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10 MWe Solar Thermal Central Receiver Pilot Plant Mid-Term Test and Evaluation Review July 20-21, 1983

Systems Evaluation Division,
Solar Central Receiver Department

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JULY 20-21, 1983

Systems Evaluation Division
Solar Central Receiver Department
Sandia National Laboratories, Livermore

ABSTRACT

A Mid-Term Review of the Barstow pilot plant was held in Barstow, California, in July 1983. At that meeting, a panel of representatives from various utilities and repowering studies gathered to review the first year of the Test and Evaluation Phase, as well as the planned activities for the second year of that phase. The panel concurred that plant checkout and testing have progressed well, and they fully support next year's test plan. The panel's comments and suggestions for the last year of testing are included in this report.

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SUMMARY

A Mid-Term Review of the 10 MWe Solar Thermal Central Receiver Pilot Plant was conducted on July 20 - 21, 1983, in Barstow, California. Organized by Sandia National Laboratories Livermore (SNLL), the meeting was held to discuss the status of the test program at the midpoint of the two-year Test and Evaluation Phase and to obtain recommendations for the final year of the testing program.

At the meeting, a panel reviewed the results of the first year of testing, which were presented by personnel involved in plant operations and evaluation. The panel was then asked to consider the second year of testing and to recommend additions or deletions to the test plan.

The panel concurred that plant checkout and testing have progressed well. Furthermore, the panel fully supported next year's test plan and suggested that all testing continue as planned. In general, the panel's recommendations fall into four categories:

(1) Information dissemination--Information about the success of the pilot plant needs to reach key decision makers.

(2) Automation--Work on the automatic control system needs to be completed.

(3) Electricity production--In this next year, the plant should operate as an energy producer as much as possible.

(4) Energy balances--Increased effort should be directed at performing energy balances.

These and other recommendations are more fully described in the body of this report. Because of the limited time at the meeting, it was not possible to make available all of the details for current or planned activities. In this report, the panel recommendations are presented as originally formulated; in many cases, the panel recommendations have already been or will be implemented.

This document also presents summaries of the presentations made at the meeting and a list of the reports that will be prepared during the last half of the Test and Evaluation Phase. The list of meeting participants and the agenda can be found in Appendixes A and B, respectively.

10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT
MID-TERM TEST AND EVALUATION REVIEW
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Introduction

The 10 MWe Solar Thermal Central Receiver Pilot Plant is a research and development project to demonstrate the technical feasibility, economic potential, and environmental acceptability of the solar central receiver concept. The plant is a joint effort of government and private industry through a Cooperative Agreement between the Department of Energy (DOE), Southern California Edison (SCE), the Los Angeles Department of Water and Power, and the California Energy Commission.

The Cooperative Agreement calls for a two-year Test and Evaluation Phase, followed by a three-year Power Production Phase. The pilot plant is now at the mid-term of the Test and Evaluation Phase. A Mid-Term Review Meeting was therefore convened in Barstow, California, on July 20 - 21, 1983, to discuss plant status and the remaining year of this testing period.

The Mid-Term Review Meeting served three purposes:

(1) it provided a follow-up to the Preoperational Readiness Review held in March 1982,

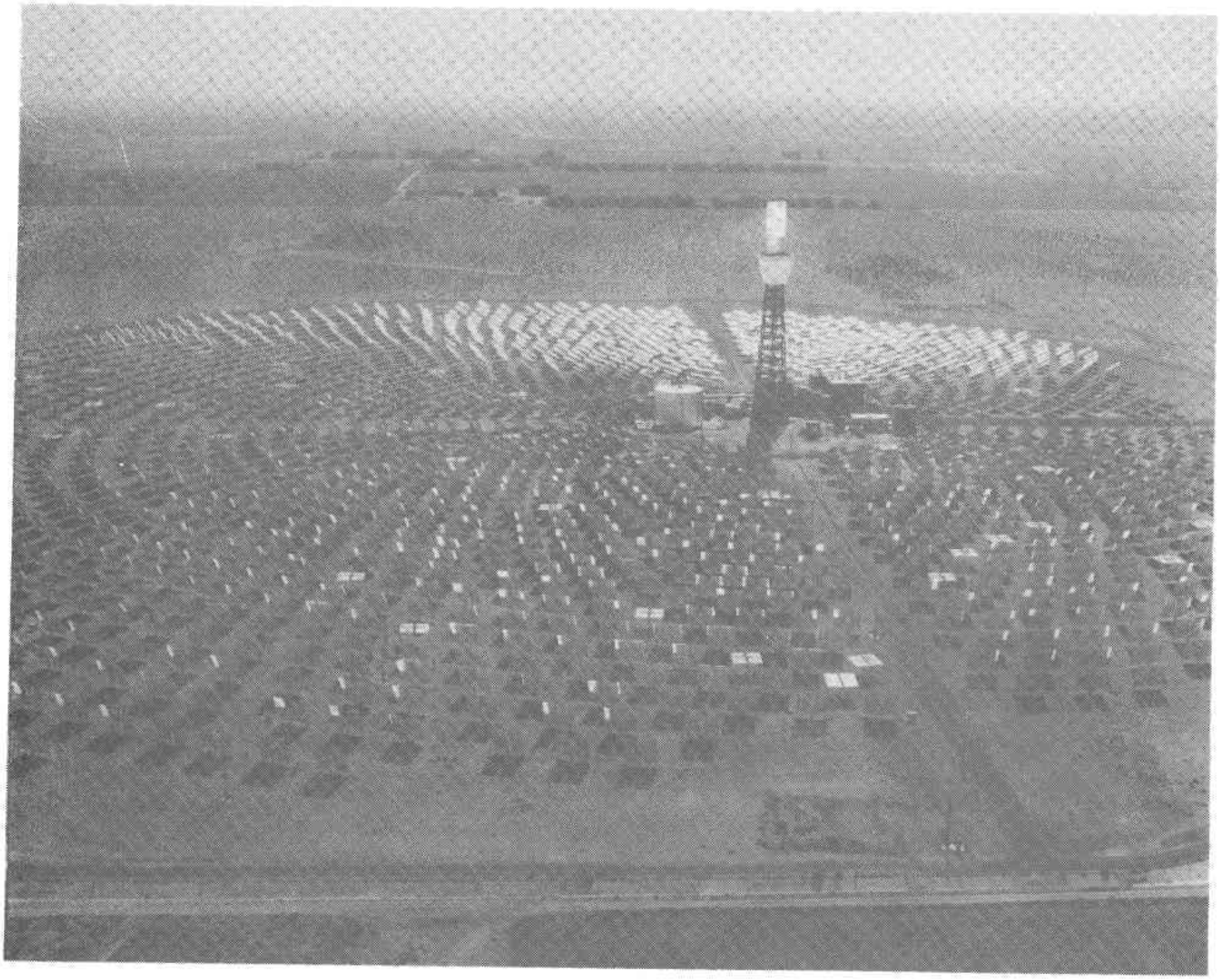
(2) it offered a means for reviewing what had been accomplished over the last year, and

(3) it presented an opportunity for adding to and revising the second half of the Test and Evaluation Phase.

At the March 1982 meeting, a selected panel evaluated the readiness of the plant for turbine roll and initiation of the Test and Evaluation Phase. The two-day Mid-Term Review Meeting, coordinated by Sandia National Laboratories Livermore (SNLL), was arranged to facilitate exchange of information about plant status. Meeting participants consisted primarily of a fifteen-member panel who represented four of the organizations sponsoring the plant (Department of Energy, Sandia National Laboratories, Southern California Edison, and Los Angeles Department of Water and Power); various utility-related groups (Electric Power Research Institute, Pacific Gas and Electric, and Arizona Public Service); engineering firms (Bechtel Group, Inc., Stone & Webster Engineering, and Rockwell International Energy Systems Group); and the university sector (University of California at Davis). Many of the panel members from the Preoperational Readiness Review were present. Appendix A provides a list of participants.

