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Data Evaluation Plan for the 10 MWe Solar Thermal Central Receiver Pilot Plant Power Production Phase

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DATA EVALUATION PLAN FOR THE 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT POWER PRODUCTION PHASE

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ABSTRACT

This report describes the planned data evaluation for the three-year Power Production Phase of the 10 MWe Solar Thermal Central Receiver Pilot Plant near Barstow, California. The Power Production Phase, which began in August 1984, will demonstrate the operational capability of the plant to reliably supply electrical power to the utility grid. Data evaluation will be performed for design point and annual plant energy output; heliostat optical performance and mirror module corrosion; receiver tube life and absorber coating life; storage fluid degradation and storage tank thermal stresses; plant availability, operating procedures, and operating costs; and component reliability and maintenance costs. The objective, test needs, data needs, approach, expected output, and planned data dissemination are presented for each evaluation.

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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
IEA	International Energy Agency
ILF	In-Line Flow Operating Mode
MDAC	McDonnell Douglas Astronautics Company
METRO	Meteorological
MWe	Megawatt-electric
MWe-hr	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

DATA EVALUATION PLAN FOR THE 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT POWER PRODUCTION PHASE

Introduction

In 1978 the Department of Energy (DOE) and the Associates* entered into a Cooperative Agreement to design, construct, and operate a solar thermal central receiver pilot plant near Barstow, California. Construction of the Pilot Plant was completed in 1981, and the plant is now undergoing a five-year Operational Test Period. The Operational Test Period consists of a two-year Experimental Test and Evaluation Phase followed by a three-year Power Production Phase.

The Experimental Test and Evaluation Phase, which began in mid-1982, is complete. During this phase operating experience was achieved for all the plant's operating modes, and the plant's system and component performance was evaluated. A description of the testing and evaluation activities conducted during this phase is given in References 1 and 2, respectively.

The Power Production Phase, which began in August 1984, will demonstrate the operational capability of the plant to reliably supply electrical power to the Southern California Edison (SCE) utility grid. During this phase the performance of the plant will be evaluated by two organizations. Sandia National Laboratories Livermore (SNLL), on behalf of DOE, will analyze and evaluate the data from the plant operations. SCE will operate the plant, record the data for the plant and its systems, and evaluate the plant from a utility perspective. Data evaluation will be conducted in three general areas: (1) data from normal, daily operations; (2) data from special tests that will be conducted to demonstrate performance objectives not achieved during the Experimental Test and Evaluation Phase; and (3) data on the effects of long-term operation.

This report describes a plan for data evaluation during the Power Production Phase. In the next section, the Pilot Plant data evaluation program objectives are discussed. A description of the data acquisition and processing capabilities and a description of each planned evaluation are given. Finally, the planned data dissemination for the evaluation program is described. A description of the plant (Reference 2) and computer codes to be used for the data analyses (Reference 3) is given in the Appendices.

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

Objectives

The objectives of the data evaluation program are to:

- Evaluate 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.

The major evaluation activities that are being performed to achieve each objective are shown in Table I for each phase of the Operational Test Period. In the Power Production Phase activities are planned to complete each objective. To complete the evaluation of technical feasibility data will be analyzed from operation of the plant in a fully commercial utility environment. The measured and predicted energy outputs of the plant will be compared on both a daily and annual basis. Of particular importance will be the determination of operating strategies to maximize the energy output of the plant. This operation will determine the plant's annual capacity factor, an important step in demonstrating the technical viability of solar central receiver technology for utility and industrial use.

Considerable information to support private sector decisions on future systems has already been generated as a result of the Pilot Plant design, construction, and testing experiences. In the Power Production Phase the plant's operation and maintenance experiences, procedures, and costs will be evaluated in a utility operating environment. Specific attention will be directed to identifying procedures for reducing costs, for example, reduced staffing. This information is an important step in determining the economic viability of solar central receiver technology.

Finally, R&D needs for future central receiver systems will be assessed in the Power Production Phase. Key areas include: (1) heliostat optical accuracy; (2) mirror module corrosion and soiling; (3) receiver absorber coating life; (4) receiver tube life; (5) storage fluid degradation; and (6) storage tank thermal ratcheting. In the Power Production Phase these areas will continue to be monitored with a particular emphasis on the effects of long-term operation and extreme environmental conditions.

