SANDIA REPORT SAND85-8216 • Unlimited Release • UC-62d
Printed May 1985

10 MWe Solar Thermal Central Receiver Pilot Plant: 1984 Summer Solstice Power Production Test

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

SF2900Q(8-81)

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

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

NTIS price codes
Printed copy: A04
Microfiche copy: A01

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10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT: 1984 SUMMER SOLSTICE POWER PRODUCTION TEST

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ABSTRACT

The 1984 summer solstice power production test for the 10 MWe Solar Thermal Central Receiver Pilot Plant near Barstow, California, was conducted June 14-28, 1984. This report presents the actual operating parameters and results of the test, compares those parameters and results to the plant's original design point conditions, and analyzes the differences.

FOREWORD

The research and development described in this report was conducted within the U.S. Department of Energy's (DOE) Solar Thermal Technology Program. The Solar Thermal Technology Program directs efforts to advance solar thermal technologies through research and development of solar thermal materials, components, and subsystems, and through testing and evaluation of solar thermal systems. These efforts are carried out through DOE and its network of national laboratories who work with private industry. Together they have established a goal-directed program for providing technically proven and economically competitve options for incorporation into the Nation's energy supply.

The two primary solar thermal technologies, central receivers and distributed receivers, use various point and line-focus optics to concentrate sunlight onto receivers where the solar energy is absorbed as heat and converted to electricity or used as process heat. In central receiver systems, which this report will consider, fields of heliostats (two-axis tracking mirrors) focus sunlight onto a single receiver mounted on a tower. The concentrated sunlight is transformed into high temperature thermal energy in a circulating working fluid. Receiver temperatures can reach 1500^{o}C.

ACKNOWLEDGMENTS

The author wishes to acknowledge the technical assistance of John Raetz (McDonnell Douglas Astronautics Company), Test Conductor at Solar One, and Duncan N. Tanner (Sandia National Laboratories Livermore), Site Technical Manager at Solar One, during the 1984 summer solstice power production test. Both men were also very helpful with the preparation of this report by their thorough and instructive reviews of report drafts.

Appreciation is also extended to the following SNLL personnel for their input and assistance in the analysis of specific component performance and/or overall plant output.

Clayton L. Mavis - collector field performance

Mary Clare Stoddard - receiver convection and radiation loss calculations

Alvin F. Baker - receiver absorptivity and C & R loss determinations

Lee G. Radosevich and James J. Bartel - overall plant operation

Southern California Edison Company operations and maintenance organizations at the Barstow pilot plant also deserve special thanks for the effort they expended in readying Solar One for maximum power and energy production.

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Goals

The 1984 summer solstice power production test for the 10 MWe Solar Thermal Central Receiver Pilot Plant was conducted June 14 - 28, 1984. This two week period spanned June 21, which was the day of the year chosen as the "Best Design Day" for the solar plant when it was designed in 1977. The plant, commonly referred to as "Solar One", was originally designed to produce 10 MWe net for 7.8 hours and a peak power of 12.4 MWe net at solar noon (Ref. 1).

The main goal of the 1984 summer solstice test was to operate the plant in a receiver-direct-to-turbine power production mode (Mode 1) to achieve 10 MWe net for 7.8 hours on at least one day during the test period. As the many parameters used to design the plant were compared to the actual operating conditions obtained in readying the plant for maximum power production for the 1984 summer solstice test, it became apparent that the design goal would not be met. A secondary goal of the test was soon adopted: to produce as much power and energy as possible on all days of good insolation and to obtain the data necessary to scale up actual test results to determine where the inefficiencies in the system were located and the causes of those inefficiencies. It must be kept in mind that some of the efficiency factors might be improved by further engineering study and design, some are the result of nature and have little promise of improvement, and some are a combination of the two effects and show promise for some, though not complete, improvement.

This report presents the actual operating parameters and results of the test, compares that data to original design parameters, and attempts to provide explanations for the differences. Suggestions are included for improving the efficiency of the various components in the system, thereby improving the power production capability of the system as a whole. Also presented are suggestions for further studies at Solar One. Timelines and descriptions of activities carried out in preparing for and conducting the 1984 summer solstice test and a suggested schedule for subsequent solstice tests can be found in Appendixes A and B.

General Results

Weather, insolation, and plant readiness provided conditions for several full power production test days during the 1984 summer solstice test period. On six of those days (June 14, 16, 17, 21, 22, and 23), receiver set point temperature was raised to 850°F and maximum plant output was undertaken. Insolation levels for the 15 days of the test are shown in Figure 1. Heavy cloud cover accounted for zero and low insolation for June 24th and 25th respectively. June 27th insolation levels were not available due to an equipment malfunction.

Figure 2 shows the gross and net electrical energy output (while connected to the grid) as well as the 24-hour plant parasitic power consumption for the 15 days of the test. Again, poor weather conditions accounted for zero energy output on June 24th and 25th.

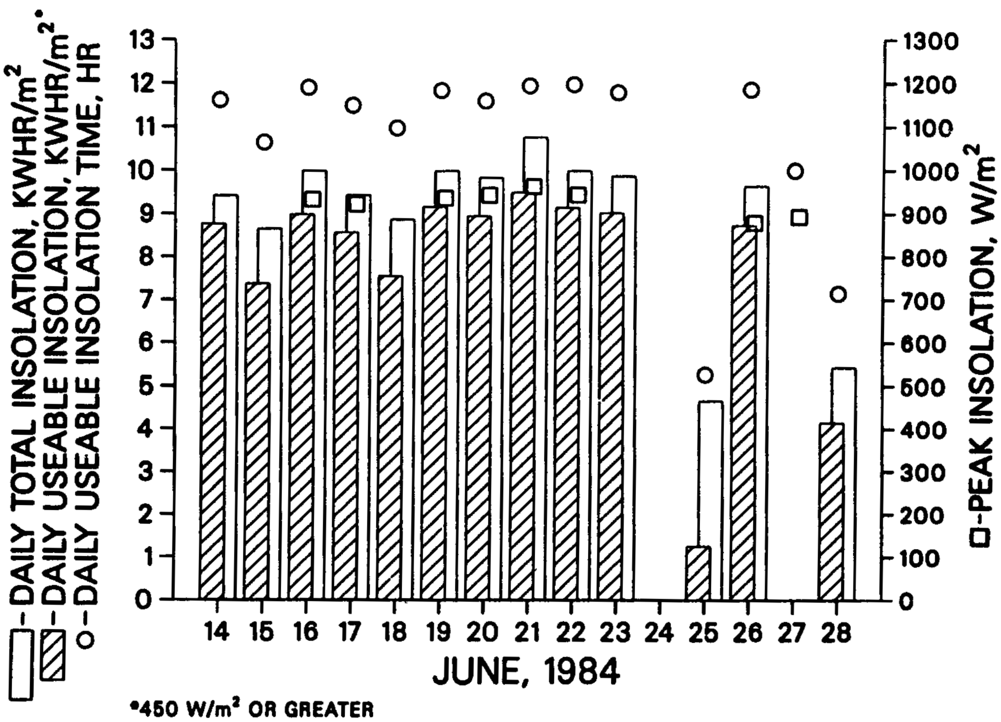


Figure 1. Insolation Data, June 14-28, 1984

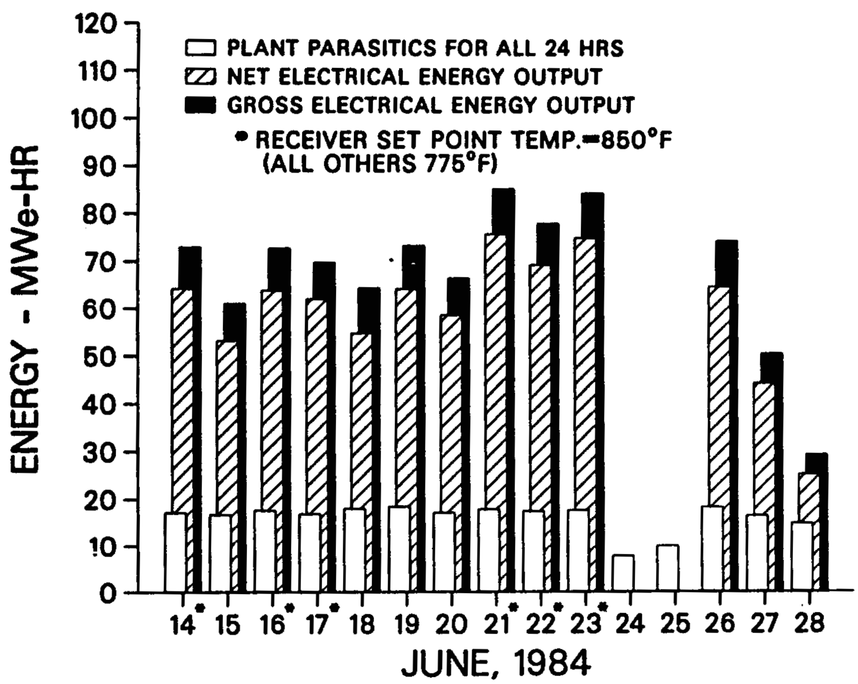


Figure 2. Gross & Net Electrical Energy Output
(while connected to the grid) and
24-Hour Plant Parasitic Power Consumption
June 14-28, 1984

Table I gives the output and key test parameters for the three best days of the test. As can be seen, June 21, 1984, was the day of highest gross and net electrical energy output while connected to the grid and thus was chosen for further analysis in this report and comparison to the pilot plant's design day (see Analysis of Test Results).

TABLE I

OUTPUT AND TEST PARAMETERS FOR THREE BEST DAYS OF 1984 SUMMER SOLSTICE POWER PRODUCTION TEST

	6/21/84	6/22/84	6/23/84
Gross Electrical Energy Output While Connected to the Grid, MW-hr.	85.072	77.756	84.120
Net Electrical Energy Output While Connected to the Grid, MW-hr.	75.593	69.086	74.787
Plant Parasitics for 24 Hours, MW-hr.	17.740	17.300	17.520
Available Heliostats (out of 1818)	1772	1781	1781
Gross Peak Power Output, MWe	9.72	9.8	9.5*
Peak Insolation, W/sq m	957	944	N/A
On Line Time, Hr.	11.37	10.47	11.43

*Saturday data taken at 1200 hours; weekday data taken at exact time of peak.

Figure 3 is a graph of net power output for the pilot plant's design day and for June 21, 1984. As can be seen, peak power for June 21st did not reach 10 MWe at any point in the day, let alone for 7.8 hours. Comparing the power plant's peak net electrical power output on June 21, 1984, (8.59 MWe) to it's design point peak net electrical power output (12.4 MWe), it can be seen that the plant was operating at a 30.7% reduction in peak power output on the best day of the 1984 summer solstice test. (See Appendix C for discussion of peak plant output subsequent to the 1984 summer solstice test period.)

Figure 4 compares the pilot plant's net energy output for June 21, 1984, (75.6 MWe-hr) to total design day net energy output (112 MWe-hr). The partially shaded area depicts the net energy lost by the system on solstice test day in relation to design day and represents a reduction in plant energy production of 33%.

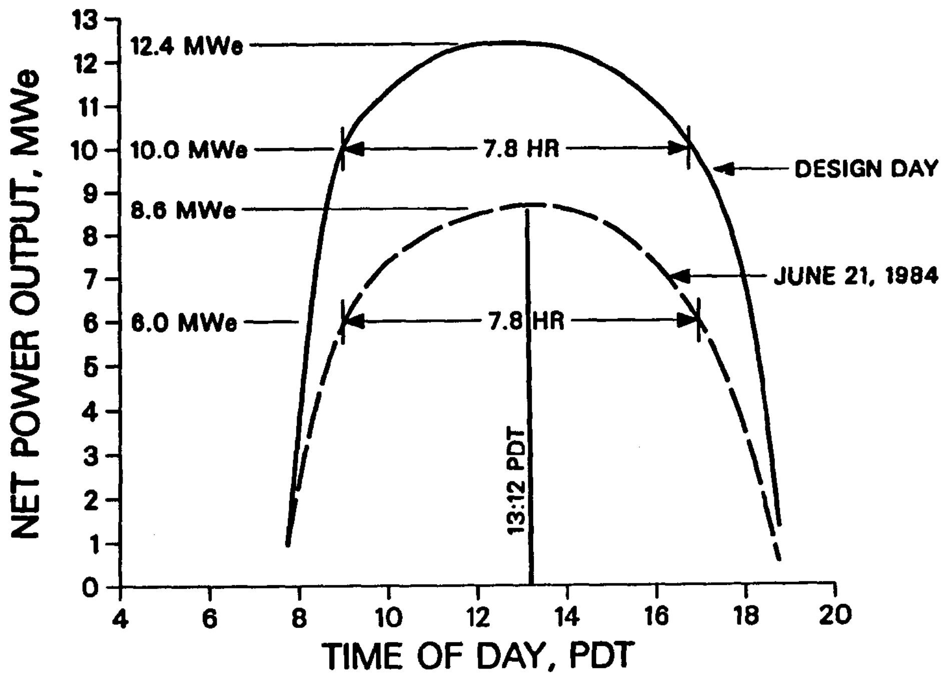


Figure 3. Net Power Output vs. Time of Day
Solar One Design Day and June 21, 1984

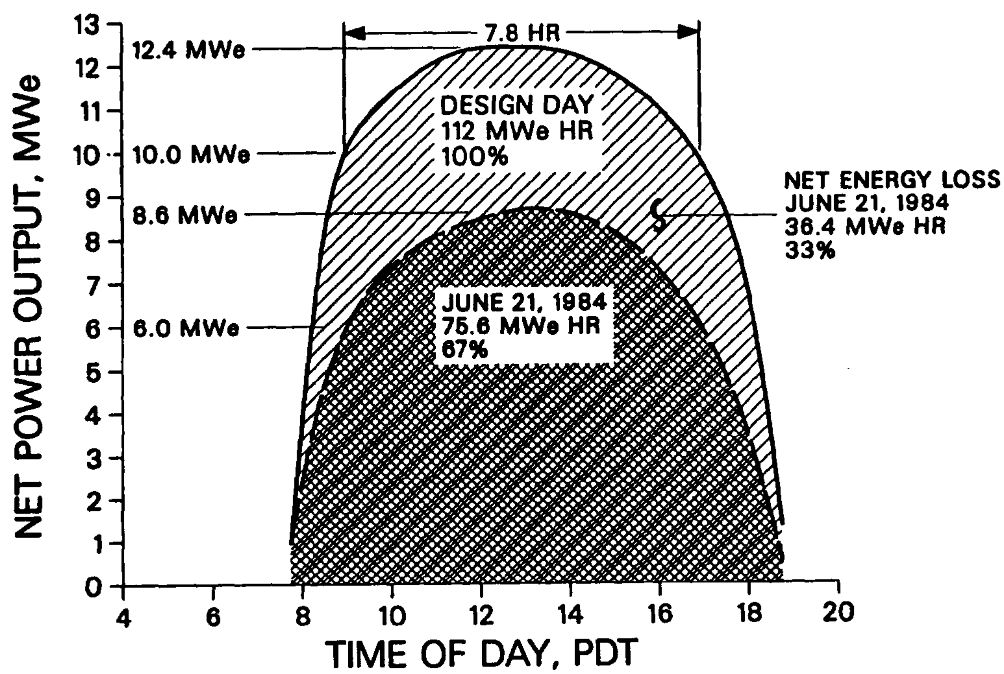


Figure 4. Total Net Energy Output, MWe-hr
Design Day and June 21, 1984

Table II, and the analysis which follows in this report, show the factors that had the greatest effect on reducing Solar One's power and energy production system efficiency on June 21, 1984, when compared to design point.

