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SANDIA REPORT SAND82-8027 • Unlimited Release • UC-62d
Printed December 1982

10 MW_e Central Receiver Solar Thermal Pilot Plant Data Evaluation Plan

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Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
for the United States Department of Energy
under Contract DE-AC04-76DP00789

SF 2900-Q(6-82)

Printed in the United States of America
Available from
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes
Printed copy: A04
Microfiche copy: A01

SAND 82-8027
Unlimited Release
Printed December 1982

UC62d

10 MWe CENTRAL RECEIVER SOLAR THERMAL PILOT PLANT DATA EVALUATION PLAN

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ABSTRACT

This report describes the Data Evaluation Plan for the 10 MWe Central Receiver Solar Thermal Pilot Plant near Barstow, California. The objective, test and data needs, approach, applicability, expected output, and planned data dissemination are presented for each evaluation.

ACKNOWLEDGMENT

The author wishes to thank the staff of the Systems Evaluation Division for providing the information described under evaluation approaches and for their assistance in reviewing the overall content of this document. The author also thanks Christine Yang for providing write-ups of the SOLTES, MIRVAL, and HELIOS computer codes and Marty Abrams for providing write-ups of the SAPPHIR and PARFLO computer codes. Numerous individuals from industrial and electric utility firms reviewed the draft document, and their comments are greatly appreciated. Special thanks are due to Pat Smith for her editorial review of the document and to Cheryl Jenson for typing the draft and final manuscripts.

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ILLUSTRATIONS

TABLES

ACRONYMS

BCS	Beam Characterization System
CS	Collector System
DAS	Data Acquisition System
DF	Dual Flow Transitional Operating Mode
DOE	Department of Energy
EPGS	Electric Power Generation System
EPRI	Electric Power Research Institute
I	Inactive Operating Mode
ILF	In-Line Flow Operating Mode
MDAC	McDonnell Douglas Astronautics Company
METRO	Meteorological
MWe	Megawatt-electric
MWeh	Megawatt-hours-electric
O&M	Operations and Maintenance
PM	Preventive Maintenance
R&D	Research and Development
RS	Receiver System
SB	Storage-Boosted Transitional Operating Mode
SC	Storage Charge Operating Mode
SCE	Southern California Edison
SD	Storage Discharge Operating Mode
SHIMMS	Special Heliostat Instrumentation and Meteorological Measurements Systems
SNLA	Sandia National Laboratories, Albuquerque

SNLL	Sandia National Laboratories, Livermore
TBD	To Be Determined
TD	Turbine Direct Operating Mode
TD&C	Turbine Direct and Charging Operating Mode
T-GF	Turbine-Generator Facilities
TSS	Thermal Storage System

10 MWe CENTRAL RECEIVER
SOLAR THERMAL PILOT PLANT
DATA EVALUATION PLAN

Introduction

The Department of Energy (DOE) and the Associates* have entered into a Cooperative Agreement to design, construct, and operate a central receiver pilot plant near Barstow, California. After construction and start-up tests have been completed, the Cooperative Agreement calls for a five-year Operational Test Period consisting of a two-year Experimental Test and Evaluation Phase followed by a three-year Power Production Phase. The Experimental Test and Evaluation Phase, scheduled to begin in mid-1982, will provide operating experience in all the operational modes, monitor plant performance, and establish the staffing needs of the Pilot Plant. The Power Production Phase will primarily demonstrate the operational capability of the Pilot Plant to supply electrical power.

The overall evaluation of the Pilot Plant is being performed by three organizations. Sandia National Laboratories, Livermore (SNLL), on behalf of DOE, will analyze and evaluate the data obtained from individual tests during start-up tests and the Experimental Test and Evaluation Phase. Southern California Edison (SCE) will keep operations and maintenance logs and records for the major plant elements. The Electric Power Research Institute (EPRI) will analyze the experiences from the design and construction of the Pilot Plant and will assemble a library of all relevant documentation.

This report describes a plan for the Pilot Plant data evaluation. In the next section, the relation between this plan and other Pilot Plant planning documents is described. The Pilot Plant data evaluation program objectives are discussed, and a description of each planned evaluation is given. Finally, the planned data dissemination for the evaluation program is described. In the Appendixes, a brief description of the Pilot Plant is presented, and the Pilot Plant data acquisition and processing capabilities are discussed. Finally, computer codes to be used for the data analyses are described.

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* Southern California Edison, Los Angeles Department of Water and Power, and the California Energy Commission.

Relation To Other Planning Documents

This plan is one of several documents that have been developed to guide the Experimental Test and Evaluation Phase of the Pilot Plant. The relationship of this plan to the other documents is shown in Figure 1.

The Pilot Plant Startup and Acceptance Test Plan (Reference 1) described the requirements for preoperational (prior to turbine roll) and acceptance (up to six months after turbine roll) tests. Construction delays, which deferred some preoperational tests past turbine roll, and the identification of additional desired tests dictated a need for an updated document that described the requirements past turbine roll. The Operational Test Requirements (Reference 2) describes these requirements. It provides top-level information on the objectives, test schedule, types and duration of tests, instrumentation and data acquisition requirements, and data reduction and analysis requirements for the operational tests. The Test Operations Plan (Reference 3) describes the specific tests necessary to achieve operational readiness of the Pilot Plant. Manual control tests are described for each operating mode; automatic control tests are described for clear- and cloudy-day scenarios. The Test Operations Plan also describes engineering tests used to investigate specific technical areas, e.g., mirror module life, that are important to the optimal operation of the Pilot Plant and the design of future central receiver power plants. The Data Evaluation Plan (this document) describes the objective, tests and data needs, approach, applicability, expected output, and planned data dissemination for each evaluation of the Pilot Plant. The Test Procedures document (Reference 4) is a detailed specification of the step-by-step procedures to be followed in conducting each test.

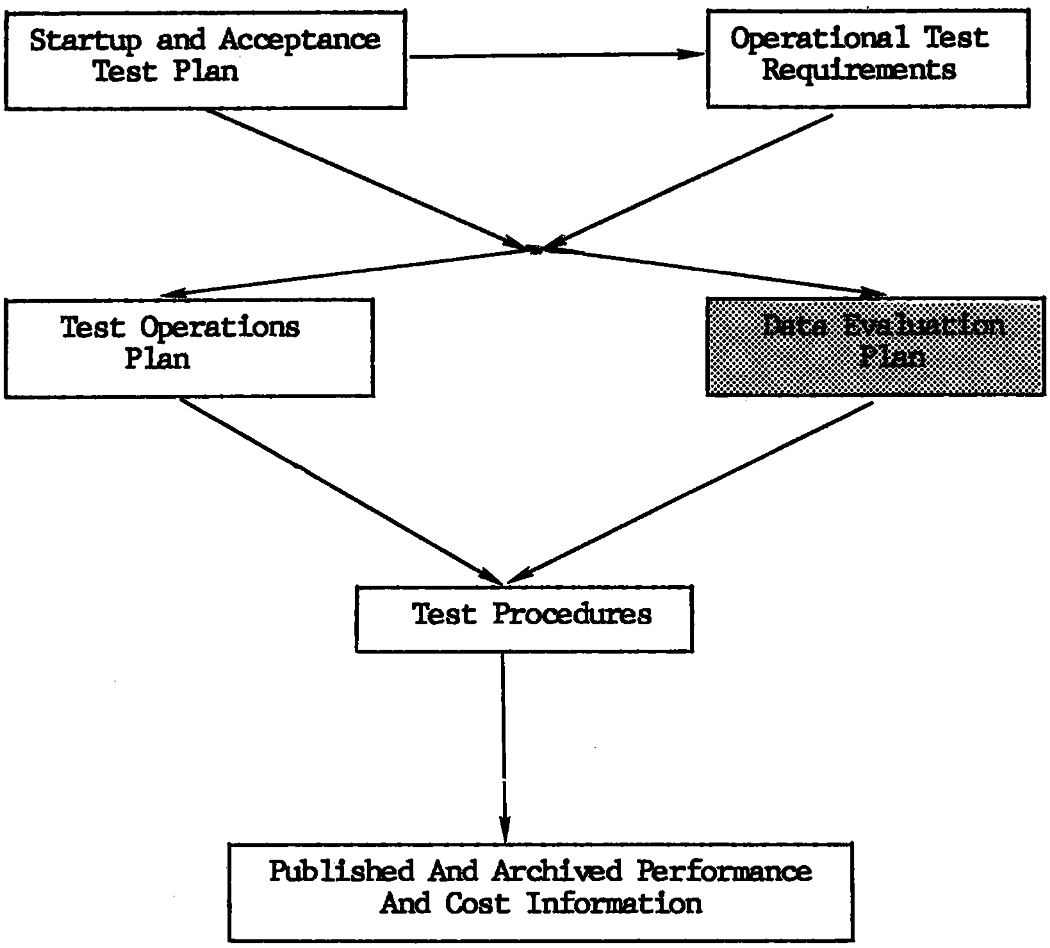


Figure 1. Pilot Plant Operational Control Documents

Objectives

The objectives of the data evaluation program are to:

- Establish the technical feasibility of the Pilot Plant;

- Provide information to support private sector decisions regarding designs and economics of future central receiver systems; and

- Identify areas where future central receiver research and development (R&D) may lead to significant performance improvements and increased capabilities.

To meet these objectives, the program will analyze data from the Pilot Plant design and construction, start-up tests, and two-year Experimental Test and Evaluation Phase. Technical feasibility will be established by comparing measured and predicted plant performance. Information to support private sector decisions will be provided by: (1) analyzing lessons learned from the Pilot Plant design and construction; (2) optimizing the performance of the Pilot Plant; (3) verifying the environmental, health, and safety impacts of the Pilot Plant; (4) establishing the operating and maintenance procedures; (5) analyzing the Pilot Plant costs; and (6) verifying and improving system design techniques. R&D needs for future central receiver systems will be assessed in several areas including: (1) heliostat optical performance; (2) mirror module corrosion and soiling; (3) heliostat wind load design criteria; (4) receiver absorber coating life; (5) receiver structural design; (6) storage fluid degradation; (7) storage tank thermal ratcheting; and (8) thermal cycling of plant equipment. Table I describes some expected benefits from this program and their applicability to the Pilot Plant and future power plants.

