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SOLAR PRODUCTION OF INDUSTRIAL PROCESS STEAM

Phase III: Operation and Evaluation of the Johnson & Johnson Solar Facility

Final Report for the Period January 1, 1980—March 31, 1981

By
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J. M. Kendall
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MASTER

March 1981

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Acurex Corporation
Alternate Energy Division
Mountain View, California

U.S. Department of Energy

Solar Energy

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SOLAR PRODUCTION OF
INDUSTRIAL PROCESS STEAM:
PHASE III --
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SOLAR FACILITY

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March 1981

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Prepared for the
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ABSTRACT

A solar facility that generates 177°C (350°F) process steam has been designed and constructed by Acurex Corporation and has operated for 1 yr supplying steam to the Johnson & Johnson manufacturing plant in Sherman, Texas. The facility consists of 1,068 m² (11,520 ft²) of parabolic trough concentrating collectors, a 18,900 l (5,000 gal) flash boiler, and an 18.6 kW (25 hp) circulating pump. In the first year of operation the system was available 97 percent of the days, and with sufficient solar radiation available it operated 70 percent of the days during this period. The measured data showed that the collector field operated at an efficiency of 25.4 percent for the year, and that at least 75 percent of the energy reaching the flash boiler was delivered to the plant as steam. A total of 309,510 kg (682,400 lb) of steam was produced by the solar facility for the first year. An analysis of the data showed that the delivered energy was within 90 to 100 percent of the predicted value. The successful completion of the first year of operation has demonstrated the technical feasibility of generating industrial process steam with solar energy.

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SECTION 1

EXECUTIVE SUMMARY

1.1 INTRODUCTION

The objective of this project is to demonstrate the technical and economic feasibility of generating low-pressure industrial process steam with solar energy. Under contract from the Department of Energy, Acurex has designed, constructed, and operated a solar system to provide low-pressure process steam for the Johnson & Johnson manufacturing plant in Sherman, Texas. The completed facility is shown in Figure 1. This report deals only with the operation and evaluation of the system (Phase III). The design (Phase I) and construction (Phase II) are the subject of previously issued reports (References 1 and 2). The objective of this phase was to operate and evaluate the solar steam facility for a 12 month period. This report summarizes the performance of the facility from January 1980 through January 1981.

As an operating system, pressurized water is circulated through the collector field where it is heated and then throttled into a flash boiler. In the boiler the heated, pressurized water flashes to steam which flows into the plant steam main for distribution to various plant processes. The flash boiler contains enough thermal storage to provide freeze protection when required. Makeup water is supplied by the plant boiler feedwater system. The principle of operation is illustrated schematically in Figure 2. The system consists of conventional, industrial steam generating equipment that can be easily maintained by plant operators and maintenance personnel. The major equipment is summarized in Table 1.

The remainder of this Executive Summary discusses: system operating experience, performance, cost and economics, and recommendations for future systems.

1.2 OPERATING EXPERIENCE

Routine daily operation of the system began on January 12, 1980 and continues to the present time, 14 months later. Data acquisition began on January 16, 1980 and was completed 12-1/2 months later on January 31, 1981. The system has had 97 percent availability to operate during this period, and actually operated 70 percent of the time that it was available. (Inclement weather, weekend downtime, etc. prevented 100 percent

Figure 1. Johnson & Johnson Manufacturing Plant in Sherman, Texas

Figure 2. Solar Steam System Schematic

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Table 1. Equipment Summary

Collector Field

- Acurex Model 3001 parabolic trough collectors
- 1,068 m² (11,520 ft²) in 4 flow loops
- Northeast/southwest-axis orientation

Pump

- Roth two-stage regenerative turbine
- Two speeds: 3,500 rpm, 3.78 l/s (60 gpm) and 1,120 rpm, 1.26 l/s (20 gpm) for freeze protection
- 18.6 kW (25 hp) motor
- Liquid cooled mechanical seals

Flash Boiler

- 18,900 l (5,000 gal) capacity
- ASME Section VIII -- 1,100 kPa at 188°C (160 psig at 370°F)
- Steam conditions: 825 kPa at 177°C (120 psi at 350°F)
0.21 kg/s (1,655 lb/hr) peak flowrate

operation.) Since the end of January 1980, the system has operated automatically except for an occasional weekend in April. At the end of April, system operation was transferred to Johnson & Johnson personnel for monitoring. Since that time, it has operated unattended most of the time, including weekends. Plant maintenance personnel have performed routine inspection and maintenance of the facility and have reported that the facility requires no special procedures and relatively little additional time to their existing plant responsibilities.

During the first year of operation several difficulties arose that caused a system shutdown (only 10 days total), loss of data, or less than optimum operation. The system was shut down to remove an obstruction in the steam discharge line from the flash boiler, to replace a leaking pump seal, and to replace two leaking flex hoses. Loss of data resulted from problems with the magnetic tape recorder (22 days), and erratic behavior of the steam flowmeter and pyranometer. Instrumentation difficulties were resolved, but the instances of tape malfunction remain unexplained. Malfunctions in the freeze protection system (temperature sensors and the three-way mixing valve) resulted in the system coming on too early and excess heat being rejected to ambient. Also, leaking steam traps allowed steam to escape from the flash boiler through the condensate lines. The freeze protection system has been repaired temporarily by using a hand valve to restrict flow to the field during the freeze protection mode (a new three-way valve is required), and the steam traps have been repaired.

1.3 PERFORMANCE SUMMARY

Analysis of the data collected over the first year of operation show that the collectors delivered 879.1 GJ (833.3×10^6 Btu) Btu to the flash boiler, that 461.5 GJ (437.4×10^6 Btu) of steam were delivered directly to the steam main, and that 205.2 GJ (194.5×10^6 Btu) were delivered to the plant condensate by leakage through faulty steam traps. The delivered energy is equivalent to 214,250 kg (472,350 lb) and 95,263 kg (210,056 lb) of steam, respectively. The faulty steam traps have been repaired and all generated steam is now delivered to the steam main. Based on 8 months of insolation data, it was determined that 25.4 percent of the energy received by the collector field was delivered to the flash boiler and that 75 percent of the energy reaching the flash boiler was delivered to the plant. (Of the energy from the collector field 52 percent was converted to steam, and 23 percent entered through faulty steam traps.)

Using the actual insolation conditions at the site, and making allowances for the inadvertent heat losses that occurred and the deterioration of the reflective surfaces, it was found that the solar system performed within 90 to 100 percent of what was predicted. Considering these factors, and having corrected the cause of these heat losses, it is estimated that during a typical year of operation the system would deliver 504,500 kg (1,110,000 lb) of steam, 60 percent more than that measured in the first year of operation.

1.4 COST/ECONOMICS

As a pilot facility, the system has demonstrated the performance potential necessary to achieve economic viability for solar industrial process heat applications. An economic evaluation of a full-scale system at various locations in the United States was performed. The results of this evaluation indicate that at current prices a solar system for industrial process heat can present an attractive investment opportunity.

1.5 RECOMMENDATIONS

The successful completion of this project has demonstrated the technical feasibility of generating low pressure industrial process steam with solar energy. The system installed at the Johnson & Johnson plant has had excellent availability and has operated well during the first year. Some problems were identified during this shakedown period and were resolved. We recommend continued operation of the system for another year together with data collection and analysis. A significant improvement in performance is expected, together with a reduction in operating and maintenance costs.

SECTION 2

SYSTEM DESCRIPTION

The main components of the solar steam system include 1,068 m² (11,520 ft²) of parabolic trough solar collectors, a two-stage regenerative turbine pump, and an 18,900 l (5,000 gal) ASME-rated flash boiler. The pump circulates pressurized water at 3.78 l/s (60 gpm) through the concentrating collectors where it is heated to 202°C (395°F) under peak insolation conditions. As shown in Figure 2, the heated pressurized water is throttled into the flash boiler where it flashes to 174°C (345°F) steam, flowing from there into the plant steam main for distribution to various plant processes. The boiler is located 120 m (400 ft) from the collector field. Makeup water is supplied by the plant's existing boiler feedwater system. The flash boiler retains enough thermal storage to protect the collector field from freezing, and a 15 kW standby gas-fired generator is available to stow the collectors and provide freeze protection should a power failure occur.

The design incorporates conventional industrial grade steam generating equipment, easily serviced by the plant maintenance staff. The major equipment for the solar system is summarized in Table 1.

The collectors are Acurex Model 3001 parabolic troughs. These collectors are designed to heat fluids from 60°C (140°F) to 315°C (600°F). The reflector surface is a polished aluminum sheet. Each collector module is 3.05 m (10 ft) in length and has a 1.83 m (6 ft) aperture. Eight modules are connected to a common drive and tracking unit to form a working group as shown in Figure 3. The receiver is a 3.175 cm (1.25 in.) diameter carbon steel tube. The receiver tube is coated with a selective black chrome, and a Pyrex glass jacket encloses the tube. Each collector group is connected to the field piping with a Teflon hose overwrapped with a stainless steel braid, insulated and enclosed in a flexible elastomeric duct. The collector field consists of four fluid flow loops connected in parallel to the field manifolds. A flow loop consists of two interconnected rows of collectors. Each row contains three collector groups.

The boiler is an ASME Section VIII rated vessel -- 1,100 kPa at 188°C (160 psig at 370°F) -- and is mounted on a skirt that is thermally isolated from the boiler to reduce heat loss. The boiler is insulated with 20.3 cm (8 in.) of fiberglass insulation. The boiler was

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Figure 3. Collector Group -- Eight Modules

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fabricated by the General Steel Company, Inc. of Fort Worth, Texas from specifications developed by Acurex.

The system circulation pump has a 18.6 kW (25 hp) motor and operates at 3,500 rpm for normal circulation and 1,140 rpm for freeze protection. The pump delivers 2,480 kPa (360 psig) of head at 183°C (361°F) under normal operating conditions. Heated water returning from the collector field is throttled across the system differential pressure regulating valve into the flash boiler where it is flashed to steam and passed to the plant steam main.

The supply and return piping for the collector field is a factory assembled preinsulated pipe (Ricwil), installed below grade for plant aesthetic reasons. The pipe is 2-1/2 in. in diameter schedule 40 pipe and has 8.89 cm (3-1/2 in.) of calcium silicate insulation. Field manifolds are 2-1/2 in. diameter schedule 40 carbon steel pipe and have 6.35 cm (2-1/2 in.) of fiberglass insulation. Interconnecting piping in the collector field is 1-1/2 in. schedule 80 carbon steel pipe and has 6.35 cm (2-1/2 in.) of fiberglass insulation. Figure 4 shows part of the manifold and interconnect piping.

The main collector field electrical box receives 480 V power that is stepped down to 110 V service for the collector drive motors. There are four loop control boxes, one for each flow loop. A 15 kW natural gas fired electrical generator provides backup power to stow the collectors or to power the pump for freeze protection.

The system control cabinet is shown in Figure 5. The upper portion of the cabinet consists of an annunciator panel for system alert and/or alarm conditions. The central portion of the panel consists of a system mimic with panel meters indicating key process temperatures and flowrates. Ambient wind speed, temperature, and total horizontal insolation are also indicated. The lower portion of the control panel consists of an Autodata 9 data logger and magnetic tape recorder.

The system weather station is located on the roof directly above the flash boiler and control cabinet. Wind speed, ambient temperature, and total horizontal insolation are measured at this station. In addition, the system direct insolation monitor (DIM) is mounted on the weather tower. The DIM "awakens" the system in the morning when adequate insolation is available for the collector field to track the sun and collect energy. The DIM shuts the system down when insolation drops below a preset value, nominally 315 W/m² (100 Btu/ft²-hr).

A detailed description of the system design is given in Reference 1. The fabrication and installation is described in Reference 2.

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Figure 4. Manifold and Interconnect Piping

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SECTION 3

SYSTEM PERFORMANCE SUMMARY

Startup and checkout of the Johnson & Johnson Solar Facility was completed in December 1979. After the plant holiday shutdown, the facility was brought online to begin a 15 month operation and evaluation period. The objective of this phase was to collect, reduce, and evaluate in detail 12 months of performance data. This objective was met and monthly performance reports were prepared for the period of February 1980 through January 1981.

3.1 OPERATION SUMMARY

The solar steam facility was placed into routine daily operation on January 12, 1980 and data acquisition began January 16, 1980. The system was available for operation for 372 days (97 percent) out of the first 382 days of data collection from January 16, 1980 to January 31, 1981. In addition, the system operated for at least 1 hr on 260 days (69.9 percent) out of the 372 days. Insufficient insolation occurred on 97 days and on 15 days the system either was not operated because of the weekend or the data was not available to determine whether the system operated. Since the end of January 1980 the system has been operating fully automatically with the exception of some weekends through the month of April 1980. The operation of the system was turned over to the Johnson & Johnson personnel on April 29, 1980. The system has been monitored by Johnson & Johnson personnel since then with the system operating unattended most of the time, including weekends. A manual has been prepared which gives a detailed description of the system operation and maintenance (Reference 3).

3.2 MEASURED PERFORMANCE SUMMARY

The solar steam system was instrumented to measure 20 parameters which are used to evaluate the performance of the system. Figure 6 is a schematic showing these parameters and their location in the various water lines in the system. The input solar radiation is measured by two pyranometers mounted on the aperture of a collector as shown in Figure 7 with the collectors stowed. One has a shadow band to measure the diffuse component (NE85B), and the other measures the total insolation (NE85A). Thus, the difference in these instrument readings gives the beam component incident on the collector aperture. The thermal energy collected and supplied to the flash boiler is evaluated by the difference between the field return temperature (TE22) and the field supply temperature (TE21).

Figure 6. Johnson & Johnson Solar Steam System Instrumentation Schematic

Figure 7. Total and Diffuse Pyranometers

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This temperature difference is multiplied by the collector field flowrate (FT30) and the density and specific heat of the water to give the energy supplied to the flash boiler. Collector field efficiency is computed by dividing the incident insolation and the field aperture area into the collected thermal energy.

The steam supplied to the plant, measured with the steam flowmeter (FT31), was assumed to have a quality of 90 percent and was measured to consistently have a temperature of 177°C (350°F). Thus, the enthalpy of the delivered steam was taken to be 2.57 MJ/kg (1,105 Btu/lb). The feedwater was measured to have a temperature of 99°C (210°F) and therefore an enthalpy of 0.41 MJ/kg (178 Btu/lb). Thus, the energy content of the generated steam is the difference of the enthalpies, i.e., 2.16 MJ/kg (927 Btu/lb). The product of the flowrate and the enthalpy difference gives the energy supplied by the system. The system efficiency is computed by dividing the product of incident insolation and field collector aperture into the energy supplied by the system.

The other measured parameters are used to evaluate other aspects of system performance. The flash boiler temperature (TE23) has been used to evaluate its heat loss. The auxiliary electrical current, (IT1) indicates when the pump is operating in either the normal mode or the freeze protect mode. Most of the other instruments have been used at various times to assess and explain any abnormal measurements or system results.

The data collected over the first year of operation show that at least 461.5 GJ (437.4×10^6 Btu) of steam -- 214,250 kg (472,350 lb) -- were delivered to the Johnson & Johnson plant steam main. Steam was generated on at least 150 days of the 260 days the system operated. Upon further analysis of the data, it was estimated that an additional 205.2 GJ (194.5×10^6 Btu) were lost to the condensate return line as a result of steam leaking through the steam traps. The solar radiation measurement for the 8 months of available data recorded a total of 1.694 MJ/m² (149,200 Btu/ft²) of beam insolation incident on the collector field aperture area of 1,068 m² (11,520 ft²). For the 8 month period of available data the collector field delivered thermal energy to the flash boiler at an efficiency of 25.4 percent. The total thermal input to the flash boiler was 879.1 GJ (833.3×10^6 Btu). It is estimated that approximately 52 percent of the energy delivered to the boiler was converted into delivered steam energy not accounting for the steam leaking through the steam traps. The freeze protect system operated on 65 days between October 30, 1980 and January 31, 1981. The decrease in field efficiency during the winter months is a direct result of the lower sun angle and lower ambient temperatures.