TABLE II. SOLAR ONE REDUCED EFFICIENCY FACTORS
JUNE 21, 1984

Efficiency Factor	Change
Heliostat Reflectivity	-9.8%
Gross (Turbine) Cycle Efficiency	-8.8%
Receiver Absorptivity	-6.2%
Insolation Availability	-4.8%
Heliostats Off-Line	-2.5%

While the 10 MWe for 7.8 hour energy production goal was not met, several new energy production records for consecutive day periods were established. These records are described in Table III.

Figure 5 compares these record energy production figures to the previously best energy production periods, which were established in 1983. (Note that on June 21, 1983, Mode 3 and Mode 5, charging and discharging thermal storage respectively, were utilized; and the system was on-line for 14.9 hours. This accounted for a larger net energy output than can be obtained by use of Mode 1 alone.)

TABLE III

NEW RECORDS FOR ENERGY PRODUCTION IN CONSECUTIVE DAY PERIODS

	7 Days 6/17-6/23/84	10 Days 6/14-6/23/84	30 Days 5/25-6/23/84
Net Energy Production While Connected to the Grid, MW-hr	458.51	639.44	1307.74
Net Energy Generated on a 24-hr Basis, MW-hr	409.94	568.96	1050.17

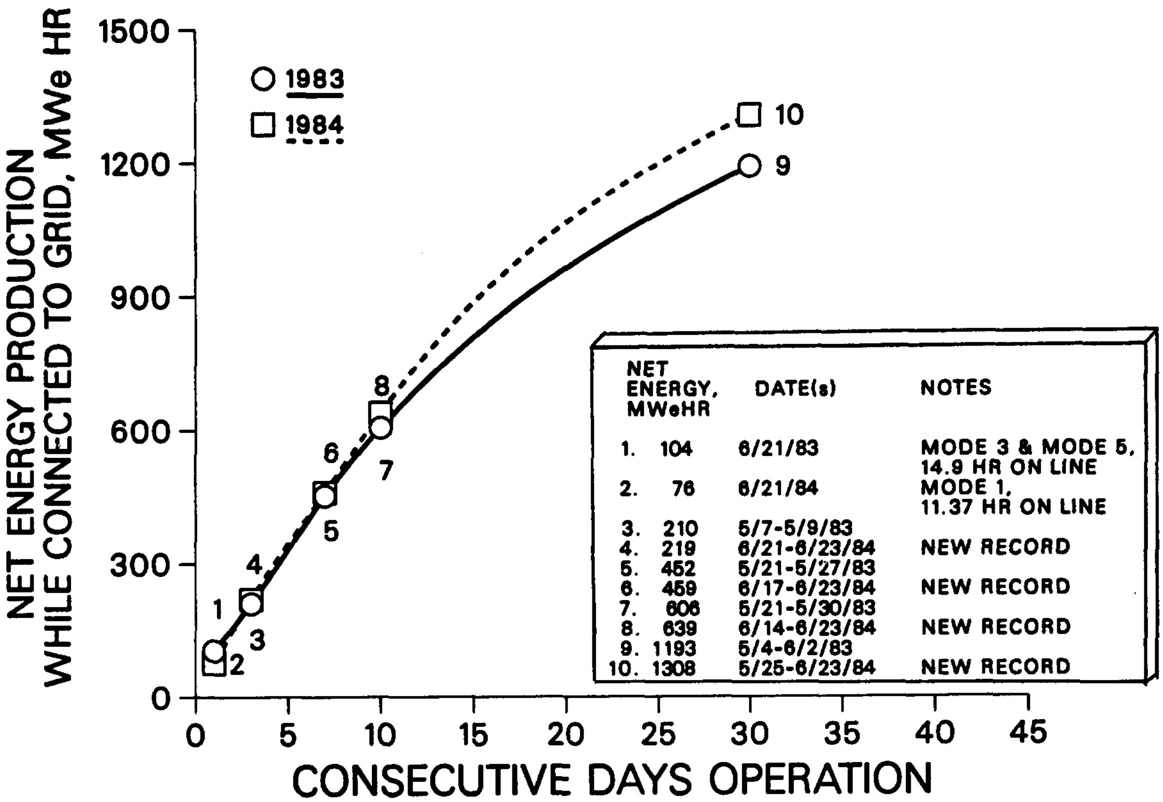


Figure 5. Total Net Energy Production in Consecutive Day Periods, 1983 & 1984

Conclusion

Solar One has been successfully performing its role as the world's first large solar central receiver pilot plant and learning facility. Design, maintenance, and operating improvements continue to be applied and analyzed at the pilot plant, resulting in increasing power production. The output of the pilot plant during the 1984 summer solstice test was a beginning, a base-line, power production level. With continued study and improvement, output in 1985 and subsequent years will be even greater. Solar One is producing data and operating experience that will be invaluable to the further refinement and advancement of solar thermal central receiver technology in the future.

1984 SUMMER SOLSTICE POWER PRODUCTION TEST

Introduction

Goals

The 1984 summer solstice power production test for the 10 MWe Solar Thermal Central Receiver Pilot Plant was conducted June 14 - 28, 1984. This two week period spanned June 21, which was the day of the year chosen as the "Best Design Day" for the solar plant when it was originally designed in 1977. The "Solar One" plant was originally designed to produce 10 MWe net for 7.8 hours and a peak power of 12.4 MWe net at solar noon (Ref. 1).

The main goal of the 1984 summer solstice test was to operate the plant in a receiver-direct-to-turbine power production mode (Mode 1) to achieve 10 MWe net for 7.8 hours on at least one day during the test period. Figure 6 describes the pilot plant's eight different operating modes involving the collector system, receiver system, thermal storage system, and electrical power generation system. All discussion in this report refers to plant operation in Mode 1 unless otherwise noted.

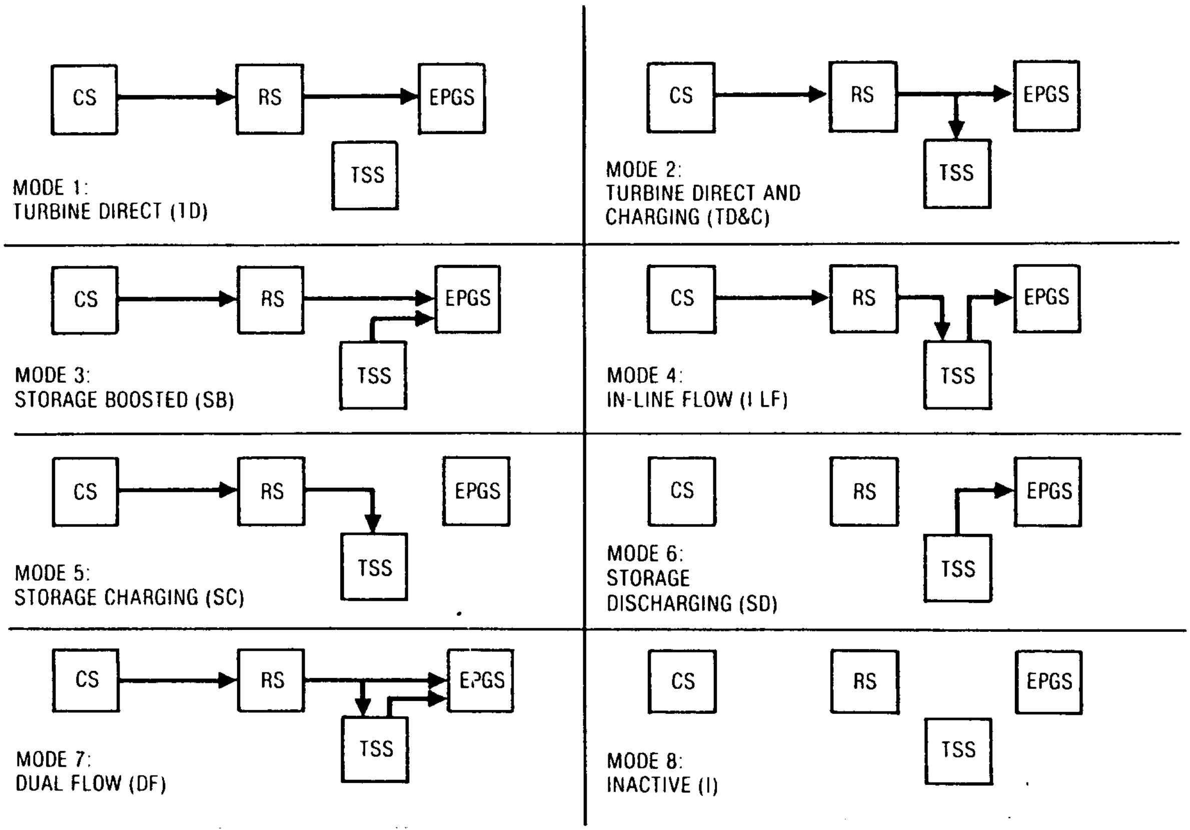


Figure 6. Pilot Plant Steady State Operating Modes (Ref. 1)

As the many parameters used to design the plant were compared to the actual operating conditions obtained in readying the plant for maximum power production for the 1984 summer solstice test, it became apparent that the design goal would not be met; and a secondary goal of the test was soon adopted: to produce as much power and energy as possible on all days of good insolation and to obtain the data necessary to scale up actual test results to determine where the inefficiencies in the system were located and the causes of those inefficiencies. Again, it must be kept in mind that some of the efficiency factors might be improved by further engineering study and design, some are the results of nature and have little promise of improvement, and some are a combination of the two effects and show promise for some, though not complete, improvement.

This report presents the actual operating parameters and results of the test, compares that data to original design parameters, and attempts to provide explanations for the differences. Suggestions are included for improving the efficiency of the various components in the system, thereby improving the power production capability of the system as a whole. Also presented are suggestions for further studies at Solar One. Timelines and descriptions of activities carried out in preparing for and conducting the 1984 summer solstice test and a suggested schedule for subsequent solstice tests can be found in Appendixes A and B.

Preparation for the Summer Solstice Test

Preparations for the 1984 summer solstice power production test were coordinated by Sandia Laboratories (SNLL) and began two months prior to the test with a campaign kickoff meeting at the pilot plant site including representatives from Southern California Edison (SCE), McDonnell Douglas Astronautics Company (MDAC), Department of Energy (DOE/SAN), and SNLL. The many tasks which needed to be performed in preparation for the test were discussed and responsibilities assigned. Key tasks are listed here and discussed in detail in subsequent sections of this report as well as in Appendix A.

1. Getting as many heliostats on line as possible,

2. Washing the heliostats,

3. Optimizing heliostat beam pointing accuracies,

4. Determining specific test parameters and data acquisition requirements, and

5. Performing maintenance to bring all components of the system to peak efficiency.

Figure 7 illustrates heliostat availability data for the 15 days of the solstice test, and Figure 8 gives collector field reflectivity and cleanness data for the same period. The design point collector field reflectivity value of 0.89 allows for a slight degradation from the field average clean reflectivity of 0.906 which represents an area weighted average for the mixture of low and high iron (glass) heliostats used in the pilot plant's collector field (Ref. 1 and 2). The 0.906 reflectivity figure corresponds to a collector field that is 100% clean; whereas the design point reflectivity of 0.89 corresponds to a collector field that is 98% clean.

