Central Receiver Development Plan 1987-1988

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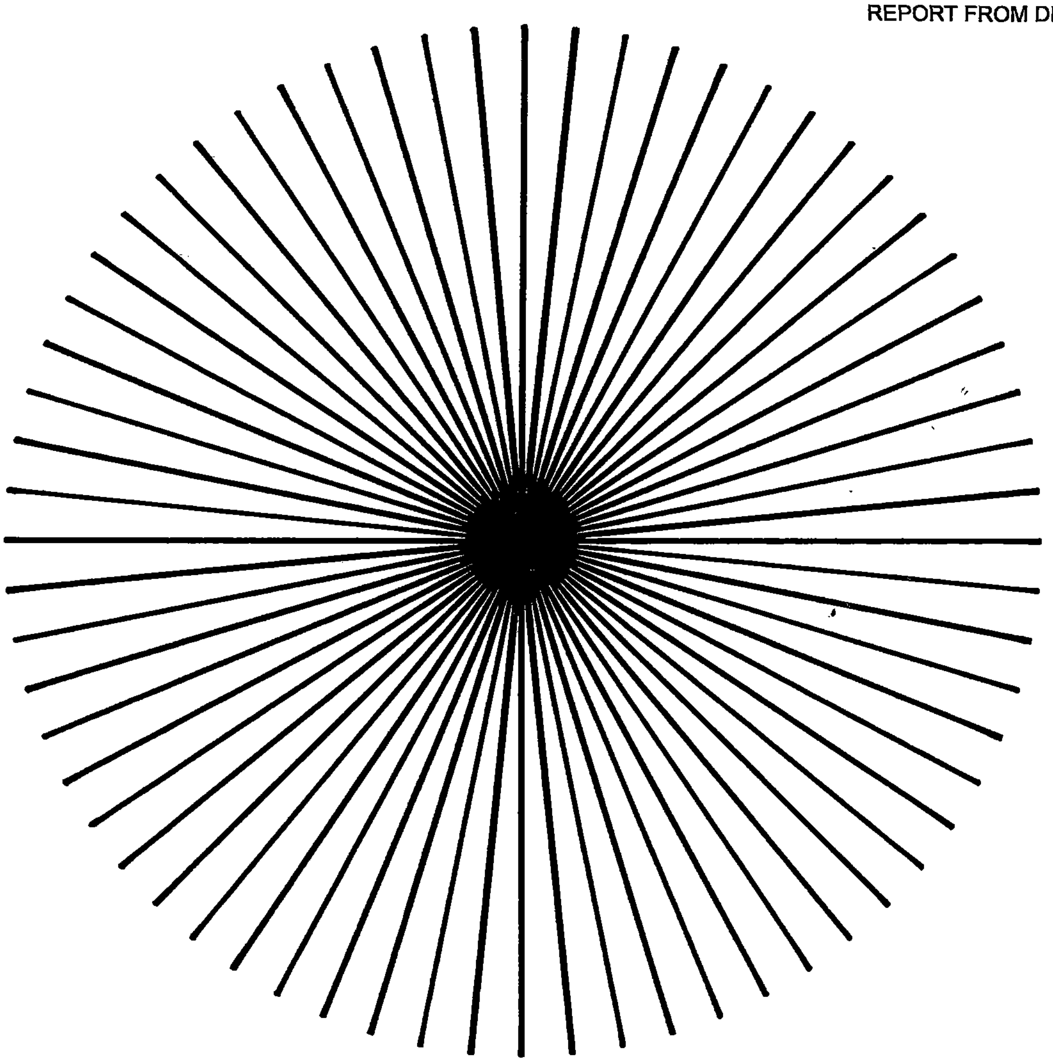
Sandia National Laboratories



National
Solar Thermal Technology
Program

CENTRAL RECEIVER DEVELOPMENT PLAN 1987-1988

FY87 ANNUAL OPERATING PLAN
SANDIA NATIONAL LABORATORIES

Central Receiver Research and Development

September 1986

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 FY87 only, and the narratives emphasize FY87. The reason for this is that the FY88 amount is uncertain. It is the intent of the Laboratory to incorporate planning for FY88 in future issues of this document.

CONTENTS

1.0 INTRODUCTION AND PROGRAM OVERVIEW

This document describes activities for Fiscal Years 1987 and 1988 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 FY87 and FY88 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 FY87 Annual Operating Plan, it also describes activities for FY88. 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 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 FY87 and FY88 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.