TABLE I. Benefits of Data Evaluation Program to Barstow Pilot Plant and Future Power Plants

Benefit	Applicability	
	Barstow Pilot Plant	Future Power Plants
Overall Plant System		
1. Improved plant performance through optimal use of thermal storage and efficient start-up procedures	X	X
2. Improved collector field design by examining interaction with receiver		X
3. Decreased engineering design time by improving analytical methods		X
4. Reduced cost by improving accuracy of design criteria and performance predictions		X
Collector System		
1. Increased reliability and life of heliostats by analysis of Barstow experience		X
2. Decreased cost of heliostats by using measured in-field wind loads		X
3. Determination of washing requirements	X	X
Receiver System		
1. Increased thermal efficiency by improving thermal analysis methods		X
2. Improved controllability by analysis of receiver dynamic tests	X	X
Thermal Storage System		
1. Improved controllability by analysis of storage dynamic tests	X	X
2. Reduced cost by improving accuracy of recoverable energy prediction		X
Plant Control System		
1. Reduced operational staffing requirements through automation	X	X
2. Improved plant performance through automation	X	X
Beam Characterization System		
Determination of future needs		X

Program Description

The data evaluations are keyed to tests described in the Test Operations Plan (Reference 3). A brief test description, excerpted from this plan, is presented below. The data evaluations are then discussed.

Test Program

The Pilot Plant test program provides an orderly completion of start-up tests and a systematic conduction of operational tests. Thus, the tests are organized under Start-Up and the two-year Experimental Test and Evaluation Phase. The general test categories are described in Table II.

Start-Up -- Start-Up is that period of time between turbine roll (construction completion) and the beginning of the two-year Experimental Test and Evaluation Phase. To accommodate construction delays, significant portions of the receiver and thermal storage tests were deferred past turbine roll. During Start-Up, receiver testing will continue, and the activation of thermal storage will be initiated. All of this testing must be completed before intersystem testing can be performed.

Experimental Test and Evaluation Phase -- During the two-year Experimental Test and Evaluation Phase, a wide variety of tests will be conducted to accumulate data on the performance of the Pilot Plant and its systems. During this period, the plant will be exercised in all of its operating modes and mode sequences, through the entire range of reasonably foreseeable normal and abnormal operating conditions. Both manual control operational tests and automatic control operational tests will be performed. The plant will be fine-tuned to operate at or near the optimal combination of annual energy output and operating and maintenance cost, and will be ready, by the end of this phase, for sustained power production operation during the Power Production Phase. Engineering tests will also be conducted in various areas of technical interest.

The manual control tests will evaluate each of the plant's operating modes (see Figure 2). The tests for each mode include:

a. normal transitions between operational modes;

b. plant status using simulated component failures to cause system trips;

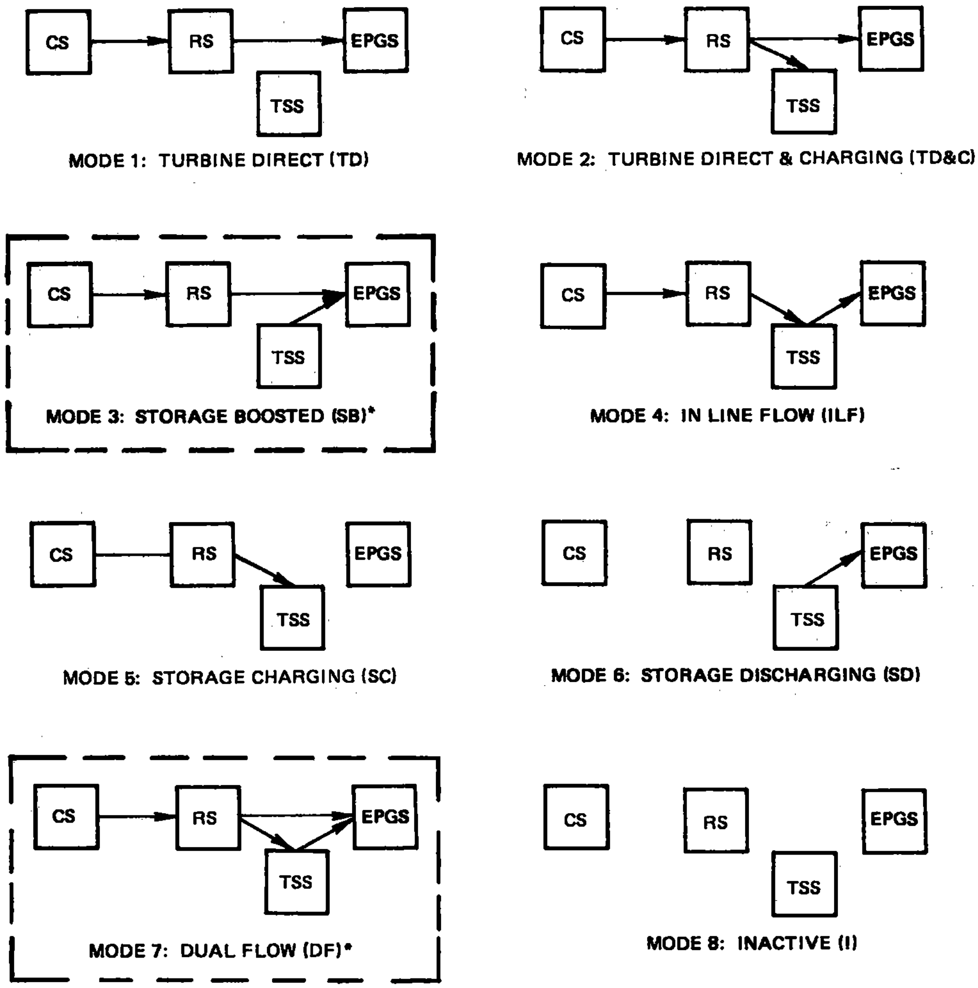
c. transitions between different power levels;

d. transitions between different steam flow rates; and

e. steady-state operation at various power levels, sun following, and load following.

TABLE II. Pilot Plant Test Categories

Start-Up	
1030 B	Completion of Receiver System Checkout
1040 A	Activation of Thermal Storage System Using Rental Boiler
1040 B	Thermal Storage System Checkout Using Receiver-Generated Steam
Two-Year Experimental Test and Evaluation Phase	
Manual Control Operational Tests	
1110	Mode 1, Turbine Direct
1120	Mode 2, Turbine Direct and Charging
1130	Mode 3, Storage Boosted
1140	Mode 4, In-Line Flow
1150	Mode 5, Storage Charging
1160	Mode 6, Storage Discharging
1170	Mode 7, Dual Flow
1180	Mode 8, Inactive
Automatic Control Operational Tests	
1220	Preliminary Tests
1230	Clear-Day Scenario
1240	Cloudy-Day Scenario
1250	Collector Power Modulation
1260	Plant Operational Status Displays
Engineering Tests	
1310	Beam Characterization System Tests
1320	Heliostat Tests
1330	Preliminary Power Production
1340	Control System Optimization
1350	Plant Optimization
1360	Associate Testing
1370	Special Heliostat Instrumentation and Meteorological Measurements Systems Tests
1380	Receiver Optical Tests
1390	Beam Safety Tests



Mode 1	Turbine Direct:	Receiver-generated steam directly powers the turbine.
Mode 2	Turbine Direct and Charging:	Receiver-generated steam powers the turbine and charges storage.
Mode 3	Storage Boosted:	Steam from the receiver and storage powers the turbine.
Mode 4	In-Line Flow:	Receiver steam charges storage, while storage steam is stimultaneously discharged powering the turbine.
Mode 5	Storage Charging:	Receiver steam charges the storage system.
Mode 6	Storage Discharging:	Steam generated by the storage system is used to power the turbine.
Mode 7	Dual Flow	A combination of Modes 2 and 3 (probably only achieved during transitions).
Mode 8	Inactive	Major systems are standing by for operation.

*Engineering Test and Transitory Modes

Figure 2. Pilot Plant Steady-State Operating Modes

The automatic control tests will evaluate the automatic operation of the plant. The automatic capability includes automatic mode transitions and automatic control for clear- and cloudy-day operation. To cover the range of possible operating conditions, collector-to-receiver power will be modulated by the defocus of heliostats. Tests are also planned to check out the plant operational status displays that will be installed during the Experimental Test and Evaluation Phase. Operational display capability is required for integrated manual and automatic control. The displays will minimize the number of operators needed to observe overall plant operation, monitor data, and control the plant through transitions. (The existing plant displays show data from one system at a time; several operators are required to monitor several system displays to observe full plant status.)

Evaluation Program

The planned data evaluations are summarized in Table III and described on the following pages. During the data evaluation program, data from those tests described in the Test Operations Plan will be analyzed. The required tests are listed using the same notation as that used in the Test Operations Plan. No additional tests are currently planned. This approach will minimize disruption of the operational testing needed to establish the operational readiness of the Pilot Plant. A description of the major computer codes used for the data analyses is provided in Appendix C.

TABLE III. Pilot Plant Planned Evaluations

No.	Evaluation
1	Meteorological Summaries
2	Plant Steady-State Performance
3	Plant Transient-State Performance
4	Collector Performance
5	Receiver Performance
6	Thermal Storage Performance
7	Plant Operations
8	Plant Maintenance
9	Plant Safety
10	Lessons Learned
11	Plant Costs
12	Environmental Assessment

Evaluation Specification 1

Title: Meteorological Summaries

SNLL Key Contact: Clay Mavis, (415) 422-3031 - FTS 532-3031

Objective: Collect meteorological data to evaluate plant performance and plant maintenance needs.