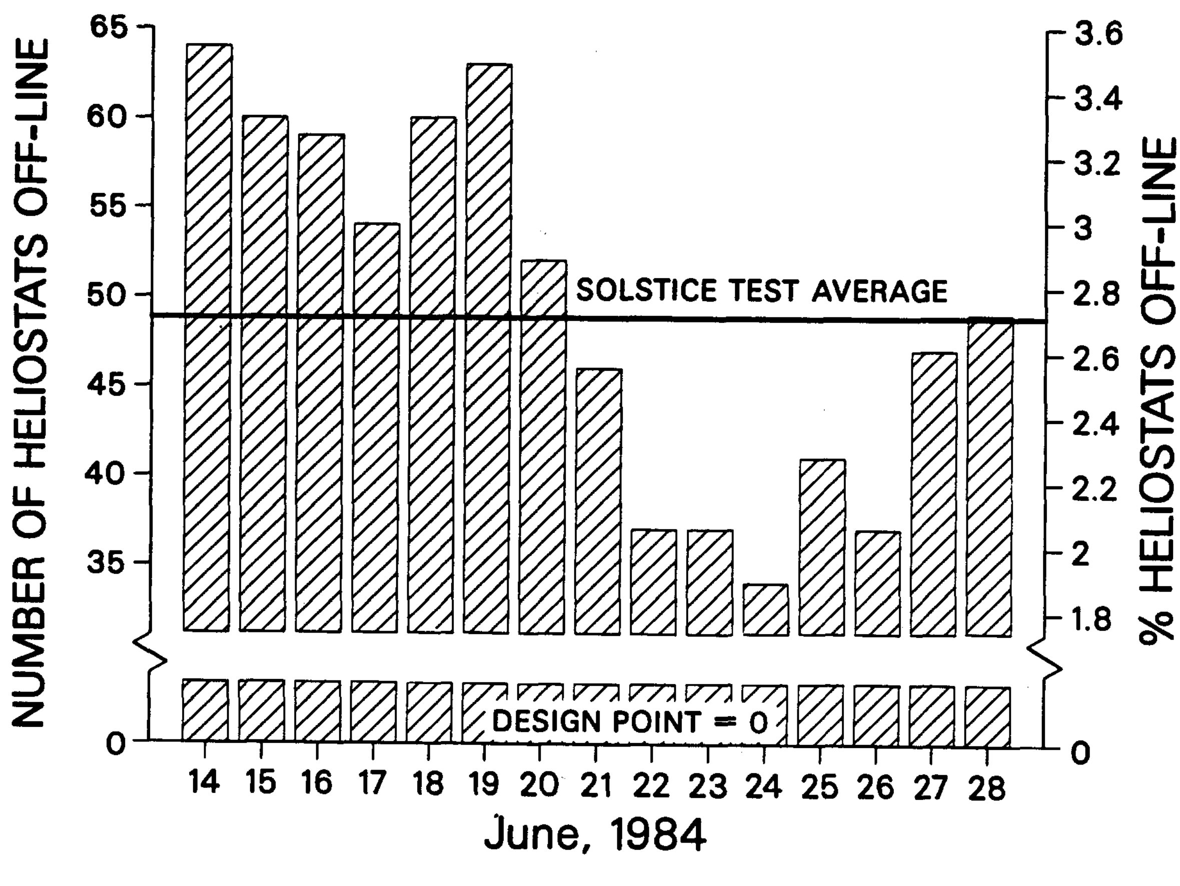


Figure 7. Heliostat Availability
June 14-28, 1984

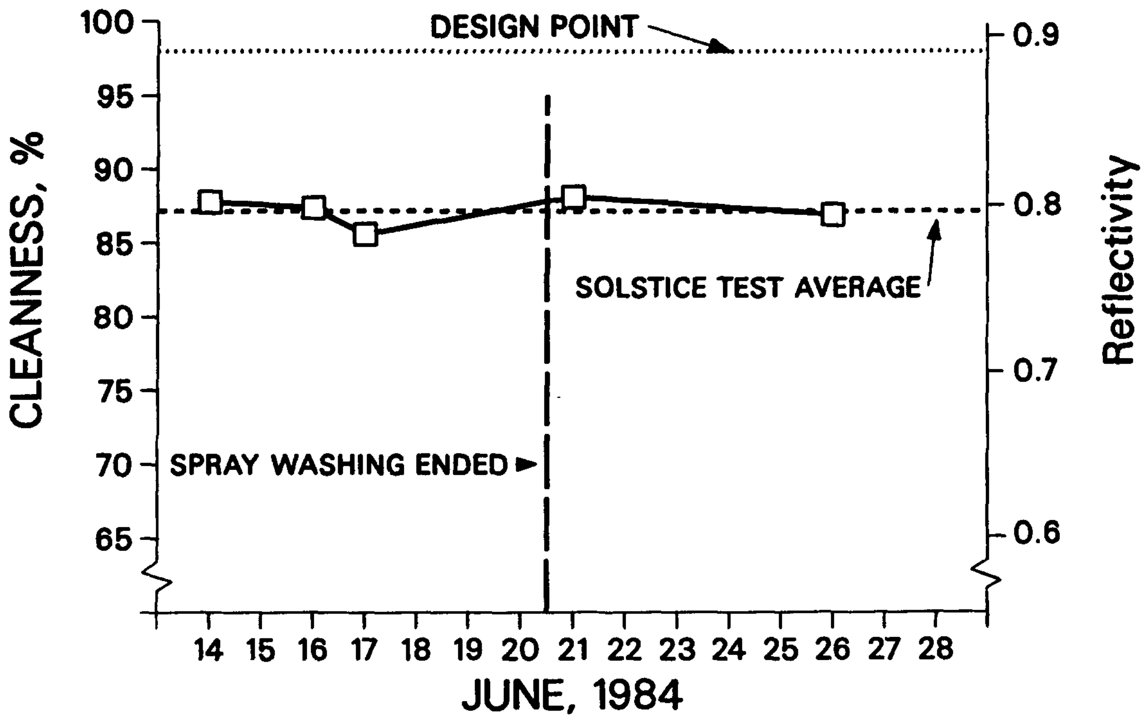


Figure 8. Collector Field Reflectivity & Cleanness
June 14-28, 1984

The receiver system was designed to operate at a receiver set point (or outlet) temperature of 950°F (Ref. 1). However, due to concerns about extreme thermal stresses and leakage in the receiver tubes, normal plant operations in 1984 were carried out at 775°F receiver set point. For the 1984 summer solstice test, the decision was made that on the days of good weather, comparatively high insolation levels, and general plant readiness, the receiver set point temperature would be raised to 850°F to increase system output. (Inspection of the receiver tubes at the end of each day revealed no apparent harm to the tubes from operation at the higher temperature.)

A "Solstice Test Preparation Timeline" is included in Appendix A of this report, as is a list of "Tasks and Responsibilities During Actual Test Days." The preparation timeline covers the two months prior to the test; however, for future tests, any tasks which may require purchase orders or contracting to outside firms (such as heliostat washing, wash/brush truck repair, or stocking spare parts for the collector field, piping, valves, etc.) should be initiated in ample time to assure their completion before test time.

Appendix B presents a suggested schedule that might be helpful in planning and conducting future solstice tests. The schedule draws a great deal upon the experience gained in the 1984 summer solstice test.

Analysis of Test Results

As shown previously in Table I, June 21st was the best energy production day during the 1984 summer solstice test period. In this section of the report, the test results of June 21, 1984, will be compared with corresponding original design parameters of the pilot plant. The reduced efficiencies in the system on June 21, 1984, will be analyzed and suggestions made of ways to increase those efficiencies, thus increasing overall plant performance.

Design day parameters at solar noon (12.4 MWe peak power output) will be compared to actual test results at 13:12 Pacific Daylight Time (PDT) on June 21, 1984, (9.72 MWe peak power output) by use of "waterfall efficiency charts" for each of the two days. Figure 9 is the pilot plant's "Design Day Waterfall Efficiency Chart" (Ref. 2). At the top (left) of the chart, the total power available to the heliostat collector field is shown; then each subsequent bar on the chart depicts the power output resulting after the specified corresponding efficiency factor is applied. The net power output after all efficiency factors have been applied is shown at the bottom (right) of the chart. In the following sections of this report, each of the corresponding bars, or steps, for 13:12 PDT, June 21, 1984, will be determined and compared to design day (or design point) values. A waterfall efficiency chart for 13:12 PDT, June 21, 1984, will then be constructed and compared to the design day chart.

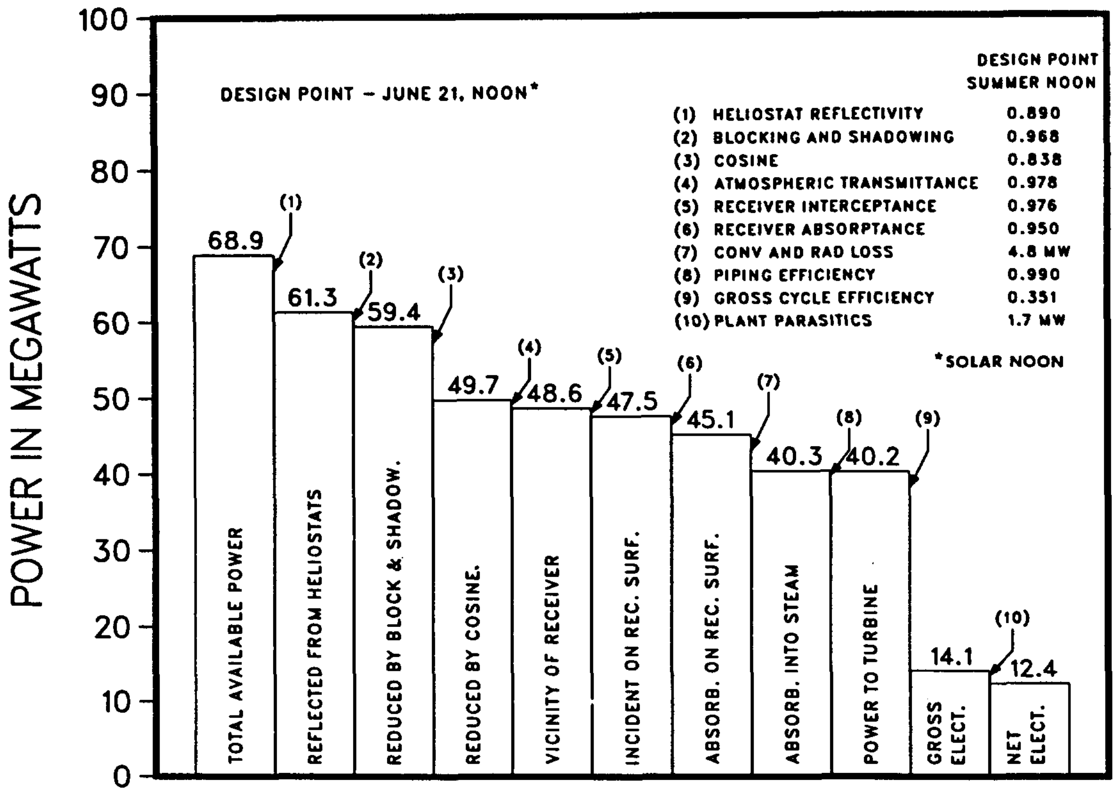


Figure 9. Solar One Mode 1 Summer Noon
Best Design Day Waterfall Efficiency Chart

Power plant data needed in the following analysis was collected by the Data Acquisition System (DAS) during the 1984 summer solstice test. This data is presented here in graph form (Figure 10) and tabular form (Table IV). Figure 10, a graph of gross power output, net power output, plant parasitic load, insolation, and receiver outlet temperature for June 21, 1984, was obtained by using the McDonnell Douglas Astronautics Company P210 computer program to plot the DAS data. Both the graph and the table have been simplified somewhat for purposes of clarity. The original graph and table are shown in Appendix D.

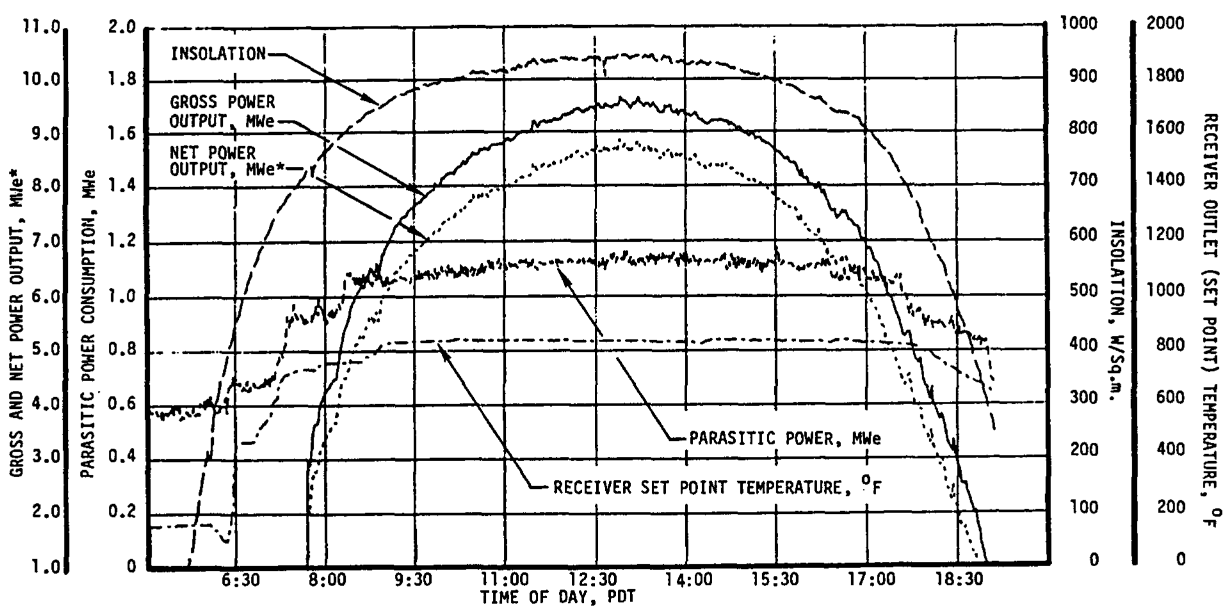


Figure 10. Gross Power Output,
Net Power Output,
Plant Parasitic Power Load,
Insolation,
& Receiver Outlet Temperature,
vs. Time of Day, June 21, 1984

TABLE IV

DATA OUTPUT AT 13:12 PDT, JUNE 21, 1984

DATA TITLE	DATA VALUE
Gross Power Output	9720.0 KWe
Net Power Output	8586.8 KWe
Plant (Parasitic) Load	1128.4 KWe
Insolation	0.94442 KW/sq m
Receiver Outlet Temperature	835.5^{o}F
Receiver Inlet Temperature	368.5^{o}F
Receiver Inlet Pressure	1597.5 psig
Receiver Mass Flow Rate	99.56248 Klb/hr
Receiver Outlet (Downcomer) Pressure	1346.0 psig

"Total Available Power"

P(Tot) = (Insolation)(No. Heliostats)(Individual Heliostat Area)

= (0.94442 KWt/sq m)(1772 Heliostats)(39.1272 sq m/Heliostat)

P(Tot) = 65.48 MWt

This total available power, 65.48 MWt, is less than design point total available power (i.e. 68.9 MWt) by 3.42 MWt or 5%. Three reasons for this drop in available power are

1. The 944 W/sq m insolation at 13:12 PDT, June 21, 1984, was 4.8% lower than it was at design point, 992 W/sq m, in 1976. (See Figure 11.)

