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10 MWe Solar Thermal Central Receiver Pilot Plant Design Day Performance Monograph

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10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT DESIGN DAY PERFORMANCE MONOGRAPH

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ABSTRACT

Performance of the 10 MWe Solar Thermal Central Receiver Pilot Plant near Barstow, California, is evaluated against the design day performance predictions. Actual conditions at the pilot plant were assessed and used to calculate plant performance. The effects of weather, available heliostats, mirror reflectivity, field and receiver efficiency, and turbine efficiencies are presented and discussed.

FOREWORD

The author would like to thank Lee Radosevich for his help in formulating the information needed to perform this analysis and his comments concerning the interpretation of the results.

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°C.

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SUMMARY

On August 1, 1982, the 10 MWe Solar Thermal Central Receiver Pilot Plant, located near Barstow, California, began a two-year test and evaluation phase. During this phase, operation of the plant has been characterized by success with respect to expected performance. System design criteria which have been met or exceeded include delivery of 10 MWe net from receiver steam (Mode 1 operation), delivery of 7 MWe net from thermal storage, and delivery of 28 MWe-hr net from thermal storage.

However, two other performance criteria, specified for the pilot plant, have not yet been met. These criteria are, delivery of 10 MWe net for 7.8 hours on the most favorable clear day of the year and for 4 hours on the least favorable clear day of the year. Actual conditions at the plant were evaluated to examine the reasons for this and to identify areas in which plant performance can be improved. Insolation during this period was lower than the 1976 Southern California Edison (SCE) Barstow, California data used for the original design day performance calculations. Also, the entire field of heliostats was never available at any time. Around summer solstice and winter solstice, mirror reflectivity was, in general, less than that assumed in the original calculations. Additionally, there is a significant difference in the predicted and the actual power delivered to the working fluid of the receiver. Another difference between assumed characteristics and parameters calculated from data is the apparent lower efficiency of the turbine-generator. Collectively, these factors account for most of the difference between the predicted and the actual power production achieved at the pilot plant.

This preliminary analysis indicates that the predicted design performance on the best and worst days of the year cannot be met unless plant operating characteristics can be improved. With insolation at the same level as in 1976 plus a full field of heliostats and clean mirrors, the lower efficiencies of the collector field, receiver, and turbine-generator reduce the duration of 10 MWe power output below the 7.8 and 4.0 hours predicted for summer solstice and winter solstice, respectively. For these reasons, a concerted program to improve plant performance will be conducted during the next three years of power production.

10 MWe SOLAR THERMAL
CENTRAL RECEIVER PILOT PLANT
DESIGN DAY PERFORMANCE MONOGRAPH

Introduction

During the design stage, predictions were made concerning the performance of the 10 MWe Solar Thermal Central Receiver Pilot Plant (Solar One). Delivery of 10 MWe net from receiver steam, delivery of 7 MWe net from thermal storage, and delivery of 28 MWe-hr net (7 MWe net for 4 hours) from thermal storage have already been demonstrated. The pilot plant was sized based on the predicted performance on the most favorable day of the year and on the least favorable day of the year. These two days correspond to summer solstice (June 21st) and winter solstice (December 21st). The calculations (Ref. 1) made for determining the design performance of the pilot plant predicted that the following power production could be achieved:

10 MWe net for 7.8 hours on Summer Solstice (June 21st)
10 MWe net for 4 hours on Winter Solstice (December 21st)

During the two year Experimental Test and Evaluation Phase of Solar One which began on August 1, 1982, neither of these performance predictions has been demonstrated. Lower insolation than that seen in the 1976 Southern California Edison (SCE) Barstow, California data used for the original design day performance calculations is one reason for this. Another contributing factor is a significant difference in the predicted and the actual power delivered to the working fluid of the receiver.

In order to better understand plant performance, calculations were made using the STEAEC (Solar Thermal Electric Annual Energy Calculator) computer code (Ref. 2). This code requires a description of the system which includes collector field efficiencies as a function of sun azimuth and elevation, field size, mirror reflectivity, receiver efficiency, piping losses, turbine-generator efficiency, synchronization delays and ramp times, and auxiliary power requirements. The user provides all information required to interpolate performance over the time period of interest. No performance models are incorporated in STEAEC. Further information is included in Appendix A.

Performance Calculations

The performance calculations presented in this monograph are for turbine operation directly from the receiver only with no energy provided by thermal storage (Mode 1). Calculations were made starting with the original design data. When data required for the calculations were not available from the original design data, values were used which were consistent with actual plant performance. Net power was calculated for each of the design days. In order to evaluate the maximum power production for the plant, representative days which had both good insolation and good power production near summer and winter solstice were selected for comparison to design performance predictions. For this reason, summer solstice performance calculations were based on weather data collected on June 19, 1983 and June 24, 1983, and winter solstice performance calculations were based on December 25, 1982 and January 2, 1984 weather data. The input data used to make these calculations is presented in Appendix B.

Original Design Data

The original design day performance calculations were based on weather data collected by SCE in Barstow during 1976 (Ref. 3). The actual Barstow weather data was further modified using observations made at the plant site at 16 second intervals (Ref. 4). Furthermore, the original summer solstice design performance was based on June 24, 1976 data since June 21, 1976 happened to be a cloudy day.

All 1818 heliostats were assumed to be operational. However, the full field of heliostats was assumed to contain 71733 square meters of reflector area which is larger than the actual maximum available mirror area. During the detailed design of the heliostats, an edge seal was added to each each mirror module reducing the effective area of each heliostat from 39.457 to 39.127 square meters. Mirror reflectivity was assumed to be constant at 0.89. The efficiency at which the collector field delivered power to the receiver varied as a function of time and accounted for the cosine effect of the sun angle and heliostat shadowing and blocking. Atmospheric attenuation and tower shadowing and blocking were also constant at 0.97 and 0.993, respectively.