The system performance for each month as well as for the year is summarized in Table 2. Only the measured values are reported (except for the steam energy delivered). When an instrument failed to provide an accurate reading, only the recorded values are reported. However, the steam delivered was estimated, since the steam flowmeter was not operating properly from January 1980 through July 1980. It was assumed that steam was generated whenever the temperature in the flash boiler was approximately 177°C (350°F). The steam energy leaving the boiler was

Table 2. Performance Summary
January 1980 Through January 1981

	Jan 80 ^a	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan 81	Total
Days system available	14	28	31	28	31	30	31	31	25	31	30	31	31	372
Days system operated	5	17	15	20	16	25	29	26	18	27	20	23	19	260
Direct insolation (MJ/m ²) on collector plane (Btu/ft ²)	47.3 4,163	NA ^c	173.4 15,271	208.0 18,319	151.4 13,331	NA ^c	NA ^c	NA ^c	NA ^c	452.5 39,844	274.0 24,129	163.6 ^e 14,409	224.1 ^f 19,737	1.695 ^h 149,203
Energy to flash boiler (GJ) (10 ⁶ Btu)	7.9 7.5	52.6 49.9	45.6 43.2	77.1 73.1	56.8 53.8	113.8 107.9	178.3 169.0	39.7 ^d 37.6	36.8 34.9	121.9 115.5	64.5 61.1	33.9 ^e 32.1	50.3 ^f 47.7	879.1 ^h 833.3
Steam energy delivered (GJ) (10 ⁶ Btu)	3.2 ^b 3.0	31.6 ^b 30.0	14.3 ^b 13.6	20.4 ^b 19.3	26.4 ^b 25.0	83.8 ^b 79.4	140.3 ^b 133.0	27.3 ^d 25.9	17.0 16.1	62.0 48.8	20.3 19.2	8.5 ^e 8.1	6.3 ^f 6.0	461.5 ^{b,h} (666.7) ^j 437.4 (631.9)
Fossil fuel displacement (GJ) (10 ⁶ Btu)	4.4 4.2	44.3 42.0	19.9 18.9	28.3 26.8	36.6 34.7	116.0 110.0	194.9 184.7	38.0 ^d 36.0	23.6 22.4	86.2 81.7	28.2 26.7	11.9 ^e 11.3	8.8 ^f 8.3	641.1 ^h (925.9) ^j 607.7 (877.6)
Days steam produced	4	12	6	9	6	22	27	8 ^d	9	21	10	9	7	150
Field efficiency, ^g (percent)	15.0	NA ^c	25.0	35.0	35.0	NA ^c	NA ^c	NA ^c	NA ^c	25.0	22.1	19.4	21.1	25.4

^aSystem began operation January 16, 1980

^bBased on estimated steam flow

^cNot available due to insolation sensor malfunction

^dData available for only 12 days

^eData available for only 21 days

^fData available for only 27 days

^gField efficiency = $\frac{\text{Monthly collected energy}}{\text{Direct insolation on collector plane} \times \text{collector area}} \times 100$

^hOnly data available included

ⁱBased on 8 month of available data

^jEstimate including the steam leak to condensate (see Section 4)

taken to be 90 percent of the collected energy entering the boiler at that time. The measurements for the month of August were used to validate the estimation method.

A summary of daily system operation is given in Appendix A. Appendix B contains the hourly average values of system parameters for a single clear day of each month. These values are presented in graphical form in Appendix C. The daily values are tabulated in Appendix D and plotted for each month of operation in Appendix E. Appendix F defines the terms used in the plots and tables presented in the Appendices.

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SECTION 4

ANALYSIS OF PERFORMANCE

4.1 THERMAL ANALYSIS

An analysis of the measured data has been made to assess the system performance for the first year of operation. The collected energy and delivered steam were calculated using a computer code and compared against the predicted values. The following discussion compares the hourly measurements for June 13, 1980 with the predicted values. Following this is a comparison of the system output for the first 10 months of system operation. Finally, a discussion of the energy loss from the flash boiler and the underground pipes is presented to assess the measured values with the expected values.

Predicted Performance for June 13, 1980

A prediction of the system performance was made for a single day in June (June 13, 1980). The measured insolation data for that day were used in the computer program which modeled the system performance. From the computer simulation for that day, a direct comparison of the predicted and measured system performance was made. The actual system performance deviated from the predicted due to energy losses which were identified and quantified. In addition, any necessary refinements and improvements in the computer simulation were identified.

The hourly values of predicted collected thermal energy and corresponding measured values are shown in Figure 8. The uncertainty of ± 8.5 percent about the nominal measured values was derived from the analysis in Section 4.2. Most of the hourly predicted values are within or close to the band on the measured values. The measured collected energy for the day is 7 percent lower than the predicted value. The differences between the predicted and measured performance values have been separated into two categories and are listed in Table 3. First, there are differences between the collector parameters as modeled and those in the field; second, there are differences between the system operation and the system modeling.

The collector efficiency equation was modeled with the measured values from Sandia for an Acurex Model 3001 collector with a Coilzak reflector. Their measurements were for a single collector group under ideal conditions with new reflectors and receiver tubes, whereas the

Figure 8. Comparison of Actual and Predicted Energy Collected Versus Time
Day 165, June 13, 1980

Table 3. Reasons for Differences Between Predicted and Measured Performance

Reason	Cause
Differences in collector performance	<ol style="list-style-type: none"> 1. Coilzak reflectivity deteriorates with time 2. Reflective surfaces were not clean 3. Receiver tubes were not clean 4. Instrumentation uncertainties
Deficiencies in simulation model	<ol style="list-style-type: none"> 1. Lack of sophisticated modeling of transient events 2. Heat losses greater than calculated

measurements at Johnson & Johnson were made on the entire collector field. The collectors had been aligned 3 months earlier and washed 2 weeks prior to June 13. The modeled heat losses were taken from the insulation manufacturer's tables for straight pipe losses. Any deficiencies in the installation of the insulation and heat losses around valves and flanges were not included in the calculations.

Finally, there are some differences in the modeling and the actual system operation. The feedwater is modeled as entering the system continuously at the same flowrate as steam is leaving the boiler, whereas the feedwater, in fact, is off most of the time. When the water level in the boiler drops to a certain value, the feedwater enters at a constant rate until a specific level is reached and then shuts off. In addition, the morning warm-up of the collectors, as the pump first comes on, is modeled as coming up to the boiler temperature very quickly, but in reality it may take a minimum of 20 to 30 minutes for this transient to occur. As a result, an accurate modeling in the first hour of operation would require a much more detailed transient calculation for the collector field. However, for steady-state operation, the computer modeling can adequately define the large energy losses in the system and the overall impact on the system performance.

Performance Evaluation for January through October, 1980

An evaluation of the performance of the solar steam system was made using data from the first 10 months of operation. The primary objective was to determine the extent to which the actual performance agrees with the predicted values. To minimize the difference between the typical year prediction and the first year of operation, the predicted results were adjusted to reflect the actual insolation data obtained from the site. Secondly, the prediction was modified to include the incident angle modifier to improve the prediction. As a result, the agreement between

the prediction for energy delivered to the flash boiler and the measured values was within 10 percent for monthly average values.

Since the computer prediction was made in 1977 before the Typical Meteorological Year (TMY) data were available from the National Climatic Center (NCC), a typical year of insolation data was generated from several years of available data. Each month was modeled with 7 days of hourly data rather than a full month, thus the year consisted of 84 days. Upon comparing the insolation values obtained in this manner with the TMY values from the NCC, it was found that the monthly values of available beam insolation were within 5 percent.

Because of instrumentation problems, data were not available for every day in the month. As a result the monthly value of insolation is taken as the value measured for those days in which a measurement exists and then projected to the actual number of days in the month. Table 4 presents the projected measured values and the predicted values for each month. For those months where only a few days of data were available, e.g. February and August, the projected monthly value is not accurate. For the month of July the insolation was computed from the energy to the boiler divided by the field efficiency (25 percent) and the collector area. It is seen to be 30 percent higher than the typical value. The month of July 1980, however, was an extraordinarily high insolation month. (Ambient temperatures exceeded 100°F every day of the month.) Also shown in the table is the ratio of actual to predicted insolation. The predicted output energy will be adjusted by this factor before comparing with the measured collector field output energy.

A prediction of the annual steam production of the solar steam facility was originally made in December, 1977. Since then several new factors have been evaluated to more accurately predict the actual output energy from the collectors. Perhaps the largest of these is the incident angle modifier which accounts for additional collector losses when the incoming insolation is not normal to the collector aperture. The original and the recent prediction incorporating the incident angle modifier are shown in Table 5. Since the incident angle is farther off normal in the winter months, the correction is largest at that time. The result over the year was a decrease in collector field output energy of 8.3 percent.

Using the information from Tables 4 and 5, a revised prediction was computed accounting for incident angle modifier effects and actual insolation. A comparison of this revised predicted output with the measured values is given in Table 6 for the 5 months with the most days of recorded data.

The results of the performance comparison shown in Table 6 indicate a reasonably consistent performance of about 100 percent of the predicted. The difference between predicted and actual performance is small enough to be attributable to a number of sources. Instrument error could account for essentially all of the difference. Adjusting the controls so that the system shuts down at the proper time would increase performance by about 3 percent. Effects of dirt on the collectors were not included in the predictions, and tracker performance degradation could

Table 4. Measured and Predicted Insolation Values

Month	Number of Days of Data	Projected Measured Monthly Insolation ^a		Predicted Monthly Insolation ^b		Ratio of Actual to Predicted
		(MJ/m ²)	(Btu/ft ²)	(MJ/m ²)	(Btu/ft ²)	
January	14	104.7	9,218	208.3 GJ	18,344	0.503
February	4	185.7	16,350	268.7	23,662	0.691
March	23	173.4	15,271	326.3	28,737	0.531
April	21	230.7	20,317	368.3	32,430	0.626
May	25	172.1	15,152	469.4	41,336	0.367
June	19	372.9	32,839	496.2	43,691	0.752
July	0	671.0	59,091 ^c	518.9	45,692	1.293
August	5	625.1	55,044	536.5	47,243	1.165
September	13	156.1	13,747	387.7	34,137	0.403
October	31	452.5	39,844	294.1	25,899	1.538

^aMeasured insolation values divided by number of days data available and multiplied by number of days in month

^bPredicted insolation based on typical 7 days in each month projected to full month

^cEstimated from measured energy to flash boiler and 25 percent field efficiency

Table 5. Collector Field Output Energy Predictions

Month	Original		Revised ^a		Difference (Percent)
	(GJ)	(10 ⁶ Btu)	(GJ)	(10 ⁶ Btu)	
January	67.1	63.6	56.1	53.2	-16.4
February	78.3	74.2	74.9	71.0	- 4.3
March	112.9	107.0	100.6	95.4	-10.8
April	133.7	126.7	123.4	117.0	- 7.7
May	187.3	177.5	173.5	164.5	- 7.3
June	187.9	178.1	173.4	164.4	- 7.7
July	200.6	190.1	193.9	183.8	- 3.3
August	216.6	205.3	201.8	191.3	- 6.8
September	143.7	136.2	130.7	123.9	- 9.0
October	104.4	99.0	94.4	89.5	- 9.6
November	72.3	68.5	62.4	59.1	-13.7
December	61.5	58.3	51.2	48.5	-16.8
Annual	1,566.3	1,484.5	1,436.3	1,361.6	- 8.3

^a Revised prediction includes the incident angle modifier in the collector efficiency equation

Table 6. Comparison of Actual and Predicted Collector Field Output Energy

Month	Measured ^a		Adjusted Prediction ^b		Ratio of Measured to Predicted
	(GJ)	(10 ⁶ Btu)	(GJ)	(10 ⁶ Btu)	
March	54.1	51.3	53.5	50.7	1.01
April	83.1	78.8	77.3	73.3	1.07
May	65.0	61.6	63.6	60.3	1.02
June	129.4	122.7	130.4	123.6	0.99
October	138.3	131.1	145.3	137.7	0.95
Total	470.0	445.5	470.1	445.6	1.00

^aMeasured values are based on the energy results reported in Appendix D adjusted upward for the low outlet temperature readings of 1.4°C (2.5°F)

^bAdjusted prediction is the revised prediction from Table 5 multiplied by the ratio of actual to predicted insolation from Table 4

also be a factor. Overall, the results are very positive and indicate the system is performing close to predictions.

Evaluations of Flash Boiler Losses

The performance data indicate a major reduction in energy delivered from the flash boiler to the steam main relative to the energy delivered by the field to the flash boiler. The difference is much greater than could be attributable to measurement errors combined with initial predictions of conduction/convection losses associated with the flash boiler. Operating data indicated a flash boiler cooldown rate of approximately 0.56°C (1°F) per hour corresponding to a heat loss of about 8.8 kW (30,000 Btu/hr). Further investigation of operating data showed that the loss mechanism was not present during initial operation, but appeared suddenly during the second month (February 1980). Various potential loss mechanisms were evaluated as discussed below.

The potential effect of convection and radiation losses was analyzed by looking at worst-case conditions. Convective losses were calculated for a vertical surface 111°C (200°F) above ambient temperature, resulting in a heat loss of 694 W/m^2 (220 Btu/hr-ft^2). Radiation losses under these conditions, assuming an emissivity of 50 percent, would be about 568 W/m^2 (180 Btu/hr-ft^2) for a combined convection/radiation loss of 1.262 W/m^2 (400 Btu/hr-ft^2). The observed cooldown rate would require approximately 7 m^2 (75 ft^2) of surface at 132°C (270°F) to be explained by convection/radiation losses alone. This is unrealistic; thus, convection/radiation losses are not likely to be a major cause of the observed behavior.

Pipes, connected to the boiler, act as fins for heat loss. However, an analysis of heat loss due to an infinitely long 2-1/2 in. insulated pipe resulted in a heat loss of about 15 W (50 Btu/hr) which is too small to be a factor.

Blowdown of the flash boiler is another loss term although not related to the overnight heat losses. Blowdown occurs twice a week with a loss of about 380 l (100 gallons) per blowdown. Assuming 163°C (325°F) water is drained and replaced with 99°C (210°F) feedwater, the result is a loss of about 95 MJ (90,000 Btu) per blowdown. Thus, blowdown would not be a major contributor to the disparity between energy delivered to the flash boiler and energy delivered to the steam main.

Another potential loss mechanism could be a steam leak from the boiler. Since a steam leak would be proportional to flash boiler pressure, while the mechanisms discussed above would be proportional to flash boiler temperature, the two types of losses would have different characteristics as a function of flash boiler temperature. In Figure 9 the cooldown rate is shown as a function of flash boiler temperature for both the heat loss and for the proposed steam leak. Also plotted in Figure 9 are a number of points taken from operating data. The data strongly indicate a steam leak as the dominant source of cooldown of the flash boiler. Since no steam leaks to the atmosphere could be observed,

Figure 9. Characteristics of Convection/Conduction Heat Losses and a Steam Leak

the most likely source is through the steam traps, since the leakage would be piped to the condensate system and thus not readily detected.