Test Requirements: All tests

Data Requirements:

Wind speed
Wind direction
Ambient dry bulb temperature
Ambient dew point temperature
Ambient pressure
Diffuse insolation
Direct insolation
Rainfall intensity and duration
Atmospheric attenuation

Approach:

Meteorological (METRO) data will be taken by the Special Heliostat Instrumentation and Meteorological Measurements System (SHIMMS). This system gathers data from sensors located on the receiver tower, on the control room roof, and throughout the heliostat field.

These data will be used in the evaluation of the plant and its systems. For example, temperature, insolation, and attenuation are required for field performance calculations; rainfall will be used in evaluating heliostat washing requirements.

Output and Applicability:

Output	Applicability	
	Pilot Plant	Future Power Plants
1. Direct & Diffuse Insolation	X	X
2. Wind Speed & Direction	X	X
3. Ambient Temperature	X	X
4. Rainfall	X	X
5. Atmospheric Attenuation	X	X

Evaluation Specification 2

Title:	Plant Steady-State Performance
SNLL Key Contacts:	Al Baker, (415) 422-2171 - FTS 532-2171 Christine Yang, (415) 422-2016 - FTS 532-2016 Jim Smith, (415) 422-2297 - FTS 532-2297
Objective:	Verify Pilot Plant steady-state performance. Optimize Pilot Plant annual performance. Identify areas where R&D may lead to performance improvements and increased capabilities.
Test Requirements:	1110-7 to 1110-10, 1140-15 to 1140-23
Data Requirements:	Fluid temperatures Fluid pressures Flow rates Plant control logic METRO data Heliostat field performance Receiver performance Thermal storage performance Electrical power generation system performance Plant electrical output

Approach:

SOLTES is a collection of component subroutine models orchestrated by a system manager to simulate the thermal-hydraulic performance of an actual system (see Figure 3). SOLTES input requirements are the heliostat field, receiver, thermal storage, and electrical power generation system performance, the system status at the beginning of an evaluation period and, thereafter, at specified time intervals. Many of the SOLTES inputs will be obtained from the results of other evaluations, e.g., receiver performance. SOLTES will provide mass and energy flows, temperature, pressure, and entropy predictions at the entrance and exit of each component. SOLTES will also perform general energy accounting and can provide both instantaneous and integrated values of system performance parameters.

SOLTES will be used in two ways. First, differences between the SOLTES predicted and actual plant parameters will be investigated. Hardware problems or software inadequacies will be identified and resolved. Second, SOLTES will be used to identify operating strategies (e.g., optimal use of thermal storage) to increase plant output. Ultimately, information from SOLTES will lead to the design of more efficient solar central receiver systems.

Output and Applicability:

Output	Applicability: Pilot Plant	Applicability: Future Power Plants
1. Verification of Steady-State Heat & Mass Balances	X	X
2. Optimized Use of Thermal Storage	X	X
3. Optimized Start-up Procedures	X	X

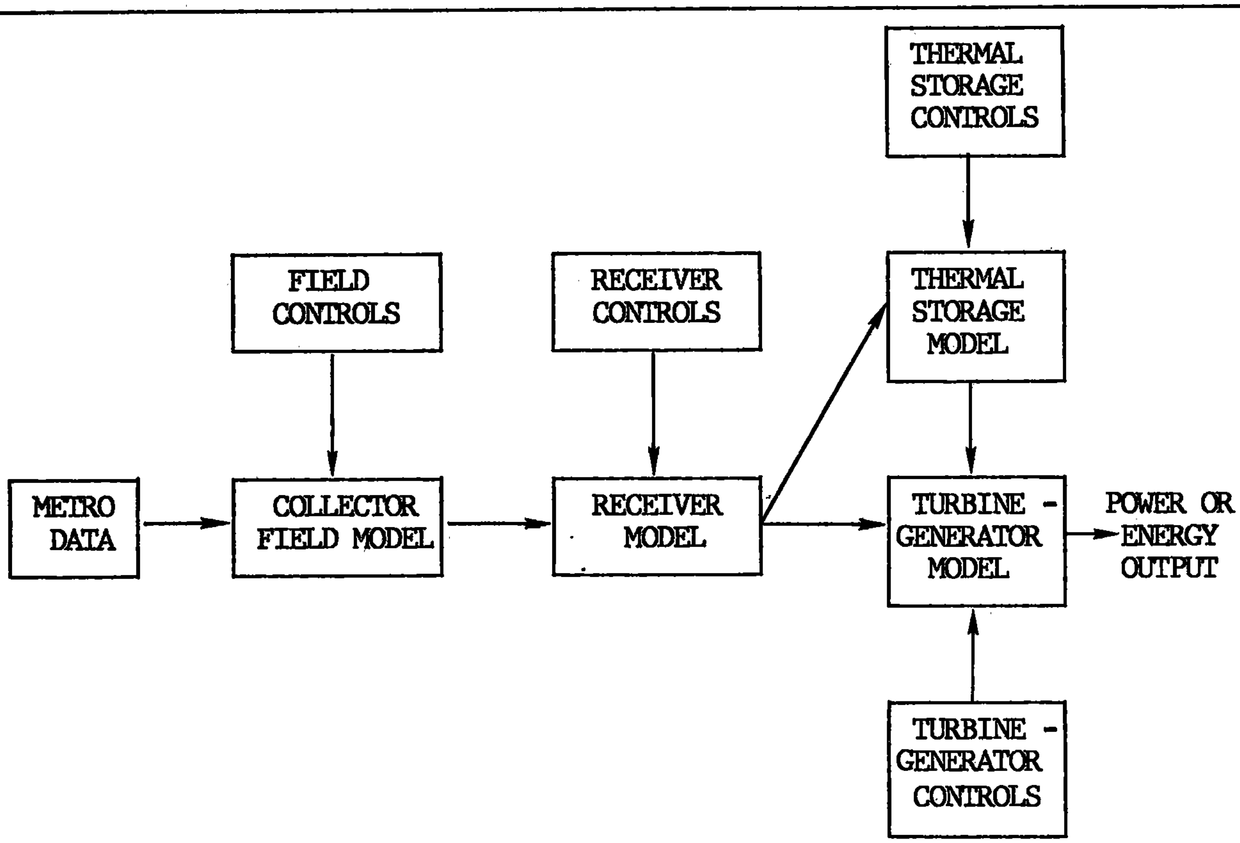


Figure 3. SOLTES System Model

Evaluation Specification 3

Title: Plant Transient-State Performance

SNLL Key Contact: Hal Norris, (415) 422-2620 - FTS 532-2620

Objective: Verify Pilot Plant transient-state performance.

Test Requirements: TBD

Data Requirements:

Receiver incident heat flux (from HELIOS or MIRVAL)
Fluid temperatures
Fluid pressures
Flow rates
Fluid levels of flash tanks
Valve positions
Controller commands

Approach: The response of the plant to transients, both planned (i.e., load changes) and unplanned (i.e., insolation variations or trip conditions) will be analyzed as required. If the actual control responses are not those desired, then modifications to the control system or operating strategy may be necessary. These modifications will be evaluated with the RELAP computer code (see Figure 4) prior to incorporation in the actual plant. RELAP requires flux maps, system controls logic, set points, and steady-state data for initialization. RELAP will output transient thermodynamic conditions and control element responses that can be compared to actual plant responses at various locations.

Output and Applicability:

Output	Applicability: Pilot Plant	Applicability: Future Power Plants
Verification of Plant Transient Performance	X	X

