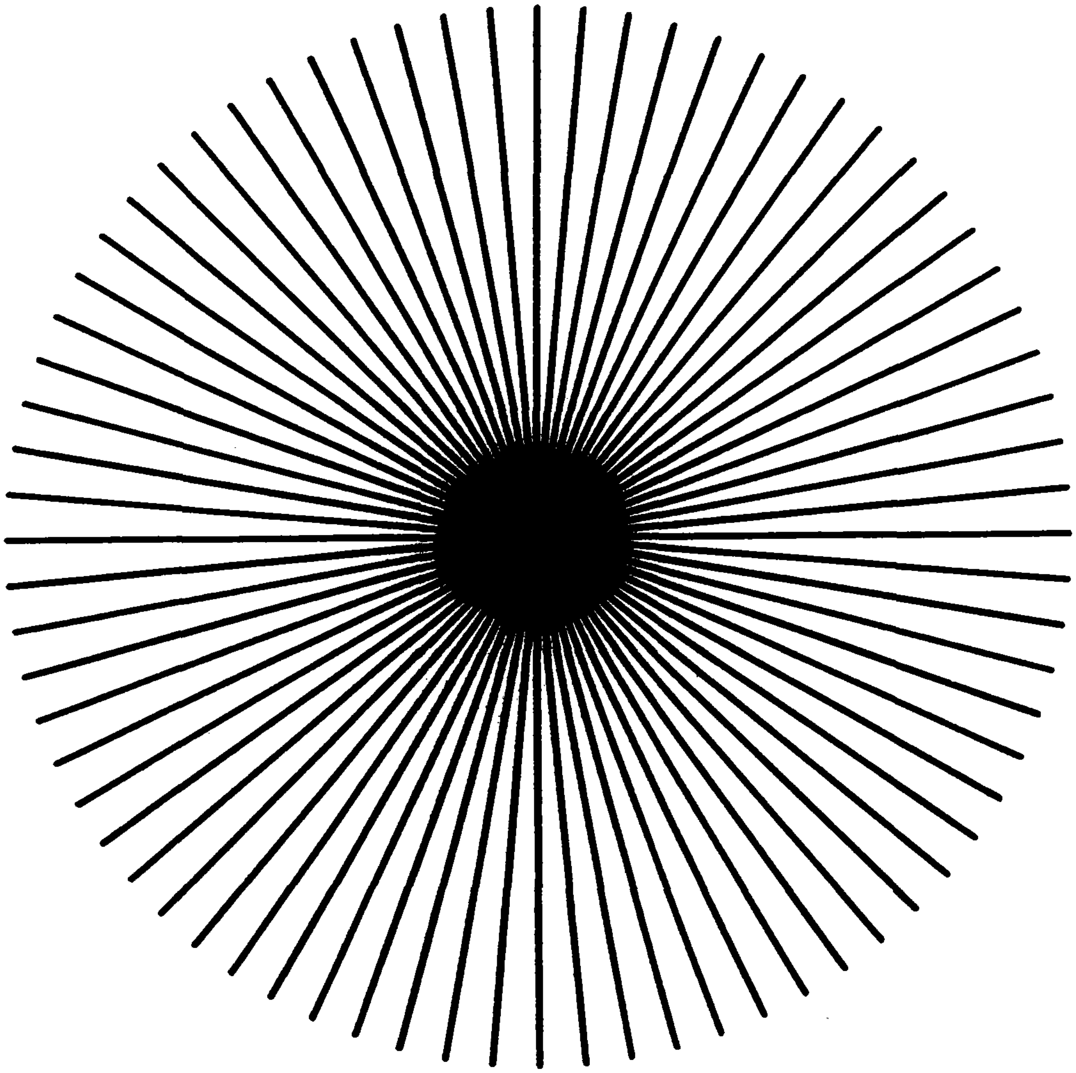
Sandia National Laboratories



National
Solar Thermal Technology
Program

CENTRAL RECEIVER DEVELOPMENT PLAN 1988-1989

FY88 ANNUAL OPERATING PLAN
SANDIA NATIONAL LABORATORIES

Central Receiver Research and Development

September 1987

SOLAR ENERGY DEPARTMENT
SANDIA NATIONAL LABORATORIES
ALBUQUERQUE, NEW MEXICO 87185

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FOREWARD

Sandia National Laboratories supports the concept of a two-year development plan. In this issue of the plan, however, budget amounts are given for FY88 only, and the narratives emphasize FY88. The reason for this is that the FY89 amount is uncertain. It is the intent of the Laboratory to incorporate planning for FY89 in future issues of this document.

CONTENTS

1.0 INTRODUCTION AND PROGRAM OVERVIEW

This document describes activities for Fiscal Years 1988 and 1989 in the National Solar Thermal Technology Program to be performed by Sandia National Laboratories for the development of Central Receiver technology.

1.1 Purpose of Annual Operating Plan

This Plan is the Central Receiver Annual Operating Plan for Sandia National Laboratories. It references other operating plans (specifically, the plan for activities at the Albuquerque Office of the Department of Energy) which include work related to Central Receivers in order to provide an overview of all Central Receiver technology development activities.

Solar thermal research and technology development are carried out under the direction of the Division of Solar Thermal Technology at the Department of Energy. Other organizations involved with implementing the solar thermal technology program and their specific responsibilities are shown in Figure 1.

This Central Receiver Development Plan has been prepared to accompany the Distributed Receiver Development Plan also prepared by Sandia National Laboratories and the Research Plan prepared by the Solar Energy Research Institute. The three program plans describe the specific activities to be carried out in FY88 and FY89 to meet the objectives of the National Solar Thermal Technology Program as stated in its Five Year Research and Development Plan. Although this document serves as the FY88 Annual Operating Plan, it also describes activities for FY89. This approach provides continuity since actual research and development activities are planned at least a year in advance and then revised before being carried out.

1.2 Relationship of the Program to the Five Year Plan

The controlling document for long-term planning is the Solar Thermal Technology Program Five-Year Research and Development Plan. The plan establishes overall program goals consistent with national energy policy and provides five-year and long-term quantified goals for both total systems, subsystems, and components. This plan is updated annually to reflect progress and new budget impacts.