During the first day and one-half, presentations were made on actions taken since the Preoperational Readiness Review. Topics also included current plant status, operations and maintenance, the major subsystems, plant automation, and cataloging of research, design, and construction documents. The last portion of the meeting was devoted to recommendations for next year's test and evaluation plan. The meeting agenda is shown in Appendix B.

The next section presents a compilation of the panel's recommendations. Summaries of the presentations follow. Finally, a list of reports that will be published in the last half of the Test and Evaluation Phase is provided.



Panel Recommendations

One of the purposes of the Mid-Term Test and Evaluation Review was to obtain the panel's recommendations for the last year of the Test and Evaluation Phase. After the meeting presentations had been made, panel members were asked to respond to two basic questions:

-- Should any planned evaluation activities be cancelled?

-- Should other evaluation activities be added?

The panel agreed that testing to date has been successful; furthermore, they fully supported next year's plan. Thus, in response to the first question, the panel recommended that all of the planned test activities be carried out. Some suggestions were also made for future work.

In general, the recommendations were directed at four areas:

(1) Relating the Barstow "Success Story"
The word of the success of the Barstow plant is not adequately being disseminated. Reams of technical data and reports are being prepared, but the information needs to be distilled for use by senior decision makers.

(2) Automation
The completion of automation should be given high priority. The knowledge gained will be of great value not only to solar power plants but also to conventional power plants.

(3) Production of Electricity
Added emphasis should be given to producing electrical energy at the pilot plant.

(4) Energy Balances
Increased efforts should be directed at performing energy balances. Emphasis should be on accurately determining by measurement or analysis the energy input to the receiver.

On the following pages, these recommendations are further described. Additional comments, representing a collection of the statements made by one or more panel members, are also presented. It should be noted that panel members did not unanimously agree on all remarks and suggestions.

Documentation

> "The most urgent single need is an effective communications program to mine the gold...and put those nuggets securely into the hands of decision makers in the financial community, in the utility industry, Congress, the Administration, state and federal regulatory agencies, and...the public."

The panel expressed concern that the success of Solar One has not been sufficiently communicated to decision makers. Failure to communicate will be detrimental to the future of central receiver technology. The panel recommended development of relatively brief, technically accurate reports that would describe the successful performance, efficiency, reliability, costs, and achievements of the plant and what these data mean to the viability of future plants. This information should be distributed to those people who, directly or indirectly, determine the fate of the central receiver program--senior decision makers from utilities and industry, financial institutions, Congress, DOE, and professional societies.

Other documentation-related suggestions were made:

-- Presentations and reports should include information on data accuracy.

-- Training requirements should be documented; the pilot plant experience must be able to be extrapolated to commercial-scale plants.

-- The decision-making process used for the master control system should be documented (as well as its design, hardware, etc.).

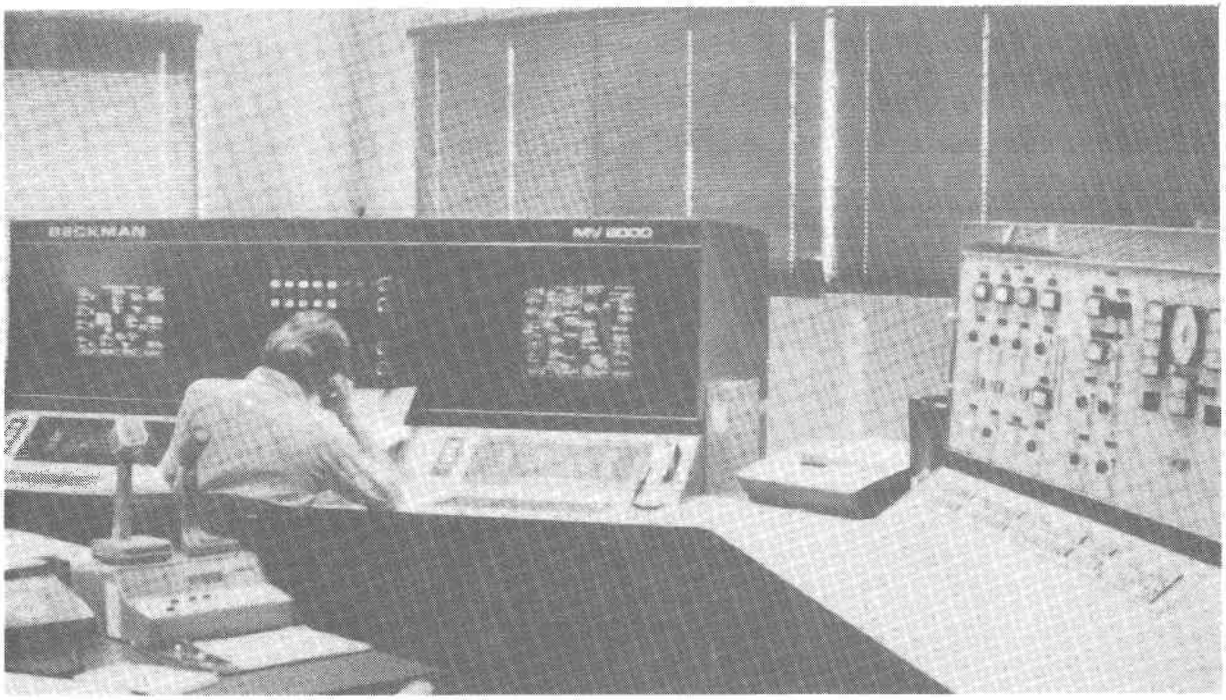
-- A recommended methodology for calculating receiver incident power based on data from the Beam Characterization System, heliostat reflectivity measurements, and MIRVAL modeling should be documented.

-- Plant conceptual design information should be updated on the basis of experience.

Automation/Master Control

> "I recommend that the installation and implementation of the Master Control System be continued and completed to the full extent which DOE funding permits."
>
> "Automation should not be justified on manpower reduction alone. We should look for justification in terms of increased power production, reduction of errors, work reduction and better operation."

The panel agreed that completion of automation work was important. Furthermore, expenditures of funds should be based not on staff reductions (which, in actuality, might represent a cost savings of only $200,000 to $300,000 per year) but rather on optimizing the plant revenue stream for future solar plants. The pilot plant serves a critical role as a learning tool; demonstration of how automation affects component lifetime and plant reliability, maintainability, and availability is extremely useful.



The panel also made the following suggestions:

-- Automation should be considered for activities other than plant operation, such as:
  - optimizing power production
  - charging thermal storage
  - minimizing steam flow to the flash tank
  - improving efficiency

-- Data should be compiled in an easily usable form so that the effect of the control system, subsystem automation, and introduction of the Operational Control System can be documented and extrapolated to other plants.

-- Graphic display call-ups need to be completed more quickly.

-- Control algorithms in which the system is as good as or better than the operator should be designed by:
  - using data from manual tests to design optimum strategies
  - using information from subsystems and integrating it into control algorithms
  - designing less-conservative algorithms for control

-- Careful consideration should be given to the optimum "clear day" start-up procedure, including the possibility of full-field start-up.

-- A separate monochrome display should be used to display alarm information.

-- A software check should be added that prohibits the use of an outdated floppy disk in the control system.

-- Control panel displays should be developed to be compatible with repowering applications and for less-sophisticated operators (i.e., touch screens that resemble portions of conventional configurations).

-- Manual operator response should be correlated to automated control to reduce required operator decisions.

-- SCE will look into the possibility of automating the switch over from the 33 kV to the 4 kV system so that switch over can occur as quickly as possible.

-- The procedure whereby SCE operators help develop displays should be continued.

-- Automatic systems that are based on concepts developed for the chemical processing industry are worth considering. The first few commercial plants will probably operate as nonutility property; thus standard utility work rules may not be initially applicable.