The steam traps have recently been examined and were found to have been leaking. They have now been repaired. A measurement of the overnight drop in temperature in the tank of 0.20°C/hr (0.35°F/hr) has since verified the above hypothesis. Thus, a substantial amount of energy being delivered to the plant steam system is unaccounted for since this leaking steam would be heating the condensate return water without passing through the steam flowmeter. This is, therefore, the major factor in the large difference between energy delivered to the flash boiler and measured energy delivered to the steam main.

Upon investigating the data from the solar steam facility, it was found that prior to February 20, 1980 the temperature drop in the flash boiler was considerably smaller than was measured after that date (e.g., compare Figures C-1 and C-2 of Appendix C). Assuming that an average temperature drop of 0.44°C/hr (0.80°F/hr) is a result of steam leaking to the condensate return, an additional 11 kg/hr (25 lb/hr) of steam could have been supplied to the plant steam system since February 20, 1980. This would account for an additional 205.2 GJ ($194.5 \times 10^6\text{ Btu}$) of useful steam energy being supplied which would increase the delivered steam energy that was measured and estimated from 461.5 GJ ($437.4 \times 10^6\text{ Btu}$) to 666.7 GJ ($631.9 \times 10^6\text{ Btu}$) for the reporting period of 382 days. This corresponds to 75.8 percent of the energy delivered from the collector field to the flash boiler being delivered to the plant steam system as useful energy for the first year of operation.

The conversion of collected thermal energy to delivered steam for the flash boiler should be very efficient. The hourly measurements under steady state conditions show a conversion of approximately 100 percent within measurement uncertainty as seen in the single day tables (Tables B-7 to B-12) in Appendix B. The daily conversion is less because of heat losses from the flash boiler and the resulting morning warmup requirement when the pump is started. This heat loss must be made up by the collector field each day of operation to bring the water back up to the saturation temperature of 177°C (350°F). A conservative estimate of heat losses results in a daily loss of 163.5 MJ ($155,000\text{ Btu}$). This corresponds to a loss of 7 percent of the collected energy delivered to the flash boiler for the 382 day period. Additional losses during the winter months due to freeze protection would reduce the conversion efficiency. Also, since the steam flow measurements were estimated through July, 1980 and the estimated values were conservative, the annual conversion efficiency would not be expected to have been greater than 80 to 85 percent. The measured 75.8 percent is somewhat below the expected value. Given the measurement problems, however, it appears to be a reasonable value.

Evaluation of Underground Piping Thermal Losses

During system operation, a consistent drop in indicated temperature between the field outlet header and the flash boiler inlet of approximately 1.7°C (3°F) was observed. This led to a concern that the buried field supply and return pipes were experiencing heat losses much higher than the design

values. Since the observed difference could be instrument error, a test was performed to measure the thermal resistance of the underground pipe. After a routine afternoon shutdown, the data acquisition system was adjusted to allow rapid scanning prior to startup the following morning. This allowed a determination of the water temperature in the pipe prior to startup. From the overnight temperature drop, the thermal resistance of the underground pipe was determined.

On December 14, 1980 the system was shutdown with the temperature in the underground return pipe at 160.6°C (321°F) as indicated by TE 22 (see Figure 6). At 8:40 a.m. on December 15, 1980 the system was started. The temperature response of TE22 immediately after startup is shown in Figure 10. Since the transit time of the 120 m (400 ft) underground pipe is 95 sec, the response indicated that the water in the pipe at startup was at a temperature of approximately 73.9°C (165°F), i.e., the water temperature dropped 83.3°C (150°F) in 16.33 hr.

For a lumped thermal mass surrounded by insulation, the temperature response is given by:

$$T(t) = T_{amb} + [T(0) - T_{amb}]e^{-\frac{t}{\tau}}$$

where

$$\tau = \frac{mc_p}{UA}$$

For the current test conditions the time constant was computed to be 16.8 hr. From the pipe specifications the time constant was determined to be 15.2 hr. Thus, the thermal resistance between the water in the pipe and the ambient ground was measured to be 10 percent higher than the computed value. Consequently, the actual drop in return line temperature is less than 10 percent of the value indicated by the difference between TE11 and TE22. Therefore, the indicated value from the temperature difference is in error due primarily to instrument uncertainty. Since the field header temperature TE11 is in general agreement with the loop outlet temperatures, the flash boiler inlet temperature sensor TE22 is reading low by approximately 1.4 °C (2.5°F). Since this instrument is used to determine field output energy, the calculation of the actual collector field output energy requires correcting the measured value TE22 by this error in the temperature reading.

4.2 MEASUREMENT UNCERTAINTY ANALYSIS

Errors of two types occur in data analysis: system measurement errors, and performance measurement errors. Errors in system measurements, such as solar insolation and fluid temperatures, result from intrinsic instrument accuracy and inaccuracies associated with signal conditioning and data acquisition equipment. Performance measurements (collector and system efficiency) incur errors as a result of the

Figure 10. Underground Pipe Temperature Response

propagation of errors in system measurements. In addition, daily averaged values for both system and performance measurements are subject to sampling errors.

System Measurement Errors

System measurement uncertainties were calculated on an absolute error basis. That is, the accuracy values for each of the instruments were directly summed with the accuracy values for the signal conditioning and data acquisition system. Accuracies for transducers, signal conditioning and data acquisition equipment were based on manufacturer's specifications. The results of these uncertainties are summarized in Table 7.

Performance Measurement Errors

Performance measurements are derived quantities; that is, performance measurements are calculated from system measurements (References 4 and 5). The results of the uncertainty analysis on the performance measurements are given in Table 8. These uncertainties were calculated assuming that the errors were random and uncorrelated.

In Table 8, uncertainties are given for instantaneous and daily averaged values. The instantaneous values correspond to the uncertainty expected if the system is operating in a quasi steady-state mode. The daily averaged uncertainties include the errors associated with sampling rates.

The Solar Energy Research Institute guidelines state that all final performance measurements be determined to within 6 percent accuracy when uncertainties in sensors, signal conditioning, and sampling rate are accounted for (Reference 6). The instantaneous system efficiency conforms to this guideline. Both system efficiency and the daily averaged collected efficiency are outside of the guideline. In the case of the system efficiency, the dominant factor is the uncertainty in the steam flowrate measurement. This measurement is dependent on steam quality. Based on the system conditions, the steam quality was assumed to have a ± 3 percent uncertainty. The uncertainty in the system efficiency could be reduced to approximately ± 2 percent for instantaneous uncertainty and ± 5 percent for daily averaged uncertainty if the steam quality value could be reduced to zero uncertainty.

The dominant factor in the collector efficiency uncertainty is the uncertainty in the field supply and return temperature measurements relative to the temperature rise across the collector field. This uncertainty is bounded by the accuracy of the instruments measuring the field inlet and outlet temperatures. To reduce the uncertainty in the daily collector field efficiency to 6 percent, the uncertainty in the supply and return temperature measurements (TE21 and 22) would need to be reduced to $\pm 10^\circ\text{F}$ or approximately ± 0.3 percent of full scale. The current uncertainty as seen in Table 7 is ± 0.70 percent for the field supply and return temperatures.

Table 7. System Measurement Uncertainties

<u>Temperatures</u>	<u>Instrument I.D.</u>	<u>Accuracy, Percent of Full Scale</u>
Header return	TE-11	+1.10
Pump coolant -- inlet	TE-16	+0.75
Pump coolant -- outlet	TE-17	+0.75
Field water supply	TE-21	+0.70
Field return	TE-22	+0.70
Flash boiler	TE-23	+1.10
Steam	TE-25	+0.70
Feedwater	TE-27	+0.75
Ambient	TE-84	+1.20
Loop 1 outlet	TE-106	+0.90
Loop 2 outlet	TE-116	+0.90
Loop 3 outlet	TE-126	+0.90
Loop 4 outlet	TE-136	+0.90
<u>Flowmeters</u>		
Field water supply	FT-30	+0.50
Steam flow	FT-31	+1.30
<u>Pyranometers</u>		
Total horizontal insolation	NE-81	+0.15
Total insolation normal to collectors	NE-85A	+1.2
Diffuse insolation normal to collectors	NE-85B	+1.2
Wind speed	ST-82	+1.50
Auxiliary electrical current	IT-1	+0.60

Table 8. Performance Measurement Uncertainties

	<u>Instantaneous Values (Percent)</u>	<u>Daily Values (Percent)</u>
Collector field efficiency	<u>+8.5</u>	<u>+9.6</u>
System Efficiency		
With a steam quality Uncertainty of + 3 percent	<u>+5.8</u>	<u>+7.4</u>
With a steam quality Uncertainty of 0 percent	<u>+2.1</u>	<u>+5.1</u>

4.3 COST/ECONOMICS

The fossil fuel displacement for the first year of operation, 382 days, was as follows:

	<u>Measured and Estimated Through Steam Flowmeter</u>	<u>With the Leakage Through Steam Traps Included</u>
Delivered steam	461.5 GJ (437.4 x 10 ⁶ Btu)	666.7 GJ (631.9 x 10 ⁶ Btu)
Fossil fuel displaced (at 72 percent efficiency)	640.9 GJ (607.5 x 10 ⁶ Btu)	925.9 GJ (877.6 x 10 ⁶ Btu)
Value (at \$2.30/10 ⁶ Btu)	\$1,397.25	\$2,018.57

As discussed elsewhere in this report, the savings generated during this first year of operation can be expected to increase substantially in subsequent years following correction of minor problems identified. As a pilot facility, the system has demonstrated the performance potential necessary to achieve economic viability for solar industrial process heat applications. The economics of a given installation depend on a number of factors including local insolation levels, system efficiency, system cost, fuel price, fuel escalation projections, local incentives, etc.

To illustrate the economics of a parabolic trough steam system, and the effect of location-related factors, a large-scale facility was evaluated at this and other sites. (Johnson & Johnson is in fact considering the following system.) The evaluation considered a 18,580 m² (200,000 ft²) collector aperture area parabolic trough solar system utilizing an aluminized acrylic film reflector, generating steam at 825 kPa (120 psig). The estimated capital cost for the system was \$9,000,000 assumed to be independent of location. Typical meteorological year insolation data were used to generate annual system fuel savings, given local fuel (natural gas) prices, an assumed boiler efficiency of 80 percent, and a fuel escalation rate of 25 percent per year. A cash flow analysis was performed including the effect of federal and state taxes applicable to an industrial facility to determine the after-tax internal rate of return.

The results of this evaluation are shown in Table 9. As illustrated by these results, the primary factors affecting system economics vary substantially with location. The composite effect on the internal rate of return shows a substantial advantage for states with higher insolation and tax credits, such as Arizona and California, and it is likely that the majority of near-term installations will be in these states. However, since the acceptable rate of return varies considerably among industries and individual companies, and since other intangibles can be valued quite differently, the internal rate of return is not a complete measure of relative viability. Other factors may combine to make a solar system an attractive investment at a location with a relatively low rate

of return. In any case, the results indicate that at current system prices a solar system for industrial process heat can present an attractive investment opportunity.

Table 9. Solar Steam System Economics

Location	Nashville Tennessee	Sherman (Forth Worth) Texas	Phoenix Arizona	Fresno California
Fuel Cost (\$/10 ⁶ Btu)	3.20	2.45	2.74	4.46
Fuel Displaced (10 ⁶ Btu/yr)	28,200	44,500	71,000	63,100
State tax credit (percent)	0	0	35	25
Internal rated return (percent)	12.2	14.3	21.5	23.9
Common assumptions:				
Field size:	18,580 m ² (200,000 ft ²)		Fuel escalation: 25 percent/yr	
Capital cost:	\$9,000,000		825 kPa (120 psig) steam system	
System life:	20 years		Total Federal tax credit: 25 percent	

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SECTION 5

OPERATION HISTORY

The first year of operation of the Johnson & Johnson solar steam system was very successful. The system was available for operation over 97 percent of the first 382 days. The collector field was unavailable for only 10 days due to several minor component failures. During the first 9 months, however, several instrument failures occasionally prevented measurement of various parameters. As a result, the performance tables, i.e., Table 2 and the Appendices, show periods where the data from some instruments are missing for some days in the months.

The following is a history of all the incidents that affected the operation and performance or the measurements of the system for the first year of operation.

- Determination of steam flowrate during the first 7 months of system operation was hampered by recurring problems with the steam flowmeter. After considerable investigation, the problem was identified to be associated with the flowmeter electronics. After replacing a portion of the flowmeter electronics and recalibrating the instrument in July, 1980 the flowmeter has performed satisfactorily every day since then.
- The DIM was bringing the system up too late in the mornings and allowing the system to run too late in the afternoons. An adjustment of the blinders on the DIM was made in March 1980, which corrected the problem.
- In April 1980, it was noted that when the system operated under high insolation conditions the pressure in the flash boiler would exceed the predicted value. The suspected cause of this anomaly was an obstruction in the steam flow line. On April 23 and 24 the system was shut down and the flash boiler was drained. The flash boiler was opened and a loose-fitting blind flange was found to be blocking the steam outlet. The flange was removed and the boiler temperature subsequently has never exceeded the design value of 180°C (355°F).
- During the first week in September a leaking pump seal was replaced. A total of 4 days of operation was lost as a result.

- Some problems with the pyranometer instrumentation limited the available insolation data for the months of July, August, and September. The problem was traced to two sources: (1) a defective Foxboro transmitter and (2) burnt-out resistors on several of the Autodata 9 datalogger input modules. The problems were corrected near the end of September, and the pyranometers have been operating satisfactorily since then.
- During the month of November the freeze protection system exhibited abnormal behavior. First, a small electronic sensor failed which resulted in the freeze protection system being turned on at ambient temperatures well above the 1.7°C (35°F) set point. This was easily corrected. Second, a failure of the Ashcroft three-way mixing valve caused the flow of water to the field to be made up almost entirely of hot water from the flash boiler. This resulted in an excessive amount of heat from the flash boiler being used to warm the collector field to prevent freezing. A hand valve has been used to temporarily reduce the flowrate of hot water from the flash boiler; however, this has not eliminated the large heat loss.
- A problem with the magnetic tape recorder resulted in a loss of data from August 24 through 31, 1980 and December 22, 1980 through January 4, 1981. In each case the data on the first part of the tape was successfully read. However, upon attempting to read the last part of the tape, the data was unreadable despite using several different methods to retrieve the data. The data on succeeding tapes was read and reduced without any problem; thus, in each instance the condition was corrected by simply using a different magnetic tape.
- In early December 1980 and in late January 1981 a flex hose on the collectors was found to be leaking and these were replaced with available spares. Upon investigation of the hose the Teflon liner was found to be cracked through the wall.

In addition, standard maintenance and replacement were performed throughout the reporting period. The collectors were realigned for proper focus of the receiver tubes in March 1980. Most of the instruments were recalibrated in April and August. All the instruments were found to be reading accurately and only small adjustments were necessary. The collector reflectors were washed six times throughout the first year. Twice they were washed by commercial firms and at least four other times the collectors were turned up in the rain to be washed.