TABLE I. Pilot Plant Data Evaluation Activities

Activity	Major Evaluation Period(s)	
	Experimental Test and Evaluation Phase	Power Production Phase
<u>Evaluate Technical Feasibility</u>		
1. Analyze plant operating modes and mode transitions	X	
2. Analyze design point performance	X	X
3. Analyze annual performance		X
<u>Provide Information for Private Sector Decisions on Future Systems</u>		
1. Analyze lessons learned from design and construction	X	
2. Analyze environmental, health, and safety impacts	X	
3. Analyze design and construction costs	X	
4. Analyze operations and maintenance procedures, experiences, and costs	X	X
<u>Identify Future R&D Needs</u>		
1. Assess heliostat optical accuracy	X	X
2. Assess mirror module corrosion and soiling	X	X
3. Assess receiver absorber coating life	X	X
4. Assess receiver tube life	X	X
5. Assess storage fluid degradation	X	X
6. Assess storage tank thermal ratcheting	X	X

Data Acquisition and Processing

Data acquisition and processing fall 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 collects and records all plant and system data. These data include performance evaluation data, control 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 recorded on magnetic tape that is sent to SNLL and McDonnell Douglas Astronautics Company (MDAC) for further analysis.

The DAS archiving that is required for data evaluation during the Power Production Phase will be considerably less than the DAS archiving for the Experimental Test and Evaluation Phase. A reduction in size of the measurement list and a reduction in recording rate will result in the production of 3-4 archived tapes per week versus the approximately 14 tapes per week produced during the Experimental Test and Evaluation Phase. Data processing during the Power Production Phase will consist of: (1) a continuation of the MDAC effort, whereby they would receive and process archived tapes from the site and transmit a summary tape to SNLL each month; or (2) processing of the archived tapes by SNLL.

As part of the Pilot Plant operational responsibility during the Power Production Phase, SCE will maintain equipment and record 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 were made and used during the Experimental Test and Evaluation Phase. Further information on these cost accounting modifications can be found in Reference 2.