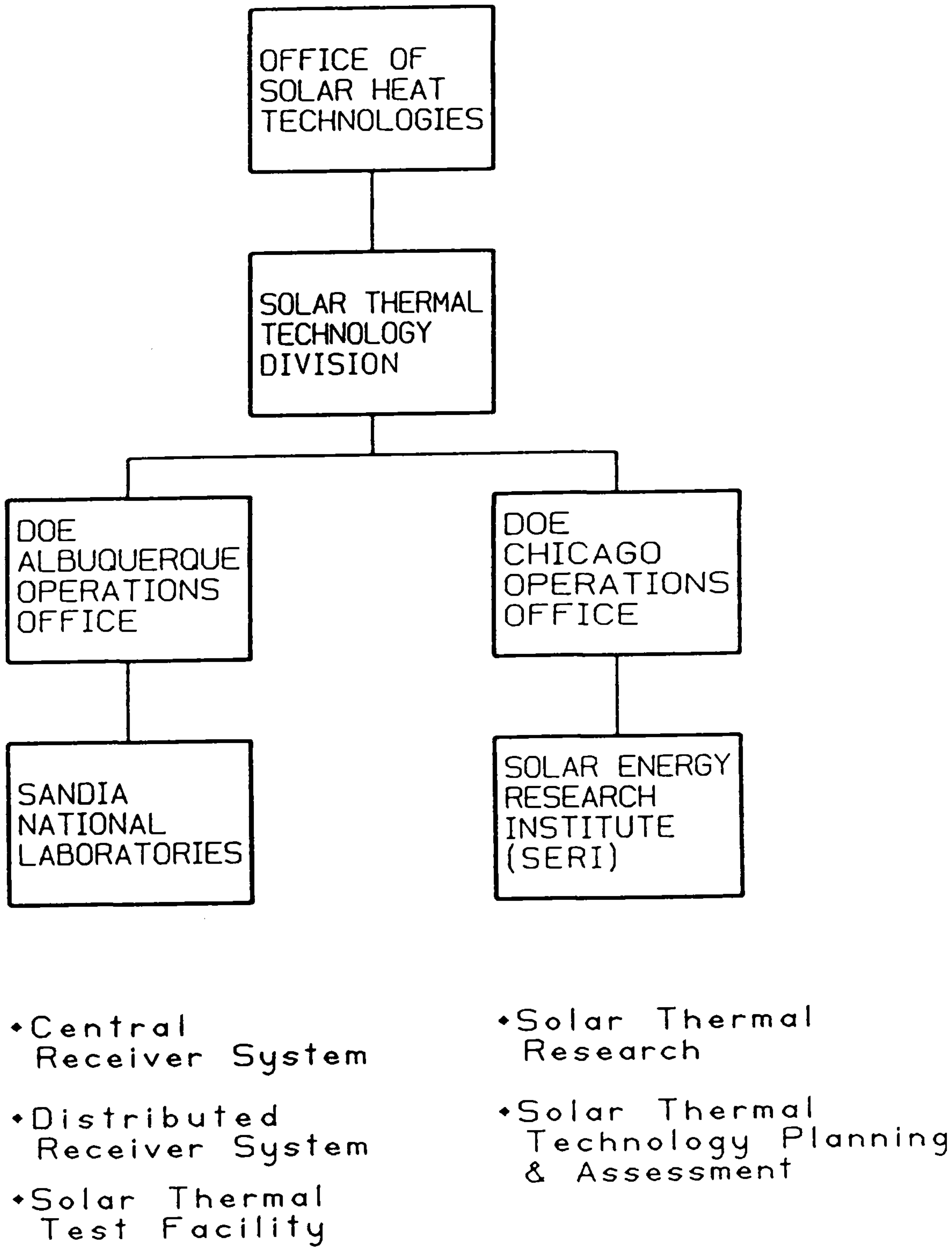

Figure 1. Solar Thermal Technology Organizational Structure And Responsibilities

To contribute to an adequate national energy supply at reasonable prices, solar thermal energy must eventually be economically competitive with other energy sources. System-level performance targets expressed in terms of solar thermal capital cost, efficiency, and energy cost have been developed to meet the need for quantitative program goals. These targets are used to evaluate alternative system options and to guide component research and development decisions.

Research and development activities are structured as tasks specifically directed toward achieving these targets. The tasks fall into the general areas of collection technology, energy conversion technology, and systems and applications technology.

THE MAJOR TASKS OF THE SOLAR THERMAL TECHNOLOGY PROGRAM

Collection Technology

1. Optical Materials
   Development of materials for the reflective surface of concentrators or the transmissive and absorptive components of receivers

2. Concentrators
   Development of heliostats, dishes, and troughs (not including receivers)

3. Receivers
   Development of components which convert solar radiation into thermal or chemical energy

Energy Conversion Technology

4. Heat Engines
   Development of components which convert thermal energy into electricity or shaft power via thermodynamic processes

5. Direct Conversion Technology
   Development of components that convert solar radiation into electricity or chemical energy without the use of a heat engine

6. Transport and Storage
   Development of components which convey energy to the eventual consumption point or allow delay of its usage Systems & Applications Technology

Systems & Applications Technology

7. Innovative Concepts and Applications
   Entry point activities for promising component and system concepts which constitute major departures from conventional solar thermal technology

8. Balance of Plant
   Development, characterization and optimization of other components necessary to construct and operate a complete solar thermal facility

9. Central Receiver Systems
   Activities related to the analysis and development of Central Receiver applications from a system perspective

10. Distributed Receiver Systems
    Activities related to the analysis and development of dish and trough applications from a system perspective

11. System Experiments
    Activities related to the design construction, startup, operation, and testing of solar thermal installations.

1.3 Goals, Objectives, and Strategy

The objective of the Central Receiver program is to establish the technical and economic feasibility of the Central Receiver concept. Through the performance of applied research and engineering development, the federally-funded efforts are organized to achieve the goals of Central Receiver-supplied electricity and thermal energy as described in the Solar Thermal Technology Five Year Research and Development Plan.

Specific near-term goals for the Central Receiver program are established on a yearly basis. These goals are designed to keep the program moving toward the long-term goals described in the approved Solar Thermal Technology Program Five-Year Research and Development Plan. The long-term goals are themselves consistent with the overall program goals of the national energy policy.

The strategy of the Central Receiver Development Plan, described later in this section, is the guiding mechanism for selecting activities and near-term goals that will lead to the successful accomplishment of the long-term goals.

Specific goals that will be addressed in FY88 and FY89 are summarized below. More detailed descriptions of the goals are given in each task description later in the plan. The summary of the goals is followed by a discussion of the strategy which is used to implement the Central Receiver program.

