FWC/FWDC/TR-84/39

FOSTER WHEELER DEVELOPMENT CORPORATION

FWC/FWDC/TR-84/39

FINAL REPORT

SOLAR PRODUCTION OF INDUSTRIAL PROCESS STEAM FOR THE DOW CHEMICAL COMPANY

PHASE 3--OPERATION AND PERFORMANCE EVALUATION

Prepared for

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Albuquerque Operations Office

by

M. D. Garber
D. J. Allen

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FOSTER WHEELER DEVELOPMENT CORPORATION
12 Peach Tree Hill Road, Livingston, New Jersey 07039

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The contents of this report have been reviewed and approved by:

R. J. Zoschak
Technical Director

G. D. Gupta
Manager, Engineering Science and Technology Department

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INTRODUCTION

In September 1978 Foster Wheeler Development Corporation (FWDC) began work on a three-phase project to design, construct, and operate a solar process steam plant for The Dow Chemical Company's latex manufacturing plant in Dalton, Georgia. The primary objective of Phase 1, completed in September 1979, was to design a cost-effective solar steam generating system. Phase 2--Fabrication and Installation began in October 1979 and was completed in November 1981. Phase 3--Operation and Performance Evaluation began in December 1981, and the results of that phase are presented in this report. Specifically, a summary of the operation, including incidents, experience, and insights, is presented along with a complete record of system performance, operating and maintenance activities, and cost.

The solar steam generating system utilizes a heat-transfer loop to deliver a hot organic fluid (Dowtherm LF) from the solar collectors to a heat exchanger where steam is generated. The fluid is then recirculated to the collectors by a centrifugal pump. As it passes through the tubes of the heat exchanger, the hot Dowtherm furnishes the heat required to convert boiler feedwater from the existing plant into saturated steam at 1.03 MPa gage (150 lb/in^{2}g).

At peak heat absorption, 0.19 kg/s (1500 lb/h) steam would be produced. The temperature and pressure of the boiler feedwater are 96°C (205°F) and 1.30 MPa gage (190 lb/in^{2}g).

Normal plant operation is controlled by automatic analog controllers, and a microcomputer-based data-logging system collects data and evaluates the solar steam generating system performance.

INDUSTRIAL APPLICATION

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The solar steam system is designed to supply 1.03 MPa gage (150 lb/in^2g) process steam to Dow's plant, where styrene butadiene latex is manufactured for carpet backing. In the latex process, steam is used for heating the reaction kettle and for steam distillation of the unreacted monomer from the raw latex. Dow's plant consumes about 45 Gg/yr (100 x 10^6 lb/yr) steam, 50 percent of which is used by the steam stripping operation. The process steam is produced by two package boilers--each with 2.53 kg/s (20,000 lb/h) nominal capacity--and is distributed to various processes within the plant. The average steam consumption by the plant is 1.39 kg/s (11,000 lb/h) with intermittent peaks to 3.16 kg/s (25,000 lb/h). The steam is produced by combusting natural gas and fuel oil, with approximately 90 percent obtained from natural gas and 10 percent from fuel oil. The solar-produced steam interfaces with the steam from the package boilers and supplements the plant steam. Solar steam system design specifications and original performance predictions indicated that the solar steam system would provide approximately 2.5 percent of Dow's total yearly steam requirements.

SYSTEM DESCRIPTION

SYSTEM DESCRIPTION

The system consists of 15 rows of single-axis line-focusing parabolic trough collectors manufactured by Suntec Systems, Inc. The total collector aperture area is 929 m^2 (9930 ft^2), and the collector rows are oriented in a north-south direction with a 10-deg tilt to the south. Figure 1 is a general arrangement drawing of the solar collector assembly.

Each collector row is supported by steel stanchions mounted on concrete foundations. A horizontal torque tube installed on top of the stanchions is driven in the center by a chain drive and an electric motor/gearbox. Honeycomb reflector panels with an acrylic film (3M's FEK 244) as the reflective surface are attached to the torque tubes. The torque tube assembly rotates with the reflective panels and maintains optical alignment. Electronic controls on each collector row provide tracking and safety control and interface with the system master controller.

The sun sensor, a field-mounted photocell, signals the master controller that sufficient solar intensity is available to begin operation. Upon receiving this signal, and sensing that there is a demand for steam, the master controller sends a command to the pump control for pump start-up. Once fluid-loop flow is sensed, a signal to each local collector controller begins rotation of the collector upward from the "protect" position. As the sun's image is centered on the receiver tracking heads, feedback signals are sent to the local controllers and tracking begins.

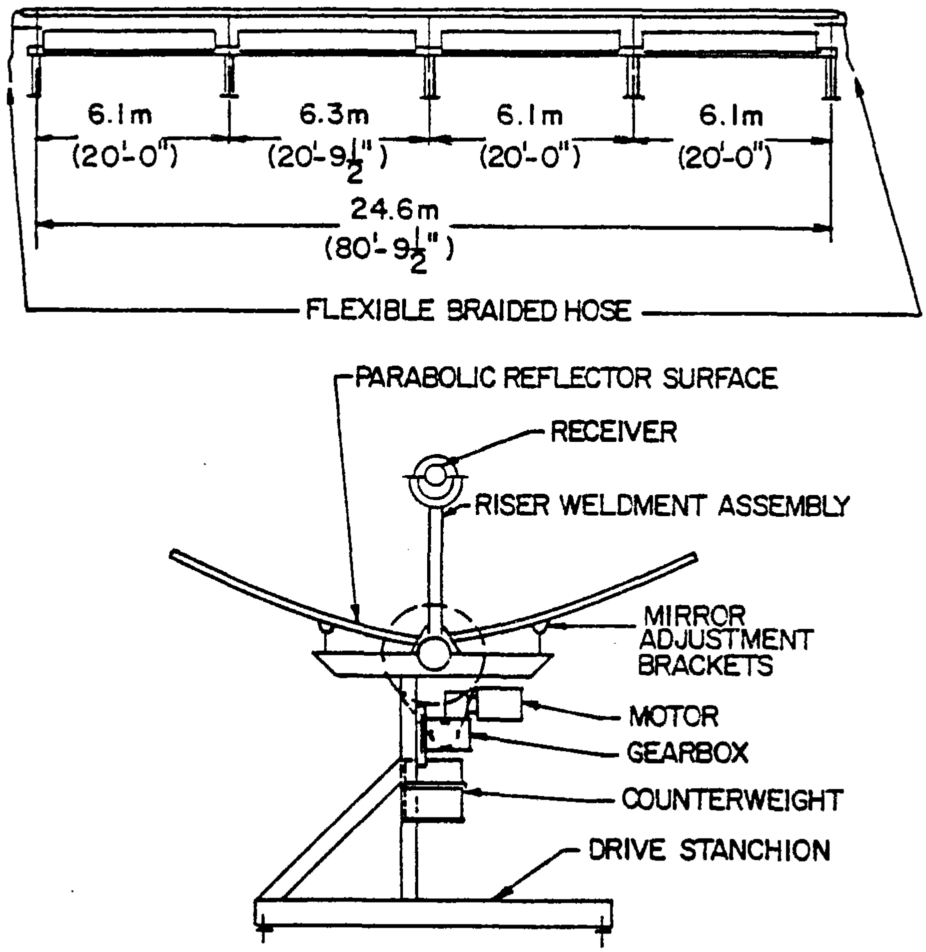

Figure 1 General Arrangement of Solar Collector Assembly

Each collector row is supported from the ground by five steel stanchions bolted to their foundations. Four sections [three 6.1 m (20 ft) long and one 6.3 m (20.75 ft) long] make up the torque tube, which is supported at the center drive stanchion by a thrust bearing and at the other stanchions by pipe roller supports. Eight counterweights (two per torque tube section) are mounted on the back of a module assembly.

Four reflector panel assemblies are attached to each of the four torque tube sections (Figure 2). As measured along the arc, each panel is 2.9 m long x 1.5 m wide (9.5 ft long x 4.9 ft wide). The panels are constructed of an aluminum hexagonal honeycomb with front and back aluminum skins 0.5 mm (0.02 in.) thick. Spectral reflectance is 82 percent (average), rim angle is 72 deg, and the solar concentration ratio is 40:1.

A receiver is installed at a focal length of 0.9 m (3 ft) from the parabolic reflector. A receiver housing encloses and insulates the receiver on one side; curved glass panels cover the receiver on the other. The receiver housing is shipped to the field as a 6.1-m (20-ft) long assembly consisting of housing, insulation, and internal reflective surface.

The receiver is supplied in 3-m (10-ft)-long sections ready for field welding. It is coated with a black chrome film for maximum solar radiation absorption and minimum radiated thermal losses. It is made of 1.5-in. Sch 40 carbon steel pipe and has an annular flow passage created by centering a tube with closed ends inside the receiver. Each collector row is 24.4 m (80 ft) long, and the rows are spaced 5.5 m (18 ft) apart. Figure 3 is a schematic of the solar

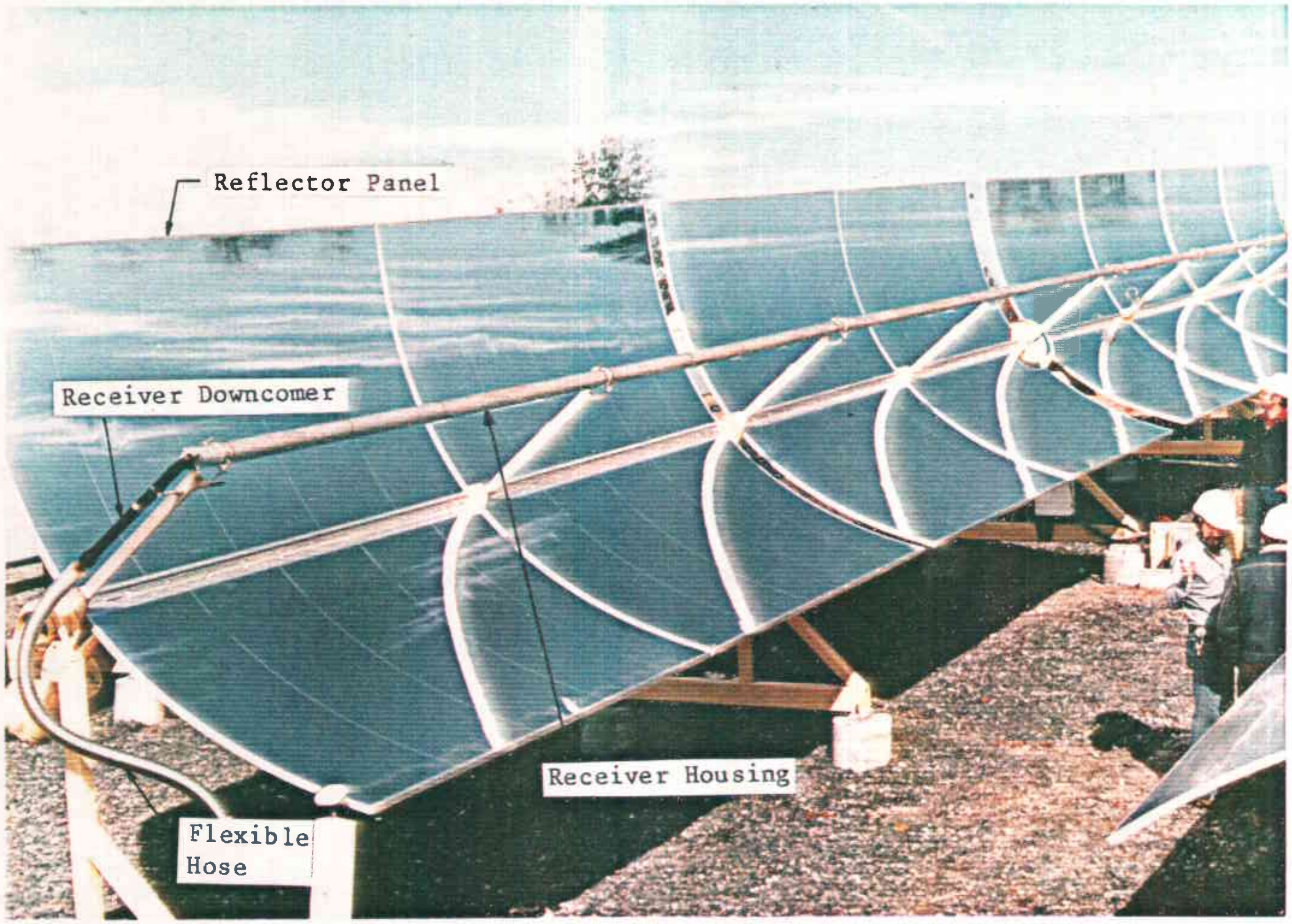

Figure 2 Collector Row Assembly at Dow Plant in Dalton, Georgia

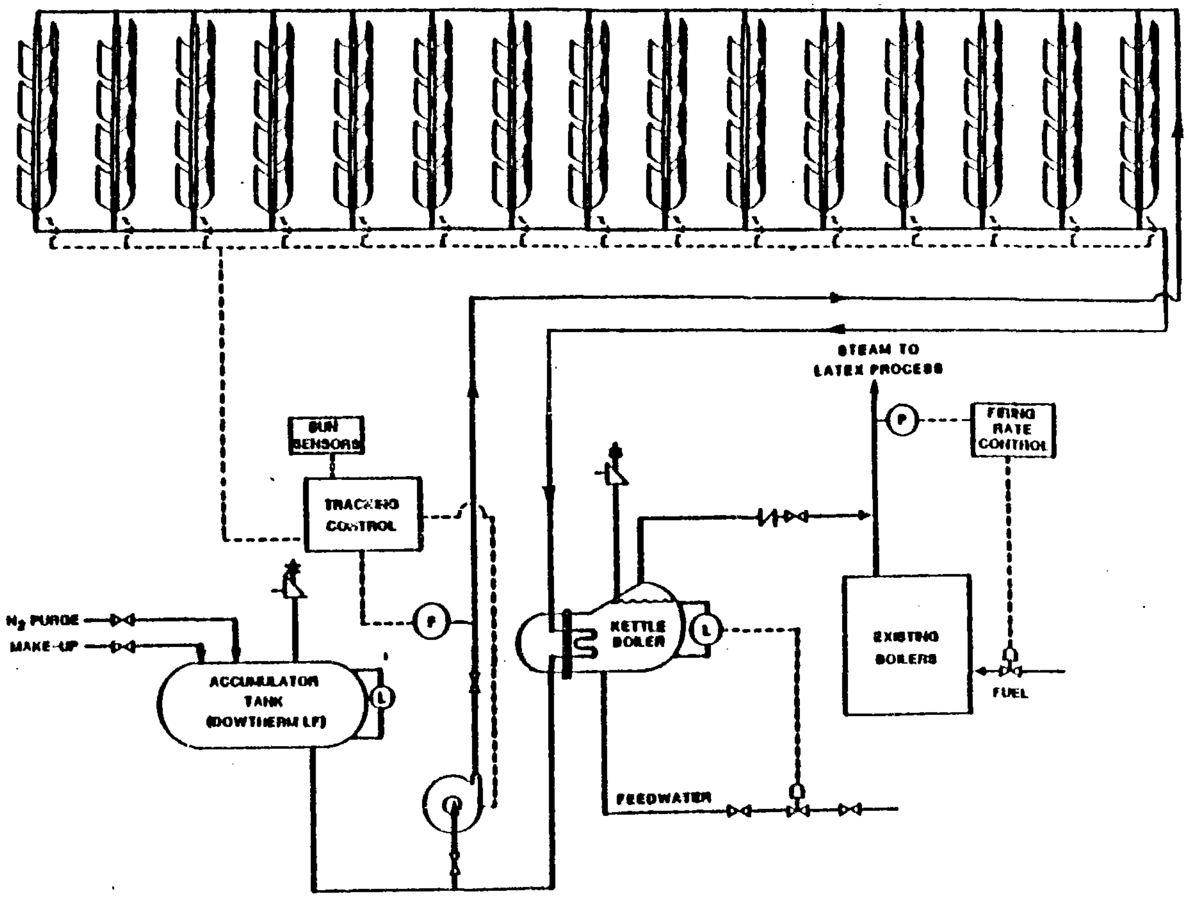

Figure 3 Schematic of the Dow Solar Steam Facility

thermal system. Dowtherm LF, the intermediate heat-transfer fluid, is circulated in parallel through the receiver tubes to an unfired steam generator and then returned to the solar collectors. A constant-speed pump circulates the Dowtherm through the system, which is pressurized with nitrogen. The system is automated to ensure safe operation. The collectors are rotated to the stow or "protect" position if:

- There is inadequate insolation.
- No steam is demanded.
- Wind speed is excessive.
- The pump fails.
- The temperature in any row exceeds a preset limit. (Only that row is stowed.)
- The water level in the boiler is too high.
- Power to the system is lost.
- Pressure in the boiler exceeds a preset limit.

Steam pressure control in the solar thermal system is simple. A check valve at the interface between the solar and the conventional steam systems allows steam to be delivered from the solar thermal system only if the solar steam pressure is higher than the process steam pressure. An accumulator tank serves as a dump tank, if needed; it also accommodates thermal expansion of the Dowtherm. No overnight freeze protection is required in the Dowtherm loop; however, the feedwater piping is electrically heat traced.

In summary, the process steam equipment (Figure 4) consists of:

- Boiler - Kettle type, boiler surface area 23.2 m^2 (250 ft^2) fitted with a pressure-relief valve, high- and low-level alarms, a level transmitter to the feedwater flow control valve, a high-pressure shutoff switch, and a high-level shutoff switch. The heat exchanger consists of a 406 mm (16-in.)-dia removable tube bundle of 57 U-tubes inserted into a 762 mm (30-in.)-dia shell. The tubes are 19 mm (0.75-in.) O.D. x 2.1 mm (0.083 in.) thick x 3.7 m (12 ft)

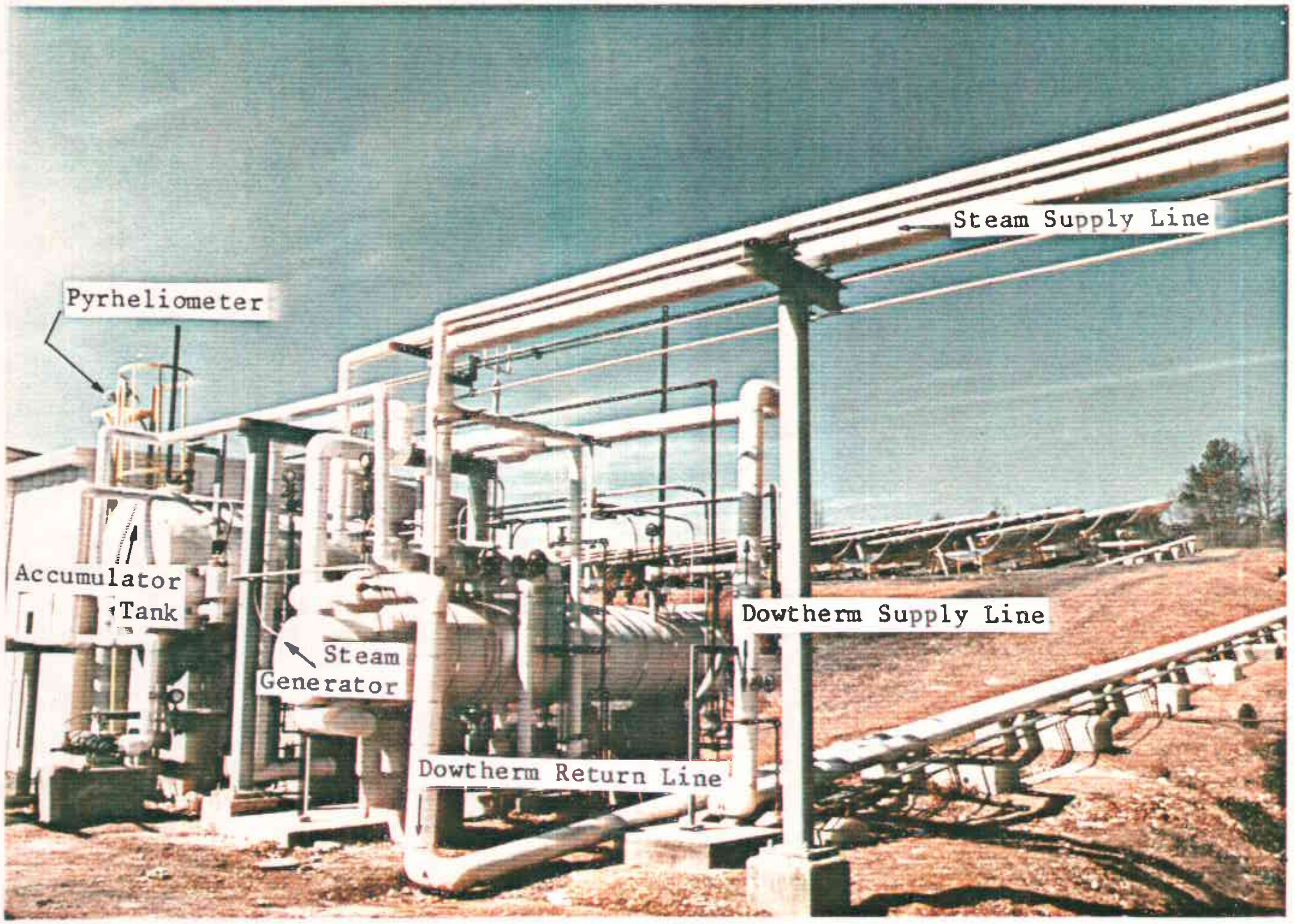

Figure 4 Auxiliary Equipment at Dow Plant in Dalton, Georgia

long, arranged in six passes. The design pressure and temperature on the shell side are 2.06 MPa gage (300 lb/in^{2}g) and 204°C (400°F) and on the tube side, 0.69 MPa gage (100 lb/in^{2}g) and 316°C (600°F). The boiler is manufactured by Manning and Lewis Engineering Company.

- Accumulator Tank - 1.2 m (4 ft)-dia x 2.4 m (8 ft) long; is fitted with a pressure-relief valve, a level gage, a low-level alarm, and a steam coil; charged with 1.05 m^2 (37 ft^3) cold Dowtherm. The tank has a total volume of 3.11 m^3 (110 ft^3). The design pressure and temperature are 0.45 MPa gage (65 lb/in^{2}g) and 316°C (600°F) The tank was manufactured by Centennial Industries Division of Douglas and Lomason Company.