Plant Operation

> "We must operate Solar One more as a production facility next year....Solar One will have to clearly demonstrate an ability to generate kilowatt-hours sufficient to pay back the investment involved and return an adequate profit."
>
> "Without interfering with the test program, as much data as possible should be accrued on Barstow during operation as a normal utility power plant. These data should be separated from data applying to test operations."

Several panel members recommended that during the last year of the Test and Evaluation Phase the plant be operated as a power production facility for a period of time. The more information that is gained now about the plant's ability to produce electricity, the more data that will be available for decision makers who are using Solar One to establish the technical merits of the central receiver concept. In particular, data are needed on operations and maintenance by subsystem and component, availability by subsystem, reliability by subsystem, energy production, efficiency by subsystem, and mean time to repair components.

One panel member stated, "This 'visibility' that the Solar I plant presents to the industry and investment communities in terms of private-sector-funded follow-on plants emphasizes the need to remain cognizant of the importance of the overall plant performance and appearance." Operation of the plant as a power producer is viewed as critical to the viability of the central receiver industry.

The panel commented on other aspects of plant operation and performance:

-- Operational strategies should be developed to optimize total energy production over the life of the plant.

-- Failure modes (loss of power to the heliostat field, flux migration to the tower, etc.) should be evaluated.

-- Quantitative comparison of subsystem predictions versus subsystem performance has been very limited.

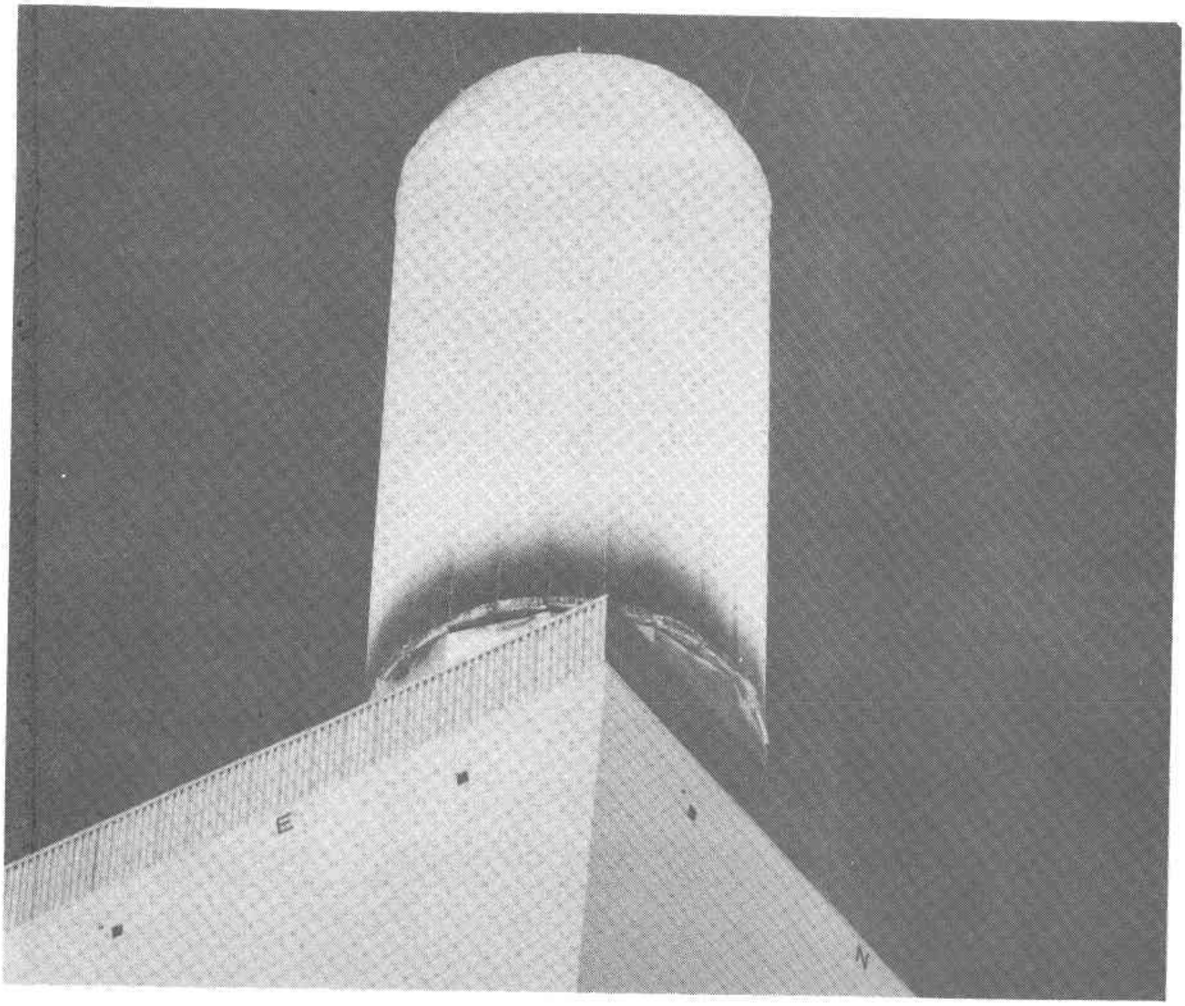
-- The discrepancies between expected insolation for Barstow and actual plant operating results should be resolved.

The panel also voiced several questions:

-- What are the criteria for proof of concept and proof of performance? How does Solar One performance compare on a subsystem or component basis with tests performed in the R&D phase? Be prepared to explain performance numbers that both exceed and fall short of design numbers.

-- Are there future plans to operate Solar One as a test facility for new components and subsystems?

-- What can be learned from Solar One to improve the design, efficiency, etc., of larger follow-on systems?



Energy Balance and Plant Efficiency

> "Energy balance--not convinced you have done all you should"
>
> "Need to obtain a good approach to assess plant performance in terms of energy loss and system efficiency backed by performance measurements."

The panel strongly recommended that increased efforts be made to perform energy balances. In particular, work is necessary to accurately determine the energy input to the receiver. Attempts should continue to measure the overall plant efficiency and to measure, where possible, component and subsystem efficiencies.

Panel members offered general suggestions as well as particular ways to improve plant efficiency:

-- A detailed spaghetti chart of energy flows would be valuable. Losses and parasitic loads, identified in more detail than in the waterfall chart, would be especially useful to repowering designs.

-- The effect of improved plant start-up on plant energy output should be quantified.

-- Energy is wasted to the flashtank and heavy parasitic losses occur; the collector system should operate at 100% capacity as much as possible; the receiver loss problem should be investigated.

-- Energy is being lost due to drains to the condenser; many of these lines are small, have no instrumentation, and are not regularly inspected. Some effort to instrument and monitor drains to the condenser should be made.

Systems Evaluation

After considering the information provided by the speakers, the panel provided recommendations for next year's testing and evaluation of the receiver, collector, and thermal storage systems. The panel's comments are summarized below.

Receiver System--

-- Emphasis should continue on measurement of receiver efficiency.

-- Experimental comparisons should be made with HELIOS and MIRVAL analytical code predictions.

-- Inputs should be obtained from boiler manufacturers regarding the bowing of panels (conventional fossil boiler tubes also bow). What is the mechanism by which panel warpage will reduce lifetime?

-- Receiver absorptivity should be monitored for lifetime. The stability and characteristics of the absorptive coating must be followed. Has the 2% decline in absorptivity stabilized, or is it continuing? What are the projections on Pyromark lifetime? Prospects for and the cost-effectiveness of painting the receiver to improve absorptivity should be evaluated. A coating other than Pyromark should be tried on one or more receiver panels at the next opportunity.

-- The stress assessment of receiver panels should be completed for other receiver designs (e.g., a cavity receiver that uses the same panel material as the Solar One receiver).

-- Additional evaluation should be performed on receiver design problems and high-maintenance components.

Collector System--

-- The heliostat field is the largest investment of the plant; its cleaning, degradation, availability, reliability, and operation are of primary concern and should continue to be documented.