2. Design point assumes all 1818 heliostats are on line; whereas on June 21, 1984, only 1772 were on line, a drop of 2.5%.

3. The reflective area of an individual heliostat at design point was specified to be 39.59 sq m (Ref. 2); whereas edge seals added around the outer perimeters of the heliostat modules late in the heliostat design reduced the actual reflective area to 39.1272 sq m per heliostat, a decrease of 1.2%. (Note: some variation exists in the specified design point individual

heliostat reflective area. Ref 3. states a "nominal" reflector area of 38.48 sq m or 425 sq ft, and Ref. 4 gives 39.9 sq m or 430 sq ft. These discrepancies appear to be the result of rounding off numbers when converting units and supplier provided data that changed in the course of heliostat manufacture. All of the figures are within 1% of each other.)

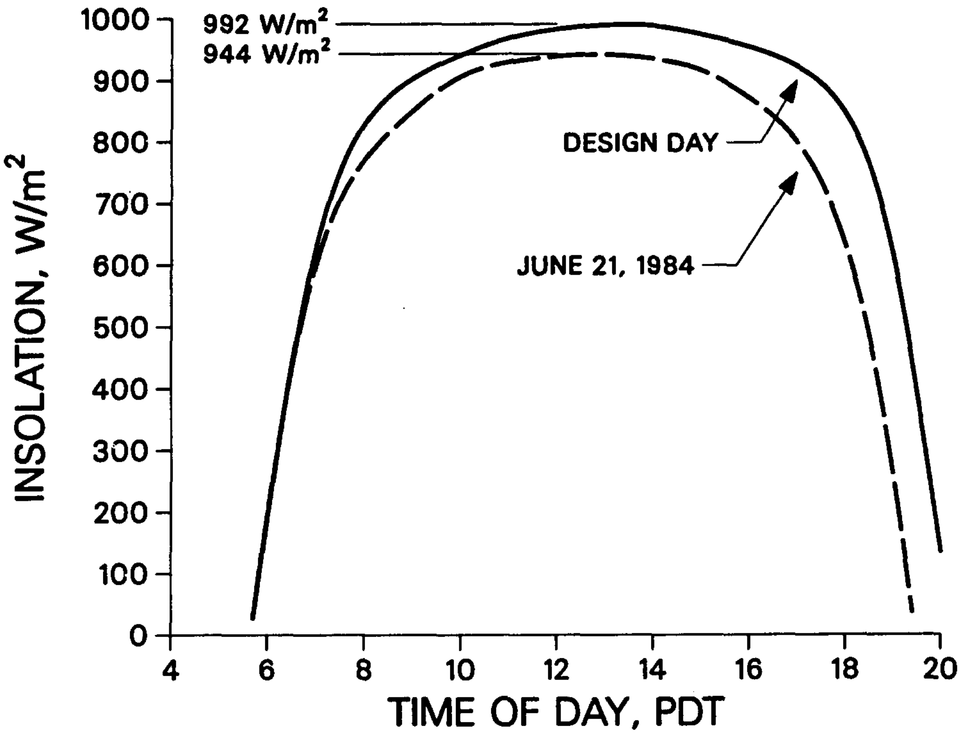


Figure 11. Insolation vs. Time of Day
Design Point & June 21, 1984

The accuracy of the total available power calculation, P(Tot), is somewhat questionable for two reasons.

1. The pyrheliometer, which measures insolation levels, has a collective cone angle of about six degrees while the receiver is much smaller than six degrees as seen from any of the heliostats. The power available as measured by the pyroheliometer could be high by some unknown amount.

2. Subsequent to the 1984 summer solstice test period, the pilot plant's two normal incident pyrheliometers were compared to a working standard absolute cavity pyrheliometer and were found to be (reading) 2 and 4% low (Ref. 5).

Further study on the accuracy of insolation measurements by this method is recommended in order to improve confidence in total available power calculations.

Power "Reflected from Heliostats"

P(ReflHelio) = [P(Tot)] [Heliostat Reflectivity]

Heliostat (field) reflectivity for June 21, 1984, was measured with a portable reflectometer to be 0.803. This reflectivity is 9.8% less than the design point field reflectivity of 0.89 specified by the Department of Energy (Ref. 1).

Two observations indicate that the actual field reflectivity may have been even less than 0.803 on June 21, 1984:

1. Reflectivity measurements had been taken at the same spots on the same heliostats five times during the two weeks prior to June 21st, the collective action of which may have wiped those spots cleaner than the remaining "untouched" heliostats.

2. Recent farming activity, dust storms, and ineffective washing methods had left the heliostat reflective surfaces extremely dirty (see Figure 12).

However, with present reflectivity measuring procedures:

P(ReflHelio) = (65.48 MWt)(0.803)

= 52.58 MWt

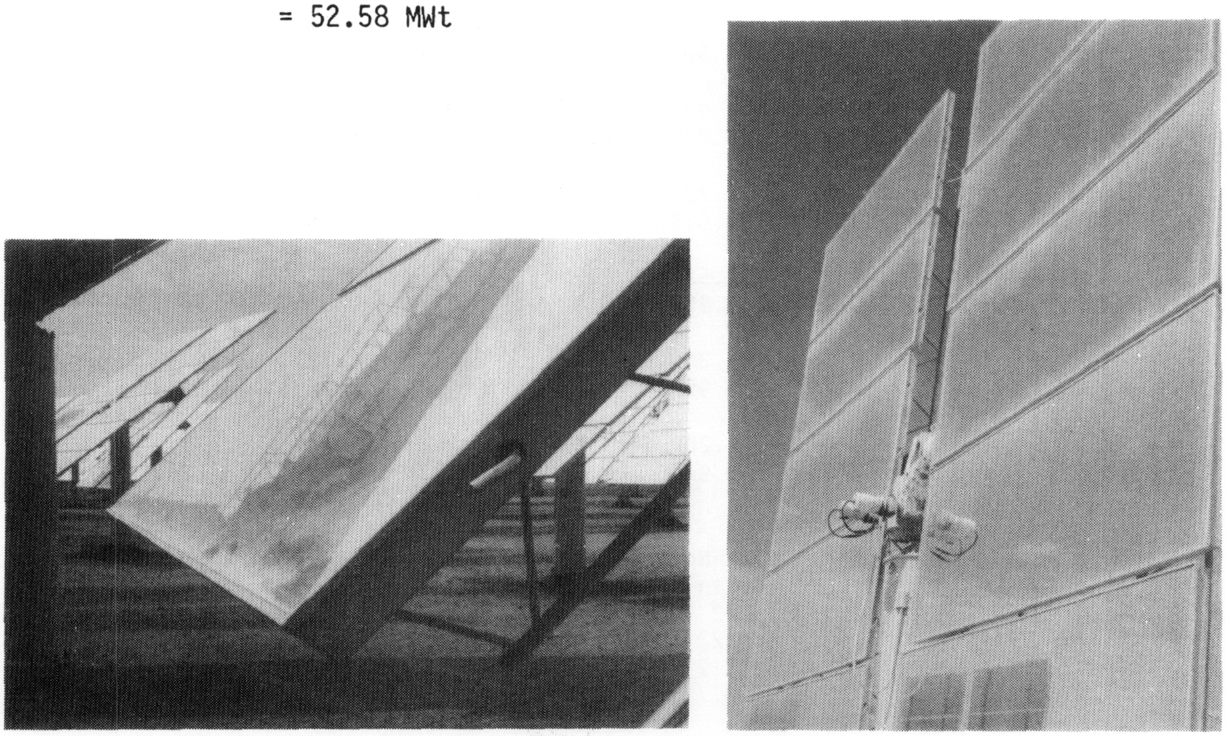


Figure 12. Soiled Heliostats at Solar One

Power "Reduced by Blocking and Shadowing"

$$P(RedB\&S) = [P(ReflHelio)]\begin{bmatrix}\text{Field Average Blocking}\\ \text{\& Shadowing Factor}\end{bmatrix}$$

Referring to Collector Field Average Blocking & Shadowing Performance Factors (U of H, 1981) (Ref. 2) reproduced in Table V, the blocking & shadowing factor for June 21 at 13:12 PDT (Day = 93. Solar noon occurred at 12:49; therefore Hour = 23 minutes, or 0.38 hour, after solar noon) is 0.968, the same as design point. Therefore

$$P(RedB\&S) = (52.58MWt)(0.968)$$

$$= 50.90\ MWt$$

TABLE V

COLLECTOR FIELD AVERAGE BLOCKING AND SHADOWING PERFORMANCE FACTORS
(PREPARED BY THE UNIVERSITY OF HOUSTON, NOVEMBER, 1981)

		(Solar Noon)						(10^{0} Sun Elev)
	Hour =	0.	1.05	2.09	3.14	4.18	5.23	6.28
Day =	93	0.9682	0.9670	0.9682	0.9726	0.9705	0.9190	0.7341
	Hour =	0.	1.02	2.04	3.06	4.07	5.09	6.11
Day =	124	0.9674	0.9667	0.9682	0.9723	0.9698	0.9187	0.7288
	Hour =	0.	0.95	1.90	2.85	3.81	4.76	5.71
Day =	155	0.9664	0.9668	0.9688	0.9714	0.9665	0.9123	0.7245
	Hour =	0.	0.86	1.72	2.59	3.45	4.31	5.17
Day =	186	0.9680	0.9684	0.9695	0.9694	0.9569	0.8951	0.7113
	Hour =	0.	0.77	1.53	2.30	3.06	3.83	4.60
Day =	216	0.9683	0.9683	0.9675	0.9619	0.9376	0.8690	0.7001
	Hour =	0.	0.68	1.36	2.04	2.71	3.39	4.07
Day =	246	0.9631	0.9616	0.9558	0.9418	0.9083	0.8375	0.6953
	Hour =	0.	0.64	1.28	1.92	2.56	3.20	3.85
Day =	276	0.9564	0.9541	0.9460	0.9288	0.8925	0.8240	0.6883

Legend: "Hour" - Hours from Solar Noon (appropriate to morning or afternoon)
Day 93 - June 21 (summer solstice)
124 - May 21 or July 22
155 - April 20 or Aug 22
186 - March 20 or Sept 22 (equinox)
216 - Feb 18 or Oct 22
246 - Jan 19 or Nov 21
276 - Dec 21 (winter solstice)

Power "Reduced by Cosine"

Power(RedCos) = [P(RedB&S)] [Field Average Cosine Factor]

From the Field Average Cosine Performance Factors (U of H, 1981) (Ref. 2) given below in Table VI, again at Day = 93 and Hour = .38, the cosine factor is 0.835. Therefore

P(RedCos) = (50.90 MWt)(0.835)

= 42.50 MWt

TABLE VI

COLLECTOR FIELD AVERAGE COSINE PERFORMANCE FACTORS
(PREPARED BY THE UNIVERSITY OF HOUSTON, NOVEMBER, 1981)

		(Solar Noon)						(10^o Sun Elev)
	Hour =	0.	1.05	2.09	3.14	4.18	5.23	6.28
Day =	93	0.8376	0.8315	0.8134	0.7842	0.7451	0.6978	0.6451
	Hour =	0.	1.02	2.04	3.06	4.07	5.09	6.11
Day =	124	0.8406	0.8346	0.8172	0.7888	0.7506	0.7043	0.6524
	Hour =	0.	0.95	1.90	2.85	3.81	4.76	5.71
Day =	155	0.8455	0.8401	0.8242	0.7983	0.7632	0.7203	0.6714
	Hour =	0.	0.86	1.72	2.59	3.45	4.31	5.17
Day =	186	0.8463	0.8418	0.8284	0.8065	0.7767	0.7399	0.6974
	Hour =	0.	0.77	1.53	2.30	3.06	3.83	4.60
Day =	216	0.8409	0.8374	0.8269	0.8098	0.7863	0.7570	0.7229
	Hour =	0.	0.68	1.36	2.04	2.71	3.39	4.07
Day =	246	0.8327	0.8300	0.8221	0.8090	0.7910	0.7685	0.7420
	Hour =	0.	0.64	1.28	1.92	2.56	3.20	3.85
Day =	276	0.8288	0.8264	0.8195	0.8080	0.7922	0.7724	0.7489

Legend: "Hours" - Hours from Solar Noon (appropriate to morning or afternoon)
Day 93 - June 21 (summer solstice)
124 - May 21 or July 22
155 - April 20 or Aug 22
186 - March 20 or Sept 22 (equinox)
216 - Feb 18 or Oct 22
246 - Jan 19 or Nov 21
276 - Dec 21 (winter solstice)

Power "Vicinity of Receiver"

P(VicR) = [P(RedCos)] [Atmospheric Transmittance]

The design point atmospheric transmittance of 0.978 "was analytically based on assumptions for water vapor and aerosols consistent with a dry desert environment. No attempt was made during the plant design activities to include values as a function of time of day or season." (Ref. 2) Observations at the Solar One pilot plant and the surrounding area during June, 1984, indicate that the atmospheric transmittance factor is somewhat optimistic. Two main factors lead to this conclusion:

1. Prevailing winds and farming activity in the area cause dust to be suspended in the air, and

2. Readily visible smog enters the Barstow area from the Los Angeles basin during the summer months.

A nephelometer (mounted about 125 feet up on the receiver tower) which indicates the degree of smog and ground haze, recorded a visibility of 31 miles at test time. This is at the lower limit of "typical desert conditions (31 to 75 miles visibility)" (Ref. 6). A 1981 study by Pitman and Vant-Hull of the University of Houston predicts annual field average percent energy loss at Solar One due to atmospheric conditions to be about 2.8% (i.e., atmospheric transmittance = 0.972) at visual ranges between 25 to 37 miles (Ref. 7). This represents a less than 0.6% decrease over design point atmospheric transmittance of 0.978.