- Circulating Pump - Centrifugal, with single 3-hp motor manufactured by Haight Hydraulics Company. The design pumping rate is 3.6 L/s (57 gal/min).

- Piping - Collector field about 30.5 m (100 ft) from the process equipment; restriction orifices installed in the receiver piping near the inlet manifold (north side of the collector field). Piping sizes are:

Collector Inlet:	2 in. Sch 40
Collector Outlet:	2 in. Sch 40
Feedwater:	1 in. Sch 40
Steam Outlet:	3 in. Sch 40

Dowtherm LF, manufactured by the Dow Chemical Company is a stable, organic liquid that remains in a liquid phase from -32 to 316°C (-25 to 600°F). Dowtherm LF has a low vapor pressure [at 316°C (600°F), the vapor pressure is 0.14 MPa gage (20 lb/in^{2}g)] and a high autoignition temperature [549°C (1020°F)]. The vapor pressure is lower than the nitrogen pressure available at the plant and the autoignition temperature is substantially higher than the system operating temperature. Pumping power for Dowtherm LF is low compared with other heat-transfer fluids [kinematic viscosity at 204°C (400°F) is 0.405 mm^2/s (0.0157 ft^2/h)]; and for a 30-year life, the maximum thermal stability temperature is 338°C (640°F).

OPERATING EXPERIENCE

OPERATING EXPERIENCE

The objective of Phase 3 was to obtain 12 months of performance data along with information on system reliability, availability, and maintainability. Foster Wheeler began Phase 3 in December 1981; however, the initial 1-year operating period proved to be one of extended shakedown because of many problems with the mechanical equipment, instrumentation, controls, and data-acquisition system. By the latter part of 1982, the system debugging and shakedown was completed and the solar thermal system became fully operational. In January 1983, the first monthly operating and performance report was submitted. In the fall of 1983, because of the high heat losses measured, the calcium silicate pipe insulation used originally was replaced with high-temperature fiberglass insulation. Careful attention was paid to insulating all exposed piping and valves. In addition, the piping supports--originally uninsulated welded "T's"--were cut off and replaced with saddles so that pipes could be completely insulated and thermal losses minimized.

The following paragraphs summarize operation and maintenance work done at the plant. Where known, the causes of the problem are discussed. Insights gained and recommended improvements to system components are presented at the end of this section.

December 1981 - March 1982

- In mid-December, the feedwater line to the solar boiler froze and ruptured in several places as a result of faulty electric heat tracing and the omission of the thermostat originally specified to control the activation temperature of the heat-tracing. Bad weather in December, January, and February delayed the repair of the feedwater line. In March the line was repaired and new heat tracing and insulation, along with the required thermostat, were installed.

- Because the mechanical whisker-type limit switches were unreliable, temperature insensitive mercury limit switches were installed on the collectors by Suntec Systems, Inc.

- As a result of oil leaks between the top and bottom chambers of the collector drive motor/gearbox assemblies, the bottom chamber was "piped" to the top chamber to allow the oil to seek its own level.

- The drive chains were tightened to improve collector focusing and, where necessary, were shortened by removing a link.

- The collector tracking heads were cleaned to improve tracking, and their wire connections were sprayed with a weather-protective sealant.

- The tracking motor for the pyrheliometer failed; a new motor was ordered from the manufacturer and installed.

April 1982 - September 1982

- Several flexible hoses failed at the connection to the receiver downcomer on the south side of the collector field. A close examination of the hoses revealed fatigue failures similar to those found on the north side in October 1981. (All the north-side hoses were replaced in October 1981; the new hoses had an outer strip-wound cover to limit their bend radius above a specified value, thus increasing fatigue life.)

- A problem with inconsistent temperature readings from the field-mounted RTDs was diagnosed and corrected. A faulty ground wire was the cause of this problem.

- Continued collector row tracking problems led to replacement of the photodiodes in the tracker heads.

- Breaking receiver glass continued to be a problem. During construction of the system, excessive loads were applied at the receiver supports, causing local crimping of the receiver housing. Using a specially designed tool, the aluminum housings surrounding the receiver were expanded to allow the glass to fit properly.

- An automatically activated ball valve was installed in the steam line to prevent undesired reverse steam flow from Dow's main steam line into the solar boiler. This valve closes when the Dowtherm pump is off and opens when the pump comes on.

October 1982 - December 1982

- The new flexible hoses (same type as installed on the north side in October 1981) were installed on the south side of the collector field, and the adjacent piping was reinsulated.
- A ruptured valve gasket in the steam line was repaired.
- The Dowtherm flow meter was overhauled, having apparently been freeze damaged.
- A new level sensor on the solar boiler had also been freeze damaged and was replaced.
- A small leak was noticed in the seal of the Dowtherm pump.

January 1983 - March 1983

- The leak in the Dowtherm pump worsened and its seal was replaced. Upon normal start-up, the pump impeller jammed because of improper alignment and had to be repaired.
- The steam line was reinsulated (a ruptured valve gasket had been replaced in December 1982).
- The new level d/p cell on the solar boiler was recalibrated because level readings were inconsistent.
- A leaking gate valve on the steam line was replaced, and a new RTD was installed at the boiler outlet because a lead was broken on the old one.
- Several local control boards went bad, and the respective collector rows had to be "jumped" to bring them back to stow. Component fatigue and moisture in the control boxes were the causes for the control board failures. The spare control board was installed in one of the stowed rows, but it failed to respond to the authorization signal. The control boards (two plus a spare) were returned to the manufacturer for repair.
- Surface temperature measurements were taken on the piping insulation, and areas of high heat loss were identified. Because water had saturated the calcium silicate insulation, vent holes were cut in it to allow it to dry.

April 1983 - June 1983

- Repaired local control boards were installed in the two collector rows that were out of operation.
- At the request of Dow, a boiler high-level safety shutoff switch was installed in mid-May and all required electrical wiring was completed.

- On May 15 the collectors were rain-washed.

- The pump seal flush line was repaired to stop a small Dowtherm leak around the pump.

- Because Dow raised some environmental concerns, a concrete dike was installed around the solar boiler, accumulator tank, and pump to confine possible Dowtherm spills.

July 1983 - September 1983

- Control boards in two collector rows continued to cause intermittent tracking problems in these rows. Although manual on and off cycling of the authorization signal would correct the problem, these boards were returned to the manufacturer for repair.

- The pyrheliometer was also sent back to the manufacturer for repair. The lens seal in the pyrheliometer had deteriorated, and water had condensed under the lens. The pyrheliometer was repaired and reinstalled at the site.

- The flow-meter d/p cells were recalibrated.

- Because Dowtherm was leaking, the mechanical seal in the Dowtherm pump and the pump gasket were replaced.

- Because of reverse steam flow from Dow's main steam line into the solar boiler, and the subsequent overfilling of the boiler, the automated ball valve and adjacent check valve were replaced.

- The system was shut down in mid-September to improve system performance by modifying the pipe supports and upgrading the pipe insulation.

October 1983 - December 1983

- Insulation upgrading was completed during this period, and the system was back in operation by mid-October.

- New pressure-relief valves were installed on the solar boiler and accumulator tank, and recertified pressure-relief valves were installed in each collector row.

- Because of excessive Dowtherm pump leaks, the mechanical seal had to be replaced again. A face-plate pin had broken, and the plate failed to make a good seal with the mechanical seal.

- Several adjustments were made to the feedwater flow controller to reduce fluctuations in the boiler water level.

- A flexible hose on the south side of the collector field developed a leak adjacent to the receiver downcomer and was replaced. A pinhole leak discovered in a receiver weld joint was repaired.

- The pyrheliometer motor failed and was sent back to the manufacturer for repair.

January 1984 - March 1984

- Intermittent tracking problems were observed in four collector rows, and in early March, spare control boards were installed in the system.

- The pyrheliometer solar tracker was repaired by the manufacturer and reinstalled at the site. However, water had again been discovered under the lens of the pyrheliometer, and once again it was sent back to the manufacturer.

- The system remained in stow throughout February because of a leak in the Dowtherm circulating pump. The pump seal was repaired at the end of February, and the system was back in operation on March 1.

Table 1 lists the man-hours incurred and the associated costs for operation and maintenance.

During the operational phase, problems continued to plague the system. Instrumentation problems (pyrheliometer, RTDs, etc.) were the main cause of the limited data available. Problems were experienced in the solar and nonsolar components. These problems were of both a routine nature (i.e., pump seal, valve gaskets/packing) and a nonroutine nature (i.e., replacement of flexible hoses, repair of local control boards).

Table 1 Operation, Maintenance, and Associated Expenditures in 1983

Month	Activity	Hours Incurred	Cost ($)
January	Calibrate Instrumentation and Controls	2	64
	Reinsulate Steam Valves	1.5	48
	Cut Receiver Glass (Subcontract)	---	165
	Dow System Monitoring and Reporting	50	1,600
February	Repair Pump, Replace Seal	28	353
	Replace Gate Valve in Steam Line	2	85
	Dow System Monitoring and Reporting	10	320
March	Troubleshoot Local Control Boards	2	64
	Dow System Monitoring and Reporting	10	320
April	Repair Local Control Boards	---	371
	Dow System Monitoring and Reporting	10	320
May	Tighten Packing on Dowtherm Valves	2	25
	Repair Pump Seal Flush Line	2	28
	Dow System Monitoring and Reporting	10	320
June	Repair Local Control Board	---	151
	Dow System Monitoring and Reporting	4	128
July	Replace Valve in Feedwater Line	1	25
	Dow System Monitoring and Reporting	6	192
August	Replace and Test Pressure-Relief Valves	6	192
	Repair Local Control Board	---	219
	Dow System Monitoring and Reporting	20	640
September	Replace Pump Seal and Gasket	14	196
	Replace Steam Valves	12	568
	Dow System Monitoring and Reporting	10	320
October	Repair of Pump and Replacement of Seal	6	203
	Replace Pressure-Relief Valves	4	2,822
	Dow System Monitoring and Reporting	10	320
November/ December	Replace Pressure-Relief Valves	4	128
	Install New Flex Hose and Repair Dowtherm Leaks	---	150
	Dow System Monitoring and Reporting	24	768
	Total	250.5	11,105*

*Includes normal O&M activities (i.e., relief-valve testing, pump seal replacement), activities caused by design flaws, and data acquisition problems.

DATA ACQUISITION AND EVALUATION

DATA ACQUISITION AND EVALUATION

The data-acquisition, reduction, and performance evaluation system enables on-line performance evaluation of the solar steam plant. It consists of a Data General MP100 Microcomputer, two floppy disk drives, and a printer. A Consolidated Control Data Logger (Model 90MC) is utilized for data acquisition, along with a Kennedy Magnetic Tape for back-up data storage.

This system collects data from the various field sensors that measure temperature, flow, pressure, etc., and processes these data on-line, producing complete daily and monthly summaries of system thermal performance.

The instrument transducers are embedded in the solar steam system to measure the operating variables used in evaluating system performance. These measurements are recorded on a continuous basis throughout the day:

- Incident normal solar energy (I001)
- Wind speed (V001)
- Ambient temperature (T001)
- Collector inlet header temperature (T100)
- Collector outlet header temperature (T101)
- Steam pressure (P400)
- Feedwater temperature (T400)
- Electrical power to collectors (EP101)
- Electrical power to circulating pump (EP600)
- Boiler inlet fluid temperature (T403)
- Boiler outlet fluid temperature (T401)
- Fluid flow rate (W100)
- Feedwater flow (W400).

The performance of the system was calculated using:

- Boiler Heat Losses - During the testing period, the boiler was completely isolated under hot conditions. Boiler pressure decay with time was recorded. The total amount of water in the boiler, ambient temperature, and boiler pressure vs. time curve were used to establish boiler heat losses (LB).

- Energy Delivered to Process by the Solar Steam System - Energy delivered to process (Btu/h):

$$E1 = E2 - LB$$

and

$$E2 = (Cp_3)(W100)(T403 - T401)$$

where

Cp_3 = Specific heat of Dowtherm LF

LB = Boiler heat losses

- Amount of Steam Generated - Having calculated the energy delivered to water by the solar steam system (E1), the amount of steam generated is calculated as:

$$\text{Amount of steam produced (lb/h)} = E_1 / \left[h_{fg} + C_{p1}(T_{sat} - T400)\right]$$

where

h_{fg} = Heat of vaporization of water at the steam pressure (P400)

T_{sat} = Saturation temperature corresponding to the steam pressure (P400)

C_{p1} = Specific heat of water

A redundant check of the amount of steam generated was provided by a feedwater flow totaler.

- Collector Array Efficiency - Collector Array Efficiency = $E_3/(I001)(A)(B)$

where

$$E3 = (Cp_3)(W100)(T101 - T100)$$

A = Collector aperture area

B = Factor to convert direct normal insolation to insolation on the collector plane

- Electrical Parasitic Losses.

  Total electrical parasitic losses = EP101 + EP600

- Piping Thermal Losses. The piping losses operating were computed by subtracting the heat delivered to the boiler from the heat collected in the solar collectors. Thus

  Piping Losses = E3 - E2

- Overnight Thermal Losses. The overnight thermal (nonoperating) losses are determined from the cumulative value of energy collected (E3), from the time between collector start-up and the onset of steam generation.

The data-acquisition, reduction, and analysis program are written in Advanced FORTRAN IV for an interactive mode of operation. Once the software is activated, the data-acquisition system operates automatically--without operator assistance. Data are scanned every 7 seconds for possible alarm conditions. Every 5 minutes the computer accesses the data from the data logger and stores it along with any alarm conditions on the magnetic tape. Channels that are accessed are displayed by the data logger. The daily performance summary is printed automatically at midnight for the day just ended. The monthly performance summary is printed on the first day of the new month for the preceding month. On demand, the computer will print the daily and monthly summaries as well as a diagnostic summary of all operating and performance variables. The magnetic tape is replaced every month, and data are accessed as needed.

PERFORMANCE

PERFORMANCE

Beginning in January 1983, monthly operating and performance data were reported. Table 2 is a monthly summary of the solar steam system performance. As this table shows, collector array efficiencies for the first 6 months of 1983 ranged from 15.4 to 22.8 percent, and system thermal efficiencies ranged from 4.2 to 15.6 percent. The collector array efficiencies are significantly lower than the 55 percent Sandia predicted based on their earlier testing of the Suntec collector.[1]* The system efficiencies are also lower than the 40 percent commonly predicted for parabolic trough solar thermal systems.[2,3] Although the exact cause or causes of the low collector performance have not been identified, suggested probable causes are degradation of the black chrome receiver coating, accumulation of dirt and grime on the reflector or receiver tubes, imprecise collector focusing, and dust in the annulus between the receiver and the glass cover. Because of problems with instrumentation, particularly the pyrheliometer, a significant amount of data is not available.

Table 3 summarizes the system availability and utilization and also shows the number of days that the system operated in each month. With the exception of downtime in September and October to upgrade the pipe insulation and modify the pipe supports, system availability and the corresponding utilization were quite high.

*References are listed at the end of the report.

Table 2 Experimental Performance Results*

Month	Incident Solar Energy on Collector Plane (GJ)	Energy Collected (GJ)	Collector Array Efficiency (%)	Energy Delivered to Process (GJ)	Operating Losses (GJ)	Nonoperating Losses (GJ)	System Thermal Efficiency (%)
1983							
January	202.47	31.22	15.42	8.44	11.28	11.47	4.2
February	219.40	42.23	19.25	14.77	10.74	16.67	6.7
March	297.23	68.40	23.01	42.31	18.02	8.07	14.2
April	467.88	92.44	19.76	64.84	21.73	5.87	13.9
May	451.18	95.86	21.25	68.34	20.55	6.97	15.1
June[†]	334.35	76.20	22.79	52.04	16.14	8.02	15.6
July	DNA[§]	65.50	DNA[§]	41.42	18.19	5.89	DNA[§]
August	DNA[§]	80.95	DNA[§]	52.31	20.32	8.32	DNA[§]
September[¶]	76.18**	20.94	DNA[§]	11.45	6.47	2.94	DNA[§]
October[¶]	259.64[†]	DNA[††]	DNA[††]	DNA[††]	DNA[††]	DNA[††]	DNA[††]
November	310.58	DNA[††]	DNA[††]	DNA[††]	DNA[††]	DNA[††]	DNA[††]
December	DNA[§]	22.03	DNA[§]	11.18	8.01	2.84	DNA[§]
1984							
January	DNA[§]	29.62	DNA[§]	12.47	13.68	3.47	DNA[§]
February[§§]	---	---	---	---	---	---	---
March	DNA[§§]	65.72	DNA[§]	52.35	5.95	7.42	DNA[§]

*Conversion: 1 kJ = 0.95 Btu.
†Some data missing.
§Data not available--pyrheliometer malfunction.
¶System down for repairs from September 14 to October 14.
**Pyrheliometer put back in operation on September 16.
††Data not available--bad RTD readings.
§§System down--pump repair

Table 3 System Operation Summary--1983

Month	Days of System Operation	Availability* (%)	Utilization† (%)
January	20	96.8	90
February	15	89	100
March	21	100	100
April	22	100	83
May	20	93.5	100
June	24	100	96.7
July	25	100	80.6
August	31	100	100
September	10	47	100
October	12	58	100
November	24	100	100
December	17	80.6	100

*Availability equals the days the solar facility was not down for repairs divided by the total number of days in the month.

†Utilization equals the days of actual system operation divided by the number of days the system was not down for repairs.

Table 4 shows the parasitic energy used each month and the amount of steam provided to Dow's process. Appendix A contains monthly performance summaries of daily performance; Appendix B presents clear-day performance data--hourly data for the best day each month; and Appendix C provides monthly system operation summaries--a qualitative assessment of the daily weather conditions and the status of the system.

While the plant performance data described are sufficient to indicate system efficiencies that are significantly lower than expected, these data do not allow us to identify and quantify the causes of discrepancies between the anticipated and realized system performance. Furthermore, comparisons between the actual performance and that predicted using TMY or other such data tell us little because they ignore the actual insolation and temperatures experienced. Accordingly, we devised a rigorous and detailed model of the system that allows us to:

- Identify discrepancies between the actual and anticipated performance of the system and various subsystems
- Quantify these discrepancies in terms of both the nature of the problem and its effect upon the system's annual performance
- Examine the effect of changes to the design of the system and its operating procedures.

In modeling the solar thermal system, we emphasized transient operating states and the effects of heat loss and thermal inertia.

Having devised a model, we fitted it to actual field data by selecting the set of parameters used to describe the solar thermal system that gave the best fit

Table 4 Parasitic Energy Used and Steam Production During 1983

Month	Parasitic Energy Used (kWh)	Steam Produced (lb)
January	441	7,726
February	442	15,000
March	524	36,383
April	498	60,558
May	525	63,852
June	501	48,398
July	581	37,620
August	609	47,706
September	558	10,295
October	459	DNA*
November	DNA*	DNA*
December	473	6,742
	5611	334,280

*Data Not Available.

between the model and the series of temperature data collected:

- Heat-loss coefficients
- Rate of flow between the heat-transfer loop and the accumulator tank
- Boiling temperature of water in the steam generator
- A factor accounting for the degradation of collector efficiency.

Three sets of data were selected, each set comprising simultaneous temperature measurements made over several hours at the entrance and exit to the steam generator and collectors. The field data exhibited transient behavior.

In selecting the parameters, we assumed that the thermal masses of subsystems can be determined from design data. Discrepancies between actual and estimated thermal masses are, in general, related to inadequate insulation or insolation; thus they can be adequately represented as enhanced heat losses. In fitting the model to the temperature data, we used actual insolation, ambient temperature, and heat-transfer fluid mass flow rate data.

The model and simulation procedure are described in detail in Appendix D.

The results of the parametric studies are interesting, not only in that they demonstrate the adequacy of the model, but also in that we are able to discern the effect of maintenance, etc. Of most importance we noted that the performance of the collectors was significantly lower than early test data had led us to expect.

Having demonstrated the applicability of the model and obtained best estimates of the parameters needed to define the system, we used the model to predict the annual performance of the system and the effect of various changes in design and and operation. The results of these predictions are presented in Table 5 and Figure 5. [The simulated performance is based on monthly climatic data (insolation) for Atlanta, Georgia]. In addition, we note that the long time required to warm up and achieve steam production precludes the use of simple models of solar thermal systems that basically ignore thermal inertia.

Table 5 Predicted Solar Thermal System Performance*

System Status	Annual Average System Efficiency (%)
Collectors operate at design efficiency	30.78
Collectors operate at 90 percent of design efficiency	27.99
Collectors operate at 80 percent of design efficiency	24.66
Collectors operate at 60 percent of design efficiency	15.95
Collector field on level ground	28.92
Operation with no heat loss except from collectors	39.01
Steam generator placed adjacent to field	32.16
20 percent of fluid flow passes through the expansion tank	29.85

*Except where specifically indicated to the contrary, in making predictions we assumed the collectors operated at design efficiency and there was no flow through the expansion tank.