Constant values were used for all receiver efficiencies. A surface absorptivity of 0.95 was used with losses due to radiation and convection set at 4.7 MWth. It was also assumed that 97.6% of all energy incident on the receiver was intercepted.

A loss of 0.1 MWth from the downcomer was used in the design performance calculations. Turbine-generator efficiency for operation from receiver steam only was assumed to be 35.19% at rated conditions of 950 deg F, 1465 psia with 12.5 MWe gross power output and 112,140 lbm/hr of steam flow. This value corresponds to the manufacturer's specifications. It was also assumed that 15 MWth was required to bring the plant up from overnight shutdown to turbine synchronization.

Plant parasitics were obtained from McDonnell Douglas data which was compiled in September 1980. Total parasitics for Mode 1 operation amounted to 1.691 MWe and are shown in Table 1.

Table 1

Mode 1 Plant Parasitic Load
(Ref. 1)

Collector System	54	kW
Motor Control Center (MCC) "A" and "L"		
SCE Rotating Equipment	1097	
SFDI, Control, DAS and Equipment	40	
Warehouse	22	
SCE Control Building A/C, Lighting, Other	100	
SCE Administrative Building	90	
Motor Control Center "B" (TSS)	13	
Motor Control Center "C" (Water Treatment) . .	149.7	
Power Panel A (Receiver)	25.6	
Other (includes Special Data Acquisition System, Beam Characterization System, Weather Station, Etc.)	100	
TOTAL	1691	kW

Actual Plant Conditions

As described previously, design day calculations were made using weather data for days in which both insolation and power production were good. Only days where power production was exclusively from receiver steam were considered. Using these criteria, June 19, 1983 and June 24, 1983 were selected for summer solstice performance calculations, while December 25, 1982 and January 2, 1984 were used to make winter solstice performance calculations. Figures 1 and 2 show the insolation used for both the original performance calculations and the actual plant condition calculations.

The actual mirror area of 39.127 sq m per heliostat was used to calculate the total reflector area. The number of heliostats available on each of the selected days was used. On June 19, 1983, there were 1795 heliostats operational. On June 24, 1983, there were 1801 heliostats available, while on December 25, 1982 and January 2, 1984, there were 1730 and 1709 heliostats, respectively. Mirror reflectivity for each of these days was 0.857, 0.852, 0.892 and 0.883, respectively. Total field efficiency was generated for a matrix of sun azimuth and elevation