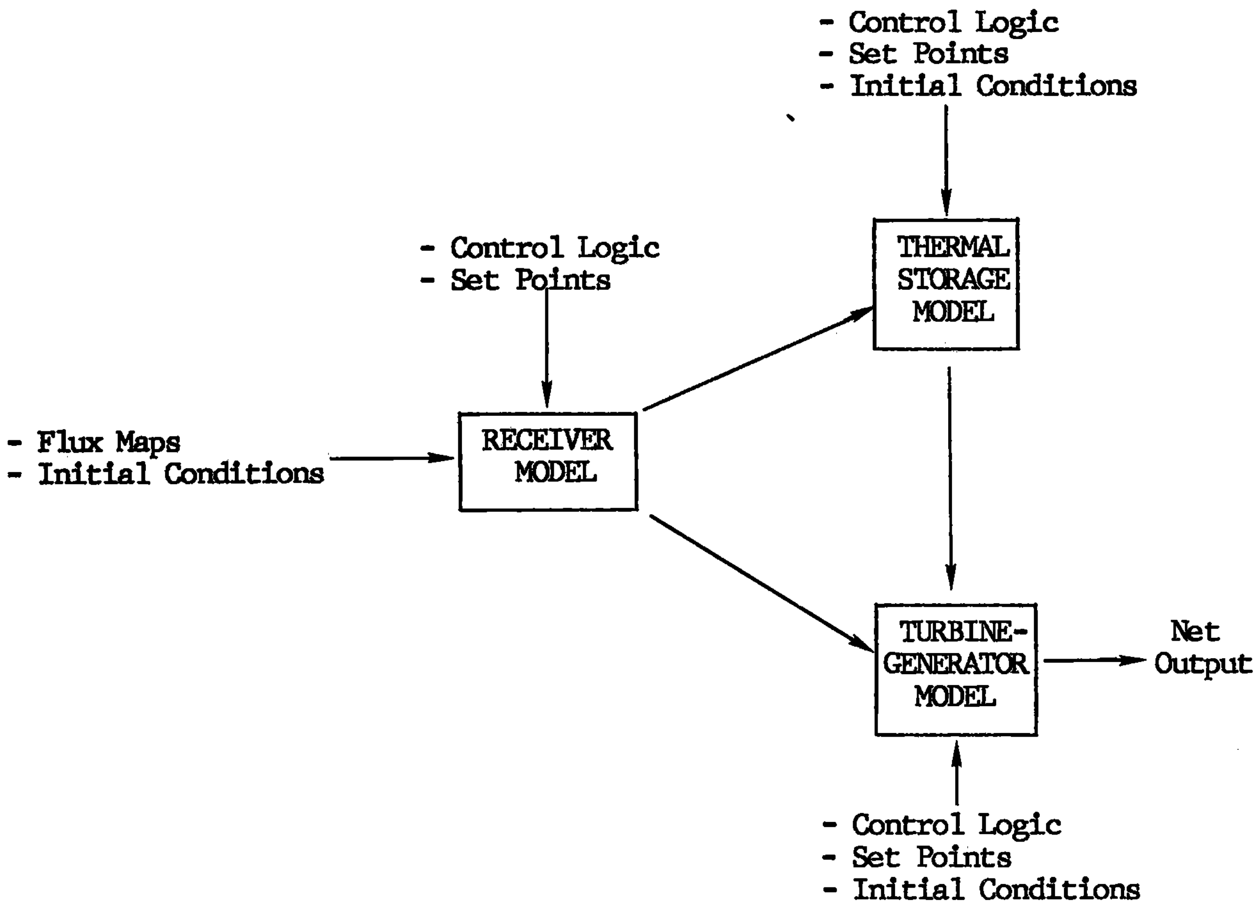


Figure 4. RELAP Transient Model

Evaluation Specification 4

Title:	Collector Performance
SNLL Key Contact:	Clay Mavis, (415) 422-3031 - FTS 532-3031
Objective:	Characterize heliostat performance. Identify areas where heliostat R&D may lead to performance improvements. Establish the need for a Beam Characterization System (BCS) in future power plants.
Test Requirements:	1310, 1320, 1370, and all operational tests
Data Requirements:	Time/sun position Individual aim points Heliostat geometry/position Equipment temperatures Ambient dry bulb temperature Ambient dew point temperature Wind speed Wind direction Rainfall intensity and duration Reflectivity Beam quality Beam pointing Heliostat loading

Approach:

This activity will evaluate heliostat optical performance and environmental survival over a two-year operational period.

Optical Performance

Heliostat optical performance will be derived from beam pointing, beam quality, and reflectivity data. Beam pointing is the measure of how accurately a heliostat tracks its reflected beam on a designated aim point. It is mainly a function of drive mechanism performance, wind loads, and control system accuracy. Beam quality describes the flux distribution of the reflected beam image at the aim point. Beam quality is affected by mirror module focal length and waviness, and accuracy of the module mounting on the heliostat. Reflectivity is the fraction of insolation incident on the heliostat that is contained in the reflected beam.

Beam pointing and quality will be measured on every heliostat by the BCS. Individual heliostats will be aimed to reflect their beams onto large tower-mounted targets. Field-mounted cameras will send the target images to a computer, where the images will be analyzed to determine the flux distribution (quality) and the centroid (pointing). The BCS interfaces directly with the Heliostat Array Controller (HAC). Daily operation is automatic and only requires that the operator input the list of heliostats to be tested. This system is capable of characterizing the entire field every 60 days. If the heliostats do not change much with time, it is possible that future plants will not require a BCS of the type used at the Pilot Plant.

Beam pointing accuracy is output directly by the BCS. The effect of the wind loads on beam pointing will be evaluated with SHIMMS. Six heliostats located near wind sensors have been instrumented with load cells. Tracking accuracy will be determined as a function of wind loads. This will be compared with the static load testing previously performed on prototype and production heliostats at the CRTF, SNLA, and SNLL.

Assessment of beam quality requires the analysis of the flux distribution using HELIOS or MIRVAL. Because of the time and expense of running these codes, detailed analysis of beam images will be performed for selected heliostats throughout the field. A simplified functional approximation, developed from these analyses, will provide a method for quantifying heliostat images and will allow rapid evaluation of beam quality by the operator. Since beam quality is strongly influenced by focal length (which is a function of temperature), SHIMMS data will be used in this analysis to determine module temperature and focal length.

Reflectivity measurements will be taken by trained SCE operators with a portable specular reflectometer. Biweekly measurements will be taken of several heliostats throughout the field. Some of these heliostats will be used in an experimental washing program to assess different washing techniques and frequencies. Other heliostats will be stowed vertically to assess this design alternative.

Beam pointing and quality will be compared with specifications. Heliostats out of specification will be corrected and reported under plant O&M. Probability distributions of pointing accuracy, beam quality and reflectivity, and their changes over time will be determined.

Environmental Survival

Heliostats are designed to have a service life in excess of 30 years. The major environmental conditions which affect this lifetime are the drive and structure loads imposed by high winds, corrosion of mirror module silvering as a result of attack by water, and survival of controllers and motors under operating thermal loads.

SHIMMS data will be analyzed to evaluate load distributions for individual heliostats throughout the field as a function of wind speed and angle of attack. Results will be used to derive aerodynamic design criteria for future heliostats.

Sensors, which will provide measurements of motor, controller, mirror module, and structure temperatures, have been installed on the six SHIMMS heliostats. These measurements will be compared with design specifications including ambient operating conditions, allowable temperature rise under load, and duty cycle. Mirror module temperature, which affects the focal length, will be input into HELIOS or MIRVAL as part of the optical performance evaluation.

Mirror module silver corrosion occurs when water attacks the silvering on the back surface of the mirror. Leak testing, controlled thermal cycling, in-situ temperature and humidity measurements, radiography to locate water, and computer simulation of mirror modules will be performed to determine the extent and source of water in modules and possible remedies.

Output and Applicability:

Output	Applicability: Pilot Plant	Applicability: Future Power Plants
1. Verification of Heliostat Optical Performance	X	X
2. Need for a BCS		X
3. Assessment of Heliostat Wind Load Design Criteria		X
4. Assessment of Mirror Module Corrosion	X	X
5. Assessment of Preferred Heliostat Stowage Position & Washing Techniques	X	X

Evaluation Specification 5

Title:	Receiver Performance
SNLL Key Contacts:	Al Baker, (415) 422-2171 - FTS 532-2171 Hal Norris, (415) 422-2620 - FTS 532-2620
Objective:	Characterize receiver performance. Identify areas where receiver R&D may lead to performance improvements.
Test Requirements:	1110, 1120, 1130, 1140, 1150
Data Requirements:	Fluid temperature Fluid pressure Flow rates Flash tank fluid level Valve positions Controller commands Feedwater pump speed and power Panel metal temperatures Panel deflections Air temperature Wind speed Wind direction Receiver incident power (from HELIOS or MIRVAL) Receiver incident heat flux (from HELIOS or MIRVAL)
Approach:	This activity will evaluate receiver steady-state performance, transient-state performance, thermal stresses, and absorber coating.

Steady-State

The conversion efficiency of the receiver will be determined as a function of total incident solar power. The data from the collector field will be used as input to the HELIOS or MIRVAL computer codes. HELIOS or MIRVAL will compute the total solar energy incident on the receiver as well as the energy distribution. The power absorbed by the water/steam flowing through the total receiver and the power absorbed by individual panels will be calculated from the water/steam flow rates and the enthalpy change through the receiver and individual panels. The receiver efficiency is simply the ratio of the energy absorbed by the water/steam to the total incident energy supplied by the collector field. Individual panel efficiencies and the apportioning of the receiver losses will be calculated with the SNLL thermal hydraulic computer codes, SAPPHIR and PARFLO. These codes use the calculated HELIOS or MIRVAL incident energy distribution, the measured water/steam flow rates, fluid inlet and outlet intensive properties, receiver geometry, receiver metal temperatures, and ambient temperature and wind data to calculate the reflected energy loss, the emitted radiative energy loss, and the convective energy loss. Tabulations of the receiver efficiency as a function of incident power and atmospheric conditions (temperature, wind speed, and wind direction) will describe the receiver's steady-state performance. Comparisons with the design estimates will be made.

Transient-State

The response of the receiver (outlet steam conditions) to transients, both planned (i.e., load changes) and unplanned (i.e., insolation variations, or trip conditions) will be evaluated if required. The evaluation will determine the suitability of the receiver operating strategy and control system. The receiver response to specific transients will be calculated with the RELAP receiver computer model. The model response will be compared with the actual response to determine if the receiver controls are responding as designed. If the actual control responses are other than desired, then modifications to the control system or strategy can be evaluated with the RELAP model prior to incorporation into the actual plant.

Thermal Stresses

Receiver thermal stresses will be analyzed based on operating data. These include panel lateral stresses, tube-to-header stresses (including welds), and tube front-to-back stresses. These analyses, along with thermal expansion data, will determine if the receiver is operating as designed. The effect of relaxing the design temperature difference constraint between the panel metal and steam temperatures will be studied.

Absorber Coating

The performance and environmental survival of the receiver absorber coating will be determined. The absorptivity of each receiver panel will be measured at several locations and as a function of time. Visual inspections of the panel surfaces will also be performed.

Output and Applicability:

Output	Applicability: Pilot Plant	Applicability: Future Power Plants
1. Verification of Receiver Efficiency	X	X
2. Verification of Receiver Transient Response	X	X
3. Verification of Receiver Structural Design Criteria	X	X
4. Verification of Absorber Coating Performance	X	X

Evaluation Specification 6

Title: Thermal Storage Performance

SNLL Key Contact: Scott Faas, (415) 422-2287 - FTS 532-2287

Objective: Characterize thermal storage performance. Identify areas where thermal storage R&D may lead to performance improvements.

Test Requirements: 1120, 1130, 1140, 1150, 1160

Data Requirements:
Fluid temperature distribution in storage tank
Fluid pressures in storage tank
Flow rates
Flash tank fluid level
Valve positions
Controller commands
Pump speed and power
Air temperature
Wind speed
Storage tank fluid level
Strain gauge outputs
Oil replenishment rate
Oil chemical analyses

Approach: This activity will evaluate the thermal storage steady-state performance, transient-state performance, fluid degradation, and tank thermal ratcheting.

