DOE/SF/11432--T1

CONCEPTUAL DESIGN OF A SOLAR COGENERATION FACILITY AT PIONEER MILL CO., LTD.

Topical Report

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DE82 008642

Prepared By
BECHTEL GROUP, INC.
SAN FRANCISCO, CA

SUBCONTRACTORS: AMFAC SUGAR COMPANY
FOSTER WHEELER DEVELOPMENT CORP.
NORTHRUP, INC.

MASTER

For The
UNITED STATES DEPARTMENT OF ENERGY
SAN FRANCISCO OPERATIONS OFFICE

APRIL 1981

Contract No.:
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Bechtel Job No. 14481

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Section 1

EXECUTIVE SUMMARY

This topical report presents the results to date of a conceptual design study of the retrofit of a solar central receiver system to an existing cogeneration facility. The facility in question is Pioneer Mill Company, Ltd., a raw sugar factory near Lahaina, Hawaii. Bechtel Group, Inc., is the prime contractor for the U.S. Department of Energy (DOE). In this effort, Bechtel is assisted by Amfac Sugar Company (the owner of Pioneer Mill), Northrup, Inc., and Foster Wheeler Development Corporation.

This site-specific study is being conducted as one part of the DOE Solar Cogeneration Program. The general objectives of this program are to demonstrate that (1) solar central receiver systems and cogeneration facilities can be integrated in such a way as to save oil and gas in a cost-effective manner, and that (2) an integrated facility of this sort has the potential for widespread commercial application.

The study is organized into six technical tasks and one management task. Task 1 is the preparation of a system specification. Task 2 covers the major choices of system configuration and size. The remaining tasks include the conceptual design of the solar cogeneration facility, the preparation of cost and performance estimates, and the preparation of a development plan. These tasks have not been completed and will be described in the final report.

Section 2 of this report provides background information on the site, the existing facility and the project organization. Section 3 presents the results of Task 2. Appendix A is the current version of the system specification (Task 1). Other pertinent information is included in Appendices B through F.

1.1 SITE CHARACTERISTICS

Pioneer Mill is located on the west coast of the island of Maui. The area is sheltered from the tradewinds by the West Maui Mountains and is characterized by excellent insolation (estimated to average 7.4 kWh/m^2-day), low winds, and a mild tropical climate. Sugarcane is grown on 35.5×10^6 km^2 (8,776 acres) along the coast between the coast road and the foothills. The land has a gentle west-facing slope, and the soil is mainly stony, silty clay of volcanic origin.

1.2 EXISTING FACILITY

Pioneer Mill generates steam at 5.96 MPa (850 psig) and 404C (750F) in two boilers which are designed for bagasse and fuel oil. Bagasse is a cellulose by-product of sugarcane processing, produced by the raw sugar factory at the mill, and accounts for 76 percent of the energy input to the boilers. The remaining energy is supplied by No. 6 fuel oil, of which the mill consumes an average of 11,000 m^3/yr (70,000 bbl/yr).

The boilers supply steam to the main double-automatic-extracting/condensing turbine generator, which produces electric power with a maximum rating of 9,375 kVA. High-pressure extraction steam at 1.83 MPa (250 psig) and 260C (500F) is used for mechanical-drive turbines in the factory. Low-pressure extraction steam at 205 kPa (15 psig) and 135C (275F) is used for process evaporators in the factory.

The factory operates 5 days/wk for about 40 weeks in an average year and is idle during the winter for maintenance. The power generation is continued during weekends and the off season to satisfy irrigation requirements on the plantation. Excess power is supplied to the Maui Electric Company grid.

1.3 SELECTED SOLAR FACILITY CONFIGURATION

The concept of adding solar energy to Pioneer Mill is to construct a solar central receiver system that operates in parallel with the existing boilers and displaces as much oil consumption as economically possible. Bagasse will be used for energy storage to accommodate the variation in solar energy input.

Water-steam is the choice for the receiver working fluid. There are several reasons for this selection: the technology required for systems using water-steam has been developed and is widely used; the existing boilers at Pioneer Mill utilize water-steam; and the disadvantage associated with thermal storage in a water-steam system is not a factor, since in this application thermal storage is not needed. A cavity-type receiver was chosen over an external receiver because it appears to represent a lower risk design.

Two heliostat field sites were evaluated during Task 2: one site is on a south-facing hillside, about a mile from the mill, with soil too rocky for agriculture; the alternative site is in the cane fields adjacent to the mill. Because of the disadvantages associated with displacing agricultural operations, the dual use of the alternative site for heliostats and crops was also examined. It was concluded that the alternative site is superior and that dual use of this site is not economically justified.

Once the alternative site adjacent to the mill was shown to be the economic choice, Pioneer Mill management expressed a preference for shifting this site to the north side of the mill yard. The new site, shown in Figure 1-1, has the economic advantages of the alternative site since it is the same distance from the mill. Moreover, it has the additional advantage of permitting the tower and collector field to be placed farther from the town of Lahaina.

The preferred size of the solar facility was found through an analysis of the energy utilization characteristics of the existing facility and the estimated solar energy input. The result was determined by the weekend operational limits of the turbine generator and allows the displacement of about 75 percent of the oil currently consumed during the harvest season, or about 6,400 m^3/yr (40,000 bbl/yr).

The characteristics of the selected system form the basis for the conceptual design. For the collector field, the principal characteristics are as follows:

- 785 heliostats
- 52.76 m^2 (568 ft^2) per heliostat
- Northrup II second-generation heliostat
- North field, 150° sector
- Total mirror area, 41,420 m^2 (445,880 ft^2)
- Collector field area, 171,000 m^2 (42 acres)

For the receiver, the principal characteristics are as follows:

- Water-steam receiver fluid
- Twin-cavity configuration
- Natural circulation
- Elements
    - Preheater
    - Boiler
    - Superheater
- Outlet temperature, 711K (820F)
- Outlet pressure, 6,805 kPa (987 psia)
- Flow, 34,422 kg/hr (75,900 lb/hr)
- Thermal power to steam, 25.93 MWt

The selected field layout is shown in Figure 1-1.

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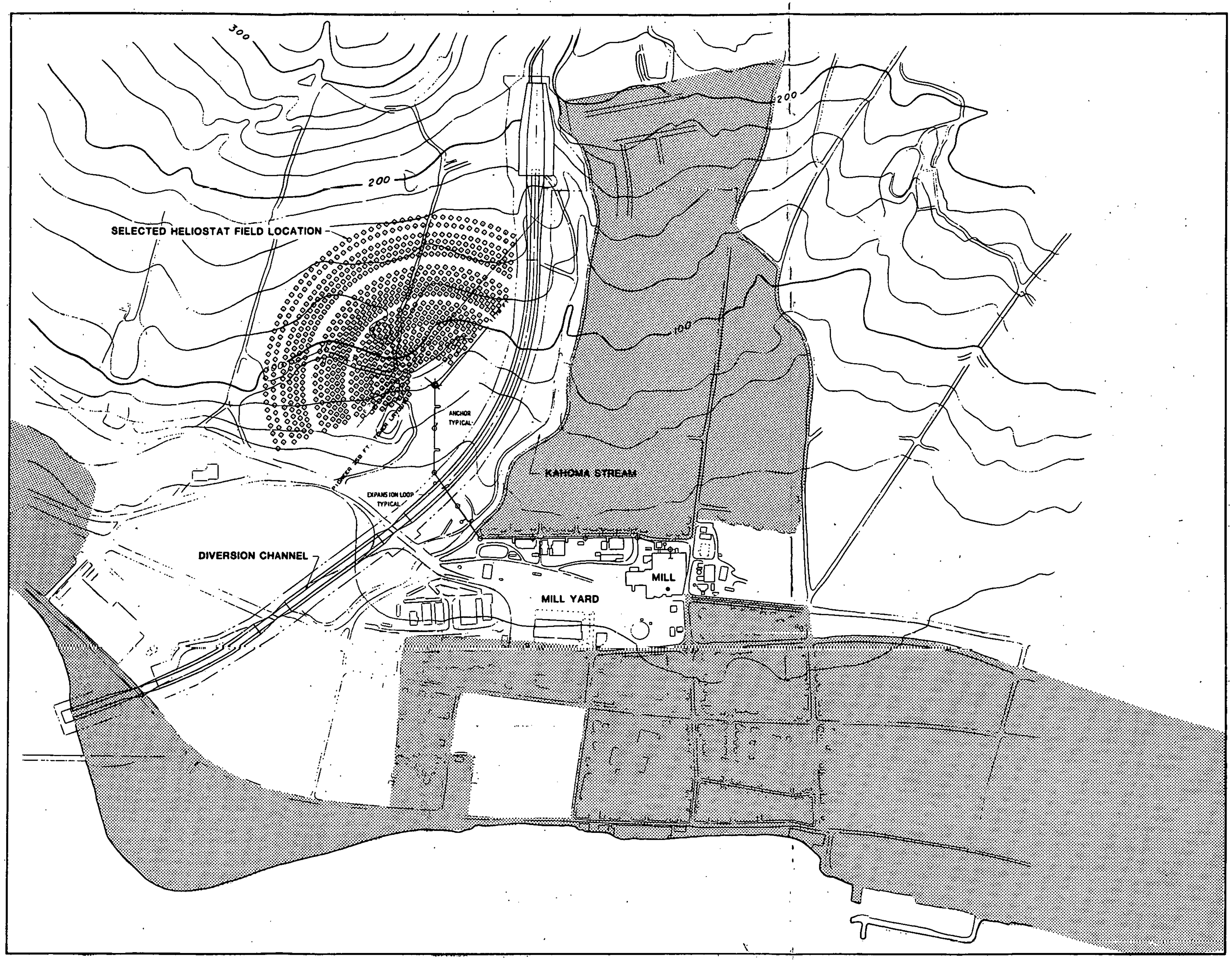

▨ RESIDENTIAL AREA

Figure 1-1 HELIOSTAT FIELD SITE OF THE PIONEER MILL SOLAR COGENERATION FACILITY

Section 2

INTRODUCTION

This topical report was prepared by Bechtel Group, Inc., to present the interim results of a study entitled "Conceptual Design of a Solar Cogeneration Facility at Pioneer Mill Company, Ltd." The study is being performed for the San Francisco Operations Office of the United States Department of Energy (DOE) under Contract Number DE-AC03-80SF11432. The study began on September 30, 1980 and is scheduled for completion on July 31, 1981, at a total cost of $437,558. Project direction is being provided by Sally Fisk and Larry Prince of the DOE and technical advice by John S. Anderson of Sandia National Laboratories, Livermore.

The Bechtel project manager is Jack R. Darnell and the project engineer is Robert L. Lessley. The Bechtel mailing address is:

Bechtel Group, Inc.
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San Francisco, CA 94119

2.1 STUDY OBJECTIVE

The overall objective of the DOE Solar Cogeneration Program is the development of site-specific conceptual designs that:

- Make effective use of solar thermal energy from a solar central receiver system integrated with a cogeneration facility
- Can be constructed and can provide high-reliability operation by 1986
- Give the best overall economics for the particular application and offer the potential for wide commercial success
- Have the potential for significant savings of critical oil and gas fuels.

The specific objectives of this project are to develop a conceptual design, to prepare performance and cost estimates, and to outline a development plan for the retrofit of a solar central receiver steam supply system to the existing cogeneration facility at Pioneer Mill Company, Ltd.

2.2 TECHNICAL APPROACH AND SITE SELECTION

2.2.1 Technical Approach

The study was organized into six technical tasks and a management task:

- Task 1 - Preparation of system specification
- Task 2 - Selection of site-specific configuration
- Task 3 - Facility conceptual design
- Task 4 - Facility performance estimates
- Task 5 - Facility cost estimates and economic analyses
- Task 6 - Development plan
- Task 7 - Project management.

The system specification defines the requirements for the solar facility and the site. The current version of the system specification is included as Appendix A of this report.

The selection of the site-specific configuration was the main focus of the first several months of the study. After the decision had been made to use a cavity-type receiver and water-steam as the working fluid, two potential sites for the collector field were selected and compared. Appropriate collector field and receiver configurations were chosen for each site, and the concurrent use of one site for both the collector field and agricultural activities was evaluated. The best size for the solar facility was also determined. A number of smaller tradeoff studies were performed in support of these major evaluations. The selection process is described in Section 3 of this report.

The conceptual design will be based on the configuration selected in Task 2. Major equipment and piping will be designed, the interfaces with the existing plant will be defined, and the operational characteristics of the solar facility will be determined. Performance and cost estimates will be prepared for the completed conceptual design, and the economics of the solar facility will be analyzed. These tasks are in progress and will be discussed in Sections 4, 5, and 6 of the final report. A development plan and schedule will also be prepared and be presented in Section 7 of the final report.

2.2.2 Site Selection

The Pioneer Mill Company, Ltd., facility was chosen for this study for two reasons: it can furnish an excellent demonstration of solar cogeneration, and it has the potential of achieving all the objectives of the Solar Cogeneration Program.

Pioneer Mill is an existing cogeneration facility. Steam generated in the boilers is supplied to the main turbine generator (which produces electric power), to mechanical drive turbines (which supply shaft power for mill equipment), and to the evaporators as process heat. When these three uses are combined with one energy source, the overall efficiency of energy use, or cogeneration efficiency, is significantly higher than for a large modern power plant.

The Hawaiian sugar mills have a long history of cogeneration experience in cooperation with the utilities on the islands. There is no electrical interconnection of the islands; each island has a small, isolated utility grid. The sugar mills contribute significantly to the electrical power generation, supplying about 31 percent of the annual generation on Maui and approximately 10 percent of the annual generation of the entire state.

With a total steam production capacity of 131,500 kg/hr (290,000 lb/hr) and a total generation capacity of 13.5 MWe, Pioneer Mill is comparable in size with a large number of industrial facilities. The basic design concept of using extraction steam from a turbine generator is also very flexible, and can be adapted to many types of industrial plants. This combination of size and flexibility of design permits a cost-effective and credible demonstration of a solar central receiver retrofit to an industrial plant.

The State of Hawaii depends on imported oil for more than 90 percent of its electrical generation. This fact, along with the small size of the typical generating units on the islands, causes utility rates to be among the highest in the United States. Hawaii is also especially vulnerable to a disruption of its oil supply, and, as a result, is aggressively pursuing a policy of renewable energy resources and development. Hence, the political climate in the state is supportive of this type of demonstration project.

The Lahaina area has an excellent solar resource. Since the area is shielded from the tradewinds and is very dry, Pioneer Mill is the only Hawaiian sugar plantation that must irrigate its fields throughout the entire year. As a result, the impact of agricultural seasons on the design of the solar facility is not very significant. Also, because of the 21° latitude, there is less annual variation in daily insolation than in most areas of the country.

The operations at Pioneer Mill produce a by-product biomass fuel called bagasse, which provides about 76 percent of the annual energy input to the steam produced. The remainder of the energy is supplied by No. 6 oil. Bagasse can be stored for a few days, and can therefore be used in place of thermal storage for the solar facility, which would be designed to displace the maximum possible oil consumption at Pioneer Mill. The solar cogeneration facility has the potential of utilizing a very high percentage of the energy derived from the sun.

A demonstration project would increase public awareness. Maui is visited by approximately 1.4 million people annually. Thus, a solar cogeneration facility at Pioneer Mill would expose a large number of people to solar central receiver systems who would not otherwise visit a demonstration plant.

2.3 SITE LOCATION

As shown in Figure 2-1, Pioneer Mill Company is located on the west coast of Maui in the Hawaiian Islands. It is adjacent to the town of Lahaina at coordinates 20.9° north latitude and 156.7° west longitude.

2.4 SITE GEOGRAPHY

Maui is the second largest island in the State of Hawaii. It is 77 km (48 mi) long and 42 km (26 mi) wide, and its total land area is 1,886 km^2 (728 mi^2). The island was formed by two volcanoes that are now connected by the isthmus of central Maui. East Maui is dominated by the 3,056 m (10,025 ft) Haleakala volcano, which has been dormant since 1790. West Maui is a deeply dissected, extinct volcano that rises to 1,765 m (5,788 ft) at Puu Kukui. Kahului, the major city on the island, is located at the northern end of the isthmus and has a commercial airport and a deep-water harbor. The population of Maui is approximately 63,000.

Pioneer Mill is located adjacent to the town of Lahaina on the west coast of west Maui. The town has been designated a national historical landmark because it was a major whaling port in the 19th century. The current population is approximately 6,000. The Lahaina-Kaanapali area is a well-known tourist resort area.

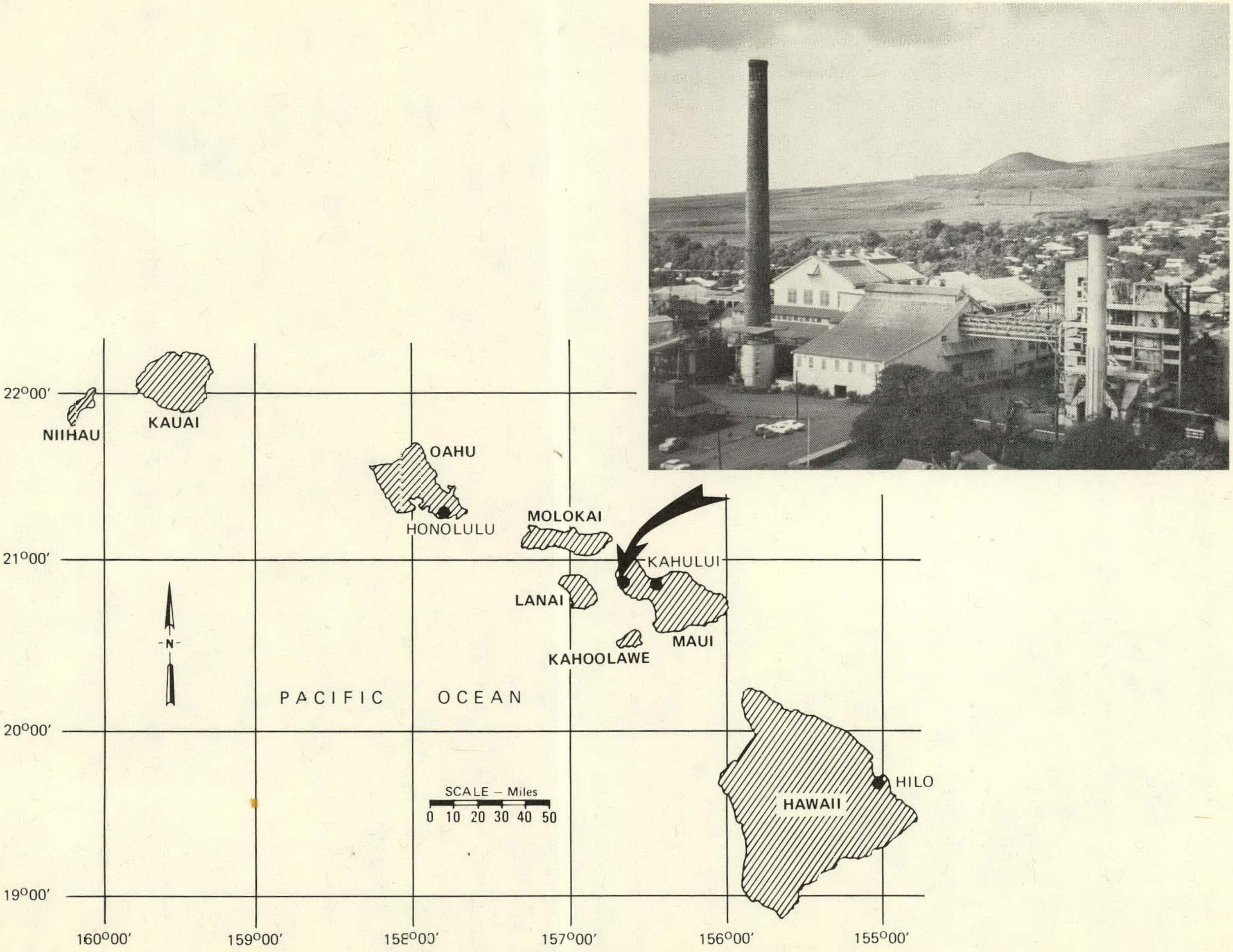


Figure 2-1 LOCATION OF PIONEER MILL

The area has a general west-facing slope, which ranges from gradual near the coast to steep ridges and stream valleys in the foothills. The summit of Puu Kukui is located 10 km (6 mi) east of Pioneer Mill. Because the mountain blocks the view of the sun early in the morning, the actual horizon for determining sunrise is about 10° above the true horizon.

The primary use of the alluvial plain is sugarcane agriculture. Pioneer Mill cultivates a total of 35.5 x 10^6 m^2 (8,776 acres) of owned or leased land in this area. The cane fields extend 28 km (17.5 mi) along the coast, with an average width of 2.5 km (1.5 mi) and up to 4 km (2.5 mi) up the slopes. The elevation of the fields ranges from 3 m (10 ft) above mean sea level to approximately 585 m (1,925 ft).

Access to Pioneer Mill is via the Honoapiilani Highway, the main coastal road in west Maui.

A new commuter airport is proposed for construction by 1984 near the coast highway about 6.5 km (4 mi) south of Pioneer Mill. Restrictions of flight paths over the town of Lahaina will cause most air traffic to remain over the water rather than over the area of the proposed solar facility.

The mill yard is bounded on the north by Kahoma Stream, on the east by a residential housing area, on the south by sugarcane fields, and on the west by a commercial area along the coast highway.

The Army Corps of Engineers is planning a flood control project for Kahoma Stream to prevent occasional flooding of the residential area.

A catch basin will be built upstream of the mill, and a new channel will direct the stream to the sea. Construction is expected to begin in 1982.

The water supply to the mill comes from wells. The large amount of rainfall on the upper slopes of the mountains is absorbed in the porous soil and flows underground. A series of pumps and tunnels convey water to the mill and supply the irrigation pumps. The site is quite dry.

The geology of the area is volcanic. The soil in the alluvial plains is well drained and contains some coral layers. On the steeper slopes, a thin soil covering is over hard basaltic rock. The island is designated as Seismic Zone 2 in accordance with the Uniform Building Code.

2.5 SITE CLIMATE

The general climatic pattern at the site is dominated by the trade winds that blow consistently from the northeast. Because of its location relative to the West Maui Mountains, the Lahaina area is classified as a leeward lowland (Ref. 2-1). These areas are typically sunny and dry and have relatively light winds. The only exception to this pattern is caused by major storm systems that cross the islands from the west between October and March. These storms are usually of several days' duration and characterized by high winds and heavy rainfall.