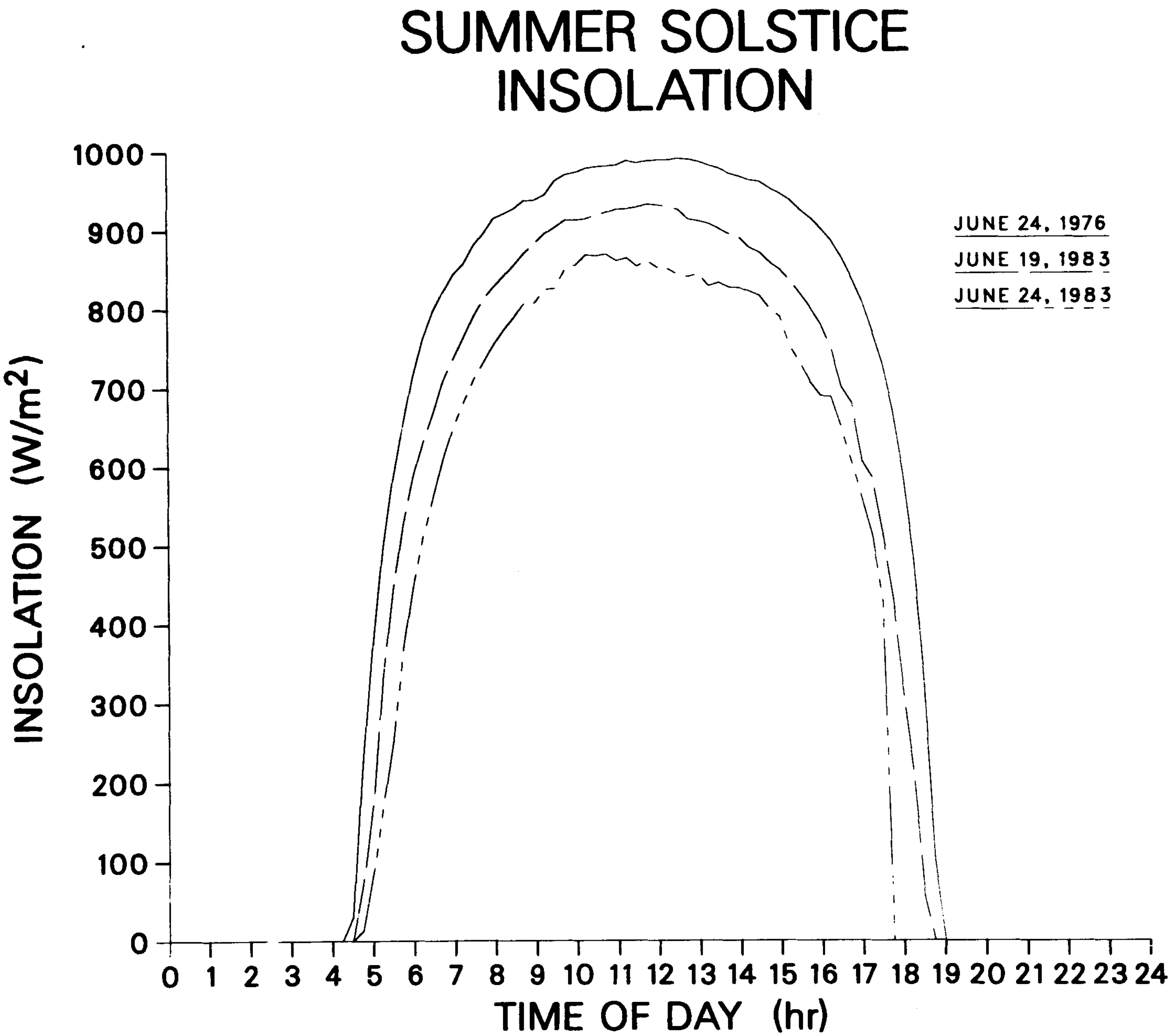

Figure 1. Summer Solstice Insolation

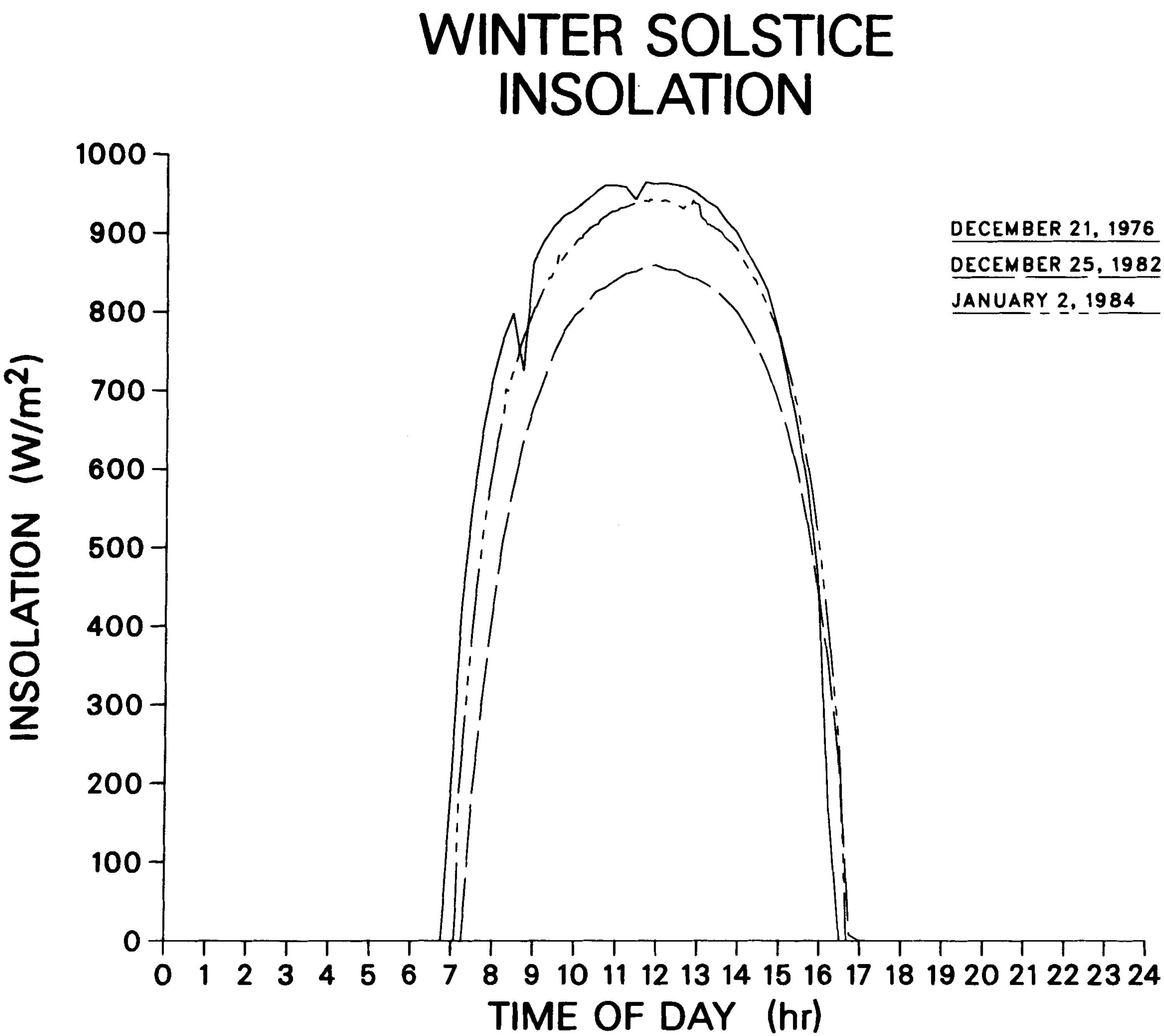

Figure 2. Winter Solstice Insolation

angles sufficient to represent the operation of the plant throughout the year. The calculation of field efficiency included atmospheric attentuation, cosine effects, heliostat shadowing and blocking, receiver and tower shadowing, and receiver intercept so that variations corresponding to each combination of azimuth and elevation and, thus, the implied time were taken into account. These calculations were made using the MIRVAL computer code (Ref. 5).