FY88 and FY89 Program Goals

Task 1 Optical Materials

Silvered Metal Mirrors

- initiate commercialization of sol gel protected, silvered metal foil for use on membrane heliostats (FY89)

Task 2 Concentrators

Heliostats

- evaluate performance of large area and stretched membrane heliostats at CRTF
- reduce cost while maintaining accuracy and longevity
- initiate study of "commercial heliostat" in FY89
- evaluate prototype low-cost drive system for pedestal-mount heliostats
- initiate collector cleaning development program

Task 3 Receivers

- reduce construction and operation cost while optimizing performance and longevity
- identify advanced receiver designs and materials for long-term applications
- conduct a large DAR water test
- design and build a $3MW_t$ DAR solar receiver test for FY89

Task 6 Transport and Storage

- address important technical risks for near-term molten salt technology by testing full scale pumps and valves

- investigate salt/water and ternary salt solutions

Task 8 Balance of Plant

- utilize dynamic simulator developed in FY87 to study control and performance issues in Tasks 3 and 9

Task 9 Central Receiver Systems

- investigate optimum applications and support central receiver component development through system trade-off studies

- provide technical support to the utility based teams studying the development of near-term central receiver electric power production

Task 9A Central Receiver Test Facility

- maintain and operate the Central Receiver Test Facility in support of the Central Receiver technology program:

  - upgrade heliostat field controls

  - relocate control room to observation tower

  - complete new heliostat evaluation system

Task 11 Systems Experiments

- provide technical support through the semi-commercial phase of the 10 MWe Solar Thermal Central Receiver Pilot Plant (Solar One)

2.0 CENTRAL RECEIVER TECHNOLOGY STATUS

This chapter reviews the current status of Solar Central Receiver Technology to provide a foundation for understanding the future direction, tasks, and goals of the Central Receiver program.

Central Receiver research and development includes the development of designs, the analysis of parameters, and the experimental testing of components, subsystems and systems. The 10 MWe Solar One has demonstrated the concept of electric power production using the steam-Rankine conversion cycle with water/steam serving as the receiver heat transfer fluid. The 750 kWe Molten Salt Electric Experiment (MSEE) and the advanced salt receiver experiment have demonstrated the technical feasibility and advantages of using molten salt as a heat transfer fluid and storage medium. At the International Energy Agency/Small Solar Power Systems (IEA/SSPS) project in Almeria, Spain, a number of countries including the United States completed testing of a 0.5 MWe central receiver system using sodium as the heat transfer fluid.

Research and development on Central Receiver systems has in recent years produced cost reductions based upon improved designs and operational experience. Individual heliostat costs have decreased from over $\$1000/m^2$ to current quotes of near $\$150/m^2$. At the same time the reflectivity of mirror surfaces has increased from 70% for the earlier systems to over 90%. During the course of the program, the heliostats used have constituted 30-50% of the total power plant cost and have been the principal cost reduction target. Research has shown that improved system performance and lower costs can be achieved with heat transfer fluids such as sodium or molten salts due to their better heat transfer and thermal energy storage characteristics. Advances in component cost and performance have reduced energy costs, while increased reliability and system operating experience have significantly reduced O&M expense and downtime. These advances during the last 10 years have decreased overall energy costs from $1.25/kWhe to an estimated $0.13/kWhe (levelized in real dollars) for currently proposed solar electric power plants.

Major achievements and status in the Central Receiver program are summarized below.

Concentrators

- Glass/metal heliostats have increased in size from 37 m^2 to 200 m^2 reflective area while the cost has been reduced to about \$150/m^2.

- Two 50 m^2 stressed membrane mirror modules have been fabricated and installed at the CRTF. These modules by Solar Kinetics, Inc. and Science Application International Corp. will be evaluated during FY88. The stressed membrane concept has the potential of reducing heliostat costs to the \$40/m^2 range.

- Solar Kinetics, Inc. and Science Application International Corp. have recently been contracted to design and build second generation prototype stressed membrane heliostats.

- Additional cost reduction is being sought through a "Low Cost Heliostat Drive" development contract with Peerless Winsmith.

- SERI and Sandia have jointly started a mirror cleaning program which will apply to heliostat, dish trough and PV concentrators.

Receivers

- The Central Receiver Test Facility has been used to demonstrate the feasibility of hot air, water/steam, sodium and salt receivers in the cavity and/or external configuration. These experiments were forerunners to the Solar One, Molten Salt Electric Experiment and IEA/SSPS system projects. Testing of an advanced molten salt receiver, which is a prototype of commercial designs, will be concluded in FY88.

- A Direct Absorption Receiver will be designed, built and tested during FY88 and FY89.

Transport and Storage

- The following storage subsystems have been successfully demonstrated:

  Oil/rock
  Sodium
  Nitrate salt

- A full scale molten salt pump and valve experiment will be concluded at the CRTF in FY88.

Balance of Plant

- A real time control "dynamic simulator" is being used to guide future system performance studies and control system development.

Systems

- Construction, evaluation and operation of four separate pilot plants have demonstrated then technical feasibility of Central Receiver technology while using water, salt and sodium as the heat transfer fluid.

- Two separate utility based teams are currently performing conceptual designs of full scale power plants using Central Receiver technology.

3.0 CENTRAL RECEIVER PROGRAM STRUCTURE

Solar Central Receiver program activities are oriented toward the achievement of the goals delineated in the Five Year Research and Development Plan. In fiscal years 1988 and 1989, Sandia's Central Receiver activities fall into seven of the eleven solar thermal task categories.

The seven Central Receiver research and development tasks are:

Task 1	Optical Materials
Task 2	Concentrators
Task 3	Receivers
Task 6	Transport and Storage
Task 8	Balance of Plant
Task 9	Central Receiver Systems
Task 9A	Central Receiver Test Facility
Task 11	System Experiments

Specific activities in each of these tasks together with their respective resource requirements are described in this chapter. The task and subtask structures used to organize these descriptions are listed in Table 1.

TABLE 1

SOLAR CENTRAL RECEIVER TASK AND SUBTASK STRUCTURES

Task 1* OPTICAL MATERIALS

- Silvered Metal Reflectors

TASK 2. CONCENTRATORS

- Stressed Membrane Heliostat
- Large-Area Glass/Metal Heliostat
- Low Cost Tracking Drives
- Cleaning
- Commercial Heliostat

TASK 3. RECEIVERS

- Advanced Molten Salt-in-Tube Receiver Extended Test
- Direct Absorption Receiver
- Materials
- High Temperature Receivers

TASK 6. TRANSPORT AND STORAGE

- System Thermal Conditioning
- Full Scale Molten Salt Pump and Valve Experiment
- Heat Trace

TASK 8. BALANCE OF PLANT

- Controls and Automation

TASK 9. SYSTEMS STUDIES

- Utility Study Support
- Annual Energy Improvement
- Applications
- International Activities

TASK 9A. CENTRAL RECEIVER TEST FACILITY

- Operation Maintenance Upgrades

TASK 11. SYSTEM EXPERIMENTS

- Solar One Technical Support

*The Task numbers are those used in the National Solar Thermal Research and Development Technology Program Plan.

3.1 - TASK 1 - OPTICAL MATERIALS

Low cost, high performance reflective materials are needed to achieve the cost and performance goals of Central Receiver heliostats. SERI is responsible for the development of long-life silvered polymer films. Laboratory work at Sandia over the past few years has shown that smooth metal can be used as the substrate for silvering if the metal is smoothed by a sol gel process that deposits silica on the metal and the silver is protected by a similar sol gel coating or sputtered silica. The laboratory developments will continue in FY88 supported by the Solar Thermal Distributed Receiver and Central Receiver programs.