<u>Steady-State</u>

The throughput efficiency of thermal storage will be determined, and the effects of charging rate, discharging rate and hold time will be evaluated. Energy delivered to and removed from storage will be monitored by an axial string of thermocouples in the thermal storage tank. The throughput efficiency is the total electrical energy generated by using storage divided by the total thermal energy sent to storage.

To evaluate this efficiency, both heat losses from the system to the environment and heat transfer within the oil/rock/sand bed must be analyzed. The oil/rock/sand bed operates as a regenerative heat exchanger where the oil is the heat transfer fluid, and the rock and sand are stationary. Energy is stored by establishing a thermocline with the hot region on top of the cold. The hot region of the thermocline provides the useful energy from storage; energy in the interface and cold regions is not useful except for low-temperature seal and blanket steam production. The relative size of each region depends on the thermal storage system operation (charging rate, charging duration, hold time, etc). Minimizing the interface region will maximize the useful energy that can be recovered from the storage tank.

Heat losses from the storage tank will be derived from thermocouples embedded in the foundation, rock/sand bed, tank shell, and exterior surfaces of the storage tank.

Information concerning the size of the hot, cold, and interface regions is provided by thermocouples embedded in the rock/sand. Both axial and radial measurements are available. Axial measurements will be compared to those predicted by a modified version of TESVR4, a one-dimensional, variable property, finite-difference computer model. Plots of the radial profiles will be studied for nonisothermal characteristics; an ideal thermocline has isothermal radial profiles. The extent of the three regions and the energy contained in each, referenced to the lowest useful temperature, will be analyzed.

Transient-State

The response of the thermal storage system to transients, both planned (i.e., charging steam conditions, or load changes) and unplanned (i.e., trip conditions), will be evaluated if required. The evaluation will determine the suitability of the thermal storage operating strategy and control system. The thermal storage response data to specific transients will be calculated with a RELAP storage computer model. The model response will be compared with the actual response to determine if the thermal storage controls are responding as designed. If the actual control responses are other than desired, then modifications to the control system or strategy can be evaluated with the RELAP model prior to incorporation into the actual plant.

Fluid Degradation

The heat transfer oil, Caloria HT-43, will be used at temperatures at which it will undergo thermal cracking as well as form sludges. The rate of Caloria replenishment and light hydrocarbon removal will be tabulated on a monthly basis. Samples of the oil will be taken monthly or more frequently if conditions require and sent to labs for analysis.

Tank Thermal Ratcheting

A primary concern with dual media thermocline systems is the phenomenon of thermal ratcheting. Thermal ratcheting is caused when the tank expands as a result of heating, and the oil/rock/sand bed settles to fill the space. When the tank cools, it is unable to contract because of the settling of the bed and stresses are increased in the tank shell.

Strain gauges are mounted on the tank's external surface to monitor local strain from which stress may be calculated. The data provided by the strain gauges will be tabulated on a weekly basis, and a plot of stress or strain versus time for each of the gauge locations will be provided.

Output and Applicability:

Output	Applicability: Pilot Plant	Applicability: Future Power Plants
1. Verification of Thermal Storage Efficiency	X	X
2. Verification of Thermal Storage Transient Response	X	X
3. Verification of Storage Fluid Makeup Needs	X	X
4. Verification of Storage Tank Design Criteria	X	X
5. Verification of Thermocline Design Criteria	X	X

Evaluation Specification 7

Title:	Plant Operations
SNLL Key Contact:	Jim Bartel, (619) 254-2971
Objective:	Establish the Pilot Plant operating procedures and costs. Determine the Pilot Plant availability.
Test Requirements:	All operational tests
Data Requirements:	Operating costs Daylight hours Insolation Test hours Scheduled maintenance outage hours Unscheduled maintenance outage hours Weather outage hours Training hours Power production hours Energy production (MWeh gross and net)

Approach:

Operating Procedures

Typical daily operating and special procedures and manpower requirements will be reported, including start-up, shutdown, and plant trips. Operation of the collector subsystem will be addressed in detail.

Operating Costs

SCE currently operates computerized data acquisition and processing systems for the conventional power generating plants on its grid. These systems will be modified to accommodate the Pilot Plant solar equipment and additional levels of cost accounting.

The multilevel system allows accumulation and totalizing of costs with a great deal of flexibility. For example, operations labor and maintenance labor may be accumulated separately and charged to each system or equipment type. The costs will be accumulated continuously by the SCE computerized system and will be summarized and reported monthly. A current itemized listing by account and subaccount number is presented in Appendix B.

Plant Availability

Availability is defined as the percentage of total time -- insolation and wind permitting -- that the plant is operable. The Data Acquisition System (DAS) will provide the insolation and wind data to establish the time base for operable conditions and the time that the plant is in actual operation. Operator daily logs will identify the amount of and reason for down times in order to derive the availability. Availability will be reported on a system and total plant basis.

Output and Applicability:

Output	Applicability	
	Pilot Plant	Future Power Plants
1. Operating Procedures	X	X
2. Operating Costs	X	X
3. Plant Availability	X	X

Evaluation Specification 8

Title:	Plant Maintenance
SNLL Key Contact:	Jim Smith, (415) 422-2297 - FTS 532-2297
Objective:	Establish the Pilot Plant maintenance needs and costs. Determine plant and equipment reliability.
Test Requirements:	All operational tests
Data Requirements:	Maintenance costs Maintenance records

Approach:

Maintenance Needs

1. History

SCE, using the computerized data acquisition and process systems for its conventional power generating plants, will accumulate historical data by equipment number for plant equipment items. Data will be accumulated from preventive maintenance work orders and work orders originated by plant operators as a result of equipment breakdown or malfunction. The collected data will include a description of the work performed, replacement parts required, and labor time associated with repair. The data will be entered into the SCE Computerized Maintenance Generation Management System and may be accessed by equipment number.

2. Preventive Maintenance (PM)

The PM system will be managed by the SCE Maintenance Generation Management System. PM instructions and schedule will be entered into the system by equipment number. PM work orders in hard copy format will be issued on schedule by the system. The status and disposition of issued work orders will be available from the system. Required repairs will be added to the equipment history.

3. Spare Parts

SCE will maintain an inventory of spare parts unique to the solar plant in an on-site warehouse. Parts for equipment items common to other SCE generating stations may be drawn from corporate-wide inventory. The central, corporate-wide, computerized Materials Management System will be used for full inventory control and access to required spare parts.

Maintenance Costs

The SCE computerized data acquisition and processing system that was described under Operating Costs (see Evaluation Specification 7) will also be used to report maintenance costs.

Reliability

The reliability of key plant components will be evaluated to identify marginal system elements that require improvement. Special attention will be directed to the plant computer sytems to identify high and low failure components. A monthly status report of the collector field, which is made up of 1818 essentially identical heliostats, is also planned. This report will describe the number of heliostats repaired, type of repairs, number of new failures during the month, and number of adjustments required. The percent of the field in operation at the end of each month will be reported.

Output and Applicability:

Output	Applicability	
	Pilot Plant	Future Power Plants
1. Plant Reliability	X	X
2. Equipment Maintenance History	X	X
3. Preventive Maintenance Needs	X	X
4. Spare Parts Needs	X	X
5. Maintenance Costs	X	X

Evaluation Specification 9

Title: Plant Safety

SNLL Key Contact: Tom Brumleve, (415) 422-2941 - FTS 532-2941

Objective: Verify Pilot Plant safety.

Test Requirements: 1360, 1390, and all operational tests

Data Requirements: TBD

Approach: This activity will evaluate heliostat beam and receiver optical safety and the ability of the plant to safely shutdown following the loss of power or the failure of a major component.

<u>Heliostat Beam Safety</u>

The eye hazards of heliostat beams in the airspace above the plant and at ground level will be evaluated. Beam brightness will be measured at various altitudes and locations when heliostats are at standby, face-down, and face-up stowage positions, or are undergoing maneuvers (i.e., wire-walk or expanding ring) to achieve these positions.

<u>Receiver Brightness</u>

The eye hazard of the reflected light from the receiver will be evaluated. Receiver brightness will be measured at several ground locations when the receiver is operating at or near full power.

<u>Plant Safe Shutdown</u>

The ability of the plant to shutdown safely will be evaluated for three conditions: (1) loss of power to the collector field; (2) loss of power to the collector field and all the plant auxiliaries; and (3) failure of major components.

Output and Applicability:

Output	Applicability	
	Pilot Plant	Future Power Plants
1. Verification of Heliostat Beam Safety	X	X
2. Verification of Receiver Brightness Safety	X	X
3. Verification of Plant Safe Shutdown Procedures	X	X

Evaluation Specification 10

Title: Lessons Learned

EPRI Key Contact: John Bigger, (415) 855-2178

Objective: Analyze Pilot Plant design and construction experience and compile a library of all relevant documentation.

Test Requirements: None

Data Requirements: None

Approach: The lessons learned during the design and construction of the Pilot Plant will be evaluated by an architectural and engineering firm under contract to EPRI. Both management and contracting operations will be explored.

An index and abstracts of all reports that were prepared during the Pilot Plant component testing, design, construction, and operation will also be issued by the firm. A complete set of reports will be assembled at the Pilot Plant administrative offices.

Output and Applicability:

Output	Applicability: Pilot Plant	Applicability: Future Power Plants
1. Design & Construction Lessons Learned		X
2. Compilation of Reports	X	X

Evaluation Specification 11

Title: Plant Costs

SNLL Key Contacts: Hal Norris, (415) 422-2620 - FTS 532-2620
Jim Bartel, (619) 254-2971

Objective: Analyze the Pilot Plant project costs. Estimate the costs of future 10 MWe plants and scaled plants using the Pilot Plant technology.