The 4-year average wind speed measured at Pioneer Mill is 1.6 m/s (3.5 mph). The maximum recorded wind at the mill from 1964 to 1968 was 15 m/s (33 mph). There are reports of rare conditions where winds reach 40 m/s (90 mph). The direction of the wind at the mill is generally upslope during the day and downslope at night.

The site has a mild tropical climate. The average annual temperature is 24C (75F), with extremes from long-term data at the Kahului Airport of 35.5C (96F) and 9C (48F). Because of the tropical latitude, the annual temperature variation is relatively small. Typical relative humidity ranges from 58 percent in the afternoon to 82 percent at night.

The Hawaiian Islands are characterized by extreme variation in precipitation. The top of the West Maui Mountains receives more than 7.6 m (300 in.) annually, but the leeward lowlands are quite dry. Long-term data at Lahaina show an average of 34.5 cm (13.6 in.). Most of this occurs during the winter storms, and what little occurs in the summer is generally at night. Typical annual variation in environmental data is shown in Table 2-1.

The peaks and windward slopes of the mountains normally have a dense cloud cover, and completely cloudless days are rare. During most of the year, the leeward lowlands have only scattered clouds.

No direct insolation data were available for the Lahaina area at the initiation of this study. A solar model was developed and calibrated to several sets of total insolation data from Lahaina and the direct insolation data available from the University of Hawaii at Manoa (near Honolulu). This solar model predicts an average of 7.4 kWh/m^2-day of direct insolation at the site. This model is described in Appendix B.

Table 2-1

SITE ENVIRONMENTAL DATA

Month	Precipitation, in.			Temperature, F			Wind Speed, mph[a]	
	Normal[b]	Extremes[b]		Normal[c]	Extremes[c]		Mean	Maximum
		High	Low		High	Low		
January	2.79	13.66	0.35	71.7	84	48	4.7	20
February	2.09	8.31	0.12	71.6	87	50	4.2	24
March	1.93	8.31	0.12	72.2	87	55	3.8	16
April	1.05	2.93	0.08	73.8	88	57	3.6	18
May	0.35	2.66	0.00	75.4	91	57	3.1	10
June	0.06	2.50	0.00	77.1	92	60	3.0	10
July	0.11	1.13	0.02	78.2	93	58	2.9	10
August	0.42	1.33	0.02	78.8	94	61	2.8	10
September	0.29	1.17	0.02	78.4	95	61	2.6	10
October	1.00	3.94	0.03	77.3	96	58	2.9	17
November	1.21	9.27	0.24	75.3	92	55	3.4	20
December	2.29	9.46	0.14	72.6	89	53	4.4	33
Annual	13.59	-	-	75.2	96	48	3.5	33

(a) Pioneer Mill Pump "E", hourly data, Sept. 1964 to Sept. 1968.
(b) Lahaina, Maui, 1931 to 1960.
(c) Kahului Airport, Maui, 1941 to 1975.

A site solar data monitoring program was established in October 1980. This was considered essential to the study because of the lack of site-specific direct insolation data. This program is sponsored by Amfac, with the cooperation of Dr. Paul Ekern of the University of Hawaii. Both analog traces and hourly integrated values are being gathered. Typical data collected to date are presented in Appendix C.

2.6 EXISTING PLANT DESCRIPTION

Pioneer Mill Company, Ltd., operates a sugarcane plantation and raw sugar factory. The factory processes sugarcane as it is harvested and produces molasses and raw crystalline sugar, which is shipped to California for refining and sales. A by-product of this operation is bagasse, the cellulose residue of the sugarcane. The bagasse is burned as a fuel.

The factory consumes intermediate-pressure steam for motive power, low-pressure steam for process heating, and electricity for motors and controls. The major electrical demand on the plantation is for irrigation pumping. The boilers consume bagasse and No. 6 oil to produce high-pressure steam that is supplied to the main turbine generator. Two controlled extraction points supply steam for the factory. Excess electric power is supplied to the Maui Electric Company grid through the mill substation.

2.6.1 Boiler Equipment

Pioneer Mill operates two Combustion Engineering boilers (Type VU-40S), which were installed in 1966. The boilers are in excellent condition and have an expected remaining useful life of 25 years. They are designed for dual-fuel operation with bagasse and No. 6 oil. Bagasse is fired as it is delivered from the mill; its moisture content is 48 percent and its higher heating value is approximately 9,300 kJ/kg (3,980 Btu/lb).

Each boiler is rated for a maximum steaming capacity of 65,800 kg/hr (145,000 lb/hr) on oil or dual fuel. The maximum steam capacity with bagasse only is approximately 45,400 kg/hr (100,000 lb/hr). The rated steam conditions at the superheater outlet are 5.96 MPa (850 psig) and 404C (760F). Minimum steaming rates are 18,100 kg/hr (40,000 lb/hr) with bagasse and 9,050 kg/hr (20,000 lb/hr) with oil. The efficiency of the boilers is about 70 percent with bagasse and 89 percent with oil.

Each boiler is equipped with an economizer, fly ash arrestor, Ljungstrom rotary air preheater, and an attemperator on the superheater outlet. Makeup water is supplied to a common deaerator, and there is one common high-pressure feedwater heater. All auxiliaries are electric-motor-driven, except for one standby boiler feed pump.

The boilers feed steam into a common main steam header. The boilers are controlled from one single-element, steam-header-pressure master controller with a three-mode control. The master signal goes to a dynamic balancing device, which sends to both boiler controls a signal that compensates for any difference in firing rate. Each boiler control system has a preferential fuel feature that will automatically feed bagasse up to an operator-set capacity, then feed fuel oil to maintain header pressure. This is an Amfac-designed system that can automatically control bagasse or dual-fuel firing without exceeding EPA smoke opacity limits.

Fuel oil is delivered to the site by Pioneer Mill's 18 m^3 (113 bbl) tank truck over a 40 km (25 mi) route from the Union Oil Company storage depot. Fuel is purchased as required without a long-term contract. The oil storage capacity is 290 m^3 (1,810 bbl) for No. 6 oil and 45 m^3 (286 bbl) for No. 2 oil, which is used as igniter fuel.

Bagasse is dewatered in the factory, pneumatically conveyed to the boiler conveyors, and introduced by mechanical means into the boiler. There, 95 percent is burned in suspension; the remaining material falls on a traveling grate and is consumed, except for about 1 percent ash.

To accommodate rapid load changes, excess bagasse is maintained on the boiler conveyors. Bagasse beyond boiler demand is diverted to the bagasse house for storage. An operator with a front-end loader reclaims the bagasse and places it on the the reclaim conveyor. The bagasse house is located adjacent to the boilers and has a capacity without manual compaction of 4,400 m^3 (156,000 ft^3). This is equivalent to 35,000 kg (390 tons) at a density of 80 kg/m^3 (5 lb/ft^3), although gravity compaction would increase this bulk density. The bagasse house is 37.2 m by 22 m (122 ft by 72 ft) and the supply conveyor is 10.8 m (35.5 ft) above the floor.

2.6.2 Turbine Generator Equipment

Pioneer Mill has three turbine generators. The main unit is a General Electric 3,600 rpm, double-automatic-extracting/condensing turbine generator rated at 9,375 kVA. The design steam inlet conditions are

5.96 MPa (850 psig) and 399C (750F). It was installed in 1966 and completely overhauled in 1980 after it had suffered damage. It has a remaining service life expectancy of 25 years.

The high-pressure extraction is controlled at 1.82 MPa (250 psig) and the steam is attemperated to 260C (500F). The high-pressure extraction steam supplies the high-pressure feedwater heater and the mechanical drive turbines in the factory. The low-pressure extraction is controlled at 205 kPa (15 psig) and is used at the extraction temperature of 135C (275F). The low-pressure extraction steam supplies the deaerator and the remainder of the factory steam requirements not satisfied by the exhaust of the mechanical drive turbines.

The main condenser is rated to provide 7.5 kPa (1.08 psia) back pressure for the turbine at 37,000 kg/hr (81,000 lb/hr) exhaust flow with 24C (75F) cooling water. The maximum turbine exhaust flow is limited to 29,000 kg/hr (64,000 lb/hr). The cooling water is pumped from an irrigation tunnel to the condenser and is returned to the irrigation system. Condenser vacuum is maintained with a two-stage steam ejector.

The two other turbine generators are old, and though serviceable, are not operated unless necessary. They are both supplied by the 1.83 MPa (250 psig) steam header. One is an Allis-Chalmers 3,750 kVA turbine generator with a single automatic extraction at 205 kPa (15 psig). The other is a General Electric 3,750 kVA, straight-condensing turbine generator.

2.6.3 Process Description

A schematic diagram of the existing facility is shown in Figure 2-2.

Sugarcane Production. Sugarcane is a 2-year crop in the Hawaiian Islands. The field planting times are staggered so that half of the field acreage, or about 17.8 km^2 (4,400 acres), is harvested each year. Irrigation is stopped several weeks before the harvest of each field to dry out the crop. The fields are burned under controlled conditions to minimize handling weight just prior to harvest. Harvesting is carried out with a rake-equipped dozer, and a mobile crane loads the sugarcane into large utility trailers which are hauled to the mill for processing. From November to February, the fields are typically too wet for harvesting.

Cane Cleaning. After the cane has been unloaded from the trucks, it is transferred to a flotation bath which removes some soil and heavy material such as rocks. The cane is then washed by a series of spray jets which separate small pieces of cane and leafy trash and the remainder of the soil from the cane stalks. Wash water is recycled from a hydroseparator, is sent to the settling basins, and eventually ends up in the irrigation system.

Sugar Extraction. Next, the cleaned cane is processed through a set of rotary knives and two fiberizers in series to open the fibrous cells of the cane. The crushed cane then enters the diffuser, where it is washed with a counter-current stream of water. The diffuser extracts about 98 percent of the sugar and yields watery bagasse and

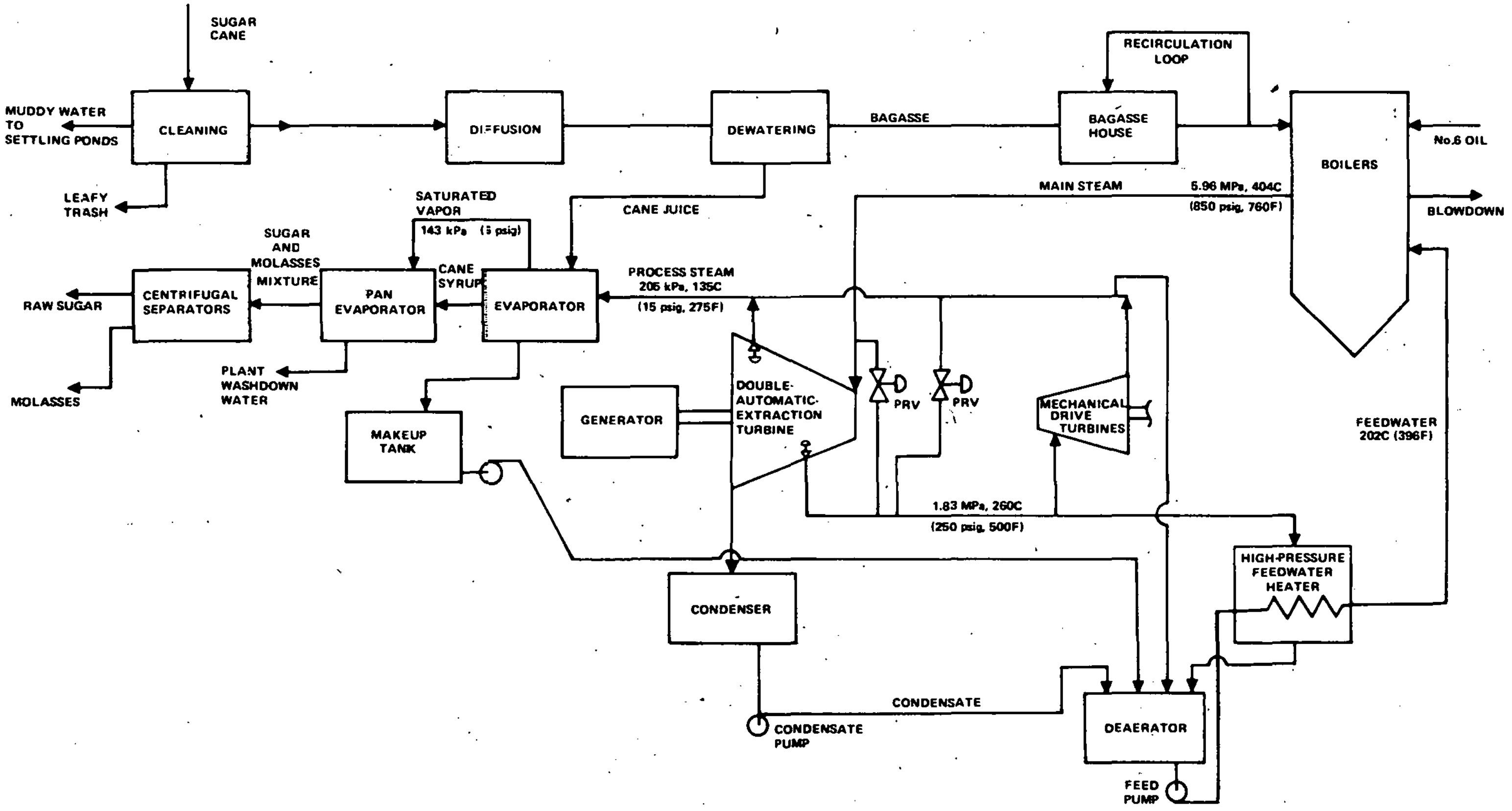


Figure 2-2 PROCESS SCHEMATIC DIAGRAM FOR THE EXISTING PIONEER MILL

cane juice. The bagasse is dewatered to 48 percent moisture (by weight) in screw presses and sent by pneumatic conveyors to the boilers. Lime is added to the cane juice, heated to 100C (212F), and introduced into a clarifier.

Evaporation. The clarified cane juice is then fed into a five-effect evaporator, which reduces the water content to produce cane syrup. The syrup is moved to vacuum pan evaporators with mechanical agitators.

Separation. The resulting mixture of molasses and sugar is separated in centrifuges, and the raw sugar is finished by further heating in batch crystallizers.

2.6.4 Factory Equipment

In a solar retrofit, the following steam-consuming factory components are of principal interest: the mechanical-drive turbines, the evaporators, and the process heaters. There are three drive turbines in the factory, two rated at about 750 kW (1,000 hp) on the fiberizers and one 950 kWe (1,250 hp) drive on one of the bagasse dewatering screw presses. A fourth mechanical-drive turbine is connected to the backup boiler feed pump. These turbines are supplied with steam from the 1.83 MPa (250 psig) header and exhaust into the 205 kPa (15 psig) header. Steam at 1.83 MPa (250 psig) is also supplied through a pressure-reducing valve (PRV) to the makeup evaporator. Steam from the 205 kPa (15 psig) header is supplied to the first stage of the multieffect evaporator and to the juice heater. A lower pressure vapor header at 143 kPa (6 psig) supplies steam to the pan evaporators, to the second stage of the multieffect evaporator, and to other process heaters.

2.7 EXISTING PLANT PERFORMANCE

The operating goal of Pioneer Mill is to maximize sugar output from the fields under cultivation as economically as possible. The primary variable in the annual output is the agricultural operation, since the factory consistently extracts 98 percent of the sugar from the cane processed.

The factory consumes the available bagasse in the boilers and supplements this with fuel oil to meet the steam and electric demands. Steam demands occur only during factory operation, but electrical demands due to irrigation requirements and Maui Electric Company needs continue throughout the year. Typical annual operating data are shown in Table 2-2.

2.7.1 Factory Operating Schedule

The factory is expected to operate 40 weeks during the year to coincide with the sugarcane harvest. During this harvest season, the factory operates on a 24 hr/day, 5 day/wk schedule. The nominal operating rate, based on cleaned cane, is 109,000 kg/hr (120 tons/hr), but outages and interruptions reduce this to an average of 92,500 kg/hr (102 tons/hr).

Table 2-2

PIONEER MILL ANNUAL PERFORMANCE DATA

Year	Area Harvested, acres	Net Cane, tons	Start Grinding Season	Stop Grinding Season	Grinding Time, hr	Raw Sugar, tons	Molasses, tons	Bagasse Produced, tons	Fuel Oil Consumed, bbl	Electric Energy, MWh			
										Generated	Factory Consumption	Other Consumption	Sold to Maui Electric
1970	4,695	428,144	Feb 23	Nov 25	4,290	57,520	16,841	133,215	54,053	52,969	20,328	27,425	5,216
1971	4,636	427,899	Feb 23	Nov 18	4,115	56,868	16,295	134,213	65,901	57,316	20,783	31,752	4,782
1972	4,676	412,216	Feb 14	Nov 17	4,026	55,377	15,538	131,582	92,419	60,322	21,119	33,437	5,767
1973	4,760	396,549	Feb 12	Nov 02	3,908	53,462	16,105	124,971	98,378	60,422	20,069	35,753	4,600
1974	4,262	368,626	Feb 14	Nov 25	3,740	49,451	15,307	114,532	65,319	50,133	17,373	29,304	3,456
1975	4,849	402,870	Feb 17	Oct 31	3,880	53,719	16,425	123,445	73,693	58,927	19,080	35,775	4,072
1976	4,494	362,216	Feb 18	Oct 29	3,553	48,425	14,213	109,721	71,705	56,635	17,259	34,498	4,878
1977	4,516	377,775	Feb 03	Nov 23	3,700	49,772	17,400	114,850	71,307	56,699	17,419	34,801	4,479
1978	4,445	372,667	Feb 13	Dec 02	3,637	46,173	17,260	114,913	70,403	54,123	16,156	32,554	5,413
1979	4,402	431,181	Mar 08	Dec 30	4,345	50,775	16,879	138,980	46,325	45,774	17,862	23,083	4,829
10-Year Average	4,574	398,010	Feb 17	Nov 20	3,919	52,155	16,226	124,042	70,950	55,332	18,745	31,838	4,750

The steam demands during factory operation are approximately 32,200 kg/hr (71,000 lb/hr) from the 1.82 MPa (250 psig) header and an additional 16,800 kg/hr (37,000 lb/hr) from the 205 kPa (15 psig) header. Electrical demands for factory equipment during this condition is 2,300 kWe.

On weekends, the factory production is stopped and the equipment undergoes maintenance, if necessary. There are no steam demands on weekends, but the electrical load continues at the 250 kWe level (the weekend factory house load).

2.7.2 Boiler and Turbine Operating Cycle

The boilers and turbine generator are operated to meet the needs of the plantation and supply electric power to Maui Electric on demand. During factory operation, each boiler is operated at approximately 40,800 kg/hr (90,000 lb/hr). The operating conditions of the turbine are shown in Figure 2-3. The conditions shown are generator-limited; the maximum electrical output is 8,400 kWe with a 0.9 power factor. If a reduced electrical output is required, the factory steam demands remain constant while the other steam flows are reduced in proportion to the reduction in main steam flow.

During weekend operation, the factory steam demand is eliminated and the turbine is operated to match electrical demand. The maximum condition in this mode is shown in Figure 2-4. The output is limited by the low-pressure turbine section flow limit of 29,000 kg/hr (64,000 lb/hr). The turbine is typically operated between 3 MWe and 6 MWe with only one boiler operating.

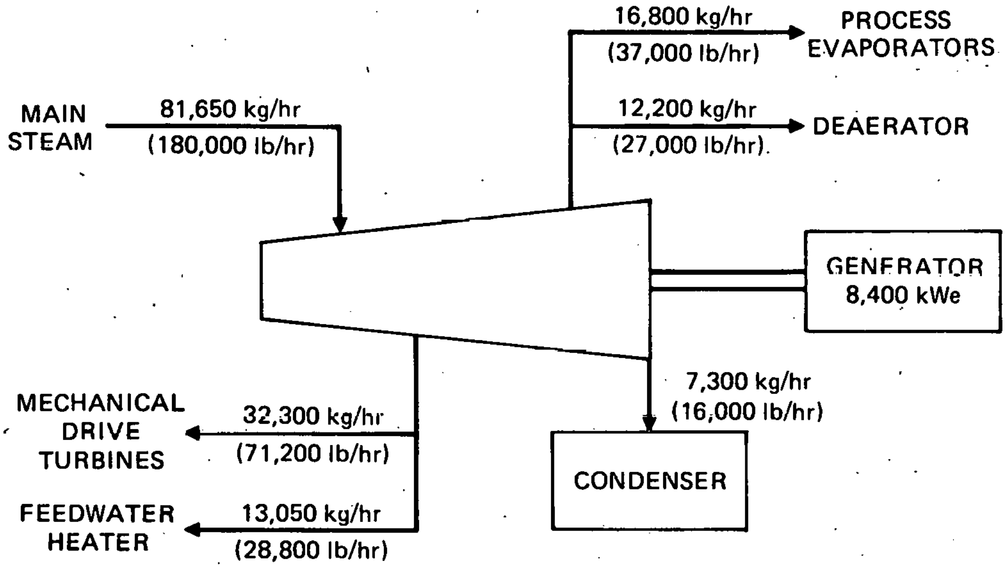


Figure 2-3 TYPICAL MAXIMUM TURBINE CONDITIONS FOR FACTORY OPERATION

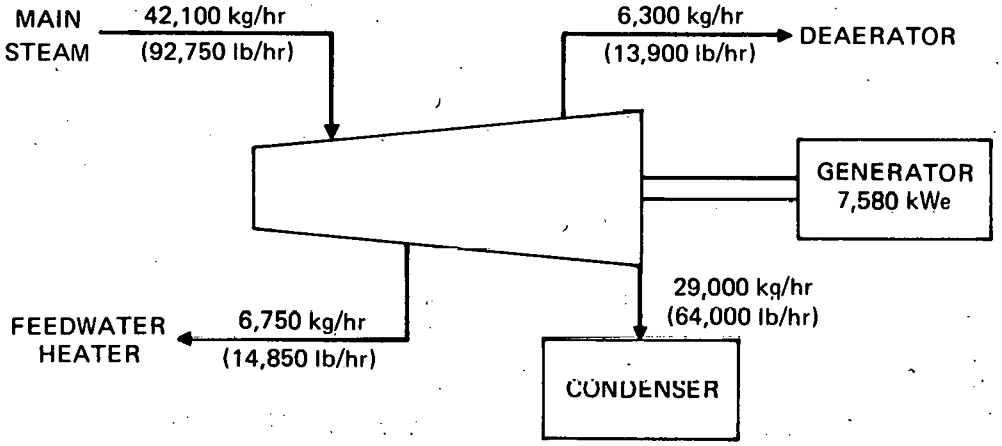


Figure 2-4 TYPICAL MAXIMUM TURBINE CONDITIONS FOR WEEKEND OR OFF-SEASON OPERATION

In the off-season, turbine operation is similar to turbine operation during weekends. The boilers are alternately taken out of service for scheduled maintenance. The main turbine has a maintenance schedule that requires a 1-week inspection each year and a 4-week outage every fourth year. Pioneer Mill attempts to draw enough power from Maui Electric during this turbine outage to meet irrigation requirements, but usually one of the older turbine generators must be brought into operation.