-- Data are needed so that results can be applied to future systems. Solutions to problems need not be carried out at Barstow to be acceptable for future situations; solutions on paper may be sufficient.

-- High priority should be placed on developing a "fix" for the mirror corrosion problem. If the vent fix of the heliostats is not detrimental, a fix for all heliostats should be expedited.

-- Performance of the new washing rig is of interest. What are the projections on the difficulties of cleaning the 100 m^2 heliostats?

-- Further data on optimum stow position should be obtained.

-- Will the plant be ready if and when the heliostats require updated alignment and adjustment?

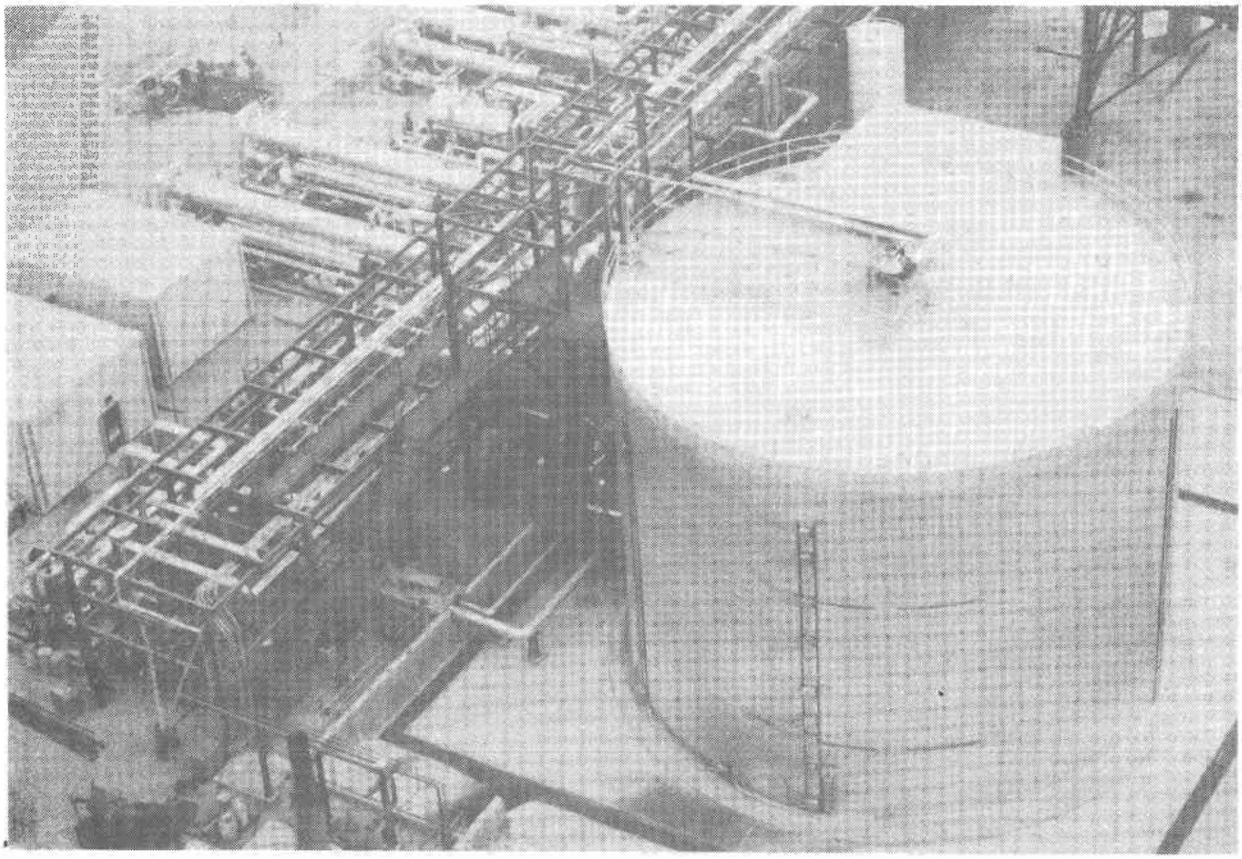
-- More samples should be used for information about heliostats.

Thermal Storage System--

-- Extensive testing on thermal storage would support automation, as well as two repowering programs and their storage tanks. Testing will also be of considerable help in the design, costing, and substantiation of the performance of future systems.

-- The thermal storage tank stress assessment should be completed, along with assessment of the heat losses through the foundation.

-- Additional information should be obtained on thermocline history, status of insulation of the tank, material/oil reaction, and reason for overdesign. Data on thermocline stability with time, ratcheting, long-term efficiency, pumping power, rock stability, and pressure drop will be valuable as benchmarks for other designs that use other heat transfer fluids.



Plant Staffing

> "After May 1984...where will the expertise come from to train new operators and to evaluate problems which arise [and] which are beyond the understanding of the SCE operating staff?"
>
> "I strongly suggest that an 'Operator's Review Panel' be assembled for one day. This panel would consist of experienced operators and operating foremen who, after being exposed to a brief presentation on each subsystem, would provide their comments and suggestions."

The panel had a variety of input to the topic of plant staffing, as is illustrated by the above remarks. Comments pertained to the operators, to operations and maintenance staff, and to general staffing concerns. Whatever the situation, however, the panel emphasized that staffing at Solar One provides valuable information for future plants.

Like every plant system, staffing is a factor that will be evaluated over the next year. The panel made several suggestions:

-- Some designer expertise needs to remain in the operator training loop. Sandia, McDonnell Douglas, etc., should be retained to help provide that expertise for the rest of the five-year test program.

-- Future projects (at Coolwater, Coal Gasification, etc.) might affect Solar One's ability to hold operators; Solar One must prepare for this situation.

-- Is the private sector getting a realistic accounting of what is needed in terms of O&M to run a plant? The staffing needed for O&M should be extrapolated to larger plants, and O&M expenditures relevant to commercial plants should be isolated.

-- O&M personnel on site should be interviewed to obtain worthwhile information.

-- Detailed estimates of required manpower from a utility standpoint would be valuable to repowering programs as well as to commercial-size units.

-- Continuing efforts to minimize staff are of great interest for economic reasons. It would be helpful to identify tradeoffs confronting cuts in staff. Possibly new "craft" definitions could be suggested to consolidate work functions or to provide more flexibility.

-- Perhaps a "crack" team of SCE operators should go through the Molten Salt Electric Experiment (MSEE) training. This procedure might give insight into future training programs in terms of the amount and type of information required.

Plant Conditions and Hardware

The following recommendations deal with plant conditions and hardware:

-- Suitable and sufficient freeze protection must be in place before the end of the summer. SCE is looking into additional freeze protection for the auxiliary bay.

-- Everything practical that can be done to eliminate fires should be done.