Test Requirements: None

Data Requirements: Townsend and Bottum, Inc., Solar 10 MWe Pilot Plant cost estimate
Operations and maintenance costs (see Evaluation Specifications 7 and 8)

Approach: Pilot Plant Project Costs

The Pilot Plant project costs (design, engineering, construction, and owners costs) will be sorted into a standardized cost breakdown structure being formulated by Polydyne, Inc. Data will be used from the Townsend and Bottum Probe code listing and from other cost records as required. The data will be preserved in a Cost Data Management System and will be part of a data bank of central receiver estimated and actual cost information.

Future Plant Costs

Pilot Plant costs will be analyzed to identify unique costs associated with the Pilot Plant, such as special instrumentation costs, special procurement costs, special testing costs, as well as non-recurring costs. O&M costs will be estimated based on recorded plant data.

Future plant costs will be estimated for additional plants of the same size as the Pilot Plant as well as for larger plants, e.g., 100 MWe.

Output and Applicability:

Output	Applicability: Pilot Plant	Applicability: Future Power Plants
1. Pilot Plant Project Costs	X	
2. Future Plant Costs		X

Evaluation Specification 12

Title: Environmental Assessment

SNLL Key Contact: TBD

Objective: Evaluate the environmental, health, and safety experiences of the Pilot Plant. Identify mitigation techniques for future power plants.

Test Requirements: TBD

Data Requirements: TBD

Approach: This activity will evaluate six Pilot Plant environmental issues that must be resolved prior to significant public deployment of central receiver technology: handling and disposal of system fluids and wastes, potable water contamination, heliostat reflection, ecological impacts of the heliostat field, alteration of the microclimate, and land use. Each issue will be addressed by reporting actual experiences for the Pilot Plant and by suggesting techniques for mitigation.

Output and Applicability:

Output	Applicability: Pilot Plant	Applicability: Future Power Plants
1. Environmental, Health, and Safety Experiences	X	X
2. Identification of Mitigation Techniques		X

Data Dissemination

Technology transfer activities are a crucial part of the Pilot Plant Experimental Test and Evaluation Phase. These activities will include both technical presentations and written reports. Information about the Pilot Plant will be disseminated at technical conferences and workshops. A DOE-sponsored workshop, similar to the recent International Workshop on the Operation of Solar Central Receiver Plants, will be held in late 1984 to discuss the Pilot Plant testing and evaluation after the Experimental Test and Evaluation Phase is complete.

SNLL, SCE, and EPRI will issue reports that describe the Pilot Plant design and construction experience, Pilot Plant costs, evaluation methodologies, and evaluation results. The topics and actual or planned date of issuance are described in Table IV. McDonnell Douglas Astronautics Company (MDAC), under contract to SNLL, will be conducting the operational tests during the Experimental Test and Evaluation Phase. As part of this activity MDAC will issue reports that provide a record of the operational tests. The reports, which are listed in Table V, are primarily test reports and will contain only a very limited number of analyses.

Meteorological data evaluation reports will not be issued separately but will be summarized in annual reports (described below) and combined with other topical reports. Evaluation reports on specific topics will generally not be issued until the Experimental Test and Evaluation Phase is complete. Several topics may be combined into a single report depending on the content. Annual reports that describe the status of both the testing and evaluations, and monthly and quarterly reports that highlight operational and maintenance data for the Pilot Plant, will be issued. To assure that any significant findings are disseminated quickly SNLL will issue several monographs. These short reports (2-4 pages) will provide timely evaluation information on subjects of special interest.

All reports will be prepared for general distribution. Monthly and quarterly reports and monographs will be issued to a limited number of interested parties. Topical and annual reports will be sent directly to a limited number of persons, but copies will be available through the National Technical Information Service (NTIS), U. S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161. Much of this information will also be described in articles that will be submitted to appropriate journals (e.g., Solar Energy and Solar Energy Engineering) for publication.

TABLE IV. Evaluation Reports

Evaluation Category	Topic/Report	Issuing Organization	Date
1. Meteorological Summaries	FY82 Annual Report	SNLL	Apr 1983
	FY83 Annual Report	SNLL	Apr 1984
	FY84 Annual Report	SNLL	Apr 1985
2. Plant Steady-State Performance	Plant Steady-State Performance Monograph	SNLL	Jan 1984
	Final Report	SNLL	Dec 1984
3. Plant Transient-State Performance	RELAP Receiver Model (SAND81-1220)	SNLA	Aug 1981
	RELAP Thermal Storage Model (SAND81-1831)	SNLA	Oct 1981
	RELAP Turbine-Generator Model	SNLA	TBD
	Final Report	SNLL	Dec 1984
4. Collector Performance	Collector Performance Monograph	SNLL	Apr 1983
	Optical Performance	SNLL	Dec 1984
	Need for a BCS	SNLL	Dec 1984
	Heliostat Washing	SNLL	Dec 1984
	Heliostat Wind Loads	SNLL	Dec 1984
	Mirror Module Corrosion	SNLL	Dec 1984
5. Receiver Performance	1030 Test Evaluation Monograph	SNLL	Feb 1983
	Receiver Performance Monograph	SNLL	Apr 1983
	Receiver Efficiency	SNLL	Dec 1984
	Receiver Thermal Stresses	SNLL	Dec 1984
	Receiver Absorber Coating	SNLL	Dec 1984
6. Thermal Storage Performance	1040 Test Evaluation Monograph	SNLL	Mar 1983
	Storage Performance Monograph	SNLL	May 1983
	Storage Efficiency	SNLL	Dec 1984
	Storage Fluid Degradation	SNLL	Dec 1984
	Tank Thermal Ratcheting	SNLL	Dec 1984
7. Plant Operations	Operating Costs	SNLL	TBD
	Operations	SCE	Monthly
	Operations Summary	SNLL	Quarterly
	Operations Monograph	SNLL	Mar 1983

TABLE IV. (continued)

8. Plant Maintenance	Maintenance Costs	SNLL	TBD
	Maintenance	SCE	Monthly
	Maintenance Summary	SNLL	TBD
	Maintenance Monograph	SNLL	Sep 1983
9. Plant Safety	Heliostat Beam Safety	SNLL	Mar 1983
	Receiver Brightness	SNLL	Mar 1983
	Plant Safe Shutdown	SNLL	Dec 1984
10. Lessons Learned	Final Report	EPRI	TBD
	Index and Abstracts of Pilot Plant Reports	EPRI	TBD
11. Plant Costs	Pilot Plant Project Costs	SNLL	TBD
	Future Plant Costs	SNLL	TBD
12. Environmental Assessment	Environmental, Health and Safety Experiences	TBD	TBD
	Mitigation Techniques	TBD	TBD
13. General	FY82 Annual Report	SNLL	Apr 1983
	FY83 Annual Report	SNLL	Apr 1984
	FY84 Annual Report	SNLL	Apr 1985

TABLE V. Test Reports

Topic/Report	Preparing Organization	Date
1030 Tests	MDAC	Feb 1983
1040 Tests	MDAC	Mar 1983
Meteorological Tests	MDAC	Mar 1983
1110 Tests	MDAC	Mar 1983
1150/1160 Tests	MDAC	Apr 1983
1120/1130/1140 Tests	MDAC	Oct 1983
1200 Tests	MDAC	TBD
1300 Tests	TBD	TBD

Special requests for information from private and government organizations are expected to range from raw data on system and component performance to complex analyses of component interactions. Requests, which will be handled as quickly as possible, should be directed to:

J. F. Genoni
Solar Central Receiver Department - 8450
Sandia National Laboratories
Livermore, CA 94550

or

P. Tong
Pilot Plant Visitor's Center
Southern California Edison
Cool Water Generating Station
Daggett, CA 92327

APPENDIX A -- PILOT PLANT DESCRIPTION

The Pilot Plant consists of seven major systems: the collector, receiver, thermal storage, plant control, plant support, beam characterization, and electrical power generating systems (see Figure A-1). The heliostats in the collector system reflect the solar energy onto the receiver, which is mounted on a central tower. The receiver absorbs the solar energy in water that is boiled and converted to high-pressure steam. This steam powers a turbine-generator for the generation of electrical energy. Steam from the receiver, in excess of the energy required for the generation of 10 MWe net power to the utility grid, is diverted to thermal storage for use when output from the receiver is less than that needed for rated electrical power.

Collector System - The collector field consists of 1818 heliostats. Each heliostat has 39.3 m^2 reflective area, and the total field reflector area is 71,447 m^2.

Receiver System - The receiver system consists of a single-pass-to-superheat boiler with external tubing, a tower, pumps, piping, wiring, and controls necessary to provide the required amount of steam to the turbine. The receiver is designed to produce 516°C steam at 10.3 MPa. The receiver is 7 m in diameter and 13.7 m high with a total surface area of 330 m^2. The tower supporting the receiver is 72 m to the bottom of the receiver.

Thermal Storage System - The thermal storage system provides for storage of thermal energy to extend the plant's electrical power generating capability. It also provides steam for keeping selected portions of the plant warm during nonoperating hours. The storage tank is 13.7 m high and 19.8 m in diameter. The tank is filled with rock, sand, and thermal oil. When fully charged, the mixture has a temperature of 302°C. When the system is discharging, the oil is pumped through a heat exchanger to produce steam at 274°C, 2.7 MPa, for delivery to the turbine. The net rated electrical capacity of the plant operating on thermal storage is 28 MWhe or 7 MWe for four hours.

Plant Control System - The plant control system provides for plant control from the control room. It supplies overall coordinated supervisory control to individual system controls. In the final configuration, the plant can be operated automatically.

Plant Support System - The plant support system is composed of all supporting systems, such as service water, nitrogen, air, electrical power distribution, and fire protection.

Beam Characterization System - The beam characterization system consists of vidicon cameras, a microcomputer, and associated automatic controls. It is used to calibrate each heliostat with respect to its aim point on the receiver and its beam shape.