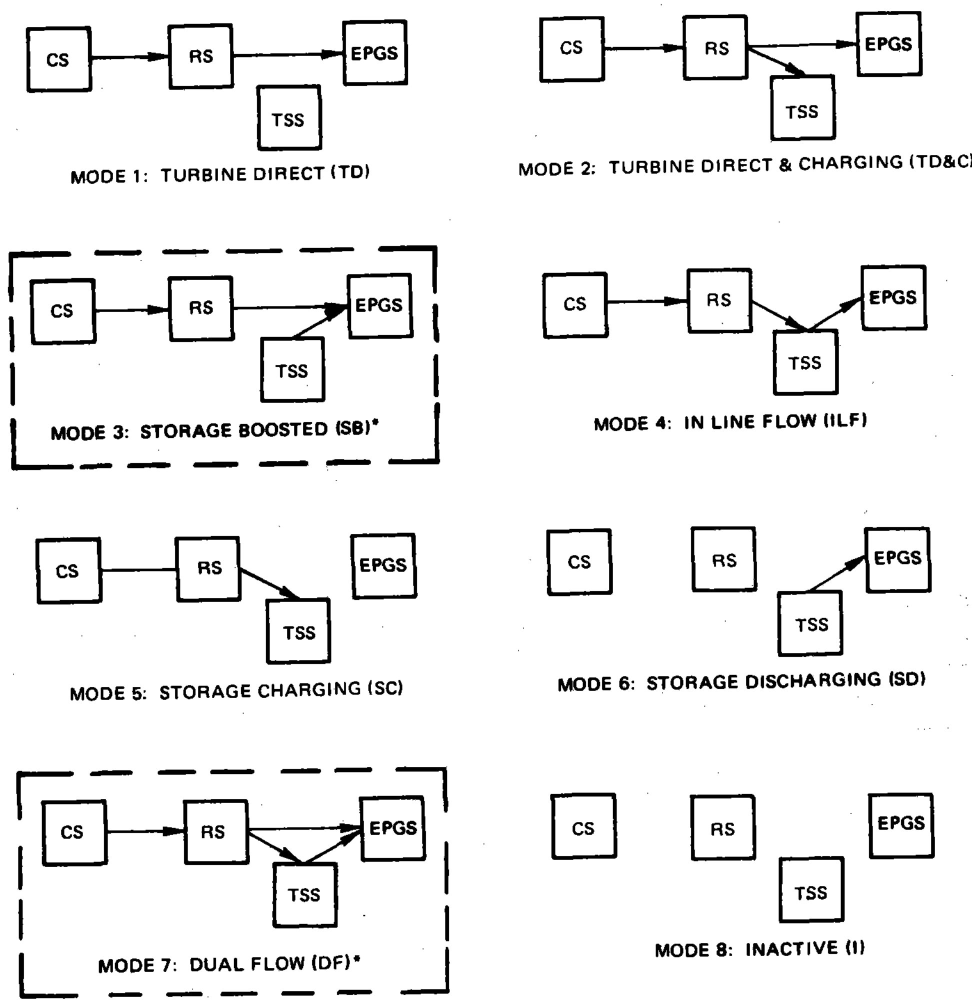
Program Description

The evaluation program for the Power Production Phase consists of the evaluation of data from: (1) normal, daily plant operations; (2) special tests that will be performed because they were not completed during the Experimental Test and Evaluation Phase; and (3) monitoring of key components to deduce the effects of long-term operation. Normal operation refers to the daily start-up, operation, and shut-down of the plant in a way that provides an optimal combination of annual energy output and operating and maintenance cost. In normal operation the plant operates in one of several steady-state modes (see Figure 1) or mode transitions, depending on the current operating conditions, e.g., insolation level.

Special tests planned for the Power Production Phase include system performance tests that demonstrate the capability of the Pilot Plant to achieve 10 MWe net for 4 and 7.8 hours on winter and summer solstice, respectively. Finally, key components of the collector, receiver, and thermal storage systems will be monitored to evaluate any changes in performance induced by long-term operational effects, such as thermal cycling, etc. The planned data evaluations are summarized in Table II and described on the following pages.

TABLE II. Planned Evaluations for Power Production Phase

No.	Evaluation
1	Plant Performance
2	Collector Performance
3	Receiver Performance
4	Thermal Storage Performance
5	Plant Operations
6	Plant Maintenance



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 1. Pilot Plant Steady-State Operating Modes

Evaluation Specification 1

Title: Plant Performance

SNLL Key Contacts: Al Baker, (415) 422-2171 - FTS 532-2171
Lee Radosevich, (415) 422-2648 - FTS 532-2648

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: Mode 1 operation for measurement campaign

Data Requirements:

- Fluid temperatures
- Fluid pressures
- Flow rates
- Plant control logic
- Meteorological data
- Heliostat field performance
- Receiver performance
- Thermal storage performance
- Electrical power generation system performance
- Plant electrical output

Approach: Two computer codes, SOLTES and STEAEC, will be used to assess differences between the predicted and actual plant energy output. SOLTES is a thermodynamic, heat-and-mass balance code that simulates the quasi-transient or steady-state response of thermal energy systems to time-varying inputs, such as weather or loads. STEAEC uses a nonthermodynamic approach that facilitates data input and makes the code somewhat easier to use, albeit less versatile, than SOLTES. Both codes can provide estimates of the plant's daily or annual energy output. A description of the features of each code is given in Appendix B.

Energy Production on Summer and Winter Solstices

At the present time two major power/energy system requirements remain to be demonstrated: 10 MWe net for 4 hours on winter solstice and 10 MWe net for 7.8 hours on summer solstice. The demonstration of both requirements was unsuccessful during the Test and Evaluation Phase. Measurement campaigns will therefore be needed during the Power Production Phase to demonstrate the winter solstice and the summer solstice power/energy system requirements. Each campaign will require about two weeks centered about December 21 or June 21. Performance data, including energy output, will be recorded and compared to design values.

Annual Energy Production

An objective of the Power Production Phase is to maximize the energy production from the Pilot Plant. Achievement of this objective will require an optimal operating strategy and maintenance procedure that assure a high plant reliability and performance. This evaluation activity will assess differences between the predicted and actual plant energy output. Factors that contribute to any differences will be identified along with operating strategies and maintenance procedures that can increase plant output.

Output and Applicability:

Output	Applicability	
	Pilot Plant	Future Power Plants
1. Verification of Summer Solstice, Winter Solstice, and Annual Energy Outputs	X	X
2. Optimized Use of Thermal Storage	X	X
3. Optimized Start-up Procedures	X	X

Evaluation Specification 2

Title:	Collector Performance
SNLL Key Contact:	Clay Mavis, (415) 422-3031 - FTS 532-3031
Objective:	Characterize heliostat performance for the effects of long-term operation and extreme environmental conditions. Identify areas where heliostat R&D may lead to performance improvements.
Test Requirements:	None
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

Approach:

This activity will evaluate heliostat long-term optical performance and environmental survival. Specific attention will be directed to a comparison of the optimal performance and environmental survival characteristics of two mirror module designs. The first design, which consists of second-surface silvered glass bonded to a steel-aluminum honeycomb-steel sandwich, is the baseline design and was installed on all the Pilot Plant heliostats. A second design, which uses laminated, silvered glass bonded to steel hat sections, will replace about 150 baseline modules. The new modules will be installed on the Pilot Plant heliostats during the Power Production Phase.