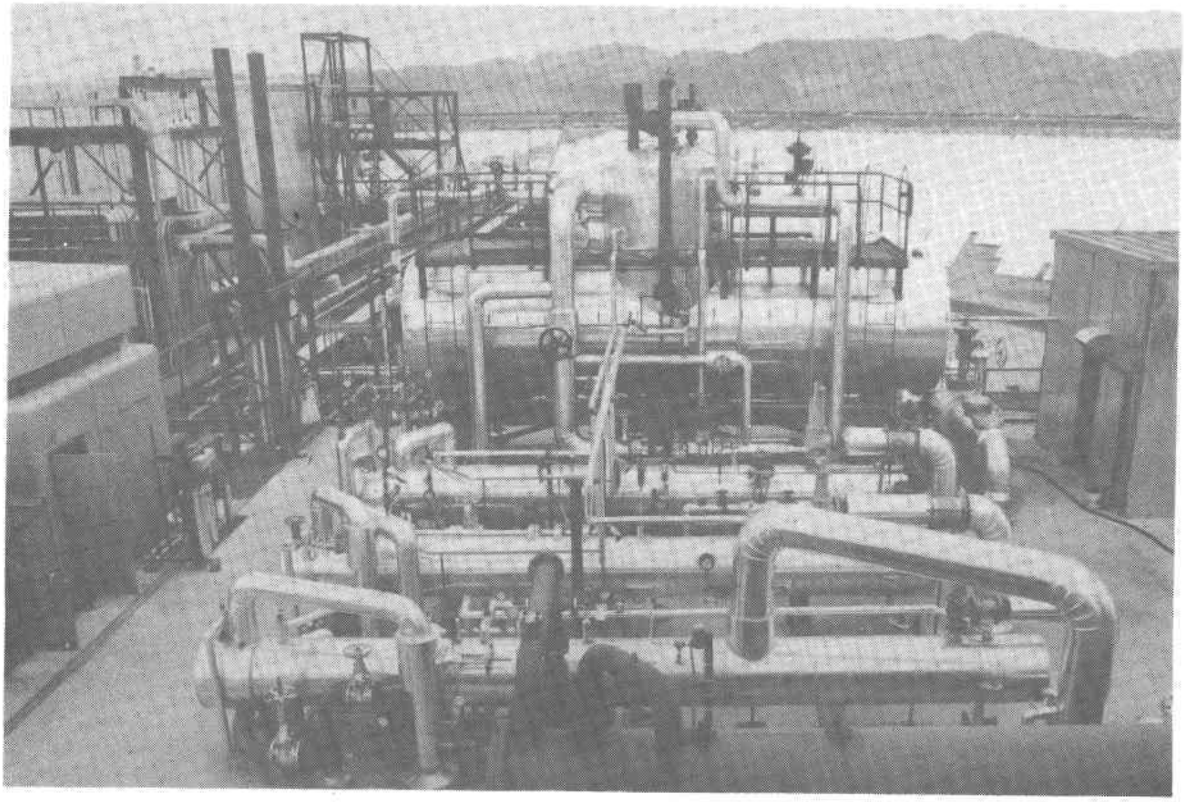
-- Control of visitors in the control console area should be reviewed and possibly tightened up. Inadvertent "button-pushing" could result in equipment damage or personal harm.

-- Water leaks should be corrected.

-- The steam flowmeters in the receiver and thermal storage have invalidated test data and interrupted test hours. Measures should be taken to correct this situation.

-- An oil-in-water detector should be installed, if such an instrument exists.

-- Normally, new steam turbines are inspected and overhauled before the end of the first year of operation; there is some concern because this was NOT done at Solar One.



Major Activities During the Test and Evaluation Phase

J. J. Bartel
Sandia National Laboratories

The major activities performed at the 10 MWe Solar Thermal Central Receiver Pilot Plant during the Test and Evaluation phase include:

- Checkout of all plant operational modes
- Upgrade of the control operator displays and addition of automatic control
- Performance testing and evaluation

Since turbine roll on April 12, 1982, all major plant systems have been activated. All seven major operating modes have been functionally verified. Plant operation in Mode 1 (receiver steam directly driving the turbine), Mode 5 (receiver steam charging storage), Mode 8 (storage extraction supplying seal steam), and Mode 6 (storage extraction steam powering the turbine) has been released to Southern California Edison (SCE).

Progress has been made with installation of the Plant Operational Display System (PODS). This system will provide an integrated display overview of the plant systems on two high-resolution CRTs. Automation continues on a system level, e.g., receiver, thermal storage, and electric power generation systems.

Many start-up and shutdown operations are now automatic. For example, once water flow is established in the receiver and heliostats are tracking, the eighteen boilers automatically switch from flow control to metal temperature control. Once in blended steam control, a panel which exceeds preset temperature limits will automatically switch back to metal temperature control.

In the thermal storage system, prewarming of oil piping and heat exchangers is accomplished automatically. Changes in flow rates of oil or steam to charge are accomplished by simple operator-entered commands of desired turbine load or flow rates. Components are automatically adjusted to deliver the power or flow rate while uniform pressures are maintained.

System automation activities differ from planned plant automation. Control will be at a plant level via PODS. Currently the operator coordinates changes of the heliostat field, receiver, and thermal storage; at the plant level, a desired change in one system will be compensated for automatically in another.

The following tables compare design performance criteria with what has been demonstrated. The balance will be completed in FY84.

Requirement	Status
System	
O Deliver 10MWe net, direct receiver steam	10.4 MWe net achieved 10/10/82
duration: 4 hours least favorable	not demonstrated
8 hours most favorable	not demonstrated
o Maximum thermal storage charge rate equal to thermal power to operate turbine at 10MWe net	not demonstrated
O Deliver 7MWe net from thermal storage	7.3 MWe net achieved 2/25/83
O Deliver 28 MWe hours net from thermal storage	demonstrated-- 28 MWeh delivered at 7.1 MW; 43 MW total generated May 19, 1983
O 30-year plant lifetime	not demonstrated
O 90% plant availability	demonstrated February - June 1983

REQUIREMENTS	STATUS
Steady State	
Minimum power level 2 MWe net	demonstrated to 0.5 MWe
Provide 10 MWe net Modes 1, 2, 3, 7	demonstrated Modes 1, 3
Provide 7 MWe net Modes 4, 6	demonstrated Mode 6
Mode Transitions	
Perform start-up and shutdown procedures	Mode 1, Mode 5 demonstrated Mode 6 start-up demonstrated
Receiver	
O Accommodate at least 0.3 MWth/m^2 flux	demonstrated Test 1030
Storage	
O Transfer energy from steam to oil, retransfer energy back to steam	demonstrated Test 1040
O Perform transfer operations simultaneously	demonstrated September 29, 1982

REQUIREMENT	STATUS
	Heliostats
Safe control of reflected beams	verified--report in progress
Maintenance by plant operators	demonstrated--160 man-hours/mo to provide 97% operating
Mirror cleaning	demonstrated with rain and insulator washer at 60 heliostats/manhour on 1800 heliostats
30-year design life	mirror corrosion will preclude 30-year life
90 percent plant availability	heliostats--97% available 99% of the time
Direct insolation onto receiver	demonstrated--spillage data available in October 1983
Survive environmental conditions: stow position-90 mph operating position-50 mph	demonstrated for: 60 mph gust front, lightning, rain, and 70 mph wind
Operating steady-state and transition modes	demonstrated
Survive power loss transients	demonstrated

Plant Status and Test Program

J. Raetz
McDonnell Douglas Astronautics Corporation

The major plant operational and test activities that have occurred since turbine roll include the following items:

- controls development testing
- plant operating mode performance testing
- start-up and mode transition testing
- testing of automatic sequences
- special tests

The controls development testing involved the initial activation of the receiver and thermal storge systems. This culminated with the systems reaching a fully operational status. In this presentation, basic test methodology and significant test results were reviewed for both systems.

Principal mode performance testing to date has been for Modes 1 (turbine direct), 5 (charging only), and 2 (turbine direct and charging). Limited testing has been conducted for Mode 6 (storage discharging), while only minimal operating times have been spent in Modes 3 (storage boosted), 4 (in-line flow), and 7 (dual flow).

Start-up and mode transition testing has been partially accomplished to finalize operating procedures and to develop requirements for plant automation. Selected subsystem-level automatic sequences have been programmed and implemented through the Subsystem Distributed Process Control System (SDPC) and the Interlock Logic System (ILS). The functions of these sequences were reviewed. Additional testing and requirements generation activities to support the Operational Control System (OCS) were also outlined.

Additional special tests in the following areas include:

- special performance tests
- "off design" sensitivity studies
- turbine start-up on admission steam
- collector field aimpoint sensitivity tests
- "automatic" collector/receiver start-up tests
- collector field beam safety
- beam characterization system tests

Hardware problems have impacted plant operation and performance testing. Most attention was directed at the poor reliability of steam flowmeters and thermal storage heat exchanger leaks, which have resulted in lengthy heat exchanger outage periods. The normal "work around" involved keeping one of the two heat exchanger trains in service as much as possible.