In FY89 the process will be started to bring the sol gel treated metal mirrors out of the laboratory and into commercial production. In FY88 we will share our resources with the Distributed Receiver program to achieve that goal. FY88 tasks will include reviewing industrial capabilities for mass producing mirror material by the sol gel methods.

Task 1

FY88 - Resource Allocation - Optical Materials

Internal ($K)	
External ($K)	50
Total	50

3.2 - TASK 2 - CONCENTRATORS

The solar concentrators in Central Receiver systems are the heliostats. Heliostats comprise the single largest hardware cost element of a Central Receiver system and their performance has a direct effect on overall system efficiency. Therefore, attainment of the long-term cost and performance goals require that more efficient, durable and cost effective heliostat designs be developed. Current heliostat technology is based on the use of silvered-glass reflectors. These heliostats have been under development since about 1973. This silvered-glass technology has been used and improved by private industry (Arco Solar). Current estimates of costs for silvered-glass heliostats are about $150/m^2 at moderate production rates. It is estimated that mass production could reduce the cost to about $80/m^2.

To obtain the long-term cost goal of $40/m^2, the program will require the development of innovative concentrators utilizing lightweight reflective surfaces and improved drive systems. Promising design concepts, such as polymer film reflectors on a thin stressed metal membrane are now entering the early phases of development.

Stressed membrane mirrors are much simpler and lighter than silvered-glass modules; their weight per unit reflector area should be approximately one-third that of glass/metal. The lower weight will result in lower hardware costs. In addition, field assembly and checkout of stressed membrane heliostats will be less costly than for glass/metal heliostats because there are no individual mirrors to attach and optically align. When fully developed, stressed membrane mirror modules coupled with low-cost pedestal drive mechanisms offer to meet the long-term heliostat cost goal of $40/m^2.

The overall strategy for achieving the cost and performance goals is to continue the stepwise improvements in glass/metal technology while also pursuing innovative concepts that have the potential for dramatic cost reductions. Work in the FY88 and FY89 Central Receiver program will be directed at specific improvements not being explored in industry. Efforts will be focused on developing durable heliostat designs that are simpler, lighter in weight and, therefore, less costly to produce. Major activities in FY88 and FY89 include testing and evaluation of large-area glass/metal heliostats, evaluation and further development of stressed membrane heliostat designs, and development of a low-cost heliostat drive mechanism. Because heliostat performance has a direct impact on overall Central Receiver plant performance efficiency, cost effective cleaning systems will be studied for large-area glass/metal and stressed membrane heliostats.

Large-Area Glass/Metal Heliostats - One approach to cost reductions for heliostats that has been developed in the private sector is the design of heliostats two to four times larger than those developed in early DOE programs. Estimates indicate that the cost per unit area of mass-produced, large-area heliostats can reduce the costs to about $80/m^2.

To evaluate their performance and potential cost savings, two large-area heliostats have been purchased through competitive industrial procurement. One heliostat, with an area of 150 m^2, was purchased from Advanced Thermal Systems, Inc. The second, a 200 m^2 prototype, was built by the Solar Power Engineering Company, Inc. Both were delivered to the CRTF in FY86. The test and evaluation program will be completed on the large-area heliostats during FY88. A major question to be addressed is the optical performance and survival of large-area glass/metal heliostats under field operating conditions (especially wind loads) as compared to smaller heliostats tested previously. Minor structural modifications may be incorporated to optimize the performance of the prototypes.

Stressed Membrane Heliostats - The stressed membrane mirror modules consist of a silvered polymer film mirror supported by a thin metal membrane stretched over a large diameter ring. A second membrane is stretched over the backside of the ring. Air pressure (vacuum) between the membranes controls the heliostat's focal length as well as defocuses the reflected image upon command. Due to weight reduction and design simplification, the production cost for stressed membrane heliostats is estimated to be 30-50% less than for glass/metal heliostats of the same size.

Two development contracts were awarded to industry to study the design, manufacturing and cost of stressed membrane mirror modules. The contracts are with Solar Kinetics, Inc. and Science Applications International Corp. In addition, each contractor designed and built a 50 m^2 prototype stressed membrane mirror module. These mirror modules were installed on existing heliostat drives at the CRTF for test and evaluation.

In FY87 the first aluminum membrane mirror module was under evaluation at the CRTF. The first steel membrane mirror module was of poor optical quality and was not evaluated. Based on the cost and performance promise of the membrane mirror technology, a decision was made to improve both the steel and aluminum commercial designs and to build second 50 m^2 prototype mirror modules for evaluation in FY88. The designs were initiated in late FY87. The goal of the work is to bring one or both concepts to the point where performance and cost goals can be met. The results of these second prototype module programs, in addition to the FY88 and FY89 budget, will determine the future course of action as concerns the steel and aluminum commercial design program. If both designs prove favorable, it is hoped that FY88 and FY89 funds can be budgeted to support them into the next phase of development.

An initiative by the Pacific Gas and Electric Co. in FY88 to gain experience with membrane heliostat technology will be supported, if funded by the California Energy Commission, in order to gain additional in-field experience. Sandia will provide in-kind technical support regarding the performance characterization and testing.

Low-Cost Tracking Drives - After the mirror module, the heliostat drive mechanisms are the second most costly component of a heliostat. A multi-year effort is currently underway to develop a low-cost heliostat drive. The anticipated result of this effort will be to bring the per unit mirror area production costs of heliostat drives down to about $14/$m^2$.

In FY87 a contract was placed with Peerless-Winsmith, Inc. for development of an innovative low-cost drive for a 150 m^2 pedestal-mounted glass/metal or stressed membrane mirror module.

The design phase of the low-cost heliostat drive program was completed in FY87. Prototype drives will be built and tested under real and simulated gravity and wind load conditions in FY88. This work is being coordinated with the needs of the solar photovoltaic and solar distributed receiver programs.

Work in FY87 indicated that the cost goals can be achieved. Prototype evaluations in FY88 will confirm the performance requirements. It is possible a design and prototype itteration will be required at the end of the FY88 test program if some performance goals are not met. Assuming the cost and performance goals for the pedestal drive will be met, it is unlikely that other drive concepts (non-pedestal, rim drives) will provide more than marginal overall cost and performance benefits to the heliostat development program. The low-cost pedestal drive mechanism will become the baseline drive concept for glass/metal and membrane mirror modules.