Optical Performance

Heliostat optical performance data are needed for the plant performance evaluations. 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 of a select number (100) of heliostats will be measured every six months by the Beam Characterization System (BCS) to assess their long-term optical performance. 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).

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. These data will be used with washing data and rainfall to evaluate heliostat washing requirements. The ability of a heliostat washing machine to meet these requirements will be assessed (e.g., manhours per heliostat wash). Data pertaining to both operation and maintenance of a washing machine will be analyzed.

Beam pointing and quality will be compared with specifications. Heliostats out of specification will be corrected and reported under plant Operations and Maintenance (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. Major environmental conditions which affect this lifetime are the corrosion of mirror module silvering as a result of attack by water and survival of controllers and motors under operating thermal loads.

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. 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 silver corrosion occurs when water attacks the silvering on the back surface of the mirror. The silver corrosion area of the entire mirror field has previously been measured by SCE. In order to deduce the corrosion growth rate and the effectiveness of mirror venting this measurement will be repeated on an annual basis. Data will be reported separately for vented and unvented mirror modules as well as any replacement modules that are installed in the field. Leak testing, controlled thermal cycling, in-situ temperature and humidity measurements, radiography to locate water, and computer simulation of mirror modules will be performed as required 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. Assessment of Heliostat Washing Needs	X	X
3. Assessment of Mirror Module Corrosion	X	X

Evaluation Specification 3

Title: Receiver Performance

SNLL Key Contact: Al Baker, (415) 422-2171 - FTS 532-2171

Objective: Characterize receiver performance for the effects of long-term operation. Identify areas where receiver R&D may lead to performance improvements.

Test Requirements: None

Data Requirements:

Panel fluid temperatures
Panel fluid pressures
Panel flow rates
Valve positions
Panel metal temperatures
Panel deflections

Approach: This activity will evaluate receiver tube life and absorber coating life.

Receiver Tube Life

The metal temperatures of several receiver tubes are being measured to determine receiver thermal stresses. This activity will continue until an adequate understanding of receiver tube failures can be achieved. Ultrasonic inspections of the receiver tubes will be performed to detect cracks. Receiver thermal stresses will be analyzed based on operating temperature data. These include panel lateral stresses, tube-to-header stresses (including welds), and tube front-to-back stresses. These measurements and 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 Life

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 on an annual basis. Visual inspections of the panel surfaces will also be performed.

Output and Applicability:

Output	Applicability	
	Pilot Plant	Future Power Plants
1. Verification of Receiver Structural Design Criteria	X	X
2. Verification of Absorber Coating Performance	X	X

Evaluation Specification 4

Title: Thermal Storage Performance

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

Objective: Characterize thermal storage performance for the effects of long-term operation. Identify areas where thermal storage R&D may lead to performance improvements.

Test Requirements: None

Data Requirements:
Fluid temperature distribution in storage tank
Fluid pressures in storage tank
Flow rates
Storage tank fluid level
Oil replenishment rate
Oil chemical analyses
Strain gauge outputs

Approach: This activity will evaluate the thermal storage fluid degradation and tank thermal ratcheting.

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. Samples of the oil will be taken every four months 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 semiannual basis, and a table of stresses and strains for each of the active gauge locations will be developed and analyzed.

Output and Applicability:

Output	Applicability: Pilot Plant	Applicability: Future Power Plants
1. Verification of Storage Fluid Makeup Needs	X	X
2. Verification of Storage Tank Design Criteria	X	X

Evaluation Specification 5

Title:	Plant Operations
SNLL Key Contact:	Jim Smith, (415) 422-2297 - FTS 532-2297
Objective:	Establish the Pilot Plant operating procedures and costs. Determine the Pilot Plant availability.
Test Requirements:	None
Data Requirements:	Operating costs Daylight hours Insolation Scheduled maintenance outage hours Unscheduled maintenance outage hours Weather outage hours Power production hours Energy production (MWe-hr gross and net)

Approach:

<u>Operating Procedures</u>

Operating procedures will be studied to optimize the energy output of the Pilot Plant. Typical daily operating and special procedures and manpower requirements will be reported, including start-up, shutdown, and plant trips.