O&M Experience, Plant Reliability, and Safety

C. W. Lopez
Southern California Edison

O&M Experience

The Solar One operating and maintenance organization has undergone several revisions in the last year. These revisions have generally effected changes in personnel job classifications, rather than in the total number of assigned personnel. Organizational revisions will continue through the end of this year to effect an organization that will ensure the plant's safe, reliable, and efficient operation.

Plant Reliability

Generally, solar-dedicated systems have demonstrated exceptional reliability, giving consideration to their uniqueness and the start-ups and shutdowns to which they are subjected. Conventional plant systems have, on the other hand, evidenced less than expected reliability. Conventional system failures are attributable to both improper design criteria as well as improper construction practices and quality assurance.

Safety

The SCE Accident Prevention Manual is the primary reference regarding general industry safety practices during the plant's O&M period. During the plant's start-up, it was necessary to identify a safety policy regarding the solar-unique plant systems. Accordingly, McDonnell Douglas, in conjunction with O&M personnel, established a site safety plan. Following a collector field power-level test by Sandia, selected heliostat pedestals were banded with red tape to identify areas within the collector field that might expose individuals to hazardous light intensities.

All site personnel have received training with regards to general industry safety, Solar One specific safety, first aid including use of burn paks, and use of fire fighting equipment. Site participants who have attended the safety training sessions are now allowed access to all collector field and selected receiver areas. Such access generally requires close coordination between operators and the work party in compliance with the site's safety plan.

The solar facility has experienced three fires to date, two of which were the direct result of thermal storage heat exchanger oil leakage and one due to the ignition of lumber by an adjacent uninsulated steam lead drain line. Effort is presently being directed to correcting oil leakage in the thermal storage area. Consideration is being given to the installation of a permanent auxiliary bay winterization protective barrier to eliminate use of the temporary canvas tarp and supporting wood structure. Because the thermal storage system continues to be subject to the oil leakage, and final resolution has not been established, it was deemed appropriate to conduct a joint DOE, SCE, Sandia, and Stearns-Roger fire safety survey. The survey identified areas of improvement (for which correction was expedited) and certain other design changes (which are being reviewed by an on-site review committee). The effort of the above groups will minimize the plant's exposure to fires as well as improve detection of any fire condition.

Ongoing Activities

Operating and maintenance personnel are now primarily engaged in the plant operation and maintenance with a decreasing responsibility in the start-up of plant systems. Operators are routinely engaged in the plant's daily operation and establishment of standard operating procedures as plant system control configurations and operations are finalized. Operators have also made significant contributions in the following areas: (a) reduced plant auxiliary power consumption, (b) reduced start-up times, and (c) extended plant operating hours. Maintenance personnel have been involved in (a) equipment reliability improvements, (b) reduced maintenance costs, and (c) revision of control system logic to effect control stability.

Receiver Evaluation

A. F. Baker
Sandia National Laboratories, Livermore

Evaluation of the 10 MWe Solar Thermal Central Receiver Pilot Plant receiver has emphasized three major tasks: incident power and distribution predictions, single tube and receiver panel performance predictions, and total receiver performance predictions. The second and third tasks use the results from the first task and measured data from the pilot plant for their performance predictions.

Heliostat characteristics required by the MIRVAL heliostat field performance code, which is used for incident power predictions, are based on data taken from prototype heliostats tested at the Central Receiver Test Facility in Albuquerque, New Mexico. The single exception is the beam pointing error, which is based on limited data taken at the pilot plant using the Beam Characterization System (BCS). When the pilot plant BCS is fully operational, heliostat characteristics will be updated to represent the actual pilot plant heliostats. The MIRVAL code has been upgraded to account for the specific heliostats tracking the receiver, individual heliostat aimpoints, changes in mirror module focal lengths (both short and long axis) with temperature, and different mirror module mirror reflectivity. Even though significant changes are not expected between pilot plant heliostats and prototype heliostat characteristics, it should be recognized that there is uncertainty in the incident power predictions on the receiver used to calculate panel and receiver performance.

The evaluation of panel and receiver performance using detailed heliostat field performance predictions has been performed for thirty-three cases. These cases include several test times during each of nine days. The first day was May 19, 1982; the last day was March 12, 1983. Analyses of the results of the panels' performance indicate that for times near solar noon and with incident power above about 2.5 MW, panel efficiencies (absorbed power divided by incident power) vary between 70% and 95%. However, at incident powers below about 2.5 MW, the variation is less. For times greater than one or two hours from solar noon, the panel efficiencies again vary but for almost all incident power levels. A possible cause of this variation (i.e., panels with the same incident power absorbed different amounts of power) could be the distribution of the power on the panels. The distribution of the power on a panel can change as a function of the heliostats' aimpoints and/or time of day. The desire would be to have the optimum incident power distribution at all times to maximize the amount of absorbed power for each panel.

An analysis of the results of receiver efficiency for the thirty-three cases evaluated indicates that for a normal incident power of 40 MW, the receiver efficiency is 75.7% (+8.2%, -7.4%). The plus and minus values were developed from curves in which all of the data falls within these bounds.

The equation for the nominal efficiency of the receiver is:

$$\text{Rec Efficiency (\%)} = 79.11 - \frac{136.11}{\text{incident power}}$$

A comparison of receiver efficiency for wind speeds up to about 19 mph shows an apparent decrease in efficiency with increasing wind speed.

Data from "Summary Data Tapes" (which are available to interested parties from Sandia Livermore) are being used to evaluate start-up times for the receiver. The time it takes from sunrise to get steam to the bottom of the tower is one of several start-up times being evaluated. Others include the time from sunrise to get all available heliostats to track and the time to get the turbine on-line from receiver steam.

Next year's plans for receiver evaluation include adding more detailed data to the thirty-three cases which exist (these include full heliostat field performance calculations), developing steady-state trend data from the summary data tapes and a simplified incident power calculation, and performing analytical studies on thermal losses and their mechanism, changes to heliostat aimpoints on panel and receiver performance, and changes to receiver length on performance and peak heat fluxes. Experimental work will include investigating receiver front surface temperatures, convective losses, and measurement of the receiver incident power.

Collector Evaluation

C. L. Mavis
Sandia National Laboratories, Livermore

The pilot plant collector system is made up of 1,818 heliostats and their computer control system. The heliostats have operated successfully since November 1981 with over 3,000 hours of operation in 1982. There have been no significant problems.

The heliostats have demonstrated their ability to supply power to the receiver in all operating modes as well as survive all environmental conditions including lightning and 70 mph winds. One hundred sixty man-hours of maintenance per month will keep 99 percent of the heliostats in operation. Safe control of the reflected light has been verified for the mirror-down stow position as well as for one mirror-up stow strategy in which the stand-by aimpoints are tangent to a circle around the receiver. A "mirror vertical" stow position has been used since January 1983 except during high winds. Vertical stow is being used to keep water from standing on the mirror module seals where it can be sucked into the modules through leaky seals. Vertical stow also keeps water in the modules from standing on the back of the mirrors.

The special heliostat test and evaluation instrumentation, including the meteorological data system, is operational. The special instrumentation includes:

- Load cells for heliostat wind loads
- Heliostat temperature sensors
- Heliostat electrical power measurements
- Beam Characterization System

In 1982 the meteorological data system was off-line 50 percent of the time. The wind and rain data for 1982 are not usable because of instrumentation problems, and the insolation data are incomplete. Much better results are expected for 1983. The heliostat load cells have had a high failure rate--31 out of 120 have failed due to water entering the load cell. All of the load cells were sealed in January 1983. The baseline beam characterization system was completed in September 1982; the complete system will be operational in August 1983. The final system will automatically measure heliostat beam power, power distribution, beam centroid and sunshape. Only beam centroid and total power could be measured with the baseline system, and a high percentage of the data was bad. Software changes have been made to eliminate bad data. Measurements to date indicate that the heliostats are performing as expected and that field performance may be improved with heliostat bias adjustments and recanting of some mirror facets based on beam characterization system measurements. Data will be available in the next few months to quantify field performance.