Receiver efficiency was defined by dividing measured absorbed power by calculated incident power (Ref. 6). Absorbed power at selected times near noon on Mode 1 power production days was plotted against incident power. Incident power was calculated using the MIRVAL computer code. A least squares fit of the data gave the following equation of absorbed power as a function of incident power:

Absorbed Power = 0.8056 x Incident Power - 1.5690 (MW)

The turbine-generator efficiency was determined from a plot of gross heat rate versus gross electric power which was generated from actual plant data (Ref. 7). Only those points corresponding to rated steam conditions were used in the design day performance calculations. Maximum actual turbine-generator efficiency based on this information was 32.8%. It should be noted that this method of determining turbine-generator efficiency actually includes all water/steam cycle inefficiencies such as internal leak paths to the condenser.

Differences between the original design data and actual plant conditions which were used in the calculations are shown in Table 2.

Table 2

Performance Data For Design Day Calculations

	Original	Summer Solstice		Winter Solstice	
Weather	6/24/76, 12/21/76	6/19/83	6/24/83	12/25/82	1/2/84
Available Heliostats	1818	1795	1801	1730	1709
Mirror Area (sq m)	71733.	70233.	70468.	67690.	66868.
Mirror Reflectivity	0.89	0.857	0.852	0.892	0.883
Receiver Absorptivity	0.95	0.8056*	0.8056*	0.8056*	0.8056*
Radiation, Convection, Conduction Losses (MWth)	4.7	1.569*	1.569*	1.569*	1.569*
Turbine-Generator efficiency (rated steam conditions)	0.3519	0.328	0.328	0.328	0.328

*from equation, Absorbed Power = 0.8056 x Incident Power - 1.569 (MW)

Results

Net power is plotted for each of the selected days in Figures 3, 4, 5 and 6. The parameters shown in Table 2 were changed one at a time so that the contribution of each condition could be cumulatively assessed. The limit imposed by the maximum turbine-generator output is reflected where the curves are flat. Hours of net power output of at least 10 MWe are tabulated in Table 3 for each case.

Table 3

Hours of 10 MWe Net Power Output

	Summer Solstice			Winter Solstice		
	6/24/76	6/19/83	6/24/83	12/21/76	12/25/82	1/2/84
1. Original Design Data	7.75	--	--	4.50	--	--
2. (1) with Actual Weather	--	6.00	5.00	--	3.00	4.25
3. (2) with Available Heliostats	--	5.75	4.50	--	0.50	3.50
4. (3) with Actual Mirror Reflectivity	--	5.00	2.50	--	0.75	3.25
5. (4) with Derived Receiver/Field Efficiency	--	2.50	0.00	--	0.00	0.50
6. (5) with Actual Turbine-Generator Efficiency	--	0.00	0.00	--	0.00	0.00
7. Actual Net Power Production	--	0.00	0.00	--	0.00	0.00

Discussion

The original design data calculations were used as the baseline against which the relative effects of the various actual conditions at the pilot plant could be assessed. These calculations show that a net power output of at least 10 MWe can be produced for 7.75 hours on June 24, 1976. Net power output of 10 MWe or more is produced for 4.50 hours using the original design data and December 21, 1976 weather. Since all calculations were at 15 minute intervals, calculations with original data reasonably verify design day predictions. All known assumptions used in the original calculations were included.