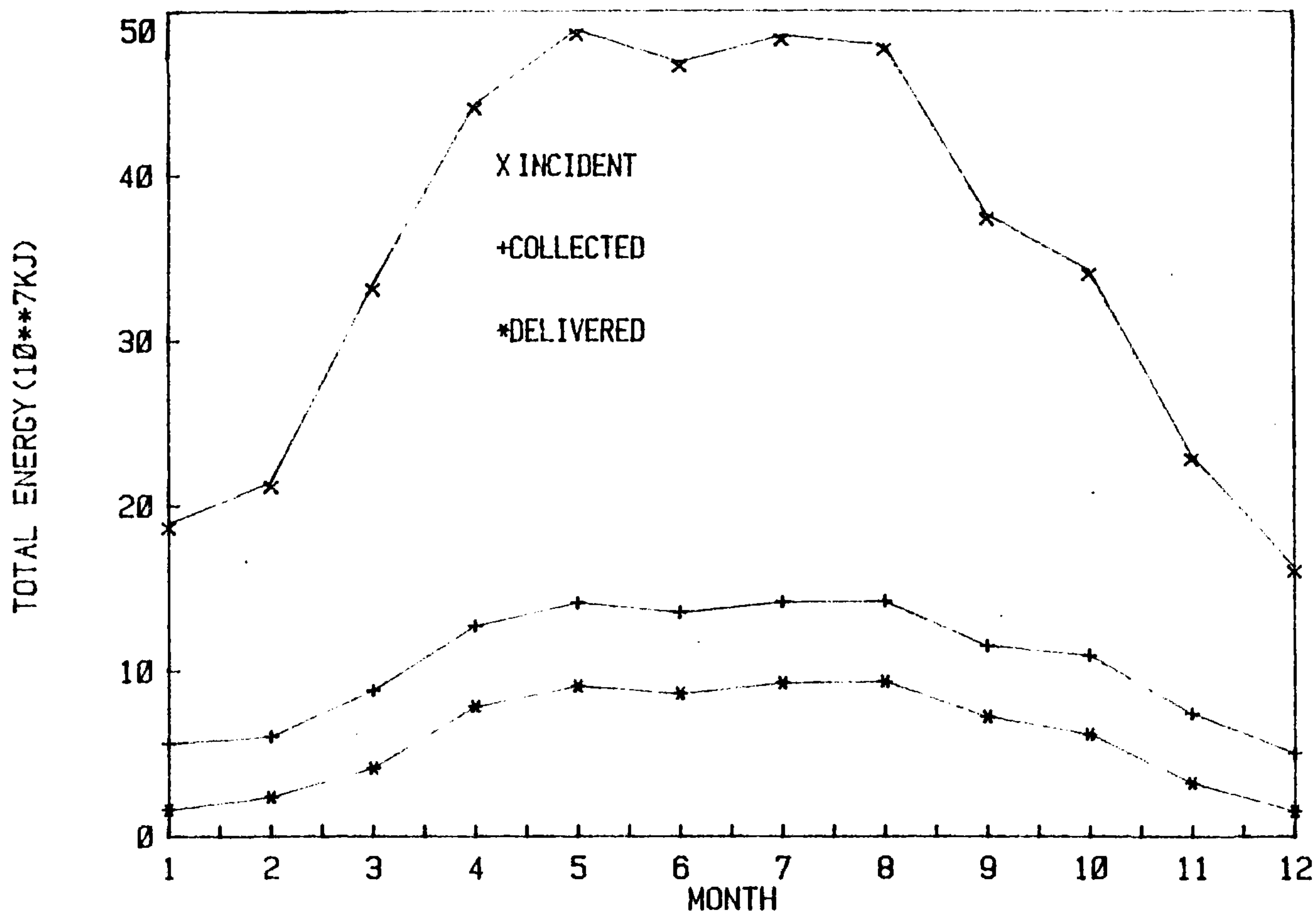

Figure 5 Simulated Performance Prediction

CONCLUSIONS/RECOMMENDATIONS

CONCLUSIONS/RECOMMENDATIONS

Based on the problems that were experienced and our observations of system performance, we recommend these improvements:

- Mercury switches should be used in lieu of mechanical whisker-type switches to limit the extreme forward and reverse positions of the collectors. The originally installed mechanical switches proved unreliable because of extremes in ambient temperature fluctuations.
- The collectors are currently chain-driven by a dc motor. Focusing inaccuracies occur when the chain slips or stretches. A direct gear-driven system would improve performance.
- Sleeving on the tracker head wiring should be eliminated to reduce corrosion.
- Flexible hose design should be further studied specifically for inclined installations such as Dow. We believe that strip-wound hose is preferable to a bellows-type hose because of its increased rigidity. However, because of the recent failures of the strip-wound hoses, alternative designs need to be evaluated.
- An automated ball valve should be used at the solar/fossil fuel interface to prevent backfilling of the solar boiler overnight.
- A boiler high-level shut-off switch should be installed in the solar steam system to reduce the possibility of water slugs in the plant steam line.
- A more reliable pyrheliometer should be developed for use in data evaluation. Particular attention should be paid to a slip-ring connector to eliminate the need for regular unwinding of the connector wire.
- Areas of potential heat loss should be minimized. Care should be taken to insulate all piping, piping supports, equipment supports, and valves.
- The reasons for the 35-percent degradation observed during the parametric studies are difficult to identify without further experimentation; degradation could result from the accumulation of grime on the reflector or receiver tubes, an increase in the emissivity of the receiver tubes, or collector malfocusing.
- The results of annual performance predictions clearly demonstrate the need to identify and eliminate the causes of low collector efficiency, the need to minimize heat losses and thermal inertia, and the desirability of avoiding continuous flow through the accumulator.

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APPENDIX A

MONTHLY PERFORMANCE SUMMARIES

Monthly Performance Summary--January 1983*

Julian Date	Date	Incident Solar Energy on a Collector Surface (GJ)	Energy Collected (GJ)	Collector Array Efficiency (%)	Energy Delivered (GJ)	Losses (GJ) Operational	Losses (GJ) Non-Operational	System Thermal Efficiency (%)	Parasitic Energy Used (GJ)
1	1	0.02	---	---	---	---	---	---	0.039
2	2	---	---	---	---	---	---	---	0.039
3	3	10.93	---	---	---	---	---	---	0.039
4	4	12.86	2.78	21.60	0.93	0.81	1.04	7.2	0.055
5	5	12.69	1.80	14.17	0.50	0.65	0.64	3.9	0.073
6	6	8.74	---	---	---	---	---	---	0.039
7	7	9.11	0.76	8.32	---	0.26	0.50	---	0.061
8	8	1.08	0.17	15.99	---	0.06	0.11	---	0.048
9	9	2.59	0.24	9.18	---	0.07	0.17	---	0.054
10	10	---	---	---	---	---	---	---	0.040
11	11	10.14	1.65	16.26	0.23	0.58	0.84	2.3	0.068
12	12	2.79	0.37	13.41	---	0.16	0.21	---	0.049
13	13	16.12	3.45	21.43	1.13	1.33	1.00	7.0	0.080
14	14	15.89	2.89	18.20	0.91	1.22	0.77	5.7	0.081
15	15	0.59	---	---	---	---	---	---	0.040
16	16	17.89	3.79	21.16	1.66	1.32	0.80	9.3	0.082
17	17	18.16	4.09	22.53	1.78	1.36	0.94	9.8	0.087
18	18	19.45	3.67	18.87	1.27	1.12	1.28	6.5	0.082
19	19	10.01	0.74	7.37	---	0.36	0.38	---	0.064
20	20	---	---	---	---	---	---	---	0.040
21	21	---	---	---	---	---	---	---	0.040
22	22	---	---	---	---	---	---	---	0.040
23	23	---	---	---	---	---	---	---	0.040
24	24	---	---	---	---	---	---	---	0.040
25	25	1.03	---	---	---	---	---	---	0.040
26	26	4.64	0.50	10.77	---	0.17	0.33	---	0.057
27	27	---	---	---	---	---	---	---	0.040
28	28	13.94	2.54	18.19	0.03	1.09	1.41	0.2	0.073
29	29	3.10	0.30	9.72	---	0.13	0.16	---	0.053
30	30	5.14	0.86	16.75	---	0.36	0.50	---	0.060
31	31	5.58	0.62	11.09	---	0.23	0.39	---	0.062
Total		202.47	31.22	15.42	8.44	11.28	11.47	4.2	1.586

*All collector rows operational.

Monthly Performance Summary--February 1983*

Julian Date	Date	Incident Solar Energy on a Collector Surface (GJ)	Energy Collected (GJ)	Collector Array Efficiency (%)	Energy Delivered (GJ)	Losses (GJ) Operational	Losses (GJ) Non-Operational	System Thermal Efficiency (%)	Parasitic Energy Used (GJ)
32	1	---	---	---	---	---	---	---	0.015
33	2	4.06	---	---	---	---	---	---	0.039
34	3	---	---	---	---	---	---	---	0.040
35	4	18.28	0.16	0.90	---	0.08	0.08	---	0.047
36	5	0.18	---	---	---	---	---	---	0.040
37	6	---	---	---	---	---	---	---	0.039
38	7	3.00	---	---	---	---	---	---	0.039
39	8	21.12	4.40	20.85	2.0†	1.1†	1.3†	9.5†	0.086
40	9	---	---	---	---	---	---	---	0.039
41	10	---	---	---	---	---	---	---	0.039
42	11	---	---	---	---	---	---	---	0.039
43	12	1.65	---	---	---	---	---	---	0.039
44	13	0.65	---	---	---	---	---	---	0.039
45	14	15.20	3.90	25.68	1.7†	1.0†	1.2†	11.2†	0.069
46	15	11.09	2.22	20.02	0.32	0.86	1.04	2.9	0.073
47	16	0.18	---	---	---	---	---	---	0.039
48	17	23.32	6.08	26.09	2.19	1.51	2.39	9.4	0.086
49	18	16.88	3.67	21.72	0.54	1.12	2.00	3.2	0.087
50	19	21.10	5.44	25.79	1.07	0.89	3.48	5.1	0.090
51	20	20.85	5.15	24.71	2.94	0.74	1.47	14.1	0.086
52	21	15.71	3.92	24.93	2.36	0.70	0.86	15.0	0.078
53	22	4.47	0.62	13.75	---	0.27	0.35	---	0.054
54	23	5.87	0.25	4.22	---	0.08	0.16	---	0.064
55	24	1.15	0.05	4.03	---	0.01	0.01	---	0.046
56	25	15.44	3.02	19.55	0.53	0.92	1.56	3.4	0.083
57	26	14.45	2.88	19.91	1.12	1.23	0.52	7.8	0.083
58	27	4.77	0.48	10.05	---	0.23	0.25	---	0.073
59	28	---	---	---	---	---	---	---	0.039
Total		219.40	42.23	19.25	14.77	10.74	16.67	6.7	1.592

*All collector rows operational.
†Estimated Values.

Monthly Performance Summary--March 1983*

Julian Date	Date	Incident Solar Energy on a Collector Surface (GJ)	Energy Collected (GJ)	Collector Array Efficiency (%)	Energy Delivered (GJ)	Losses (GJ) Operational	Losses (GJ) Non-Operational	System Thermal Efficiency (%)	Parasitic Energy Used (GJ)
60	1	20.28	5.30	26.16	3.51	1.26	0.54	17.3	0.065
61	2	23.36	6.36	27.22	4.45	1.56	0.35	19.0	0.090
62	3	19.61	5.08	25.91	3.34	1.41	0.34	17.0	0.087
63	4	14.50	2.56	17.64	1.52	0.72	0.33	10.5	0.084
64	5	2.79	0.18	6.55	---	0.11	0.07	---	0.051
65	6	21.07	4.62	21.92	2.86	1.24	0.52	13.6	0.075
66	7	13.74	3.63	26.45	2.12	1.17	0.34	15.4	0.077
67	8	17.76	3.42	19.27	1.90	1.14	0.38	10.7	0.087
68	9	8.49	0.84	9.91	---	0.34	0.50	---	0.069
69	10	---	---	---	---	---	---	---	0.040
70	11	0.04	---	---	---	---	---	---	0.039
71	12	2.27	0.45	19.72	---	0.13	0.32	---	0.048
72	13	11.51	6.75	59.65	5.30	1.01	0.44	46.0	0.089
73.	14	11.63	3.84	33.04	2.63	0.85	0.37	22.6	0.078
74	15	8.50	0.95	11.12	0.12	0.60	0.23	1.4	0.082
75	16	0.04	---	---	---	---	---	---	0.036
76	17	---	---	---	---	---	---	---	0.035
77	18	---	---	---	---	---	---	---	0.036
78	19	16.57	4.24	25.59	2.47	1.18	0.58	14.9	0.074
79	20	---	---	---	---	---	---	---	0.036
80	21	---	---	---	---	---	---	---	0.036
81	22	20.43	4.80	23.51	3.19	1.03	0.58	15.6	0.085
82	23	4.42	0.40	9.14	---	0.15	0.25	---	0.059
83	24	---	---	---	---	---	---	---	0.036
84	25	30.99	7.26	23.42	5.00	1.59	0.66	16.1	0.085
85	26	6.92	0.94	13.61	0.25	0.39	0.30	3.6	0.057
86	27	15.63	2.03	12.97	0.81	0.78	0.43	5.2	0.065
87	28	---	---	---	---	---	---	---	0.036
88	29	23.26	4.67	20.06	2.84	1.35	0.48	12.2	0.082
89	30	0.90	---	---	---	---	---	---	0.036
90	31	2.56	0.8	3.11	---	0.03	0.06	---	0.047
Total		297.23	68.40	23.01	42.31	18.02	8.07	14.2	1.898

*March 15 to 31: 13 rows operational.

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DATE: November 1984

Monthly Performance Summary--April 1983*

Julian Date	Date	Incident Solar Energy on a Collector Surface (GJ)	Energy Collected (GJ)	Collector Array Efficiency (%)	Energy Delivered (GJ)	Losses (GJ) Operational	Losses (GJ) Non-Operational	System Thermal Efficiency (%)	Parasitic Energy Used (GJ)
91	1	16.47	3.40	20.63	1.73	1.14	0.53	10.5	0.062
92	2	1.27	0.06	4.97	---	0.03	0.04	---	0.043
93	3	6.02	0.78	13.01	0.03	0.31	0.44	---	0.047
94	4	20.66	4.40	21.30	2.53	1.51	0.35	12.2	0.085
95	5	---	---	---	---	---	---	---	0.036
96	6	0.54	---	---	---	---	---	---	0.036
97	7	0.25	---	---	---	---	---	---	0.036
98	8	0.06	---	---	---	---	---	---	0.036
99	9	7.39	---	---	---	---	---	---	0.036
100	10	6.38	---	---	---	---	---	---	0.036
101	11	17.39	---	---	---	---	---	---	0.036
102	12	28.01	---	---	---	---	---	---	0.036
103	13	24.00	---	---	---	---	---	---	0.036
104	14	0.06	---	---	---	---	---	---	0.036
105	15	28.80	6.70	23.28	4.33	1.88	0.49	15.0	0.095
106	16	31.05	7.68	24.74	5.50	1.78	0.40	17.7	0.090
107	17	28.16	7.03	24.96	5.09	1.64	0.30	18.1	0.089
108	18	1.54	0.03	1.03	---	0.02	0.01	---	0.042
109	19	34.47	8.53	24.76	6.20	1.79	0.54	18.0	0.091
110	20	33.83	8.38	24.78	6.31	1.73	0.33	18.7	0.087
111	21	27.16	6.66	24.51	4.83	1.49	0.34	17.8	0.087
112	22	---	---	---	---	---	---	---	0.037
113	23	0.01	---	---	---	---	---	---	0.037
114	24	0.78	---	---	---	---	---	---	0.038
115	25	31.87	8.36	26.22	6.00	1.78	0.58	18.8	0.089
116	26	32.11	9.41	29.30	7.41	1.68	0.31	23.1	0.088
117	27	33.15	8.74	26.38	6.82	1.61	0.31	20.6	0.087
118	28	23.88	5.55	23.22	3.83	1.38	0.33	20.6	0.089
119	29	17.18	3.41	19.87	2.16	1.03	0.22	12.6	0.000
120	30	15.61	3.33	21.34	2.07	0.93	0.33	13.3	0.072
Total		467.88	92.44	19.76	64.85	21.73	5.87	13.9	1.794

*April 1 to 14: 13 rows operational. April 15 to 30: 14 rows operational.

Monthly Performance Summary--May 1983*

Julian Date	Date	Incident Solar Energy on a Collector Surface (GJ)	Energy Collected (GJ)	Collector Array Efficiency (%)	Energy Delivered (GJ)	Losses (GJ) Operational	Losses (GJ) Non-Operational	System Thermal Efficiency (%)	Parasitic Energy Used (GJ)
121	1	15.82	3.18	20.09	1.83	0.96	0.39	11.6	0.070
122	2	†	†	†	†	†	†	†	†
123	3	†	†	†	†	†	†	†	†
124	4	22.45	5.92	26.39	4.49	1.29	0.14	20.0	0.075
125	5	27.87	7.46	26.79	5.72	1.47	0.28	20.5	0.088
126	6	32.07	8.73	27.23	6.96	1.49	0.28	21.7	0.090
127	7	31.07	5.80	18.66	4.09	1.39	0.32	13.2	0.089
128	8	11.74	2.34	19.97	1.28	0.68	0.39	10.9	0.071
129	9	31.73	7.20	22.70	5.41	1.47	0.32	17.1	0.091
130	10	12.67	2.22	17.53	1.08	0.83	0.31	8.5	0.077
131	11	14.04	2.99	21.31	1.97	0.88	0.15	14.0	0.077
132	12	0.06	---	---	---	---	---	---	0.035
133	13	10.52	---	---	---	---	---	---	0.031
134	14	16.99	0.91	5.35	0.22	0.38	0.30	1.3	0.061
135	15	0.07	---	---	---	---	---	---	0.042
136	16	8.96	0.18	2.01	0.01	0.07	0.10	---	0.062
137	17	14.90	---	---	---	---	---	---	0.039
138	18	†	†	†	†	†	†	†	†
139	19	†	†	†	†	†	†	†	†
140	20	†	†	†	†	†	†	†	†
141	21	5.58	---	---	---	---	---	---	---
142	22	1.56	---	---	---	---	---	---	---
143	23	21.72	5.45	25.08	3.36	1.55	0.53	15.5	0.091
144	24	34.06	9.27	27.21	6.91	2.00	0.35	20.3	0.096
145	25	27.26	8.37	30.69	6.30	1.74	0.32	23.1	0.092
146	26	17.57	3.66	20.81	2.09	1.15	0.41	11.9	0.088
147	27	35.43	8.58	24.22	6.76	0.64	1.18	19.1	0.086
148	28	16.99	4.01	23.60	2.90	0.70	0.41	17.1	0.080
149	29	10.29	2.29	22.26	1.40	0.50	0.40	13.6	0.068
150	30	29.06	7.32	25.20	5.57	1.36	0.39	19.2	0.095
151	31	0.73	---	---	---	---	---	---	0.040
Total		451.18	95.86	21.25	68.35	20.55	6.97	15.1	1.831

*May 1 to 12: 14 collector rows operational. May 13 to 31: 10 collector rows operational.
†No Data Available.

Monthly Performance Summary--June 1983*

Julian Date	Date	Incident Solar Energy on a Collector Surface (GJ)	Energy Collected (GJ)	Collector Array Efficiency (%)	Energy Delivered (GJ)	Losses (GJ) Operational	Losses (GJ) Non-Operational	System Thermal Efficiency (%)	Parasitic Energy Used (GJ)
152	1	18.18	5.42	29.80	4.34	0.84	0.25	23.87	0.060
153	2	12.72	2.92	22.98	2.00	0.54	0.38	15.72	0.041
154	3	†	†	†	†	†	†	†	†
155	4	†	†	†	†	†	†	†	†
156	5	†	†	†	†	†	†	†	†
157	6	6.13	0.98	15.99	0.14	0.33	0.51	2.28	0.050
158	7	---	---	---	---	---	---	---	0.040
159	8	24.37	4.91	20.16	3.67	0.77	0.47	15.06	0.095
160	9	17.15	2.52	14.70	1.55	0.70	0.27	9.04	0.080
161	10	21.50	5.50	25.58	3.80	1.17	0.53	17.67	0.088
162	11	31.82	9.46	29.73	7.78	1.42	0.25	24.45	0.094
163	12	31.56	7.78	24.66	6.03	1.28	0.47	19.11	0.096
164	13	11.45	2.93	25.57	2.09	0.54	0.30	18.25	0.041
165	14	†	†	†	†	†	†	†	†
166	15	4.55	0.39	8.65	---	0.14	0.25	---	0.095
167	16	15.71	4.45	28.34	3.13	0.86	0.46	19.92	0.089
168	17	5.27	0.83	15.78	0.15	0.34	0.34	2.85	0.064
169	18	0.25	---	---	---	---	---	---	0.041
170	19	---	---	---	---	---	---	---	0.040
171	20	4.59	0.44	9.50	---	0.16	0.28	---	0.053
172	21	15.92	2.94	18.50	1.39	0.97	0.58	8.73	0.087
173	22	1.94	0.10	5.26	---	0.03	0.07	---	0.046
174	23	7.44	1.98	26.59	0.89	0.60	0.50	11.96	0.056
175	24	18.21	5.26	28.89	3.80	1.14	0.32	20.87	0.082
176	25	25.95	6.79	26.18	5.33	1.16	0.30	20.54	0.083
177	26	18.17	2.86	15.75	1.66	0.89	0.31	9.14	0.080
178	27	4.86	1.14	23.48	0.79	0.31	0.04	16.26	0.040
179	28	9.23	0.96	10.38	0.13	0.37	0.46	1.41	0.067
180	29	11.91	1.96	16.45	0.91	0.64	0.41	7.64	0.079
181	30	15.47	3.68	23.82	2.48	0.94	0.27	16.03	0.089
Total		334.35	76.20	22.79	52.06	16.14	8.02	15.57	1.776

*All collector rows operational.
†No Data Available.

REF.: DE-AC04-78CS32199
DATE: November 1984

Monthly Performance Summary--July 1983*

Julian Date	Date	Incident Solar Energy on a Collector Surface (GJ)	Energy Collected (GJ)	Collector Array Efficiency (%)	Energy Delivered (GJ)	Losses (GJ) Operational	Losses (GJ) Non-Operational	System Thermal Efficiency (%)	Parasitic Energy Used (GJ)
182	1	†	0.60	†	0.03	0.23	0.34	†	0.040
183	2	†	5.24	†	3.81	1.07	0.36	†	0.079
184	3	†	4.78	†	3.48	1.17	0.12	†	0.087
185	4	†	2.36	†	1.34	0.73	0.29	†	0.087
186	5	†	---	†	---	---	---	†	0.040
187	6	†	---	†	---	---	---	†	0.040
188	7	†	---	†	---	---	---	†	0.040
189	8	†	---	†	---	---	---	†	0.040
190	9	†	---	†	---	---	---	†	0.039
191	10	†	---	†	---	---	---	†	0.040
192	11	†	5.40	†	3.84	1.21	0.35	†	0.085
193	12	†	5.44	†	4.37	0.73	0.33	†	0.091
194	13	†	4.59	†	2.86	1.51	0.22	†	0.087
195	14	†	2.18	†	1.15	0.77	0.26	†	0.068
196	15	†	0.57	†	0.15	0.28	0.14	†	0.057
197	16	†	0.89	†	0.14	0.47	0.29	†	0.073
198	17	†	0.06	†	---	0.04	0.02	†	0.044
199	18	†	1.07	†	0.21	0.48	0.38	†	0.069
200	19	†	0.86	†	0.27	0.44	0.15	†	0.067
201	20	†	0.89	†	0.22	0.43	0.24	†	0.063
202	21	†	5.26	†	3.88	1.21	0.17	†	0.084
203	22	†	1.74	†	0.86	0.72	0.15	†	0.074
204	23	†	2.45	†	1.43	0.87	0.16	†	0.077
205	24	†	0.82	†	0.12	0.36	0.34	†	0.062
206	25	†	0.54	†	---	0.24	0.30	†	0.068
207	26	†	4.45	†	3.03	0.95	0.47	†	0.078
208	27	†	2.87	†	1.70	0.99	0.18	†	0.082
209	28	†	5.58	†	4.22	1.25	1.12	†	0.090
210	29	†	2.37	†	1.23	0.78	0.36	†	0.086
211	30	†	3.87	†	2.80	1.07	---	†	0.094
212	31	†	0.62	†	0.29	0.19	0.14	†	0.056
Total		---	65.50	---	41.41	18.19	5.89	---	2,090

*All collector rows operational.
†No Data Available.