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APPENDICES

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APPENDIX A
SYSTEM OPERATION SUMMARIES

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Table A-1. System Operation Summary
January and February 1980

	Date	Julian Day	System Status				Remarks
			System Available	System Operated	Steam Delivered	Overcast	
January	16	16	X	X	X		Calib. of instruments completed
	17	17	X	X			
	18	18	X	X	X		
	19	19	X			X	
	20	20	X			X	
	21	21	X			X	
	22	22					System being checked out
	23	23	X	X	X		
	24	24	X	X	X		
	25	25					System being checked out
February	26	26	X			X	
	27	27	X			X	
	28	28	X			X	Freeze protection on continuously during this period
	29	29	X			X	
	30	30	X			X	
	31	31	X			X	
	1	32	X	X	X		Freeze protection on when collectors stowed
	2	33	X	X			
	3	34	X	X	X		
	4	35	X			X	Freeze protection on
	5	36					System being checked out
	6	37	X	X	X		DOE walk-thru, shadow band removed
	7	38	X			X	
	8	39	X			X	Freeze protection on continuously during this period
	9	40	X			X	
	10	41	X			X	
	11	42	X	X			
	12	43	X	X	X		
	13	44	X	X	X		
	14	45	X			X	
	15	46	X			X	System operated only 1 hour
	16	47	X			X	Freeze protection on 1900 2/15
	17	48	X			X	until 1000 2/19. Flowswitch/pressure
	18	49	X			X	gage failure 2/17. Pump serviced
	19	50	X	X			to eliminate leaks 2/18. Freeze
	20	51	X	X	X		protection on when field stowed.
	21	52	X	X	X		
	22	53	X	X	X		
	23	54	X	X			Freeze protection on when field stowed
	24	55	X	X			
	25	56	X	X	X		
	26	57	X	X	X		
	27	58	X	X	X		
	28	59	X	X	X		Shadow band replaced
	29	60	X			X	

Table A-2. System Operation Summary
March 1980

	Date	Day	System Status				Remarks
			System Available	System Operated	Steam Delivered	Overcast	
March	1	61	X	X			High wind gusts sent collectors into stow several times
	2	62	X				Freeze protected; weekend -- system not operated
	3	63	X	X			Freeze protect
	4	64	X	X			Sun shone for 1 hour; tank drained overnight
	5	65	X	X			Freeze protection on; Kates & Griswold valves removed
	6	66	X	X	X		New steam flowmeter sensor installed; tank pressure relief valve leaking sporadically
	7	67	X			X	} Weekend -- system not operated; } freeze protect
	8	68	X				
	9	69	X				
	10	70	X	X			Pump was run to check system
	11	71	X			X	
	12	72	X	X			
	13	73	X	X			Contractor insulated flex hoses; system operated less than 1 hour
	14	74	X	X	X		
	15	75	X			X	
	16	76	X			X	Freeze protection on after collectors stowed
	17	77	X	X			
	18	78	X	X	X		
	19	79	X			X	Freeze protection on until 7:30 a.m.
	20	80	X	X	X		
	21	81	X	X	X		
	22	82	X				Freeze protection on for 1-1/2 hours in morning
	23	83	X				} Weekend -- system not operated
	24	84	X	X	X		
	25	85	X			X	
	26	86	X			X	Checked steam flowmeter
	27	87	X			X	
	28	88	X			X	
	29	89	X			X	West D.I.M. blinder raised slightly
	30	90	X				
	31	91	X	X			
							Realignment of collectors finished
							Replaced 12 sheets of Coilzak
							} Weekend -- system not operated
							Freeze protection on for 3 hours in the morning

Table A-3. System Operation Summary
April 1980

	Date	Day	System Status				Remarks
			System Available	System Operated	Steam Delivered	Overcast	
April	1	92	X	X			Freeze protection on for short time
	2	93	X	X			System operated for 1 hour
	3	94	X	X	X		Steam flowmeter now functioning
	4	95	X	X	X		Flash boiler relief valve opened; freeze protection on 1 hour
	5	96	X	X	X		} Weekend -- system not operated
	6	97	X				
	7	98	X	X			Flash boiler relief valve venting steam
	8	99	X	X			Flash boiler relief valve venting steam; collector on approximately 1 hour, freeze protect on approximately 1 hour
	9	100	X	X			Flash boiler burst diaphragm replaced; collectors on approximately 1 hour
	10	101	X	X	X		Tested new relief valve
	11	102	X			X	System operated about 25 minutes
	12	103	X			X	
	13	104	X			X	
	14	105	X	X	X		Slight leak from relief valve; freeze protection on 3 hours
	15	106	X	X			Flash boiler relief valve opened; freeze protection on 3 hours
	16	107	X	X	X		Flash boiler relief valve opened; freeze protection on 3 hours
	17	108	X	X	X		
	18	109	X	X			System operated only 2 hours
	19	110	X				Instruments calibrated today
	20	111	X				} Weekend -- system not operated
	21	112	X	X			
	22	113	X	X	X		Flash boiler freeze protection for short while, pressure 185 psig; flow restriction between flash boiler and J&J steam header discovered
	23	114					Flash boiler emptied
	24	115				X	Flash boiler steam flow restriction removed
	25	116	X	X			System operated less than 2 hours
	26	117	X			X	} Weekend -- system not operated
	27	118	X				
	28	119	X	X	X		Steam flowrate of 1300 lb/hr noted
	29	120	X	X			System being checked out
	30	121	X	X			System operated only 3 hours

Table A-4. System Operation Summary
May 1980

Date	Day	System Status				Remarks	
		System Available	System Operated	Steam Delivered	Overcast		
May	1	122	X			X	System ran 1 hour; total insolation monitor not working
	2	123	X			X	System ran less than 1 hour; total insolation monitor fixed
	3	124	X	X			System on approximately 4 hours
	4	125	X			X	
	5	126	X	X			Cloudy in the afternoon
	6	127	X	X			System ran approximately 3 hours
	7	128	X	X	X		System on 7.5 hours
	8	129	X			X	
	9	130	X	X			System on approximately 1 hour in late afternoon
	10	131	X	X	X		
	11	132	X			X	
	12	133	X			X	Washed collectors in rain
	13	134	X			X	
	14	135	X	X			
	15	136	X			X	
	16	137	X	X	X		
	17	138	X	X	X		
	18	139	X	X			Cloudy in morning
	19	140	X	X	X		Cloudy in afternoon
	20	141	X	X	X		Cloudy in afternoon; system operated approximately 1 hour
	21	142	X			X	Heavy clouds in afternoon
	22	143	X			X	
	23	144	X	X			System ran in morning
	24	145	X				} Weekend -- system not operated
	25	146	X				
	26	147	X	X			System ran less than 2 hours
	27	148	X			X	System operated less than hour
	28	149	X	X			
	29	150	X	X			System on & off all day -- dedication day
	30	151	X			X	Horizontal pyranometer installed
	31	152	X			X	

Table A-5. System Operation Summary
June 1980

			System Status				
			System Available	System Operated	Steam Delivered	Overcast	
Date	Day						Remarks
June	1	153	X			X	System off all day
	2	154	X			X	Sun in & out - mainly overcast
	3	155	X	X			Sun in & out - no heat collected
	4	156	X	X	X		Sys. on late in day (11am) - gen. steam
	5	157	X	X	X		Cloudy in the afternoon
	6	158	X	X	X		Sys. on late in day (11am) - gen. steam
	7	159	X			X	Cloudy all day - sys. run for movie crew
	8	160	X			X	Overcast all day
	9	161	X			X	Overcast all day
	10	162	X	X	X		
	11	163	X	X	X		Gen. steam within 3 hrs of sys. startup
	12	164	X	X	X		System down due to clouds in afternoon
	13	165	X	X	X		Steam generation started in mid-morning (10am)
	14	166	X	X	X		System shutdown before noon due to plant shutdown
	15	167	X	X	X		System on all day
	16	168	X	X	X		System on until 1:45 pm - then overcast
	17	169	X	X	X		System on & off several times during day
	18	170	X	X	X		System on approximately 9am
	19	171	X	X	X		Rain in morning - sys. on approx. 11am
	20	172	X	X			Insolation monitor malfunctioning - system up late due to overcast
	21	173	X	X	X		Cloudy in morning. No insolation data
	22	174	X	X			Malfunction in data collection system - no operating data
	23	175	X	X	X		Same as June 22, Day 174
	24	176	X	X	X		No insolation data
	25	177	X	X	X		No insolation data
	26	178	X	X	X		No insolation data
	27	179	X	X	X		No insolation data
	28	180	X	X	X		No insolation data
	29	181	X	X	X		No insolation data
	30	182	X	X	X		Malfunction in data collection system

Table A-6. System Operation Summary
July 1980

Date	Day	System Status				Remarks
		System available	System operated	Steam generated	Overcast	
July 1	183	X	X	X		Steam flow before 11 a.m.
2	184	X	X	X		
3	185	X	X	X		
4	186	X	X	X		
5	187	X	X	X		
6	188	X	X	X		
7	189	X	X	X		
8	190	X	X	X		
9	191	X	X	X		
10	192	X	X	X		System on late, approximately 8:45 a.m., steam flow at 10:30 a.m. Steam flow at 10:30 a.m.
11	193	X	X	X		
12	194	X	X	X		
13	195	X				
14	196	X	X	X		Low pressure in plant instrument air caused system to malfunction System down once at 12:30 p.m.
15	197	X	X	X		
16	198	X	X	X		
17	199	X	X	X		
18	200	X	X	X		
19	201	X	X	X		
20	202	X	X	X		
21	203	X	X			
22	204	X	X	X		Partly cloudy in afternoon Mag tape malfunction at approximately 6:00 p.m. System on late, approximately 12:00 p.m. Mag tape restored approximately 9:00 a.m. Sun in and out System on and off today -- clouds System on and off today -- clouds Cloudy in morning Mag tape malfunction
23	205	X	X	X		
24	206	X	X	X		
25	207	X	X	X		
26	208	X	X	X		
27	209	X	X			
28	210	X	X	X		
29	211	X	X	X		
30	212	X	X	X		
31	213	X	X	--		

Table A-7. System Operation Summary
August 1980

Date	Day	System Status				Remarks
		System Available	System Operated	Steam Generated	Overcast	
Aug	1	214	X	X	X	
	2	215	X	X	X	
	3	216	X			
	4	217	X	X		X
	5	218	X	X	--a	Cloudy -- system ran some in afternoon only
	6	219	X	X	--	Cloudy in morning -- system on in afternoon
	7	220	X	X	--	System up until 3 p.m. -- cloudy after 3 p.m.
	8	221	X	X	--	Cloudy in afternoon
	9	222	X		--	Cloudy in afternoon
	10	223	X		--	X
	11	224	X	X	--	X
	12	225	X		--	X
	13	226	X	X	--	Cloudy
	14	227	X	X	--	System ran 1 hr
	15	228	X	X	--	System down after 2 p.m. -- cloudy
	16	229	X	X		System ran less than 2 hr
	17	230	X	X		} Sun in and out -- system did not run much
	18	231	X	X	X	
	19	232	X	X	X	
	20	233	X	X	X	
	21	234	X	X	X	Cloudy in afternoon
	22	235	X	X	X	
	23	236	X	X	X	
	24	237	X	X	--a	
	25	238	X	X	--	
	26	239	X	X	--	Hazy in afternoon
	27	240	X	X	--	System down at noon -- clouds
	28	241	X			X
	29	242	X	X	--	Cloudy in a.m. and p.m. -- system ran some
	30	243	X	X	--	Occasional clouds
	31	244	X	X	--	Occasional clouds, pump leaking excessively

aSteam generated data not available due to magnetic tape malfunction

Table A-8. System Operation Summary
September 1980

Date	Day	System Status				Remarks
		System Available	System Operated	Steam Generated	Overcast	
Sep	1	245				System down to investigate pump seal leak
	2	246	X	X		
	3	247	X	X	X	
	4	248	X	X	X	System shutdown at 4 p.m. due to high wind
	5	249	X	X	X	
	6	250				System down to cool pump prior to seal replacement
	7	251				System down to cool pump prior to seal replacement
	8	252				Pump seal replaced
	9	253	X	X		Operated midmorning — cloudy otherwise
	10	254	X	X		
	11	255	X	X		Rupture disc blown — replaced
	12	256	X	X	X	
	13	257	X	X	X	
	14	258	X	X	X	
	15	259	X	X	X	Cloudy in afternoon
	16	260	X	X		System shut down at 11:00 a.m. due to plant boiler problems
	17	261	X	X	X	
	18	262	X	X		Partly cloudy
	19	263				General maintenance performed; collectors cleaned; one tracker motor replaced
	20	264	X	X	X	
	21	265	X		X	Partly cloudy and high winds
	22	266	X	X		Cloudy
	23	267	X	X		Cloudy
	24	268	X	X		Rain after 10:30 a.m.
	25	269	X		X	
	26	270	X		X	
	27	271	X		X	
	28	272	X		X	
	29	273	X		X	
	30	274	X		X	

Table A-9. System Operation Summary
October 1980

Date	Day	System Status				Remarks
		System Available	System Operated	Steam Generated	Overcast	
Oct 1	275	X	X			
2	276	X	X	X		
3	277	X	X	X		
4	278	X	X	X		
5	279	X	X	X		
6	280	X	X			Cloudy with rain until late afternoon
7	281	X	X	X		Partly cloudy morning
8	282	X	X	X		
9	283	X	X	X		Partly cloudy afternoon
10	284	X	X	X		
11	285	X	X	X		
12	286	X	X	X		
13	287	X	X	X		
14	288	X	X			Cloudy with rain until late afternoon
15	289	X			X	
16	290	X			X	
17	291	X	X			Partly cloudy morning
18	292	X	X			Partly cloudy
19	293	X	X	X		
20	294	X	X	X		
21	295	X	X	X		Partly cloudy afternoon
22	296	X	X	X		
23	297	X	X	X		
24	298	X	X	X		
25	299	X	X	X		
26	300	X			X	
27	301	X	X			
28	302	X				High winds: 25 to 40 mph; freeze protection system operated
29	303	X	X	X		Freeze protection system operated
30	304	X	X	X		Freeze protection system operated
31	305	X	X	X		

Table A-10. System Operation Summary
November 1980

Date	Day	System Status				Remarks
		System Available	System Operated	Steam Generated	Overcast	
Nov 1	306	X	X	X		24 superior drive motors replaced
2	307	X	X	X		
3	308	X	X	X		
4	309	X	X	X		
5	310	X	X	X		Freeze protect on
6	311	X	X			
7	312	X	X	X		
8	313	X	X	X		Partly overcast freeze protect on
9	314	X	X	X		Partly overcast freeze protect on
10	315	X	X	X		Partly cloudy
11	316	X			X	Turned off for test of heat loss
12	317	X	X	X		Ran test of heat loss
13	318	X	X			
14	319	X			X	Freeze protect on
15	320	X			X	Freeze protect on
16	321	X			X	Freeze protect on
17	322	X			X	Freeze protect on
18	323	X	X			Freeze protect on
19	324	X	X			Freeze protect on
20	325	X	X			Freeze protect on
21	326	X			X	Freeze protect on
22	327	X			X	Freeze protect on
23	328	X			X	Freeze protect on
24	329	X			X	Freeze protect on
25	330	X	X			Freeze protect on, partly cloudy
26	331	X			X	Freeze protect on
27	332	X	X			Freeze protect on, partly cloudy
28	333	X	X			Freeze protect on
29	334	X	X			Freeze protect on
30	335	X	X	X		Freeze protect on

Table A-11. System Operation Summary
December 1980

Date	Day	System Status				Remarks
		System Available	System Operated	Steam Generated	Overcast	
Dec 1	336	X	X			Freeze protect on
2	337	X	X			↓
3	338	X			X	
4	339	X			X	
5	340	X			X	
6	341	X			X	Freeze protection repaired and collectors washed
7	342	X			X	
8	343	X			X	
9	344	X	X			
10	345	X	X			Freeze protect on
11	346	X	X	X		↓
12	347	X	X	X		
13	348	X	X			
14	349	X	X	X		
15	350	X	X	X		
16	351	X	X	X		
17	352	X	X	X		Freeze protect on
18	353	X	X	X		
19	354	X			X	Freeze protect on
20	355	X			X	↓
21	356	X	X	X		Freeze protect on, clear days, cold nights
22	357	X	X			Freeze protect on, data tape unreadable
23	358	X	X			↓
24	359	X	X			
25	360	X	X			
26	361	X	X			
27	362	X	X			
28	363	X	X			
29	364	X	X			
30	365	X	X			
31	366	X	X	X		↓