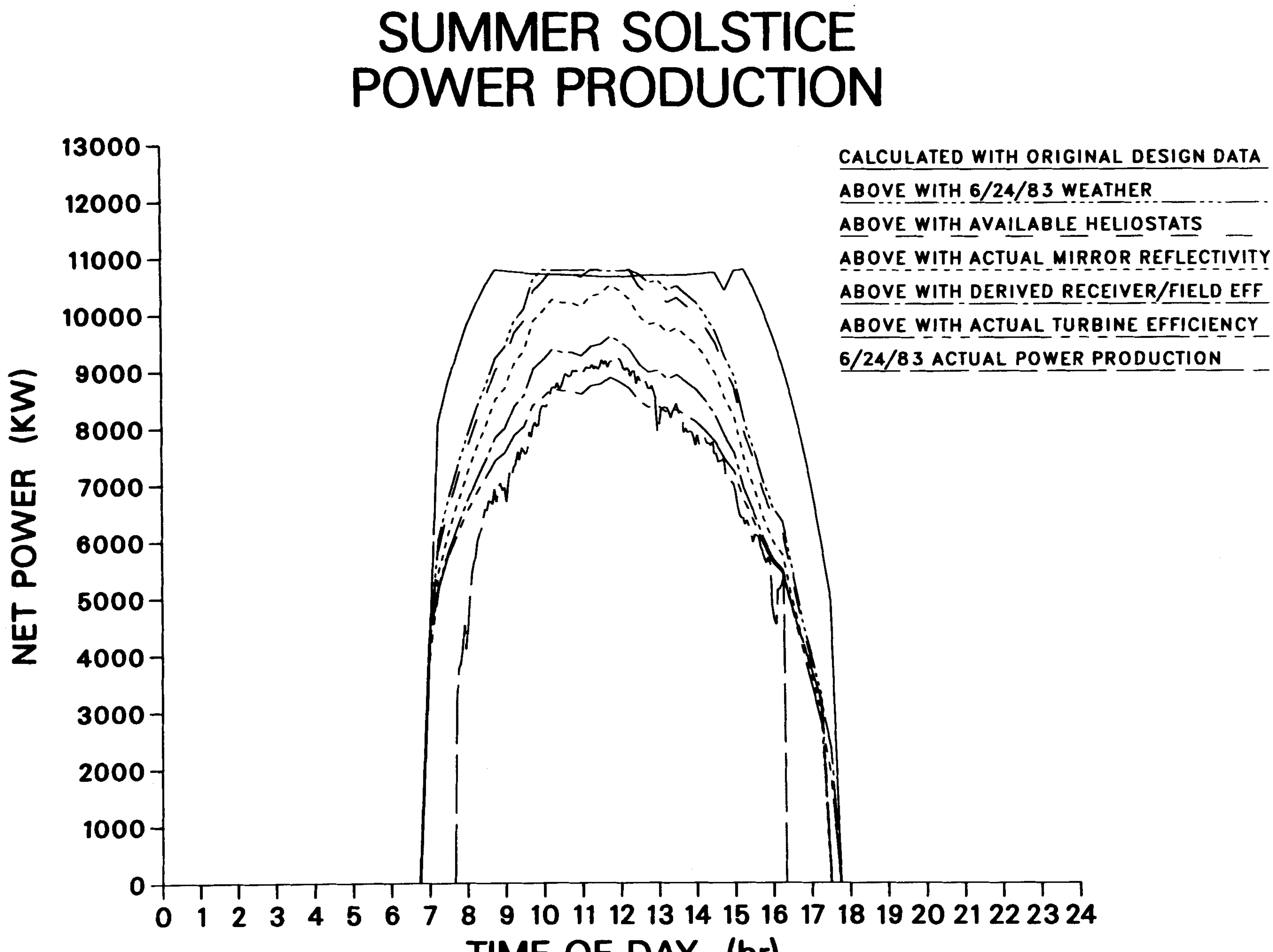

Figure 3. Summer Solstice Power Production (6/19/83)

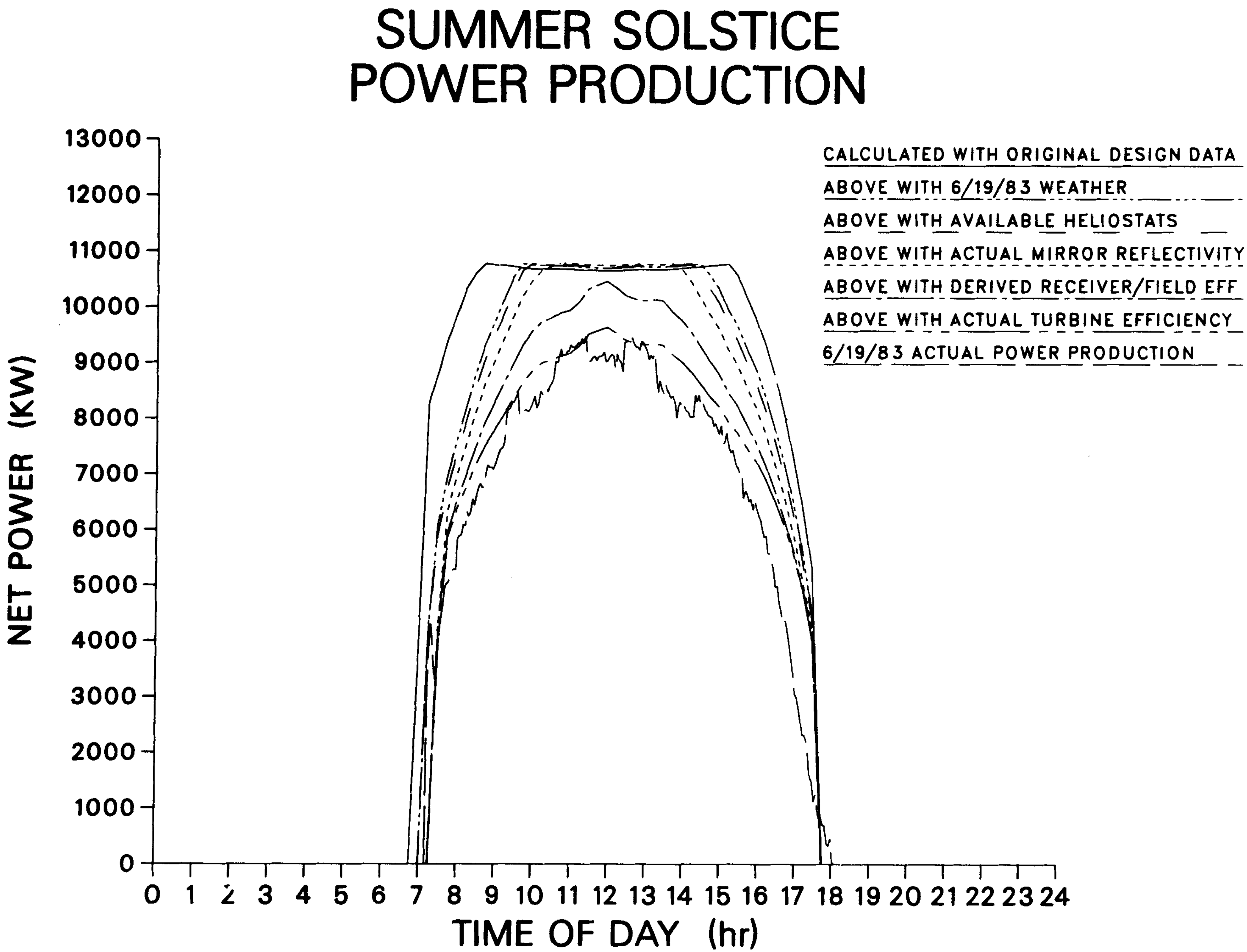

Figure 4. Summer Solstice Power Production (6/24/83)