Monthly Performance Summary--August 1983*

Julian Date	Date	Incident Solar Energy on a Collector Surface (GJ)	Energy Collected (GJ)	Collector Array Efficiency (%)	Energy Delivered (GJ)	Losses (GJ) Operational	Losses (GJ) Non-Operational	System Thermal Efficiency (%)	Parasitic Energy Used (GJ)
213	1	†	0.37	†	0.01	0.13	0.23	†	0.051
214	2	†	1.21	†	0.67	0.44	0.09	†	0.049
215	3	†	2.39	†	1.32	0.61	0.45	†	0.070
216	4	†	3.92	†	2.74	1.06	0.12	†	0.088
217	5	†	2.74	†	1.83	0.68	0.23	†	0.072
218	6	†	1.30	†	0.67	0.48	0.23	†	0.061
219	7	†	1.00	†	0.22	0.47	0.32	†	0.069
220	8	†	2.02	†	†	†	†	†	0.072
221	9	†	2.03	†	0.57	0.64	0.81	†	0.074
222	10	†	1.06	†	0.36	0.49	0.20	†	0.062
223	11	†	1.54	†	0.61	0.61	0.32	†	0.076
224	12	†	4.24	†	3.08	0.78	0.38	†	0.076
225	13	†	8.22	†	6.65	1.19	0.37	†	0.091
226	14	†	5.98	†	4.49	1.09	0.40	†	0.090
227	15	†	3.22	†	2.09	0.74	0.39	†	0.071
228	16	†	0.65	†	0.08	0.25	0.32	†	0.051
229	17	†	1.44	†	0.54	0.51	0.39	†	0.065
230	18	†	2.87	†	1.35	1.28	0.24	†	0.083
231	19	†	3.60	†	2.55	0.81	0.24	†	0 081
232	20	†	3.73	†	2.56	0.85	0.32	†	0.083
233	21	†	5.45	†	4.35	0.95	0.16	†	0.084
234	22	†	2.95	†	2.08	0.70	0.17	†	0.073
235	23	†	1.89	†	1.18	0.56	0.15	†	0.070
236	24	†	2.75	†	1.82	0.72	0.21	†	0.076
237	25	†	0.89	†	0.12	0.42	0.35	†	0.072
238	26	†	1.00	†	0.58	0.40	0.02	†	0.077
239	27	†	3.50	†	2.43	0.81	0.26	†	0.083
240	28	†	1.12	†	0.48	0.43	0.21	†	0.062
241	29	†	5.71	†	4.47	0.89	0.35	†	0.087
242	30	†	2.09	†	1.05	0.66	0.38	†	0.080
243	31	†	0.01	†	---	0.01	---	†	0.048
Total		---	80.95	---	52.35	20.32	8.32	---	2.244

*August 1 to 9: Intermittent problem with two collector rows. August 10 to 31: All collector rows fully operational.
†No Data Available.

Monthly Performance Summary--September 1983*

Julian Date	Date	Incident Solar Energy on a Collector Surface (GJ)	Energy Collected (GJ)	Collector Array Efficiency (%)	Energy Delivered (GJ)	Losses (GJ)	System Thermal Efficiency (%)	Parasitic Energy Used (GJ)
244	1	†	0.41	†	0.02	0.39	†	†
245	2	†	---	†	---	---	†	0.040
246	3	†	---	†	---	---	†	0.040
247	4	†	0.27	†	---	0.27	†	0.052
248	5	†	2.07	†	0.93	0.14	†	0.077
249	6	†	2.15	†	1.22	0.93	†	0.076
250	7	†	0.48	†	0.04	0.44	†	0.055
251	8	†	1.76	†	0.99	0.77	†	0.070
252	9	†	3.38	†	2.33	1.05	†	0.082
253	10	†	2.97	†	1.89	1.08	†	0.077
254	11	†	2.73	†	1.68	1.05	†	0.080
255	12	†	---	†	---	---	†	†
256	13	†	†	†	†	†	†	†
257	14	†	4.72	†	2.35	2.37	†	0.062
258	15	†						0.040
259	16	11.67						0.039
260	17	11.02						0.039
261	18	15.64						0.039
262	19	15.16						0.039
263	20	7.35						0.040
264	21	---			System Down			0.040
265	22	0.82						0.040
266	23	4.57						0.038
267	24	†						0.040
268	25	†						0.040
269	26	†						0.038
270	27	†						†
271	28	†						0.038
272	29	6.71						0.039
273	30	3.24						0.039

*All collector rows fully operational.
†No data available.

Monthly Performance Summary--October 1983*

Julian Date	Date	Incident Solar Energy on a Collector Surface (GJ)	Energy Collected (GJ)	Collector Array Efficiency (%)	Energy Delivered (GJ)	Losses (GJ) Operational	Losses (GJ) Non-Operational	System Thermal Efficiency (%)	Parasitic Energy Used (GJ)
274	1	14.09	---	---	†	†	†	†	0.039
275	2	20.59	---	---	†	†	†	†	0.039
276	3	†	---	---	†	†	†	†	0.039
277	4	†	---	---	†	†	†	†	0.039
278	5	†	---	---	†	†	†	†	0.039
279	6	†	---	---	†	†	†	†	0.039
280	7	†	---	---	†	†	†	†	0.039
281	8	10.10	---	---	†	†	†	†	0.039
282	9	18.20	---	---	†	†	†	†	0.039
283	10	0.82	---	---	†	†	†	†	0.039
284	11	---	---	---	†	†	†	†	0.039
285	12	0.15	---	---	†	†	†	†	0.039
286	13	3.81	---	---	†	†	†	†	0.039
287	14	8.67	0.59	6.86	†	†	†	†	0.064
288	15	22.91	7.99	34.89	†	†	†	†	0.086
289	16	21.50	7.08	32.93	†	†	†	†	0.084
290	17	16.86	5.55	32.91	†	†	†	†	0.084
291	18	4.61	0.83	17.95	†	†	†	†	0.055
292	19	2.58	0.61	23.54	†	†	†	†	0.039
293	20	7.23	1.22	16.91	†	†	†	†	0.064
294	21	0.02	---	---	†	†	†	†	0.039
295	22	0.02	---	---	†	†	†	†	0.039
296	23	---	---	---	†	†	†	†	0.039
297	24	0.01	---	---	†	†	†	†	0.039
298	25	0.84	0.09	10.26	†	†	†	†	0.046
299	26	24.11	5.78	23.97	†	†	†	†	0.088
300	27	24.56	6.59	26.84	†	†	†	†	0.083
301	28	22.95	6.92	30.14	†	†	†	†	0.084
302	29	15.15	3.37	22.28	†	†	†	†	0.085
303	30	17.67	4.08	23.07	†	†	†	†	0.082
304	31	1.39	0.04	2.55	†	†	†	†	0.045
Total		259.64	50.74	26.56§	---	---	---	---	1.652

*All collector rows operational.
†No data available.
§Based on days when system operated.

Monthly Insolation Values--November 1983*†

Julian Date	Date	Incident Solar Energy On a Collector Surface (GJ)
305	1	7.70
306	2	12.06
307	3	4.64
308	4	---
309	5	23.06
310	6	14.40
311	7	1.24
312	8	16.75
313	9	17.76
314	10	4.76
315	11	---
316	12	20.14
317	13	7.55
318	14	2.84
319	15	3.13
320	16	2.05
321	17	16.31
322	18	20.04
323	19	12.93
324	20	2.06
325	21	14.63
326	22	19.55
327	23	0.53
328	24	---
329	25	20.23
330	26	17.46
331	27	---
332	28	18.41
333	29	20.67
334	30	9.68
Total		310.58

*Faulty ground wire (field RTDs).
†Approximately 30,000 lb steam produced during the month.

Monthly Performance Summary--December 1983*

Julian Date	Date	Incident Solar Energy on a Collector Surface (GJ)	Energy Collected (GJ)	Collector Array Efficiency (%)	Energy Delivered (GJ)	Losses (GJ) Operational	Losses (GJ) Non-Operational	System Thermal Efficiency (%)	Parasitic Energy Used (GJ)
335	1	†	0.68	†	0.55	0.14	---	†	0.025
336	2	†	---	†	---	---	---	†	0.039
337	3	†	---	†	---	---	---	†	0.039
338	4	†	---	†	---	---	---	†	0.039
349	5	†	---	†	---	---	---	†	0.039
340	6	†	0.01	†	---	0.01	---	†	0.049
341	7	†	1.40	†	0.02	0.54	0.84	†	0.079
342	8	†	2.61	†	1.40	0.88	0.33	†	0.081
343	9	†	2.19	†	1.12	0.79	0.28	†	0.075
344	10	†	0.83	†	0.24	0.41	0.17	†	0.059
345	11	†	---	†	---	---	---	†	0.039
346	12	†	---	†	---	---	---	†	0.039
347	13	†	---	†	---	---	---	†	0.039
348	14	†	---	†	---	---	---	†	0.039
359	15	†	0.72	†	0.38	0.28	0.07	†	0.061
350	16	†	0.48	†	0.18	0.21	0.09	†	0.054
351	17	†	3.12	†	1.85	0.83	0.44	†	0.076
352	18	†	2.22	†	1.22	0.63	0.37	†	0.069
353	19	†	0.63	†	0.25	0.26	0.12	†	0.075
354	20	†	---	†	---	†	†	†	0.039
355	21	†	---	†	---	†	†	†	0.039
356	22	†	---	†	---	†	†	†	0.039
357	23	†	0.18	†	---	0.08	0.10	†	0.051
358	24	†	0.14	†	0.05	0.06	0.03	†	0.066
359	25	†	1.43	†	0.83	0.59	0.01	†	0.088
360	26	†	0.61	†	0.35	0.26	---	†	0.074
361	27	†	---	†	---	---	---	†	0.041
362	28	†	---	†	---	---	---	†	0.040
363	29	†	1.32	†	0.72	0.61	---	†	0.066
364	30	†	1.46	†	0.83	0.63	---	†	0.070
365	31	†	2.01	†	1.19	0.82	---	†	0.075
Total		---	22.03	---	11.18	8.01	2.84	---	1.704

*December 1 to 14: 12 collector rows operational. December 15 to 31: All collector rows operational.
†No data available.

Monthly Performance Summary--January 1984*

Julian Date	Date	Incident Solar Energy on a Collector Surface (GJ)	Energy Collected (GJ)	Collector Array Efficiency (%)	Energy Delivered (GJ)	Losses (GJ) Operational	Losses (GJ) Non-Operational	System Thermal Efficiency (%)	Parasitic Energy Used (GJ)
1	1	---	---	---	---	---	---	†	---
2	2	†	---	†	---	---	---	†	0.025
3	3	†	1.95	†	0.64	0.94	0.37	†	0.081
4	4	†	0.67	†	0.03	0.37	0.27	†	0.059
5	5	†	1.63	†	0.56	0.79	0.28	†	0.082
6	6	†	0.99	†	0.12	0.60	0.27	†	0.078
7	7	†	2.24	†	1.26	0.97	0.01	†	0.081
8	8	†	2.37	†	1.39	0.95	0.03	†	0.082
9	9	†	1.18	†	0.64	0.53	0.01	†	0.070
10	10	†	---	†	---	---	---	†	0.040
11	11	†	1.83	†	0.77	1.05	---	†	0.080
12	12	†	1.50	†	0.82	0.68	---	†	0.074
13	13	†	---	†	---	---	---	†	0.039
14	14	†	0.89	†	0.36	0.53	---	†	0.068
15	15	†	---	†	---	---	---	†	0.040
16	16	†	---	†	---	---	---	†	0.039
17	17	†	0.47	†	0.26	0.21	---	†	0.063
18	18	†	---	†	---	---	---	†	0.040
19	19	†	1.84	†	0.89	0.95	---	†	0.077
20	20	†	---	†	---	---	---	†	0.047
21	21	†	2.08	†	1.18	0.90	---	†	0.079
22	22	†	1.56	†	0.85	0.71	---	†	0.084
23	23	†	---	†	---	---	---	†	0.045
24	24	†	---	†	---	---	---	†	0.039
25	25	†	---	†	---	---	---	†	0.039
26	26	†	0.91	†	---	0.42	0.49	†	0.068
27	27	†	1.89	†	0.60	0.76	0.54	†	0.072
28	28	†	0.14	†	---	0.06	0.07	†	0.049
29	29	†	1.74	†	0.62	0.68	0.44	†	0.067
30	30	†	1.31	†	0.35	0.67	0.29	†	0.075
31	31	†	2.43	†	1.13	0.91	0.39	†	0.091
Total		---	29.42	---	12.47	13.68	3.47	---	1.874

*11 of 15 collector rows operational.

REF.: DE-AC04-78CS32199
DATE: November 1984

Monthly Performance Summary--March 1984*

Julian Date	Date	Incident Solar Energy on a Collector Surface (GJ)	Energy Collected (GJ)	Collector Array Efficiency (%)	Energy Delivered (GJ)	Losses (GJ) Operational	Losses (GJ) Non-Operational	System Thermal Efficiency (%)	Parasitic Energy Used (GJ)
61	1	†	1.32	†	0.40	0.46	0.46	†	0.034
62	2	†	2.09	†	1.08	0.62	0.39	†	0.074
63	3	†	3.93	†	3.13	0.80	---	†	0.082
64	4	†	0.17	†	0.09	0.08	---	†	0.045
65	5	†	---	†	---	---	---	†	0.039
66	6	†	0.07	†	0.04	0.03	---	†	0.045
67	7	†	6.59	†	6.78	---	---	†	0.087
68	8	†	4.38	†	4.43	---	---	†	0.083
69	9	†	4.79	†	4.46	---	0.41	†	0.094
70	10	†	0.12	†	---	0.02	0.10	†	0.043
71	11	†	3.29	†	2.73	0.05	0.52	†	0.070
72	12	†	0.57	†	0.08	0.10	0.39	†	0.056
73	13	†	---	†	---	---	---	†	0.049
74	14	†	---	†	---	---	---	†	0.072
75	15	†	4.70	†	3.38	0.64	0.69	†	0.081
76	16	†	0.22	†	---	0.07	0.15	†	0.047
77	17	†	---	†	---	---	---	†	0.036
78	18	†	1.49	†	0.59	0.35	0.55	†	0.062
79	19	†	2.83	†	1.66	0.57	0.60	†	0.071
80	20	†	---	†	---	---	---	†	0.036
81	21	†	---	†	---	---	---	†	0.036
82	22	†	5.17	†	3.77	0.84	0.56	†	0.078
83	23	†	7.28	†	6.18	0.75	0.35	†	0.082
84	24	†	0.89	†	0.21	0.26	0.42	†	0.060
85	25	†	2.95	†	1.98	0.51	0.46	†	0.072
86	26	†	0.50	†	---	0.14	0.36	†	0.047
87	27	†	---	†	---	---	---	†	0.036
88	28	†	---	†	---	---	---	†	0.036
89	29	†	---	†	---	---	---	†	0.036
90	30	†	6.88	†	6.27	---	0.65	†	0.088
91	31	†	5.48	†	5.11	0.03	0.35	†	0.078
Total		---	65.72	---	52.35	5.95	7.42	---	1.856

*March 1 to 8: 15 rows in operation. March 9 to 31: 14 rows in operation.
†No data available.

REF.: DE-AC04-78CS32199
DATE: November 1984

APPENDIX B

CLEAR-DAY PERFORMANCE SUMMARIES

Clear-Day Performance Summary for January 17, 1983

HOUR	AMBIENT TEMP. DEG C	WIND SPEED M/S	INCIDENT SOLAR ENERGY ON A COLLECTOR SURFACE GJ	COLLECTOR ARRAY FLOW RATE KG/S	COLLECTOR ARRAY TEMPERATURE * INLET DEG C	COLLECTOR ARRAY TEMPERATURE * OUTLET DEG C	ENERGY COLLECTED GJ	COLLECTOR ARRAY EFFICIENCY %	ENERGY DELIVERED GJ	LOSSES GJ	PARASITIC ENERGY MJ
1	-4.1	0.2	0.00	0.0	22.9	24.6	0.000	0.00	0.00	0.000	1.678
2	-2.6	0.4	0.00	0.0	18.5	19.4	0.000	0.00	0.00	0.000	1.661
3	-1.3	1.1	0.00	0.0	14.0	15.3	0.000	0.00	0.00	0.000	1.646
4	-3.4	0.6	0.00	0.0	11.7	12.1	0.000	0.00	0.00	0.000	1.654
5	-4.4	0.4	0.00	0.0	9.2	9.4	0.000	0.00	0.00	0.000	1.713
6	-5.4	1.0	0.00	0.0	7.2	7.3	0.000	0.00	0.00	0.000	1.679
7	-5.0	0.4	0.00	0.0	5.4	5.4	0.000	0.00	0.00	0.000	1.729
8	-5.9	0.0	0.00	0.0	4.1	3.8	0.000	0.00	0.00	0.000	1.645
9	0.3	0.2	0.78	0.0	77.6	29.7	0.000	0.09	0.00	0.000	3.994
10	4.7	0.4	1.87	2.8	112.6	135.4	0.299	15.99	0.16	0.135	9.391
11	7.3	0.7	2.22	2.8	170.0	195.1	0.516	23.20	0.29	0.221	8.000
12	8.7	0.5	2.25	2.8	177.8	204.0	0.582	25.91	0.39	0.191	7.375
13	10.4	1.6	2.31	2.8	174.2	202.7	0.598	25.93	0.43	0.172	6.913
14	11.0	3.4	2.33	2.8	176.7	204.4	0.589	25.32	0.41	0.175	6.628
15	13.0	3.4	2.34	2.8	174.8	202.8	0.616	26.34	0.45	0.170	6.175
16	13.4	3.1	2.20	2.8	172.8	200.4	0.603	27.38	0.44	0.165	6.270
17	12.1	1.2	1.67	2.8	171.4	173.9	0.285	17.11	0.15	0.133	6.161
18	6.3	1.6	0.19	0.0	104.9	130.0	0.002	1.26	0.00	0.002	2.491
19	3.4	4.9	0.00	0.0	79.7	97.1	0.000	0.00	0.00	0.000	1.722
20	0.9	2.0	0.00	0.0	62.3	74.3	0.000	0.00	0.00	0.000	1.727
21	-0.5	4.6	0.00	0.0	47.4	57.9	0.000	0.00	0.00	0.000	1.730
22	-1.8	2.2	0.00	0.0	37.1	45.6	0.000	0.00	0.00	0.000	1.667
23	-2.6	1.5	0.00	0.0	29.1	35.3	0.000	0.00	0.00	0.000	1.685
24	-3.0	2.5	0.00	0.0	22.6	27.3	0.000	0.00	0.00	0.000	1.676
TOT.	2.1	1.6	16.16	----	----	----	4.09	22.53	1.78	2.306†	87.008

*ALL COLLECTOR ROWS OPERATIONAL.
†INCLUDES OVERNIGHT PIPING LOSSES.

Clear-Day Performance Summary for February 17, 1983

HOUR	AMBIENT TEMP. DEG C	WIND SPEED M/S	INCIDENT SOLAR ENERGY ON A COLLECTOR SURFACE GJ	COLLECTOR ARRAY FLOW RATE KG/S	COLLECTOR ARRAY TEMPERATURE * INLET DEG C	OUTLET DEG C	ENERGY COLLECTED GJ	COLLECTOR ARRAY EF-FICIENCY %	ENERGY DELIVERED GJ	LOSSES GJ	PARASITIC ENERGY MJ
1	8.4	0.0	0.00	0.0	11.4	10.8	0.000	0.00	0.00	0.000	1.641
2	8.6	0.4	0.00	0.0	10.9	10.4	0.000	0.00	0.00	0.000	1.632
3	8.2	0.0	0.00	0.0	10.6	10.0	0.000	0.00	0.00	0.000	1.644
4	8.9	0.4	0.00	0.0	10.3	9.7	0.000	0.00	0.00	0.000	1.640
5	9.9	1.5	0.00	0.0	10.2	9.6	0.000	0.00	0.00	0.000	1.642
6	10.0	1.5	0.00	0.0	10.1	9.5	0.000	0.00	0.00	0.000	1.634
7	9.2	1.1	0.00	0.0	10.0	9.4	0.000	0.00	0.00	0.000	1.635
8	9.9	0.9	0.12	0.0	9.8	9.2	0.000	0.00	0.00	0.000	1.634
9	13.6	1.6	1.46	2.4	54.3	63.7	0.012	0.81	0.00	0.012	3.912
10	16.2	1.1	2.20	2.8	126.1	158.1	0.542	24.65	0.37	0.171	8.380
11	17.7	2.0	2.46	2.7	172.7	207.4	0.638	25.96	0.42	0.219	7.305
12	18.2	2.8	2.72	2.8	172.8	213.0	0.810	29.78	0.59	0.219	6.572
13	18.8	1.5	2.80	2.7	173.5	211.5	0.844	30.10	0.64	0.205	6.591
14	20.1	1.0	2.79	2.7	172.9	212.2	0.837	30.05	0.67	0.170	6.457
15	20.9	3.2	2.76	2.8	173.3	213.3	0.853	30.92	0.71	0.145	6.302
16	21.8	0.5	2.63	2.7	173.2	211.0	0.823	31.30	0.68	0.144	6.521
17	20.1	3.7	2.28	2.8	173.1	190.4	0.643	28.15	0.47	0.173	6.441
18	15.7	1.8	1.10	0.0	121.8	146.9	0.084	7.60	0.03	0.052	4.136
19	12.3	0.8	0.00	0.0	87.9	111.5	0.000	0.00	0.00	0.000	1.671
20	10.7	0.4	0.00	0.0	72.4	88.1	0.000	0.00	0.00	0.000	1.635
21	9.5	0.6	0.00	0.0	57.8	70.7	0.000	0.00	0.00	0.000	1.691
22	8.4	2.1	0.00	0.0	47.4	57.7	0.000	0.00	0.00	0.000	1.660
23	7.2	2.1	0.00	0.0	39.3	46.9	0.000	0.00	0.00	0.000	1.673
24	6.3	0.8	0.00	0.0	32.7	38.4	0.000	0.00	0.00	0.000	1.711
TOT.	12.9	1.3	23.32	----	----	----	6.08	26.09	2.19	3.898†	85.762

*ALL COLLECTOR ROWS OPERATIONAL.
†INCLUDES OVERNIGHT PIPING LOSSES.