Reflector Cleaning - Mirror reflectivity has a direct effect on overall system performance efficiency. Methods will be sought to cost-effectively clean advanced heliostat designs that incorporate large areas (40 to 50 foot tall structure) and/or polymer film reflectors. This effort will be initiated in FY88 and will draw heavily on prior work at Solar One and research at SERI. A joint SERI and SNL program was developed in FY87 to address the important aspects of the soiling and cleaning issue. The large-area and stressed membrane mirror modules at the CRTF will be used in FY88 to evaluate potential cleaning methods.

Commercial Heliostat Development - Based on the results of the above component development programs, a competitive request for quotation may be placed in FY89 for the study of the effects of integration of the best state-of-the-art components on the potential performance and production costs of an "optimum" heliostat. Based on these study results, prototypes may be fabricated and evaluated after FY89.

Task 2

FY88 - Resource Allocation - Concentrators

Internal ($K)	680
External ($K)	700
Total	1,380

3.3 - TASK 3 - RECEIVERS

Receivers convert 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 receivers operate at temperatures near 600°C with efficiencies between 75 and 90%. Consistent with the five year goals, receiver research and development focuses on: receivers operating at moderate (600°C) temperatures in the near term, and receivers operating at high temperatures in the long term.

Over the past ten years, extensive development has been done on receivers operating below 600°C. This work will continue to be the principal focus of receiver development in the Central Receiver program since the 600°C receivers enable electricity production through coupling with the common Rankine-cycle steam turbines or use in intermediate temperature industrial processes. Emphasis will be on improving the reliability and decreasing the fabrication cost of moderate temperature receivers. The development path outlined is intended to achieve the long-term goal of $30/m^2. In the nearer term, the goal is to reduce receiver costs to $45/m^2 and improve performance to 90% or higher.

The second area of receiver research and development is high temperature receivers. These activities have the goal of extending the temperature capability of Central Receivers to 800-1000°C with up to 90% efficiency. High temperature receivers have a potential for making Central Receiver technology suitable to many new process heat, fuels and chemicals, and high-efficiency electric conversion applications.

Receiver development activities include continuing the testing of the advanced molten salt-in-tube receiver subsystem, a solar research test of a direct absorption molten salt receiver concept that promises to meet the long-range program goals, and assessment of high temperature work at SERI, in Europe and in Israel.

<u>Advanced Molten Salt-in-Tube Receiver</u> - The Molten Salt Subsystem Component Test is directed at the resolution of technical uncertainties currently associated with conventionally designed molten salt-in-tube receivers, subsystems and components. In addition, this work provides a sound technological base for development of molten salt Central Receiver systems and supports the design for advanced central receiver plants. This work is a joint, cost-shared effort among industry, utilities, and the DOE.

In April 1984, a contract was initiated for the design, construction, and testing of an advanced 5 MWt molten salt receiver (prototypical of expected commercial receivers) at the Central Receiver Test Facility (CRTF). Design of the receiver was completed in February 1985 with procurement and fabrication of the hardware complete in September 1985. The advanced subscale molten salt receiver consists of absorber panels designed and fabricated by two different manufacturers. Incoloy 800 was selected as the tube material. The panels are arranged in a cavity configuration with wing panels. The receiver has been in the performance characterization phase of testing during FY87. The advanced receiver replaced the previously-tested, flat panel Martin Marietta molten salt receiver, thus enabling a direct comparison of the performance of the two receivers.

Performance testing of the receiver was completed in early FY88. A decision not to proceed with the extended test of the current receiver was made in early FY88 as a result of recommendations from the Utility Studies (Task 9) and on the FY88 budget.

Direct Absorption Receiver - Major cost and performance improvements to receiver technology can be achieved by use of a Direct Absorption Receiver (DAR) concept. The DAR eliminates the metal tube used to contain the salt in current receiver designs. The DAR uses a blackened nitrate salt that flows in a thin film down a near-vertical panel and is directly heated by the solar beam. Higher solar flux densities can be accommodated, thus reducing the size and cost of the receiver. The performance is improved via lower optical and thermal losses that result from high absorptivity and lower surface temperatures.

The DAR is the only current receiver concept that promises to achieve the long-range program goals. However, the DAR has significant, as yet unanswered, technical uncertainties including: practical salt blackeners, salt film stability in variable flux densities and in wind, backing panel and salt distribution manifold designs, and practical maximum operational flux densities. Prior small scale work at SNLL with nitrate salts, and at SERI with carbonate and nitrate salts indicates that these uncertainties will not prevent achieving the improvements promised by the DAR.

A joint, three-year research and development plan between SNL and SERI has been formulated to address these uncertainties and will bring the DAR concept to a point where decisions can be made regarding: 1) technical feasibility of the DAR, and 2) its value to the Central Receiver program. As part of this plan, we will perform a solar subscale DAR test at the CRTF and near-full-scale water and, possibly, full scale salt flow demonstrations.

The SNL-SERI plan includes research on film stability, blackener properties, and salt and dopant chemistry; large-scale water flow testing of full-scale distributor designs, film stability, and wind effects; and a solar research experiment (~ 3MWt) at the CRTF. A contract has been placed with the Lawrence Berkeley Laboratory to investigate the potential for carbon dopants that will react with the salt and not be transported through the thermal storage and heat recovery systems. Reactive carbon dopant should have good optical properties and not present abrasion or deposition problems in the heat transport systems. An experienced receiver designer is under contract to perform structural and thermal analysis of conceptual commercial DAR designs during early FY88. Their work will aid in defining the requirements for solar and non-solar experimental work to be conducted by SNL and SERI. We will explore the potential of using a multi-layer wire mesh absorber substrate as a way to eliminate the need for dopants and avoid the thermal stresses on solid, flat metal substrates. The SERI research effort and the SNL small-scale water flow testing will be completed in FY88, and the full-scale water flow test and the construction of the 3 MWt solar test at the CRTF will be completed in FY88. Non-solar and solar testing will start in FY89. Follow-up, commercial receiver size salt flow testing will begin in FY90 if previous results justify continued work.

High Temperature Receivers - Because of limited resources in the U.S. program, efforts in the area of high temperature receiver development will be confined to providing minimum support to tests of a volumetric (wire mesh, air) receiver at the IEA/SSPS facilities in Spain and a ceramic tube receiver in Israel. Both of these concepts promise to produce hot gases in the 800 to 1000°C range. The European PHOEBUS project currently favors a system that uses solar heated hot air to generate steam. This temperature range is also of long-range program interest for process heat, fuels and chemicals, thermochemical energy transport and high efficiency electric conversion cycles.

Task 3

FY88 Resource Allocations - Receivers

Internal ($K)	800
External ($K)	1400
Total	2200

3.4 - TASK 6 - TRANSPORT AND STORAGE

This Task addresses technological issues that must be answered in order to confidently build a Central Receiver plant that uses molten salt. Specifically, commercial scale salt pumps and low cost (packed) valves must be shown to perform well under the cyclic nature of an operating solar plant. Also, many operational benefits will be realized and parasitic power requirements will be reduced if ways can be discovered to lower the 230°C melting point of the sodium-potassium nitrate salt currently being used. Additions of water and/or calcium nitrate show promises in achieving those benefits.