Mirror reflectivity measurements have been made since February 1982. Rain cleaning has been shown to be effective. A half-inch rain will restore 97 percent of the clean reflectivity; however, even though 1982 was a rainy year, 3 or 4 mechanical washes would have been required to maintain a 90 percent cleanliness. The maximum decrease in cleanliness during 1982 was 8 percent per month, and the more common rate was 3 percent per month.

Mirror silver corrosion exists over approximately 0.01 percent of the mirror area. The corrosion area is increasing by a factor of 10 every 6 to 12 months. The cause of the corrosion is water which enters the mirror modules through leaks in the seals. Additional vents that were added to 14 mirror modules have demonstrated that the mirrors can be dried out and that water can be kept out. Further experiments are plannd to identify a low-cost vent design that can be incorporated to stop, or at least significantly decrease, the corrosion growth rate. Southern California Edison is currently inspecting all 21,816 mirror modules to accurately determine the extent of the problem. Preliminary results for 1,333 heliostats show that 60 percent of the heliostats have some corrosion on 2,368 or 15 percent of the mirror modules. This figure compares with corrosion on approximately 500 mirror modules on 1,818 heliostats (2.3 percent) in July 1982.

Thermal Storage Subsystem Evaluation

S. E. Faas
Sandia National Laboratories, Livermore

The Thermal Storage Subsystem (TSS) is routinely operated for both charging and extraction purposes. Most design objectives have been attained. Start-up and activation of the TSS were completed last year. Controls testing and final controls configuration are nearly complete with documentation; some final details have been delayed because of flowmeter and other hardware problems.

Rated net electrical output power and energy of 7 MW and 28 MWh have been demonstrated. The Thermal Storage Unit (TSU) heat loss is less than design. The remaining objective is to demonstrate that the TSS charging heat exchangers can accept 130 klbh of steam (the maximum design receiver output). When the solar insolation increases to normal levels, the receiver should be able to produce its rated output and the TSS charging capacity tested. Since one of the two trains of charging heat exchangers has accepted receiver output at around 100 klbh, it is expected that both trains will be able to accept 130 klbh of steam.

On May 18, 1983, 43.4 MWh (net) of electricity were generated; the design requirement was 28 MWh. This discrepancy can be explained when one examines the true thermal capacity of the TSU and the conditions under which the TSS operated that day. The design thermal capacity of the TSU included not only capacity for electrical power generation of 135 MWht, but also the thermal capacity for turbine roll, hot standby, and a 15 percent contingency. This additional capacity boosts the total design available energy to 168 MWht. Furthermore, in the actual construction of the TSU, more rock and sand were compacted into the tank than design, which raised the thermal capacity of the TSU by 3 percent (rock having a greater heat capacity than oil).

In the operation of the TSS on May 18, the inlet and outlet temperatures of the extraction heat exchangers were 580 F and 400 F, respectively, rather than the design conditions of 575 F and 425 F. This was due to the TSU bed being largely at 580 F and to the excess heat transfer area in the extraction heat exchangers, since they are only lightly fouled. This larger temperature change resulted in a 20 percent increase in the TSU thermal capacity. Using the design TSS net conversion efficiency of 21 percent, the predicted net electrical output would be

$$168 \times 1.03 \times 1.2 \times 0.21 = 43.6 \text{ MWhe net}$$

which compares very favorably with the actual electrical output of 43.4 MWhe net.

Several start-up requirements can be addressed. A certain amount of energy must be invested to drive out volatiles from the TSU and to heat the TSU to its operating temperature. The energy to heat the foundation and inactive regions of the TSU bed (51 MWht) and the energy to drive out the volatiles (142 MWht) are fairly small compared to the energy to heat the TSU bed to its operating temperature (419 MWht). Water, a major portion of the volatiles, amounted to 1 to 3 percent of the mass of rocks and sand in the TSU. The steam generated during the drying-out time was released through a disassembled 8-inch safety vent. The heat transfer oil volatiles were largely condensed and amounted to 2.8 to 5.6 percent of the initial oil inventory.

The capacity of the TSS is underutilized at this time as a result of bad weather, hardware problems, and an active testing program which precludes normal operation. The TSU heat loss was measured in November 1982 as 0.12 MWt, or about 60 percent of design. In terms of the TSU thermal capacity, this amount represents a 1.7 percent energy loss per day. One would then predict the ratio of energy extracted from the TSU to the energy deposited in the TSU to be around 0.98. However, since the TSS is used at low power levels and intermittently, the ratio of energy extracted from the TSU to the energy deposited from start-up (May 5, 1982) to March 14, 1983, is 0.82. Looking only at the time period from January 1 to March 14, 1983, the ratio is 0.91. While below prediction, the trend is upwards and is expected to approach the predicted value in the future.

Data on thermal degradation of the heat transfer oil in the system are available only from May 5, 1982, through October 7, 1982. More recent samples have been taken but not analyzed. Through October 7, 1982, the oil has undergone very little thermal degradation. Changes in the oil composition as detected by a gas chromatograph-mass spectrometer are negligible. This result is correlated by a temperature-time history of the oil, which reveals that the oil has spent very little time above 270°C (518°F) where the thermal degradation rate exceeds 1 percent per year of mass loss. Future plans include nuclear magnetic resonance and physical properties testing, as well as examination with the gas chromatograph-mass spectrograph.

The tank wall stress is monitored by strain gauges placed at various elevations for unusually high stress states, i.e., greater than +/- 200 MPa (+/- 30 ksi). To date, these gauges show no unusually high values; most values reside in the range of +/- 100 MPa (+/- 15 ksi), with many much lower. The phenomenon whereby the bed settles continuously as the tank is thermally cycled, thus building up high stresses, is not present.

Solar One Generating Station

C. W. Lopez
Southern California Edison Company

General

The Southern California Edison Company had lead responsibility for the design, procurement, and construction of the Electrical Power Generation System (EPGS) and shared similar responsibility with Department of Energy contractors for the Plant Support System (PSS). In the last year, the Southern California Edison O&M organization, aside from having responsibility for the plant's operation and maintenance, has had responsibility for correction of EPGS deficiencies and has shared responsibility with Department of Energy contractors for correction of all other plant system deficiencies.

During the Pilot Plant Preoperational Readiness Review Meeting of March 9-10, 1982, certain concerns regarding the EPGS were defined. These concerns as well as their status are tabulated below.

Plant Operational Displays	The absence of the host computer did not significantly impact plant operations.
Computer Maintenance	Work has been awarded to contractors and services are good.
Spare Parts Stockage	Spare parts are being added to stock as needs are identified.
Process Water Oil Detection	No action; no oil contamination problem to date.
Freeze Protection	Additional heat tracing installed. Flow maintained or equipment drained. Need to improve auxiliary bay enclosure.

Electrical Power Generation System

The Electrical Power Generation System (EPGS) has demonstrated acceptable reliability, considering the frequent start-ups that the equipment contained within the system are subjected to. Generally, this equipment has proven to be reliable and properly sized for the plant's eight operating modes. Problem areas and corrective actions are tabulated below.

Turbine Admission Stop Valve	Internal bypass valve modified to full arc admission.
Freeze Protection	Additional heat tracing/revised operating procedures.
Plant Auxiliary Load	TSS availability/revised operating procedures.
Water Sampling System	Additional sampling points being installed.
Slow Control System Update	No action at this time.
In-Line Demineralizer	Programmer software revisions.
Electric Boiler Reliability	Upgrade circuit breakers/minimize service.
Control Logic	Software revised.
Back-Up Power Reliability	Back-up power/unit circuit breaker revisions.
Gland Steam Condenser	System revision/chemical cleaning.
Circulating Water Chemical	Chemical feed/sampling being revised.