Clear-Day Performance Summary for March 2, 1983

HOUR	AMBIENT TEMP. DEG C	WIND SPEED M/S	INCIDENT SOLAR ENERGY ON A COLLECTOR SURFACE GJ	COLLECTOR ARRAY FLOW RATE KG/S	COLLECTOR ARRAY TEMPERATURE * INLET DEG C	OUTLET DEG C	ENERGY COLLECTED GJ	COLLECTOR ARRAY EFFICIENCY %	ENERGY DELIVERED GJ	LOSSES GJ	PARASITIC ENERGY MJ
1	4.0	0.0	0.00	0.0	30.3	36.4	0.000	0.00	0.00	0.000	1.622
2	3.2	0.4	0.00	0.0	26.1	30.6	0.000	0.00	0.00	0.000	1.673
3	2.3	0.0	0.00	0.0	22.2	25.8	0.000	0.00	0.00	0.000	1.640
4	1.7	0.0	0.00	0.0	19.0	21.8	0.000	0.00	0.00	0.000	1.668
5	1.0	0.5	0.00	0.0	16.1	18.4	0.000	0.00	0.00	0.000	1.659
6	0.6	0.3	0.00	0.0	13.6	15.6	0.000	0.00	0.00	0.000	1.641
7	0.0	0.0	0.00	0.0	11.4	13.2	0.000	0.00	0.00	0.000	1.629
8	4.8	0.0	0.28	0.0	9.8	11.2	0.000	0.00	0.00	0.000	1.616
9	9.2	0.3	1.72	2.6	82.3	103.9	0.043	2.52	0.02	0.020	5.884
10	14.4	0.6	2.29	2.8	159.0	189.9	0.583	25.52	0.36	0.225	8.762
11	18.7	0.6	2.63	2.7	177.3	217.2	0.793	30.15	0.57	0.220	7.809
12	20.8	1.4	2.39	2.7	173.7	218.4	0.729	30.52	0.55	0.174	7.658
13	22.6	1.4	2.70	2.7	175.7	219.3	0.847	31.40	0.66	0.184	6.696
14	23.3	2.7	2.71	2.7	175.6	218.9	0.856	31.63	0.68	0.188	6.488
15	25.7	1.5	2.71	2.7	177.1	216.1	0.883	32.53	0.71	0.170	6.571
16	25.6	2.2	2.63	2.7	175.8	214.6	0.866	32.96	0.69	0.171	6.541
17	26.3	1.3	2.23	2.8	174.8	193.7	0.663	29.73	0.51	0.158	6.654
18	20.9	0.4	1.00	0.0	134.3	153.8	0.096	9.57	0.04	0.055	3.934
19	16.0	0.7	0.00	0.0	95.1	119.5	0.000	0.00	0.00	0.000	1.643
20	12.7	0.0	0.00	0.0	76.7	95.2	0.000	0.00	0.00	0.000	1.678
21	9.7	0.0	0.00	0.0	62.4	77.6	0.000	0.00	0.00	0.000	1.680
22	8.4	0.0	0.00	0.0	51.6	64.4	0.000	0.00	0.00	0.000	1.680
23	7.2	0.6	0.00	0.0	43.4	53.4	0.000	0.00	0.00	0.000	1.682
24	6.1	0.0	0.00	0.0	36.9	44.6	0.000	0.00	0.00	0.000	1.651
TOT.	11.9	0.6	23.28	----	----	----	6.36	27.32	3.77	2.577†	90.159

*ALL COLLECTOR ROWS OPERATIONAL.
†INCLUDES OVERNIGHT PIPING LOSSES.

REF.: DE-AC04-78CS32199
DATE: November 1984

Clear-Day Performance Summary for April 26, 1983

HOUR	AMBIENT TEMP. DEG C	WIND SPEED M/S	INCIDENT SOLAR ENERGY *ON A COLLECTOR SURFACE GJ	COLLECTOR ARRAY FLOW RATE KG/S	COLLECTOR ARRAY TEMPERATURE * INLET DEG C	COLLECTOR ARRAY TEMPERATURE * OUTLET DEG C	ENERGY COLLECTED GJ	COLLECTOR ARRAY EFFICIENCY %	ENERGY DELIVERED GJ	LOSSES GJ	PARASITIC ENERGY MJ
1	4.7	.6	.00	.0	31.1	39.1	.000	.00	.00	.000	1.578
*2	3.1	.1	.00	.0	26.3	32.6	.000	.00	.00	.000	1.573
3	2.9	.7	.00	.0	22.2	27.4	.000	.00	.00	.000	1.587
4	1.8	.0	.00	.0	18.7	23.1	.000	.00	.00	.000	1.547
5	1.4	.1	.00	.0	15.8	19.5	.000	.00	.00	.000	1.573
6	.8	1.1	.00	.0	13.3	16.5	.000	.00	.00	.000	1.586
7	5.6	.0	.30	.0	11.3	14.2	.000	.00	.00	.000	1.552
8	13.9	1.0	1.22	2.6	85.6	90.3	.007	.55	.00	.007	3.736
9	16.6	.6	2.10	2.7	170.6	206.8	.674	32.17	.42	.250	7.753
10	19.9	.6	2.85	2.7	169.7	222.8	.998	34.95	.81	.191	6.685
11	22.1	1.7	3.27	2.7	176.5	228.1	1.066	32.57	.89	.174	6.214
12	23.2	.9	3.44	2.7	180.1	231.6	1.103	32.06	.93	.169	6.336
13	22.8	1.2	3.45	2.7	177.7	230.8	1.108	32.11	.95	.157	6.175
14	25.2	.9	3.46	2.7	177.6	229.7	1.096	31.67	.93	.164	6.093
15	27.5	1.7	3.39	2.7	172.9	227.5	1.035	32.03	.93	.154	6.291
16	27.5	1.6	3.18	2.7	173.7	222.4	1.020	32.12	.86	.156	6.112
17	26.8	1.2	2.84	2.7	178.3	211.8	.882	31.05	.73	.152	6.166
18	24.7	2.7	2.31	.0	170.2	178.6	.367	15.90	.26	.108	5.530
19	22.2	.8	.29	.0	113.6	138.3	.000	.00	.00	.000	1.585
20	15.4	.1	.00	.0	87.8	110.2	.000	.00	.00	.000	1.587
21	12.5	.0	.00	.0	70.7	89.5	.000	.00	.00	.000	1.563
22	10.2	.0	.00	.0	57.6	73.2	.000	.00	.00	.000	1.593
23	8.7	.1	.00	.0	47.7	60.4	.000	.00	.00	.000	1.558
24	7.5	.6	.00	.0	39.9	50.2	.000	.00	.00	.000	1.585
TOT.	14.5	.8	32.11	----	----	----	9.41	29.30	7.41†	1.991†	87.555

*ALL COLLECTOR ROWS OPERATIONAL.
†INCLUDES OVERNIGHT PIPING LOSSES.

REF.: DE-AC04-78CS32199
DATE: November 1984

Clear-Day Performance Summary for May 24, 1983

HOUR	AMBIENT TEMP. DEG C	WIND SPEED M/S	INCIDENT SOLAR ENERGY ON A COLLECTOR SURFACE GJ	COLLECTOR ARRAY FLOW RATE KG/S	COLLECTOR ARRAY TEMPERATURE * INLET DEG C	COLLECTOR ARRAY TEMPERATURE * OUTLET DEG C	ENERGY COLLECTED GJ	COLLECTOR ARRAY EFFICIENCY %	ENERGY DELIVERED GJ	LOSSES GJ	PARASITIC ENERGY MJ
1	16.1	0.0	0.00	0.0	41.0	50.4	0.000	0.00	0.00	0.000	1.709
2	15.9	0.0	0.00	0.0	36.5	43.9	0.000	0.00	0.00	0.000	1.743
3	15.3	0.3	0.00	0.0	32.7	38.6	0.000	0.00	0.00	0.000	1.681
4	14.4	0.0	0.00	0.0	29.7	34.3	0.000	0.00	0.00	0.000	1.651
5	15.0	1.0	0.00	0.0	27.1	30.0	0.000	0.00	0.00	0.000	1.707
6	14.6	1.2	0.00	0.0	24.7	27.0	0.000	0.00	0.00	0.000	1.652
7	14.2	1.0	0.00	0.0	22.7	25.3	0.000	0.00	0.00	0.000	1.691
8	16.9	1.0	0.96	0.0	21.2	23.3	0.000	0.00	0.00	0.000	1.673
9	19.7	0.8	2.09	2.7	89.1	111.6	0.076	3.66	0.03	0.046	5.720
10	21.7	1.4	2.71	2.8	164.5	196.0	0.599	22.11	0.35	0.245	7.733
11	22.5	1.7	3.04	2.8	179.9	222.4	0.840	27.68	0.61	0.228	6.524
12	23.8	2.1	3.19	2.8	173.0	204.1	0.950	29.81	0.77	0.181	6.740
13	23.4	3.7	2.85	2.8	179.1	224.6	0.875	30.72	0.68	0.190	6.383
14	24.4	2.8	3.34	2.7	175.9	224.2	1.001	29.97	0.82	0.177	6.543
15	26.0	1.2	3.31	2.7	175.7	233.4	1.091	32.93	0.90	0.195	6.500
16	26.3	1.2	3.24	2.8	178.9	232.7	1.217	37.52	1.02	0.197	6.887
17	26.7	2.1	3.07	2.7	176.3	228.3	1.177	38.37	0.99	0.182	6.531
18	25.8	2.5	2.68	2.8	178.5	210.4	0.978	30.40	0.80	0.176	6.399
19	24.2	3.4	2.15	2.0	175.6	185.7	0.432	20.15	0.27	0.161	6.626
20	22.9	0.9	1.29	0.0	121.1	147.6	0.029	2.27	0.00	0.025	3.187
21	17.4	0.5	0.15	0.0	89.9	116.7	0.000	0.00	0.00	0.000	1.699
22	14.7	0.4	0.00	0.0	72.6	95.0	0.000	0.00	0.00	0.000	1.682
23	14.7	0.0	0.00	0.0	58.8	77.6	0.000	0.00	0.00	0.000	1.692
24	14.8	0.6	0.00	0.0	49.1	64.4	0.000	0.00	0.00	0.000	1.696
TOT.	19.6	1.3	34.06	----	----	----	9.27	27.21	6.91 †	2.356 †	96.047

*ALL COLLECTOR ROWS OPERATIONAL.
†INCLUDES OVERNIGHT PIPING LOSSES.

REF.: DE-AC04-78CS32199
DATE: November 1984

Clear-Day Performance Summary for June 11, 1983

HOUR	AMBIENT TEMP. DEG C	WIND SPEED M/S	INCIDENT SOLAR ENERGY ON A COLLECTOR SURFACE GJ	COLLECTOR ARRAY FLOW RATE KG/S	COLLECTOR ARRAY TEMPERATURE * INLET DEG C	COLLECTOR ARRAY TEMPERATURE * OUTLET DEG C	ENERGY COLLECTED GJ	COLLECTOR ARRAY EFFICIENCY %	ENERGY DELIVERED GJ	LOSSES GJ	PARASITIC ENERGY MJ
1	18.8	0.0	0.00	0.0	45.0	51.2	0.000	0.00	0.00	0.000	1.655
2	17.6	0.0	0.00	0.0	40.4	45.4	0.000	0.00	0.00	0.000	1.651
3	16.8	0.0	0.00	0.0	36.4	40.6	0.000	0.00	0.00	0.000	1.667
4	15.6	0.0	0.00	0.0	32.9	36.0	0.000	0.00	0.00	0.000	1.654
5	14.6	0.0	0.00	0.0	29.9	33.0	0.000	0.00	0.00	0.000	1.660
6	14.0	0.0	0.00	0.0	27.3	30.1	0.000	0.00	0.00	0.000	1.670
7	13.9	0.0	0.00	0.0	25.8	27.5	0.000	0.00	0.00	0.000	1.673
8	18.8	0.0	0.71	0.0	23.5	25.6	0.000	0.00	0.00	0.000	1.682
9	24.8	0.2	1.67	2.8	95.2	115.3	0.093	5.55	0.05	0.043	5.730
10	26.3	0.2	2.18	2.8	155.8	186.4	0.467	22.30	0.29	0.180	7.330
11	26.7	2.4	2.85	2.8	180.1	220.6	0.864	30.34	0.69	0.171	6.340
12	26.8	1.7	3.10	2.8	178.0	224.7	1.053	34.01	0.92	0.132	6.364
13	27.3	0.0	3.15	2.8	176.6	233.8	1.095	34.74	0.96	0.135	6.637
14	28.0	1.0	3.24	2.8	179.3	233.6	1.202	37.04	1.07	0.130	6.269
15	29.9	1.3	2.99	2.8	176.9	225.6	1.106	37.02	0.99	0.117	6.283
16	31.4	1.7	3.11	2.8	178.8	231.9	1.137	36.55	1.00	0.135	6.390
17	30.0	1.5	2.93	2.8	179.5	226.9	1.101	37.53	0.98	0.126	6.390
18	29.8	1.1	2.58	2.8	178.3	206.9	0.828	32.12	0.71	0.117	6.261
19	29.7	0.8	2.03	2.8	178.4	189.2	0.471	23.15	0.36	0.114	6.526
20	26.9	0.8	1.18	0.0	134.9	158.3	0.040	3.42	0.02	0.024	3.435
21	20.4	0.0	0.17	0.0	97.6	125.0	0.000	0.00	0.00	0.000	1.678
22	17.8	0.0	0.00	0.0	79.6	96.1	0.000	0.00	0.00	0.000	1.689
23	15.7	0.0	0.00	0.0	69.1	66.4	0.000	0.00	0.00	0.000	1.709
24	15.1	0.0	0.00	0.0	58.2	55.9	0.000	0.00	0.00	0.000	1.689
TOT	22.4	0.5	31.82	----	----	----	9.46	29.73	7.78†	1.673*	94.032

*ALL COLLECTOR ROWS OPERATIONAL.
†INCLUDES OVERNIGHT PIPING LOSSES.

Clear-Day Performance Summary for July 12, 1983

HOUR	AMBIENT TEMP. DEG C	WIND SPEED M/S	INCIDENT SOLAR ENERGY ON A COLLECTOR SURFACE GJ	COLLECTOR ARRAY FLOW RATE KG/S	COLLECTOR ARRAY TEMPERATURE * INLET DEG C	COLLECTOR ARRAY TEMPERATURE * OUTLET DEG C	ENERGY COLLECTED GJ	COLLECTOR ARRAY EFFICIENCY %	ENERGY DELIVERED GJ	LOSSES GJ	PARASITIC ENERGY MJ
1	23.0	0.0	NO DATA AVAILABLE	0.0	53.2	58.9	0.000	NO DATA AVAILABLE	0.00	0.000	1.705
2	22.8	0.0		0.0	48.1	52.3	0.000		0.00	0.000	1.700
3	21.9	0.0		0.0	43.8	47.0	0.000		0.00	0.000	1.659
4	21.5	0.6		0.0	40.1	42.6	0.000		0.00	0.000	1.703
5	20.9	0.2		0.0	36.9	38.9	0.000		0.00	0.000	1.687
6	20.3	0.0		0.0	34.4	35.9	0.000		0.00	0.000	1.674
7	20.2	0.4		0.0	32.2	33.4	0.000		0.00	0.000	1.661
8	24.4	0.0		0.0	30.7	31.4	0.000		0.00	0.000	1.645
9	29.9	0.6		2.4	104.2	27.8	0.000		0.00	0.000	2.512
10	32.8	0.6		2.8	142.6	164.3	0.384		0.23	0.158	7.985
11	33.2	2.2		2.8	175.5	201.7	0.349		0.19	0.162	6.415
12	34.2	1.7		2.8	174.7	210.1	0.681		0.55	0.130	6.285
13	34.6	1.5		2.8	175.1	213.1	0.771		0.65	0.125	6.382
14	35.3	1.5		2.8	173.8	202.1	0.710		0.65	0.058	6.503
15	35.9	2.1		2.8	179.2	207.8	0.690		0.66	0.030	6.460
16	37.1	1.2		2.8	177.1	203.4	0.642		0.62	0.024	6.647
17	37.8	1.4		2.8	174.7	201.2	0.589		0.58	0.008	6.387
18	35.8	0.5		2.8	177.7	189.6	0.423		0.40	0.019	6.304
19	34.7	0.7		2.8	172.9	180.6	0.196		0.18	0.014	6.572
20	32.2	0.3		0.0	128.1	146.2	0.000		0.00	0.000	2.243
21	27.9	0.6		0.0	98.8	118.4	0.000		0.00	0.000	1.684
22	26.7	1.5		0.0	83.3	98.3	0.000		0.00	0.000	1.710
23	26.3	0.0		0.0	72.6	83.3	0.000		0.00	0.000	1.696
24	23.8	0.0		0.0	63.8	71.6	0.000		0.00	0.000	1.648
TOT.	28.9	0.7	25.37	----	----	----	5.44	21.43	4.37†	1.061†	90.868

*ALL COLLECTOR ROWS OPERATIONAL.
†INCLUDES OVERNIGHT PIPING LOSSES.

REF.: DE-AC04-78CS32199
DATE: November 1984

Clear-Day Performance Summary for August 13, 1983

HOUR	AMBIENT TEMP. DEG C	WIND SPEED M/S	INCIDENT SOLAR ENERGY ON A COLLECTOR SURFACE GJ	COLLECTOR ARRAY FLOW RATE KG/S	COLLECTOR ARRAY TEMPERATURE * INLET DEG C	COLLECTOR ARRAY TEMPERATURE * OUTLET DEG C	ENERGY COLLECTED GJ	COLLECTOR ARRAY EF-FICIENCY %	ENERGY DELIVERED GJ	LOSSES GJ	PARASITIC ENERGY MJ
1	21.6	1.2	NO DATA AVAILABLE	0.0	78.0	32.3	0.000	NO DATA AVAILABLE	0.00	0.000	1.657
2	20.9	1.6		0.0	71.8	29.1	0.000		0.00	0.000	1.691
3	20.1	0.1		0.0	62.8	27.1	0.000		0.00	0.000	1.679
4	19.1	0.3		0.0	54.7	25.4	0.000		0.00	0.000	1.679
5	18.1	0.5		0.0	47.8	24.1	0.000		0.00	0.000	1.675
6	16.8	0.0		0.0	41.9	22.8	0.000		0.00	0.000	1.663
7	17.5	1.0		0.0	37.0	21.8	0.000		0.00	0.000	1.700
8	20.6	0.0		0.0	33.3	21.1	0.000		0.00	0.000	1.647
9	24.2	0.2		2.4	87.3	22.5	0.000		0.00	0.000	2.439
10	27.0	0.7		2.9	141.2	169.0	0.473		0.31	0.166	8.468
11	27.6	1.6		2.9	180.3	217.2	0.728		0.55	0.176	6.604
12	29.2	0.6		2.9	179.3	224.1	0.938		0.82	0.117	6.382
13	29.8	0.8		2.9	179.5	225.7	1.015		0.89	0.120	6.534
14	30.8	2.0		2.9	180.2	223.2	1.046		0.94	0.109	6.368
15	33.7	2.0		2.9	179.3	223.4	0.936		0.83	0.107	6.387
16	33.4	1.3		2.9	177.9	220.1	0.935		0.83	0.107	6.498
17	35.9	1.7		2.9	180.4	224.9	0.974		0.86	0.112	6.377
18	35.6	0.8		2.9	179.2	214.0	0.822		0.72	0.100	6.446
19	30.7	1.0		0.0	177.1	180.7	0.351		0.27	0.082	6.352
20	28.0	0.0		0.0	129.6	142.3	0.000		0.00	0.000	1.765
21	25.1	0.0		0.0	108.9	94.6	0.000		0.00	0.000	1.699
22	23.9	0.3		0.0	85.8	68.5	0.000		0.00	0.000	1.697
23	21.0	0.4		0.0	80.8	50.7	0.000		0.00	0.000	1.698
24	20.0	0.2		0.0	82.3	38.8	0.000		0.00	0.000	1.642
TOT.	25.4	0.8	113.98	----	----	----	8.22	7.21	6.65†	1.567†	98.746

*ALL COLLECTOR ROWS OPERATIONAL.
†INCLUDES OVERNIGHT PIPING LOSSES.