FY87 and FY88 Program Goals

1. 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 FY88

   - evaluate prototype low-cost drive system for pedestal-mount heliostats

2. Receivers

   - reduce construction and operation cost while optimizing performance and longevity

   - identify advanced receiver designs and materials for long-term applications

   - evaluate advanced molten salt receiver design performance and longevity from test operations at the CRTF

3. Transport/Storage

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

4. Balance of Plant

   - develop control systems to improve overall performance and lower operating costs

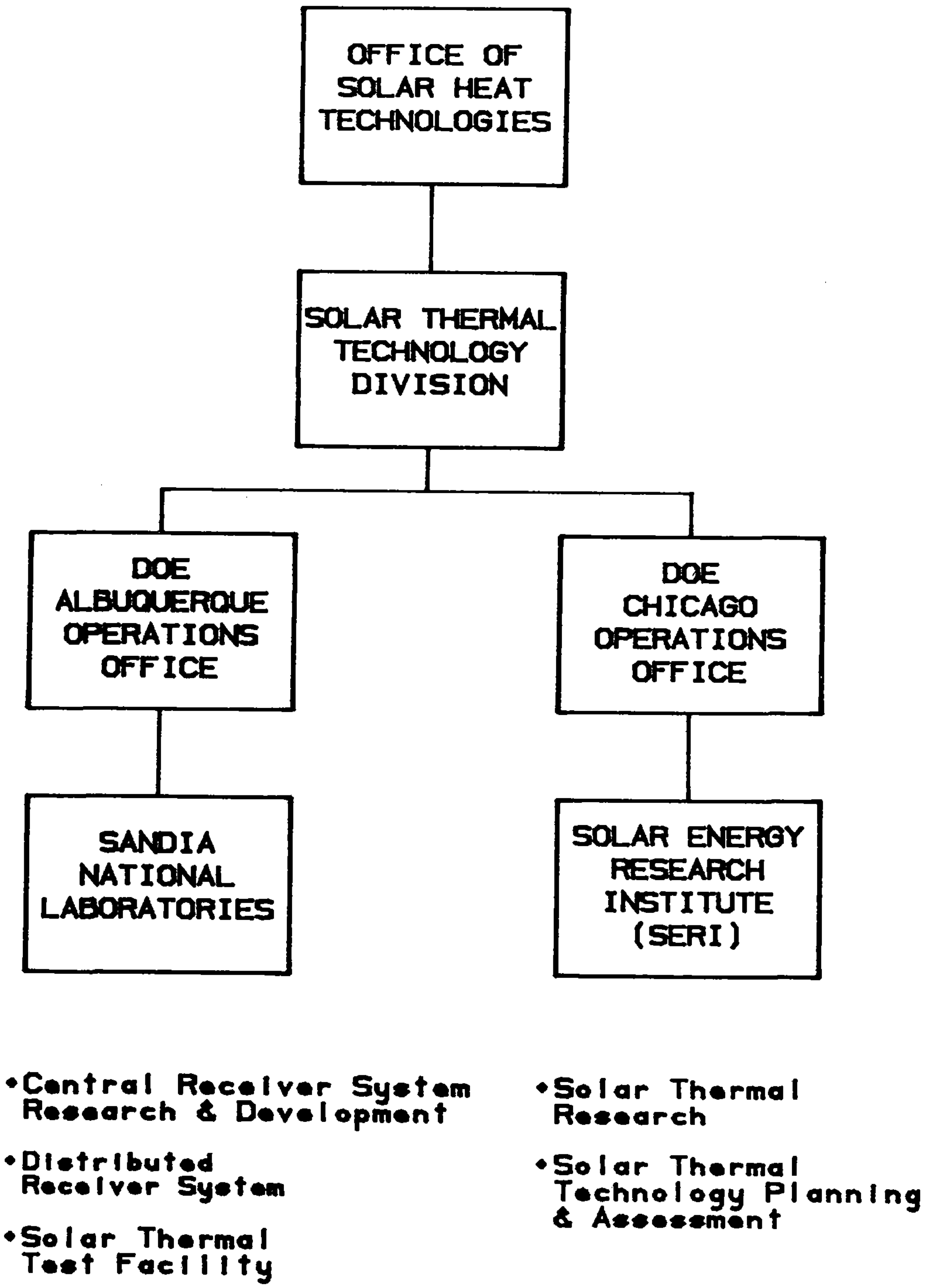


Figure 1. Solar Thermal Technology Organizational Structure and Responsibilities

5. 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

- provide technical support through the completion of the power production phase of the 10 MWe Solar Thermal Central Receiver Pilot Plant (Solar One)

- 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

6. Management

- complete orderly transition of the Central Receiver technology program from Sandia's facilities in Livermore, California to those in Albuquerque, New Mexico

1.3 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 as well as components. This plan is updated annually to reflect progress and new budget impacts.

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.

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) has demonstrated the technical feasibility and advantages of using molten salt as a heat transfer fluid and storage medium. At the IEA Small Solar Power Systems 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 $\$200/m^2$ 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 down time. These advances during the last 10 years have decreased overall energy costs from $1.25/kWhe to an estimated $0.16/kWhe (levelized in real dollars) for currently proposed solar electric power plants.

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

<u>Systems</u>

- Construction, evaluation and operation of three separate pilot plants have demonstrated the technical feasibility of central receiver technology while using water, salt and sodium as the heat transfer fluid.

- Two separate utility based teams and one A&E firm are currently performing conceptual designs of full scale power plants using central receiver technology.