Plant Support System

This system, although generally demonstrating satisfactory performance, experienced significant problems with fire, service water, and plant effluent subsystems. The problems were primarily attributable to improper material selection and improper construction practices. Problem areas and corrective actions are tabulated below.

Fire/Service Water	Installed originally designed thrust blocks and hydrant pads.
	Replace all improperly prepared fiberglass flange sand coupling connections.
Plant Effluent Line	A selected section of PVC line replaced with temperature-tolerant fibercast piping.
Fire Alarms	Original supplier will be requested to assist in correction of system faults.

Plant Automation Master Control System

D. N. Tanner, Sandia National Laboratories
J. C. Grosse, McDonnell Douglas Astronautics Company

Introduction

The master control system is an overall command, control, and data acquisition system that performs control management, supervision, and data collection for display functions. The purpose of the system is to integrate and automate the control of the other subsystems (collector, receiver, thermal storage, and turbine-generator) to achieve effective single-console control and evaluation capability.

The major benefits of an automated master control system are a reduction in work load for operating personnel and an increase in plant energy output by improving operating efficiency. The knowledge gained from this plant will be the basis for future solar central receiver plants; the results will also be available for use by fossil and nuclear plants.

Automation is planned to be completed by August 1984, with a minimum of hardware changes. This work will be finished in parallel with other plant test and evaluation activities.

Description

The plant control system consists of independent distributed digital controllers for the receiver, collector, thermal storage, turbine generator, and balance of plant subsystems, and the Operational Control System (OCS) which integrates the control of the subsystems. The subsystem controllers and the OCS have color graphic displays and an operator input control capability (man-machine interface) including keyboards, function keys, and light pens.

Plant automation is being accomplished in both the subsystems and the OCS. Most functions requiring coordination of more than one subsystem cannot be automated within the subsystem controllers. The OCS is used to integrate the subsystems to complete the master control system.

The following table lists some automation activities and notes those which will be accomplished in FY83 and those which are planned for FY84.

PLANT AUTOMATION

Year	Activity
FY83	Documentation of Automation Objectives Automation goals and objectives System sequences and control Plant surveillance Overall plant sequences and control Plant operational displays Man-machine interface objectives
FY83	Collector System Automatic beam characterization system - Provides minimum operator involvement during the measurement phase - Automatically re-establishes communication with heliostats which get out of synchronization Command Files - Aimpoint changes - Heliostat sequencing for start-up - Off-line heliostats assignment Displays - Improvements to man-machine interface to provide better information on collector field status
FY83	Receiver Initialization of control loops Receiver feedpump control sequencing Receiver start-up sequencing from application of power to all panels through all panels at temperature control Transition from flash tank to steam dump Transition from steam dump operation to flash tank operation

Year	Activity
FY83	Thermal Storage
	Initialize control loops, charging and extraction
	Start-up sequence of charging train from initial flow to achieving temperature control
	Extraction train start-up from initial flow through pressure control for blanket steam conditions
	Extraction train admission steam warm-up sequence
	Extraction train sequence to power production; turbine roll and operation
	Charging and extraction train shut down
FY83	Operational Control System
	Collector field aimpoint control
	Plant Operational Displays System (PODS) (basic tool for OCS automation)
	Graphics design for plant status monitoring
	Completion of subsystem communication to the OCS computer
FY84	Automatic mode transitions and trip sequences
	Plant surveillance information displays
	Clear- and cloudy-day operation
FY84	Turbine-Generator
	Roll turbine on admission or main steam

Catalogue of Research, Design, and Construction Documentation

M. Soderstrum
Burns & McDonnell

Burns and McDonnell has been hired by Electric Power Research Institute (EPRI) to catalogue the tremendous amount of documentation produced in conjunction with the research, design, and construction of Solar One.

As each piece of formal documentation was found, the following information was extracted for the catalogue:

1. document number
2. type of document
3. priority
4. document source
5. date of publication
6. contract number
7. physical location of document
8. author
9. primary recipients
10. other recipients
11. related documents
12. table of contents
13. titles
14. abstract

These pieces of information were compiled in a specific format for use in a computer program which can search the catalogue for key words and compile a list of those documents which deal with a specified subject.

Appendix A of the catalogue lists the document number, source, and title within one of the following subject groups:

1. Collector Subsystem
2. Receiver Subsystem
3. Thermal Storage Subsystem
4. Master Control Subsystem
5. Plant Support Subsystem
6. Beam Characterizations
7. Electric Power Generation
8. Environment
9. Safety
10. Priority 1 system-level documents
11. General background and miscellaneous

All documents in the catalogue have been placed in at least one of the above subject groups. Some are in more than one of the groups.

Future work planned by Burns and McDonnell for EPRI to complete this effort include:

1. verifying the completeness of the catalogue with all the organizations involved with Solar One.
2. establishing a working library at the Solar One plant site.
3. assisting the Technical Information Center (TIC) and the National Technical Information Service (NTIS) in completing their sets of documents.
4. verifying with TIC and NTIS the information a document requestor needs to successfully retrieve a document from either of their systems.

A document requestor is strongly urged to obtain any documents required from either NTIS or TIC. DOE, EPRI, and contractors are not equipped either financially or in terms of manpower to duplicate documents for requestors.

Efforts are currently under way to obtain an SCE computer printout of the catalogue of project drawings. It is anticipated that the drawing catalogue will be published at a later date, as an appendix to the EPRI formal document catalogue.

This catalogue documentation effort is half of a project by Burns and McDonnell for EPRI. The other half is a formal "lessons learned" document. This entire report will be printed and distributed by EPRI in early September of 1983. Volume I will be the "lessons learned" document, the recommendations for Solar One, and recommendations for documentation of future projects. Volume II will contain an explanation of the catalogue, the catalogue itself, Appendix A (mentioned above), and Appendix B which is a listing of Solar One acronyms. Either volume of this report can stand alone.

Planned Reports

Documents that will be published during the last half of the Test and Evaluation Phase include:

1982 Operational Test Report	1983
1983 Operational Test Report	1984
Beam Safety Tests Report	1984
Environmental Evaluation Report	1984
1983 Meteorological Summary	1984
Plant Steady-State Performance Report	1984
Heliostat Evaluation Report	1984
Mirror Module Corrosion Report	1984
Thermal Storage Evaluation Report	1984
Plant Maintenance Report	1984
Cost Analysis	1984
Plant Automation Evaluation Report	1984
Overall Final Report	1985

APPENDIX A--MEETING PARTICIPANTS

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APPENDIX B--MEETING AGENDA

<u>July 20, 1983</u>

8:30 - 8:45	Welcome & Panel Purpose	K. T. Cherian, DOE/HQ
8:45 - 9:00	Discussion of Purpose	Panel
9:00 - 10:00	Overview and Review of Preoperational Readiness Panel Findings	J. J. Bartel, SNLL
10:00 - 10:15	Break	
10:15 - 11:15	Plant Status and Test Program	J. Raetz, MDAC
11:15 - 12:15	Operations and Maintenance	C. Lopez, SCE
12:15 - 1:15	Lunch	

Announcements

1:15 - 2:15	Receiver Subsystem	A. F. Baker, SNLL
2:15 - 3:15	Collector Subsystem	C. L. Mavis, SNLL
3:15 - 3:30	Break	
3:30 - 4:30	Thermal Storage Subsystem	S. E. Faas, SNLL
4:30 - 5:00	Electric Power Generation Subsystem	C. Lopez, SCE

<u>July 21, 1983</u>

7:30 - 9:00	Plant Tour (Optional)	
9:30 - 10:30	Plant Automation	D. Tanner, SNLL J. Grosse, MDAC
10:30 - 11:00	Documentation of Construction	M. Soderstrum, Burns & McDonnell
11:00 - 12:00	Panel Discussion and Documentation of Findings	
12:00 - 1:00	Lunch	
1:00 - 3:00	Panel Discussion (Continued)	
3:00	Adjourn	

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