There is a monthly variation in energy consumption which is dependent on irrigation requirements and Maui Electric demand. This pattern is illustrated in Table 2-3. Oil provides about 24 percent of the total energy input, measured as energy supplied to main steam. The remainder is supplied by bagasse. The monthly variation of oil consumption is important to the sizing of a solar retrofit and is discussed further in Subsection 3.4.

2.7.3 Operation and Maintenance Experience

The seasonal nature of operations at Pioneer Mill is a significant advantage in the scheduling of outages. Therefore, unscheduled outages are kept to a minimum. One notable exception was a turbine incident that resulted in significant turbine outage. Table 2-4 shows the scheduled, unscheduled, and economy outages for 1980.

The actual O&M costs for 1979 and 1980 were $590,000 and $887,000, respectively. During 1980, the unusual turbine repairs account for the significant increase over 1979 and are considered nonrecurring. The

Table 2-3

PIONEER MILL MONTHLY PERFORMANCE DATA
(1975 to 1980 Average)

Month	Bagasse Production, tons/wk	Fuel Oil Consumption, bbl/wk	Total Energy Consumption as Main Steam, 10^9 Btu/wk	Oil Percent of Total Energy as Main Steam	Rainfall, in.
Jan	0	934	4.5	100	3.2
Feb	3,101(a)	1,127	12.9	42	3.8
Mar	2,237	1,393	19.2	35	1.5
Apr	2,603	1,228	20.4	29	2.0
May	3,156	1,146	23.1	24	0.4
June	3,476	1,091	24.6	21	0.1
July	3,493	981	24.2	20	0.1
Aug	3,800	1,054	26.3	19	0.1
Sept	3,245	958	22.7	20	0.1
Oct	3,404	1,462	26.0	27	0.4
Nov	2,387(b)	1,226	14.8	40	1.1
Dec	0	1,535	7.4	100	1.5
Year Total			992.9		14.3
Year Average	3,183(c)	1,177		24	

(a) After harvest season begins.
(b) Before harvest season ends.
(c) During harvest season.

Table 2-4

MAJOR EQUIPMENT OUTAGES FOR 1980
(Hours)

	Boiler #1		Boiler #2		Turbine #1	
Planned outages	Off-season overhaul	1,114.0	Off-season overhaul	1313.6	Clean condenser	20.4
	High-voltage switchgear inspection	11.2	Off-season overhaul	934.5	Off-season overhaul	910.5
	Off-season overhaul	939.7		2,249.1		930.9
		2,064.9				
Forced outages	Pressure-reducing valve failure	16.3	Relay failure in the burner control	22.9	Turbine damage	1,493.3
	Relay failure in the burner control	6.0		22.9	Loss of boilers	5.5
	ID fan motor failure	65.0			Rupture disk leak	1.5
	Steam flow transmitter failure	0.5			Faulty trip device	0.5
		87.8				1,500.6
Economy outage		645.2		738.4		175.5
Total		2,797.9		3,009.4		2,607.0

O&M cost is expected to escalate in line with the general inflation rate for the remaining 25-year life of the existing facility, with a levelized annual cost of $1,370,000.

2.8 PROJECT ORGANIZATION

Bechtel Group, Inc., is the prime contractor in this study and heads the team composed of Amfac Sugar Company, Foster Wheeler Development Corporation, and Northrup, Inc. An organization chart showing the key individuals is presented in Figure 2-5.

As prime contractor, Bechtel is responsible for the overall project management and coordination, the technical direction of the project team, the integration of the output of the team into the technical reports, and the design, analysis, and costing of all those parts of the solar cogeneration facility not within the scope of the subcontractors.

Amfac Sugar is the owner of Pioneer Mill Company, Ltd., and is the end user of this study. Amfac provided data on the existing facility, parameters for economic analyses, a review of the technical products, and interface information with Maui Electric Company. Okahara, Shigioka & Associates assisted Amfac in developing performance data for the facility and in preparing environmental and licensing inputs.

Northrup furnished the design and analysis of the collector field and supplied information on the design and cost of second-generation heliostats. Foster Wheeler provided the design and analysis of the solar receiver and supplied cost figures for this receiver.

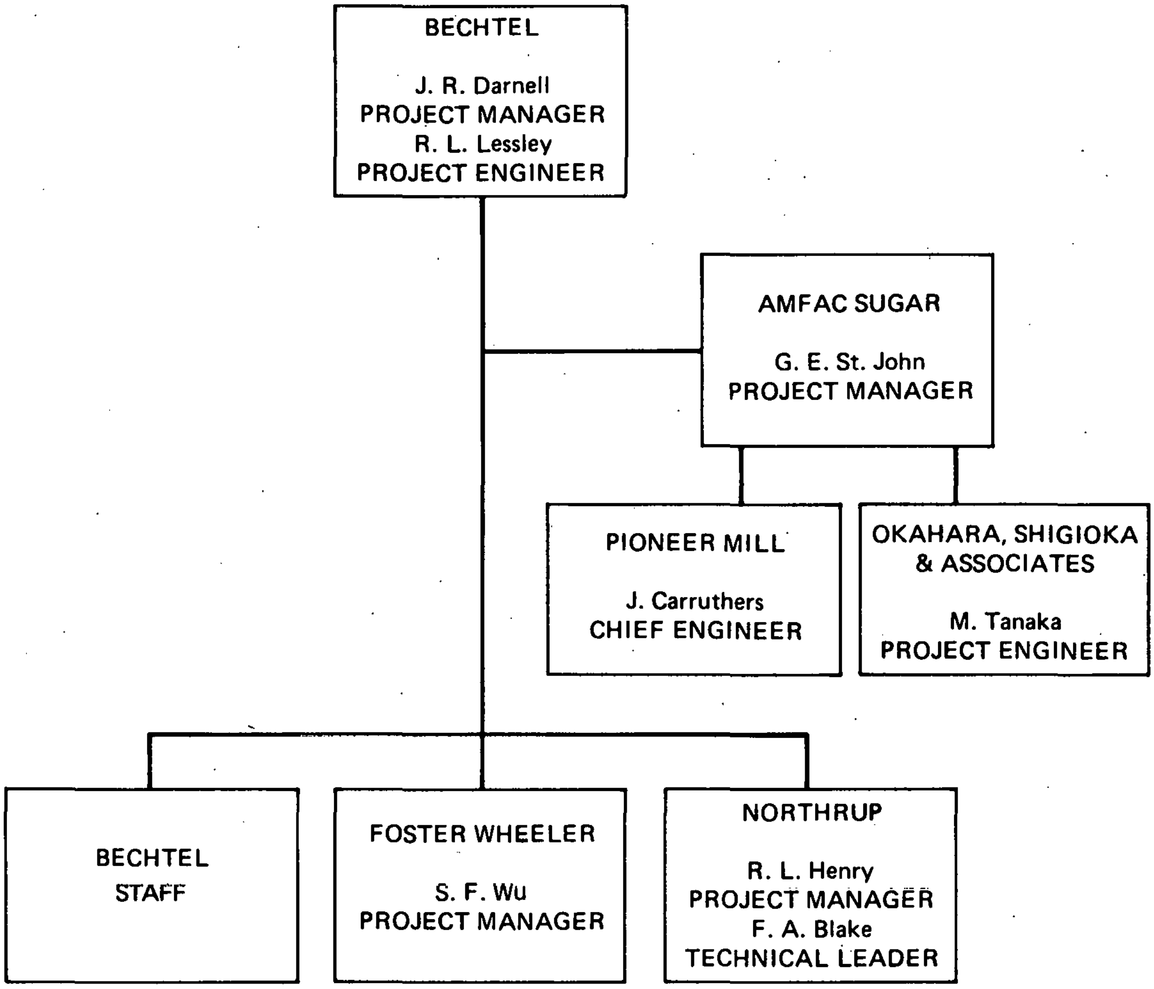


Figure 2-5 PROJECT ORGANIZATION CHART

Section 3

SELECTION OF THE PREFERRED SYSTEM

3.1 INTRODUCTION

The general guidelines for the conceptual design of the Solar Cogeneration Facility at Pioneer Mill call for the following:

- The use of the existing turbine and plant equipment
- The displacement of as much oil as feasible
- Minimum interference with plant operations.

This section covers Task 2 — the selection of a site-specific configuration. The principal subtasks of Task 2 are as follows:

- Selection of a working fluid
- Selection of a receiver concept
- Selection of one of the two alternative heliostat field sites
- Determination of the appropriate size of the solar facility
- Determination of the role of thermal storage.

Of the above substasks, the two key ones are the determination of solar facility size and the selection of the heliostat field site. These two questions were studied concurrently and independently. Other questions, such as control system design and minimizing of the impact on existing plant operation, are reserved for the Task 3 conceptual design, along with a more complete engineering design for all parts of the solar facility.

To select the plant size, the Pioneer Mill harvesting records were studied in order to determine the variation and timing of bagasse production. Past records on the timing and amounts of oil consumption were also evaluated. The various operating modes of the mill during the harvest season and during the annual period when harvesting operations are suspended were identified. Finally, estimates of the annual energy production of a solar facility by month of the year made it possible to determine the maximum solar facility size that does not exceed the capacity of existing mill plant equipment. The sizing analysis is discussed in Subsection 3.4.

The selection of the heliostat field site was based on preconceptual plant designs for each candidate site, with greatest emphasis being placed on design aspects that are different for the two sites. Plant and capital costs, annual charges, energy production, and revenues were estimated for each site, and a comparison was made based on dollars per million Btu at the required turbine steam inlet conditions. The selection of the preferred site is discussed in Subsection 3.5.

3.2 SYSTEM CONFIGURATION

The simplicity of the required system configuration is one of the most attractive features of the solar facility for Pioneer Mill. This simplicity is largely due to the fact that (1) Pioneer Mill is already a functioning cogeneration plant using bagasse and fuel oil to generate electricity while supplying the sugar mill with extraction steam, and (2) no thermal energy is stored. To displace oil, the solar facility must simply deliver 5.96 MPa

(850 psig), 399C (750F) steam to the existing turbine. The solar facility configuration required to accomplish this is shown in Figure 3-1. It consists of:

- A heliostat field
- A water-steam solar receiver
- Steam and condensate piping connecting the mill and the receiver
- A steam mixing station at the mill
- A condensate transfer pump station at the mill
- A holding tank and receiver feed pump station at the base of the receiver tower

Bagasse, which is normally consumed as it is produced, would be stored during periods of high solar input and consumed during periods of low solar input. Although the use of thermal storage would permit the displacement of slightly more fuel oil, as discussed in Subsection 3.4, it is unlikely that the extra oil displaced would justify the expense and risk associated with thermal storage.

In selecting the interfaces with the existing facility, the principal criteria were minimum impact on existing plant operations and maximum operational flexibility. A solar superheater was found to be preferable to existing boilers in superheating solar-generated saturated steam. There are two reasons for this: the increased operational complexity of operating such a long (over a half mile) saturated steam line to the boilers, and the need to modify the existing boilers. It was felt that the existing deaerator for the receiver supply source would provide better water quality and more efficient operation of the system, using low-pressure extraction steam, than using either condensate from the

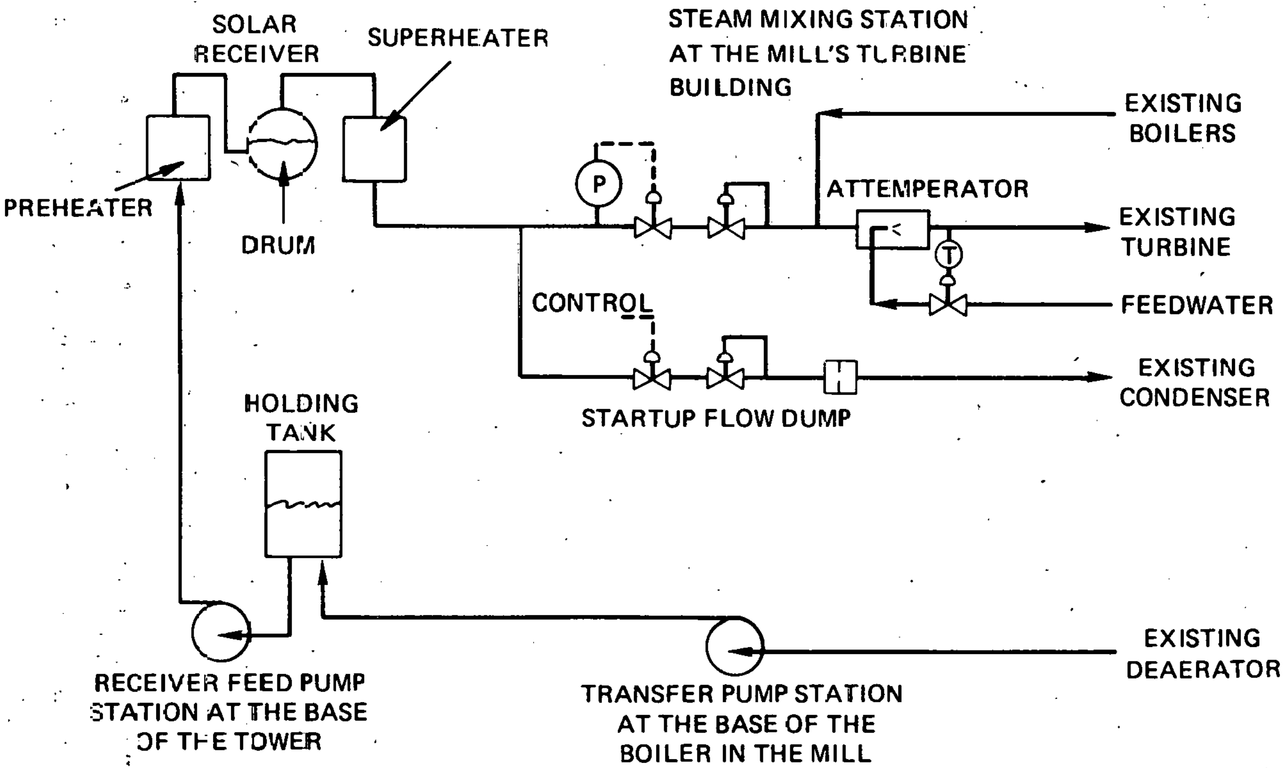


Figure 3-1 SOLAR FACILITY CONFIGURATION

hot well or boiler feedwater. The choice of a holding tank at the base of the receiver allows a low-pressure rating for the long condensate piping run from the deaerator to the tower.

3.3 TECHNOLOGY

The choice of water-steam as a working fluid and of the cavity receiver configuration keeps the solar facility simple and firmly based on existing technology.

Water-steam technology is well developed, and the operators of Pioneer Mill are conversant with it. In addition, this technology is available to support the operation of the solar facility by 1986.

By contrast, molten salt technology, while showing promise for applications where thermal storage is essential, is not yet field-proven for this type of application. The molten salt heat transfer loops currently in the process industry do not shut down and start daily, often contain no valves, and utilize reliable but very crude and inefficient pumps. These loops do not operate in the kind of environment existing in solar facilities that use molten salt. The demonstration of molten salt technology involving a suitably large molten salt loop that is thermally cycled daily to serve as a test bed for both components and operating procedures is not currently planned within the DOE solar program. This demonstration could be carried out without solar heat input at lower expense than would be necessary for a solar demonstration project. Until equipment and procedures are proven by a large molten salt loop, molten salt solar facilities may experience higher operations and maintenance costs than otherwise necessary.

The personnel at Pioneer Mill are primarily engaged in running a sugar mill, and would like to minimize the amount of operator attention required to run the solar facility. The design therefore emphasizes simple and inherently self-regulating components, redundancy (where cost-effective), and diagnostic instrumentation for major components.

The desire for simple and inherently self-regulating components led to the selection of a conventional, natural-circulation, drum-type water-steam receiver. This type of receiver had been the choice in a number of previous solar receiver designs engineered by Foster Wheeler Development Corporation.

Natural circulation has a history of high reliability in fossil-fueled boilers, and a great deal of experience exists regarding the design, construction, and operation of this type of boiler at the pressure and temperature required for Pioneer Mill. Natural circulation eliminates both the capital and maintenance costs and the power consumption associated with a forced-circulation pump. The boiler circuitry of a natural-circulation receiver is inherently self-compensating for energy input variations with both time and location in the receiver. It is also relatively tolerant of impure feedwater because of its large tubes, large water inventory, and drum blowdown capability. Testing of natural-circulation water-steam solar receivers with 1 MWt and 5 MWt capacities has demonstrated their thermal and hydraulic stability and ease of control under steady-state and transient conditions.

A cavity receiver configuration was selected in preference to an exposed receiver configuration. This was based not on an economic tradeoff study, but on a number of qualitative considerations, such as:

- An external receiver can result in a lower tower height. This is not possible if the field layout is constricted by site topography, as is the case for one of the two alternatives discussed in Subsection 3.5
- An external receiver can be less costly and weigh less than a cavity receiver. However, the uncertainty of heat loss predictions for both configurations makes any tradeoff between capital cost and efficiency only approximate
- The design of a door to reduce overnight heat losses is much easier for the cavity. Excessive overnight cooldown is a special problem for this application because of the relatively long steam line to the turbine.

The final selection of the cavity receiver configuration was strongly influenced by the belief that it is the lower risk design with perhaps more flexibility to adapt to the overall requirements at Pioneer Mill. The resemblance to the configurations of a conventional boiler also inspired confidence.

3.4 SYSTEM SIZE

In the selection of solar system size, a number of factors had to be considered, such as the oil and bagasse energy consumption pattern, the operating limits of the existing boiler and turbine, the daily and annual variation in solar energy availability, and the potential impact of thermal energy storage. After the initial consideration of these factors, a set of criteria was developed as a framework for the determination of system size. These criteria are:

- The solar facility will maximize the displacement of oil consumption while permitting the solar equipment to be operated at the most economical capacity factor

- Increased bagasse storage capacity will be used to shift the bagasse consumption pattern to accommodate solar energy input. All bagasse displaced during the 5-day factory week will be consumed the following weekend

- All electric power generated in excess of Pioneer Mill demand will be exported to the Maui electric grid, where it will displace No. 2 oil consumption by Maui electric units

- At least one boiler will be operated at minimum load during solar system operation, and the boilers operating must be able to meet the entire steam demand in the event of a solar interruption

- No new turbine generator capacity will be installed with the solar facility, and the two older turbine generators will not be operated except on a standby basis.

The first step in determining system size was to ascertain the relevant equipment operating limits. These are listed in Table 3-1. A typical operating week was also established, and the bagasse production and oil consumption profiles were calculated for this typical week. These parameters are illustrated in Figure 3-2. Net factory output is the gross electric generation less the power plant auxiliary load and the factory equipment load. Net factory output is used for irrigation pumping and/or sold to Maui Electric.

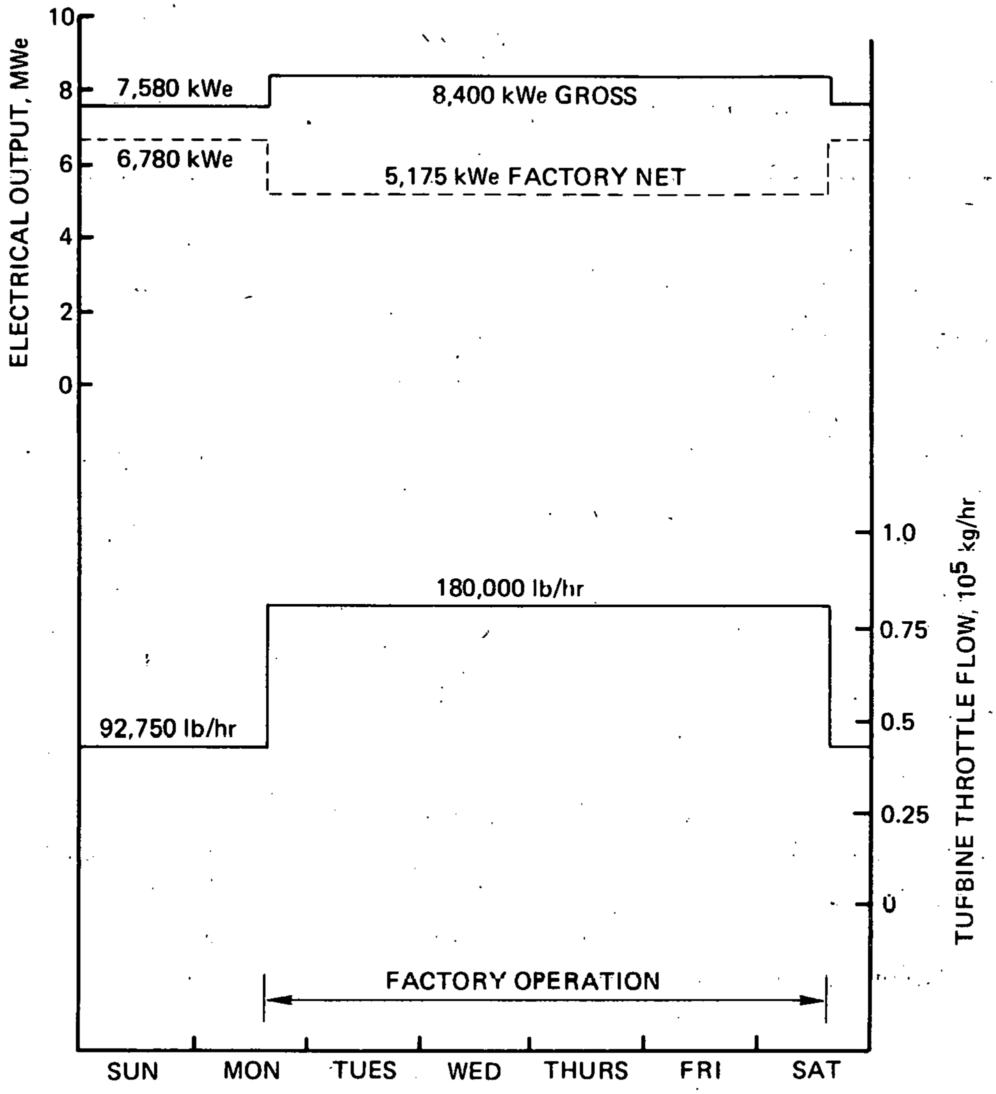
The STEAEC programs runs that are discussed in Subsection 3.5 were used to determine the solar steam supply characteristics

It was necessary to determine whether the weekday or the weekend operating condition controlled the solar system sizing. This was done by comparing

Table 3-1

OPERATIONAL LIMITS FOR SYSTEM SIZING STUDY

Item	Limit
Boiler steam capacity (each)	
Maximum	
Oil	65,800 kg/hr (145,000 lb/hr)
Bagasse	45,400 kg/hr (100,000 lg/hr)
Minimum	
Oil	9,100 kg/hr (20,000 lb/hr)
Bagasse	18,100 kg/hr (40,000 lb/hr)
Maximum generator output	8,400 kWe at 0.9 power factor
Turbine low-pressure section flow	
Maximum	29,000 kg/hr (64,000 lb/hr)
Minimum	1,680 kg/hr (3,700 lb/hr)
Condenser flow	
Maximum	36,700 kg/hr (81,000 lb/hr)



GROSS POWER PLANT OUTPUT	1,372 MWhe
NET FACTORY OUTPUT	946 MWhe
BAGASSE PRODUCTION AND CONSUMPTION	3.43×10^6 kg (3,700 tons)
OIL CONSUMPTION	540 m^3 (1,035 bbl)

Figure 3-2 TYPICAL MAXIMUM OPERATING WEEK FOR EXISTING FACILITY

the maximum turbine throttle flow with the minimum boiler flow for these two conditions. The difference is the maximum solar design point flow, and it depends on the fuel used in the boilers at minimum flow. Table 3-2 shows the results of this analysis. If the facility were designed for weekday operation, the weekly oil displacement would exceed the current oil consumption of 540 m^3 (1,035 bbl) (See Figure 3-2). Moreover, there would be a relatively low capacity factor for the solar equipment because of excess solar capability during weekend and off-season operation. Neither weekend case (oil or bagasse) would displace all the oil normally consumed; some oil would be required during solar operation on the weekend. This would allow the use of an oil-fired boiler at minimum flow as a backup for solar weekend operation, which would result in a larger solar system size than would be possible if bagasse firing at minimum boiler flow during weekend days were necessary. During the week, when the factory is operating, bagasse would be used as a backup for daytime solar operation.