<u>Operating Costs</u>

SCE currently operates computerized data acquisition and processing systems for the conventional power generating plants on its grid. These systems have been 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.

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 6

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: None

Data Requirements: Maintenance costs
Maintenance records

Approach: <u>Maintenance Needs</u>

1. History

SCE, using the computerized data acquisition and processing 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 Generation Management System and may be accessed by equipment number.

2. Preventive Maintenance (PM)

The PM system will be managed by the SCE 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 5) 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 identifying high and low failure components in the plant computer systems and the collector field. The number of heliostats repaired, type of repairs, number of new failures during each month, number of adjustments required, and the percent of the field in operation at the end of each month will be reported.

Output and Applicability:

Output	Applicability: Pilot Plant	Applicability: 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

Data Dissemination

Technology transfer is an important activity of the evaluation program during both phases of the Pilot Plant Operational Test Period. The activity includes both technical presentations and written reports. Information about the Pilot Plant is disseminated at technical conferences and workshops. An International Workshop on the Operation of Solar Central Receiver Plants was sponsored by DOE in October, 1982 (Reference 4), to discuss the initial Pilot Plant testing and evaluation. Additional workshops will be held in conjunction with the DOE solar central receiver annual meetings.

During the Experimental Test and Evaluation Phase, SNLL, SCE, and the Electric Power Research Institute (EPRI) prepared reports that describe the Pilot Plant design and construction experience, Pilot Plant costs, meteorological data, evaluation methodologies, and evaluation results. The topics and actual or planned date of issuance are described in Table III. McDonnell Douglas Astronautics Company (MDAC), under contract to SNLL, conducted the operational tests during the Experimental Test and Evaluation Phase. As part of this activity MDAC prepared reports that provide a record of the operational tests. The reports, which are included in Table III, are primarily test reports and contain only a very limited number of analyses.

Meteorological data evaluation reports will not be issued separately during the Power Production Phase but will be summarized in annual plant performance reports (described below) and other topical reports. The topics and planned date of issuance are listed in Table IV. Evaluation reports on specific topics will generally not be issued until the Power Production Phase is complete. Several topics may be combined into a single report depending on the content. Annual reports that describe the plant operations, maintenance, and performance, and monthly reports that highlight operational and maintenance data for the Pilot Plant, will be issued.

All reports will be prepared for general distribution. Monthly reports 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 III. Reports for Experimental Test and Evaluation Phase

Evaluation Category	Topic	Issuing Organization	Date
1. Meteorological Summaries	CY82 Annual Report (SAND83-8216)	SNLL	Jun 1983[1,2]
	CY83 Annual Report (SAND84-8180)	SNLL	Jun 1984[1,2]
	CY84 Annual Report (First Half)	SNLL	Jan 1985[1]
2. Plant Steady-State Performance	Mode 1 Test Report	SNLL	Oct 1984[1]
	Modes 5 & 6 Test Report	SNLL	Mar 1985[1]
	Modes 2,3,4 & 7 Test Report	SNLL	Mar 1985[1]
	Plant Steady-State Performance Monograph	SNLL	Mar 1985
	Plant Summer Solstice Performance	SNLL	Feb 1985
3. Plant Transient-State Performance	RELAP Receiver Model (SAND81-1220)	SNLA	Aug 1981[2]
	RELAP Thermal Storage Model (SAND81-1831)	SNLA	Oct 1981[2]
4. Collector Performance	Collector Performance Monograph (SAND83-8220)	SNLL	May 1983[2]
	Mirror Module Corrosion Interim (SAND84-8214)	SNLL	Mar 1984[2]
	Mirror Module Corrosion Final	SNLL	Feb 1985
	Final Report	SNLL	May 1985
5. Receiver Performance	1010/1030 Test Report (MDC H0141)	MDAC	Jan 1983[1,2]
	1030 Test Evaluation Report (SAND83-8005)	SNLL	Mar 1983[2]
	Receiver Performance Monograph	SNLL	Jan 1985
	Convective Losses	SNLL	Mar 1985
	Final Report	SNLL	May 1985
6. Thermal Storage Performance	1040 Test Evaluation Report (SAND83-8015)	SNLL	Jul 1983[2]
	1020/1040 Test Report	SNLL	Jan 1985[1]
	Final Report	SNLL	Feb 1985