Clear-Day Performance Summary for September 9, 1983

HOUR	AMBIENT TEMP. DEG C	WIND SPEED M/S	INCIDENT SOLAR ENERGY ON A COLLECTOR SURFACE GJ	COLLECTOR ARRAY FLOW RATE KG/S	COLLECTOR ARRAY TEMPERATURE * INLET DEG C	COLLECTOR ARRAY TEMPERATURE * OUTLET DEG C	ENERGY COLLECTED GJ	COLLECTOR ARRAY EFFICIENCY %	ENERGY DELIVERED GJ	LOSSES GJ	PARASITIC ENERGY MJ
1	20.2	0.2	NO DATA AVAILABLE	0.0	54.4	28.2	0.000	NO DATA AVAILABLE	0.00	0.000	1.682
2	20.2	0.0		0.0	47.7	26.7	0.000		0.00	0.000	1.665
3	19.7	0.0		0.0	42.4	25.4	0.000		0.00	0.000	1.663
4	19.4	0.0		0.0	38.1	24.4	0.000		0.00	0.000	1.637
5	19.3	0.3		0.0	34.7	23.6	0.000		0.00	0.000	1.666
6	18.9	0.0		0.0	31.9	22.9	0.000		0.00	0.000	1.666
7	18.8	0.0		0.0	29.7	22.3	0.000		0.00	0.000	1.658
8	19.8	0.6		0.0	27.9	21.9	0.000		0.00	0.000	1.681
9	23.4	0.0		0.0	27.2	21.9	0.000		0.00	0.000	1.624
10	27.1	0.5		2.8	85.3	100.3	0.097		0.06	0.041	5.672
11	30.8	0.7		2.9	113.7	127.1	0.185		0.09	0.091	7.314
12	31.1	1.0		2.9	161.6	173.2	0.359		0.22	0.140	6.910
13	33.1	0.4		2.9	179.2	197.8	0.374		0.25	0.126	6.418
14	33.6	0.9		2.9	179.9	206.4	0.562		0.46	0.104	6.516
15	34.3	0.7		2.9	182.2	209.5	0.673		0.57	0.102	6.473
16	35.5	1.7		2.9	178.1	207.5	0.629		0.54	0.091	6.407
17	35.0	0.2		2.9	176.3	179.5	0.386		0.31	0.079	6.539
18	31.6	0.2		0.0	157.3	158.6	0.117		0.07	0.046	4.793
19	30.2	0.6		0.0	124.8	109.1	0.000		0.00	0.000	1.713
20	27.1	0.1		0.0	99.9	75.6	0.000		0.00	0.000	1.655
21	25.1	0.2		0.0	100.4	53.6	0.000		0.00	0.000	1.670
22	24.3	0.0		0.0	105.4	42.7	0.000		0.00	0.000	1.684
23	23.8	0.0		0.0	99.9	30.8	0.000		0.00	0.000	1.689
24	22.9	0.0		0.0	89.9	36.8	0.000		0.00	0.000	1.683
TOT.	26.1	0.3	116.97	----	----	----	3.38	----	2.33†	1.049†	82.079

*ALL COLLECTOR ROWS OPERATIONAL.
†INCLUDES OVERNIGHT PIPING LOSSES.

REF.: DE-AC04-78CS32199
DATE: November 1984

REF.: DE-AC04-78CS32199
DATE: November 1984

Clear-Day Performance Summary for October 28, 1983

HOUR	AMBIENT TEMP. DEG C	WIND SPEED M/S	INCIDENT SOLAR ENERGY ON A COLLECTOR SURFACE GJ	COLLECTOR ARRAY FLOW RATE KG/S	COLLECTOR ARRAY TEMPERATURE * INLET DEG C	OUTLET DEG C	ENERGY COLLECTED GJ	COLLECTOR ARRAY EF-FICIENCY %	ENERGY DELIVERED GJ	LOSSES GJ	PARASITIC ENERGY MJ
1	3.9	0.0	0.00	0.0	85.3	75.9	0.000	0.00	NO DATA AVAILABLE	NO DATA AVAILABLE	1.641
2	3.0	0.0	0.00	0.0	77.2	67.7	0.000	0.00			1.620
3	2.6	0.0	0.00	0.0	69.8	60.4	0.000	0.00			1.631
4	1.8	0.0	0.00	0.0	63.1	53.8	0.000	0.00			1.644
5	1.4	0.0	0.00	0.0	57.1	47.9	0.000	0.00			1.620
6	0.8	0.0	0.00	0.0	51.6	42.8	0.000	0.00			1.616
7	0.1	0.0	0.00	0.0	46.7	38.3	0.000	0.00			1.613
8	0.3	0.0	0.00	0.0	42.2	34.2	0.000	0.00			1.618
9	6.6	0.0	0.10	0.0	38.2	30.8	0.000	0.00			1.647
10	10.0	0.0	2.03	2.7	138.6	173.2	0.282	13.90			6.340
11	15.2	0.0	2.62	2.7	179.9	224.7	0.818	31.17			7.342
12	18.5	1.0	2.73	2.6	179.6	224.1	0.939	34.35			7.565
13	21.0	0.5	2.80	2.6	180.5	224.0	0.918	32.80			6.853
14	23.8	0.5	2.78	2.6	178.6	222.3	0.886	31.88			6.329
15	25.2	0.0	2.90	2.6	179.8	224.6	0.912	31.50			6.518
16	25.4	1.4	2.90	2.7	176.9	222.3	0.933	32.17			6.397
17	26.0	0.8	2.73	2.7	179.7	218.0	0.868	31.86			6.351
18	23.4	0.0	1.37	0.0	176.9	178.6	0.359	26.31			3.620
19	16.7	0.0	0.00	0.0	159.2	156.8	0.000	0.00			1.715
20	12.8	0.0	0.00	0.0	143.8	137.3	0.000	0.00			1.625
21	10.6	0.0	0.00	0.0	130.0	121.1	0.000	0.00			1.641
22	9.1	0.0	0.00	0.0	117.7	107.6	0.000	0.00			1.639
23	7.2	0.0	0.00	0.0	106.6	95.9	0.000	0.00			1.630
24	6.3	0.0	0.00	0.0	96.6	85.7	0.000	0.00			1.649
TOT.	11.3	0.2	22.95	----	----	----	6.92	30.14	3.89†	3.024†	83.861

*ALL COLLECTOR ROWS OPERATIONAL.
†INCLUDES OVERNIGHT PIPING LOSSES.

Clear-Day Performance Summary for December 17, 1983

HOUR	AMBIENT TEMP. DEG C	WIND SPEED M/S	INCIDENT SOLAR ENERGY ON A COLLECTOR SURFACE GJ	COLLECTOR ARRAY FLOW RATE KG/S	COLLECTOR ARRAY TEMPERATURE * INLET DEG C	OUTLET DEG C	ENERGY COLLECTED GJ	COLLECTOR ARRAY EF-FICIENCY %	ENERGY DELIVERED GJ	LOSSES GJ	PARASITIC ENERGY MJ
1	3.3	0.0	NO DATA AVAILABLE	0.0	33.4	25.6	0.000	NO DATA AVAILABLE	0.00	0.000	1.617
2	3.1	0.0		0.0	30.4	23.2	0.000		0.00	0.000	1.609
3	3.2	0.0		0.0	27.8	21.0	0.000		0.00	0.000	1.597
4	3.2	0.0		0.0	25.3	19.1	0.000		0.00	0.000	1.625
5	3.3	0.0		0.0	23.2	17.4	0.000		0.00	0.000	1.581
6	2.8	0.0		0.0	21.2	15.9	0.000		0.00	0.000	1.576
7	1.4	2.2		0.0	19.2	14.4	0.000		0.00	0.000	1.612
8	0.9	0.9		0.0	17.4	12.9	0.000		0.00	0.000	1.659
9	2.1	1.1		0.0	15.8	11.6	0.000		0.00	0.000	1.594
10	6.3	3.7		2.2	70.7	16.2	0.000		0.00	0.000	3.161
11	8.3	3.1		2.7	132.2	155.3	0.444		0.29	0.157	8.044
12	11.6	1.5		2.7	176.8	201.0	0.412		0.26	0.154	7.371
13	12.2	4.1		2.7	178.7	203.1	0.508		0.39	0.113	6.739
14	12.2	4.5		2.7	177.9	202.2	0.537		0.42	0.113	6.291
15	13.8	1.8		2.7	178.7	205.1	0.543		0.43	0.116	6.460
16	13.5	2.1		2.7	177.7	197.8	0.514		0.40	0.111	6.451
17	9.4	1.7		0.0	169.9	170.8	0.160		0.09	0.067	5.435
18	5.5	1.5		0.0	151.8	149.5	0.000		0.00	0.000	1.757
19	4.4	1.4		0.0	136.2	131.4	0.000		0.00	0.000	1.617
20	3.8	1.7		0.0	122.2	115.8	0.000		0.00	0.000	1.648
21	3.2	1.6		0.0	109.8	102.4	0.000		0.00	0.000	1.588
22	2.4	0.0		0.0	97.1	90.8	0.000		0.00	0.000	1.631
23	1.8	0.0		0.0	87.4	79.6	0.000		0.00	0.000	1.617
24	1.1	0.0		0.0	78.8	70.5	0.000		0.00	0.000	1.591
TOT.	5.5	1.4	---	----	----	----	3.12	---	1.85†	1.267†	75 870

*ALL COLLECTOR ROWS OPERATIONAL.
†INCLUDES OVERNIGHT PIPING LOSSES.

REF.: DE-AC04-78CS32199
DATE: November 1984

Clear-Day Performance Summary for January 8, 1984

HOUR	AMBIENT TEMP. DEG C	WIND SPEED M/S	INCIDENT SOLAR ENERGY ON A COLLECTOR SURFACE GJ	COLLECTOR ARRAY FLOW RATE KG/S	COLLECTOR ARRAY TEMPERATURE * INLET DEG C	COLLECTOR ARRAY TEMPERATURE * OUTLET DEG C	ENERGY COLLECTED GJ	COLLECTOR ARRAY EFFICIENCY %	ENERGY DELIVERED GJ	LOSSES GJ	PARASITIC ENERGY MJ
1	-3.0	0.0	NO DATA AVAILABLE	0.0	73.9	62.8	0.000	NO DATA AVAILABLE	0.00	0.000	1.641
2	-3.2	0.0		0.0	66.4	55.5	0.000		0.00	0.000	1.689
3	-3.7	0.0		0.0	59.6	49.0	0.000		0.00	0.000	1.621
4	-4.1	0.0		0.0	53.4	43.3	0.000		0.00	0.000	1.671
5	-4.4	0.0		0.0	47.9	38.2	0.000		0.00	0.000	1.676
6	-4.7	0.0		0.0	43.8	33.7	0.000		0.00	0.000	1.671
7	-4.7	0.0		0.0	38.4	29.7	0.000		0.00	0.000	1.676
8	-4.7	0.0		0.0	34.9	26.1	0.000		0.00	0.000	1.662
9	2.9	0.0		0.0	31.3	23.0	0.000		0.00	0.000	1.679
10	6.8	0.0		2.7	114.4	130.2	0.174		0.09	0.087	7.782
11	9.2	0.0		2.7	156.1	171.4	0.298		0.15	0.143	7.394
12	12.6	0.5		2.7	178.2	199.9	0.317		0.17	0.149	7.032
13	14.8	0.0		2.7	179.2	199.4	0.345		0.22	0.124	7.231
14	16.2	0.0		2.7	180.5	195.6	0.356		0.23	0.125	6.497
15	16.8	0.0		2.7	183.8	198.3	0.349		0.24	0.113	6.594
16	17.3	1.1		2.7	179.4	198.2	0.351		0.24	0.115	6.478
17	16.3	0.4		0.8	179.5	181.2	0.180		0.08	0.098	6.571
18	11.4	0.0		0.0	159.7	146.3	0.000		0.00	0.000	1.829
19	6.3	0.0		0.0	144.4	129.0	0.000		0.00	0.000	1.650
20	4.6	0.0		0.0	129.9	114.7	0.000		0.00	0.000	1.649
21	2.4	0.0		0.0	114.8	102.1	0.000		0.00	0.000	1.645
22	1.1	0.0		0.0	103.4	90.8	0.000		0.00	0.000	1.656
23	0.3	0.0		0.0	93.1	80.9	0.000		0.00	0.000	1.658
24	-0.5	0.0		0.0	83.8	71.1	0.000		0.00	0.000	1.633
TOT.	4.4	0.1	---	----	----	----	2.37	---	1.39†	0.979†	82.286

*ALL COLLECTOR ROWS OPERATIONAL.
†INCLUDES OVERNIGHT PIPING LOSSES.

Clear-Day Performance Summary for March 2, 1984

HOUR	AMBIENT TEMP. DEG C	WIND SPEED M/S	INCIDENT SOLAR ENERGY ON A COLLECTOR SURFACE GJ	COLLECTOR ARRAY FLOW RATE KG/S	COLLECTOR ARRAY TEMPERATURE * INLET DEG C	OUTLET DEG C	ENERGY COLLECTED GJ	COLLECTOR ARRAY EF-FICIENCY %	ENERGY DELIVERED GJ	LOSSES GJ	PARASITIC ENERGY MJ
1	4.4	.1	.00	.0	32.4	38.7	.000	.00	.00	.000	1.649
2	3.4	.0	.00	.0	27.8	32.8	.000	.00	.00	.006	1.645
3	2.6	.0	.00	.0	23.8	27.7	.000	.00	.00	.000	1.646
4	1.8	.0	.00	.0	20.3	23.3	.000	.00	.00	.000	1.672
5	1.2	.0	.00	.0	17.3	19.7	.000	.00	.00	.000	1.665
6	.6	.0	.00	.0	14.6	16.7	.000	.00	.00	.000	1.648
7	.1	.2	.00	.0	12.3	14.2	.000	.00	.00	.000	1.650
8	1.6	.0	.00	.0	10.4	11.9	.000	.00	.00	.000	1.630
9	7.5	.3	1.16	.0	9.3	10.4	.000	.00	.00	.000	1.651
10	11.7	.6	2.12	2.7	125.5	157.8	.360	17.00	.22	.142	16.376
11	17.4	.7	2.51	2.7	177.4	216.4	.700	27.88	.46	.244	7.671
12	20.0	1.0	2.35	2.7	170.6	179.5	.772	32.83	.61	.166	7.450
13	21.9	1.1	2.68	2.7	177.0	216.0	.805	30.09	.61	.198	6.762
14	23.3	2.0	2.73	2.7	178.3	217.8	.854	31.34	.67	.182	6.726
15	24.1	1.4	2.75	2.7	179.1	217.0	.876	31.91	.70	.175	6.463
16	25.8	2.2	2.72	2.7	177.5	216.9	.879	32.39	.71	.169	6.565
17	27.6	1.4	2.47	2.7	174.8	207.6	.803	32.45	.64	.167	6.561
18	23.5	.4	1.76	.0	166.6	171.8	.309	17.53	.19	.115	5.925
19	18.2	.2	.12	.0	105.9	132.2	.000	.00	.00	.000	1.706
20	13.6	.1	.00	.0	83.4	104.3	.000	.00	.00	.000	1.662
21	10.6	.3	.00	.0	68.0	84.4	.000	.00	.00	.000	1.666
22	9.3	.5	.00	.0	55.6	69.7	.000	.00	.00	.000	1.652
23	7.7	.0	.00	.0	46.5	57.7	.000	.00	.00	.000	1.626
24	6.6	.0	.00	.0	39.5	48.0	.000	.00	.00	.000	1.652
TOT.	11.6	.5	23.36	----	----	----	6.36	27.22	4.45†	1.905†	49.542

*ALL COLLECTOR ROWS OPERATIONAL.
†INCLUDES OVERNIGHT PIPING LOSSES.

REF.: DE-AC04-78CS32199
DATE: November 1984

APPENDIX C
SYSTEM OPERATION SUMMARIES

System Operation Summary--January 1983

Date	Julian Day	Status Code	Weather	Remarks
1	1	6	C	Plant holiday.
2	2	6	C	Plant holiday.
3	3	3	P	
4	4	1	F	
5	5	1	F	Discovered problem with new d/p cell for boiler water level.
6	6	2	P	Solar steam system down, d/p cell calibrated.
7	7	1	P	
8	8	1	C	
9	9	1	C	
10	10	1	R	Rain all day.
11	11	1	F	Adjusted pyrheliometer.
12	12	1	C	Reinsulated valves in steam line.
13	13	1	F	
14	14	1	F	Dowtherm pump seal leak worsened.
15	15	1	C	
16	16	1	F	
17	17	1	F	
18	18	1	F	Printer problem discovered.
19	19	1	F	Adjusted pyrheliometer.
20	20	1	S	
21	21	1	C	
22	22	1	C	
23	23	1	C	
24	24	1	R	
25	25	1	C	
26	26	1	C	Adjusted pyrheliometer.
27	27	1	R	Analyzed water sample from solar boiler.
28	28	1	P	Adjusted pyrheliometer.
29	29	1	C	
30	30	1	C	
31	31	1	C	

Weather Codes

F: Fair
P: Partly cloudy
C: Fog or overcast
R: Rain
S: Snow

Status Codes

1: Normal operation
2: Solar energy system down
3: Solar energy system not turned on
6: Plant down; solar energy system idled

System Operation Summary--February 1983

Date	Julian Day	Status Code	Weather	Remarks
1	32	2	R	Replaced seal in Dowtherm pump
2	33	2	R	Adjusted pyrheliometer
3	34	1	C	
4	35	2	P	Pump impeller froze upon start-up. Filed burr that had formed between top of impeller and housing. Adjusted pyrheliometer.
5	36	1	R	
6	37	1	R	
7	38	1	C	
8	39	1	F	Replaced leaking gate valve in steam line.
9	40	1	C	Discovered broken lead on boiler outlet RTD.
10	41	1	R	Printer problem discovered.
11	42	1	R	
12	43	1	C	
13	44	1	C	
14	45	1	P	Installed new RTD at boiler outlet.
15	46	1	F	
16	47	1	C	
17	48	1	F	
18	49	1	F	
19	50	1	F	
20	51	1	F	
21	52	1	F	Adjusted pyrheliometer.
22	53	1	C	
23	54	1	C	
24	55	1	C	Tightened union on seal flush line for Dowtherm pump.
25	56	1	C	
26	57	1	F	
27	58	1	C	
28	59	1	C	

Weather Codes

F: Fair
P: Partly cloudy
C: Fog or overcast
R: Rain

Status Codes

1: Normal operation
2: Solar energy system down

System Operation Summary--March 1983

Date	Julian Day	Status Code	Weather	Remarks
1	60	1	F	Adjusted pyrheliometer.
2	61	1	F	Took surface temperature measurements on piping insulation.
3	62	1	F	Modified on-site computer program (Re: Calculation of steam production).
4	63	1	F	
5	64	1	C	
6	65	1	F	
7	66	1	P	Adjusted pyrheliometer.
8	67	1	P	Cut vent holes in Dowtherm piping insolation.
9	68	1	C	
10	69	1	C	
11	70	1	C	
12	71	1	C	
13	72	1	F	
14	73	1	P	Adjusted pyrheliometer.
15	74	1	P	Two rows in stow because of bad local control boards.
16	75	1	R	
17	76	1	R	
18	77	1	R	
19	78	1	P	
20	79	1	R	
21	80	1	C	
22	81	1	P	Adjusted pyrheliometer.
23	82	1	C	Problem with Insolation data on daily printout.
24	83	1	R	
25	84	1	P	
26	85	1	R	
27	86	1	P	
28	87	1	C	Sent bad local control boards to Suntec for repair.
29	88	1	P	Adjusted pyrheliometer.
30	89	1	C	
31	90	1	C	

Weather Codes

F: Fair
P: Partly cloudy
C: Fog or overcast
R: Rain

Status Codes

1: Normal operation

System Operation Summary--April 1983

Date	Julian Day	Status Code	Weather	Remarks
1	91	1	P/F	Adjusted pyrheliometer. Two rows in stow because of bad local control boards.
2	92	1	C	
3	93	1	P	
4	94	1	F	Adjusted pyrheliometer.
5	95	1	R	
6	96	1	C	Discovered error in insolation valves listed in daily printout.
7	97	1	C	
8	98	1	R	
9	99	6	C	Plant shutdown.
10	100	6	P	
11	101	6	F	
12	102	6	F	
13	103	6	F	
14	104	1	R	
15	105	1	P	Installed repaired control board in Row 4. Row 10 still in stow.
16	106	1	P	
17	107	1	P	
18	108	1	C	
19	109	1	F	
20	110	1	F	
21	111	1	P	
22	112	1	C	
23	113	1	R	
24	114	1	R	
25	115	1	F	
26	116	1	F	
27	117	1	F	
28	118	1	F	
29	119	1	P	
30	120	1	P	

Weather Codes

F: Fair
P: Partly cloudy
C: Fog or overcast
R: Rain

Status Codes

1: Normal operation
6: Plant down; solar energy system idled

System Operation Summary--May 1983

Date	Julian Day	Status Code	Weather	Remarks
1	121	1	F	Row 10 in stow because of bad local control board.
2	122	1	R	
3	123	1	R	
4	124	1	P	Adjusted pyrheliometer.
5	125	1	P	
6	126	1	F	Tightened packing on valves. Took measurements for installing boiler high-level switch.
7	127	1	F	
8	128	1	P	
9	129	1	P	
10	130	1	P	
11	131	1	P	Prepared drawing for installation of boiler high-level switch.
12	132	1	R	
13	133	2	R	Installed boiler high-level switch and repaired pump seal flush line. Installed spare local control board in Row 10.
14	134	1	P	
15	135	1	R	Turned collectors up for rain-wash.
16	136	1	C	
17	137	2	C	Added Dowtherm to bring level up in accumulator tank. Looked into dual settings on boiler high-level switch.
18	138	1	C	Modified on-site computer program to calculate
19	139	1	C	energy delivered to process. Debugged computer
20	140	1	C	program to determine why solar insolation values were going to zero.
21	141	1	R	
22	142	1	R	
23	143	1	P	
24	144	1	P	
25	145	1	P	Ordered spare pressure relief valves for steam generator and accumulator tank.
26	146	1	P	
27	147	1	P	
28	148	1	P	
29	149	1	P	
30	150	1	F	
31	151	1	C	

Weather Codes		Status Codes	
F:	Fair	1:	Normal operation
P:	Partly cloudy	2:	Solar energy system down
C:	Fog or overcast		
R:	Rain		

System Operation Summary--June 1983

Date	Julian Day	Status Code	Weather	Remarks
1	152	1	P	Installed dike around steam generator, circulating pump, and accumulator tank. Adjusted pyrheliometer.
2	153	1	F	Power failure brought system down around noon.
3	154	1	---	No data available.
4	155	1	---	No data available.
5	156	1	---	No data available.
6	157	1	P	Computer restarted.
7	158	1	C	Completed work on dike.
8	159	1	F	Received repaired local control board.
9	160	1	F	
10	161	1	F	
11	162	1	F	
12	163	1	F	
13	164	1	F	Power failure brought system down around noon.
14	165	6	F	No data available. Adjusted pyrheliometer.
15	166	1	C	Recharged collector field batteries.
16	167	1	F	
17	168	1	C	
18	169	1	R	
19	170	1	R	
20	171	1	R	
21	172	1	P	
22	173	1	C	
23	174	1	C	Replaced computer disk drive.
24	175	1	F	
25	176	1	F	
26	177	1	F	
27	178	1	C	Corrected computer error in daily printout.
28	179	1	C	
29	180	1	C	
30	181	1	C	