Table 3-2

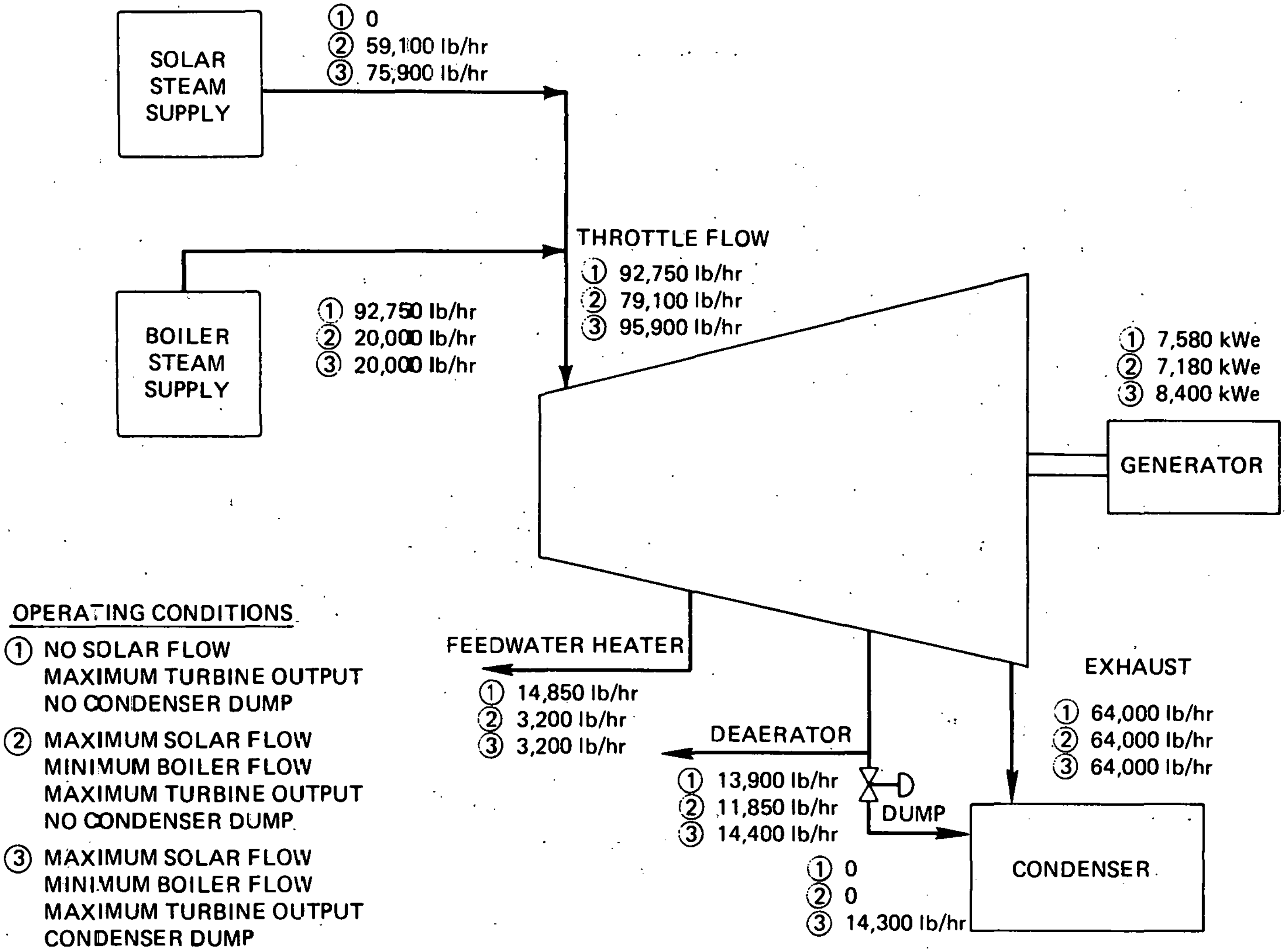
PRELIMINARY SOLAR DESIGN FLOW OPTIONS

Operation	Oil-Fired Boiler[a]		Bagasse-Fired Boiler[a]	
	Throttle Flow less Boiler Flow	Estimated Weekly Oil Displacement[b]	Throttle Flow less Boiler Flow	Estimated Weekly Oil Displacement[b]
Weekday	55,350 kg/hr (122,000 lb/hr)	847 m^3 (1,623 bbl)	39,500 kg/hr (87,100 lb/hr)	603 m^3 (1,159 bbl)
Weekend	26,800 kg/hr (59,100 lb/hr)	409 m^3 (786 bbl)	19,400 kg/hr (42,800 lb/hr)	296 m^3 (569 bbl)

(a) At minimum flow conditions.
(b) Clear weather and 100 percent availability are assumed.

The choice of a maximum solar steam capacity of 26,800 kg/hr (59,100 lb/hr) apparently satisfies all the criteria, but it displaces only about 75 percent of the oil consumption during a typical harvest week with clear weather and 100 percent availability. To determine if additional oil displacement is possible, the operating limits in Table 3-1 were reexamined. A relatively simple cycle modification was found to increase the oil displacement. Figure 3-3 shows the effect of adding a condenser dump line from the 205 kPa (15 psig) extraction line. Condition 2 in the figure shows the maximum case without the dump line. The throttle flow is governed by the flow limit in the low-pressure section of the turbine. The generator output is not at the maximum. To increase generator output and solar steam flow capacity, a dump line is added (Condition 3). The generator output is maximized when the dump flow reaches 6,500 kg/hr (14,300 lb/hr). This allows the solar portion of the throttle flow to increase from 26,800 kg/hr (59,100 lb/hr) to 34,000 kg/hr (75,900 lb/hr), an increase of 28 percent. The condenser can accept this added flow because it has a capacity greater than 35,000 kg/hr (78,300 lb/hr), the sum of the dump and exhaust flows.

This modification reduces the efficiency of the steam cycle, increasing the steam rate from 3.73 kg/kWe to 4.10 kg/kWe. However, the use of the condenser dump line is needed only during the day on weekends and the off-season (when the factory steam demand is zero), about 14 percent of the operational year. This percentage can be further reduced by allowing the turbine to follow the solar input during this time and modulating the condenser dump. An example of this type of operation is shown in Figure 3-4.



OPERATING CONDITIONS

① NO SOLAR FLOW
MAXIMUM TURBINE OUTPUT
NO CONDENSER DUMP

② MAXIMUM SOLAR FLOW
MINIMUM BOILER FLOW
MAXIMUM TURBINE OUTPUT
NO CONDENSER DUMP

③ MAXIMUM SOLAR FLOW
MINIMUM BOILER FLOW
MAXIMUM TURBINE OUTPUT
CONDENSER DUMP

Figure 3-3 WEEKEND OPERATION SIZING ANALYSIS

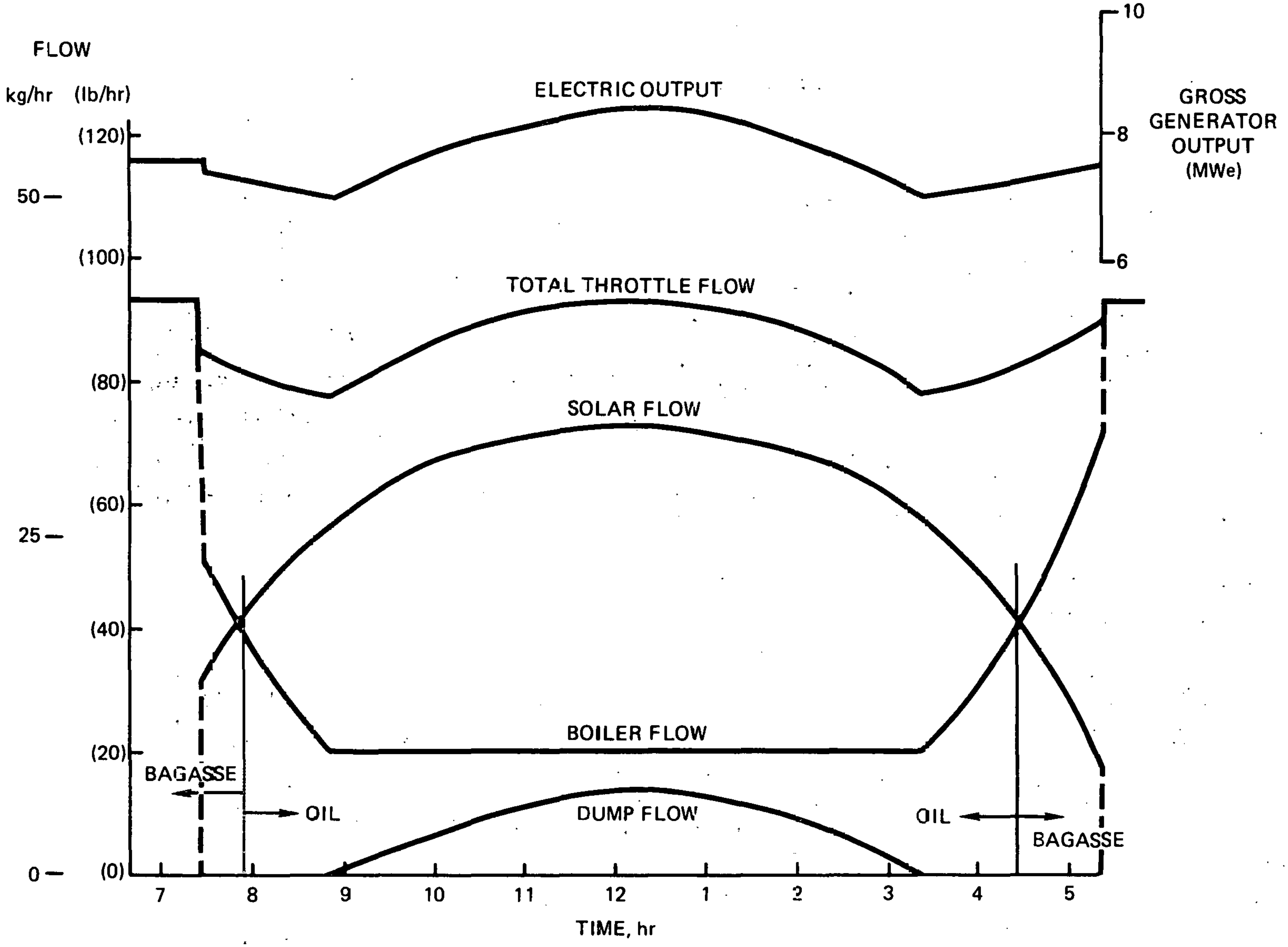


Figure 3-4 WEEKEND DAY OPERATING SCENARIO

The dump can also be operated to provide maximum generator output at any time. For example, with no solar flow and no factory steam demand, the required throttle flow for a generator output of 8,400 kWe is 47,800 kg/hr (105,400 lb/hr) with a dump flow of 3,950 kg/hr (8,700 lb/hr). This constrasts with Condition 1 in Figure 3-3, in which the dump line is not used.

Sizing the solar system for 34,400 kg/hr (75,900 lb/hr) is estimated to displace about 96 percent of the oil consumed in a typical week with clear sky and 100 percent availability. Average weather conditions and a 90 percent availability assumption for the solar facility reduce the average oil displacement to 73 percent. The maximum case (clear sky and 100 percent availability) must be used for sizing, however, to prevent the accumulation of excess bagasse during periods of good weather.

It is appropriate to examine the potential value of thermal energy storage for this system in light of the preceding discussion. Thermal storage could eliminate the maximum turbine flow limit on weekends from consideration by allowing a larger solar steam flow than can be accommodated by the turbine alone. However, during weekdays with factory operation, thermal storage would not be useful, since all the solar steam could be used as generated in the receiver. The resulting utilization factor of thermal storage would be about 40 percent. The benefit that could be achieved would be the displacement of the last 4 percent of the oil used during the typical week. In addition, the thermodynamic disadvantage of thermal storage on a superheated steam system would significantly reduce the turnaround efficiency of the storage system. For these three reasons, thermal storage is judged to offer little improvement to the displacement potential for Pioneer Mill, and it would not be cost-effective with such a low utilization factor. For the Pioneer Mill system, the weekly storage of bagasse offers the best combination of flexibility and cost-effectiveness.

The additional bagasse storage capacity that would be required for a solar system with a 34,400 kg/hr (75,900 lb/hr) peak capacity can be estimated from this analysis. For clear weather and maximum availability, the required additional capacity is approximately 567,000 kg (625 tons), and the average value needed is 455,000 to 480,000 kg (500 to 530 tons).

3.5 HELIOSTAT FIELD SITE SELECTION

3.5.1 Candidate Sites

The initial two sites studied were a southward-sloping hillside site nearly a mile from the mill on land that is too rocky for growing sugarcane, and a relatively level site about half a mile from the mill on land currently used to grow sugarcane. The hillside site was proposed as the preferred site because it occupies relatively inexpensive and presently unused land and involves the displacement of only a small amount of sugarcane production. Interest in the economic merits of the alternative site using cane land is also high. If the displacement of a required amount of cane land for the generation of steam with solar energy is economical, then solar energy may be applicable to many other plants in Hawaii and the continental U.S. which are surrounded by agricultural land. In an effort to minimize the displacement of cane land, dual use of the alternative heliostat site (by growing of cane or other crops between heliostat rows) was examined.

The locations of the two heliostat field sites, relative to the mill, are shown in Figure 3-5. The figure shows the two heliostat field layouts, and the routing of condensate and main steam piping. It also shows the location of the sugar mill, the mill yard, and the existing fueled boilers.

3.5.2 Preconceptual Design Features

Preconceptual designs were formulated for each of the candidate heilostat field sites. These designs provided the bases for capital cost estimates which, together with the annual performance estimates and dual-use crop studies, provided the bases for the heliostat field site selection.

Many of the features and criteria for the two preconceptual designs were identical, including:

- 8-inch, Schedule 80 main steam lines with 4-inch calcium silicate insulation
- 4-inch, Schedule 40 condensate lines with 2-inch calcium silicate insulation
- Spacing and design of pipe line supports
- Steam line drain designs
- Transfer and receiver feed pump station equipment cost (but slightly different pumping power requirements)
- Mixing station equipment cost
- Emergency power supply at the base of the tower (each with a Terry turbine and a generator driven by receiver steam)
- A steel tower with costs calculated from the Sandia National Laboratories, Livermore (SNLL) tower model (Ref. 3-1)
- Master control system design and cost
- Heliostat costs, except for the foundations

Features that were different for the two sites were:

- Heliostat field arrangements, tower heights, and tower foundations
- Receiver designs
- Heliostat foundation designs
- Piping run lengths
- Impact on agricultural operations

3.5.3 Preconceptual Design Descriptions

This discussion of the preconceptual designs covers the receiver designs, heliostat field layouts and performance, heliostat foundations, the piping and pumping systems, and the impact of each site on agricultural operations at Pioneer Mill.

Each design uses the cavity-type water-steam receiver discussed earlier. The adaptability of a single cavity to the southward-sloping hillside site is one factor that led to the selection of the cavity receiver. Accordingly, the hillside site conceptual design is based on the use of a single-cavity receiver with an acceptance angle of 90°. A twin-cavity receiver with a total acceptance angle of 150° was selected for the alternative site. This selection was strongly influenced by the desire for a lower tower height for the site that is closer to the mill and the adjacent Lahaina area.

The mountains east of Pionner Mill delay sunrise by nearly an hour; hence, solar insolation is prevented from being symmetrically distributed about solar noon. As a result, the preferred orientation of the heliostat field varies slightly from the normal north-of-the-tower location. A "1 o'clock"

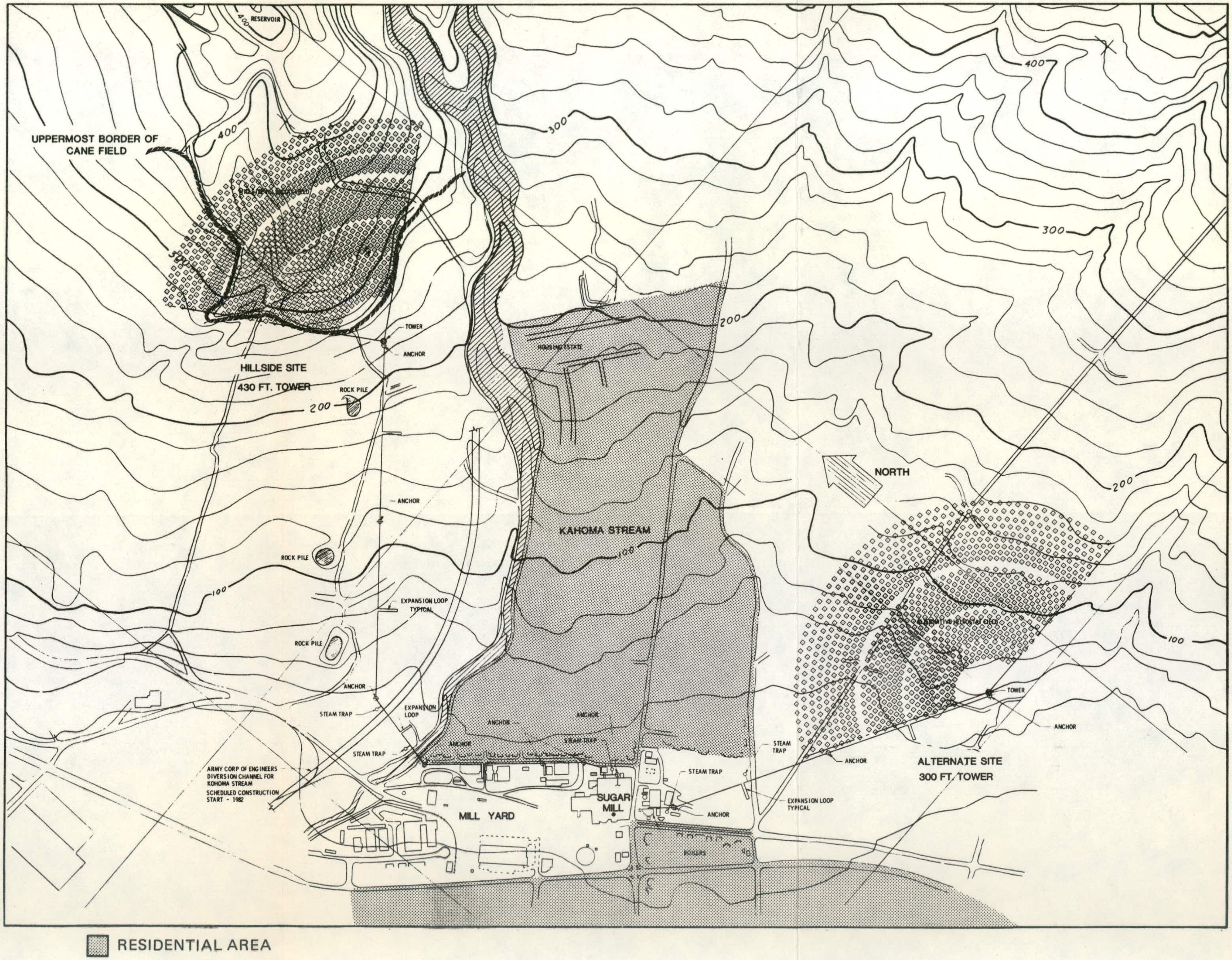


Figure 3-5 CANDIDATE HELIOSTAT FIELD SITES FOR THE PIONEER MILL SOLAR COGENERATION FACILITY

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field orientation, symmetric about an axis that is rotated 15° east from due north, was selected for both candidate heliostat field sites. Such an orientation gives peak performance almost an hour after solar noon.

Collector System Design and Performance. One of the key factors in the selection process is the efficiency of the heliostat array in concentrating the solar energy on the receiver. The field efficiency is a function of several factors:

- Field configuration, orientation, and size
- Heliostat configuration and packing density
- Land availability and topography

Land availability is extremely important in Hawaii and was the principal factor in the selection of the two sites to be evaluated. It was a major influence in establishing the overall field layout and packing factors, which affect the tower height and ultimately influence the receiver design.