Concentrators

- Glass/metal heliostats have increased in size from 37 m^2 to 150 m^2 reflective area while the cost has been reduced to about $\$200/m^2$. A 200 m^2 glass/metal heliostat is now under construction by the Solar Power Engineering Company and scheduled for evaluation in FY87.

- A 50 m^2 stressed membrane mirror module has been fabricated and installed at the CRTF. This module by Solar Kinetics, Inc. and another to be delivered by Science Application International Corp. will be evaluated during FY87. The stressed membrane concept has the potential of reducing heliostat costs to the $\$40/m^2$ range.

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

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.

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 conducted at the CRTF in FY87.

Balance of Plant

- A real time control "dynamic simulator" is scheduled for delivery in FY87. This will be used to guide future research and development.

- A "state-of-the-art" process control survey is currently underway.

3.0 CENTRAL RECEIVER PROGRAM STRUCTURE

Central Receiver program activities are oriented toward the achievement of the goals delineated in the Five Year Research and Development Plan. These activities rely on the breadth of research and development efforts in all eleven research tasks of the solar thermal program. In fiscal years 1987 and 1988, central receiver activities fall into six of the eleven task categories.

The six Central Receiver research and development tasks are:

- Concentrators
- Receivers
- Transport and Storage
- Balance of Plant
- Central Receiver Systems
- System Experiments

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

Table 1. Task and Subtask Structures

TASK 2*.	CONCENTRATORS	
	Stressed Membrane Heliostat Large Area Heliostat Low Cost Drives Wind Loading Cleaning Commercial Heliostat	
TASK 3.	RECEIVERS	
	Advanced Molten Salt Receiver Experiment Direct Absorption Receiver Receiver Design Improvements Materials High Temperature Receivers	
TASK 6.	TRANSPORT AND STORAGE	
	System Thermal Conditioning Full Scale Molten Salt Pump and Valve Experiment Low Cost Storage Sodium/Salt Heat Exchanger Thermal Chemical Transport	
TASK 8.	BALANCE OF PLANT	
	Controls Systems Solar Plant Automation	
TASK 9.	SYSTEMS STUDIES	
	Utility Study Support Annual Energy Improvement Non-Electric 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 2 - CONCENTRATORS

The 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 will 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 original DOE-developed technology has been used by private industry (Arco Solar) for further heliostat development. Current estimates of costs for glass/metal heliostats are about $200/m^2$ at moderate production rates. It is estimated that mass production could reduce the cost to about $80/m^2$.

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

Stressed membrane mirrors represent a new phase in the long-range development program. Stressed membrane mirror modules are much simpler and lighter than glass/metal modules; their weight per unit reflector area should be approximately one-third that for 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 align. When fully developed, stressed membrane heliostats 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 step-wise improvements in glass/metal technology while also pursuing innovative concepts that have the potential for dramatic cost reductions. Work in the FY87 and FY88 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 FY87 and FY88 include testing and evaluation of large area glass/metal heliostats, evaluation and further development of stressed membrane heliostat designs, development of a low-cost heliostat drive mechanism, and characterization of wind-induced dynamic loading on heliostats. Because heliostat performance has a direct impact on overall central receiver plant efficiency, cost effective cleaning systems will be studied for large-area glass/metal and stressed membrane (polymer film reflector) heliostats.

<u>Large-Area Heliostats</u> - 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 both small build and mass-produced, large-area heliostats will be reduced from that of smaller area designs.

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. A one year test and evaluation program will be completed on the large-area heliostats during FY87. A major question to be addressed is the overall performance of large area heliostats under field operating conditions (especially wind loads) as compared to smaller heliostats tested previously.

<u>Stressed Membrane Heliostats</u> - Two development contracts have been 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. The design, manufacturing, and cost studies were completed in FY86. In addition, each contractor designed and built a 50 m^2 prototype stressed membrane mirror module. These mirror modules have been installed on existing heliostat drives at the CRTF for test and evaluation.

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.

In FY87, the one prototype mirror assembly will be tested at the CRTF and its performance evaluated. Based on early test results, further development of the design and fabrication techniques will be pursued in FY87. The first prototype of a steel mirror module was not capable of being tested for its optical performance. A redesign of the steel prototype will be initiated in FY87 with testing in late FY87 or early FY88. The goal of this work is to bring stressed membrane technology to the point where performance goals are met and large scale manufacturing is possible. Larger, 150 sq m prototype mirror modules will be developed in FY88 for testing at the CRTF.

<u>Low-Cost Heliostat Drives</u> - 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 the range of \$11 to \$14/m^2.

During FY86, a review of ideas on drive cost reduction was completed. An RFQ was issued for a complete design and procurement package including production of prototypes. Following review of the quotations, 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 heliostat. This design should also be compatible with a stressed membrane mirror module of similar size.

The design phase of the low-cost heliostat drive program will be completed early in FY87. Prototype drives will be built and tested under simulated gravity and wind load conditions in FY87 and FY88. This work is being coordinated with the needs of the photovoltaic and distributed receiver programs as well as with related research projects at SERI.