Molten Salt Pumps and Valves - The goal of the project is to demonstrate the operation of full-scale pumps and valves under conditions typical of a molten salt Central Receiver system. State-of-the-art components are assumed to be suitable for molten salt use but require proof testing. The work supports the potential use of either salt-in-tube or direct absorption nitrate salt receivers. Valve packing evaluations were completed in FY87. A combination of commercially available packings was demonstrated to work in 290°C salt. Packed valves can be used with 565°C salt if the valve stem seal temperature can be kept lower with an extended bonnet design. Commercial bellows-sealed valves provide the backup position if lower cost packed valves do not work in the salt environment.

Two independent test loops have been installed at the CRTF. Each loop will have a large salt pump and several full-size valves capable of handling either 290°C or 565°C salt at the appropriate flow rates and pressures to simulate full-scale solar plant conditions. In FY88 the components will be operated cyclically to evaluate lifetime performance. The failure of or a major maintenance requirement for any component may force premature termination of testing because of the limited FY88 budget for this work. This cooperative, cost-shared utility/industry/DOE project will reduce the risks and cost of these critical components for future Central Receiver plants.

Salt Transport - Two new ideas were under evaluation in FY87 to reduce the operational difficulties associated with using 60% sodium nitrate and 40% potassium nitrate salt mixture that melts at 220 to 230°C.

The melting point of the 60/40 salt can be reduced to below normal ambient temperature by dissolution in water. The salt/water solution can then be pumped through parts of a Central Receiver system that are difficult to maintain hot by heat tracing. The water will boil off as the solution is heated (by solar energy) until the salt is "dry" and molten above 230°C. Physical-chemical and corrosion properties of the salt/water solution will be documented in FY88. A trade-off of the use of salt/water versus extensive heat trace will determine if demonstration tests need to be performed in an engineering scale system in FY89.

The addition of calcium nitrate to sodium and potassium nitrate mixtures can lower the melting point of the ternary salt mixture to just above that of atmospheric boiling water. This could allow for the use of conventional steam or hot water heat tracing rather than the current low efficiency electric heater system. Sketchy literature on these ternary mixtures suggests that they are chemically stable. The physical-chemical and thermal properties, chemical stability, and corrosiveness of ternary mixtures will be measured in FY88. An engineering scale demonstration of the low melting point salt mixture may be scheduled for FY89.

CRTF Thermal Storage Performance - The results of a recharacterization of the performance of the two-tank, molten salt thermal storage subsystem at the CRTF was performed in late FY87. The results indicate no degradation in insulating properties after about five years of use. Details will be documented in FY88.

Task 6

FY88 Resource Allocations - Transport and Storage

Internal ($K)	160
External ($K)	40
Total	200

3.5 - TASK 8 - BALANCE OF PLANT

This Task addresses development of the non-solar components necessary to construct, maintain, and operate a complete Central Receiver plant. Conventional balance-of-plant equipment constitutes a significant portion of Central Receiver costs. The scope includes characterization and optimization of site construction, plant service facilities, power conditioning equipment and spare parts inventory, and the design and development of plant controls. The primary goals are the reduction of balance-of-plant capital costs, minimization of parasitic and auxiliary power requirements, and characterization and reduction of operation and maintenance costs for Central Receiver installations.

Advanced Controls Program - An automated Central Receiver plant which can operate with minimal personnel, or even at times unattended, is a desirable goal. Benefits of automation include an estimated reduction in plant operating costs of 20 to 80% and a reduction in capital costs for heliostats of 2 to 5% (because the required number is reduced). Additional benefits include a potential increase in plant efficiency on clear days, a decrease in equipment failures (because operator errors are minimized and operation outside design limits is eliminated), and prolonged component lifetimes. Improvements in plant performance will result from decreased startup time, increased maximum output power level, extension of the daily operating time, reduction of parasitic loads, and more effective management of the available energy from the receiver, thermal storage, and auxiliary systems.

In FY87 and FY88 a dynamic process simulator was developed for the receiver/storage operation at the CRTF. The simulator operates in real time and mimics the thermal and hydraulic characteristics of the system. No additional work on the simulator development is planned for FY88. The simulator will be used in Tasks 3 and 9 to understand control and system performance issues.

Task 8

FY88 Resource Allocations - Balance-of-Plant

Internal ($K)	-
External ($K)	-
Total	-

3.6 - TASK 9 - CENTRAL RECEIVER SYSTEMS

Central Receiver systems effort includes the development of designs and the analysis of system components and parameters for complete solar Central Receiver plants. The integration of components and subsystems into a complete system is necessary to understand the interactions which occur among elements of the system and to define cost and performance trade-offs. This makes it possible to identify critical technology development requirements.

The goal of this effort is to establish the economic feasibility of solar systems which produce electricity or industrial process heat. Current Central Receiver system designs for electricity generation have an annual efficiency of about 16% and a capital cost of about $4600/peak kWe. Current system designs for industrial process heat production have annual efficiency of 48% and a capital cost of about $1300/peak kWt. Long-term objectives for electricity generation are an efficiency of 22% and a cost of $1600/peak kWe; while for heat production, the objectives are an efficiency of 56% and a capital cost of $470/peak kWt. Achievement of these goals is necessary to meet the overall program cost targets of the Five Year Research and Development Plan.

Utility Study - A group of western utilities is studying the appropriate path to eventual commercialization of solar Central Receiver technology. DOE has established cooperative agreements with two utility teams to develop utility-scale conceptual designs and to define an experimental program to verify the adequacy of these designs. Sandia supports this utility initiative through representation on technical evaluation committees. The teams agreed that the best Central Receiver plant for electric production will: 1) use molten salt for the receiver and thermal storage system, 2) have a large solar multiple and thermal storage capacity, and 3) have an optimum size about 200 MWe. Work in FY88 will address technical performance and cost uncertainties, and define the preferred next steps along the path to commercialize the Central Receiver. Sandia will provide technical support to the utility teams as their studies progress in FY88.

Annual Energy Improvement Study - The first phase of this study was completed in FY87 with the successful validation of our annual energy prediction code, SOLERGY, using performance data from Solar One. The results will be documented in FY88. With confidence in the SOLERGY model, we will mimic the commercial Central Receiver plant of the size and type selected in the Utility Study. The code will predict the annual plant output for a variety of weather data bases, operating scenarios, and value of power schedules. Based on the PHOEBUS program conclusions, a new initiative for FY88 will be to compare utility-selected molten salt Central Receiver plants to the use of hot air as the receiver working fluid, a solid thermal storage, and a hot air heated steam generator to produce electricity in the conventional Rankine cycle. The code will be refined to include expected component and subsystem availability data. The value of redundancy will be assessed. Methods of improving performance and reducing parasitics will be sought and tested with the model in FY88 and 89.