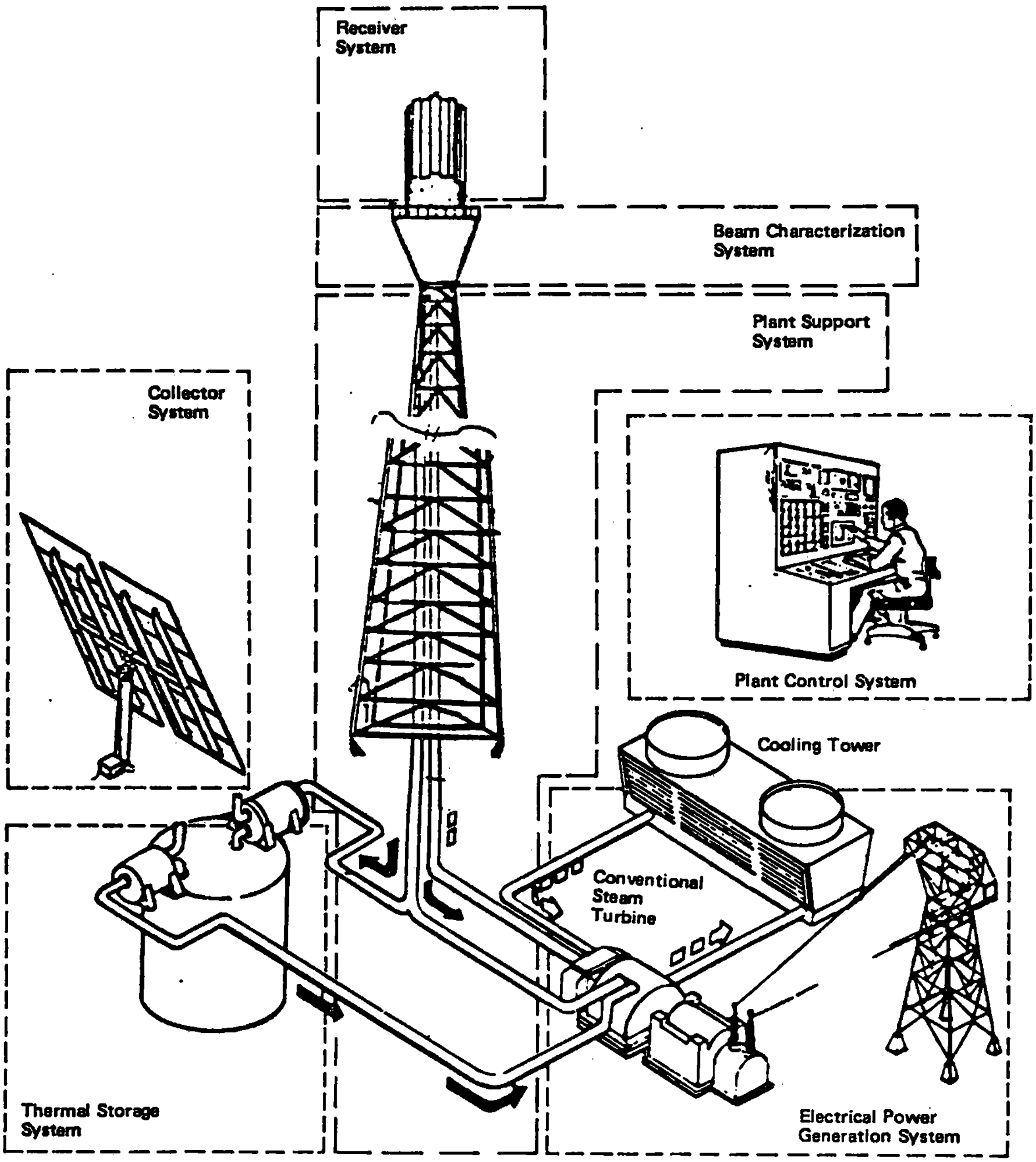


Figure A-1. Pilot Plant System Schematic

Electrical Power Generating System - The electrical power generating system consists of the turbine-generator, rated at 12.8 MWe, and associated support functions, such as feedwater chemistry, uninterruptible power supply, condenser, and cooling and lubrication systems.

APPENDIX B -- DATA ACQUISITION AND PROCESSING

Data acquisition and processing falls into two categories: collection of data for performance evaluations by the plant Data Acquisition System (DAS) and the collection of operations and maintenance data. The main purpose of the DAS is to create archival data files for all engineering analyses and evaluations. The DAS will collect and record all plant and system data. These data include performance evaluation data, control and alarm data, and environmental (weather) data. Some data are converted to engineering units within the DAS computer and are available in near real time at the site. The information can be displayed in tabular and graphical form, and hard copy can be generated on demand. DAS data are also sent, via communication lines, to McDonnell Douglas Astronautics Company (MDAC) in Huntington Beach, California, where they are converted to engineering units. The information is then available for analysis by SNLL or MDAC. Direct terminal connections from MDAC to the plant and SNLL allow quick and easy access to the information. Both tabular and graphical data can be displayed. Reduced data will be sent to SNLL on magnetic tape for further analysis.

As part of the Pilot Plant operational responsibility, SCE will maintain records and accumulate data to evaluate operation and maintenance costs, equipment maintenance needs, plant availability, and reliability. SCE will use computerized data acquisition and processing systems that now perform similar functions for the conventional power generating plants on their grid. Modifications of programs to accommodate additional levels of cost accounting associated with the Pilot Plant and the solar equipment will be made. Plant costs will be accumulated under several major categories:

1. Field office
2. Operations
3. Miscellaneous nonproductive costs
4. Maintenance (this category is further divided into several system categories)

Under these accounts, two sublevels are provided. The first sublevel generally identifies activities, plant systems, and equipment categories. The second sublevel defines a minimum of ten cost categories:

0. Labor
1. Materials
2. Contract services
3. TBD
4. TBD
5. Construction/Start-Up completion items
6. TBD
7. TBD
8. Field design change requests
9. Miscellaneous

A current itemized listing by account and subaccount number is given in Table B-I.

TABLE B-I. Pilot Plant O&M Accounts

FIELD OFFICE	ACCOUNT NUMBER
Research & Development	931.10X
Engineering & Construction Department	.20X
Office Services	.30X
Valuation Department	.40X
Supervision	908.00X
-----------	.01X
Engineering	.02X
Accounting and Clerical	.03X
Stationery and Office Supplies	.04X
-----------	.05X
Grievance Under Labor Contract	.06X
Automotive Expense	.07X
OPERATIONS	
Operation Supervision	908.10X
Beam Safety/Air Pollution	.11X
Plant Operation General	.12X
Receiver Operation	.13X
Thermal Storage Operation	.14X
Collector Operation	.15X
Turbine/Generator Operation	.16X
Auxiliary Equipment Operation	.17X
Water and Chemical Analysis	.18X
MISCELLANEOUS NON-PRODUCTIVE COSTS	
Station Supplies/Services	908.20X
Safety Meetings	.21X
Security Officers	.22X
Expendable Small Hand Tools	.23X
Job Training Meetings	.24X
Station Ground Keeping	.25X
Station Rentals	.26X
MAINTENANCE	
Maintenance Supervision	908.30X
Warehousing and Store Keeping	.31X
Maintenance Indirect Costs	.32X
Miscellaneous Maintenance Material	.33X

	ACCOUNT NUMBER
CONTROL SYSTEMS - General	.40X
Beckman - Remote Station	.41X
Beckman - Control Room	.42X
Modcomp - Heliostat Array Control	.43X
Modcomp - All Other	.44X
Modicon - Interlocking Logic System	.45X
Modicon - Red Line Unit	.46X
Cyber	.47X
Intelligent System Corp.	.48X
HFCs, HCs and I/O	.49X
RECEIVER SYSTEM - General	908.50X
Preheat Panel	.51X
Boiler Panel	.52X
Temperature Control Valves	.53X
Receiver Steam Dump Equipment	.54X
Valves	.55X
Controls Primary Elements and Transmitters	.56X
Chemical Cleaning	.57X
Electrical	.58X
Daily Start-Up/Shutdown	.59X
THERMAL STORAGE SYSTEM - General	908.60X
Thermal Storage Tank	.61X
TSS Charging System (Steam)	.62X
TSS Extraction System (Steam)	.63X
TSS Charging System (Caloria)	.64X
TSS Extraction System (Caloria)	.65X
Strainers and Filters	.66X
Attemperator	.67X
Valves	.68X
Ulleage Maintenance System	.69X
COLLECTOR SYSTEM - General	908.70X
Heliostat	.71X
Heliostat Motors	.72X
Mirror Facets	.73X
Collector Field Electrical	.74X
Encoder	.75X
Rectifier	.76X
Gear Drive	.77X
Electrical	.78X
Heliostat Wash	.79X
EPGS SYSTEMS - General	908.80X
Secondary Steam Production (Aux. Boiler)	.81X
Condensate System	.82X
Switchgear	.83X
Feedwater System	.84X
Steam Turbine	.85X
Generator	.86X
Cooling Water System	.87X

	ACCOUNT NUMBER
Miscellaneous	
SHIMMS	.90X
Fire Water/Service Water System	.91X
Repairing Shop and Miscellaneous Equipment	.92X
Buildings and Grounds	.93X
PROGRAM ADMINISTRATION	938.00X
(Not to be billed to DOE)	

Note: The last significant digit (X) represents the following activities:

Activities:

0. Labor
1. Materials
2. Contract Services
3. -----------
4. -----------
5. Construction/Start-Up Completion Items
6. -------------
7. -------------
8. Field Design Change Requests
9. Miscellaneous

APPENDIX C -- COMPUTER CODES

SOLTES
(Simulator of Large Thermal Energy Systems)

SOLTES is a modular, thermodynamic, heat-and-mass balance code which simulates the quasi-transient or steady-state response of thermal energy systems to time-varying data such as weather and loads. The modular form of SOLTES allows very complex systems to be modeled. Component performance is described by thermodynamic models. A preprocessor is used to construct and edit system models and to generate the main SOLTES program. Computer core requirements are minimized because only those routines required for a particular system simulation are included in the SOLTES program. With SOLTES, it is possible to realistically simulate a wide variety of thermal energy systems such as solar, fossil or nuclear power plants, solar heating and cooling, geothermal energy, and solar hot water.