Wind-Induced Dynamic Loading - Parallel to developing a low-cost heliostat drive, an effort has been initiated to characterize the wind-induced loads on heliostats. This work is necessary to insure the high reliability of heliostats over system life necessary for successful commercialization. In qualifying current heliostat drives, little if any attention has been paid to the dynamics of the working environment. A preliminary study of tracking systems for photovoltaic concentrators (95 m^2 ARCO design) found that drive units failed due to variable wind loading of the heliostat, even in the stow position. The objective of this work is to characterize the dynamic wind loading of heliostats so that: 1) cost effective drives can be designed to perform under these loads and 2) methods can be developed to reduce the load environment so the cost of the structure and drives can be minimized.

The principal tasks of this effort are: 1) characterization of wind turbulence in heliostat fields and 2) measurement of full-scale array wind loadings for alternative heliostat and field layout configurations. The full-scale array measurements will also be used for validation of wind tunnel measurements and to develop methods (e.g., spoilers and fences) for minimizing dynamic loads. Because of the common interest in the problem of dynamic wind loading, this work will be jointly sponsored by the three SNL solar research divisions, photovoltaic, distributed receivers and central receivers. In addition, research efforts at SERI will support the SNL development programs.

Reflector Cleaning - Because of its direct effect on overall system 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 FY87 and will draw heavily on prior work at Solar One and research at SERI. A joint SERI and SNL program will be developed in FY87 to address the long-range aspects of the soiling and cleaning issue. The large area and stressed membrane heliostats at the CRTF will be used in FY88 to evaluate potential cleaning methods.

Commercial Heliostat Development - Based on the results of all of the above component development programs, a competitive RFQ will be placed in FY88 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, production models may be fabricated and evaluated.

Task 2

Resource Allocation - Concentrators

Internal ($K)	750	
External ($K)	1050	
	1800	Total

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

<u>Subscale Molten Salt Receiver</u> - The Molten Salt Subsystem/Component Test (Category B Receiver 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 and construction plans 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. The panels are arranged in a cavity configuration with wing panels. The receiver is currently mounted on top of the CRTF tower for solar testing. The advanced receiver replaced the previously-tested Martin Marietta molten salt receiver, thus enabling a direct comparison of the performance of the two receivers as part of a full central receiver system.

Installation, checkout and initial operations of the receiver at the CRTF was completed in FY86. Performance testing of the receiver will be completed by mid-FY87. Testing in a "power production" mode and an extended period of performance and life testing are being considered as additions to the original scope of the test plan, and will begin in FY87 if a decision is made to proceed.

Sandia will provide technical management and support for the receiver testing and evaluation of the test results.

<u>Direct Absorption Receivers</u> - 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 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 developed that addresses these uncertainties and will bring the DAR concept to a point where a decision can be made regarding: 1) technical feasibility of the DAR and 2) its value to the central receiver program. In that time, we will also be able to assess the need for a subscale DAR test at the CRTF (or elsewhere) and/or a near-full-scale salt flow demonstration.

The contents of the plan include research at SERI on film stability, blackener properties, and salt and dopant chemistry; large scale water flow testing to assess full-scale distributor designs, film stability, and wind effects; and a joint (SERI/SNL), small DAR panel research experiment (~ 2MWt) at the CRTF. The SERI research effort and the SNL water flow testing will be completed in FY87 and FY88, and the 2 MWt test at the CRTF will be conducted in FY88. Follow-up, full-scale salt flow testing and/or subscale solar testing will begin in FY89 if previous results justify continued work.

<u>Molten Salt Receiver Design Improvements</u> - The major near-term efforts to develop advanced salt-in-tube receivers will be to study ways to simplify and lower their costs and improve operational reliability. Potential areas of salt-in-tube receiver improvements include: reducing complexity by eliminating unneeded valves and by integrating heat trace and insulation

into the design; using materials with improved performance, simpler fabrication techniques, and modular design; and reducing design conservatism.

A study of mechanical/thermal properties of potential alloy materials for metal tubes will be completed in FY87 in support of the salt-in-tube development effort. A competitive RFQ may be initiated in FY88 to study the potential cost and performance improvements and scale-up issues that should result from a simplified salt-in-tube receiver design.

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. This temperature range is of long-range program interest for process heat, fuels and chemicals, thermochemical energy transport and high efficiency electric conversion cycles.

Task 3

FY87 Resource Allocations - Receivers

Internal ($K)	620	
External ($K)	880	
	1500	Total

3.3 - TASK 6 - TRANSPORT AND STORAGE

System Thermal Conditioning - Effort in FY87 will be directed at optimizing the preheating of pipes and components to prevent salt freezing when the system is filled and operated. A study of trace heat experience for sodium cooled nuclear reactors and solar molten salt applications in France and the U.S. will be made as part of an effort to define an optimum trace heat system. Salt/water slurries that freeze below 0°F and other fluids will be considered as potential alternates to electric heaters.