Non-Electric Applications - A small effort will be maintained to assess potential non-electric applications for the Central Receiver. These will be current or new industrial process heat applications or processes that benefit from the solar photons. The search for new applications will consider processes that are: 1) experiencing growth in production capacity, 2) used to store or transport energy, 3) generate materials, fuels, or chemicals of high value, low volume and batch produced, and 4) can uniquely benefit from the environmental benefits of the solar system. Preliminary conceptual designs will be developed and cost/benefit studies will be performed as warranted.

3.6 - TASK 9A - CENTRAL RECEIVER TEST FACILITY

The Central Receiver Test Facility (CRTF) is an integral part of the DOE Solar Thermal Test Facility. The CRTF comprises a 5.5 MWt Solar Tower, Heliostat Test Facility, and a 40 KWt Solar Furnace. The CRTF is the nation's primary source for testing and evaluating solar Central Receiver components, subsystems and systems. The CRTF will also be used on a noninterference basis to provide thermal effects testing that simulates aerodynamics or re-entry heating, nuclear thermal, and other intense radiant heating environments.

Task 9A funding is provided to manage, operate, maintain and upgrade the CRTF. The FY88 and FY89 activities will include the following:

- CRTF Management, Operation and Maintenance

- Tower Modification to Increase Capabilities and Improve Operations
- Upgrade Control Room Equipment and Move Control Room into the Original Control Tower
- Upgrade One-third of the Central Receiver Test Facility Heliostat Field with New Control Electronics, Motors, and Encoders

Tasks 9 & 9A

FY88 Resource Allocations - Central Receiver Systems

Internal ($K)	890
External ($K)	600
Total	1490

3.7 - TASK 11 - SYSTEM EXPERIMENTS

System experiments provide valuable data on capital cost, performance, and operations and maintenance of complete solar thermal systems. System experiments are conducted with major participation from solar equipment manufacturers and potential users. These experiments lead to the establishment of technical feasibility, to the development of a valuable cost and performance data base, to technology transfer which can be used in private sector decisions, and to the identification of future research and development needs.

Solar One - Solar One completed its scheduled, three-year-long power production phase in FY87. The results showed steadily improving performance as the operating team learned the best strategies, and the maintenance effort provided improved reliability. The results will be documented in FY88.

Starting in FY88, Solar One will be operated in a "semi-commercial" mode with minimum government support. The plant will reduce its crew and operate only five days (M - F) per week. Preventive maintenance will be stressed in the winter when the value of power is lowest. Intense operation will be conducted in the summer to benefit from peak load electric rates. This new mode of operation will provide valuable data and experience about operating the plant at minimum cost while at the same time maximizing high value output. The work in FY88 will provide important additional data on component and subsystem reliability, heliostat cleaning effectiveness, and short time interval weather data for a typical solar site. All of this information will improve the validity of the Annual Energy Improvement Study. Sandia will continue to provide technical support and will utilize the data and experience resulting from the new mode of operation. Sandia's SOLERGY code will be used to instruct the operators on how to maximize plant output.

Task 11

FY88 Resource Allocations - System Experiments

Internal ($K)	70
External ($K)	30
Total	100

4.0 RESOURCES AND IMPLEMENTATION

A strategy for performing the work described in the previous chapter, together with the required resources, is described in this chapter. In addition to the resources, major milestones for the period covered by this plan, the Sandia organizational structure, a procurement plan and summary are included.

4.1 Resource Summary

A detailed breakdown of resources required in FY88 to carry out the work described in this document are summarized in Table 2.

4.2 Capital Equipment

In FY88, $150K is required for capital equipment in the Central Receiver program. These funds will be used for upgrading the technical capability of the Central Receiver Test Facility as well as for dedicated equipment for Central Receiver program experiments such as flux measurement, heliostat beam characterization, and heliostat control.

4.3 Major Milestones

Major milestones for the Central Receiver program are shown in Figure 2.

4.4 Major Reports FY88

Report	Draft	Publish	Reviewers

To be determined

TABLE 2. FY88 RESOURCES

Task		External $K	Internal $K	Total $K
1	OPTICAL MATERIALS	50	-	50
2	CONCENTRATORS	700	680	1380
3	RECEIVERS	1400	800	2200
6	TRANSPORT AND STORAGE	40	160	200
8	BALANCE OF PLANT	-	-	-
9 & 9A	CENTRAL RECEIVER SYSTEMS	600	890	1490
11	SYSTEM EXPERIMENTS	30	70	100
		2820	2600	5420 ?

2600 / 21 = 124

not 5350 ?

+ 230 = 5650

5320
5650
11030

Figure 2

MAJOR MILESTONES

JUNE	o	COMPLETE 1ST GENERATION STRESSED-MEMBRANE HELIOSTAT EVALUATION PROGRAM
JUNE	o	COMPLETE LARGE-AREA HELIOSTAT EVALUATION PROGRAM
JUNE	o	COMPLETE DIRECT ABSORPTION RECEIVER (DAR) WATER FLOW EXPERIMENT
JULY	o	INITIATE 2ND GENERATION STRESSED-MEMBRANE PROTOTYPE(S) EVALUATION PROGRAM
SEPT	o	COMPLETE DIRECT ABSORPTION RECEIVER (DAR) SALT LOOP CONSTRUCTION
SEPT	o	COMPLETE FULL-SCALE PUMP & VALVE EXPERIMENT (1ST GENERATION
SEPT	o	COMPLETE 1ST YEAR SOLAR ONE SEMI-COMMERCIAL OPERATION

4.5 Management Plan

Management Structure

The Solar Central Receiver Program is managed within Sandia National Laboratories' Solar Energy Department. The Solar Energy Department reports to the Director of Advanced Energy Technology. This management structure is shown in Figure 3.