Weather Codes

F: Fair
P: Partly cloudy
C: Fog or overcast
R: Rain

Status Codes

1: Normal operation
6: Plant down; solar energy system idled

System Operation Summary--July 1983

Date	Julian Day	Status Code	Weather	Remarks
1	182	1	P	Replaced valve in feedwater line.
2	183	1	P	
3	184	1	F	
4	185	1	P	
5	186	6	---	No data available.
6	187	6	---	No data available.
7	188	6	---	No data available.
8	189	6	F	
9	190	6	---	No data available.
10	191	6	F	
11	192	1	F	Adjusted pyrheliometer.
12	193	1	F	Adjusted pyrheliometer.
13	194	1	F	
14	195	1	P	
15	196	1	C	
16	197	1	C	
17	198	1	C	
18	199	1	C	
19	200	1	C	Adjusted pyrheliometer. Adjusted feedwater flow meter.
20	201	1	C	
21	202	1	C	Two collector rows not operating properly.
22	203	1	F	
23	204	1	F	
24	205	1	P	
25	206	1	C	
26	207	1	R	Two collector rows still in stow.
27	208	1	P	Adjusted pyrheliometer.
28	209	1	C	
29	210	1	C	Received spare parts.
30	211	1	F	
31	212	1	C	

Weather Codes

F: Fair
P: Partly cloudy
C: Fog or overcast
R: Rain

Status Codes

1: Normal operation
6: Plant down; solar energy system idled

System Operation Summary--August 1983

Date	Julian Day	Status Code	Weather	Remarks
1	213	1	R	Received spare parts for solar collectors. Two collector rows still in stow.
2	214	1	C	Replaced pressure-relief valves in Rows 12, 13, 14 and 15.
3	215	1	C	Discovered that pyrheliometer had water under lens cover. Will send it back to the manufacturer for repair.
4	216	1	F	
5	217	1	P	
6	218	1	C	Installed spare control board in Row 3 and sent defective control board for repair.
7	219	1	P	
8	220	1	F	
9	221	1	F	
10	222	1	F	Repaired control board in Row 14. All collector rows up and tracking.
11	223	1	P	
12	224	1	C	
13	225	1	F	
14	226	1	F	
15	227	1	F	
16	228	1	C	Tested pressure-relief valves removed on August 2. Three are acceptable.
17	229	1	P	Replaced pressure relief valves in Rows 9, 10, and 11. Tightened two valves downstream of Dowtherm pump.
18	230	1	P	
19	231	1	P	
20	232	1	F	
21	233	1	F	
22	234	1	P	
23	235	1	P	
24	236	1	P	
25	237	1	C	

System Operation Summary--August 1983 (cont)

Date	Julian Day	Status Code	Weather	Remarks
26	238	1	P	Tested pressure-relief valves removed on August 17. None are acceptable.
27	239	1	P	
28	240	1	C	
29	241	1	F	
30	242	1	F	
31	243	1	C	

Weather Codes

F: Fair
P: Partly cloudy
C: Fog or overcast
R: Rain

Status Codes

1: Normal operation

System Operation Summary--September 1983

Date	Julian Day	Status Code	Weather	Remarks
1	244	1	C	
2	245	1	C	
3	246	1	C	
4	247	1	C	
5	248	1	P	
6	249	1	P	
7	250	1	P	
8	251	1	C	
9	252	1	P	
10	253	1	P	
11	254	1	P	
12	255	1	C	
13	256	1	P	Calibrated flow d/p cells.
14	257	1	F	Installed repaired pyrheliometer. Began insulation upgrading.
15	258	2	C	Dowtherm drained from system.
16	259	2	C	Replaced pump seal.
17	260	2	P	
18	261	2	P	
19	262	2	C	
20	263	2	R	
21	264	2	R	
22	265	2	P	
23	266	2	C	
24	267	2	C	
25	268	2	C	
26	269	2	F	
27	270	2	F	Replaced pump gasket and lapped impeller.
28	271	2	F	Adjusted pyrheliometer. Zeroed Dowtherm flow meter.
29	272	2	F	Replaced actuated ball valve in steam line.
30	273	2	P	

Weather Codes

F: Fair
P: Partly cloudy
C: Fog or overcast
R: Rain

Status Codes

1: Normal operation
2: Solar energy system down

System Operation Summary--October 1983

Date	Julian Day	Status Code	Weather	Remarks
1	274	2	P	Continued insulation upgrading work. Replaced check valve in steam line.
2	275	2	F	
3	276	2	F	
4	277	2	C	
5	278	2	R	
6	279	2	F	
7	280	2	C	Replaced pressure-relief valves on boiler and accumulator tank. Repaired pyrheliometer wire and adjusted instrument. Noticed excessive leaking from Dowtherm pump.
8	281	2	P	
9	282	2	P	
10	283	2	R	Removed pump from system.
11	284	2	R	Installed new mechanical seal.
12	285	2	R	
13	286	2	R	
14	287	1	F	Demand turned on. Adjusted pyrheliometer.
15	288	1	F	
16	289	1	F	
17	290	1	F	Adjusted pyrheliometer.
18	291	1	P	
19	292	1	C	
20	293	1	C	
21	294	1	C	
22	295	1	C	
23	296	1	R	
24	297	1	C	
25	298	1	C	
26	299	1	F	Adjusted pyrheliometer.
27	300	1	F	
28	301	1	F	
29	302	1	F	
30	303	1	C	
31	304	1	C	

Weather Codes

F: Fair
P: Partly cloudy
C: Fog or overcast
R: Rain

Status Codes

1: Normal operation
2: Solar energy system down

System Operation Summary--November 1983

Date	Julian Day	Status Code	Weather	Remarks
1	305	1	C	Adjusted pyrheliometer.
2	306	1	F	
3	307	1	P	
4	308	1	R	
5	309	1	F	
6	310	1	P	
7	311	1	C	
8	312	1	F	Adjusted pyrheliometer.
9	313	1	F	Checked chemistry of boiler feedwater.
10	314	1	R	
11	315	1	C	
12	316	1	R	
13	317	1	C	
14	318	1	C	
15	319	1	R	
16	320	1	C	
17	321	1	F	Adjusted pyrheliometer.
18	322	1	F	
19	323	1	P	
20	324	1	C	
21	325	1	C	
22	326	1	F	
23	327	1	C	
24	328	1	C	
25	329	1	F	
26	330	1	F	
27	331	1	C	
28	332	1	F	Noticed several Dowtherm leaks in system.
29	333	1	F	Disconnected faulty ground wire.
30	334	1	F	Valved off three collector rows.

Weather Codes

F: Fair
P: Partly cloudy
C: Fog or overcast
R: Rain

Status Codes

1: Normal operation

System Operation Summary--December 1983

Date	Julian Day	Status Code	Weather	Remarks
1	335	1	C	Three collector rows valved off because of Dow-therm leaks.
2	336	1	C	
3	337	2	---	No data available.
4	338	2	---	No data available.
5	339	2	C	
6	340	2	C	Adjusted pyrheliometer.
7	341	2	F	Replace pressure-relief valves in remaining six collector rows.
8	342	1	F	Intermittent problems with tracking in Row 7.
9	343	1	F	
10	344	1	---	No data available.
11	345	1	---	No data available.
12	346	1	R	
13	347	1	C	
14	348	1	R	
15	349	2	P	Replaced leaking flexhose in Row 2. Tightened bolts in Row 2 flange. Welded pin hole leak in Row 11 receiver.
16	350	1	F	
17	351	1	F	
18	352	1	P	
19	353	1	P	
20	354	1	R	
21	355	1	C	
22	356	1	---	No data available.
23	357	1	---	No data available.
24	358	1	---	No data available.
25	359	1	---	No data available.
26	360	1	---	No data available.
27	361	1	---	No data available.
28	362	1	---	No data available.
29	363	1	---	No data available.
30	364	1	---	No data available.
31	365	1	---	No data available.

Weather Codes

F: Fair
P: Partly cloudy
C: Fog or overcast
R: Rain

Status Codes

1: Normal operation
2: Solar energy system down

System Operation Summary--January 1984

Date	Julian Day	Status Code	Weather	Remarks
1	1	1	F	Intermittent tracking problems in four collector rows.
2	2	1	C	
3	3	1	F	
4	4	1	P	
5	5	1	F	
6	6	1	F	
7	7	1	F	
8	8	1	F	
9	9	1	F	
10	10	1	C	
11	11	1	F	
12	12	1	P	
13	13	1	C	
14	14	1	P	
15	15	1	C	
16	16	1	C	
17	17	1	C	
18	18	1	C	
19	19	1	F	
20	20	1	C	
21	21	1	C	Sent solar tracker to manufacturer for repair.
22	22	1	P	
23	23	1	P	
24	24	1	C	
25	25	1	P	
26	26	1	P	
27	27	1	P	
28	28	1	C	
29	29	1	P	
30	30	1	F	
31	31	1	F	

Weather Codes

F: Fair
P: Partly cloudy
C: Fog or overcast

Status Codes

1: Normal operation

APPENDIX D

THE MODEL AND STATISTICS

Appendix D

THE MODEL AND STATISTICS

In preparing our model and fitting it to the operating data obtained from the solar thermal system, we have followed the precepts postulated by Sharney, et al.:[1]*

- Approximating equations should be simple, containing only a priori terms which are detectable and statistically significant.
- Approximating equations should lend themselves to interpretation as solutions for the behavior of mathematical models which represent an "idealization" of the processes considered. They should not contradict physical reality.
- Such models should elucidate processes beyond the mere numerical representations of the experimentally available data.

In modeling the solar thermal system, we seek to calculate the instantaneous temperature distribution within the system. In contrast to those commonly used to predict system performance,[2] our model will explicitly account for transient effects caused by heat losses and thermal inertia. To this end, we divide the solar thermal systems into subsystems, placing nodes at each interface between the subsystems (Figure D.1). The interior volume, thermal mass, and heat loss associated with each subsystem can be estimated.

To model the system, we will consider the behavior of elements of fluid that pass through each subsystem. By assuming plug flow and a linear relationship between temperature and time within small time increments that exceed the transit time of fluid through any subsystem, the processes by which thermal energy is acquired or

*References are listed at the end of the Appendix.

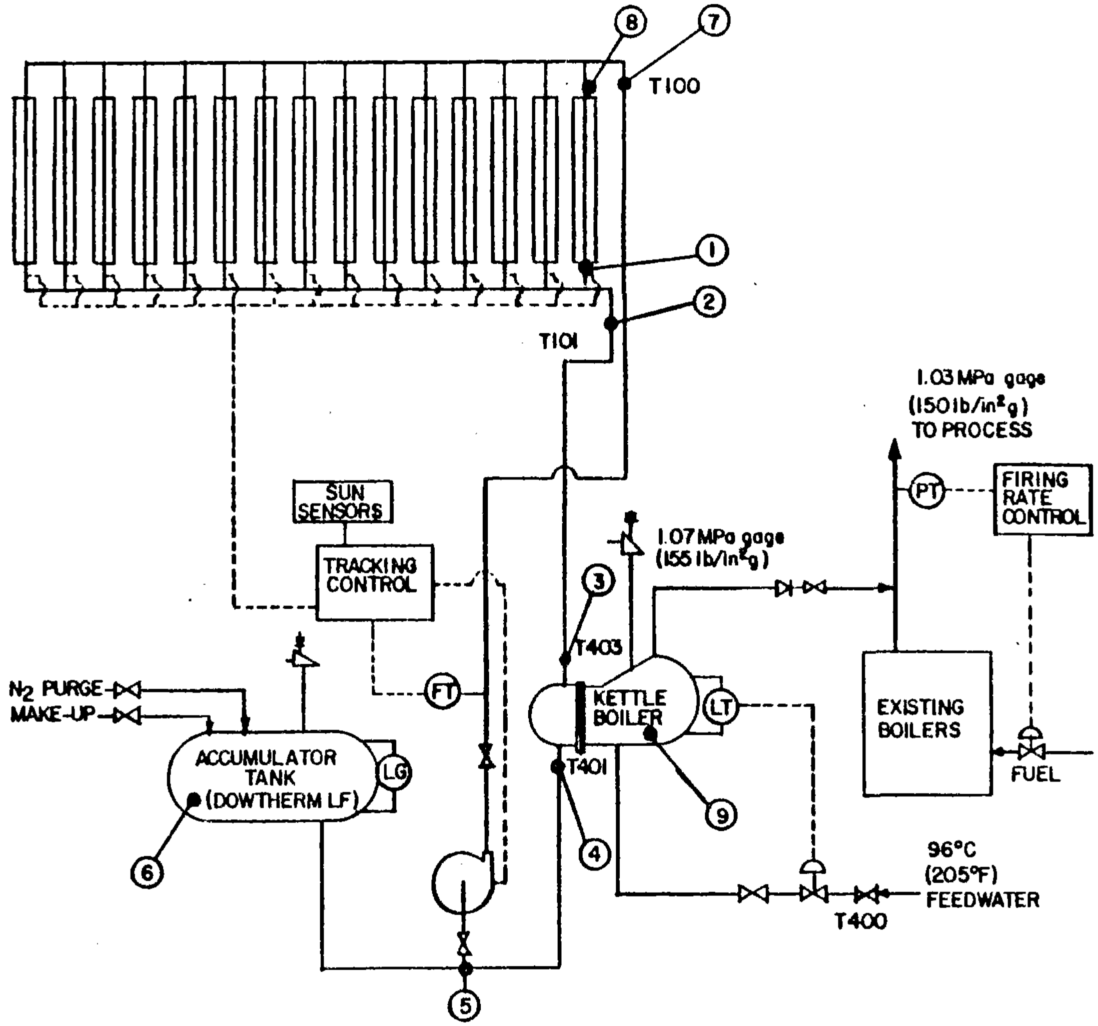

Figure D.1 System Schematic

lost can be described using simple equations. To develop these equations, we consider an element of fluid that passes through a piping subsystem bounded by Nodes A and B. If the transit time of the element through the subsystem is S_B, then if the element leaves the subsystem (reaches Node B) at time $t + \Delta t$, it must have entered at Node A at time $t + \Delta t - S_B$. The temperature of the element at that time is

$$\left(1 - S_B/\Delta t\right) \cdot T_A(t + \Delta t) + T_A(t) \cdot S_B/\Delta t \tag{1}$$

where

$T_A(t)$ = Temperature at Node A at time t.

If the element of fluid comprises all the fluid that enters the subsystem in the time interval

$$\left[t + \Delta t - S_B,\ t + \Delta t - S_B + \delta t\right],\ \delta t << S_B < \Delta t \tag{2}$$

then on entering, the heat content of this element is

$$H_w = m\delta t\left[\left(1 - S_B/\Delta t\right) \cdot T_A(t + \Delta t) + S_B/\Delta t \cdot T_A(t)\right] \tag{3}$$

where

m = Thermal mass flow rate at A.

Assuming a linear relationship between temperature and heat loss to the atmosphere, the heat loss from this element as it passes from A to B is

$$H_x' = U_B A_B \left\{\left[T_A(t + \Delta t) \cdot (1 - S_B/\Delta t) + T_A(t) \cdot S_B/\Delta t + T_B(t + \Delta t)\right]/2 - T_{amb}\right\}\delta t \tag{4}$$

where

$U_B A_B$ = Product of the heat-transfer coefficient and surface area for the system between Nodes A and B

T_{amb} = Ambient temperature.

The heat loss from the element to the fixed thermal masses (vessels, piping, etc.) necessary to change the temperature of these masses is

$$H_y = \left[T_A(t + \Delta t) + T_B(t + \Delta t) - T_A(t) - T_B(t)\right] \cdot 0.5 \cdot M_B \delta t/\Delta t \quad (5)$$

where

M_B = Fixed thermal mass of the subsystem.

Finally, the heat content of the element as it leaves the subsystem is

$$H_z = m\delta t \cdot T_B(t + \Delta t) \quad (6)$$

Equating these terms in a simple energy balance, we have

$$H_z = H_w - H_x - H_y \quad (7)$$

Substituting for H_w, H_x, H_y, and H_z and simplifying, we have

$$T_B(t + \Delta t) = \Big\{\left(m - U_B A_B/2\right) \cdot \left[T_A(t + \Delta t) \cdot \left(1 - S_B/\Delta t\right) + T_A(t) \cdot S_B/\Delta t\right] + U_B A_B T_{amb} - \left(0.5 M_B\right)\left[T_A(t + \Delta t) - T_A(t) - T_B(t)\right]\Big\} \Big/ \left[m + U_B A_B/2 + M_B/(2\Delta t)\right] \quad (8)$$

The model for the collector superimposes the effects of thermal inertia upon a steady-state model for a parabolic trough collector. If the steady-state model predicts a temperature rise (ΔT) for heat-transfer fluid entering the collectors at Node 8, Eq. 7 can be modified to reflect the absorption of solar thermal energy, recognizing that the effect of the heat losses from the collector are already incorporated in the predicted temperature rise Δt,

$$H_Z = H_W - H_y + m\delta t \cdot \Delta t \tag{9}$$

and thus we can predict a collector exit temperature at Node 1 of

$$T_1(t + \Delta t) = \left\{ m \left[T_8(t + \Delta t) \cdot \left(1 - S_1/\Delta t\right) + T_8(t) \cdot S_1/\Delta t + \Delta T \right] - 0.5M_1 \left[T_8(t + \Delta t) - T_8(t) - T_1(t) \right] \right\} \Big/ \left[m + M_1/(2\Delta t) \right] \tag{10}^*$$

where

M_1 = Thermal mass of collectors (receiver tubes).

An equation for the temperature of the heat-transfer fluid leaving the steam generator can be developed using a similar logic. If we assume the heat-transfer coefficient within the tubes of the heat exchanger and the shell-side temperature to be uniform everywhere, then for an element of fluid with temperature T

$$m(dT/dt) = -\left(U_9 A_9/S_9\right)\left(T - T_9\right) \tag{11}$$

If T_9 increases linearly with time over the time increment Δt--i.e., $T_9(t + p) = T_9(t) + Bp$, $0 \leq p \leq \Delta t$, then

$$M(dT/dp) = -\left(U_9 A_9/S_9\right)\left[T - T_9(t) - Bp\right] \tag{12}$$

Integrating this between the times $\left(t + \Delta t - S_9\right)$ and $(t + \Delta t)$--i.e., the times of entry and exit of the fluid element from the heat exchanger

*Numerical subscripts refer to nodes in Figure D.1.

$$T_4(t + \Delta t) = e^{-U_9 A_9/m}\Big\{T_3(t)\cdot S_9/\Delta t + T_3(t + \Delta t)\cdot\left(1 - S_9/\Delta t\right) + \Big[T_9(t + \Delta t) - T_9(t)\Big]\Big/\Big[\Delta t U_9 A_9/\left(S_9 m\right)\Big] - T_9(t)\Big\} + S_9\Big[T_9(t + \Delta t) - T_9(t)\Big]/\Delta t - \Big[T_9(t + \Delta t) - T_9(t)\Big]\Big/\left(\Delta t U_9 A_9/S_9 m\right) + T_9(t) \tag{13}$$

When boiling continues over the time period Δt at a temperature T_{boil},

$$T_9(t + \Delta t) = T_9(t) = T_{boil} \tag{14}$$

and

$$T_4(t + \Delta t) = e^{-U_9 A_9/m}\Big[T_3(t + \Delta t)\cdot\left(1 - S_9/\Delta t\right) + T_3(t)S_9/\Delta t - T_{boil}\Big] + T_{boil} \tag{15}$$

The model for the accumulator is based on two assumptions:

- There is a constant interchange of heat-transfer fluid between the accumulator and the main circulating stream over and above the movement of fluid resulting from the thermal expansion and contraction of fluid in the loop.
- The fluid in the tank is well mixed.

If f is the fraction of the circulating flow that interchanges with (or passes through) the expansion tank and fm is the mean thermal mass flow rate of heat-transfer fluid entering the expansion tank as a result of thermal expansion within the loop, then, applying heat and mass balances, these equations result (see Figure D.2):

If $g \geq 0$,

$$T_6(t + \Delta t) = \Big\{(fm + g)\Big[T_5(t + \Delta t) + T_5(t)\Big]\Big/2 + M_6 T_6(t)/\Delta t - fmT_6(t)/2 - U_6 A_6\Big[T_6(t)/2 - T_{amb}\Big]\Big\}\Big/\left(M_6/\Delta t + g + U_6 A_6/2 + fm/2\right) \tag{16}$$

and

$$T_{10}(t + \Delta t) = [m(1 - f) - g]\cdot T_5(t + \Delta t) + fmT_6(t + \Delta t)/(m - g) \tag{17}$$

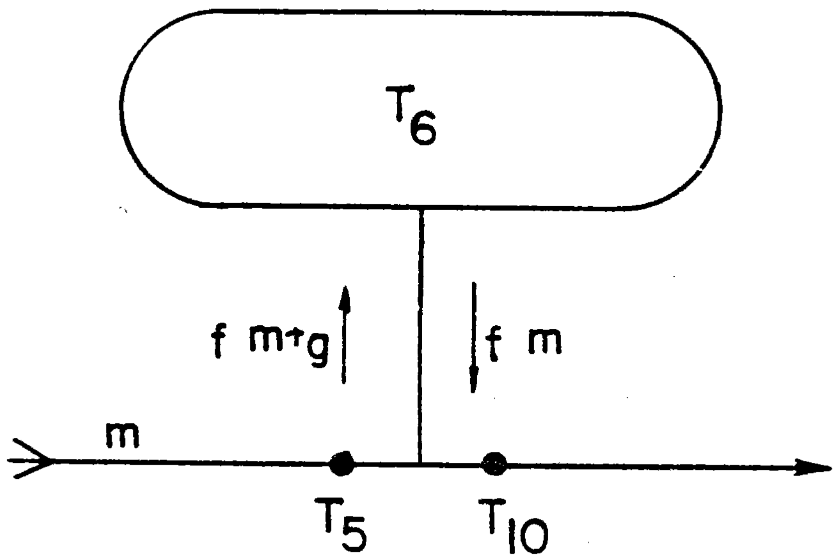

Figure D.2 Flow Rates and Temperatures Around Accumulator Tank

If $g \leq 0$,

$$T_6(t + \Delta t) = \left\{ fm \left[T_5(t + \Delta t) + T_5(t)\right]/2 + M_6 T_6/\Delta t - (fm/2 - g)T_6(t) - U_6 A_6 \left[T_6(t)/2 - T_{amb}\right] \right\} / (M_6/\Delta t + g + U_6 A_6/2 + fm/2) \quad (18)$$

and

$$T_{10}(t + \Delta t) = \left[m(1 - f) \cdot T_5(t + \Delta t) + (fm - g) \cdot T_6(t + \Delta t)\right] / (m - g) \quad (19)$$

With this series of equations, we can predict the temperature behavior of the system using an iterative procedure. Knowing the temperatures at all nodes at time t, we can estimate the temperature at a node, say C, in the heat-transfer loop at the time $t + \Delta t$. The temperatures at all nodes are then calculated using the equations just derived, including the temperature at Node C, as a final calculation. This series of calculations is then repeated until no significant change in the temperature at Node C occurs between iterations. The logical node at which to break into the loop and estimate the temperature lies between the steam generator and the collector inlet because the steam generator will dampen temperature fluctuations and, while steam is being generated, temperatures in this region will be essentially constant. Thus by selecting a break-in point between the steam generator and the collector inlet, the number of iterations required for convergence will be minimized.