For central receiver collector fields in the size range of the Pioneer Mill facility, the radial stagger heliostat array has been shown to be superior to other arrangements and was chosen for this analysis.

The heliostat characteristics used in the study correspond to those of the Northrup II, which is one of the heliostat designs being developed for the DOE under the second-generation heliostat program (Ref. 3-2). Each heliostat consists of a square array of 12 mirror modules and has a net reflective surface area of 52.8 m^2 (568 ft^2). The principal features of this heliostat are as follows:

- Total mirror area	52.76 m^2 (568 ft^2)
- Height	7.74 m (25.38 ft)
- Width	7.44 m (24.41 ft)
- Weight, excluding pedestal	2,260 kg (4,985 lb)

- Mirror modules
  - Mirror surface 1.2 m x 3.66 m (4 ft x 12 ft)
  - Galvannealed sheet steel construction
  - Longitudinal C-web bracing
- Frame structure
  - Four building truss purlins
  - Cross bracing
  - Elevation axis torque tube
- Drive assembly
  - Elevation and azimuth drives
  - Stepper motors
  - Planetary and worm stages for each drive
  - 18,108 reduction ratio
- Pedestal, 0.61 m (2 ft) diameter steel pipe

Figures 3-6 and 3-7 show the front and back views of a prototype at the Northrup plant. The collector fields were designed to deliver the same peak power to the mill. As a result, the collector system had to deliver 32.5 MWt and 33.5 MWt to the focal planes of the hillside and alternative field receivers, respectively, since the twin-cavity receiver loss exceeds that of the single cavity. In developing the collector field designs to meet this

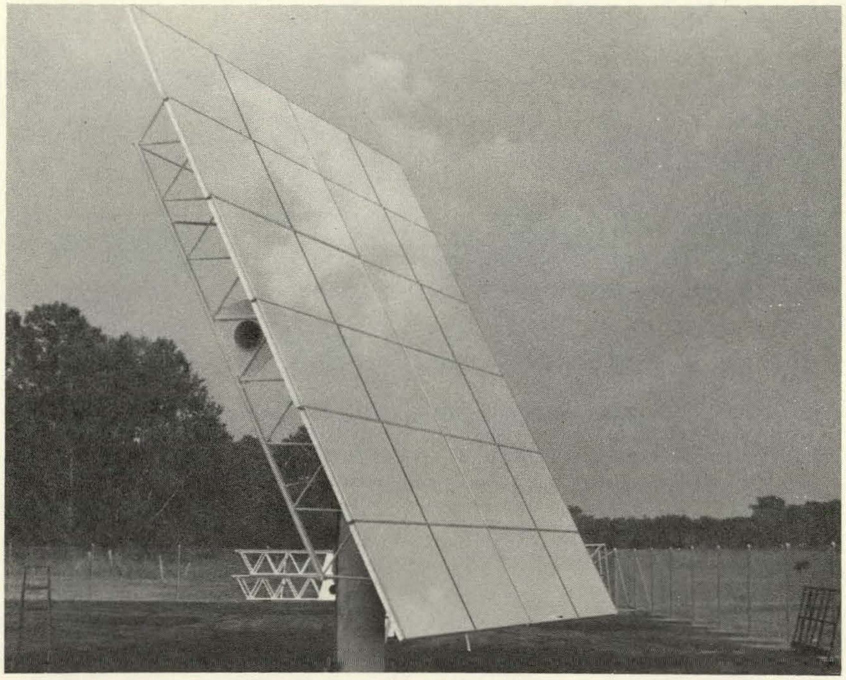


Figure 3-6 FRONT VIEW OF THE NORTHRUP SECOND-GENERATION HELIOSTAT

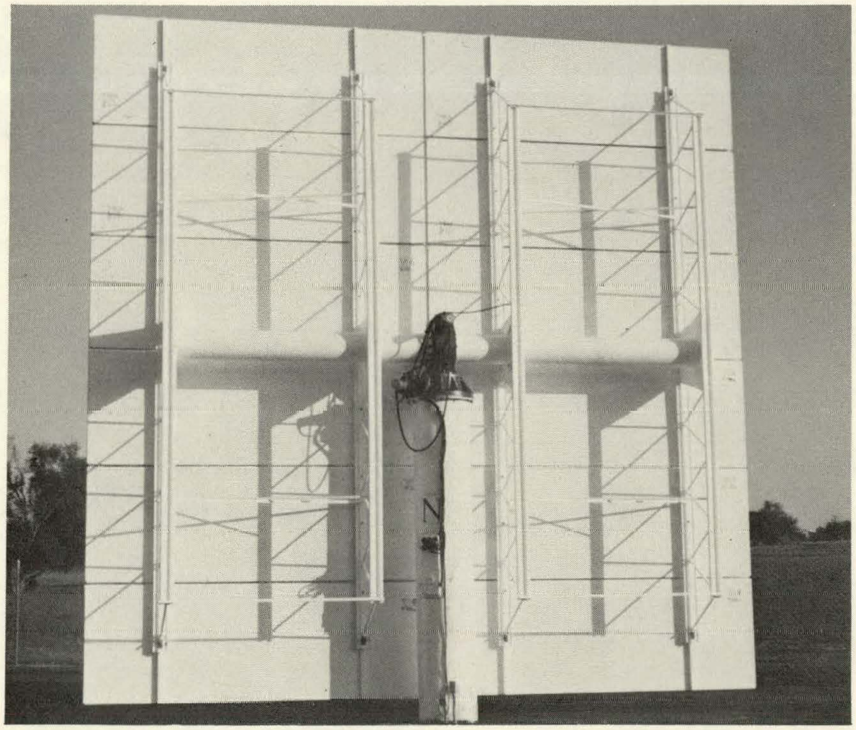


Figure 3-7 REAR VIEW OF THE NORTHRUP SECOND-GENERATION HELIOSTAT

power requirement, the optimum number and placement of heliostats at each site were determined. The determination in each case was influenced by land availability, topography, and optimum tower heights.

The primary or hillside site for the collector field lies approximately 1 mile northeast of Pioneer Mill. This site occupies the southern and slightly western lower slope of an extinct volcanic cinder cone. Because of the presence of large volcanic outcrops and boulders in combination with the relatively steep slope, this land is unsuitable for sugarcane production. The northern part of the field perimeter is approximately 49 m (160 ft) above the tower base. On the eastern boundary the land drops sharply in elevation; the slope to the west is less pronounced but still significant. These features of the terrain, coupled with the boundary configuration of the available land, exerted a strong influence on the collector field design and, in combination with the receiver power rating, resulted in the selection of a single-cavity receiver design. The field was designed to lie within a 90^{o} sector.

After the general field configuration (shape and size) had been established, the unique features of the site were evaluated to choose the best field orientation. The most significant feature was a residential area located due south of the tower. Since the residents of this area could be subject to a beam-pointing hazard, the tower was moved to the west relative to the true north-south axis. In addition to reducing a potential hazard, this move also increases total field performance slightly by increasing field efficiency during afternoon operation (because of the blocking effect of the West Maui Mountains, the day is symmetric about a time in the early afternoon).

Another factor that was considered was the tower-to-rear-heliostat row elevation difference, which decreased as the tower was shifted to the west. If the field axis were rotated to produce a 3:00 o'clock field (field performance peaks at 3 p.m.), a 380 ft tower could be used. However, the overall field performance for this arrangement was regarded as unacceptable because of a low average field cosine.

An evaluation of all of the above factors resulted in a field that is symmetric about an axis that points in a direction 15^0 east of north (a 1:00 o'clock field). The field is composed of 36 concentric rows of heliostats that lie within a 90^0 arc centered at the tower base. Figure 3-5 shows a plan view of the collector field as an overlay on the topographical map of the site.

The layout of the heliostats (row spacing) is a strong function of the tower (receiver aperture centerline) height owing primarily to blocking and shadowing of adjacent heliostats. The row spacing within the radial stagger field configuration is considered to be optimum at the point where the beam from a heliostat passes just above the top of any heliostat in the two rows in front of it. This is the threshold of blocking. With this spacing, there will be some shadowing effect, particularly at low sun angles. Although row and heliostat spacing could be increased to reduce the shadowing, the penalty in land usage would be high.

Field efficiencies for three tower heights (98 m, 116 m, 131 m) were calculated for the hillside site. An evaluation of these data, in conjunction with the site restrictions outlined above, led to the selection of a tower height of 131 m (430 ft).

The alternative heliostat field site is located south of the mill on relatively level ground. The perimeter of the available land at this site permitted a field layout to be developed that was significantly different from the layout of the hillside site. Here, the heliostats were placed on 27 concentric rows within an included angle of 150° to accommodate a dual-cavity receiver.

Fields incorporating tower heights of 275 ft and 300 ft were evaluated. As a consequence of this evaluation, the field with the 300 ft tower was selected for use in the site selection analysis. Here again, other considerations led to the adoption of a 1:00 o'clock field orientation. Chief among these was the location of the piping run along the southern edge of the field from the tower to the plant. Adoption of the 1:00 o'clock field orientation permits a straight pipe run from the tower to the mill along a continuously descending path. Thus, pipe length and drainage provisions are both minimized.

The fundamental task in collector field design is to maximize the performance of the field in delivering energy to the receiver within the imposed physical and financial constraints. Field performance is a function of several key factors. The most important of these is the geometric field efficiency. There are four components to the geometric field efficiency: the cosine efficiency, the fraction of energy lost due to shadowing of the incident beam by the relative positions of the heliostats, the fraction of energy lost due to the shadow of the receiver and tower on the field, and the blocking of the reflected energy by the adjacent heliostats.

The above parameters, which establish the geometric performance, are all functions of the solar elevation and azimuth angles, which are functions of time of day and day of the year. Since the field layout was not symmetric about a true north-south axis, it was necessary to calculate two field efficiency matrices (field efficiency as a function of solar elevation and azimuth), one for the times when the sun in in the morning (eastern) sky and one for the times when the sun is in the afternoon (western) sky. These field efficiencies were used as input to the computer program STEAEC to calculate the annual performance associated with each of the candidate heliostat fields.

Heliostat Foundations. The basic heliostat foundation for the Northrup second-generation heliostats at the Central Receiver Test Facility (CRTF) in Albuquerque was a 0.6 m (2 ft) diameter steel pipe driven slightly over 3 m (10 ft) into the ground with a vibratory hammer. The vibratory hammer permits piles to be installed rapidly and inexpensively for soils that do not contain stones. Because the cane land soil of the alternative site contains stones that would refuse a pile driven by a vibratory hammer, the steel pipe pedestal foundations must be installed in augered holes and set in concrete. A special foundation design is required on the hillside site where a 0.9 m (36 in.) layer of rocky topsoil covers a stratum of bedrock.

The heliostat pedestal-foundation designs for the candidate sites are shown in Figure 3-8. The soil survey of the islands of Kauai, Oahu, Maui, Molokai,

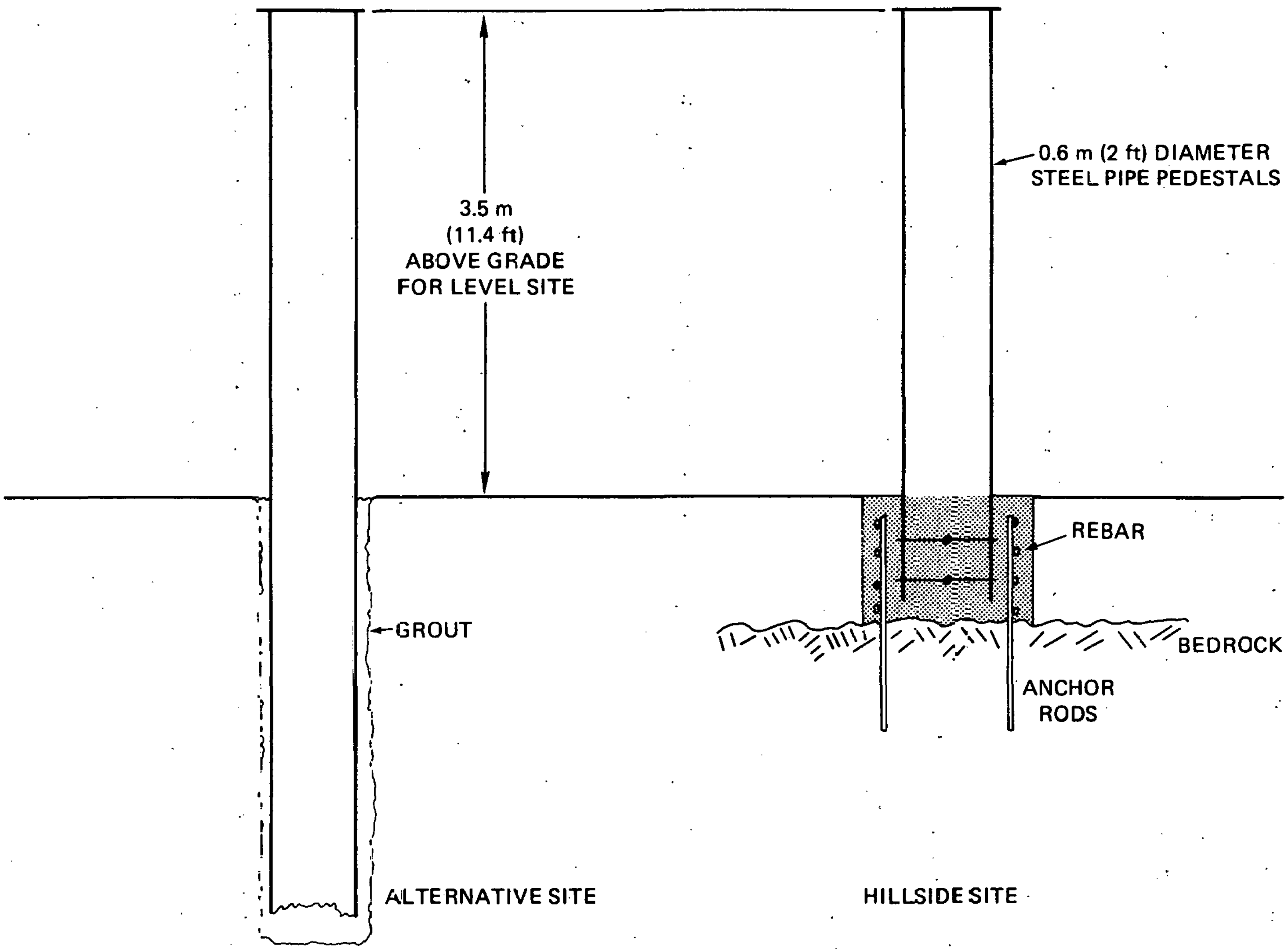


Figure 3-8 HELIOSTAT PEDESTAL-FOUNDATION DESIGNS

and Lanai (published by the State of Hawaii) describes the soil at the alternative site as Ewa silty clay loam (Ref. 3-3). It consists of two layers of silty clay loam extending to a depth of 1.5 m (5 ft) over a substratum of coal limestone or gravelly alluvium. It can be readily penetrated by an auger to provide a hole for setting the heliostat pedestal in grout. The hillside site soil is described as Wahikuli silty clay and consists of 0.5 to 1.0 m (20 to 40 in.) of silty clay over bedrock. The bedrock approximately 1 meter below grade on the hillside site requires a different foundation design. The design shown in Figure 3-8 was adopted for the Task 2 preconceptual design.

This foundation is constructed by backhoeing to bedrock and drilling four 3.2 cm (1.25 in.) diameter by 0.75 m (2.5 ft) deep holes into the bedrock. Expansion bolts anchored in these holes are welded to the rebar cage of a concrete foundation into which the heliostat pedestal is set.

The 3.5 m (11.4 ft) elevation of the heliostat pedestal flange above grade is sufficient for a level site. An increased pedestal height is necessary on sloping land to ensure clearance of the heliostat on the upslope side. This factor, illustrated in Figure 3-9, required an additional 0.1 m (0.32 ft) of above-grade pedestal height for the alternative site and an average 0.53 m (1.75 ft) of increased pedestal height for the hillside site. A still greater increase in pedestal height was required at the alternative site to clear the dual-use crops — an additional 1.2 m (4 ft) for the alfalfa crop and 3.7 m (12 ft) for the seed cane. In addition, proportional increases in the pipe length were provided below grade. The final pipe lengths for each pedestal-foundation is shown in Table 3-3.

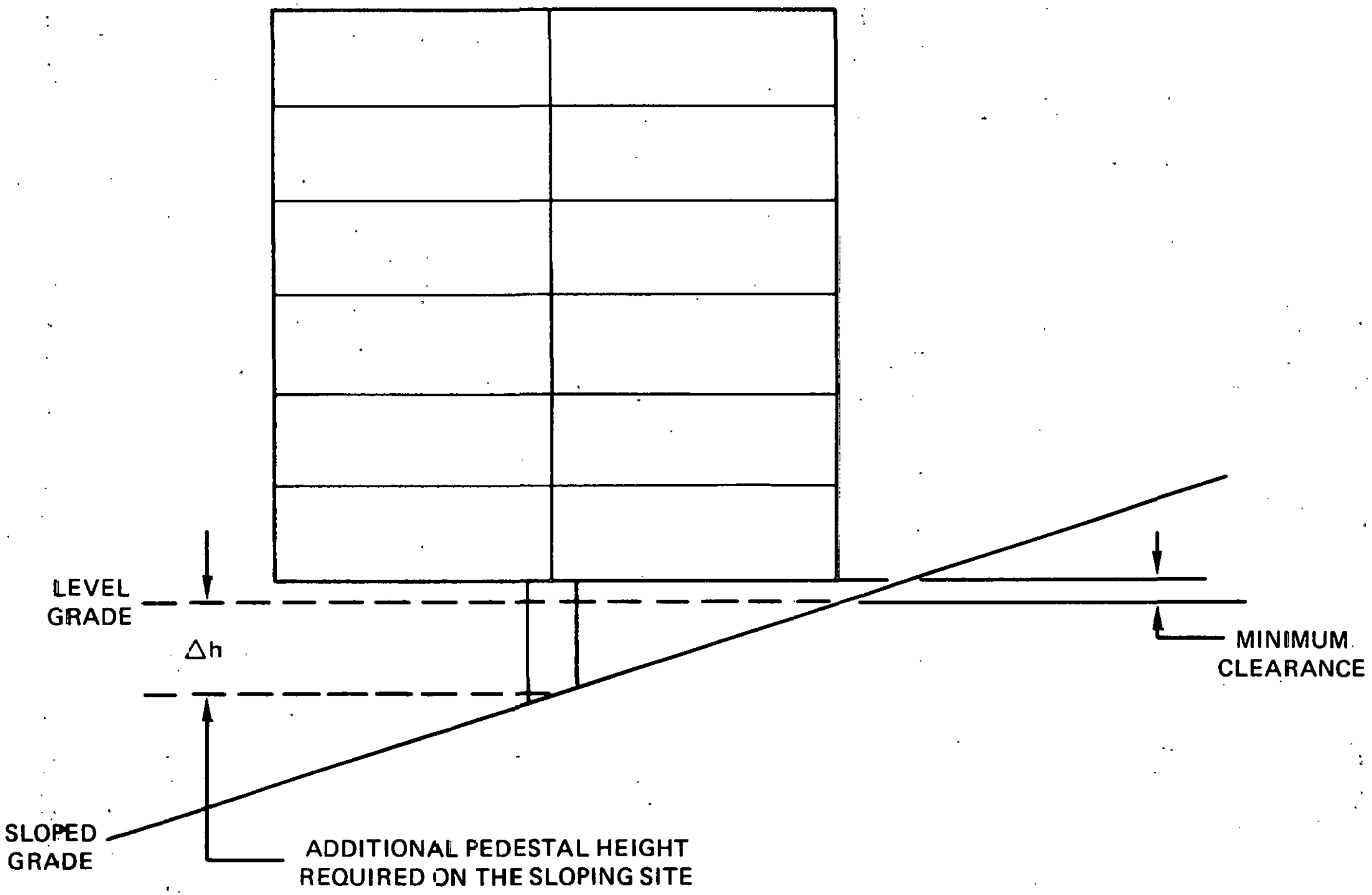


Figure 3-9 EFFECT OF SLOPING SITE ON PEDESTAL HEIGHT

Table 3-3

PEDESTAL-FOUNDATION PIPE LENGTHS
(Total Above and Below Grade)

Site	Length	
	Meters	Ft
Hillside	4.77	15.65
Alternative – no crop	6.72	22.04
Alternative – alfalfa	8.13	24.69
Alternative – seed cane	13.57	44.53

An unexpected result of the pedestal-foundation analysis was the discovery that elevating the heliostat an additional 3.7 m (12 ft) above grade to clear the seed cane crop did not require an increase in the pedestal pipe diameter or wall thickness. It was found that very little of the pedestal base moment is due to the lateral drag force at the heliostat connection (the portion of the base moment that is amplified by additional pedestal height). The major portion of the pedestal base moment is due to the pure aerodynamic moment about the heliostat elevation axis. This portion of the pedestal base moment is unaffected by pedestal height. As a result, these increases in pedestal height caused only minor changes in the pedestal base moments. No adjustments in pedestal diameter or wall thickness were required.

<u>Receiver System.</u> The receiver system consists of a feed pump station at the base of the tower, condensate piping from the pumps to the receiver, the tower, the receiver, and the main steam piping from the receiver to the

base of the tower. The receiver system equipment for the two candidate heliostat fields is the same except for the tower heights and associated pipe runs, and the receiver designs.

The tower heights were determined as part of the heliostat field design discussed earlier. The SNLL tower cost equations indicated that a steel tower should be selected for each of the candidate sites. The foundation costs for the hillside site were increased by 25 percent to account for the placement of the foundation on bedrock.

The basic receiver concept selected for use at Pioneer Mill is a natural-circulation steam generator with separate superheater circuitry. For the hillside site, a single-cavity configuration was adopted for the receiver system. The receiver was sized to produce 38,650 kg/hr (85,200 lb/hr) of superheated steam at a pressure of 6.2 MPa (900 psig) and a temperature of 413C (775F), with a thermal output of 29.3 MWt (100 x 10^6 Btu/hr).