Reporting and Control

Management control of the program is maintained through a schedule of periodic reporting and reviews in order to ensure that the program is proceeding as described in the Annual Operating Plan submitted at the start of the fiscal year. Reports to DOE/HQ keep program managers informed of development and work progress in an appropriately timely manner. These reports include:

- Weekly Significant Events Letter
- Quarterly Technical/Financial Reports
- Quarterly Oral Presentation to DOE
- Annual Technology Transfer Meeting for the Public (upon approval)

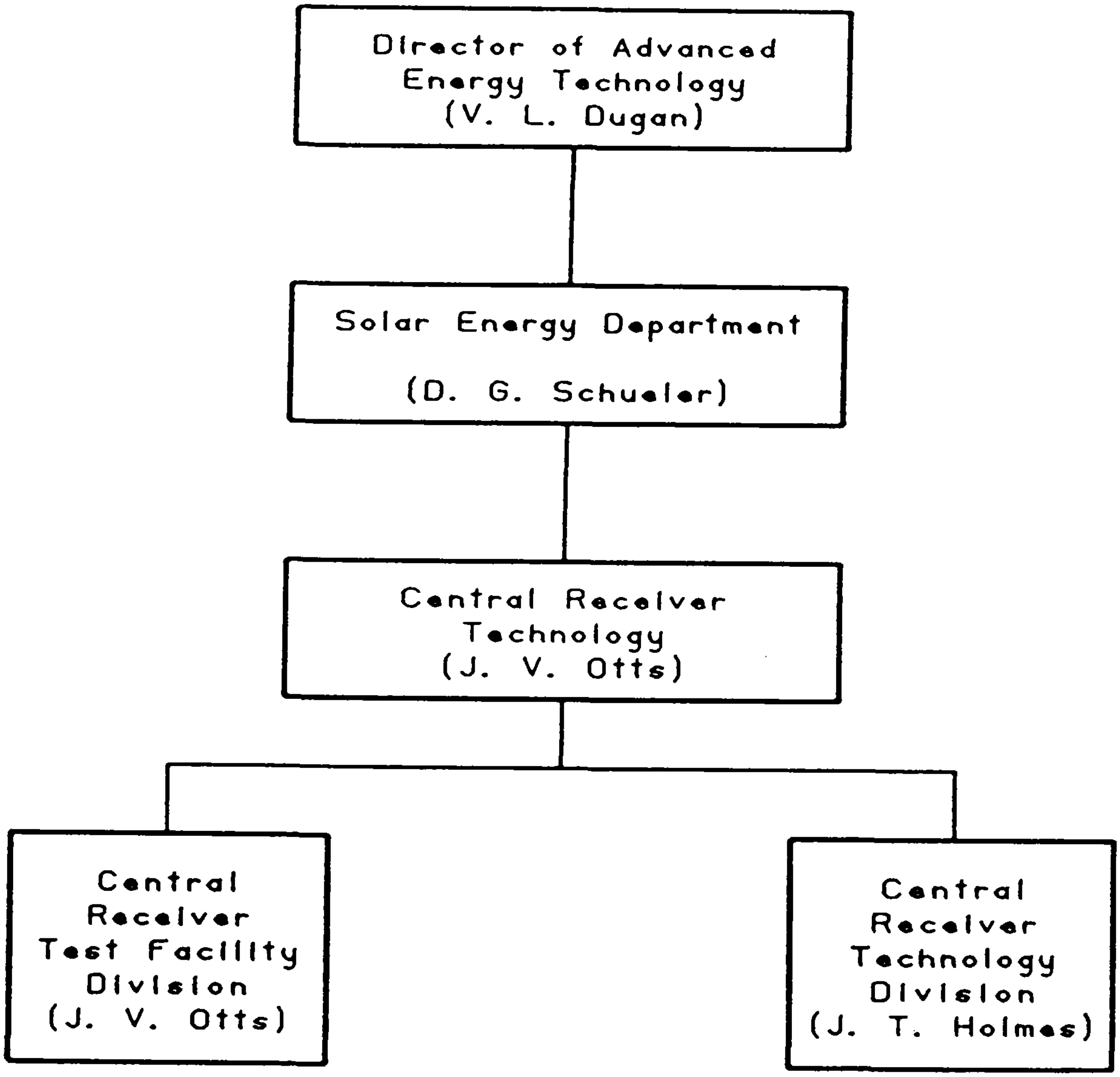

Figure 3. Management Structure for Solar Central Receiver Progra

4.6 Procurement Plan

Procurement Strategy

Procurements for the Central Receiver development program are initiated by Sandia, upon approval of the Annual Operating Plan by DOE/HQ. The procurement summary listed in Table 3 provides a list of the major new procurements which are anticipated in FY88 and FY89.

Procurement Policy and Practices

Sandia's procurement rules are similar to the DOE regulations; however, they are not identical. In the substantive cases where they are not, but which have impact on the program, measures are taken to assure that the programmatic requirements are met. An example of this is the policy of advertising competitive procurements in Commerce Business Daily and any other appropriate publication. (This is not generally done on Sandia procurements.) With very few exceptions, all research and development procurements in this program are competitive, with the sole source option being used only in instances where it is very clear that the contractor is the only one who can fulfill the function.

Unsolicited Proposal Funding - Sandia, through its prime contract held by AT&T Technologies with the U.S. Department of Energy, is excluded from funding unsolicited proposals which have been submitted to the Laboratory. These proposals are returned unopened with instructions regarding the proper route of submittal to DOE Headquarters. Once such a proposal is submitted through the proper channels, reviewed, and accepted for funding by the appropriate Division Director (DOE Headquarters), Sandia can hold the contract as a result of a written request from that Director. Contracts for any approved unsolicited proposals on heliostats, receivers, or general Central Receiver system activities would normally be held by Sandia. These will be funded by Sandia either on existing funds or, if such funds are not available, on funds to be forwarded to Sandia through ALO's financial plan accompanying the request to place the contract. In implementing this strategy, Headquarters and Sandia will reach an agreement regarding the source of funding prior to a formal request being sent to Sandia to place a contract. It is expected that most approved unsolicited proposals will be of sufficient value to fit within the scope described in this Annual Operating Plan and will not require additional

TABLE 3. FY 88 MAJOR PROCUREMENTS

TASK		$K FY88
2.	CONCENTRATORS	
	Stressed Membrane Heliostat (Large-Area Prototype)	300K
3.	RECEIVERS	50K
9A.	CENTRAL RECEIVER TEST FACILITY	
	Contract Personnel	450K
	O&M Contracts	100K

funding. Exceptions will occur where the proposals are approved using additional criteria and where funds have been reserved at Headquarters for funding such proposals.

Small and Minority Business Policy - It is both DOE policy and Sandia policy to maximize the use of small and minority businesses in carrying out the programs under their management. While goals are established and careful efforts are made to meet them, meeting the goals is done in a manner consistent with meeting the technical programmatic objectives and thus the former is not the primary objective. Every effort is made by Sandia to meet the goals set by the Solar Thermal Technology Division for small and minority businesses. Sandia policy for procurements does not permit the use of set-asides in the manner that the Federal Procurement Regulations' suggest. It does, however, permit accomplishment of the objectives by the use of a limited bidders' list. As a result, we believe it is possible to meet the Solar Thermal Technology Program goals for procurement from small and minority businesses. It is our preference to incorporate as much of this small and minority business activity in the major or mainstream procurements as possible.

Central Receiver Development Plan
1988-1989

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