Molten Salt Pumps and Valves - Valve testing began in FY85 with laboratory compatibility tests of candidate valve stem seal packing materials. This testing screened packings for a valve bonnet bench test that began in February 1985 at the CRTF. Early results of the bench test have shown that common valve packings are not suitable for molten salt, and as a result, the scope has been expanded to evaluate other valve packings and alternate stem seal configurations. A combination of commercially available packings has been demonstrated to work in 550°F salt. Packed valves can be used with 1050°F salt if the valve stem seal temperature can be kept lower with an extended bonnet design. Commercial, bellows sealed valves now in use at the CRTF 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 pump and several 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. The components will be operated cyclically to evaluate lifetime performance. This cooperative, cost-shared utility/industry/DOE project will reduce the risks and cost of these critical components for future central receiver plants. 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.

Low-Cost Thermal Storage Systems - The literature will be reviewed in FY88 and new ideas generated that have potential to reduce the cost of molten salt thermal storage systems. In order to achieve valuable electric capacity credits or to provide a continuous electric or process heat output, solar central receiver plants will benefit from large thermal storage systems. A recommendation will be made in FY88 regarding the need for a new subscale test of a low-cost thermal storage system at the CRTF (or elsewhere) in FY89.

Sodium/Salt Heat Exchanger - A promising central receiver configuration employing a sodium cooled receiver and molten salt storage system has been identified. The system concept is attractive--a high performance receiver coupled with a low-cost molten salt storage system.

A subscale component experiment may be built to verify the thermal performance and dynamic response of a sodium/salt heat exchanger. A major technical unknown is accommodating the potential temperature and/or pressure rise resulting from a leak in the sodium salt heat exchanger. The decision to proceed with this work will be based on the results and recommendations of the "Utility Studies" (Task 9).

Thermochemical Transport - Thermochemical transport is being studied in the U.S. Distributed Receiver program and in the Israel Central Receiver program. Both of these programs will be followed for applicability to the U.S. Central Receiver program. The sodium reflux, receiver-reactor now under development in these programs appears directly applicable to the U.S. central receiver long range needs. Pending positive results and favorable in-house analyses, a subscale experiment may be proposed in FY88 for implementation at the CRTF in the FY89-90 time frame.

Task 6

FY87 Resource Allocations - Transport and Storage

Internal ($K)	200	
External ($K)	200	
	400	Total

3.4 - TASK 8 - BALANCE OF PLANT

This Task addresses research on 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 research activities include 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.

In FY87 and FY88, the main development activities in this area will be the development of automated control strategies. The goal is to reduce maintenance and operating costs and to improve the overall performance of central receiver plants.

Advanced Controls Program - An automated central receiver plant which can operated 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 this program a control algorithm will be developed that will automate startup, power operation, and shutdown of the solar and molten salt unique subsystems: the heliostats, receiver, and salt storage. This algorithm will be developed in two phases. In the first phase, the effort will concentrate upon automating receiver and salt storage sub-systems. In the second phase, the heliostat subsystem will be integrated with the other two subsystems and automation of startup and shutdown of all three systems will be accomplished. The automation of the end use (electric, process heat, etc.) is not considered a part of the goals of this effort.

The algorithms will be developed and tested using a dynamic simulator of a central receiver. This simulator will initially mimic the MSSCTE receiver and salt storage subsystems. The accuracy of the simulation model will be verified with data collected from the MSSCT experiments. The model will then be modified for central receiver salt plants that represent a hypothetical commercial scale. The dynamic simulator developed in this task will also be used by the Annual Energy Improvement Study performed as part of Task 9 - Central Receiver Systems.

Development of the automation control algorithms will be closely coordinate with similar work being performed for the distributed receiver project in their Balance of Plant task program.

A decision will be made in FY88 on whether the CRTF should upgrade its control system to demonstrate the automation algorithms.

Task 8

FY87 Resource Allocations - Balance-of-Plant

Internal ($K)	85
External ($K)	115
	200

3.5 - 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.

Central receiver systems tasks include systems application studies and support of international central receiver development programs.

Utility Systems - A group of western utilities is studying the appropriate path to eventual commercialization of solar central receiver technology. DOE is establishing cooperative agreements with one or more utility teams to develop utility-scale conceptual designs and to define an experimental program to verify the adequacy of these designs. Sandia will support this utility initiative through: representation on technical evaluation committees, completion of computations, performance of trade-off studies, and performance of material tests as agreed upon by study participants. Results of the analysis developed in the FY86 SNL System Improvement Studies will be used in this element.

Annual Energy Improvement Study - Results from studies performed by Sandia during FY86 indicate that significant improvements in central receiver salt system technology must be made to achieve the Five Year Plan efficiency goal for annual energy production. The Annual Energy Improvement Study will be performed in FY87 and FY88 to help bridge the gap between current technology and the goal. The Solar One data base, the SOLERGY computer code, and a dynamic simulator of a central receiver power plant that will be developed as part of Task 8 - Balance of Plant, will be tools used in the analysis. Validation calculations using Solar One performance and weather data will be performed to add credence to annual energy predictions for other system designs. Issues important to annual energy will be identified and studied via cost-benefit sensitivity analyses.