Solar Energy Research Institute (SERI) conducted a study of spectral characteristics of the atmosphere at Solar One in August, 1984, which should provide even more site-specific data (Ref. 8). Until that data is available, this report will use the most recent U of H figure of 0.972. Therefore

P(VicR) = (42.50 MWt)(0.972)

= 41.31 MWt

Power "Incident on Receiver Surface"

P(IncRS) = [P(VicR)] [Receiver Interceptance]

Moving on to the next bar on the waterfall efficiency chart, the receiver interceptance (or spillage) factor comes into effect. This factor is based on heliostat beam quality and pointing accuracy.

Recent studies (Ref. 9), plus a concerted effort to optimize the collector field pointing accuracy prior to the solstice test with the Beam Characterization System (BCS), indicate that the design point receiver interceptance factor of 0.976 is still valid. Figure 13 is a graph of calculated receiver spillage for three different circumsolar ratios and shows that for insolation levels well above 900 W/sq m the receiver spillage will be less that two percent. (The circumsolar ratio referred to on the x-axis of the graph is the fraction of the sun's energy outside of the solar disc. The solar disc is the angle defined by the diameter of the sun if it could be observed from earth through an absolutely clear atmosphere; i.e., no effects of atmospheric scatter.) Because the circumsolar ratio was not measured during the 1984 summer solstice test period, it is assumed to have been below 0.029 since the insolation was above 938 W/sq m. Therefore the receiver interceptance (or spillage) was less than two percent.

$$P(IncRS) = (41.31\ MWt)(0.976)$$

$$= 40.32\ MWt$$

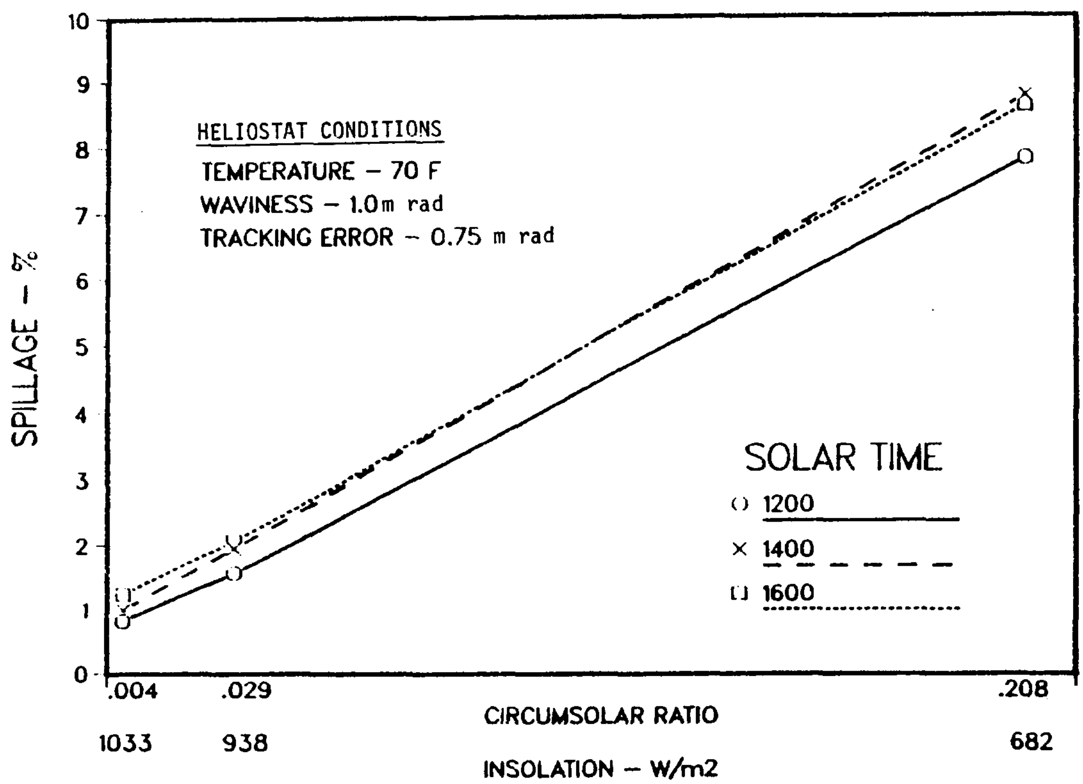


Figure 13. Pilot Plant Collector System Performance (Ref. 8)

Power "Absorbed on Receiver Surface"

P(AbsRS) =[P(IncRS)][Receiver Absorptance]

Design point receiver absorptance (or absorptivity) for "new" Pyromark paint used on the receiver was determined to be 0.95. However, subsequent absorptivity tests on the Barstow receiver have resulted in an absorptivity determination for June 21, 1984, of 0.891 (Appendix E). This 6.2% reduction is due mainly to two factors

1. A layer of dust has collected on the receiver surface from farming activity and wind/dust storms common to the Barstow area, and

2. The Pyromark paint itself has degraded over the three years since it was cured following application.

P(AbsRS) = (40.32 MWt)(0.891)

= 35.93 MWt

Power "Absorbed into Steam"

P(AbsIS) = P(AbsRS) - (Convection + Radiation Losses)

At design point receiver steam conditions of 950^{o}F and 1450 psi, convection + radiation losses were originally calculated to be 4.8 MWt (Ref. 10). Using a SNLL computer code for calculating convection and radiation losses at the Barstow plant (Ref. 11), M. C. Stoddard, SNLL, determined convection and radiation losses for plant conditions on June 21, 1984, at 13:12 PDT to be

Conv + Rad Losses = 1.56 MWt + 1.79 MWt

= 3.35 MWt

This represents an improvement in plant efficiency relative to design point of 1.45 MWt (or 2.1%).

MDAC's "Mode 1 (1110) Test Report" (Ref. 2) predicts an even lower estimated convection + radiation loss (i.e., 1.97 MWt). Although this loss was determined by earlier actual plant testing at 830-860^{o}F and 1450 psi, wind speeds were less than 10 mph and other plant conditions were somewhat different from solstice test conditions. Wind speed at 13:12 PDT on June 21, 1984, was measured to be 14.5 mph. (Note: In explaining why plant operation at reduced steam pressure and temperature conditions is preferred, the MDAC report states that performance improvements associated with off design operating conditions are due to several factors including reduced receiver heat losses resulting from lower receiver operating temperature.)

In an ongoing study by A. F. Baker, SNLL, at Solar One between 1982 and 1984 (Ref. 12) using experimental methods similar to those described in the MDAC report, 180 experimental samples at 825-850^{0}F, 1300-1700 psi, solar time between 10:00 and 14:00, and wind speeds of 1-10 mph, resulted in convection + radiation losses of 6.08 +.89 MWt; and 245 samples at 0-25 mph resulted in convection + radiation losses of 6.28 +1.02 MWt.

The differences in all of these convection + radiation loss determinations appear to be a result of the various conditions and/or assumptions of conditions at the pilot plant (i.e., heliostat reflective area, insolation, reflectivity, atmospheric attenuation, etc.) at the specific time the determinations were made. A more detailed study comparing these three convection + radiation loss determinations might help to clarify and narrow their differences.

Using the Stoddard calculations at 14.5 mph wind speed and other plant conditions specifically measured at 13:12 PDT on June 21, 1984:

P(AbsIS) = 35.93 MWt - 3.35MWt

= 32.58 MWt

Power "Absorbed into Steam" can also be determined by using "Steam Tables" (Ref. 13) and actual receiver steam conditions recorded by the DAS at the time of solstice test peak power output.

Data from DAS:

T(In) = 368.5^{0}F T(Out) = 835.5^{0}F
P(In) = 1611.2 psia* P(Out) = 1359.7 psia*
m(In) = m(Out) = 99.562 Klb/hr
*Atmospheric pressure at Barstow, CA = 13.7 psi

At these conditions,

P(AbsIS) = 30.67 MWt

The difference between the two just determined Power "Absorbed into Steam" figures (32.58 MWt - 30.67 MWt = 1.91 MWt) is less than 3% of the

"Total Available Power" and could be considered well within acceptable tolerances for an anaylsis of this magnitude. However, given all of the potential inaccuracies (from accumulated allowable tolerances and/or uncertain assumptions) in determining the Power "Absorbed into Steam" value of 32.58 MWt obtained by working down the waterfall efficiency chart from the "Total Available Power" level to the Power "Absorbed into Steam" level, the latter determination of Power "Absorbed into Steam", 30.67 MWt, is assumed to be the more accurate. Its accuracy is based only on having measured receiver inlet and outlet temperatures and pressures, and mass flow rate correctly. Therefore, the 30.67 MWt figure will be used in the remainder of this analysis.

<u>"Power to Turbine"</u>

P(to Turb) = [P(AbsIS)][Piping Efficiency]

Moving downward from the "Power Absorbed into Steam" level on the solstice test waterfall efficiency chart, the "Power to Turbine" can be calculated. As Figure 14 shows, during the 1984 summer solstice test there were areas in the piping and insulation system which were contributing to a decreased piping efficiency. Several valves were also observed to be leaking slightly. Weighing these observed deficiencies against the size of the total plant piping system, and in the absence of any site-specific piping heat loss studies, it is difficult at this time to justify a piping efficiency lower than design point. Therefore the design point piping efficiency of 0.99 will be used although it may be too large a value for actual pilot plant conditions.

P(to Turb) = (30.67 MWt)(0.99)

= 30.36 MWt

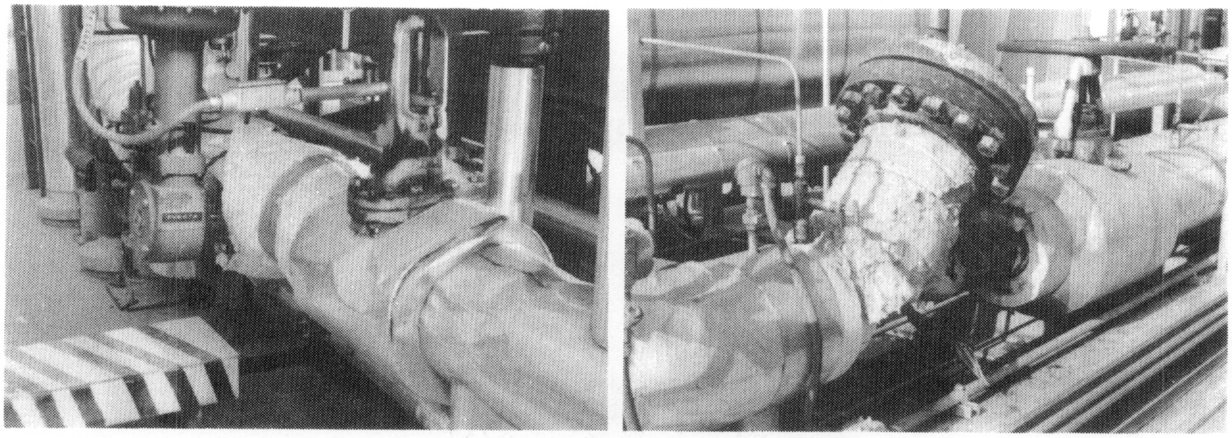


Figure 14. Solar One Piping System Heat Loss Areas

"Gross Electrical Output"

Peak gross electrical power output generated on June 21, 1984, at 13:12 PDT was measured to be 9.72 MWe (see Table I). The gross cycle efficiency can now be calculated.

$$\text{Gross Cycle Efficiency} = \frac{\text{Gross Electrical Output}}{\text{Power to Turbine}}$$

$$= \frac{9.72 \text{ MWe}}{30.36 \text{ MWt}}$$

$$= 0.320$$

This actual gross cycle efficiency is down 8.8% from design point gross cycle efficiency of 0.351. However, the 0.320 figure is verified by earlier experimental testing at Solar One by MDAC in 1983 which is reported in MDAC's "Mode 1 (1110) Test Report" (Ref. 2). To compare solstice test Gross Cycle Efficiency to efficiencies obtained by MDAC in 1983, the Gross Heat Rate must be calculated. (Gross Cycle Efficiency is directly proportional to the inverse of Gross Heat Rate.)

$$\text{Gross Heat Rate} = \frac{\text{Power Absorbed by Receiver (Btu/hr)}}{\text{Gross Electric Power (KW)}}$$

where Power Absorbed by Receiver is Power "Absorbed into Steam" from page   of this report (i.e., 30.67 MWt or 104.7 x 10(6) BTU/hr).

$$\underset{\text{(1984 solstice test)}}{\text{Gross Heat Rate}} = \frac{104.7 \times 10(6) \text{ BTU/hr}}{9.72 \times 10(3) \text{ KW}}$$

$$= 10772 \text{ Btu/KWhr}$$

Comparing solstice test gross heat rate with MDAC 1983 plant performance data as shown in Figure 15, it can be seen that the gross heat rates, and thus the gross cycle efficiencies, correlate very closely.