TABLE III. (continued)

7. Plant Operations	Operations	SCE	Monthly[2]
	CY82 Operations (SAND 83-8027)	SNLL	Mar 1985[2]
	CY83 Operations	SNLL	Apr 1985
8. Plant Maintenance	Maintenance	SCE	Monthly[2]
	Maintenance Monograph	SNLL	Mar 1985
	Final Report	SNLL	May 1985
9. Plant Safety	Heliostat Beam Safety/ Receiver Brightness (SAND83-8035)	SNLL	Jul 1984[2]
10. Lessons Learned	Final Report	EPRI	Oct 1983[2]
	Index and Abstracts of Pilot Plant Reports	EPRI	Mar 1984[2]
11. Plant Costs	Pilot Plant Project Costs	SNLL	Feb 1985
12. Environmental Assessment	Plant/Animal Environment	SNLL	Feb 1985[1]
13. Plant Automation[3]	Automation Test Report	SNLL	Apr 1985[1]
	Final Report	SNLL	May 1985
14. General	Overall Final Report	SNLL	Jun 1985

[1] Contractor Report
[2] Published Report
[3] This evaluation category was added to the data evaluation program after Reference 2 was published.

TABLE IV. Reports for Power Production Phase

Evaluation Category	Topic	Issuing Organization	Date
1. Plant Performance	CY85 Annual Report	SNLL	Jun 1986
	CY86 Annual Report	SNLL	Jun 1987
	Final Report	SNLL	Mar 1988
2. Collector Performance[1]	Effects of Long-Term Operation	SNLL	Mar 1988
3. Receiver Performance[1]	Receiver Tube Life	SNLL	TBD
	Absorber Coating Life	SNLL	Mar 1988
4. Thermal Storage Performance[1]	Storage Fluid Degradation	SNLL	Mar 1988
5. Plant Operations	Operations	SCE	Monthly
	CY84 Operations	SCE	Jun 1985
	CY85 Operations	SCE	Jun 1986
	CY86 Operations	SCE	Jun 1987
6. Plant Maintenance[1]	Maintenance	SCE	Monthly
	Final Report	SNLL	Mar 1988

[1]Timely evaluation results in this category will also be reported in the annual operations reports (Category 5).

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
Sandia National Laboratories
Solar Central Receiver Department - 8450
P. O. Box 969
Livermore, CA 94550

or

Southern California Edison
Solar One Visitor's Center
P. O. Box 325
Daggett, CA 92327

APPENDIX A -- PILOT PLANT DESCRIPTION

The Pilot Plant consists of seven major systems: the collector, receiver, thermal storage, plant control, beam characterization, electrical power generating, and plant support 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. Thermal storage also provides steam for keeping selected portions of the plant warm during nonoperating hours.

Collector System - The collector system consists of 1,818 heliostats and a control system. Each heliostat has 421 ft^2 (39.13 m^2) reflective area, and the total field reflector area is 765,700 ft^2 (71,130 m^2). The control system consists of a micro-processor controller in each heliostat, a field controller for control of groups of up to 32 heliostats, and a central computer called the heliostat array controller.

Receiver System - The receiver system consists of a single-pass-to-superheat boiler with external tubing, pumps, piping, wiring, and controls necessary to provide the required amount of steam to the turbine. The receiver is designed to produce 960°F (516°C) steam at 1,465 psia (10.1 MPa). The receiver is 23 ft (7 m) in diameter and 45 ft (13.7 m) high with a total surface area of 3,252 ft^2 (302 m^2). The top of the receiver is about 300 ft (90 m) above ground level.

Thermal Storage System - The thermal storage system consists of a tank, heat exchangers, pumps, valves, piping, and controls required for operation and monitoring. The storage tank is 45 ft (13.7 m) high and 60 ft (18.3 m) in diameter. The tank is filled with rock, sand, and thermal oil. When fully charged, the mixture has a temperature of 575°F (302°C). When the system is discharging, the oil is pumped through a heat exchanger to produce 530°F (277°C) steam at 400 psia (2.8 MPa), for delivery to the turbine. The net rated electrical capacity of the plant operating on thermal storage is 28 MWe-hr or 7 MWe for four hours.

Plant Control System - The plant control system consists of control equipment that provides for plant control from the control room. It supplies overall coordinated supervisory control to individual system controls; it also supplies data collection and display functions.