Table A-12. System Operation Summary
January 1981

Date	Day	System Status				Remarks
		System Available	System Operated	Steam Generated	Overcast	
Jan 1	1	X				Magnetic data tape unreadable
2	2	X				↓
3	3	X	X	X		Freeze protect; changed tracker board
4	4	X				↓
5	5	X			X	
6	6	X	X			
7	7	X	X			
8	8	X	X			
9	9	X	X			
10	10	X			X	Freeze protect
11	11	X	X			↓
12	12	X	X	X		
13	13	X	X	X		
14	14	X	X	X		
15	15	X	X	X		
16	16	X	X			
17	17	X	X			
18	18	X			X	
19	19	X			X	
20	20	X			X	
21	21	X			X	
22	22	X	X			
23	23	X	X			
24	24	X	X	X		
25	25	X	X			
26	26	X			X	Freeze protect
27	27	X	X			↓
28	28	X	X	X		
29	29	X	X			
30	30	X			X	Freeze protect
31	31	X			X	↓

APPENDIX B
SINGLE DAY PERFORMANCE TABLES

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Table B-1. Single Day Performance Table^a
Day 34, February 3, 1980

Hour	Direct Insolation on Collector Plane Btu/ft ² /hr	Energy to Boiler 10 ⁶ Btu/hr	Auxiliary Electrical Energy kw	Flash Boiler Temperature °F	Field ^b Efficiency %	Field Temperature		Ambient Temperature °F	Wind Speed mph
						Inlet °F	Outlet °F		
0-1			1.14	302.7				32.1	7.05
1-2			1.82	302.1				31.4	6.60
2-3			2.52	301.1				30.9	6.25
3-4			2.52	301.3				30.2	5.85
4-5			2.52	301.9				29.1	4.40
5-6			2.52	302.6				28.0	1.70
6-7			2.52	303.2				29.1	2.30
7-8			2.52	303.8				28.9	1.65
8-9			2.49	304.3				34.3	9.65
9-10	261.1	0.917	10.5	283.3	31	259	293	39.7	11.20
10-11	279.5	0.881	10.5	314.3	28	292	325	44.8	9.15
11-12	274.8	0.751	10.5	349.4	24	326	354	51.4	6.60
12-13	256.3	0.629	10.5	368.3	21	351	374	51.4	10.15
13-14	213.5	0.371	9.7	369.3	15	364	377	54.7	4.60
14-15	166.5	0.085	9.7	364.2	4	362	365	54.4	8.90
15-16	63.5	-0.043	5.3	354.0	-6	355	352	60.3	0.10
16-17			2.52	350.4				57.3	0.10
17-18			2.49	349.9				49.8	2.00
18-19			2.43	350.3				44.1	4.05
19-20			2.4	350.3				41.8	2.45
20-21			2.37	349.1				41.2	1.45
21-22			2.4	348.5				38.4	0.65
22-23			2.31	348.1				36.6	2.40
23-24			2.23	348.1				35.1	4.95
Total	1515.2 Btu/ft ²	3.54 x 10 ⁶ Btu	106 kw-hr		20%				

^aSteam data not available due to steam flow meter malfunction

^bField efficiency = $\frac{\text{Energy to boiler}}{\text{Direct insolation} \times \text{collector area}} \times 100 \text{ percent}$

Table B-2. Single Day Performance Table^a
Day 081, March 21, 1980

Hour	Direct Insolation on Collector Plane	Energy to Boiler	Auxiliary Electrical Energy	Flash Boiler Temperature	Field ^b Efficiency	Field Temperature		Ambient Temperature	Wind Speed
						Inlet	Outlet		
	Btu/ft ² /hr	10 ⁶ Btu/hr	kW	°F	%	°F	°F	°F	mph
0-1			0.843	336				41.8	3.95
1-2			1.75	335				40.7	3.8
2-3			1.09	333				39.5	3.75
3-4			0.866	332				38.1	4.57
4-5			0.866	331				39.1	5.4
5-6			1.76	329				41.2	5.88
6-7			2.21	328				41.7	4.22
7-8			1.05	327				49.7	1.15
8-9	178.1	0.561	8.96	308	27	281	307	59.5	6.57
9-10	237.3	0.777	10.8	322	28	295	318	65.4	10.8
10-11	257.9	1.08	10.6	352	38	325	358	69.0	9.5
11-12	269.8	1.14	10.7	373	38	351	386	73.8	7.45
12-13	258.9	0.994	10.7	382	34	369	399	73.0	7.13
13-14	236.1	0.801	10.6	384	31	375	400	76.3	6.02
14-15	208.2	0.683	10.4	383	30	368	389	77.4	5.67
15-16	169.9	0.343	10.3	369	18	350	360	73.7	4.55
16-17	74.1	0.146	7.84	364	18	356	363	75.0	5.75
17-18			0.843	357				69.9	7.37
18-19			0.843	355				62.0	4.18
19-20			0.866	353				55.9	3.32
20-21			0.882	352				52.5	2.92
21-22			0.882	350				50.4	3.33
22-23			0.905	349				49.5	3.85
23-24			0.782	347				47.4	1.16
Total	1890 Btu/ft ²	6.53 x 10 ⁶ Btu	107.3 k/W-hr		30%				

^aSteam data not available due to steam flow meter malfunction

^bField efficiency = $\frac{\text{Energy to boiler}}{\text{Direct insolation} \times \text{collector area}} \times 100 \text{ percent}$

Table B-3. Single Day Performance Table
Day 095, April 4, 1980

Hour	Direct Insolation on Collector Plane	Energy to Boiler	Auxiliary Electrical Energy	Flash Boiler Temperature	Field ^a Efficiency	Field Temperature		Ambient Temperature	Wind- Speed	Steam to Main		System Efficiency
						Inlet	Outlet			Flow	Energy	
	Btu/ft ² /hr	10 ⁶ Btu/hr	kW	°F	%	°F	°F	°F	mph	lb/hr	10 ⁶ Btu/hr	%
0-1			1.12	346				49	8.0			
1-2			1.14	344				49	7.0			
2-3			1.15	342				47	6.8			
3-4			1.15	340				45	7.0			
4-5			1.14	338				44	5.5			
5-6			1.05	337				43	6.2			
6-7			1.09	335				43	5.8			
7-8			2.55	330				47	9.8			
8-9	194	0.678	9.48	307	2	205	304	53	10.0			
9-10	235	0.957	9.38	337	36	311	339	54	11.1	19.8	0.018	1
10-11	257	1.12	9.35	363	39	341	374	57	10.4	442	0.410	14
11-12	262	1.19	9.53	380	41	364	399	61	8.3	732	0.679	23
12-13	255	1.10	9.65	385	39	377	410	61	6.9	807	0.748	26
13-14	237	1.03	9.48	385	39	367	397	65	7.9	764	0.708	26
14-15	204	0.663	9.55	379	29	365	385	67	8.3	670	0.621	27
15-16	171	0.431	9.46	379	23	371	383	68	5.2	636	0.590	30
16-17	50.7	0.016	5.87	369	1	368	370	68	6.6	192	0.178	31
17-18			1.06	359				66	5.4			
18-19			1.04	357				60	5.5			
19-20			1.05	355				58	2.8			
20-21			1.06	354				57	1.5			
21-22			1.07	352				55	2.8			
22-23			1.07	350				51	2.6			
23-24			0.882	349				49	1.1			
Total	1866 Btu/ft ²	7.19 x 10 ⁶ Btu	99.4 kW-hr		34%					4263 lb	3.95 x 10 ⁶ Btu	19%

^aField efficiency = $\frac{\text{Energy to boiler}}{\text{Direct insolation} \times \text{collector area}} \times 100 \text{ percent}$

Table B-4. Single Day Performance Table^a
Day 131, May 10, 1980

Hour	Direct Insolation on Collector Plane	Energy to Boiler	Auxiliary Electrical Energy	Flash Boiler Temperature	Field ^b Efficiency	Field Temperature		Ambient Temperature	Wind Speed
						Inlet	Outlet		
	Btu/ft ² /hr	10 ⁶ Btu/hr	kW	°F	%	°F	°F	°F	mph
0-1			0.836	253.8				61.1	7.3
1-2			0.859	253.2				61.8	8.6
2-3			0.866	252.9				62.2	10.4
3-4			0.866	252.1				62.0	10.8
4-5			0.851	251.6				61.8	10.9
5-6			0.836	251.1				61.2	10.8
6-7			0.828	250.5				62.1	10.3
7-8			0.851	249.8				64.1	10.6
8-9			0.889	249.5				68	16.7
9-10	21.9		4.56	245.5				72	16.7
10-11	181.9	0.727	10.6	244.9	2	223	248	76	16.4
11-12	208.9	0.949	10.3	275.7	40	248	280	79.7	18.3
12-13	223.3	1.01	10.1	308.9	40	279	314	82.5	19.2
13-14	221.0	0.897	10.1	338.3	37	311	342	84.8	18.4
14-15	210.1	0.760	10.1	352.2	32	338	364	87.9	15.7
15-16	188.4	0.697	10.2	353.5	33	348	371	89.2	15.7
16-17	162.4	0.528	10.2	353.1	29	349	367	89.2	15.1
17-18			10.6	346.6				86.7	17.3
18-19			9.84	332.6				83.0	13.3
19-20			9.83	320.2				78.8	12.2
20-21			0.859	314.2				75.5	11.2
21-22			0.866	312.8				73.6	11.2
22-23			0.882	311.6				72.3	12.1
23-24			0.751	310.5				71.7	13.5
Total	1418 Btu/ft ²	5.57 x 10 ⁶ Btu	117 kW-hr		34%				

^aSteam data not available due to steam flow meter malfunction

^bField efficiency = $\frac{\text{Energy to boiler}}{\text{Direct insolation} \times \text{collector area}} \times 100 \text{ percent}$

Table B-5. Single Day Performance Table^a
Day 165, June 13, 1980

Hour	Direct Insolation on Collector Plane Btu/ft ² /hr	Energy to Boiler 10 ⁶ Btu/hr	Auxiliary Electrical Energy kW	Flash Boiler Temperature °F	Field ^b Efficiency %	Field Temperature		Ambient Temperature °F	Wind Speed mph
						Inlet	Outlet		
						°F	°F		
0-1			0.644	330				72.9	3.4
1-2			0.629	329				70.4	3.7
2-3			0.644	328				70.2	4.4
3-4			0.652	327				68.9	4.6
4-5			0.644	326				68.9	5.6
5-6			0.652	325				67.0	4.9
6-7			0.682	325				66.6	3.2
7-8			5.56	314				70.4	4.3
8-9	126	0.17	10.64	304	11	296	302	77.2	8.0
9-10	189	0.513	10.59	318	24	302	319	83.6	11.4
10-11	233	0.781	10.56	340	30	319	345	88.1	12.8
11-12	260	1.01	10.46	352	35	341	375	90.8	14.6
12-13	272	1.25	10.47	353	41	349	391	93.3	13.6
13-14	275	1.30	10.45	355	42	338	382	95.3	13.0
14-15	267	1.14	10.37	355	38	351	389	96.9	10.8
15-16	244	1.04	10.36	354	38	339	374	97.8	11.2
16-17	217	0.833	10.33	353	34	349	377	97.2	11.5
17-18	197	0.718	10.4	353	32	349	373	95.7	9.3
18-19	46	-0.059	6.10	348	-11	347	340	91.6	12.8
19-20			.667	346				88.2	12.2
20-21			0.652	344				84.2	9.2
21-22			0.659	343				81.1	11.0
22-23			0.690	342				79.0	8.9
23-24			0.629	341				77.2	7.1
Total	2326 Btu/ft ²	8.70 x 10 ⁶ Btu	124 kW-hr		33%				

^aSteam data not available due to steam flow meter malfunction

^bField efficiency = $\frac{\text{Energy to boiler}}{\text{Direct insolation} \times \text{collector area}} \times 100 \text{ percent}$

Table B-6. Single Day Performance Table^a
Day 190, July 8, 1980

Hour	Direct Insolation on Collector Plane ^a	Energy to Boiler	Auxiliary Electrical Energy	Flash Boiler Temperature	Field ^b Efficiency	Field Temperature		Ambient Temperature	Wind Speed	Steam to Main		System ^b Efficiency
						Inlet	Outlet			Flow	Energy	
	Btu/ft ² /hr	10 ⁶ Btu/hr	kW	°F	%	°F	°F	°F	mph	lb/hr	10 ⁶ Btu/hr	%
0-1			1.07	339.7				82.9	5.02			
1-2			0.836	338.6				81.6	5.83			
2-3			0.873	337.7				80.7	4.85			
3-4			0.859	336.7				80.1	6.4			
4-5			0.828	335.8				79.3	7.04			
5-6			0.813	334.9				77.6	5.03			
6-7			0.821	334				76.9	4.62			
7-8		0.01	3.83	325.3		305	307	80.6	6.34			
8-9		0.238	10.1	313		306	313	85.8	8.03			
9-10		0.557	10.1	329.2		314	333	89.8	10.9			
10-11		0.822	10.1	348.2		332	360	94.3	9.62	556	0.516	
11-12		1.18	10.1	353		348	388	97.7	10.2	1140	1.06	
12-13		1.38	10.1	354		339	386	100	9.48	1340	1.24	
13-14		1.37	10.1	355.1		351	398	102	11.5	1330	1.23	
14-15		1.31	10.1	354.3		336	381	103	10.7	1270	1.18	
15-16		1.08	10.1	352.8		350	387	104	9.86	1050	0.976	
16-17		0.938	10.1	352.7		352	384	104	12.9	910	0.844	
17-18		0.830	10.1	350.9		337	366	102	12.5	806	0.747	
18-19		-0.018	6.14	347.3		348	344	98.4	9.7			
19-20			0.851	344.5				95.4	8.74			
20-21			0.835	343.4				91.7	6.02			
21-22			0.836	342.5				88	5.47			
22-23			0.843	341.5				85.5	5.55			
23-24			0.728	340.7				84.4	5.54			
Total		9.70 x 10 ⁶ Btu	121 kW-hr							8400 lb	7.79 x 10 ⁶ Btu	

^aNot available -- pyranometer malfunction

^bNot available -- depends on direct insolation measurement

Table B-7. Single Day Performance Table
Day 233, August 20, 1980

Hour	Direct Insolation on Collector Plane ^a	Energy to Boiler	Auxiliary Electrical Energy	Flash Boiler Temperature	Field ^a Efficiency	Field Temperature		Ambient Temperature	Wind Speed	Steam to Main		System ^b Efficiency
						Inlet	Outlet			Flow	Energy	
						°F	°F			lb/hr	10 ⁶ Btu/hr	
0-1			0.598	337				85.2	9.97			
1-2			0.598	336				84.6	9.81			
2-3			0.603	335				83.6	9.7			
3-4			0.631	334				82.3	7.69			
4-5			0.619	332				81.6	9.36			
5-6			0.608	331				80.9	9.91			
6-7			0.621	330				79.4	9.33			
7-8			1.03	329				80.1	9.18			
8-9			1.94	321				83.1	12.8			
9-10	186	0.230	10.2	309	8	295	303	86.7	12.2			
10-11	229	0.749	10.2	332	29	310	336	90.7	12.2			
11-12	260	0.968	10.2	351	33	333	368	94.8	11.2	565	0.524	18
12-13	274	1.18	10.1	353	38	336	378	98.5	11.9	991	0.918	29
13-14	273	0.996	10.1	352	33	348	383	102.	12.6	1150	1.07	34
14-15	258	0.858	10.2	353	30	349	380	103.	13.3	1070	0.996	34
15-16	232	0.680	10.3	350	26	333	357	103.	12.7	447	0.414	16
16-17	201	0.514	10.1	351	23	345	363	105.	10.1	506	0.469	20
17-18	148	0.171	9.99	351	10	348	354	105.	8.43	285	0.264	16
18-19			2.71	345				101.	9.77			
19-20			0.647	343				97.6	7.42			
20-21			0.636	342				93.6	5.21			
21-22			0.636	341				90.9	7.26			
22-23			0.636	340				89.9	7.82			
23-24			0.529	339				98.2	6.54			
Total	2061	6.35	104.		27					5010	4.65	20

$$^a \text{Field efficiency} = \frac{\text{Collected energy}}{\text{Direct insolation} \times \text{collector area}} \times 100\%$$

$$^b \text{System efficiency} = \frac{\text{Delivered energy}}{\text{Direct insolation} \times \text{collector area}} \times 100\%$$