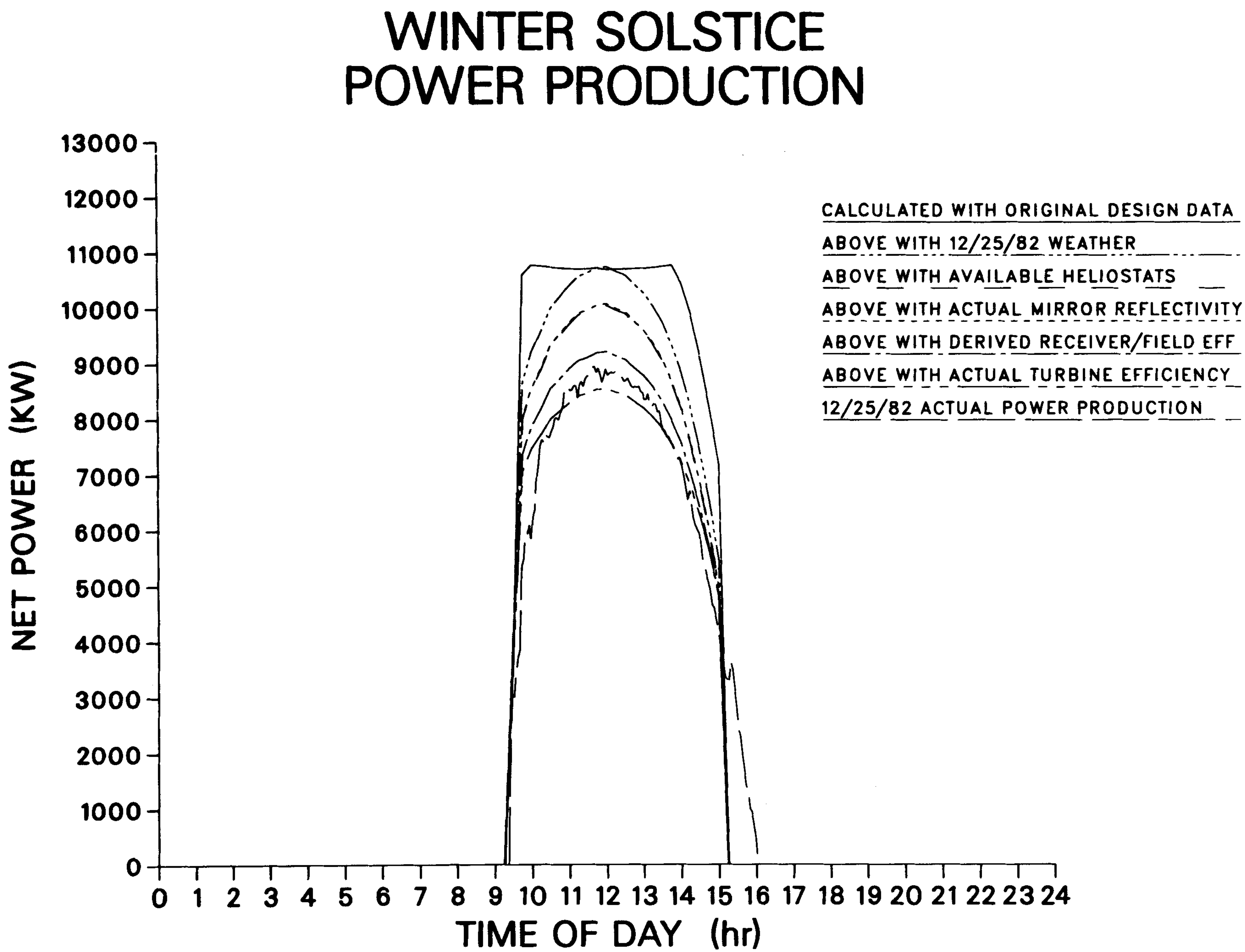

Figure 5. Winter Solstice Power Production (12/25/82)