Non-Electricity Applications - While electric power generation continues to be the main focus of the solar central receiver development program, potential alternatives which could expand the central receiver user base should be investigated. Attractive possibilities are thermally enhanced oil recovery (TEOR), desalinization or purification from agricultural wastes and fuels and chemicals (FC).

A number of previous studies have shown TEOR to be an especially good match to central receiver systems. A brief study of a TEOR plant as an option to additional work at Solar I was initiated in FY86. In FY87, follow up studies (to investigate various alternatives including plant size, co-generation options, hybrid options, and direct steam generation versus a salt system with storage) will include preliminary conceptual designs and cost estimates.

A decision will be made in FY87 on whether studies should be initiated on the design of a Central Photovoltaic Receiver plant. If pursued, it will be a joint effort of the SNLA Central Receiver and Photovoltaic groups.

Two fuels and chemicals (FC) conceptual design studies completed in FY86 were not encouraging because of technical uncertainties, limited markets, and high costs. One area considered for further study was the receiver/reactor. Work in the Receiver Task will continue in this area. An analysis effort will be maintained to support this work by evaluating potential markets, costs, etc. of receiver/reactor systems. The FC work in progress in the U.S. Distributed Receiver program and in European and Israel Central Receiver programs will be monitored in support of this effort.

Task 9

FY87 Resource Allocations - Central Receiver Systems

Internal ($K)	930	
External ($K)	70	
	1000	Total

3.5 - 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 non-interference 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 FY87 and FY88 activities will include the following:

- CRTF Management, Operation and Maintenance
- Solar Furnace Calibration/Evaluation
- Video Flux Measurement (non-contact)
- Heliostat Field Update
- Relocate Control Room

The major FY87 and FY88 expense will be required to upgrade the 222 heliostats which are currently "high maintenance" due to their ten years of service.

Task 9A

FY87 Resource Allocations - CRTF

Internal ($K)	540	
External ($K)	760	
	1300	Total

3.6 - 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.

<u>10 MWe Solar Thermal Central Receiver Pilot Plant</u> - The current system experiment in the Central Receiver development program is the 10 MWe Solar Thermal Central Receiver Pilot Plant near Barstow, California. Sandia provides technical support for the Pilot Plant on behalf of DOE. The objective of this experimental Pilot Plant is to test the various subsystems and analyze the performance of the components. Evaluation of data provides information to industry to support decisions regarding designs and economics of central receiver systems. The work also identifies areas where future central receiver research and development could lead to significant performance improvements and increased capabilities.

A three-year power production phase, begun in August 1984, is now demonstrating the operational capability of the plant to supply electrical power reliably to the utility grid. During this phase, Southern California Edison is operating the plant and recording data, and Sandia is analyzing and evaluating the data from the plant operations. Of particular importance while operating the plant in a utility environment is the determination of operating strategies to maximize the energy output of the plant. The annual capacity factor, annual performance and O&M costs are being determined. These factors are important quantities necessary to assess the technical and economic feasibility of solar central receiver technology.

In addition to evaluating the power production phase plant performance, planned Sandia activities include:

a. Completing a study to understand receiver tube cracking problems through laboratory tests and analyses

b. Identifying operations and maintenance techniques for improving plant performance

c. Supporting the operation of the plant and diagnosing and solving non-routine problems

d. Conducting an annual summer solstice performance measurement campaign

e. Completing a final report on the power production phase

Task 11

FY87 Resource Allocations - System Experiments

Internal ($K)	300	
External ($K)	0	
	300	Total

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 FY87 to carry out the work described in this document are summarized in Table 2.

4.2 Capital Equipment

In FY87, $100K 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.