Table B-8. Single Day Performance Table
Day 249, September 5, 1980

Hour	Direct Insolation on Collector Plane ^a	Energy to Boiler	Auxiliary Electrical Energy	Flash Boiler Temperature	Field ^a Efficiency	Field Temperature		Ambient Temperature	Wind Speed	Steam to Main		System ^b Efficiency
						Inlet	Outlet			Flow	Energy	
	Btu/ft ² /hr	10 ⁶ Btu/hr	kW	°F	Percent	°F	°F	°F	mph	lb/hr	10 ⁶ Btu/hr	percent
0-1			0.59	327				77	3.8			
1-2			0.58	326				75	3.0			
2-3			0.60	325				74	2.2			
3-4			0.61	324				74	0.6			
4-5			0.60	323				74	0.4			
5-6			0.58	322				75	2.5			
6-7			0.60	321				74	1.0			
7-8			0.59	320				77	0.1			
8-9	115	-0.056	10.14	299	--	272	260	87	0.7			
9-10	201	0.638	10.08	310	28	290	312	91	0.6			
10-11	242	0.883	9.99	335	32	309	340	97	2.3			
11-12	218	0.840	9.99	351	34	335	365	99	6.8	466	0.432	17
12-13	252	1.071	10.04	354	37	347	385	101	7.4	1177	1.091	38
13-14	216	0.928	10.27	354	38	349	382	103	10.9	1124	1.042	42
14-15	122	0.161	10.59	349	12	331	333	104	10.4	276	0.256	18
15-16	190	0.396	9.92	348	18	337	350	105	10.6			
16-17	122	0.099	10.27	350	7	344	348	105	11.9			
17-18	0	-0.055	2.80	348	--	346	338	103	11.7			
18-19			0.61	347				98	9.3			
19-20			0.62	346				92	9.2			
20-21			0.60	345				88	6.2			
21-22			0.61	344				85	6.0			
22-23			0.65	343				84	4.1			
23-24			0.54	342				83	5.8			
Daily value	1678 (Btu/ft ²)	4.905 (10 ⁶ Btu)	102.47 (kW-hr)	--	26	--	--	--	--	3043 (lb)	2.821 (10 ⁶ Btu)	15

$$^a \text{Field efficiency} = \frac{\text{Collected energy}}{\text{Direct insolation} \times \text{collector area}} \times 100 \text{ percent}$$

$$^b \text{System efficiency} = \frac{\text{Delivered energy}}{\text{Direct insolation} \times \text{collector area}} \times 100 \text{ percent}$$

Table B-9. Single Day Performance Table
Day 278, October 4, 1980

Hour	Direct Insolation on Collector Plane	Energy to Boiler	Auxiliary Electrical Energy	Flash Boiler Temperature	Field ^a Efficiency	Field Temperature		Ambient Temperature	Wind Speed	Steam to Main		System ^b Efficiency
						Inlet	Outlet			Flow	Energy	
	Btu/ft ² /hr	10 ⁶ Btu/hr	kW	°F	Percent	°F	°F	°F	mph	lb/hr	10 ⁶ Btu/hr	Percent
0-1			1.03	336				66	7.0			
1-2			0.81	335				65	8.8			
2-3			0.78	334				64	8.2			
3-4			0.82	332				64	9.7			
4-5			0.82	331				63	8.1			
5-6			0.82	330				60	6.4			
6-7			0.80	329				60	5.8			
7-8			0.79	327				60	4.5			
8-9	122	-0.775	7.14	310	--	289	250	66	6.6			
9-10	232	0.967	10.40	323	36	295	328	72	10.2			
10-11	260	1.122	10.33	349	38	325	364	76	17.3	437	0.405	14
11-12	276	1.251	10.51	356	40	348	391	80	14.6	1269	1.176	37
12-13	272	1.245	10.51	359	40	353	396	81	15.8	1407	1.304	42
13-14	253	1.035	10.33	356	36	337	373	82	14.4	783	0.726	25
14-15	222	0.713	10.30	356	28	351	375	82	12.9	824	0.764	30
15-16	187	0.377	10.19	355	18	351	364	83	12.0	453	0.420	20
16-17	144	0.108	10.04	355	6	350	354	83	10.4			
17-18	11	-0.059	4.51	347	--	346	334	82	7.4			
18-19			0.84	345				80	4.6			
19-20			0.83	344				70	4.4			
20-21			0.87	343				67	3.2			
21-22			0.86	341				64	4.3			
22-23			0.86	340				62	0.5			
23-24			0.71	339				61	2.3			
Daily value	1979 (Btu/ft ²)	5.98 (10 ⁶ Btu)	105.9 (kW-hr)	—	26	—	--	—	—	5173 (lb)	4.795 (10 ⁶ Btu)	21

^aField efficiency = $\frac{\text{Collected energy}}{\text{Direct insolation} \times \text{collector area}} \times 100 \text{ percent}$

^bSystem efficiency = $\frac{\text{Delivered energy}}{\text{Direct insolation} \times \text{collector area}} \times 100 \text{ percent}$

Table B-10. Single Day Performance Table
Day 309, November 4, 1980

Hour	Direct Insolation on Collector Plane	Energy to Boiler	Auxiliary Electrical Energy	Flash Boiler Temperature	Field ^a Efficiency	Field Temperature		Ambient Temperature	Wind Speed	Steam to Main		System ^b Efficiency
						Inlet	Outlet			Flow	Energy	
	Btu/ft ² /hr	10 ⁶ Btu/hr	kW	°F	Percent	°F	°F	°F	mph	lb/hr	10 ⁶ Btu/hr	Percent
0-1			0.728	331.3				61.3	5.49			
1-2			0.729	330.0				60.6	5.96			
2-3			0.705	328.9				60.0	5.59			
3-4			0.766	327.7				59.8	5.98			
4-5			1.18	316.9				56.4	5.17			
5-6			0.751	307.7				53.9	5.08			
6-7			1.40	288.4				52.4	4.83			
7-8			0.713	286.1				52.5	7.13			
8-9	105.6	+0.153	7.80	285.7	6.0	263.4	265.9	56.8	6.36			
9-10	246.7	1.021	10.4	311.6	36.9	284.0	318.6	62.7	7.78			
10-11	267.5	1.157	10.4	344.2	38.6	317.7	357.1	72.6	8.99	296	0.274	9.0
11-12	246.4	0.983	10.5	350.2	35.9	345.2	378.9	74.3	10.8	1,038	0.962	34.1
12-13	221.7	0.871	10.2	348.8	39.0	332.2	361.8	74.4	9.21	584	0.541	21.3
13-14	217.3	0.639	10.3	349.5	26.1	346.3	368.1	77.0	6.75	728	0.675	27.2
14-15	173.7	0.312	10.2	349.0	15.7	346.8	357.4	75.7	8.07	242	0.224	11.3
15-16	128.1	0.016	10.2	348.4	1.1	345.8	346.4	73.4	8.92			
16-17	57.4	-0.189	8.50	343.3	--	342.4	334.9	73.1	5.34			
17-18			0.690	338.3				71.1	1.86			
18-19			0.683	337.3				63.8	0.41			
19-20			0.720	336.1				59.7	0.67			
20-21			0.690	334.9				57.7	0.94			
21-22			0.713	333.7				55.1	1.30			
22-23			0.713	332.5				53.7	1.40			
23-24			0.590	331.3				54.2	4.91			
Daily value	1,664.4 (Btu/ft ²)	4.964 (10 ⁶ Btu)	100.28 (kW-hr)	--	26.1	--	--	--	--	2,888 (lb)	2.68 (10 ⁶ Btu)	14.1

^aField efficiency = $\frac{\text{Collected energy}}{\text{Direct insolation} \times \text{collector area}} \times 100 \text{ percent}$

^bSystem efficiency = $\frac{\text{Delivered energy}}{\text{Direct insolation} \times \text{collector area}} \times 100 \text{ percent}$

Table B-11. Single Day Performance Table
Day 346, December 11, 1980

Hour	Direct Insolation on Collector Plane	Energy to Boiler	Auxiliary Electrical Energy	Flash Boiler Temperature	Field ^a Efficiency	Field Temperature		Ambient Temperature	Wind Speed	Steam to Main		System ^b Efficiency
						Inlet	Outlet			Flow	Energy	
	Btu/ft ² /hr	10 ⁶ Btu/hr	kW	°F	Percent	°F	°F	°F	mph	lb/hr	10 ⁶ Btu/hr	Percent
0-1			2.35	261.5				33.6	5.3			
1-2			2.35	250.4				34.6	7.1			
2-3			2.35	242.6				34.2	6.1			
3-4			2.39	236.9				34.2	4.4			
4-5			1.83	232.9				34.0	3.9			
5-6			2.35	228.0				33.3	5.4			
6-7			2.35	222.8				32.4	5.3			
7-8	0.0	0.0	2.35	217.1				33.1	5.6			
8-9	112.6	0.05	6.18	218.0	3.9	203.3	207.0	38.2	6.8			
9-10	252.5	1.17	10.6	246.6	40.5	216.3	256.0	45.9	7.8			
10-11	265.8	1.28	10.6	288.2	42.1	255.2	298.5	52.7	8.2			
11-12	251.8	1.00	10.4	322.0	34.7	296.0	329.8	56.4	9.0			
12-13	224.0	0.691	10.3	342.8	27.4	327.3	350.7	59.3	7.7			
13-14	180.9	0.317	10.3	346.8	15.5	343.8	354.5	62.5	8.7	136.9	0.126	6.1
14-15	126.3	0.01	10.2	346.4	1.4	345.8	346.2	63.7	9.9	62.0	0.057	4.0
15-16	56.1	-0.28	10.1	339.8	--	339.7	330.3	62.7	8.4	92.0	0.085	13.3
16-17	0.9	-0.11	4.1	329.2	--	331.0	320.0	59.6	7.1	0.0		
17-18	0.0	0.0	0.7	327.4				52.6	4.6			
18-19			0.7	326.4				49.2	4.4			
19-20			0.7	325.3				45.9	4.6			
20-21			0.7	324.1				45.1	5.9			
21-22			0.7	323.0				44.4	6.0			
22-23			0.7	321.8				43.0	6.1			
23-24			0.6	320.7				41.5	5.0			
Daily value	1,471.0 (8tu/ft ²)	4.128 (10 ⁶ Btu)	105.9 (kW-hr)	--	24.5	--	--	--	--	291.0 (lb)	0.268 (10 ⁶ Btu)	1.6

^aField efficiency = $\frac{\text{Collected energy}}{\text{Direct insolation} \times \text{collector area}} \times 100 \text{ percent}$

^bSystem efficiency = $\frac{\text{Delivered energy}}{\text{Direct insolation} \times \text{collector area}} \times 100 \text{ percent}$

Table B-12. Single Day Performance Table
January 24, 1981 (Day 24)

Hour	Direct Insolation on Collector Plane	Energy to Boiler	Auxiliary Electrical Energy	Flash Boiler Temperature	Field ^a Efficiency	Field Temperature		Ambient Temperature	Wind Speed	Steam to Main		System ^b Efficiency
						Inlet	Outlet			Flow	Energy	
	Btu/ft ² /hr	10 ⁶ Btu/hr	kW	°F	Percent	°F	°F	°F	mph	lb/hr	10 ⁶ Btu/hr	Percent
0-1			0.87	314				42.3	3.9			
1-2			0.89	313				40.9	3.8			
2-3			0.87	312				40.7	4.8			
3-4			0.87	311				40.5	5.9			
4-5			0.87	311				40.2	5.7			
5-6			0.90	309				40.5	6.4			
6-7			0.89	309				38.3	4.8			
7-8			0.90	308				40.6	5.2			
8-9	52.1	-0.51	7.0	296	--	274	247	46.8	5.6			
9-10	259.7	1.10	10.6	309	37.0	280	317	56.8	5.2			
10-11	277.5	1.24	10.7	342	39.1	315	357	65.7	5.6	288.3	0.267	8.4
11-12	271.7	1.18	10.7	351	38.0	345	385	71.7	5.6	1143	1.06	34.1
12-13	247.9	0.964	10.5	352	34.0	350	383	74.0	7.1	1100	1.02	36.0
13-14	208.4	0.605	10.3	349	25.4	335	355	76.5	10.0	381.5	0.354	14.8
14-15	161.9	0.183	10.3	349	9.9	345	351	78.2	8.5			
15-16	111.3	-0.088	10.2	348	--	347	344	77.5	11.2			
16-17	35.6	-0.178	7.1	340	--	341	331	74.7	7.3			
17-18			0.88	337				68.0	8.2			
18-19			0.90	336				63.3	9.0			
19-20			0.92	335				60.6	9.2			
20-21			0.92	334				58.4	11.0			
21-22			0.93	333				57.5	11.4			
22-23			0.95	332				55.6	11.0			
23-24			0.75	331				53.6	8.9			
Daily total	1626.1 (Btu/ft ²)	4.50 (10 ⁶ Btu)	100.7 (kW-hr)	--	24.2	--	--	--	--	2912.8 (lb)	2.70 (10 ⁶ Btu)	14.5

$$^a \text{Field efficiency} = \frac{\text{Collected energy}}{\text{Direct insolation} \times \text{collector area}} \times 100 \text{ percent}$$

$$^b \text{System efficiency} = \frac{\text{Delivered energy}}{\text{Direct insolation} \times \text{collector area}} \times 100 \text{ percent}$$

APPENDIX C
SINGLE DAY PERFORMANCE GRAPHS

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Figure C-1. Single Day Performance Graph
Day 034, February 3, 1980

Figure C-2. Single Day Performance Graph
Day 081, March 21, 1980

Figure C-3. Single Day Performance Graph
Day 095, April 4, 1980

Figure C-4. Single Day Performance Graph
Day 131, May 10, 1980

Figure C-5. Single Day Performance Graph
Day 165, June 13, 1980

Figure C-6. Single Day Performance Graph
Day 190, July 8, 1980

Figure C-7. Single Day Performance Graph
Day 233, August 20, 1980

Figure C-8. Single Day Performance Graph
Day 249, September 5, 1980

Figure C-9. Single Day Performance Graph
Day 278, October 4, 1980

Figure C-10. Single Day Performance Graph
Day 309, November 4, 1980

Figure C-11. Single Day Performance Graph
Day 346, December 11, 1980

Figure C-12. Single Day Performance Graph
Day 24, January 29, 1981

APPENDIX D
MONTHLY PERFORMANCE SUMMARY TABLES

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Table D-1. Monthly Performance Summary Table
January and February 1980