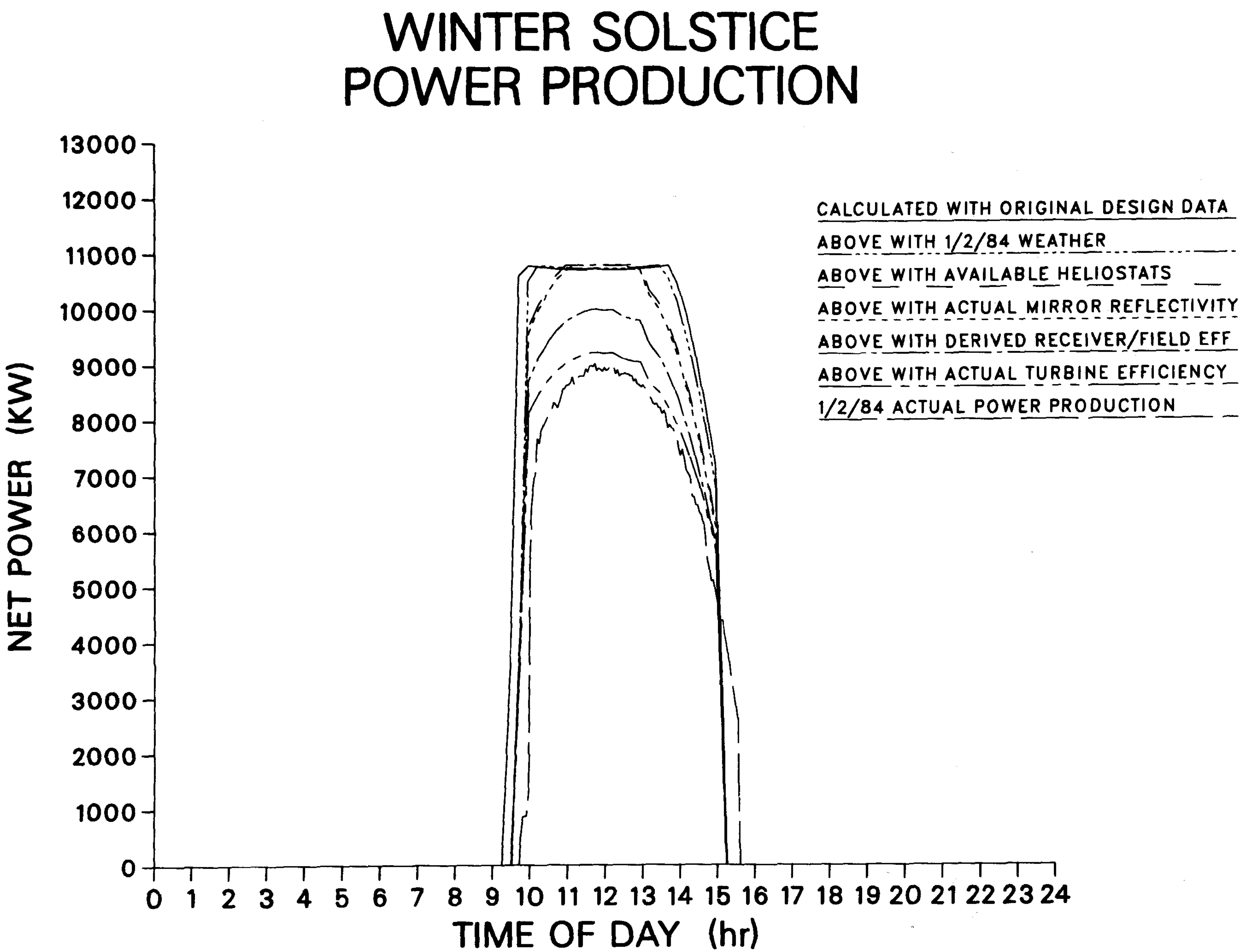

Figure 6. Winter Solstice Power Production (1/2/84)

Weather and receiver/field efficiency are major contributors to decreased net power output. In all cases except one, weather alone reduces the duration of 10 MWe net power output below the predicted design hours. On January 2, 1984, it was possible to produce 10 MWe net power for over 4 hours under the original conditions. Since the four days analyzed are days with relatively good insolation, it is apparent that weather is a significant factor in the actual performance of the pilot plant.

Receiver/field efficiency also has a significant effect on net power output. The values used in the calculations (Table 2) are derived rather than measured values. These values have been specifically identified as a combination of effects attributable to both the collector field and the receiver because it is not possible to partition them with the information available. The reason is that the power incident on the receiver from the collector field cannot be measured. Therefore, it is calculated using the design criteria for the heliostats and the actual field configuration. Absorbed power can, however, be calculated directly from the measured temperatures, pressures, and flow rates. For these reasons, the effects of collector field efficiency and receiver efficiency cannot be considered separately. At an incident power of 50 MWth, the effective receiver/field efficiency is reduced by 9.6% from 0.856 for the original assumptions to 0.774 for the actual pilot plant conditions.

The actual number of available mirrors and the actual mirror reflectivity have smaller effects on hours of net power output than either weather or receiver/field efficiency for the days examined. Their effect can be minimized with increased field maintenance to keep heliostats operational and washed. The actual reflective area available on the selected days is 2.1 to 6.8% lower than the 71733 sq m used in the original performance calculations. Mirror reflectivity was not reduced by more than 4.3% from the assumed value of 0.89. Slightly better mirror reflectivity on December 25, 1982 is reflected in the slightly longer time for which 10 MWe power production was achieved (Table 3).

Apparent turbine-generator efficiency is 6.8% lower than the 0.3519 value given by the manufacturer for operation at rated conditions. Since the method of determining turbine-generator efficiency would also include other water/steam cycle inefficiences, it is likely that this difference is smaller than assumed. The magnitude of this difference is about the same as the maximum reduction in available reflective area. Again, the effect of this difference on hours of net power output is less than that for either weather or receiver/field efficiency.

Calculated power production for the two summer solstice days does not track fluctuations in insolation exactly. The differences in the curve shapes are probably due to a combination of the relatively coarse calculational intervals (15 minutes) and the fact that parasitic power requirements vary as a function of power.

Actual power production on June 19, 1983 shows a number of steps throughout the day. The steps are due to the fact that heliostats were being washed. The procedure used for washing the collector field takes a block of heliostats offline at one time to be cleaned. The actual power production shown on Figure 3 shows that each block took about 45 minutes to an hour to be washed.

For calculated and actual net power production on June 24, 1983, there is a substantial difference in the time at which startup and shutdown occur. This is due to a slightly later start and a receiver trip on low superheat which caused a premature shutdown of the plant.

In all cases, the actual net power production does not match that calculated when the cumulative effects of all the identified differences are taken into account. Clearly, there are other factors affecting pilot plant performance which have not been taken into account. Recently, the collector field has been photographed from the top of the tower while tracking the moon. These pictures indicate that a large number of heliostats are not aimed correctly. In an effort to estimate the effect of these pointing errors, an additional calculation was made with 100 less heliostats. While it is unlikely that the level of incident power on the receiver is being reduced this dramatically, this calculation shows that an effect of this magnitude is sufficient to account for differences between actual and calculated pilot plant power production. This source of error may explain in part the relatively large difference between the assumed and derived receiver/field efficiency. Also, the actual parasitic power at the plant appears to be less than that assumed from the information in Table 1. The difference between gross power and net power while the plant is on line is roughly 0.9 MWe. The original calculations assumed 1.691 MWe. When the various differences in plant conditions are considered, the calculated parasitic power requirements are between 0.47 and 1.82 MWe while the plant is on line.