At the initiation of the preconceptual design, inputs regarding cavity dimensions and heat flux distributions were not available. Since only approximate estimates of the receiver weight and cost were sought for this trade study, it was decided that this receiver could be scaled from another existing design having a similar cavity configuration. Subsequently, the internal geometry and dimensions of this single-cavity receiver were scaled down from the pilot plant receiver previously designed by Foster Wheeler for the Central Receiver Solar Thermal Power System (CRSTPS), Phase 1 Study (Ref. 3-4). The maximum absorbed power into this reference receiver was 48.7 MWt at a peak insolation of 1.023 kW/m^2. The candidate receiver for the cogeneration facility requires 29.3 MWt, and a peak insolation of 0.945 kW/m^2 was measured at the site. Consequently, the scaling factor for linear dimensions was established by the following relationship:

$$\frac{L}{L_{ref}} = \sqrt{\frac{29.3}{48.7}} \times \sqrt{\frac{1.023}{0.945}} + \text{(Minor adjustment due to round-off of aperture dimensions)}$$

where L and L_{ref} are linear dimensions of the cogeneration and reference pilot plant receivers, respectively.

The resultant internal dimensions of the cavity for the hillside site receiver are shown in Figure 3-10. The square cavity aperture is 6.1 m (20 ft) on a side. The rear wall and a large portion of both side walls, as indicated in the plan view of the figure, are covered with vertical boiler panels. These panels are made of 38.1 mm (1.5 in.) OD carbon steel boiler tubes that are joined along their length by continuous-weld integral fins to form flat MONOWALLS^{TM}. A preliminary allocation of superheater surfaces was made on the basis of the heat flux distributions generated for the reference pilot plant receiver. The superheater consists of six horizontal passes in series. These passes are placed in front of the vertical boiler panels and aligned horizontally at two elevations as shown schematically in Figure 3-11. Each pass is made of 25 stainless steel tubes, with an OD of 25.4 mm (1 in.), arranged side by side on 28.6 mm (1-1/2 in.) centers. A spray attemperator located between Pass 3 and Pass 4 is used for temperature control. Preliminary sizing was also performed for drum, downcomers, feeders, risers, headers, and connecting piping.

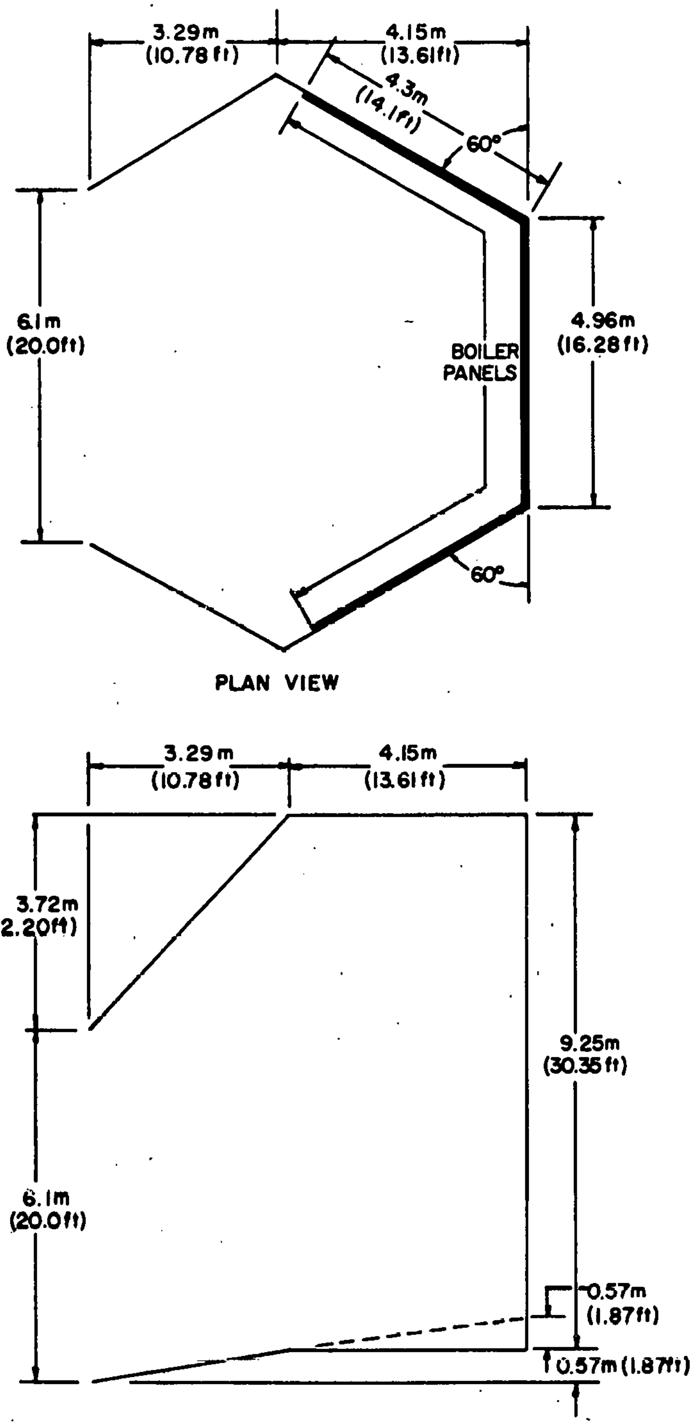
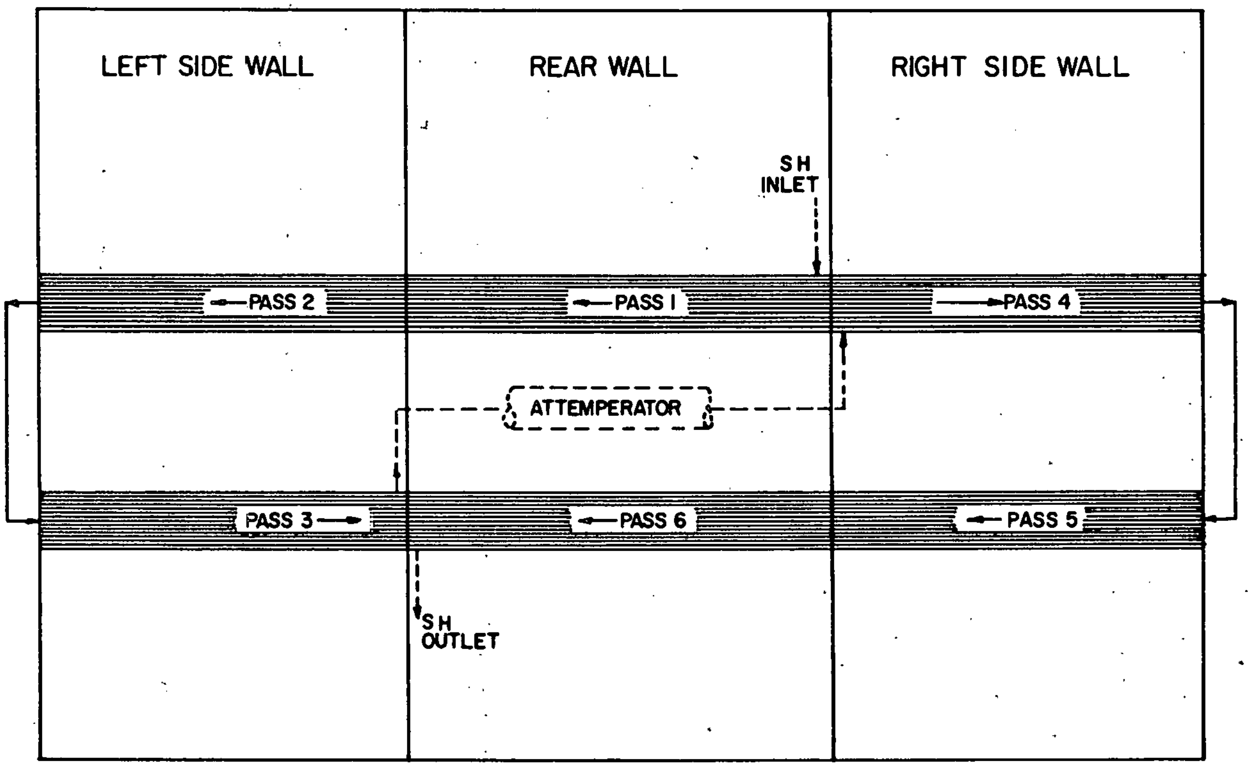


Figure 3-10 SINGLE-CAVITY RECEIVER CONFIGURATION



Superheater passes are numbered in the sequence of steam flow.

Figure 3-11 SCHEMATIC ARRANGEMENT OF SUPERHEATER PASSES FOR THE SINGLE-CAVITY RECEIVER

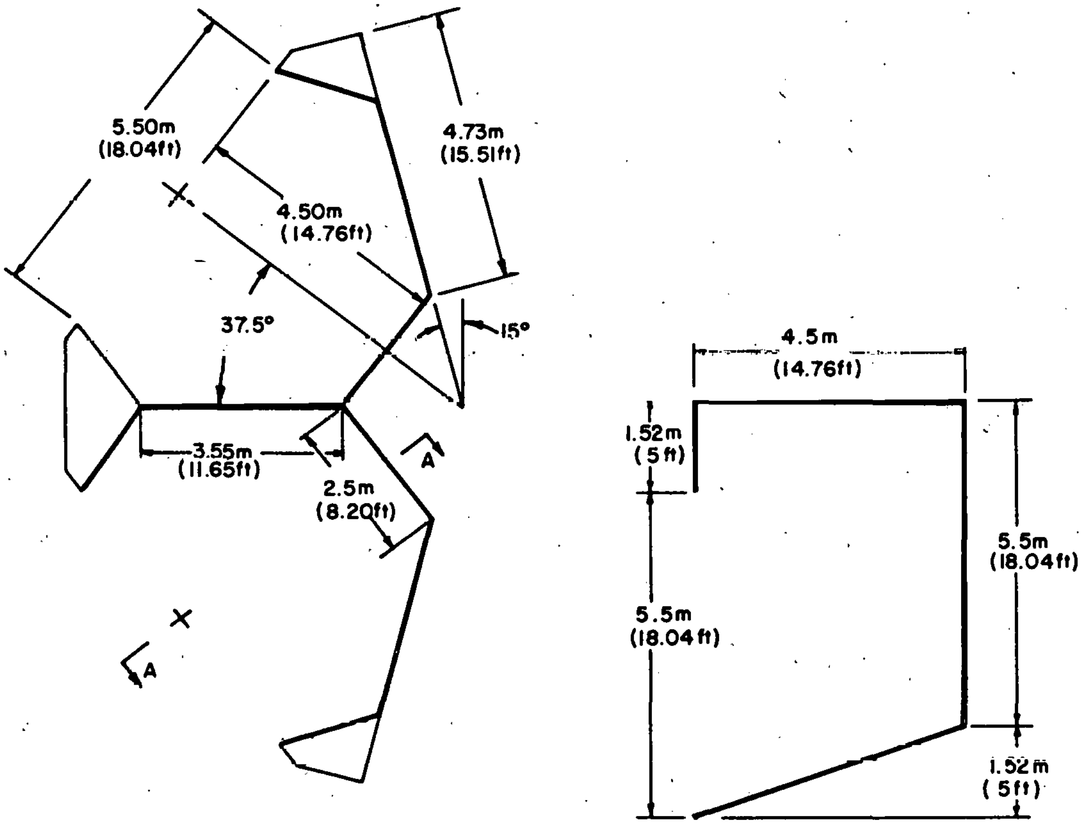
On the basis of this preconceptual design, the overall receiver dimensions were found to be approximately 12.5 m (41 ft) wide, 8.84 m (29 ft) deep, and 16.76 m (55 ft) high. The whole receiver system weighs approximately 149,100 kg (328,700 lb) empty, and 161,100 kg (355,200 lb) filled with water. The total construction cost of this receiver was estimated to be $2.48 million. The cost includes material, fabrication, erection, and home office expenditures, contingency, G&A and fee.

For the alternative heliostat field site, an integrated twin-cavity receiver configuration was adopted. Natural circulation was also chosen for the receiver design. The sizing of this receiver was based on the same thermal output and steam conditions as those used for the hillside site.

The same approach of estimating approximate receiver weight and cost without calculating the actual cavity dimensions and heat flux distributions from the proposed heliostat field was followed for this alternative receiver concept. The twin-cavity receiver designed for the Martin-Marietta/Exxon Solar Enhanced Oil Recovery System (Ref. 3-5) was selected as the reference receiver. The thermal output of this reference receiver is 29.3 MWt at an insolation of 0.95 kW/m^2, which is identical to the requirement set for the Task 2 receivers at Pioneer Mill. Therefore, for the preconceptual design of the alternative site receiver, the cavity configuration and flux distributions were taken directly from those of the reference receiver. Since no superheater was required in the reference design, it was necessary to modify the surface allocation in order to provide the proposed receiver with appropriate superheating surfaces.

Figure 3-12 shows the key dimensions of the twin-cavity receiver configuration. The receiver is symmetric with respect to a plane passing through the common wall that partitions the two cavities. The square aperture of each cavity is 5.5 m (18.04 ft) on a side with its centerline extending at an angle of 37.5° from the common wall. To illustrate the allocation of the interior surfaces, a foldout sketch of one of the two identical cavities is shown in Figure 3-13. Since a considerable amount of incident solar energy falls on the cavity roof, a large portion of the roof is covered with preheater panels. The rear wall and side wall of each cavity are lined with vertical boiler panels. Carbon steel tubes of 25.4 mm (1 in.) and 50.8 mm (2 in.) ODs serve as the preheater and boiler panels, respectively. The same type of MONOWALL^{TM} construction described previously is used for these panels. The superheater, consisting of four vertical passes in series, is located on the common wall. All superheater passes are made of a number of parallel 38.1 mm (1.5 in.) OD stainless steel tubes welded side by side to form flat panels. The transfer piping connecting superheater Passes 2 and 3 (not shown in Figure 3-13) contains the spray attemperator used for steam temperature control.

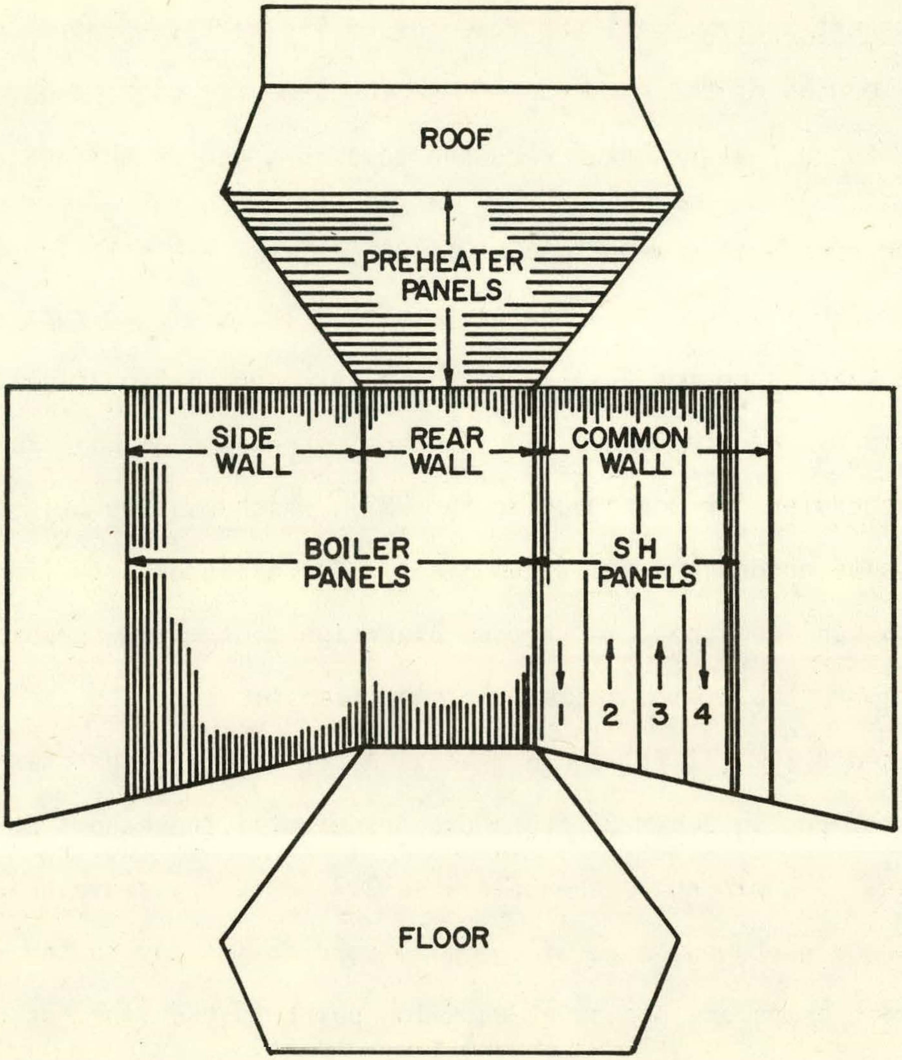
The overall dimensions of this 29.3 MWt twin-cavity receiver are approximately 12.5 m (41 ft) wide, 7.0 m (23 ft) deep, and 12.2 m (40 ft) high. The total estimated dry weight of the whole receiver system is 127,000 kg (280,000 lb), and the water-filled weight is 137,300 kg (302,600 lb). Based on the preconceptual design, the total construction cost of this receiver was estimated to be $2.47 million.



PLAN VIEW

SECTION A-A

Figure 3-12 TWIN-CAVITY RECEIVER CONFIGURATION



Superheater passes are numbered in the sequence of steam flow.
The attemperator is located between Passes 2 and 3.

Figure 3-13 CAVITY FOLDOUT SHOWING THE SURFACE ALLOCATION OF THE TWIN-CAVITY RECEIVER

Heat Transport System. All the features of the heat transport system, other than the lengths of the pipe runs, were the same for each candidate site. A list of those features that were the same is given in Subsection 3.5.2.

The piping run lengths were 1,855 m (6,087 ft) for the hillside site and 1,000 m (3,280 ft) for the alternative site. These piping runs and the expansion loops used for Task 2 are shown in Figure 3-5. This figure also shows the proposed Army Corps of Engineers' diversion channel for Kahoma Stream (scheduled for construction in 1982), which must be bridged by the hillside site condensate and steam lines. The hillside site lines were assumed to run from the tower to the diversion channel on supports approximately 0.6 m (2 ft) above grade. At the diversion channel, the pipe runs are elevated 3.7 m (12 ft) above grade. After bridging the channel, the pipe run returns to 0.6 m (2 ft) above grade until the Kahoma Stream bed is crossed. The piping is then elevated 3.7 m (12 ft) above grade as it traverses the northwest edge of the mill yard on its way to the sugar mill. Drain traps are placed at each low point in the line for collection of condensate as the line is heated each morning during startup. The pipe run from the alternative site tower to the boiler building is at 0.6 m (2 ft) above grade everywhere, except where it drops below grade to pass through a culvert beneath a road.

3.5.4 Impact on Agricultural Operations

Each of the site alternatives would have an impact on the agricultural operations on the plantation. The hillside site has significantly less impact than the alternative site; it uses unproductive land for all but 25,500 m^2 (6.3 acres) of the heliostat field.

The alternative site layout is entirely within the cane fields. If the sugarcane were displaced completely, the overall production capacity of the plantation would be reduced unless other available land were brought into production. Although the land area needed for this project is relatively small, widespread use of this type of solar thermal system in Hawaii and other agricultural regions could significantly affect local farm production. Since this is a site-specific problem with broad implications, the possibility of dual use of land for heliostats and agricultural production was studied. For this application, a second local crop, alfalfa, was also investigated.

To accommodate the crops under the heliostats, the following arrangement was found to be most suitable: The crops are planted in curved rows behind the rows of heliostat pedestals (looking from the tower). The crop row width equals the distance between heliostat rows minus a 5.5 m (18 ft) wide roadway and heliostat pedestal area for heliostat access and cleaning. The crop width varies from 5.2 m (17 ft) to 11.3 m (37 ft) for the alternative field layout. One intermediate takeup row has a 17.7 m (58 ft) wide crop strip. The heliostat pedestal is lengthened so that the crop is cleared at its maximum expected growth. This assumption may be more conservative than necessary, but it was later shown to be adequate.

In the harvesting of the sugarcane crop, the field is usually burned and the work is normally done with large pieces of equipment. This type of activity cannot be carried out between heliostats. Seed cane, however, is not burned and is harvested by hand. Pioneer Mill currently has about 0.93 km^2

(230 acres) in seed cane, and the location of the seed cane field is not critical. The seed cane is harvested every 10 months after it reaches a maximum height of about 3.6 m (12 ft). During the growing period, it needs little care except for irrigation and pest control. The changeover to drip irrigation techniques at Pioneer Mill means that irrigation will not present problems for the heliostat foundations.

Alfalfa grows rapidly in a tropical climate, yielding 10 crops per year. The maximum height attained before harvest is about 0.75 m (2.5 ft). Because it is not presently grown at Pioneer Mill, this crop requires increased capital investment for harvesting and drying equipment.

Many other crops can be considered for this dual-use application. Pioneer Mill suggested corn and sorghum, which also have a local market. Other crops that do not have a local market were not considered for this study. Pineapples were eliminated from consideration because of strong competition in the area from large producers.

Other issues, such as impact on heliostat operation, were considered only briefly, owing to budget limitations. No significant obstacles were found to this concept of dual land use, but the complications of maneuvering harvest equipment between the heliostats were noted by Pioneer Mill personnel. Table 3-4 summarizes the significant parameters that were used in the economic comparison of the alternative site with the hillside site.

Table 3-4

DUAL-USE CROP PARAMETERS
(Alternative Site)

Item	Seed Cane	Alfalfa
Total heliostat field area	210,000 m^2 (52 acres)	210,000 m^2 (52 acres)
Crop area in heliostat field	92,600 m^2 (22.9 acres)	92,600 m^2 (22.9 acres)
Net surgarcane displacement	117,400 m^2 (29.1 acres)	210,000 m^2 (52 acres)
Value of displaced sugarcane	\$1.21/km^2/yr (\$3,000/acre/yr)	\$1.21/km^2/yr (\$3,000/acre/yr)
Gross crop income	\$1.21/km^2/yr(a) (\$3,000/acre/yr)	\$5.66/km^2/yr (1,400/acre/yr)
Harvesting cost	\$0.044/kg (\$40/ton)	\$.011/kg (\$10/ton)

(a) Seed cane income is treated as equivalent reduction in sugarcane displacement.