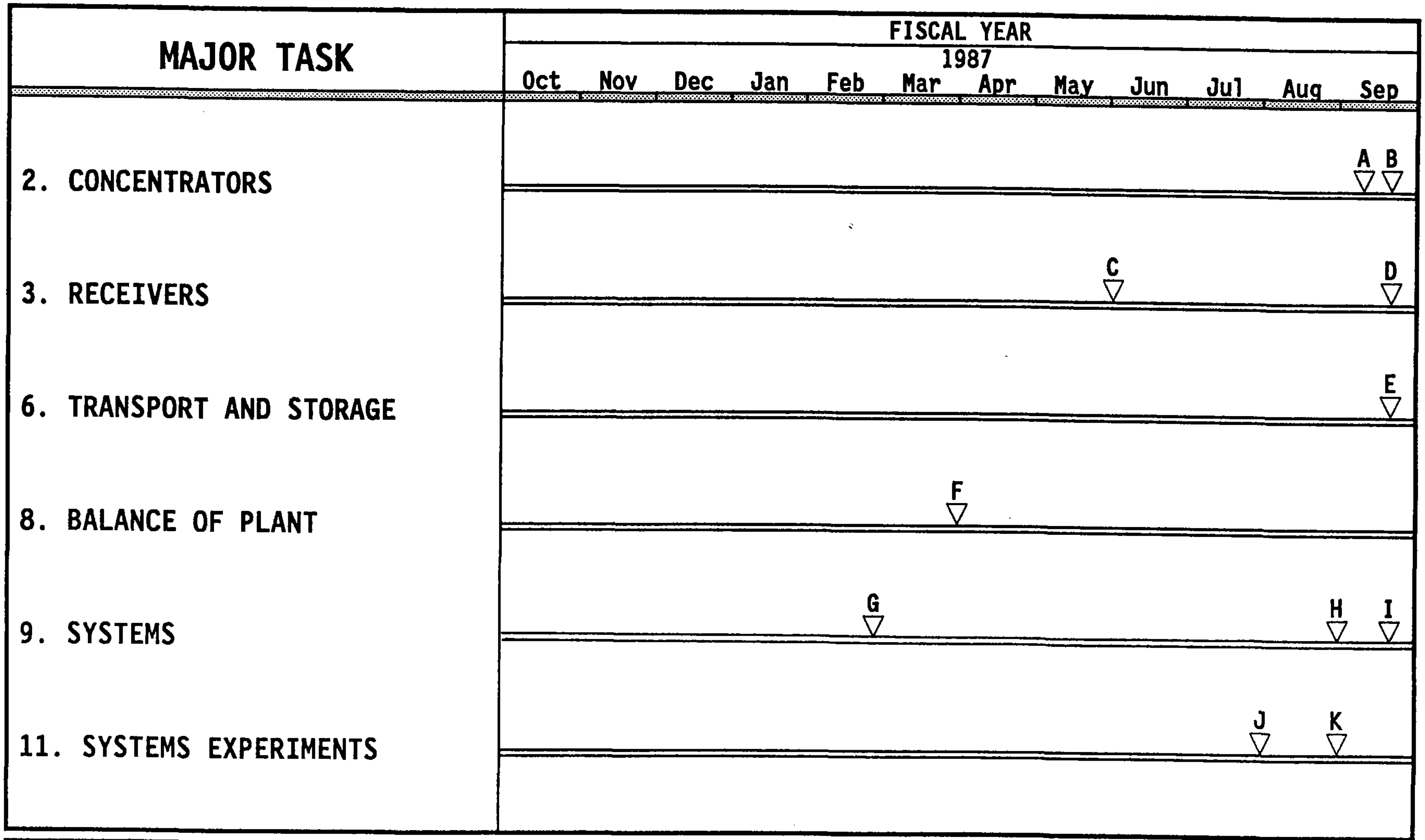
4.4 Major Reports FY87

Report	Draft	Publish	Reviewers
Solar I Final Report	Sept 87	Jan 88	McDonnell Douglas Astronautics Co. Babcock & Wilcox Utilities
Advanced Molten Salt Receiver	July 87	Sept 87	Tom Tracey Babcock & Wilcox Foster Wheeler

TABLE 2. FY87 RESOURCES

Task		External $K	Internal $K	Internal FTE	Total $K
2.	CONCENTRATORS	1050	750	5.5	1800
3.	RECEIVERS	880	620	4.5	1500
6.	TRANSPORT AND STORAGE	200	200	1.5	400
8.	BALANCE-OF-PLANT	115	85	0.5	200
9.	CENTRAL RECEIVER SYSTEMS	70	930	6.0	1000
9A.	CENTRAL RECEIVER TEST FACILITY	760	540	4.0	1300
11.	SYSTEM EXPERIMENTS	-	300	2.0	300
		3075	3425	24.0	6500

CENTRAL RECEIVER FY87 MAJOR MILESTONES



A=COMPLETE LARGE AREA HELIOSTAT EVALUATION
B=COMPLETE EVALUATION OF STR. MEMBRANE MODULES
C=COMPLETE ADVANCED SALT RECEIVER EVALUATION
D=RECOMMEND ALLOY FOR SALT-IN-TUBE DESIGNS
E=COMPLETE FULL SCALE PUMP AND VALVE TEST
F=REAL TIME C. R. DYNAMIC SIMULATOR COMPLETE
G=PUBLISH C. R. DESIGN GUIDE
H=COMPLETE PHASE I OF UTILITY STUDIES
I=COMPLETE PHASE II OF CRTF HELIOSTAT UPGRADE
J=COMPLETE 1987 SUMMER SOLSTICE TEST AT SOLAR I
K=COMPLETE THREE YEAR SOLAR I POWER PRODUCTION

CRAOP 1-27-87

Figure 2

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)

Solar Thermal Program Documentation Support

The DOE Office of Solar Heat Technologies is engaged in preparing summary technology transfer documentation of the major results of completed R&D efforts across the solar heat and solar thermal technologies. This effort is being conducted mainly by support contractors. During FY87, the Sandia Central Receiver program does not anticipate direct support to this effort; and resources, therefore, have not been budgeted for this activity.