Conclusion

Using known information about the condition of the pilot plant, it is evident that the design performance predictions could not be achieved on the days which were considered in this analysis. The factors having the most effect on net power output are weather and the combined collector field/receiver efficiency. Weather alone precludes operation for the predicted number of hours on three of the four days analyzed. The additional effects of fewer available heliostats, degraded mirror reflectivity, lower than assumed receiver/field efficiency and turbine-generator efficiency reduce the peak net power production to below 10 MWe in all cases.

Because the combined receiver/field efficiency is significantly lower than originally assumed, it is unlikely that the pilot plant in its present state will be able to achieve net power production of at least 10 MWe for 7.8 and 4.0 hours on the best and worst days of the year at all. The primary goal of the three year Power Production Phase which began August 1, 1984, is to demonstrate energy production capabilities of the Barstow Pilot Plant. A program to improve performance in the areas identified in this report is beginning.

APPENDIX A

Description of STEAEC Computer Code

STEAEC
(Solar Thermal Electric Annual Energy Calculator)

Basic Features

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

Typical Applications and Uses

STEAEC has been used to select the 10 MWe Solar Thermal Central Receiver Pilot Plant concept and to calculate annual energy production by repowering contractors.

Program Details

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

1. Collector field efficiency as a function of the azimuth and elevation angles obtained from MIRVAL or DELSOL2;

2. Collector field parameters such as size, parasitic power requirements, operating temperature limits, minimum sun elevation for operation, wind speed operating limits and mirror reflectivity;

3. Receiver parameters such as efficiency, heat capacity, size, startup and cooldown, auxiliary power requirements, derated capability and losses as a function of wind speed and power;

4. Piping losses as a function of temperature;

5. Turbine parameters such as conversion efficiency when operating from the receiver and from storage as a function of flow and ambient temperature; and

6. Storage charging and discharging parameters, initial state of charge, storage tank and heat exchanger losses and thermocline degradation.

In addition to the input namelists, STEAEC requires weather tapes that specify direct normal insolation, wind speed, wind direction, dew point temperature, ambient pressure and dry bulb temperature for the specific site. STEAEC is a Fortran IV code.

Current Status

STEAEC is used at Sandia National Laboratories, Livermore on a CDC 6600 computer.

Documentation

For further information, see Reference 2.

Source

Contact Gordon Miller, Sandia National Laboratories, Livermore.

APPENDIX B

STEAEC Input Data

```
$CEXTRA
  $END
$CONCOEF
  FR=.304,.612,.732,.8,.804,.793,.298,.587,.72,.788,.796,.777,
  .292,.564,.69,.764,.774,.778,.281,.551,.667,.745,.775,.775,
  .272,.514,.622,.708,.743,.781,.266,.488,.6,.693,.734,.777,
  $END
$CONCOLF
  FS=71733.,AOL=7.5279E-7,TLIML=16.,TLIMU=113.,ELIM=15.,WSLIM=12.1,
  RFLCTY=.89,WSEF=8*1.,
  $END
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  MODPO=1,XTD=1.,DTST=.75,RXLR(5)=50.,FXLR=25*.094,
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  $END
$CONTRBN
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  6*.254,
  $END
$CONSTRG
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  A=.00964,B=.0142,
  $END
```

The STEAEC input whose values were varied for this analysis are identified in the table on the following page.

Performance Data For Design Day Calculations

	STEAEC variable	Original	Summer Solstice		Winter Solstice	
Weather	--	6/24/76, 12/21/76	6/19/83	6/24/83	12/25/82	1/2/84
Available Heliostats	--	1818	1795	1801	1730	1709
Mirror Area (sq m)	FS	71733.	70233.	70468.	67690.	66868.
Mirror Reflectivity	RFLCTY	0.89	0.857	0.852	0.892	0.883
Receiver Absorptivity	EPS	0.95	0.8056	0.8056	0.8056	0.8056
Radiation, Convection, Conduction Losses (MWth)	FXLR	4.7	1.569	1.569	1.569	1.569
Turbine-Generator Efficiency (rated steam conditions)	FEPSR	0.3519	0.328	0.328	0.328	0.328

REFERENCES

1. "Solar Ten Megawatt Pilot Plant Performance Analysis", Solar 10 MW Project Office, Government Support Operations, The Aerospace Corporation, El Segundo, CA, Aerospace Report No. ATR-81(7747)-1, February, 1981.

2. J. B. Woodard and G. J. Miller, "STEAEC - Solar Thermal Electric Annual Energy Calculator Documentation", Sandia Laboratories, Livermore, SAND77-8278, January 1978.

3. N. W. Patapoff, "The West Associates Solar Resource Evaluation Project-Solar Energy Measurements During 1976", Southern California Edison Company, June 1977.

4. C. M. Randall, B. R. Johnson and M. E. Whitson, Jr., "Measurements of Typical Insolation Variation at Daggett, California", Aerospace Report NO. ATR-80(7747)-1, Vol. I and Vol. II, March 1980.

5. P. Leary and J. Hankins, "A User's Guide for MIRVAL-Computer Code for Comparing Designs of Heliostat Receiver Optics for Central Receiver Solar Power Plants", Sandia Laboratories, Livermore, SAND-77-8280, February 1979.

6. A. F. Baker, "Monograph Series, No. 2: 10 MWe Solar Thermal Central Receiver Pilot Plant Receiver Performance Evaulation", Sandia National Laboratories, Livermore, to be published.

7. "10 MWe Solar Thermal Central Receiver Pilot Plant Mode 1 (1110) Test Report", McDonnell Douglas Astronautics Company, Huntington Beach, CA, MDC H0625, October 1983.

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