Having developed a model and simulation procedure, we can proceed to fit the model to data. Three sets of data exhibiting transient behavior were selected, each set comprising simultaneous temperature measurements made over several hours at the entrance to and exit from the steam generator and collectors

(T_2, T_3, T_4, and T_7 in Figure D.1). In fitting the model to the data, we examined these parameters:

- Heat-loss coefficients for each subsystem
- Rate at which fluid is interchanged between the heat-transfer fluid loop and the accumulator
- Temperature at which the water boils in the steam generator
- Heat-transfer coefficient for the steam generator heat exchanger
- A collector performance factor accounting for the degradation of the thermal and optical properties of the collector.

In selecting these parameters, we assumed that the thermal masses of subsystems can be determined from design data. Discrepancies between actual and calculated thermal masses will, in general, be related to inadequate insulation or isolation of equipment and thus can be adequately represented as enhanced heat losses.

In fitting the model to the temperature data, we used actual insolation, ambient temperature, and heat-transfer fluid mass flow rate data. The steady-state temperature rise across the collector, assuming no degradation, was calculated using the model derived by Dudley and Workhoven.[3] The best estimates of the parameters are defined as that set of estimates that minimizes the multiple response criterion of Box and Draper.[4] This approach has been described elsewhere[5]; it entails the use of the expanding simplex method of Nelder and Mead[6] to search in parametric space. The best estimates of the parameters are presented in Table D.1. Although other parameters were examined, none were found to alter significantly the fit of the model to data when varied from their estimated values. The simulated and actual data are shown in Figures D.3, D.4, and D.5.

Table D.1 Parametric Estimates (95-percent confidence intervals shown in parentheses)

Parameter	October 30, 1982	March 25, 1983	June 16, 1983	Comment
Heat loss from flex hoses, etc. (Nodes 1-2, 7-8), Btu/h•°F	18 (17.1-19.1)	15.5 (14.6-16.3)	20.7 (19.1-22.5)	Some flex hoses replaced between October 30, 1982, and March 25, 1983.
Heat loss from distribution piping (Nodes 2-3), Btu/h•°F	146 (140-152)	184 (179-192)	151 (139-161)	
Heat loss from piping (Nodes 4-7), Btu/h•°F	209 (2.1-2.6)	225 (6.7-7.5)	199 (187-207)	Insulation water-saturated between October 23, 1982, and March 25, 1983.
Heat-transfer coefficient in steam generator (UA), Btu/h•°F	33,611 (28,983-55,058)	16,034 (15,382-16,712)	19,715 (18,406-21,740)	
Fraction of flow interchanging with accumulator,°F	0.4 (0.26-0.56)	---	---	One of two lines connecting the accumulator to the main loop was closed between October 30, 1982.
Factor for collector efficiency, °F	0.68 (0.66-0.70)	0.54 (0.53-0.55)	0.62 (0.60-0.64)	Two collectors experienced tracking problems on March 25, 1983.

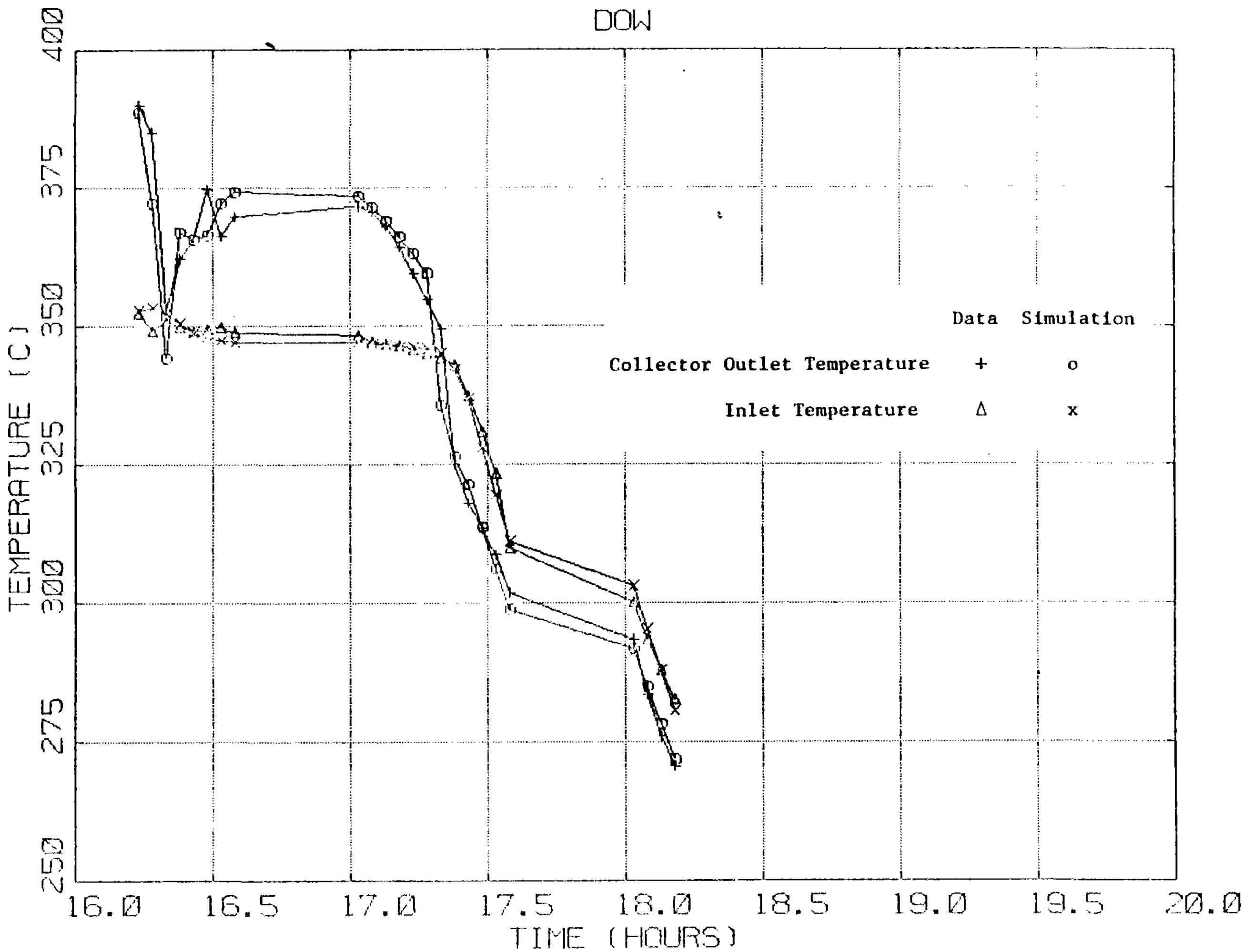

Figure D.3 Temperature Profiles--October 25, 1982

REF.: DE-AC04-78CS32199
DATE: November 1984

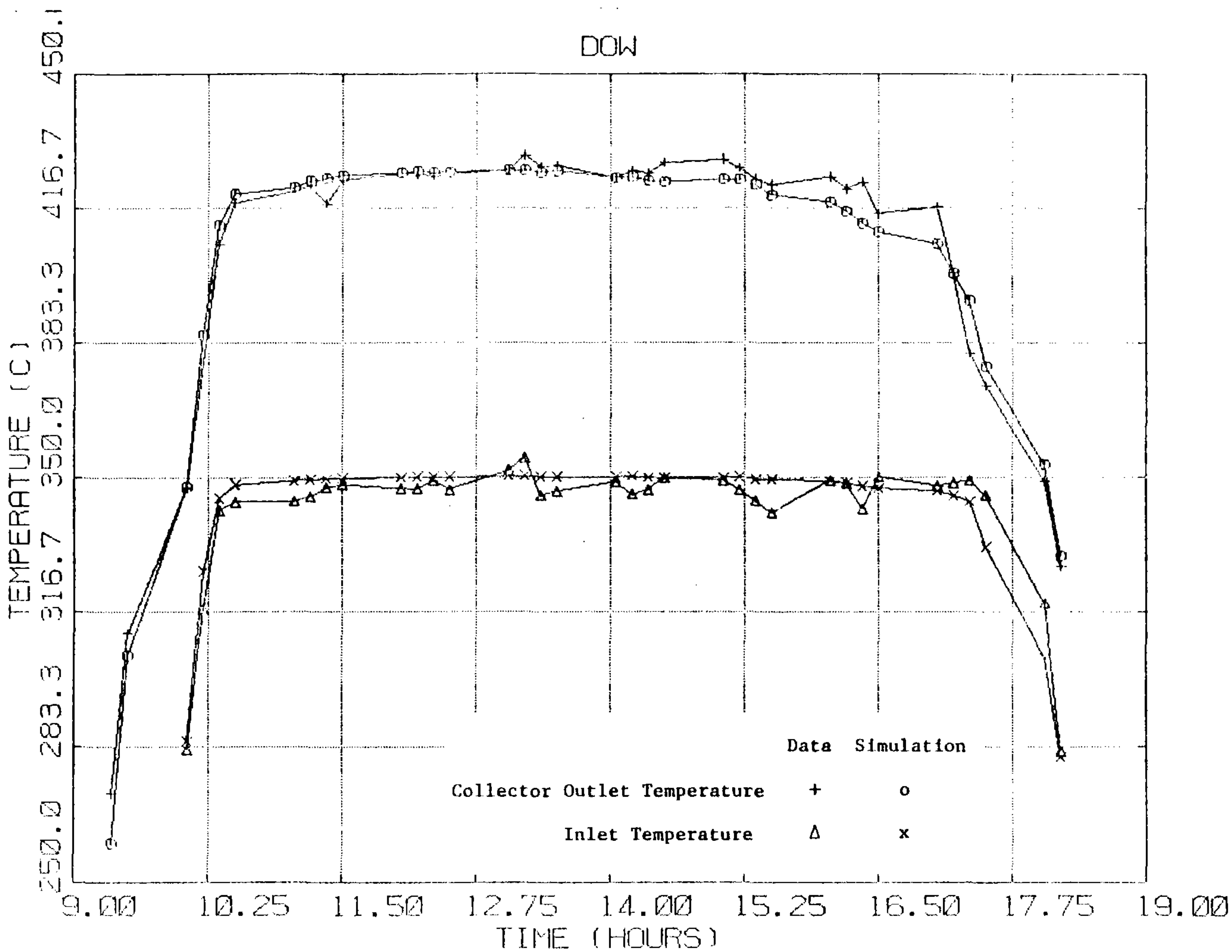

Figure D.4 Temperature Profiles--March 25, 1983

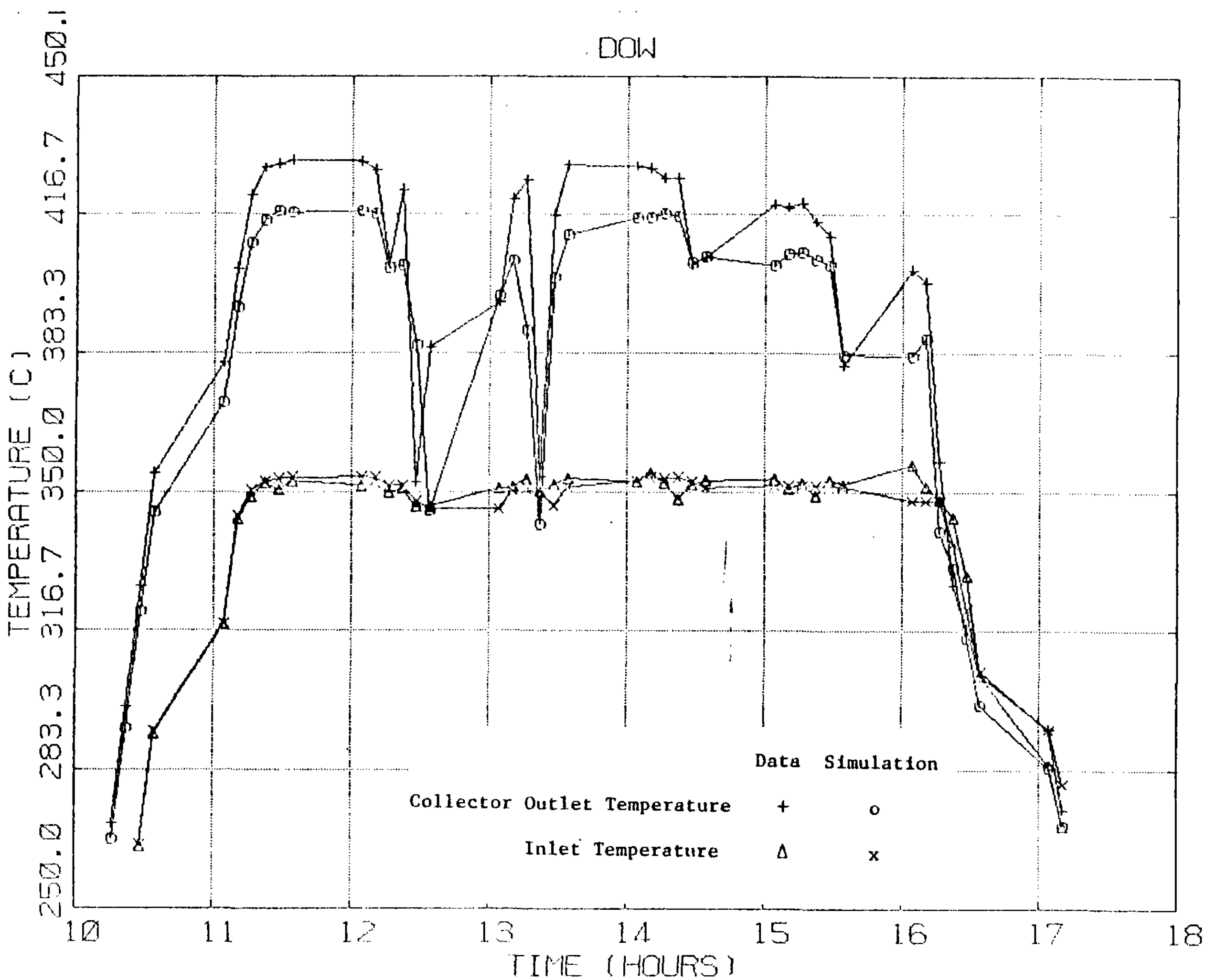

Figure D.5 Temperature Profiles--June 16, 1983

The results of the parametric estimation studies are interesting--not only in that they demonstrate the adequacy of the model, but also in that we are able to discuss the effect of maintenance work, etc. The results also demonstrate that a significant degradation of heat exchanger performance occurred between October 30, 1982 and March 2, 1983. More significantly, we note that the performance of the collectors is much poorer than early test data had led us to expect. The reasons for this degradation in collector performance are difficult to identify without further experimentation; they could result from the accumulation of grime on the reflector or the receiver tubes, an increase in emissivity of the receiver tube, or improper focusing of the collectors.

The discrepancy between collector performance on the days that system performance was simulated is in large part the result of tracking difficulties experienced by two collectors on March 25,1983. In addition, we note that the wind speed on March 25, 1983, was significantly higher than on October 30, 1982 (mean speeds of 4.58 and 2.63 m/s respectively, $p < 0.0005$), and higher wind speeds would be expected to result in distortion of the reflecting surfaces remote from the collector drive and in difficulties in tracking precisely should the wind speed fluctuate. However, we failed to improve the fit of the model to data by explicitly relating collector efficiencies and subsystem heat losses to observed wind speeds, perhaps because the time scale for variations in wind speed from the mean is much smaller than the time increment between data sampling. Increased wind speeds could also be expected to account for some of the differences in heat losses on the two dates.

Having demonstrated the applicability of the model and obtained best estimates of the parameters needed to define the system, we then used the model to predict the annual performance of the system using the insolation model devised by Liers, et al.[7] The results are presented in Table D.2 and Figure D.6. They clearly demonstrate three imperatives if high thermal performance is to be achieved:

- The causes of diminished collector performance need to be identified and eliminated.
- In general, heat losses should be minimized through the use of adequate insulation and a design that minimizes the surface area of pipes and vessels and their exposure to winds.
- Continuous flows through the accumulator tank should be avoided.

The last point is easily addressed: a single, narrow line connecting the accumulator to the heat-transfer fluid circuit should be quite adequate to accommodate the thermal expansion of fluid within the circuit while minimizing interchange between the tank and circuit. Furthermore, where this interchange is eliminated, there is no need to insulate the accumulator.

The reduction in heat losses can also be easily addressed as it requires no new technology. Possible steps include the installation of additional insulation under high quality-control standards and the positioning of the boiler and accumulator tank immediately adjacent to the collector field. If the latter action had been taken in the design of this solar thermal system, annual system efficiency would have increased to 32.16 percent from the 30.78 percent anticipated at present (assuming no degradation of the collector).

The identification and elimination of the causes of collector degradation are more difficult and are an appropriate subject for further research.

Table D.2 Predicted Solar Thermal System Performance*

System Status	Annual Average System Efficiency (%)
Collectors operate at design efficiency	30.78
Collectors operate at 90 percent of design efficiency	27.99
Collectors operate at 80 percent of design efficiency	24.66
Collectors operate at 60 percent of design efficiency	15.95
Collector field on level ground	28.92
Operation with no heat loss except from collectors	39.01
Steam generator placed adjacent to field	32.16
20 percent of fluid flow passes through the expansion tank	29.85

*Except where specifically indicated to the contrary, in making predictions we assumed the collectors operated at design efficiency and there was no flow through the expansion tank.

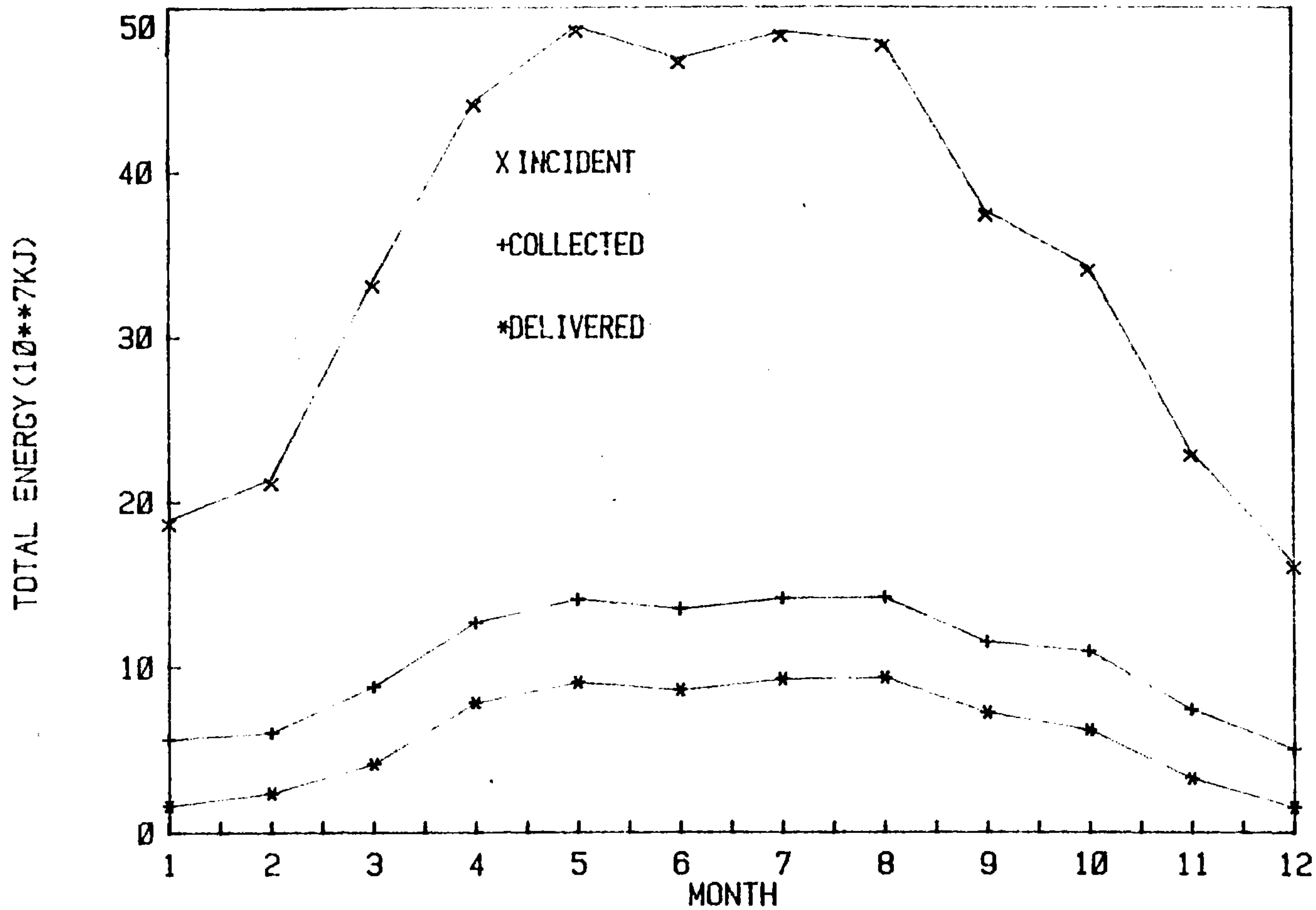

Figure D.6 Simulated Performance Prediction

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