Beam Characterization System - The beam characterization system consists of tower-mounted targets, video cameras, heat flux sensors, and supporting and display equipment. The system is used for heliostat alignment, updating the heliostat tracking equation, and the detection of heliostat anomalies.

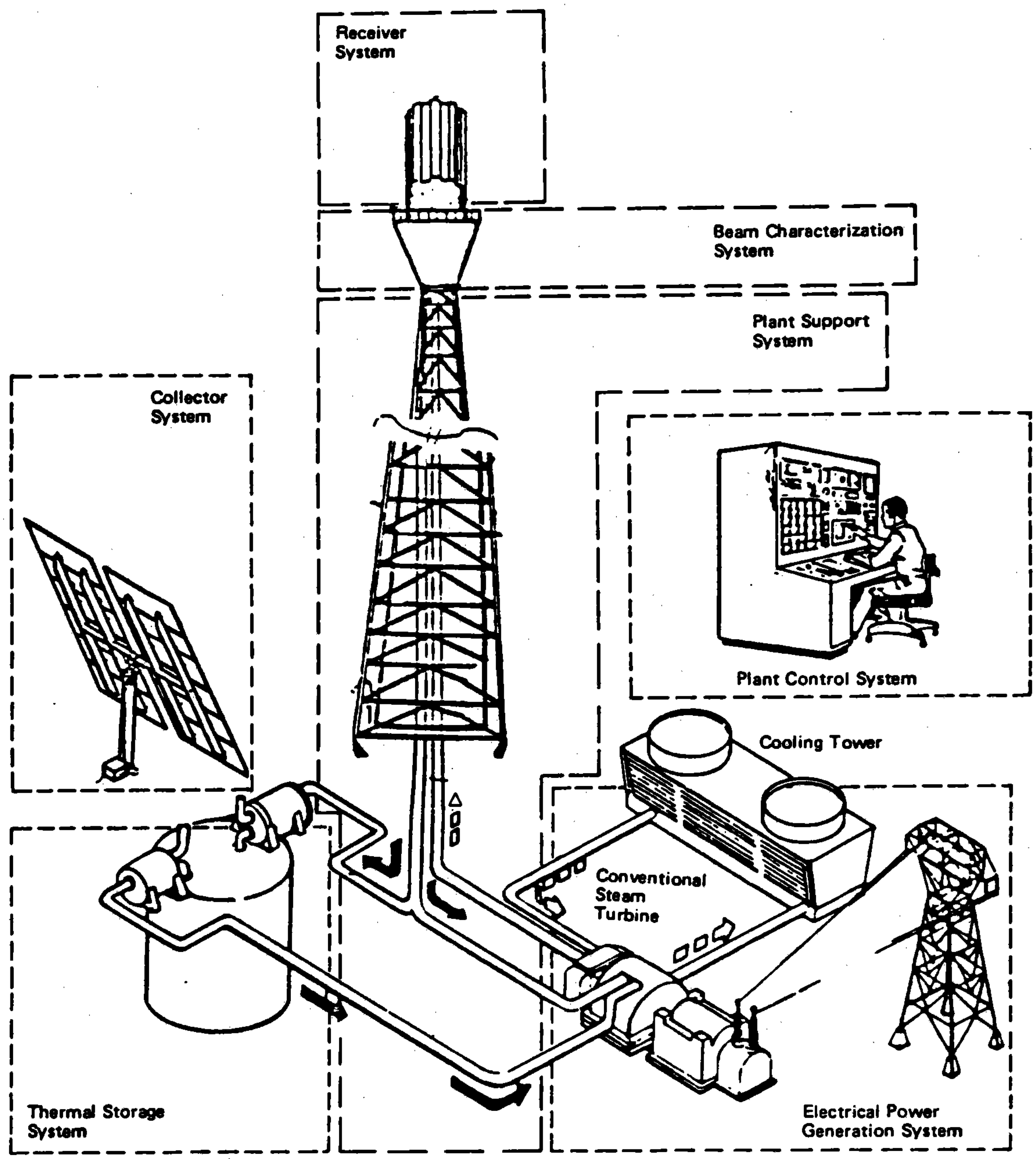


Figure A-1. Pilot Plant System Schematic

Electrical Power Generating System - The electrical power generating system consists of the turbine-generator, rated at 12.5 MWe, and associated support functions, such as feedwater chemistry, uninterruptible power supply, condenser, and cooling and lubrication systems.