It is also interesting to note that the same report concludes "that for power levels less than approximately 5 MW, virtually no difference exists in the heat rates (and thus the gross cycle efficiencies) experienced for the high (930-960^{o}F) and the low (730-760^{o}F) steam temperature. At higher power levels, the (MDAC test) data indicate that the hot steam case (930-960^{o}F) is only marginally better than the low temperature case (730-760^{o}F)." In other words, operating the 1984 solstice test at receiver set point temperature of 850°F instead of design point of 960°F had little effect on gross cycle efficiency.

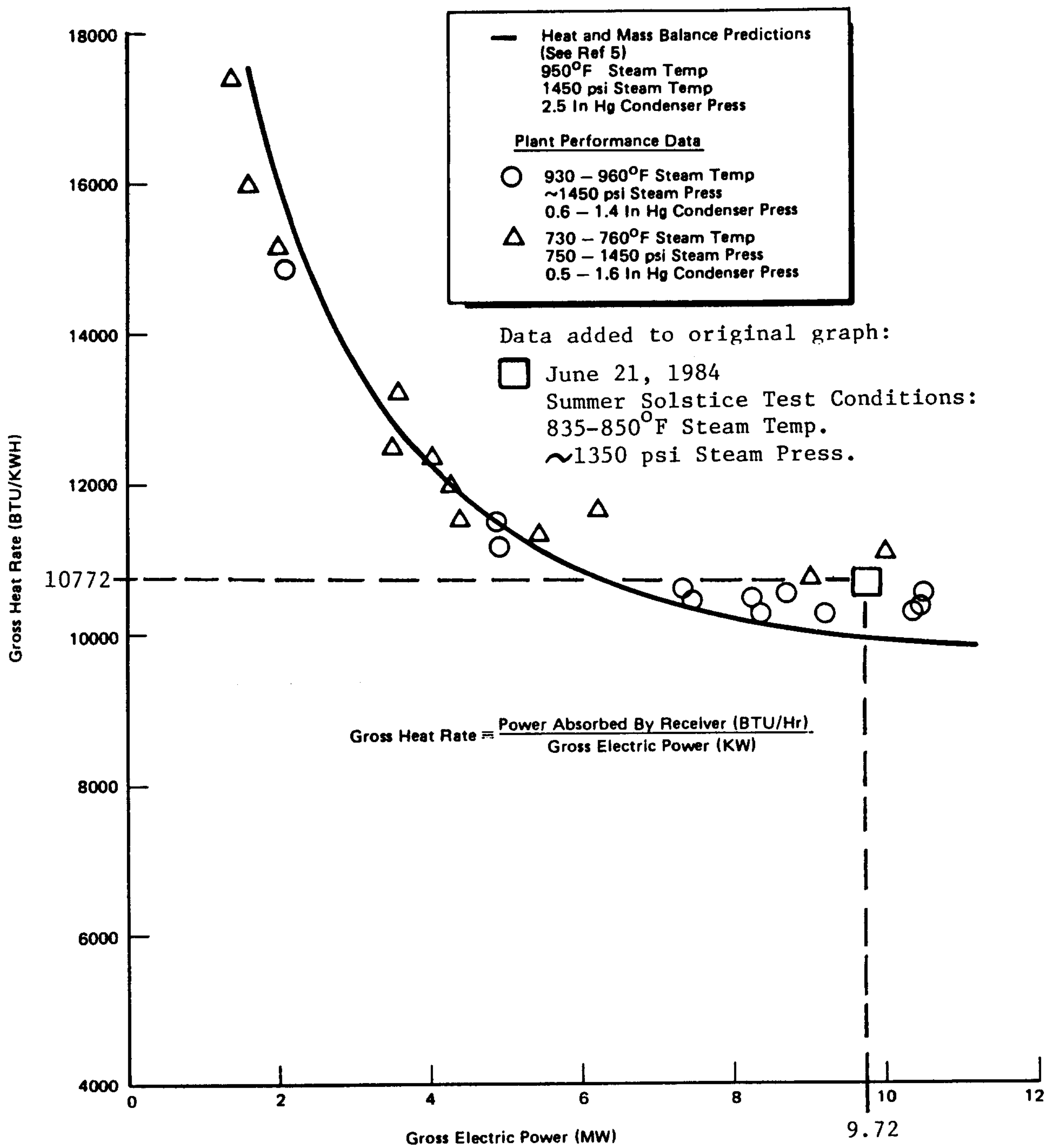


Figure 15. Gross Heat Rate for Water/Steam Cycle Portion of Plant (Ref. 2)

"Net Electrical Power Output"

Net Electrical Power Output =

Gross Electrical Power Output - Plant Parasitics

Plant parasitic (or auxiliary) power usage at point of peak power output on June 21, 1984, was recorded to be 1.13 MWe. Design point parasitic power usage was 1.7 MWe. (Ref. 1) Therefore parasitic power consumption by Solar One during the 1984 summer solstice test was actually lower than was assumed when the plant was designed. This 0.57 MWe difference (equivalent to 1.78 MWt for the pilot plant with a gross cycle efficiency of .320) represents a 2.7% increase in total plant efficiency. Two explanations for this reduced parasitic power consumption may be

1. When the pilot plant was designed, all electrical equipment that might be operating simultaneously was identified and resultant parasitic power consumption determined. In actual service, all of that equipment may not be operating simultaneously.

2. The solstice test was run at 850°F receiver set point temperature and a pressure of 1350 psi instead of design point of 950°F and 1450 psi. Along with the reduced receiver heat losses previously mentioned on page , another effect resulting from operating the system at reduced steam temperature and pressure conditions is "lower parasitic power demands associated with lower pressure operations" (Ref. 2).

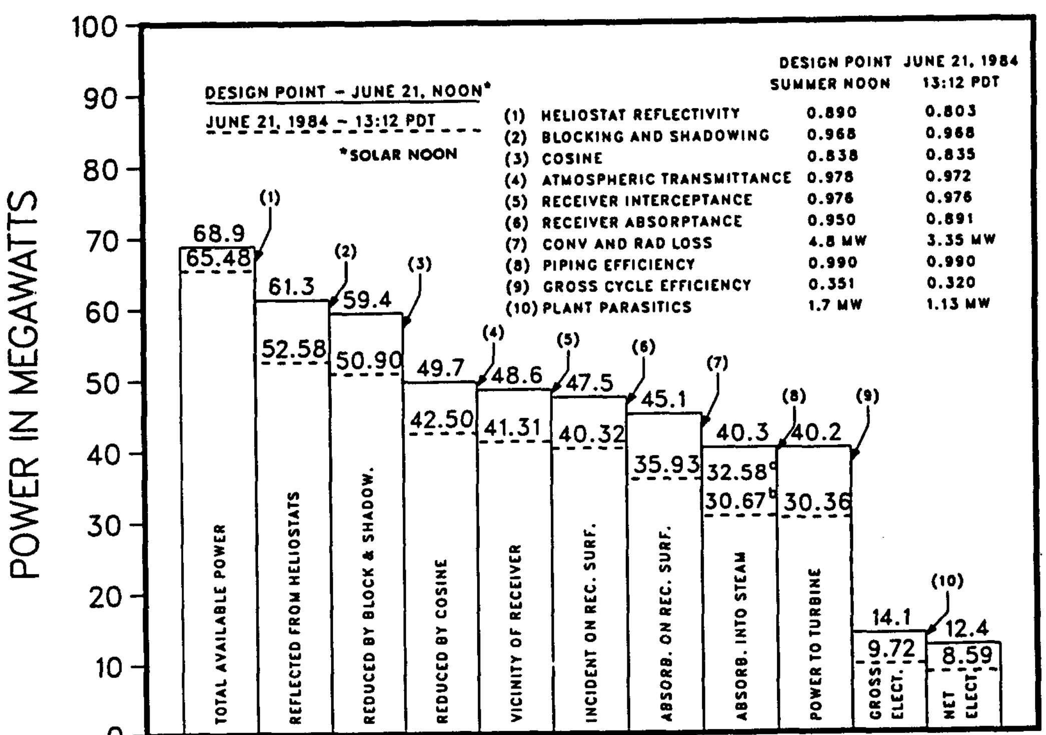
Net Electrical Power Output = 9.72 MWe - 1.13 MWe

= 8.59 MWe

Summary of Results

A waterfall efficiency chart for 13:12 PDT, June 21, 1984, can now be constructed, and is shown in Figure 16 superimposed on the design day waterfall efficiency chart.

Table VII compares the efficiency factors for the two days. It arranges the June 21, 1984, efficiency factors in order of decreasing effect on reducing total system output and efficiency. As can be seen, the factors that had the greatest effect on reducing Solar One's peak power production 30.7% below design point are heliostat reflectivity (-9.8%), gross (turbine) cycle efficiency (-8.8%), receiver absorptivity (-6.2%), insolation (-4.8%), and heliostats on line (-2.5%). As stated in the introduction of this report, at the Solar One Pilot Plant, some of the efficiency factors might be improved by further engineering study and design (i.e., turbine cycle efficiency, heliostat availability), some are the result of nature and have little promise of improvement (insolation levels, atmospheric transmittance), and some are a combination of the two effects and show promise for some improvement, though not 100% (heliostat reflectivity, convection and radiation losses).



a – Obtained by quantifying all previous steps on Waterfall Efficiency Chart

b – Determined using measured receiver steam inlet and outlet conditions and 'Steam Tables' (Ref. 13); more accurate figure

Figure 16. Solar One Waterfall Efficiency Charts Summer Noon Best Design Day and 13:12 PDT, June 21, 1984

TABLE VII. SOLAR ONE EFFICIENCY FACTORS

SUMMER NOON BEST DESIGN DAY vs. 13:12 PDT, JUNE 21, 1984

Efficiency Factor	Design Point	13:12 PDT, June 21, 1984	Change
Heliostat Reflectivity	0.89	0.803	-9.8%
Gross (Turbine) Cycle Efficiency	0.351	0.320	-8.8%
Receiver Absorptance	0.950	0.891	-6.2%
Insolation*	992 W/sq m	944 W/sq m	-4.8%
Heliostats On Line*	1818	1772	-2.5%
Individual Heliostat Reflective Area*	39.59 sq m	39.1272 sq m	-1.2%
Atmospheric Transmittance	0.978	0.972	-0.6%
Field Average Cosine Factor	0.838	0.835	-0.4%
Field Average Blocking & Shadowing Factor	0.968	0.968	0
Receiver Interceptance	0.976	0.976	0
Piping Efficiency	0.990	0.990	0
Convection & Radiation Losses	4.8 MWt	3.35 MWt	+1.45 MWt
Plant Parasitics	1.7 MWe	1.13 MWe	+0.57 MWe (= +1.78 MWt)

*Affects "Total Available Power" determination; not shown in waterfall chart efficiency factor listings.

In summary, the results of the 1984 summer solstice test indicate that the 10 MWe Solar Thermal Central Receiver Pilot Plant at Barstow was producing power at 30.7% below design point at midday and producing energy at 33% below maximum estimated daily energy, on the best day of the solstice test period. This type of relationship (where the drop in peak power, 30.7%, is somewhat less than the drop in total energy for the day, 33%) would be expected because convection and radiation losses and parasitic power losses are actually fixed numerical losses as opposed to fixed percentage losses. Therefore they become a larger percentage factor as the power level falls away from the peak midday value (Ref. 14).

Conclusions and Recommendations

Heliostat and Receiver Washing

Dust and other matter which have adhered to the surfaces of the heliostats and the receiver are major causes of reduced power output of the Solar One facility. For a month prior to the 1984 summer solstice test, the heliostat field was spray washed with a SCE insulator wash truck (each heliostat was washed at least twice); but with a lack of scrubbing action, the results were soon negated by dust readhering to the mirror surfaces. The SNLL wash/brush truck (Figure 17) could not be made operational in time to help, and efforts to bring in a team of hand washers were unsuccessful. Because the heliostats were so soiled, the latter washing method, hand washing, would have been the most effective in improving plant power production, especially if it could have been accomplished immediately prior to the 15-day summer solstice test period.

Some random field measurements of individual heliostat reflectivity and cleanness were taken during the period that the heliostats were being washed in preparation for the summer solstice test. Table VIII compares the resulting heliostat cleanness from different washing methods and times passed since washing. The data for Table VIII must be considered as somewhat rough as it was taken on various days and on different heliostats. Weather conditions, especially dust storms, may have also been a factor.

Subsequent to the conclusion of the summer solstice test period, there were some heavy rainstorms. But, because the accumulation of dirt has increased over the life of the pilot plant, rainstorms alone no longer return the heliostat reflective surfaces to the degree of cleanness and reflectivity of past years. Rainstorms on July 18, 22, and 23, 1984, returned the heliostat field to 92% cleanness. (Ref. 15).

Rain, snow, and frost during the final weeks of 1984 cleaned the heliostats somewhat better, resulting in a field average of 95.8% clean. (Ref. 16). The possibility exists of mechanically producing a similar effect.

It is this writer's opinion that the only presently available effective method of returning the heliostats to their design point of 98% clean is by hand washing. A follow-up cleaning program using the SNLL wash/brush truck would help to maintain that cleanness.