3.5.5 Performance Comparison

The annual performance of the two fields was computed using the STEAEC program. Twelve typical days were analyzed to approximate the annual energy collection. A monthly weather factor was applied to each day to account for average solar insolation availability. To meet the peak power requirement of 29.3 MWt, the hillside site required 831 heliostats and the alternative site required 864 heliostats. The results of this analysis are given in Table 3-5. The annual energy supplied by the two fields differs by only 0.5 percent.

Table 3-5

HELIOSTAT FIELD PERFORMANCE COMPARISON

Day No.	Month	Days per Month	Weather Factor	Hillside Site		Alternative Site	
				Clear Day Energy, MWht	Monthly Energy, MWht	Clear Day Energy, MWht	Monthly Energy, MWht
15	Jan	31	0.86	214	5,705	221	5,625
46	Feb	28	0.88	226	5,569	224	5,519
74	Mar	31	0.87	231	6,230	231	6,230
105	Apr	30	0.80	229	5,496	231	5,544
135	May	31	0.79	223	5,461	227	5,559
166	June	30	0.81	218	5,297	223	5,419
196	July	31	0.82	220	5,592	225	5,720
227	Aug	31	0.85	225	5,929	228	6,008
258	Sept	30	0.87	230	6,003	231	6,029
288	Oct	31	0.91	227	6,404	226	6,375
319	Nov	30	0.91	218	5,951	216	5,897
349	Dec	31	0.93	208	5,997	205	5,910
Annual			0.84 (average)	222.5 (average)	69,688	223.74 (average)	70,053
At 90% availability					62,719		63,048
No. 6 oil displaced					7,052 m^3 (44,320 bbl)		7,089 m^3 (44,550 bbl)

3.5.6 Capital Cost Comparison

Capital cost estimates were prepared for the two heliostat field sites. The purpose of these estimates was to determine the differences in cost; all major components of the solar facility were included. The estimates were consistent with the level of engineering detail available from the Task 2 effort. Costs were normalized to first-quarter 1981 price and wage levels, and represent direct-hire field construction in Hawaii. Pricing was based on informal vendor quotes obtained by Bechtel and on Bechtel historical cost data, with the following exceptions:

- Heliostat costs were supplied by Northrup
- Receiver costs were supplied by Foster Wheeler
- Tower costs were obtained from the Sandia tower cost equation

Indirect field costs for these estimates include:

- Temporary construction facilities
- Miscellaneous construction services
- Construction equipment and supplies
- Field office costs
- Preliminary checkout and acceptance testing
- Project insurance

Engineering services include engineering costs, other home office costs, and fee. The level of contingency included reflects the limited engineering detail available. The following items were specifically excluded from the estimates:

- Equipment or construction costs other than for the solar facility
- Removal of the solar facility at the end of project life

- Owner's costs
- Environmental reports and licensing
- Allowance for funds during construction
- Training of operators
- Plant startup

The estimate summaries are presented in Table 3-6. Three cases are presented for the alternative site corresponding to the three dual-use options, which differ in heliostat pedestal costs only.

The hillside site was found to be approximately $3.3 million more costly than the least expensive alternative site case. The three primary contributors to this difference are the receiver tower, the thermal transport piping, and the heliostat foundations. These are included with equipment, piping, and heliostats and installation, respectively in Table 3-6.

3.5.7 Economic Comparison

An economic comparison of the two sites was carried out to assess the impact of the other relevant factors, such as lost cane production, on the capital cost advantage of the alternative site. After consultation with Amfac, the following assumptions were made:

- General escalation rate of 10 percent
- Plant operation over 20 years, beginning in 1986
- Plant tax life of 14 years
- Federal tax rate of 46 percent
- State tax rate of 6.021 percent
- Federal investment tax credit of 25 percent
- State investment tax credit of 10 percent

Table 3-6

SITE COMPARISON CAPITAL COST SUMMARY
(in $1,000's)

Item	Hillside Site	Alternative Site[a]		
		1	2	3
Site preparation	230	270	270	270
Equipment	5,386	4,116	4,116	4,116
Piping	1,900	1,130	1,130	1,130
Electrical	250	240	240	240
Instrumentation	140	131	131	131
Total direct cost	7,906	5,887	5,887	5,887
Indirect cost	634	443	443	443
Total field cost	8,540	6,330	6,330	2,330
Engineering services	850	630	630	630
Contingency	1,700	1,260	1,260	1,260
Construction cost	11,090	8,220	8,220	8,220
Heliostats and installation	12,620	12,230	12,370	12,910
Total construction cost with heliostats	23,710	20,450	20,590	21,130

Price and wage level, first-quarter 1981.

(a) Alternative site cases are as follows:

1. No crop
2. Dual use — alfalfa
3. Dual use — seed cane

From these assumptions, a fixed charge rate of 19.7 percent was calculated. Operation and maintenance costs were assumed to be 1.5 percent of capital cost, escalating with the general inflation rate. The land lease costs for the two sites are $5/acre/yr for the hillside site, which is unused land owned by the State of Hawaii, and $2,500/acre/yr for the alternative site, which is owned by the Bishop estate and located adjacent to the town of Lahaina.

The economic analysis is summarized in Table 3-7. The annual added cost using the hillside site is about $710,000 as a result of capital charges; but when all other relevant annual costs are considered, this is reduced to $460,000.

For the alternative site, the no crop case is the practical choice. Although there is a small savings indicated for the alfalfa case, this could be easily reversed when the operational details and the effect of partial shading on crop yield are fully considered. The seed cane case has a larger, but still relatively insignificant (11 percent), economic disadvantage. The design of this facility should be based on the lower risk option of no crop among the heliostats; however, the future consideration of this dual-use approach for more mature plant designs cannot be ruled out.

3.5.8 Site Selection

The selection of the preferred site was based on the economic analysis. The alternative site is the more cost-effective choice, despite its greater impact on the agricultural land of the plantation.

Table 3-7

ECONOMIC EVALUATION SUMMARY
Levelized Annual Costs ($1000's 1981)

Site	Capital Costs[a] (10^3, 1981)	Capital Charges[b]	O&M[c] Cost	Net Lost Cane Revenue[d]	Alfalfa Net Revenue[e]	Land Lease Cost[f]	Total Annual Cost	Annual Energy Production, MWht	Levelized Unit Energy Cost, $/MWht ($/MBtu)
Hillside	26,318	5,185	762	31	-	< 1	5,978	62,719	9.53 (27.9)
Alternative								63,048	8.75 (25.6)
No crop	22,700	4,472	657	259	-	130	5,518	63,048	8.74 (25.6)
Alfalfa	22,855	4,502	662	259	(41)	130	5,512	63,048	8.84 (25.9)
Seed cane	23,454	4,620	679	145	-	130	5,574		

(a) Includes 11% contribution for AFDC based on an 18% discount rate, a 10% escalation rate, and a 2-year construction period.

(b) Based on a 0.197 fixed charge rate.

(c) Based on 1.5% of capital cost multiplied by a levelizing factor of 1.93 (10% over 20 years).

(d) Lost revenue deescalated for 2 years (construction period) and multiplied by a levelizing factor of 2.01 (10% over 22 years).

(e) Includes $80,000 initial capital cost. Revenue calculated from the gross income, less harvest cost and capital recovery.

(f) Unescalated.

The factors that make the hillside site more costly were reexamined to be sure that the economic analysis was based on the best available information. The three main contributors were examined separately to determine if any factors had been overlooked.

The tower height for the hillside site was based on an optimization with a constrained field geometry. No reasonable set of conditions were found which could reduce the height significantly without a significant penalty in annual performance. If the slope were more uniform and if the latitude of the site were greater, the optimum tower height for the hillside site would be considerably shorter. However, for this specific evaluation, the shorter tower for the relatively flat alternative site represents a distinct economic advantage.

The piping length is fixed by the topography. The alternative site is as close to the mill as is reasonably possible, and the hillside site has double the piping length. This factor would always favor the alternative site for this particular facility.

The heliostat foundation costs are another purely site-specific disadvantage of the hillside site. Although the hillside has fewer heliostats, its overall heliostat field cost is greater.

This discussion illustrates that no combination of reasonable assumptions could be found that would overcome the economic advantage of the alternative site. Therefore, this site was preferred for the conceptual design without dual use for agriculture.

During the evaluation of the two sites for the heliostat field, several other factors were uncovered which led to the consideration of a third site. This site is very similar to the alternative site except that it is located northwest of the mill, as shown in Figure 1-1.

The two primary reasons for considering a third site were:

- The tower location for the alternative site is close to the main part of Lahaina, and hence may generate opposition on the part of the citizens of the town
- The land for the alternative site is privately owned by the Bishop estate and is leased to Pioneer Mill. The current lease expires in 1984 and proposed changes in land use must compete with other options, such as housing subdivision. There is also a much higher land lease cost associated with the Bishop lease compared with the state-owned land, such as the hillside site, as can be seen in Table 3-7.

The third site was chosen for consideration because it has nearly the same topography, current use, and proximity to the mill as the alternative site. It also has two other advantages: the tower is located significantly farther from the town, and the site is on state-owned land. The economics of the third site were judged to be better than the alternative site because of the $130,000 difference in annual lease costs. Therefore, the third site was judged to be superior to either the hillside or alternative site and was deemed the preferred site for the conceptual design.

REFERENCES

2-1 Climates of the States — Hawaii, Climatography of the United States No. 60-51, National Oceanic and Atmospheric Administration, pp. 266-294.

3-1 Letter from J. W. Liebenburg and J. E. Grant to J. J. Bartel (on Sandia Laboratories letterhead) dated January 7, 1980. Subject: Tower Costs for Solar Central Towers.

3-2 Second Generation Heliostat Development for Solar Central Receiver Systems, Final Report, February 1981, Northrup Incorporated, Sandia Contract 83-2729E.

3-3 Soil Survey of Islands of Kauai, Oahu, Maui, Molokai, and Lanai, State of Hawaii. U.S. Department of Agriculture, August 1972.

3-4 Central Receiver Solar Thermal Power System, Phase I: Preliminary Design Report (Volume 4 - Receiver Subsystem), Martin Marietta Corporation, April 1977, SAN/1110-77-2.

3-5 Solar Repowering/Industrial Retrofit Systems, Category B, Solar Thermal-Enhanced Oil Recovery System, Final Report, Martin Marietta Corporation, July 1980, MCR-80-1353, Contract DE-AC03-79SF10737.

APPENDIX A

SYSTEM SPECIFICATION FOR
THE PIONEER MILL
SOLAR COGENERATION FACILITY

DOE Contract No. DE-AC03-80SF11432

Prepared by

Bechtel Group, Inc.

Amfac Sugar Co.
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Job 14481

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Section 1

GENERAL

1.1 SCOPE

This specification defines the system characteristics, design requirements, and environmental requirements for the addition of a solar central receiver facility to the existing cogeneration plant at Pioneer Mill Company, Ltd., a plantation subsidiary of Amfac Sugar Company.

The level of detail presented in this specification is consistent with the conceptual design phase of an industrial power plant project. Engineering information is developed to the extent necessary to support the conceptual plant cost estimate and the determination of technical and economic feasibility of the project. The listing of required data for the solar cogeneration facility conceptual design is included as Section 5 of this specification.

1.2 SYSTEM DESCRIPTION

A description of the solar cogeneration facility at Pioneer Mill consists of a description of the following:

- Site
- Site facilities
- Collector system
- Receiver system
- Thermal transport system
- Nonsolar energy system

- Master control system
- Specialized equipment
- Modes of operation

The plan for incorporating a solar energy facility into existing Pioneer Mill plant calls for placing a water-steam-cooled solar central receiver in parallel with the existing boilers and displacing the consumption of fuel oil when solar energy is available. Bagasse will be used for energy storage. A schematic diagram of the proposed facility is given in Figure A.1-1.

1.2.1 Site

The plantation at Pioneer Mill is adjacent to the town of Lahaina on the west coast of the island of Maui in Hawaii and occupies 35.5 x 10^6 m^2 (8,776 acres) of land.

The area has a general west-facing slope, which extends from a populated resort area along the beach to the steep foothill slopes of the West Maui Mountains. The plantation altitude varies between 3 m (10 ft) and 590 m (1,925 ft) above sea level. The site coordinates are 20° 53' north latitude and 156° 40' west longitude.

The collector field and receiver tower are located approximately 670 m (2,200 ft) northeast of the existing cogeneration facility. The collector field area has a southwest-facing slope of approximately 5 percent. Two distinct soil types are encountered on the sites: Ewa and Wahikuli.

The soil in the vicinity of the sugar factory is classified as Ewa silty clay loam. It has a surface layer of dark, reddish-brown silty clay loam about 18 inches thick. The subsoil, about 42 inches thick, is dark-red silty clay loam with a subangular blocky structure. The substratum is

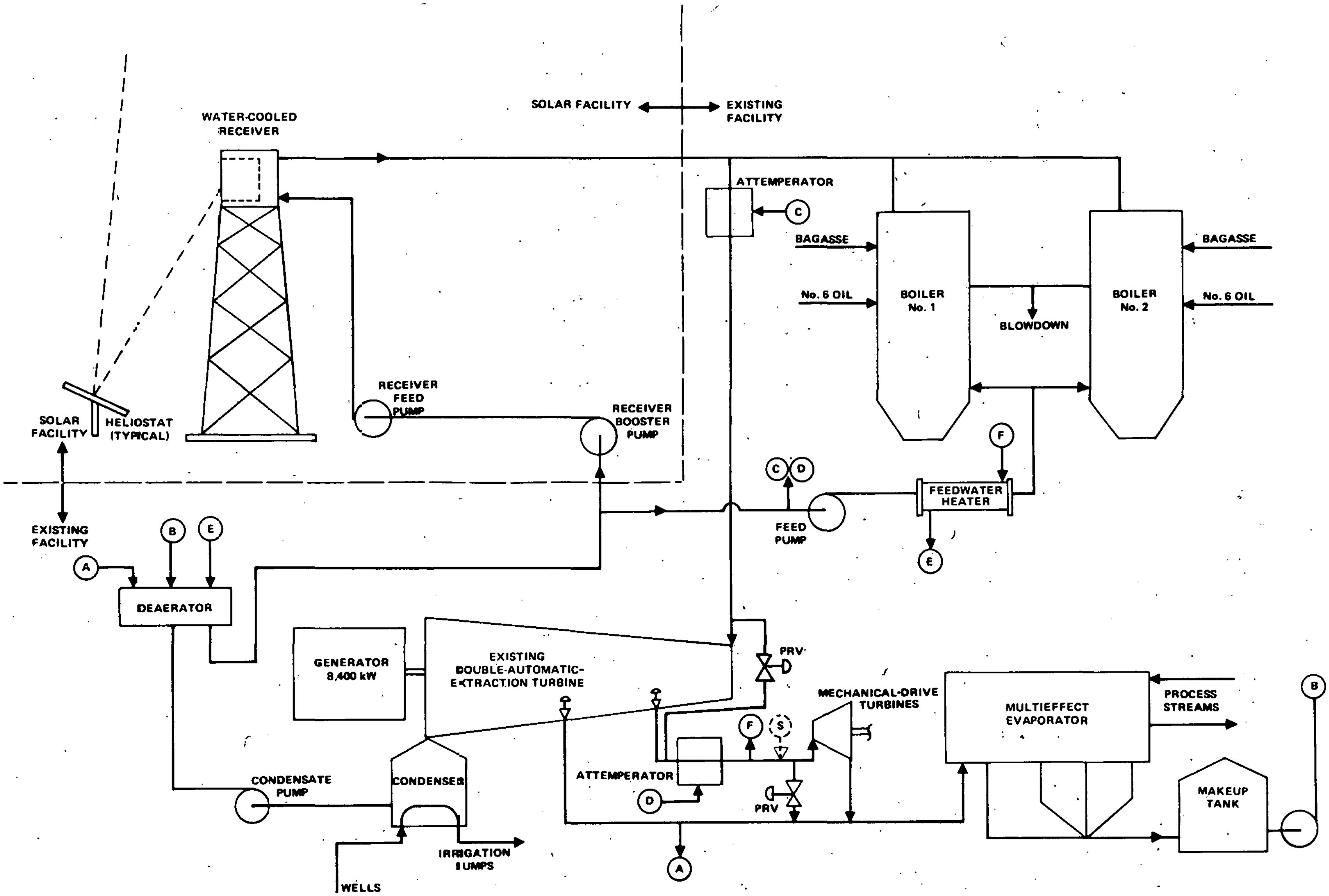


Figure A.1-1 SCHEMATIC DIAGRAM OF THE PROPOSED PIONEER SOLAR COGENERATION FACILITY coral limestone, sand, or gravelly alluvium. Ewa soil is neutral, with moderate permeability, and its mean temperature is 73F. The corrosion potential for uncoated steel is low.

Most of the canelands of Pioneer Mill are classified as Wahikuli stony (or very stony) silty clay. The surface layer is dark, reddish-brown silty clay about 15 inches thick. The subsoil, about 17 inches thick, is dark reddish-brown silty clay that has a subangular blocky structure. The substratum is hard basic igneous rock. Wahikuli soil is mildly alkaline, with moderate permeability, and its mean temperature is 75F. The corrosion potential for uncoated steel is low.

Site preparation work for the solar facility includes rough-grading the collector field area and providing improved access roads. Site work required for running piping and wiring (TBD).

1.2.2 Site Facilities

The site facilities of the solar cogeneration facility comprises both the new facilities and the modifications to existing facilities needed to bring about a solar retrofit. They include:

- Operations facilities
- Security facilities
- Storage and maintenance facilities
- Visitor's center
- Access roads

Other site facilities affected and descriptions (TBD).

1.2.3 Collector System

The collector system collects and concentrates solar radiation on the central receiver during all periods of sufficient insolation, and responds to commands from the master control system for normal focusing, sun tracking, defocusing, heliostat stow operations, and upset operating modes involving emergency defocusing to protect the receiver. The system is designed to be compatible with the receiver and provide energy to the receiver fluid consistent with the input requirements of the plant. The system includes the following:

- Heliostats, including reflective surface, structural support, drive units, control sensors, pedestals, foundations, cabling, and cable array installations
- Electromechanical and electrical controllers, including individual heliostat and heliostat field controllers, control system interface electronics, and power supplies

The heliostats are located in a radial stagger configuration and occupy a 2.62 rad (150°) circular sector of 360 m (1,180 ft) radius. The field centerline points in a direction approximately 15° east of due north. The sector contains 785 heliostats covering a land area of 1.70×10^5 m^2 (42 acres), which gives a packing efficiency of 24 percent.

The collector system design is based on the size and performance characteristics of the Northrup II second-generation heliostat. The heliostat contains 12 mirror modules, each of which is 1.22 m x 3.66 m (4 ft x 12 ft), resulting in a total reflective area (allowing for edge molding) of 52.8 m^2 (568 ft^2).

The normal stow position is vertical, but under extreme wind conditions, horizontal stow is required.

The description of collector field wiring, controls, and the heliostat foundations (TBD).

1.2.4 Receiver System

The receiver system permits the incident radiant energy to be transferred from the collector system into the water-steam working fluid. The system consists of an elevated receiver to intercept the radiant flux reflected from the collector system, a tower structure to support the receiver, feedwater riser piping from the receiver to the ground, a condensate storage tank and pumps at the base of the tower, and valves and controls that regulate the fluid flow, temperature, and pressure in such a manner as to ensure safe and efficient operation.

The receiver is a dual-cavity-type, natural-circulation steam generator with separate superheater circuitry. It is designed to produce 33,646 kg/hr (74,190 lb/hr) of superheated steam at a pressure of 6.74 MPa (978 psig) and a temperature of 439C (821F), with a thermal output of 26.2 MWt (88.5 x 10^6 Btu/hr). The receiver is fully insulated to reduce thermal losses to the environment. The aperture of each cavity is provided with an insulated door to reduce the receiver cooldown during overnight shutdown periods. Access to the receiver equipment is provided for inspection and maintenance, and provisions are made for user safety.

1.2.5 Thermal Transport System

The thermal transport system supplies condensate from Pioneer Mill to the receiver system storage tank at the base of the tower. It also carries superheated steam from the receiver system to the plant. The 1,058 m (3,472 ft) long steam pipe additionally serves as a limited-capacity buffer storage system. The steam piping is 15 cm (6 in.) in diameter with 10 cm (4 in.) of external insulation. The condensate piping is 10 cm (4 in.) in diameter with 3.8 cm (1.5 in.) of external insulation.

1.2.6 Nonsolar Energy System

The nonsolar energy system consists of the existing oil- and bagasse-fired boilers and ancillary equipment, the existing bagasse storage building, and the bagasse handling equipment. The following components in this system must be modified for the solar facility:

- Boiler instrumentation and controls
- Main steam piping and valves
- Condensate piping valves and pumps.

As part of the solar system retrofit, the capacity of the existing bagasse storage building and bagasse handling equipment will be increased. No thermal energy storage is required.

1.2.7 Master Control System

The master control system consists of the heliostat array control (HAC), the receiver system controls, the thermal transport system controls, and interfaces with the existing plant controls. The heliostat array controller is a central computer that provides all field control under normal operating conditions. Receiver controls maintain rated steam exit conditions during normal operation and act to protect the receiver during startup, shutdown, and plant upset conditions. The thermal transport system controls govern the supply of condensate to the tank at the base of the tower, monitor warmup of the steam supply pipe, and control admission of steam to the cogeneration facility during startup.

1.2.8 Specialized Equipment

The following specialized equipment has been included as part of the solar cogeneration facility:

- A vehicle for semiautomatic cleaning of the heliostats
- A vehicle for electrical/electronic troublshooting and repair of the heliostats.

Detail description and other specialized equipment (TBD).

1.2.9 Modes of Operation

The solar cogeneration facility is expected to have two steady-state operating modes:

- Solar steam generation mode
- Nonsolar steam generation mode.

In the solar steam generation mode, the solar water-steam receiver operates in parallel with the existing boilers. The existing boiler's output is reduced so that the maximum available solar-produced steam is used while the total steam demand is being met. Bagasse is displaced from the existing boilers into storage, and the use of oil is curtailed to the maximum extent possible.

In the nonsolar steam generation mode, during periods when solar-produced steam is unavailable, the existing boilers satisfy the entire steam demand, with bagasse if available. Oil is consumed only when necessary to meet the minimum steam demand.

The solar cogeneration facility is also expected to have the following transitional operating modes:

- Normal solar system startup mode
- Normal solar system shutdown mode
- Emergency solar system shutdown mode.

In the normal solar system startup mode, the solar receiver and thermal transport system are heated from cold or warm shutdown conditions to full operations temperature and pressure.