Plant Support System - The plant support system consists of most of the balance of plant hardware including site structures, buildings and facilities, and facility services. Site structures include the receiver support tower, pipe racks, and equipment foundations required for component support. Major buildings and facilities include an administration building, turbine-generator building, warehouse, pump house, weather monitoring equipment, and visitors center. Facility services include support systems such as raw water, fire protection, demineralized water, cooling water, nitrogen, compressed air, liquid waste, oil supply, and lightning protection.

APPENDIX B -- COMPUTER CODES*

MIRVAL

Basic Features

MIRVAL is a Monte Carlo ray tracing program which simulates individual heliostats and a portion of the receiver as it calculates optical performance of well-defined solar thermal central receiver systems. It was created for detailed evaluation and comparison of fixed heliostat, field, and receiver designs. It simulates shadowing, blocking, heliostat tracking, and random errors in tracking and in the conformation of the reflective surface, insolation, angular distribution of incoming solar 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 that occur 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 and 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 or 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 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 that rotates about a horizontal axis) are included in the code. MIRVAL can be modified to evaluate other heliostats or receivers by changing a small number of subroutines.

Typical Applications and Uses

MIRVAL is used to calculate field efficiencies and flux maps when a more rigorous optical model is desired. It has been used as a check on the flux calculations of other codes such as DELSOL, HELIOS, and the U of H codes.

Program Details

Three different types of information must be supplied to MIRVAL:

*These descriptions are taken from Reference 3.

(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 mirrors affected by an incoming light ray can be identified.

(2) Sunshape information which describes the angular dependence of 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.

Current Status

MIRVAL is currently used on the SNLL CDC 6600 and is being installed on the SNLL CRAY.

Documentation

For more information on MIRVAL, please see reference 5.

Source

Contact P. L. Leary, SNLL.

SOLTES
(Simulator of Large Thermal Energy Systems)

Basic Features

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.

Typical Applications and Uses

SOLTES is being used to analyze the Barstow pilot plant and the International Energy Agency (IEA) power plant in Almeria, Spain.

Program Details

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 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 mathematic models of solar collectors, pumps, switching decisions, thermal energy storage, thermal boilers, auxiliary boilers, heat exchangers, extraction turbines, extraction turbine-generators, condensers, regenerative heaters, air conditioners, and process vapor.

(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, the initial values of temperature, pressure, and 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.

SOLTES is a FORTRAN code. The central memory requirements for the modular form are usually between 70K and 150K octal words. Extended core requirements are 150 decimal words per component in the system model. Four to six tapes or disks are required.

Current Status:

SOLTES is used at SNLA on a CDC 7600. Currently, new SOLTES routines are being developed that will provide further definition for solar thermal central receiver systems. Documentation is available on many of these routines.

Documentation

For further information, see reference 6.

Source

Contact N. R. Grandjean or M. E. Fewell, SNLA.

STEAEC
(Solar Thermal Electric Annual Energy Calculator)

Basic Features

STEAEC is a computer model which estimates the annual performance of a solar thermal electric power plant. STEAEC is a quasi-steady-state model with a constant (but user-variable) time step. Factors such as energy losses and delays incurred in start-up, effects of ambient weather conditions on plant operation and efficiency, effects of hold time and charge and discharge rates on deliverable energy in storage, subsystem maximum and minimum power limits, and auxiliary power requirements are taken into account in the computation of the annual electrical output of the plant. Default parameters may be easily modified through the use of NAMELIST inputs. STEAEC does not model thermodynamics.

Typical Applications and Uses

STEAEC has been used to select the 10 MWe pilot plant concept and to calculate annual energy production by repowering contractors.

Program Details

The input to STEAEC is through namelists. The namelists include descriptions of the:

(1) Collector field efficiency as a function of the azimuth and elevation angles obtained from MIRVAL or DELSOL.

(2) The collector field parameters such as size, parasitic power requirements, temperatures, operational sun angles, wind speeds, and atmospheric attenuation.

(3) The receiver parameters such as size, parasitic power requirements, temperatures, wind speeds, efficiency, start-up and cooldown, derated capability, and receiver losses.

(4) Piping losses.

(5) Turbine operating parameters from the receiver and from storage.

(6) Storage charging and discharging parameters.

In addition to the input namelists, STEAEC requires weather tapes that include insolation, wind characteristics, and temperature and pressure for the specific site. STEAEC is a FORTRAN IV code.

Current Status

STEAEC is used at SNLL on the CDC 6600 computer.

Documentation

For further information, see reference 7.

Source

Contact Gordon Miller, SNLL.

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