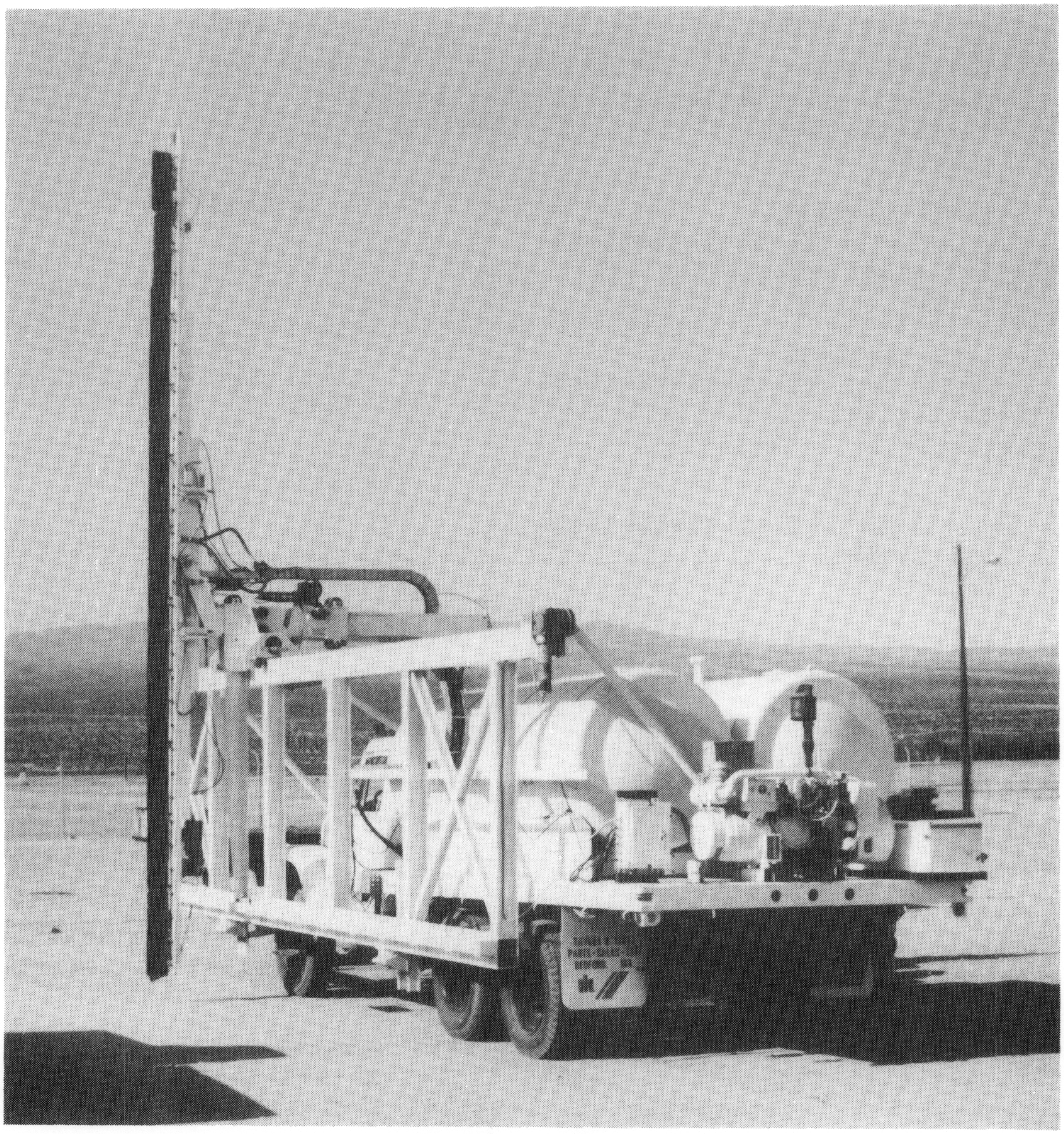


Figure 17. SNLL Solar One Heliostat Wash/Brush Truck

TABLE VIII

COMPARATIVE EFFECTIVENESS OF HELIOSTAT WASHING METHODS

Heliostat Number, Washing Method, Time Expired Since Washing, Test Date	% Cleanness
Heliostat #2712, Washed by hand with "Windex" and paper towel, No time expired, 5/23/84	99
Heliostat #0736, Washed with SCE spray/wash truck, No time expired, 6/11/84	94
Heliostat #2904, Washed with SCE spray/wash truck, One day ago, 5/23/84	92
Heliostat #2712, Washed with SCE spray/wash truck, One day ago, 5/23/84	91
Heliostat #0114, Washed with SNLL wash/brush truck, One week ago, 5/23/84	85
Heliostat #0514, Not washed for 2-1/2 months, 5/23/84	78

The receiver surface has also accumulated a layer of dust and other particles in the past three years which has contributed to a reduction in receiver absorptivity and corresponding reduction in plant power production. A SNLL study of this condition is presently in progress. (Ref. 17).

This discussion, and the results of the 1984 summer solstice test in general, point out two key factors in obtaining maximum power output from today's and future solar energy power production facilities:

1. Locate the facilities in areas where the accumulation of dust and dirt will be as minimal as possible, and

2. After the facilities are built, have a reliable, effective program of maintaining the cleanness of system components.

Realistic Power Production Rating of Solar Facilities

A considerable amount of effort was put forth by SCE, MDAC, DOE, and SNLL to prepare the Solar One pilot plant for the 1984 summer solstice power production test. Aside from the heliostats being quite dirty, extensive operations and maintenance activities had honed the pilot plant to its most efficient operating condition obtainable at that time.

As shown the preceeding analysis and in Table VI, few of the actual efficiency factors or operating parameters of the plant during the solstice test equalled or exceeded corresponding efficiencies or conditions assumed when the facility was designed. At the end of the two-year testing and evaluation period and the beginning of the three-year power production phase, Solar One was able to deliver about 6 MWe net for 7.8 hours (See Figure 3). A more efficient heliostat washing program, as well as periodic cleaning and/or painting of the receiver surface, might increase this output to 6.5 or 7 MWe net for 7.8 hours.

This reduced power plant system output raises two major questions concerning determination of design point and power production ratings for future solar energy production facilities:

1. While Summer Noon "Best Design Day" design point parameters are important and meaningful for sizing all process flow equipment, should these (maximum) parameters and their resulting design point power production be the official and commonly used title and rating for a power plant?

2. How should the design point parameters be selected so that they more accurately reflect the conditions under which the facility will operate year after year? (Plant equipment would still have to be designed to maximum conditions.)

Recommended Further Studies at Solar One

Throughout this report, suggestions have been made for further studies that might disclose methods to more accurately quantify the efficiencies of pilot plant's various components as well as methods to improve those efficiencies. Those recommendations are listed in Table IX in a general priority order for improving total system performance at Solar One. (All of these studies have been initiated or completed subsequent to 1984 summer solstice test, and are part of the total evaluation and improvement program of the pilot plant.)

TABLE IX. RECOMMENDED FURTHER STUDIES AT SOLAR ONE

Recommended Study	Comments
...Heliostat washing methods	1) Engineering study needed to determine most effective washing techniques and equipment. 2) Operations and Maintenance study to optimize washing frequency, manpower availability factors.
...Turbine-generator system efficiency	1) Steam cycle electrical conversion efficiency is approximately 9% lower than rated by turbine-generator vendor. Engineering study needed to determine cause(s) and methods/techniques to improve efficiency.
...Receiver absorptivity (Ref. 17)	1) Reduced absorptivity believed mainly due to a) dirt on receiver surface, and b) degradation of Pyromark paint. 2) Upkeep ultimately a Maintenance and Operations responsibility.
...Maximizing number of on-line heliostats	1) Engineering study to determine cause of component malfunctions. 2) Maintenance and Operations responsible for repair parts stocks and actual repair of off-line heliostats.
...Piping system heat losses	1) Visual evidence of leaking valves and damaged insulation at pilot plant. Not known whether piping efficiency is reduced significantly.

Table IX continued on next page.

TABLE IX. RECOMMENDED FURTHER STUDIES AT SOLAR ONE (continued)

...Convection and radiation loss determinations (Refs. 11 and 12)	1) Engineering studies in progress can lead to a) more accurate quantification of losses and b) equipment designs to reduce losses.
...Atmospheric transmittance, nephelometer measurement site-specific to Barstow (Ref. 8)	1) Dust particles in air and increasing smog in area indicate design point atmospheric transmittance assumptions may be too high.
...Insolation measurement, pyrheliometer accuracy (Ref. 8)	1) Accurate insolation measurements are critical to determining total power available to the collector field. Using existing measurement techniques and instrumentation, actual insolation at the site is significantly below design assumptions. Study and report (including evaluation of sunshape camera and circumsolar telescope usage) in progress.

APPENDIX

APPENDIX A.1--SOLSTICE TEST PREPARATION TIMELINE
Test Period: June 14-28, 1984

Date (Starting time prior to test period)	Task	Responsible Party
April 15 (8 weeks)	Select Solstice Test Coordinator.	SNLL/SCE
April 15 - June 13 (8 weeks)	Increase maintenance activities to get as many heliostats online as possible.	SCE Maintenance Staff
April 20 (8 weeks)	Release initial memo to all responsible parties describing operations, maintenance, and data recording parameters for June 14-28 solstice test.	Test Coordinator
April & May (nights of full moon) (8 weeks)	Photograph heliostats from Beam Characterization System (BCS) target platform to determine heliostats needing bias updating (Moontracking).	SNLL Heliostat Engineer, SCE Operations
April 20 - June 13 (8 weeks)	BCS bias updating of collector field.	SCE Operations
April 22 (7 weeks)	Select On-Site Test Conductor.	MDAC, SCE
May 1 (6 weeks)	Solstice Test Campaign Kickoff Meeting with all responsible parties. In-depth discussion of preparation tasks. Follow-up letter defining specific responsibilities.	Test Coordinator, SCE, MDAC, SNLL, DOE
May 1 - June 1 (6 weeks)	Determine data acquisition requirements (instrumentation, Data Acquisition System tag ID's, reflectivity measurements, etc.)	Test Coordinator Test Conductor, SCE Operations and Maintenance
May 1 - June 1 (6 weeks)	Determine specific test parameters (receiver set point temperature, insolation requirements, etc.).	Test Conductor, Test Coordinator

APPENDIX A.1--SOLSTICE TEST PREPARATION TIMELINE (continued)
Test Period: June 14-28, 1984

Date (Starting time prior to test period)	Task	Responsible Party
May 1 - 21	Wash entire heliostat field with wash/brush truck. (Used SCE insulator wash truck for 1984 solstice test; results poor.)	SCE Maintenance
May 1 - June 13 (6 weeks)	Wash/clean receiver to improve absorptivity. (Not done prior to 1984 summer solstice test.)	SCE Maintenance
May 1 - June 13	Review Piping and Instrumentation (P&I) diagram and inspect actual components (valves, pumps, drains, etc.) to assure proper functioning.	Test Conductor, SCE Operations and Maintenance
May 1 - June 13 (6 weeks)	Perform all maintenance tasks to assure maximum turbine efficiency.	SCE Maintenance
May 15 (4 weeks)	Select best operating crew and assure its availability during test period.	SCE, Test Conductor
May 22 (3 weeks)	Review process for obtaining collector field reflectivity measurements. Determine that reflectometer is functional. Obtain field reflectivity measurement.	SCE Operations
May 22 - June 13 (3 weeks)	Wash entire heliostat field 2nd time with wash-brush truck. Stagger point on mirror module where brushing begins between 1st and 2nd washing. (Used SCE insulator wash truck for 1984 summer solstice test; results poor.) Obtain field reflectivity measurement.	SCE Maintenance
May 29 - 31 (2 weeks)	Practice run the plant at solstice test conditions to determine any weaknesses. Make required repairs before actual test.	SCE Operations, Test Conductor, SCE Maintenance

APPENDIX A.1--SOLSTICE TEST PREPARATION TIMELINE (continued)

Test Period: June 14-28, 1984

Date (Starting time prior to test period)	Task	Responsible Party
May 29 - June 13 (2 weeks)	Practice the most efficient and fastest method of getting the power plant online in the morning.	SCE Operations
June 1 - June 13 (2 weeks)	Ideal washing plan: Wash all heliostats by hand. If contracted out, begin process in plenty of time to assure completion. Measure field reflectivity before and after completion. (Not done prior to 1984 summer solstice test.)	SCE Maintenance
June 1 - 13 (2 weeks)	Calibrate watt-hour output meter as required.	SCE Operations
June 1 - 28 (2 weeks)	Clean and align pyrheliometer. Repeat each morning of solstice test.	SCE, Test Conductor
June 14 - 28 (during solstice test)	Prepare and release daily and weekly test results and reports as required.	Test Conductor
July (after test)	Initiate final report of entire solstice test.	Test Coordinator

APPENDIX A.2--TASKS AND RESPONSIBILITIES DURING ACTUAL TEST DAYS
1984 Summer Solstice Test, June 14-28, 1984

Task	Responsible Party
Observe weather, wind speed, insolation level, plant readiness, etc., to determine which days are "go for it" days.	Test Conductor
Take collector field reflectivity measurement after each test day.	SCE Operations
Inspect receiver tubes for cracks and leakage after each test run.	SCE Operations and Maintenance, Test Conductor
Perform all tasks to assure maximum turbine efficiency (such as closing of drains, use of all extraction heaters, checking steam dump valve, etc.).	SCE Operations and Maintenance, Test Conductor
Minimize use of steam for auxiliary or parasitic uses.	SCE Operations, Test Conductor
Start-up system as early as possible in the morning.	SCE Operations
Do plant cleanup and necessary maintenance during first hour of day shift to avoid distracting control room operator during start-up period.	SCE Maintenance
Conduct non solstice test related testing activities outside of solstice test hours.	Test Conductor, SCE Operations
Determine that all required test data is being obtained to allow thorough analysis and scaling up of test results. Watch DAS so that operators can concentrate on plant operations.	Test Conductor, Test Coordinator
Print out a list of the specific heliostats that are off-line during each test day.	Test Conductor
Keep log of all test activity during day. Plot graphs of insolation, power output, receiver set point temperature, receiver flow rate, and other data as needed for quick analysis.	Test Conductor
Prepare daily written test results as needed.	Test Coordinator, Test Conductor

APPENDIX B— SOLSTICE TEST SCHEDULE

Preparation and Test Periods

Task (Responsible Party)	Weeks Before Test Period: 9	8	7	6	5	4	3	2	1	Test Period, Weeks: 1	2	Post Test
COORDINATION AND MEETINGS:												
Select Test Coordinator. (SNLL, SCE)	X											
Select On–site Test Conductor. (SNLL, MDAC, SCE)		X										
Initial memo to all participants. (Test Coordinator)		X										
Campaign Kickoff Meeting, all participants. (Test Coordinator)			X									
On–site Update Meetings, all participants. (Test Coordinator, Test Conductor)					X		X		X	X	X	
Release daily & weekly test results. (Test Coordinator, Test Conductor)										X	X	
Initiate final report. (Test Coordinator)												X
DATA DEFINITION AND ACQUISITION:												
Determine test parameters: Receiver set point temperature, insolation requirements, etc. (Test Conductor, Test Coordinator)				X	X	X						
Determine data requirements: Instrumentation, DAS Tag ID's, reflectivity measurements, etc. (Test Coordinator, Test Conductor, Operations & Maintenance)				X	X	X						
Review method and equipment for obtaining field reflectivity measurements. (Operations)						X						
Calibrate watt–hour output meter as required. (Operations)						X						
Clean and align pyrheliometer each day (Test Conductor, Operations)							X	X	X	X	X	

(Continued on next page.)