Date	Direct Insolation on Collector Aperture Btu/ft ²	Energy to Boiler 10 ⁶ Btu	Auxiliary Electrical Energy kw-hr	Daily Field Efficiency ^b Percent	To Steam Main	
					Flow lb	Energy 10 ⁶ Btu
1-16 16	845	2.75	66.5	28	NA ^d	NA ^d
1-17 17	566	0.507	58.3	8	NA	NA
1-18 18	739	1.54	51.6	21	NA	NA
1-19 19	0	0	24.3	0	NA	NA
1-20 20	0	0	25.5	0	NA	NA
1-21 21	0	0	20.2	0	NA	NA
1-22 22	0	0	40.4	0	NA	NA
1-23 23	1283	1.27	94.6	9	NA	NA
1-24 24	730	1.40	60.1	17	NA	NA
1-25 25	0	0	8.2	0	NA	NA
1-26 26	0	0	24.3	0	NA	NA
1-27 27	0	0	59.5	0	NA	NA
1-28 28	0	0	49.8	0	NA	NA
1-29 29	0	0	53.3	0	NA	NA
1-30 30	0	0	52.7	0	NA	NA
1-31 31	0	0	46	0	NA	NA
Daily Average ^a	833	1.49	46	15	NA	NA
2-1 32	1066	3.95	90.2	33	NA	NA
2-2 33	191	0.119	70.3	6	NA	NA
2-3 34	1515	3.60	106	21	NA	NA
2-4 35	47	0	43.4	0	NA	NA
2-5 36	0	0	51.6	0	NA	NA
2-6 37	NA ^c	4.23	125	NA ^c	NA	NA
2-7 38	NA	0	43.4	NA	NA	NA
2-8 39	NA	0	52.2	NA	NA	NA
2-9 40	NA	0	56.8	NA	NA	NA
2-10 41	NA	0	53.0	NA	NA	NA
2-11 42	NA	2.67	105	NA	NA	NA
2-12 43	NA	3.78	99.3	NA	NA	NA
2-13 44	NA	2.10	105	NA	NA	NA
2-14 45	NA	0	19.9	NA	NA	NA
2-15 46	NA	0	54.5	NA	NA	NA
2-16 47	NA	0	56.8	NA	NA	NA
2-17 48	NA	0	48.9	NA	NA	NA
2-18 49	NA	0	34	NA	NA	NA
2-19 50	NA	2.29	91.4	NA	NA	NA
2-20 51	NA	4.14	79.4	NA	NA	NA
2-21 52	NA	3.50	83.5	NA	NA	NA
2-22 53	NA	2.60	91.4	NA	NA	NA
2-23 54	NA	1.66	66.5	NA	NA	NA
2-24 55	NA	0.21	78.5	NA	NA	NA
2-25 56	NA	3.75	96.4	NA	NA	NA
2-26 57	NA	2.34	90.8	NA	NA	NA
2-27 58	NA	5.04	94.9	NA	NA	NA
2-28 59	NA	3.97	89.1	NA	NA	NA
2-29 60	NA	0	36.9	NA	NA	NA
Daily Average ^a		2.83	70	24	NA	NA

^aBased on days when system operated
System operated 5 days in January
System operated 17 days in February

^cNA = not available, shadow band
was removed

^dNA = not available, steam flowmeter
not operational

^bDaily field efficiency = $\frac{\text{Energy to boiler}}{\text{Direct insolation} \times \text{collector area}} \times 100 \text{ percent}$

Table D-2. Monthly Performance Summary Table
March 1980

Date	Direct Insolation on Collector Plane Btu/ft ²	Energy to Flash Boiler 10 ⁶ Btu	Auxiliary Electrical Energy kw-hr	Daily Field Efficiency ^b Percent	To Steam Main	
					Flow lb	Enthalpy 10 ⁶ Btu
3-1 61	265	0	79.1	0	NAC	NA
3-2 62	0	0	46.9	0		
3-3 63	1294	3.63	103	25		
3-4 64	104	0.164	28.7	14		
3-5 65	1026	3.53	77.4	31		
3-6 66	1590	4.65	103	26		
3-7 67	0	0	22	0		
3-8 68	0	0	21.4	0		
3-9 69	0	0	27.8	0		
3-10 70	398	0.364	52.7	8		
3-11 71	0	0	10.8	0		
3-12 72	1843	4.72	102	23		
3-13 73	90	-1.21	29.1	-117		
3-14 74	1866	6.26	114	30		
3-15 75	0	0	22.4	0		
3-16 76	0	0	22.4	0		
3-17 77	837	2.04	74.6	21		
3-18 78	1560	6.53	101	36		
3-19 79	0	0	20.4	0		
3-20 80	989	3.38	79.9	31		
3-21 81	1890	6.53	107	30		
3-22 82	0	0	24.6	0		
3-23 83	0	0	24.5	0		
3-24 84	1122	2.56	81.3	20		
3-25 85	0	0	20.7	0		
3-26 86	0	0	21.1	0		
3-27 87	0	0	20.4	0		
3-28 88	0	0	22.7	0		
3-29 89	0	0	24.3	0		
3-30 90	0	0	25.7	0		
3-31 91	397	0.025	65.8	0.6		
Sum	15271	43.2	1577			
Daily Average ^a	1020	2.88	50.9	25		

^aBased on number of days system operated -- 15 days in March

^bDaily field efficiency = $\frac{\text{Energy to boiler}}{\text{Direct insolation} \times \text{collector area}} \times 100 \text{ percent}$

^cNA = not available -- steam flowmeter not operational

Table D-3. Monthly Performance Summary Table
April 1980

Date	Direct Insolation on Collector Aperture Btu/ft ²	Energy to Boiler 10 ⁶ Btu	Auxiliary Electrical Energy kw-hr	Daily Field Efficiency ^b Percent	To Steam Main		System Efficiency ^d Percent
					Flow lb	Energy 10 ⁶ Btu	
4-1 92	891	1.95	21.5	19	NAC	NA	
4-2 93	147	0.75	18.3	45	NA	NA	
4-3 94	1619	6.23	89.7	34	2500	2.32	13
4-4 95	1866	7.19	99.4	34	4260	3.95	19
4-5 96	1429	5.98	81.2	37	2390	2.22	14
4-6 97	0	0	24.7	0	0	0	
4-7 98	669	3.05	55.5	41	0	0	
4-8 99	185	0.672	30.4	33	0	0	
4-9 100	125	0.404	30.3	29	0	0	
4-10 101	1420	5.69	73.5	36	257	0.238	1
4-11 102	0	0	24.9	0	0	0	
4-12 103	0	0	25.7	0	0	0	
4-13 104	0	0	26.3	0	0	0	
4-14 105	1067	4.58	82.0	38	237	0.220	2
4-15 106	1595	7.32	112.3	41	1573	1.46	8
4-16 107	1620	6.85	97.4	37	3980	3.69	20
4-17 108	1025	4.07	64.5	37	1650	1.53	13
4-18 109	465	1.99	44.6	38	79.2	0.073	1
4-19 110	0	0	20.7	0	0	0	
4-20 111	0	0	20.1	0	0	0	
4-21 112	820	3.35	58.9	37	15.8	0.015	0.2
4-22 113	1396	3.42	93.8	22	1510	1.40	9
4-23 114	0	0	16.2	0	0	0	
4-24 115	0	0	19.3	0	0	0	
4-25 116	187	0.626	35.8	30	0	0	
4-26 117	0	0	19.8	0	0	0	
4-27 118	0	0	15.9	0	0	0	
4-28 119	1793	9.03	105.5	44	4650	4.31	21
4-29 120							
4-30 121							
Sum	18319	73.1	1409		23100	21.4	
Daily Average ^a	1018	4.06	78.3	35	1925	1.79	15

^aBased on days when system operated

^bDaily field efficiency = $\frac{\text{Energy to flash boiler}}{\text{Direct insolation} \times \text{collector area}} \times 100 \text{ percent}$

^cSteam flowmeter not operational until Day 94 -- April 3

^dSteam efficiency = $\frac{\text{Steam energy}}{\text{Direct insolation} \times \text{collector area}} \times 100 \text{ percent}$

Table D-4. Monthly Performance Summary Table
May 1980

Date	Direct Insolation on Collector Plane Btu/ft ²	Energy to Flash Boiler 10 ⁶ Btu	Auxiliary Electrical Energy kw-hr	Daily Field Efficiency ^b Percent	To Steam Main	
					Flow lb	Enthalpy 10 ⁶ Btu
4-29 120	0	0	48.3	--	0	0
4-30 121	0	0	37.3	--	0	0
5-1 122	NA ^d	0	16.9	--	0	0
5-2 123	NA ^d	0	30.9	--	0	0
5-3 124	554	2.00	59.0	32	NAC	NAC
5-4 125	0	0	20.2	--	0	0
5-5 126	839.5	3.03	85.7	32	NAC	NAC
5-6 127	484.3	2.10	45.2	33	NAC	NA
5-7 128	1181	5.01	90.3	38	NAC	NAC
5-8 129	0	0	22.9	--	0	0
5-9 130	303.9	1.34	45.2	39	NAC	NAC
5-10 131	1418	5.57	117	34	NAC	NAC
5-11 132	0	0	21.3	--	0	0
5-12 133	0	0	30	--	0	0
5-13 134	0	0	16.7	--	0	0
5-14 135	558.5	2.66	62.2	43	NAC	NAC
5-15 136	0	0	20.4	--	0	0
5-16 137	1726	7.75	114	40	NAC	NAC
5-17 138	1858	8.65	117	42	NAC	NAC
5-18 139	80	0.29	36.7	32	NAC	NAC
5-19 140	1389	5.83	104	38	NAC	NAC
5-20 141	1232	5.30	88	38	NAC	NAC
5-21 142	0	0	30.7	--	0	0
5-22 143	0	0	17.3	--	0	0
5-23 144	682.5	2.20	74.1	29	NAC	NAC
5-24 145	0	0	22.3	--	0	0
5-25 146	0	0	23.4	--	0	0
5-26 147	219.5	0.57	41.6	23	NAC	NAC
5-27 148	0	0	37.5	--	0	0
5-28 149	184.6	0.42	70.3	20	NAC	NAC
5-29 150	301.6	1.07	81.9	31	NAC	NAC
5-30 151	NA ^e	--	--	--	--	--
5-31 152	NA ^e	--	--	--	--	--
Sum	13331	53.8	1629			
Daily Average ^a	833	3.85	52.5	35		

^aBased on number of days system operated -- 16 days

^bDaily field efficiency = $\frac{\text{Energy to boiler}}{\text{Direct insolation} \times \text{collector area}} \times 100 \text{ percent}$

^cNA = not available -- steam flowmeter not operational

^dNA = not available -- instrument not operational

^eNA = not available on data tape -- will be reported 2 next month

Table D-5. Monthly Performance Summary Table
June 1980

Date	Direct Insolation on Collector Plane Btu/ft ²	Energy to Flash Boiler 10 ⁶ Btu	Auxiliary Electrical Energy kw-hr	Daily Field Efficiency ^b Percent	To Steam Main	
					Flow lb	Enthalpy 10 ⁶ Btu
5-30 151 ^f	NA ^e	--	--	--	--	--
5-31 152 ^f	500	0.58	77.4	6	NAC	NAC
6-1 153	0	0.	53.0	--	0	0
6-2 154	0	0.	30.9	--	0	0
6-3 155	104	-413	31.5	-33	0	0
6-4 156	1484	4.66	102.0	28	NA	NA
6-5 157	1971	7.67	126.0	34	NA	NA
6-6 158	1706	5.84	93.1	31	NA	NA
6-7 159	0	0.	37.4	0	0	0
6-8 160	0	0.	19.2	0	0	0
6-9 161	0	0.	16.0	0	0	0
6-10 162	1972	7.16	110.0	32	NA	NA
6-11 163	2087	6.94	120.0	29	NA	NA
6-12 164	1566	3.24	114.0	18	NA	NA
6-13 165	2326	8.70	124.0	33	NA	NA
6-14 166	668	0.99	56.0	13	NA	NA
6-15 167	2053	6.26	122.0	27	NA	NA
6-16 168	1091	2.47	73.7	20	NA	NA
6-17 169	1184	1.97	91.1	15	NA	NA
6-18 170	1221	4.21	104.0	30	NA	NA
6-19 171	1365	6.03	93.3	39	NA	NA
6-20 172	NA ^d	1.06	65.8	NA	NA	NA
6-21 173	NA ^d	2.26	93.6	NA	0	0
6-22 174	NA ^e	--	--	--	--	--
6-23 175	NA ^e	--	--	--	--	--
6-24 176	NA ^d	6.37	122.0	NA	NA	NA
6-25 177	NA ^d	6.99	123.0	NA	NA	NA
6-26 178	NA ^d	6.65	123.0	NA	NA	NA
6-27 179	NA ^d	6.71	123.0	NA	NA	NA
6-28 180	NA ^d	6.31	123.0	NA	NA	NA
6-29 181	NA ^d	5.25	119.0	NA	NA	NA
6-30 182	NA ^e	--	--	--	--	--
Sum	NA	107.9	2487			
Daily Average ^a	NA	4.69	104.0	27	NAC	NAC

^aBased on the number of days data was available -- 23 days

^bDaily field efficiency = $\frac{\text{Energy to boiler}}{\text{Direct insolation} \times \text{collector area}} \times 100 \text{ percent}$

^cNA = not available -- steam flowmeter not operational

^dNA = not available -- instrument not operational

^eNA = not available on data tape

^fDays 151 and 152 are data from the end of May

Table D-6. Monthly Performance Summary Table
July 1980

Date	Direct Insolation on Collector Plane ^a Btu/ft ²	Energy to Boiler 10 ⁶ Btu	Auxiliary Electrical Energy kW-hr	Daily Field Efficiency ^b Percent	To Steam Main		System Efficiency ^b Percent
					Flow lb	Energy 10 ⁶ Btu	
7-1 183		6.67	122		5380	4.99	
7-2 184		6.03	122		4820	4.47	
7-3 185		6.78	123		4690	4.35	
7-4 186		4.87	120		4050	3.76	
7-5 187		6.56	123		5210	4.83	
7-6 188		5.88	121		5070	4.70	
7-7 189		8.44	121		7740	7.17	
7-8 190		9.70	121		8400	7.79	
7-9 191		8.89	114		7940	7.36	
7-10 192		7.93	117		6540	6.06	
7-11 193		8.21	121		7360	6.82	
7-12 194		8.39	121		7590	7.03	
7-13 195		0	21		0	0	
7-14 196		7.09	108		5800	5.37	
7-15 197		8.31	119		7770	7.20	
7-16 198		6.40	119		5900	5.47	
7-17 199		6.18	107		5690	5.27	
7-18 200		5.89	116		5380	4.99	
7-19 201		3.53	112		3080	2.85	
7-20 202		4.93	110		3770	3.49	
7-21 203		1.40	54		0	0	
7-22 204		4.46	96		3080	2.86	
7-23 205		8.32	120		7100	6.58	
7-24 206		3.34	109		2940	2.72	
7-25 207		3.88	116		2950	2.73	
7-26 208		2.93	89		2420	2.24	
7-27 209		-0.35	71		0	0	
7-28 210		4.27	115		2440	2.26	
7-29 211		5.90	121		5190	4.81	
7-30 212		6.29	115		5140	4.76	
7-31 213		--	--		--	--	
Sum		169	3260		143000	133	
Daily Average		5.82	113		4950	4.58	