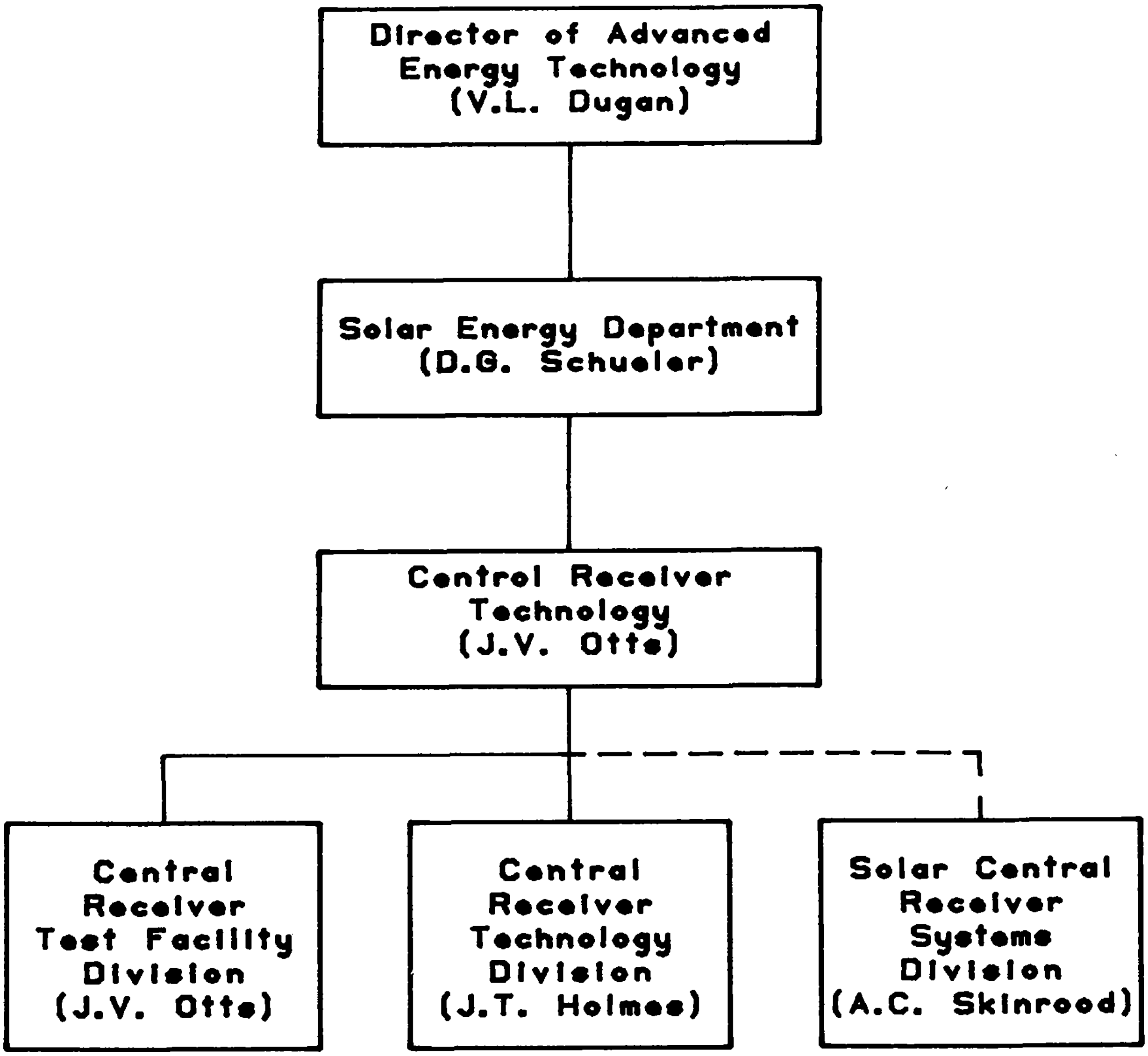


Figure 3. Management Structure for Solar Central Receiver Program

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 FY87 and FY88.

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 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

TABLE 3. FY 87 MAJOR PROCUREMENTS

		$K FY87
2.	CONCENTRATORS	
	Stressed Membrane Heliostat	900
	Wind Load	100
3.	RECEIVERS	
	Advanced Salt Receiver Test Extension	240
	Direct Absorption Receiver Tests	360
6.	TRANSPORT AND STORAGE	
	Pump and Valve Test Equipment	150
8.	BALANCE-OF-PLANT	
	Control Simulator	100
9.	CENTRAL RECEIVER SYSTEMS	
	Contracted Studies	70
9A.	CENTRAL RECEIVER TEST FACILITY	
	Heliostat Control Upgrade	300
	Contract Personnel	280
	O&M Contracts	100

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
1987-1988

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