APPENDIX B— SOLSTICE TEST SCHEDULE (Continued)

Task (Responsible Party)	Preparation and Test Periods: Weeks Before Test Period 9	8	7	6	5	4	3	2	1	Test Period, Weeks 1	2	Post Test
DATA DEFINITION AND ACQUISITION (Continued):												
Check that all required test data is being obtained to allow thorough analysis and scaling up of test results. Watch DAS so that operators can concentrate on plant operations. (Test Conductor, Test Coordinator)										X	X	
Keep log of all test activity during day. Plot graphs of insolation, power output, receiver set point temp., receiver flow rate, and other data as needed for quick analysis. (Test Conductor)										X	X	
Print out list of specific heliostats that are off-line during each test day. (Test Conductor)										X	X	
Take collector field reflectivity measurement after each test day. (Operations)										X	X	
PLANT READINESS AND OPERATION:												
Moontracking – On night(s) of full moon, photograph heliostats from BCS platform on receiver tower to determine heliostats needing bias updating. (SNLL Heliostat Engineer, Operations)	X	X	X	X	X	X						
BCS bias updating of collector field. (Operations)		X	X	X	X	X		X	X			
Increase collector field maintenance activities to get as many heliostats on line as possible. (Maintenance)		X	X	X	X	X	X	X	X			
Wash entire heliostat field with wash/brush truck. Between first and second washing, stagger point on mirror module where brushing begins. Obtain field reflectivity measurement. (Maintenance, Operations)				1st washing	1st washing	1st washing	2nd washing	2nd washing	2nd washing			

(Continued on next page.)

APPENDIX B— SOLSTICE TEST SCHEDULE (Continued)

Task (Responsible Party)	Weeks Before Test Period: 9	8	7	6	5	4	3	2	1	Test Period, Weeks: 1	2	Post Test
PLANT READINESS AND OPERATION (Continued):												
Ideal Washing Plan – Wash all heliostats by hand. Measure field reflectivity before and after. (Maintenance, Operations)							Ideal Washing	Ideal Washing	Ideal Washing			
Wash/clean receiver to improve absorptivity. (Maintenance)				■	■	■						
Review Piping & Instrumentation (P & I) diagram and inspect actual components (valves, pumps, drains, etc.,) to assure proper functioning. (Test Conductor, Operations and Maintenance)				■	■	■						
Perform all maintenance to assure maximum turbine efficiency. (Maintenance)				■	■	■						
Select best operating crew and practice the most efficient and fastest method of getting power plant on-line in the morning. (Test Conductor, Operations)					Select Crew	Select Crew	Practice	Practice				
Put pilot plant through test run to determine any weaknesses. Make repairs before actual solstice test. (Test Conductor, Operations and Maintenance)							Test Run	Test Run / Repairs	Repairs			
Observe weather, insolation level, wind speed, plant readiness, etc., to determine "go for it" days. (Test Conductor)										■	■	
Start up system as early as possible in morning. (Operations)										■	■	
Perform all tasks to assure maximum turbine efficiency (such as closing drains, use of all extraction heaters, checking steam dump valve, etc.) (Operations and Maintenance, Test Conductor)										■	■	

(Continued on next page.)

APPENDIX B—SOLSTICE TEST SCHEDULE (Continued)

Task (Responsible Party)	Preparation and Test Periods: Weeks Before Test Period 9	8	7	6	5	4	3	2	1	Test Period, Weeks 1	2	Post Test
PLANT READINESS AND OPERATION (Continued):												
Minimize use of steam for auxiliary or parasitic uses. (Operations, Test Conductor)												
Do plant cleanup and necessary maintenance during first hour of day shift to avoid distracting control room operator during start–up. (Maintenance)												
Inspect receiver tubes for cracks and leakage after each test run. (Operations and Maintenance, Test Conductor)												
Conduct non solstice test related testing activities outside of solstice test hours. (Test Conductor, Operations)												

APPENDIX C--SOLAR ONE OUTPUT SUBSEQUENT TO 1984 SUMMER SOLSTICE TEST

Since the completion of the 1984 summer solstice test, the Barstow pilot plant has had at least two peak power production days which topped the solstice test's peak gross power output:

TABLE X

SOLAR ONE OUTPUT SUBSEQUENT TO 1984 SUMMER SOLSTICE TEST

Date	Insolation	Gross Power Output
August 7, 1984	933 W/sq m	10.7 MWe Peak
August 24, 1984	936 W/sq m	11.2 MWe Peak

To accurately determine those factors which caused these peaks to be greater that the 9.72 MWe peak gross power output of the summer solstice test would require analyses similar in length to the one just reported. While such analyses will not be attempted here, certain factors and conditions at the pilot plant which have changed since the solstice test are listed here.

...Rainstorms in the Barstow area on July 18, 22, and 23, 1984, increased heliostat field reflectivity to 92% clean (Ref. 15). Field cleanness was 88% on June 21, 1984.

...The same rainstorms may have washed the receiver also, thus increasing its absorptivity from that of June 21, 1984.

...Key feedwater system valves (especially the receiver feedwater bypass valve to the flash tank, PV2002) were refurbished after the completion of the solstice test, which may have increased plant piping efficiency.

APPENDIX D--DATA ACQUISITION SYSTEM (DAS) OUTPUT FOR JUNE 21, 1984

Figure 18 and Table XI show actual data printouts for June 21, 1984, as they are produced by use of the McDonnell Douglas Astronautics Company (MDAC) P210 computer program. On Figure 18, typewritten labels have been added to the X and Y axes and to the five curves to aid in reading the data.

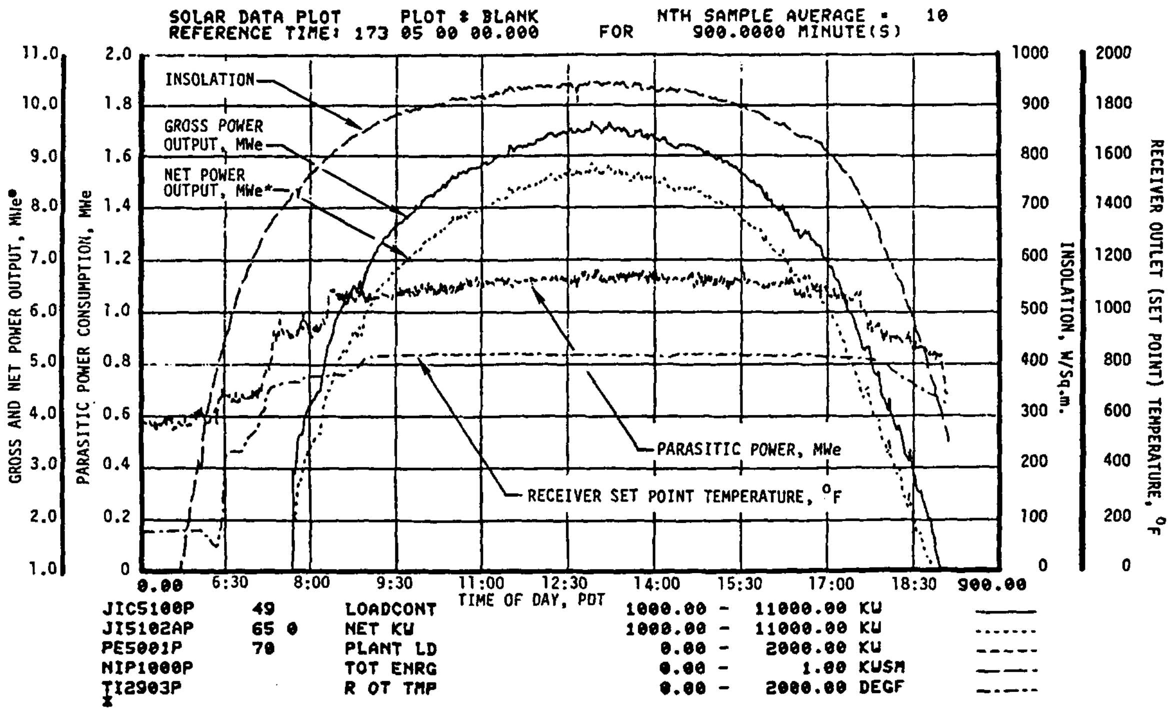


Figure 18. DAS Data Output for June 21, 1984

TABLE XI

DAS DATA OUTPUT FOR 13:12 PDT, JUNE 21, 1984

SOLAR DATA DISPLAY TAB # BLANK TIME: 173 13 12 00.000 TO 173 13 12 15.000

!	TAGID	!	TITLE	!	DATA VALUE
+02	JI5102AP*	+	NET POWER	+	8586.79993* KW
!03	PE5001P	!	70 PLANT LD	!	1128.40001* KW
+04	NIP1000P	+	TOT ENRG	+	0.94442* KWSM
!05	TI2903P	!	R OT TMP	!	835.50001* DEGF
+06	TI2001P	+	RPHTP IN	+	368.50000* DEGF
!07	PI2002P	!	R INLET	!	1597.50002* PSIG
+08	PC1105P	+	R PRESCTRL	+	1600.50002* PSIG
!09	FI2233P	!	R TOTFLO	!	99.56248* KLBH
+10	PI2902P	+	RDCMR PR	+	1346.00000* PSIG
!11	JIC5100P	!	49 LOADCONT	!	9720.00000* KW

APPENDIX E--SOLAR ONE RECEIVER ABSORPTIVITY DETERMINATION

From experimental data collected at Solar One during 1982-1984, the following graph and corresponding equation for predicting the absorptivity of the receiver at Solar One have been developed (Ref. 17).

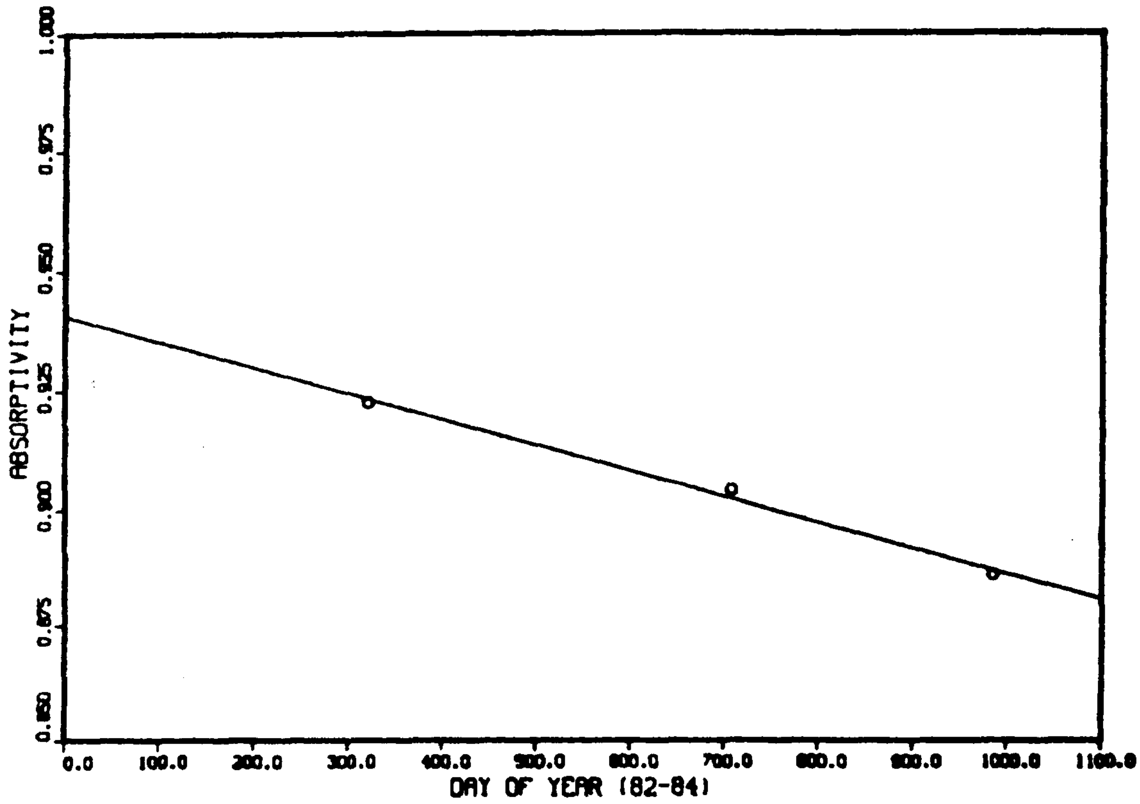


Figure 19. Solar One Receiver Absorptivity

Absorptivity = .9408 - (.5467E-4)(Day Number)

Where Day Number is	1982:	1 through 365
	1983:	366 through 730
	1984:	371 through 1096

Therefore, for June 21, 1984, (Day Number 904):

Absorptivity = .9408 - (.5467)(.0001)(904)

= .8914

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