In order to run SOLTES, four categories of input are needed; two optional categories are available depending on the system model and options chosen.

1. Component/Information Routine Data--This file contains the input needed by the various individual information, component, and system performance routines. These routines can be drawn from the SOLTES library or provided by the user. The library includes thermodynamic and mathematical models of solar collectors, pumps, switching decisions, thermal energy storage, thermal boilers, auxiliary boilers, heat exchangers, extraction turbines, extraction turbine-generators, condensers, regenerative heaters, and air conditioners.

2. Executive Routine Control Data--This file provides input data that define the simulation period, time increment, desired output, steady-state convergence criteria, and problem identification. Energy accounting is available and instantaneous and integrated values for system performance parameters may be determined.

3. Loop Definition Data--This file defines fluid loops by specifying the fluid, initial values of temperature, pressure, flow rate, and the unique integer identifiers for each component in the loop.

4. Fluid Property Data--This file contains the constants used to calculate heat transfer properties (density, specific heat, kinematic viscosity, thermal conductivity) as a function of temperature. Constants that characterize power-cycle working fluids (molecular weight, normal boiling point, critical temperature, pressure and volume, Pitzer's acentric factor, liquid density at a given reference temperature, constants for the ideal gas heat capacity equation, heat of vaporization, Goldhammer's constant) are also given in this file. Fluid property data may be obtained from the SOLTES data bank or provided by the user.

5. Weather Data--This is an optional file which can be used to supply weather data. Hourly weather data for typical meteorological years for 26 locations in the United States are available in the SOLTES library or may be supplied by the user for any time increment.

6. Load Data--This file may be provided to simulate arbitrary energy dispatch. Cooling, heating, electrical, mechanical, thermal, and hot water loads may be read from this file, then scaled or peak-shaved, and followed.

Currently, new SOLTES routines which provide further definition for solar thermal central receiver systems are being developed. Documentation is available on many of these routines. To obtain further information, a user's manual (Reference 5), or the code, contact N. R. Grandjean or M. E. Fewell at Sandia National Laboratories Albuquerque.

MIRVAL

MIRVAL is a Monte Carlo ray tracing program which simulates individual heliostats and a portion of the receiver in calculating the optical performance of well-defined solar thermal central receiver systems. MIRVAL was created for detailed evaluation and comparison of fixed heliostat, heliostat field, and receiver designs. It simulates shadowing, blocking, heliostat tracking, random errors in tracking and in the conformation of the reflective surface, insolation, angular distribution of incoming sun rays to account for limb darkening and scattering, attenuation between the heliostats and the receiver, reflectivity of the mirror surface, and aiming strategy.

Power runs at a point in time, and energy runs which integrate power over time, require about the same time to execute. Rays of light are selected from the vicinity of the sun and are traced until they are intercepted by the receiver, lost in a prior absorption process, or deflected enough to miss the receiver. For a power run, the output includes the power incident on the receiver; the power density on the terminal surface; the power shadowed by the mirrors, the receiver, or both; the power blocked by mirrors; the power incident on the ground; the power that clears the heliostats after reflection but misses the receiver; and the power that clears the heliostats but is absorbed or scattered before reaching the receiver. For energy runs, the output refers to time-averaged power.

Three different types of information must be supplied to MIRVAL:

1. A file which groups the heliostats in the heliostat field in a regular way is required for efficient calculations. The coordinates of the centers of each heliostat are read by a preprocessor which creates the necessary file, so that those mirrors which interact with an incoming light ray can be identified.

2. Sunshape information that describes the angular dependence of the power coming from the sun must be provided.

3. A namelist is used to provide the balance of the system description. This includes information regarding heliostat type, configuration, dimensions and performance; receiver type and dimensions; zoning options; insolation; attenuation; starting and stopping times for a calculation; miscellaneous parameters; and graphs.

Three receiver types (external cylinder, cylindrical cavity with a downward-facing aperture, and north-facing cavity) and four heliostat types (three which track in elevation and azimuth, including one enclosed in a plastic dome, and lowered mirror modules which are supported on a rack which rotates about a horizontal axis) are included in the code. MIRVAL can be modified for evaluation of other heliostats or receivers by changing a small number of subroutines. A user's manual (Reference 6) and the code can be obtained from P. L. Leary at Sandia National Laboratories Livermore.

HELIOS

HELIOS is a computer code originally developed for modeling the Central Receiver Test Facility. The performance of central receiver heliostats, parabolic dish, and other reflecting solar energy collector systems can now be evaluated with this code. HELIOS uses cone optics to evaluate flux density. Calculations are made with respect to fields of individual solar concentrators and a single target surface. Safety considerations with respect to abnormal heliostat tracking can be evaluated.

Effects included in HELIOS are declination of the sun, earth orbit eccentricity, molecular and aerosol scattering in several standard clear atmospheres, atmospheric refraction, angular distribution of sunlight, reflectivity of the facet surface, shapes of focused facets, distribution of errors in the surface curvature, aiming, and facet orientation, and shadowing and blocking.

Input data to HELIOS are divided into seven groups:

1. Problem and output data define amount of output, plotting, degree of shadowing and blocking, execution of flux density calculations, heliostats to be evaluated, and execution of atmospheric attenuation calculations.

2. Sun parameters define insolation, sunshape, method and frequency of evaluating sunshape convolution, sunshape error distribution, concentrator errors, sun tracking errors, and calculation bounds.

3. Receiver parameters define target points, target point output, degree and type of power density output, target orientation, focal points, aim points, type of receiver, shape and location of aperture, overall shape of the receiver, location and shape of the tower, and target surface.

4. Facet parameters define facets on heliostats, subfacets for power density calculations, shape of facet surface, facet reflectivity, and whether or not gravity or wind loading effects are to be included.

5. Heliostat parameters define number of heliostats, focusing and canting, tracking mode, criteria for shadowing and blocking, and heliostat jitter resulting from the discrete motion of the drive motors.

6. Time parameters define days and times of day to be evaluated and the day at which heliostat facets are aligned.

7. Atmospheric parameters define atmospheric pressure, standard sea level pressure, atmospheric temperature at the top of the tower, attenuation model, and propagation loss model.

HELIOS is written in a series of five overlays in order to minimize the computer core required for execution. An extensive revision of the user's manual is being prepared. For information or copies of the code and current documentation (References 7 to 9), contact C. N. Vittitoe or F. Biggs at Sandia National Laboratories Albuquerque.

RELAP

The RELAP family of computer programs is the result of an extensive effort to develop codes capable of analyzing the transient response of nuclear power plants. This code models one-dimensional, two-phase flow with a control volume approach, assuming the fluid within each volume to be in thermal equilibrium. The flow paths between volumes are called "junctions," and heat transfer to and between volumes is accomplished with models for thermal conductors called "heat slabs." The RELAP4/MOD6 version of the code was chosen to analyze solar central receiver systems, primarily because of an energy deposition option available for modeling radiant heating in the receiver system (Reference 10).

As a first step, RELAP calculations were performed for a five-tube solar panel simulating the proposed operation of the Pilot Plant receiver (References 11 and 12). With appropriate modifications, the code gave reasonably accurate representations of the experimental results. These included the achievement of operating conditions from a cold-water zero-power start-up, the presence of thermal-hydraulic oscillations after the onset of boiling, and the effect of variations in flow path resistance on those oscillations.

The next step consisted of performing RELAP calculations for a single, full-scale, 70-tube test receiver panel that essentially duplicated, both physically and functionally, the Pilot Plant design (Reference 13). The majority of these analyses addressed system response to new effects, such as lateral and axial flux gradients and flux and flow transients. The experience gained in both the five-tube and 70-tube panel test analyses is being used to develop a RELAP model for the 24-panel Pilot Plant receiver.

A RELAP model for the Pilot Plant thermal storage system has also been developed (Reference 14). A finite-difference, predictor-corrector, numerical technique has been included in RELAP to solve for fluid and solid temperature distributions in one-dimensional flow through the dual-media storage tank's packed bed. Nominal flow operating conditions can be calculated from zero-point, cold- and hot-oil start-ups for the charging and extraction modes, respectively.

SAPPHIR, PARFLO

Two codes, SAPPHIR and PARFLO, will be used to evaluate the receiver steady-state performance. In the SAPPHIR code, the thermal-hydraulic functioning of a receiver panel is approximated by a single "representative" tube within the panel. SAPPHIR will calculate (approximately) the following thermal performance parameters:

a. the circumferential and axial distributions of the temperature through the walls of a tube;

b. the axial variation of the thermodynamic state (e.g., pressure, temperature, quality) of the water-steam flow in a tube;

c. the allocation of the panel energy losses among the mechanisms of reflection, radiation, convection, and conduction; and

d. the panel and receiver efficiency (i.e., the fraction of the incident solar power retained by the working fluid).

The PARFLO code is similar to SAPPHIR, but it also calculates the distribution of the total panel flow among the individual tubes and the performance of the individual tubes. The flow distribution within an actual receiver panel is non-uniform due to the use of different-sized orifices at the tube inlets and the presence of lateral solar flux gradients.

The operational data which are input to both codes are the water flow rate to each panel and the pressures and temperatures in the inlet and outlet headers. The distribution of the solar power incident on each panel, which is also required, will be determined by the heliostat performance codes, HELIOS or MIRVAL.

SAPPHIR and PARFLO are currently under development. It is anticipated that PARFLO will require considerably more computer time to run than SAPPHIR.

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