^aNot available -- pyranometer malfunction

^bNot available -- depends on direct insolation measurement

Table D-7. Monthly Performance Summary Table
August 1980

Date	Day	Direct Insolation on Collector Plane ^a Btu/ft ²	Energy to Boiler 10 ⁶ Btu	Auxiliary Electrical Energy kW-hr	Daily Field Efficiency Percent	To Steam Main		System Efficiency Percent
						Flow lb	Energy 10 ⁶ Btu	
8-1	214	NA	NA	NA	NA ^b	NA	NA	NA ^b
8-2	215	NA ^c	5.49	117.	NA	4710	4.37	NA
8-3	216	NA	0	17.2	0	0	0	0
8-4	217	NA	--	36.5	NA	0	0	NA
8-5	218							
8-6	219							
8-7	220							
8-8	221							
8-9	222							
8-10	223							
8-11	224							
8-12	225							
8-13	226							
8-14	227							
8-15	228							
8-16	229	NA	1.38	99.	NA	0	0	NA
8-17	230	NA	--	35.8	NA	0	0	NA
8-18	231	NA	5.17	92.3	NA	2210	2.05	NA
8-19	232	1646	5.60	113.	30	4580	4.24	23
8-20	233	2061	6.35	104.	27	5010	4.65	20
8-21	234	1566	3.95	107.	23	3540	3.28	18
8-22	235	1887	5.19	110.	25	4240	3.93	18
8-23	236	1718	4.44	111.	23	3630	3.36	17
8-24	237							
8-25	238							
8-26	239							
8-27	240							
8-28	241							
8-29	242							
8-30	243							
8-31	244							
Sum ^a		NA	37.6	940.	NA	27,420	25.9	NA
Daily Average ^a		NA	3.42	85.5	25.1	2,540	2.35	19.2

^aBased on the number of days data are available

^bNot available -- depends on insolation data

^cNot available -- pyranometer malfunction

Table D-8. Monthly Performance Summary Table
September 1980

Date Day	Direct Insolation on Collector Plane ^a Btu/ft ²	Energy to Boiler 10 ⁶ Btu	Auxiliary Electrical Energy kW-hr	Daily Field Efficiency Percent	To Steam Main		System Efficiency Percent
					Flow lb	Energy 10 ⁶ Btu	
9-1 245	0	0	18.1	--	0	0	--
9-2 246	382	1.04	37.7	24	0	0	0
9-3 247	1451	3.74	101.7	22	1383	1.28	8
9-4 248	966	2.07	86.5	19	875	0.81	7
9-5 249	1678	4.91	102.5	26	3054	2.83	15
9-6 250	0	0	16.4	--	0	0	--
9-7 251	0	0	17.0	--	0	0	--
9-8 252	0	0	19.1	--	0	0	--
9-9 253	379	0.70	66.6	16	0	0	--
9-10 254	1101	3.14	81.2	25	196	0.18	1
9-11 255	NAC	-0.52	38.5	NAC	0	0	NAC
9-12 256		2.59	106.7		99	0.09	
9-13 257		5.59	109.8		4253	3.94	
9-14 258		2.30	104.5		1306	1.21	
9-15 259		1.57	108.3		869	0.81	
9-16 260		0.28	45.2		0	0	
9-17 261		4.40	99.2		2580	2.39	
9-18 262		0.10	66.7		0	0	
9-19 263		0	15.8		0	0	
9-20 264		4.72	98.4		2762	2.53	
9-21 265		0	26.4		0	0	
9-22 266		-0.85	37.5		0	0	
9-23 267		-0.65	37.2		0	0	
9-24 268	0	-0.20	37.4	--	0	0	
9-25 269	0	0	15.8	--	0	0	--
9-26 270	0	0	15.8	--	0	0	--
9-27 271	0	0	19.6	--	0	0	--
9-28 272	0	0	19.9	--	0	0	--
9-29 273	0	0	8.6	--	0	0	--
9-30 274	0	0	1.3	--	0	0	--
Monthly value ^a	5957	34.9	1559.4	23 ^b	17,377	16.1	7 ^b

^aBased on the number of days data are available

^bBased on days insolation data available

^cNot available -- pyranometer malfunction

Table D-9. Monthly Performance Summary Table
October 1980

Date	Day	Direct Insolation on Collector Plane Btu/ft ²	Energy to Boiler 10 ⁶ Btu	Auxiliary Electrical Energy kW-hr	Daily Field Efficiency Percent	To Steam Main		System Efficiency Percent
						Flow lb	Energy 10 ⁶ Btu	
10-1	275	1853	5.55	99.9	26	0	0	0
10-2	276	1493	2.72	104.6	16	1741	1.61	9
10-3	277	1888	5.61	104.3	26	4400	4.08	19
10-4	278	1979	5.98	105.9	26	5173	4.80	21
10-5	279	1879	5.39	105.2	25	4347	4.03	19
10-6	280	107	-0.21	32.6	--	0	0	0
10-7	281	1153	3.41	94.6	25	158	0.15	1
10-8	282	1826	6.46	105.3	31	4723	4.38	21
10-9	283	1527	4.97	101.5	28	3654	3.39	19
10-10	284	1771	5.84	104.8	29	4313	4.00	20
10-11	285	1856	6.27	104.2	30	5170	4.79	22
10-12	286	1792	5.28	103.7	26	4581	4.24	21
10-13	287	1765	5.39	102.6	27	4540	4.21	21
10-14	288	254	-0.92	42.3	--	0	0	0
10-15	289	0	0	15.9	--	0	0	--
10-16	290	0	0	5.8	--	0	0	--
10-17	291	730	0.84	77.3	10	0	0	0
10-18	292	33	-0.29	28.7	--	0	0	0
10-19	293	1669	5.16	103.5	27	844	0.78	4
10-20	294	1799	5.71	103.4	28	4735	4.39	21
10-21	295	753	2.28	94.4	26	0	0	0
10-22	296	1700	5.24	100.3	27	2446	2.27	12
10-23	297	1328	3.35	104.9	22	856	0.79	5
10-24	298	1865	6.04	108.0	28	3104	2.88	13
10-25	299	1826	6.04	106.4	29	3768	3.49	17
10-26	300	350	0	34.1	0	0	0	0
10-27	301	1693	4.59	108.0	24	0	0	0
10-28	302	0	0	49.2	--	0	0	--
10-29	303	1403	4.09	120.2	25	106	0.01	0
10-30	304	1812	5.78	112.0	28	618	0.57	3
10-31	305	1741	4.97	85.0	25	4208	3.90	20
Monthly value		39,844	115.5	2,668.6	25	63,486	58.8	8

Table D-10. Monthly Performance Summary Table
November 1980

Date	Day	Direct Insolation on Collector Plane Btu/ft ²	Energy to Boiler 10 ⁶ Btu	Auxiliary Electrical Energy kW-hr	Daily Field Efficiency Percent	To Steam Main		System Efficiency Percent
						Flow lb	Energy 10 ⁶ Btu	
11-1	306	1,313	3.83	97.2	0.26	2768	2.56	17.0
11-2	307	1,429	3.11	91.5	19.0	2398	2.22	13.6
11-3	308	1,639	4.83	100.0	26.4	3211	2.97	15.8
11-4	309	1,664	4.96	100.3	26.1	2893	2.68	14.1
11-5	310	1,660	4.27	96.2	23.0	3239	2.99	15.7
11-6	311	1,629	3.83	96.8	21.0	3076	2.84	15.2
11-7	312	1,619	3.45	96.7	19.0	2725	2.52	13.6
11-8	313	1,144	1.89	80.7	15.0	87	0.08	0.6
11-9	314	586.4	-0.4	74.4	--	0	0	0
11-10	315	1,054	2.55	73.8	22.0	170.6	0.16	1.3
11-11	316	0	0	24.63	--	0	0	0
11-12	317	1,129	2.32	71.9	18.0	156.9	0.15	1.2
11-13	318	982.5	0.50	89.84	4.0	18.9	0.02	0.2
11-14	319	0	0	18.9	0	0	0	0
11-15	320	0	0	27.4	0	0	0	0
11-16	321	0.35	0.04	51.75	11.4	0	0	0
11-17	322	0	0	52.07	0	0	0	0
11-18	323	1,483	5.06	119.2	30.5	0	0	0
11-19	324	1,361	4.46	103.9	29.2	0	0	0
11-20	325	1,190	3.68	93.3	27.6	0	0	0
11-21	326	0	0	38.75	0	0	0	0
11-22	327	0	0	52.06	0	0	0	0
11-23	328	0	0	52.76	0	0	0	0
11-24	329	0	0	39.81	0	0	0	0
11-25	330	144.6	0.52	57.51	40.8	0	0	0
11-26	331	0	0	47.29	0	0	0	0
11-27	332	118.6	0.32	76.91	23.9	0	0	0
11-28	333	1,577	5.40	122.1	30.6	0	0	0
11-29	334	1,491	4.56	122.1	27.3	0	0	0
11-30	335	945	1.93	102.4	18.22	0	0	0
Monthly value		24,129	61.1	2,272.08	22.1	20,743	19.2	6.9

Table D-11. Monthly Performance Summary Table
December 1980

Date	Day	Direct Insolation on Collector Plane (Btu/ft ²)	Energy to Boiler (10 ⁶ Btu)	Auxiliary Electrical Energy (kW-hr)	Daily Field Efficiency (Percent)	To Steam Main		System Efficiency (Percent)
						Flow (lb)	Energy (10 ⁶ Btu)	
12-1	336	1,043	2.05	83.8	17.6	0	0	--
12-2	337	1,189	2.17	89.9	16.4	0	0	--
12-3	338	0	0	34.9	--	0	0	--
12-4	339	0	0.135	18.7	--	0	0	--
12-5	340	0	0.923	21.4	--	0	0	--
12-6	341	0	0	10.0	--	0	0	--
12-7	342	0	0	20.9	--	0	0	--
12-8	343	0	0	23.9	--	0	0	--
12-9	344	254	0.425	46.4	14.8	0	0	--
12-10	345	1,319	3.51	114.0	23.7	0	0	--
12-11	346	1,471	4.13	106.0	24.5	291	0.268	1.6
12-12	347	1,120	1.92	92.8	15.3	585	0.541	4.2
12-13	348	687	0.394	74.5	5.1	0	0	--
12-14	349	1,335	3.24	98.6	21.7	354	0.328	2.1
12-15	350	1,139	2.42	77.1	19.0	1,319	1.22	9.4
12-16	351	1,182	3.65	80.5	27.6	2,115	1.96	14.5
12-17	352	1,087	2.77	68.0	22.8	1,549	1.43	11.5
12-18	353	1,319	2.73	88.0	18.5	2,441	2.26	15.0
12-19	354	0	0	39.1	--	0	0	--
12-20	355	0	0	57.7	--	0	0	--
12-21	356	1,267	3.70	120.4	26.0	86	0.08	0.6
12-22	357	Magnetic tape data not available						
12-23	358							
12-24	359							
12-25	360							
12-26	361							
12-27	362							
12-28	363							
12-29	364							
12-30	365							
12-31	366							
Monthly value		14,409	32.07	1,367.00	19.4	8,753	8.1	4.9

Table D-12. Monthly Performance Summary Table
January 1981

Date	Day	Direct Insolation on Collector Plane (Btu/ft ²)	Energy to Boiler (10 ⁶ Btu)	Auxiliary Electrical Energy (kW-hr)	Daily Field Efficiency (Percent)	To Steam Main		System Efficiency (Percent)
						Flow (lb)	Energy (10 ⁶ Btu)	
1-1	1	Data not available						
1-2	2							
1-3	3							
1-4	4							
1-5	5	0	0	8.1	--	0	0	--
1-6	6	264.1	-0.055	61.8	--	0	0	--
1-7	7	1,471	4.90	110.7	29.7	0	0	0
1-8	8	80.1	-0.48	34.6	--	0	0	--
1-9	9	547.4	1.17	50.0	19.1	0	0	--
1-10	10	0	0	21.4	--	0	0	--
1-11	11	1,236	1.9	100.4	13.7	0	0	--
1-12	12	1,475	3.55	121.1	21.5	56.11	0.052	0.3
1-13	13	1,499	4.20	110.4	25.01	377.1	0.350	2.0
1-14	14	1,562	4.33	110.1	24.8	1,869	1.73	9.7
1-15	15	1,514	3.90	115.6	23.0	538	0.500	2.9
1-16	16	923.5	1.12	123.4	10.9	0	0	0
1-17	17	1,255	2.82	114.2	20.1	0	0	0
1-18	18	0	0	32.1	--	0	0	--
1-19	19	0	-0.035	33.6	--	0	0	--
1-20	20	0	0	33.0	--	0	0	--
1-21	21	0	0	34.8	--	0	0	--
1-22	22	896	2.69	94.8	26.8	0	0	0
1-23	23	1,608	5.05	108.1	28.1	0	0	0
1-24	24	1,626	4.50	100.7	24.2	2,913	2.70	14.5
1-25	25	113.2	-1.43	43.3	--	0	0	--
1-26	26	0	0	22.7	--	0	0	--
1-27	27	1,539	4.49	118.5	26.1	0	0	0
1-28	28	1,508	4.07	113.4	24.1	696.9	0.646	3.7
1-29	29	620	0.99	74.4	14.2	0	0	0
1-30	30	0	0	33.2	--	0	0	--
1-31	31	0	0	40.7	--	0	0	--
Monthly value		19,737	47.68	2,035.2	21.1	6,450	5.98	2.65

APPENDIX E
MONTHLY PERFORMANCE SUMMARY GRAPHS

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Note: Shadow band removed on day 37, no insolation data available after that time

Figure E-1. Monthly Performance Summary Graph
January and February 1980

Figure E-2. Monthly Performance Summary Graph
March 1980

Figure E-3. Monthly Performance Summary Graph
April 1980

Figure E-4. Monthly Performance Summary Graph
May 1980

Figure E-5. Monthly Performance Summary Graph
June 1980

Figure E-6. Monthly Performance Summary Graph
July 1980

Figure E-7. Monthly Performance Summary Graph
August 1980

Figure E-8. Monthly Performance Summary Graph
September 1980

Figure E-9. Monthly Performance Summary Graph
October 1980

Figure E-10. Monthly Performance Summary Graph
November 1980

Figure E-11. Monthly Performance Summary Graph
December 1980

Figure E-12. Monthly Performance Summary Graph
January 1981

APPENDIX F
DEFINITIONS

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Table F-1. Definitions

Direct Insolation on Collector Plane	The difference between total insolation normal to collectors and diffuse insolation normal to collectors
Energy to Boiler	Solar energy to the flash boiler as measured by the field flowrate and the temperature rise from the collector field inlet (field supply temperature) to flash boiler inlet (field return temperature)
Auxiliary Electrical Energy	Electrical energy used by the solar system, i.e., pump, collector drives, controls, etc.
Flash boiler temperature	Temperature of water in flash boiler as measured by a RTD within a thermowell at approximately half of the flash boiler height
Field efficiency	Efficiency of the collector field is the ratio of solar energy delivered to the flash boiler divided by direct insolation to the collector plane times collector aperture area (11,440 ft ²)
Steam energy	Energy of steam delivered to the Johnson & Johnson steam main is the measured steam flowrate times the difference in enthalpy between the delivered steam (assumed to be 90 percent quality) and the feedwater
System efficiency	Efficiency of the steam system is the ratio of steam energy divided by direct insolation to the collector plane times collector aperture area (11,440 ft ²)
System available	Solar system is available so as to collect solar energy with adequate direct insolation
System operated	Solar energy collected by collector field
Steam delivered	Steam was delivered to the Johnson & Johnson steam header
Overcast	Insolation was not adequate to permit system to operate