In the normal solar system shutdown mode, the solar receiver and thermal transport systems are transferred from normal steam generation to either a temporary shutdown condition (for cloud passage or overnight outage) or cold shutdown conditions (for longer outages).

In the emergency solar system shutdown mode, solar energy input to the receiver is reduced as fast as possible to meet operational or safety requirements.

Other operational modes (TBD).

1.3 DEFINITION OF TERMS

Annual Capacity Factor, Nonsolar. The annual nonsolar MWh divided by the product of 8,760 hr and the facility or unit rating in MWt.

Annual Capacity Factor, Overall. The annual solar MWh plus the annual nonsolar MWh, divided by the product of 8,760 hr and the facility or unit rating in MWt.

Annual Capacity Factor, Solar. The solar MWh divided by the product of 8,760 hr and the facility or unit rating in MWt.

Bagasse. The cellulose by-product of sugarcane processing.

Beam Pointing Error. The angular difference between the aim point and the beam centroid of a mirror of a mirror.

Cogeneration. The combined production of electrical or mechanical energy and useful thermal energy.

Conversion Efficiency, Gross. The gross output provided by a conversion device, divided by the total input power at specified conditions.

Conversion Efficiency, Net. The actual net output (after deducting parasitics) provided by a conversion device, divided by the required input power at specified conditions.

Demand. The power versus time profile required to satisfy the energy needs of the final consumer or end use consuming process.

Design Point. The time and day of the year at which the system is sized with reference to insolation, wind speed, temperature, humidity, dewpoint, and sun angles.

Direct Insolation. The nonscattered solar flux, expressed in W/m^2, falling on a surface of given orientation.

Geometric Concentration Ratio. The ratio of the projected area of a reflector system (on a plane normal to the insolation), divided by the absorber area.

Levelized Energy Cost. The cost per unit of energy that, if held constant throughout the life of the system and multiplied by the total system energy output, exactly expresses the after-tax expenses incurred, including return on investment.

Payback Period. A traditional measure of economic viability to investment project. A payback period is defined in several ways, one of which is the number of years required to accumulate fuel savings that exactly equals the initial capital cost of the system. Payback often does not give an accurate representation of total life-cycle values.

Present Value. The present value of capital and operating costs (or annual savings) brought back over a given time period, such as the life of the plant, is a single value of the costs or savings at a reference time accounting for economic factors such as escalation rates and rate of return on the capital.

Process Heat. The thermal energy used in industrial operations.

Receiver Efficiency. The ratio of thermal power output at the receiver base to solar power incident upon the receiver.

Solar Cogeneration. The combined production of electrical or mechanical energy and useful thermal energy by a solar facility.

Solar Flux. The rate of solar radiation per unit area, expressed in W/m^2.

Solar Fraction, Annual. The ratio of solar energy to the process divided by the total energy consumption, annual average, measured at turbine inlet.

Solar Fraction, Design Point. The ratio of solar energy to total plant energy at the design point.

Storage Capacity. The amount of bagasse that can be delivered from a fully charged storage building, expressed in kilograms or tons

Thermal Power, Boiler Output. The thermal power input to the working or transport fluids from the boiler, minus stack and miscellaneous losses.

Thermal Power, Receiver Output. The thermal power derived from the receiver; does not include electrical parasitic or downcomer thermal losses.

Section 2

REFERENCES

The equipment, materials, design, and construction of the solar cogeneration plant must comply with all federal, state, and local standards, regulations, codes, laws, and ordinances currently applicable for the specific site and the user. These will include the references listed below. If there is an overlap in, or conflict between, the requirement of these references and the applicable federal, state, county, or municipal codes, laws, or ordinances, that applicable requirement which is the most stringent will take precedence. The revision of these references in effect on September 30, 1980 will be used.

2.1 STANDARDS AND CODES

The standards and codes are as follows:

- ASME Boiler and Pressure Vessel Code

Section I	Power Boilers
Section II	Materials Specification
Section V	Nondestructive Examination
Section VIII	Unfired Pressure Vessels
Section IX	Welding and Brazing Qualifications

- ANSI B31.1 — 1977 Power Piping
- Uniform Building Code — 1976 Edition by International Conference of Building Officials
- ANSI A58.1 — 1972 Building Code Requirements for Minimum Design Loads in Buildings and Other Structures
- National Electrical Manufacturers Associations (NEMA) Standards
- Collector Subsystem Requirements Specification A10772, Issue D, Sandia National Laboratories, Livermore, CA

2.2 OTHER PUBLICATIONS AND DOCUMENTS

Other publications and documents are as follows:

- Transactions, American Society of Civil Engineers, Vol. 126, Part II, 1961, "Wind Forces on Structures," ASCE Paper No. 3269
- Manual of Steel Construction, 8th Edition, 1974, American Institute of Steel Construction

2.3 PERMITS AND LICENSES REQUIRED

See Table A.2-1.

2.4 APPLICABLE LAWS AND REGULATIONS

The applicable laws and regulations are as follows:

- Pertaining to permits and licenses (See Table A.2-1)
- Crude Oil Windfall Profit Tax Act of 1980. Federal tax credit of 25% (10% general + 15% solar)
- State tax credit regulation (10% allowed)
- Public Utilities Regulatory Policy Act (PURPA)

Table A.2-1

SOLAR COGENERATION FACILITY PERMITS AND LICENSES REQUIRED

Federal Authority				
Issue	Pipeline crossing of Kahoma Stream	Receiver tower affecting navigable airspace	Environmental impact, federally funded project	Construction in flood-prone area (Kahoma Stream)
Law	Section 404, FWPCA 33 USC, 1344	49 USC 1304, 1348, 1354, 1431, 1501	National Environmental Policy Act of 1969 (NEPA), PL. 91-190	Chapter X, Title 24, Federal Reg., Federal Insurance Administration
Regulations		14 CFR Part 77	National Council of Environmental Quality Guidelines	
Agency	U. S. Corp of Engineers, Honolulu District, Building 230, Ft. Shafter, HI 96858	Department of Transportation, Federal Aviation Administration, Pacific-Asia Region, P.O. Box 4009, Honolulu, HI 96813	Department of Energy	Department of Public Works, 200 South High Street, Wailuku HI 96793 and U. S. Corp of Engineers, Honolulu District Building 230, Ft. Shafter, HI 96858
Permits	Section 404 permit — $10	Hazard determination — no fee	Environmental impact statement required — no fee	Submit plans to Department of Public Works — no fee
Time frame	30-day comment period, 30-day notice for public hearing (if required). Issued within 120 days.	Not specified	Coterminous with State EIS, I.E., acceptance or rejection within 60 days	Not specified

Table A.2-1 (Cont'd)

SOLAR COGENERATION FACILITY PERMITS AND LICENSES REQUIRED

State Authority				
Issue	Planning for federally funded projects	Use of agricultural district lands	Use of lands in vicinity of designated historic site	Use of state-owned lands
Law	Section 204, Cities and Metro Dev. Act (1966) Title IV. Intergovernmental Cooperation Act (1968)	Chapter 205, HRS	Chapter 6, HRS, Paragraph 6-11	Chapter 343, HRS
Regulations	A-95 procedure manual, State of Hawaii	State Land Use Commission rules, County of Maui, Planning Commission rules		Environmental Quality Commission EIS Regulations
Agency	Department of Planning and Economic Development, 250 S. King Street, Honolulu, HI 96813	State Land Use Commission, Pacific Trade Center, Rm 1795; Maui Planning Commission, 200 S. High Street, Wailuku, HI 96793	Department of Natural Resources, State Parks and Historic Site Division, P.O. Box 621, Honolulu, HI 96809	Maui Planning Commission, 200 South High Street, Wailuku, HI 96793
Permits	1. STD Form 424 2. Clearinghouse form	Application form, $35 fee, seven sets of information	Filing of intention — no fee	Environmental impact statement if agency action. May not apply if applicant action
Time frame	Comments in 20 days. Six steps involved		90 days to action by Department	Acceptance or rejection within 60 days

Table A.2-1 (Cont'd)

SOLAR COGENERATION FACILITY PERMITS AND LICENSES REQUIRED

County Authority			
Issue	Grading of land	Construction within county highways	Outdoor lighting for receiver tower
Law	Chapter 24, Permanent Ordinances, County of Maui, 1971	Per Article 4, Chapter 21, Permanent Ordinances, County of Maui, 1971	Chapter 13, Permanent Ordinances, County of Maui, 1971
Regulation	Ordinance No. 6	Per Article 4, Chapter 21	Ordinance No. 733, National Electric Code
Agency	Department of Public Works, Land Use and Codes Enforcement Division, County of Maui, 200 South High Street, Wailuku, HI 96793	Department of Public Works, Land Use and Codes Enforcement Division, County of Maui, 200 South High Street, Wailuku, HI 96793	Department of Public Works, Land Use and Codes Enforcement Division, County of Maui, 200 South High Street, Wailuku, HI 96793
Permits	Grading permit application fee based on amount of grading	Permit application plans needed - no fee. Performance bond required	Electrical permit fee per ordinances. Set of plans by electrical engineer.
Time frame	45 days for review	14 days for review	1 to 60 months, depending on scope of work

Table A.2-1 (Cont'd)

SOLAR COGENERATION FACILITY PERMITS AND LICENSES REQUIRED

County Authority			
Issue	Building, electrical, and plumbing permits	Construction of driveway onto county highways	Conflict with county general plan (hospital at receiver tower site)
Law	Chapters 12, 13, 14, Permanent Ordinances, County of Maui, 1971	Chapter 21, Article 7, Permanent Ordinances, County of Maui, 1971	Chapter 9, Permanent Ordinances, County of Maui, 1971
Regulations	Ordinances No. 735, 786, 852, 856, Uniform Building Code (1970), National Electric Code (1970), Uniform Plumbing Code (1969)	Ordinance No. 684	Maui County General Plan and Policies, Region 9, Lahaina, Plate 6
Agency	Department of Public Works, Land Use and Enforcement Division, County of Maui, 200 South High Street, Wailuku, HI, 96793	Department of Public Works, Land Use and Enforcement Division County of Maui, 200 South High Street, Wailuku, HI, 96793	Planning Department, 200 South High Street, Wailuku, HI 96793
Permits	Building permit fee based on evaluation. Environmental form (State DOH) coordinated with grading permit	Permit form, two sets of plans	Review of request by director to amend land use map
Time frame	3 to 6 months	30 days for review	30 days Planning Department, 45 days County Council action

Section 3

REQUIREMENTS

The solar cogeneration facility shall be designed to meet the performance requirements stated in this section. This specification is applicable as a design requirement only to the new or modified portions of the solar cogeneration facility. The solar cogeneration design specifications shall make maximum use of completed or ongoing DOE solar R&D activities. The design life of the solar cogeneration facility shall be 20 years.

3.1 SITE

The site for the solar cogeneration facility shall be on land currently owned or leased by Pioneer Mill Co., Ltd., or on land that can be leased from the State of Hawaii. The design should result in minimum impact on the agricultural operations in adjacent areas.

Site preparation shall be limited to rough grading of the heliostat field area. Natural drainage provision shall be maintained.

Access roads with crushed rock surface shall be contructed to the tower and completely around the heliostat field. Security fencing shall be put up to restrict entry into the heliostat field and tower area.

3.2 SITE FACILITIES

All maintenance, storage, and operations facilities shall be integrated with the existing plant facilities. The existing control room shall be expanded to accommodate the solar retrofit, and communication links with the solar tower shall be provided. Closed-circuit TV cameras shall be installed to give the operators visual information on system operations and approaching cloud patterns.

A visitor's center should be considered for location on the hill north of the heliostat field. This center should afford a good view of the center but should be far enought away from the factory and heliostat field so as to prevent interference with operators.

3.3 COLLECTOR SYSTEM

The collector system shall reflect solar radiation into the receiver in a manner that satisfies receiver incident heat flux requirements. In addition, the collector system shall respond to commands from the master control system for emergency defocusing of the reflected energy or to protect the heliostat array against environmental extremes. The heliostats shall be properly positioned for repair or mainenance in response to either master control or manual commands. Heliostat design shall provide for stored or safe position at night, during periodic maintenance, and during adverse weather conditions.

3.2.1 Collector Field

The collector field shall be designed so that 26.2 MWt of radiant solar power will be delivered to the fluid in the receiver at 1 p.m. of an equinox day, with a direct normal insolation value of 950 W/m^2.

The collector field design shall provide the optimum heliostat layout and shall take the following into consideration:

- Heliostat capital cost
- Field wiring cost
- Land availability

- Heliostat performance
- Receiver size
- Receiver tower height
- Shading and blocking
- Atmospheric attenuation
- Sun position
- Piping cost
- Foundation requirements
- Adjacent land use impacts

The collector system shall function as appropriate for all steady-state modes of plant operation. This shall include the capability of controlling the number of heliostats in the tracking mode so as to vary the redirected flux to the receiver between zero and the maximum achievable level with step changes of 6 percent of the total collector field output.

All power and control wiring shall be installed in a manner to prevent damage resulting from environmental conditions, personnel and vehicular activities, rodents, and insects.

3.2.2 Heliostats

Heliostats design shall be consistent with Sandia Specifications A10772, except as noted in Table A.3-1.

3.4 RECEIVER SYSTEM

3.4.1 Receiver

Design and Operation. The receiver shall be a two-cavity-type, natural-circulation steam generator with separate superheat circuitry. It shall be sized to deliver 26.2 MWt (88.5×10^6 Btu/hr) to the receiver working

Table A.3-1

EXCEPTIONS TO DOE SPECIFICATION A10772, ISSUE COLLECTOR SYSTEM REQUIREMENTS

Section	Exception
General	Change "Subsystem" to "System"
2.1	Delete "Soil and Foundation Investigation Report 5 MW STTF, Sandia Labs"
3.1.2	Delete all
3.2.1 (c&d)	Change 12 m/s (27 mps) operational wind load to 6.7 m/s (15 mph) in three places
3.2.6	Environmental conditions in this specification shall be used in place of Appendix 1
3.2.6.1	Change 12 m/s (27 mph) to 6.7 m/s (15 mph)
Appendix 1	Delete

fluid (water-steam) at the system design point (1 p.m., equinox). The receiver shall be capable of operating safely and reliably for 20 years with heat flux levels not exceeding 0.69 MWt/m^2 (220,000 Btu/hr-ft^2) for boiler tubes, 0.50 MWt/m^2 (160,000 Btu/hr-ft^2) for superheater tubes, and 0.35 MWt/m^2 (110,000 Btu/hr-ft^2) for preheater tubes.

The feedwater enters the receiver at 113C (235F). At the system design point, steam shall be generated at the rate of 33,646 kg/hr (74,190 lb/hr) with outlet conditions of 6.81 MPa (987 psia) and 439C (821F). The maximum allowable pressure drop through the superheater shall be 758 kPa (110 psi).

The major components of the receiver shall be a boiler section, a steam drum, and a superheater section. The boiler tubes generate a steam-water mixture from feedwater; the drum separates the saturated steam from the mixture; and the superheater tubes raise the steam temperature to the specified outlet conditions. These three major componenets shall be linked together by a system of downcomers, feeders, headers, risers, and connecting piping. Attemperators shall be provided between the superheater passes for steam temperature control.

The receiver shall be fully insulated to reduce thermal losses to the environment. The aperture of the cavity shall be provided with an insulated door than can be closed to minimize heat loss and resultant cooling of the receiver during overnight shutdown. The entire receiver shall be supported from a structural-steel framework attached to the tower. All structures and supports shall be designed for wind and earthquake loading in accordance with the environmental criteria as listed in Section 4.

<u>Receiver Working Fluid</u>. The receiver working fluid shall be water-steam. The water treatment system shall maintain the desired quality of feedwater entering the receiver. The maximum limits on critical impurities

in the feedwater with 2 percent continuous blowdown are:

Oxygen	7 ppb
Silica	100 ppb
Iron	10 ppb
Copper	5 ppb
Hydrazine	20 ppb
Total hardness	Minimum detectable by ASTM D-1126 B or equivalent

The concentration of impurities in the boiler water shall be limited by continuous blowdown from the drum. The recommended maximum limits on critical impurities in the boiler water are:

Total dissolved solids	300 ppm
Silica	5 ppm

3.4.2 Tower

The tower shall support the tower piping and the receiver cavities, with the aperture centerline at 76 m (250 ft), and shall satisfy the following criteria:

- Adequate access to the receiver, piping, and valves provided for inspection, maintenance, and repair
- Adequate provisions for crew safety at all times during operation, inspection, maintenance, and repair
- No permanent damage to the tower as a result of the survival wind specified in Section 4
- A tower design based on the peak ground accelerations of UBC Zone 2, combined with the response spectrum given by NRC Regulatory Guide 1.60 and the damping values given for the operating basis earthquakes in NRC Regulatory Guide 1.61
- A tower design that blends with the surrounding environment to the maximum extent practical.

3.4.3 Piping, Pumps, Tanks, and Controls

The receiver system shall include a tank of supply condensate at the base of the tower and pumps and controls sufficient to ensure the needed flow of condensate to the receiver during all operating modes. This part of the receiver system shall incorporate the following features:

- Redundant pumps
- Condensate flow-modulating capability operating in response to the receiver three-element control signal
- A steam recirculation capability (to the condensate holding tank) for use during startup and upset transients
- Deaeration capability in the condensate holding tank

3.5 THERMAL TRANSPORT SYSTEM

The thermal transport system shall convey condensate from Pioneer Mill to the receiver system condensate holding tank, and convey superheated steam from the receiver system to Pioneer Mill. This system shall incorporate the following features:

- Redundant condensate supply pumps
- Condensate flow control based on the condensate holding tank liquid level
- Condensate line vent and drain provisions
- Steam line vent and drain provisions
- Control equipment for steam admission at Pioneer Mill to ensure matching of the steam conditions with the existing boiler.

3.6 NONSOLAR ENERGY SYSTEM

The nonsolar energy system is the existing facility modified to accommodate a solar retrofit. Interfaces between this system and the rest of the solar facility shall be at the existing equipment boundaries unless otherwise noted. The design of the solar facility shall minimize operational impacts on the existing facility and shall make maximum use of the normal factory shutdown period for installation of the interfaces with the solar system.

3.7 MASTER CONTROL SYSTEM

The master control system shall consist of the collector system control, the receiver system controls, the thermal transport system controls, and the control interfaces with the existing facility.

3.7.1 Modes of Operation

A master control system shall be provided to sense, detect, monitor, and control all system and subsystem parameters necessary to ensure safe and proper operation of the solar energy producing portion of the solar cogenerating facility.

The collector system controls shall be capable of:

- Relaying time of day and aim point instructions to the heliostat and changing the operating mode to the heliostat as required
- Starting up, shutting down, and stowing the heliostats using preprogrammed automatic sequences compatible with the system condition of the solar facility
- Providing status indication and data-logging capability for the collector system

The receiver system controls shall be capable of:

- Maintaining pressure, temperature, and flow control of the receiver during all normal operating modes
- Detecting problems in the receiver operation and providing an alarm when these problems occur
- Starting up and shutting down the receiver using preprogrammed automatic sequences

- Sending emergency signals to the thermal transport system and collector system to protect the receiver from damage
- Providing receiver status and data logging for the operator.

The thermal transport system controls shall be capable of:

- Delivering the working fluid between the receiver and the existing facility during all normal operating modes
- Starting up and shutting down the thermal transport system in conjunction with the receiver system and the existing facility
- Providing system status and data logging for the thermal transport system.

3.7.2 Design Criteria

The master control system shall be designed in accordance with the following criteria:

- Design simplicity, requiring:
  - Standard control practices
  - Simple, well-defined interfaces between the master control system and the other facility system controls.
- Operational simplicity, requiring:
  - Primary operation to be automatic, with operator override capability
  - Single-console control during both automatic and manual operations
  - Easily read displays
- Design reliability, requiring:
  - Use of proven designs
  - Elimination of single-point failures through redundant elements whenever it is cost-effective to do so.

- Operational reliability, requiring:
    - Separation of facility operational controls from data acquisition and evaluation peripheral controls within the master control system (thus permitting each control to function independently)
    - Manual operating of the facility in the event of failure of the master control system (thus requiring independent controls for the other facility systems).
- Cost-effective design, requiring:
    - Selection of off-the-shelf equipment
    - Modularity of the major subsystems of the master control system
    - Generically similar equipment in each major master control system functional element.

3.7.3 Interface Requirements

In terms of an overall process control strategy, the solar-powered boiler shall operate in principle as a third fossil-fueled boiler. The solar boiler shall operate at maximum capacity, and the fossil-fueled boilers shall be modulated to make up the remainder of the process load. The fossil boiler control system shall respond to steam distribution demand. There is no restriction of solar boiler output unless fossil-fueled boilers are at minimal output.

3.8 SERVICE LIFE

Equipment shall be designed for a service life of 20 years. Exceptions must be noted.

3.9 SAFETY

The solar facility design shall include provisions for assuring the safety of crews for inspection, maintenance, and repair of equipment on and in the receiver tower and in the heliostat field. Abort switches and manual override switches shall be located in potentially dangerous areas for the protection of personnel inadvertently placed in hazard.

3.10 RELIABILITY

The addition of the solar steam facility shall not decrease overall plant availability (exclusive of insolation conditions).

3.11 MAINTAINABILITY

The solar steam facility shall be designed to be compatible with existing plant maintenance practices. Easy access for maintenance shall be provided and components such as electronic units, motors, and valves shall be easily serviced and replaced. A minimum of specialized equipment shall be required for plant maintenance.

Section 4

ENVIRONMENTAL CRITERIA

4.1 FACILITY ENVIRONMENTAL DESIGN REQUIREMENTS

The system shall be capable of operating and/or surviving under the temperature, wind, rain, earthquake, hail, and lightening conditions described below.

4.1.1 Temperature

The plant shall be able to operate in an ambient air temperature range from 10C (50F) to 35C (95F). Performance requirements shall be met throughout an ambient air temperature range selected to be consistent with efficient facility operation. The survival range is 7C (45F) to 38C (100F).

4.1.2 Wind

The facility shall be capable of operating with the approximate wind profile shown in Figure A.4-1.

For the calculation of wind speed at other elevations, the following mode is assumed:

$$V_H = V_1 \ (H/H_1)^c$$

where V_H = wind velocity at height
V_1 = reference wind velocity
H_1 = reference height, 10 m (30 ft)
c = 0.15

Performance requirements shall be met for the most adverse combination of wind and temperature conditions selected to be consistent with efficient facility operation. Wind analysis shall satisfy the requirements of ANSI A58.1-1972.

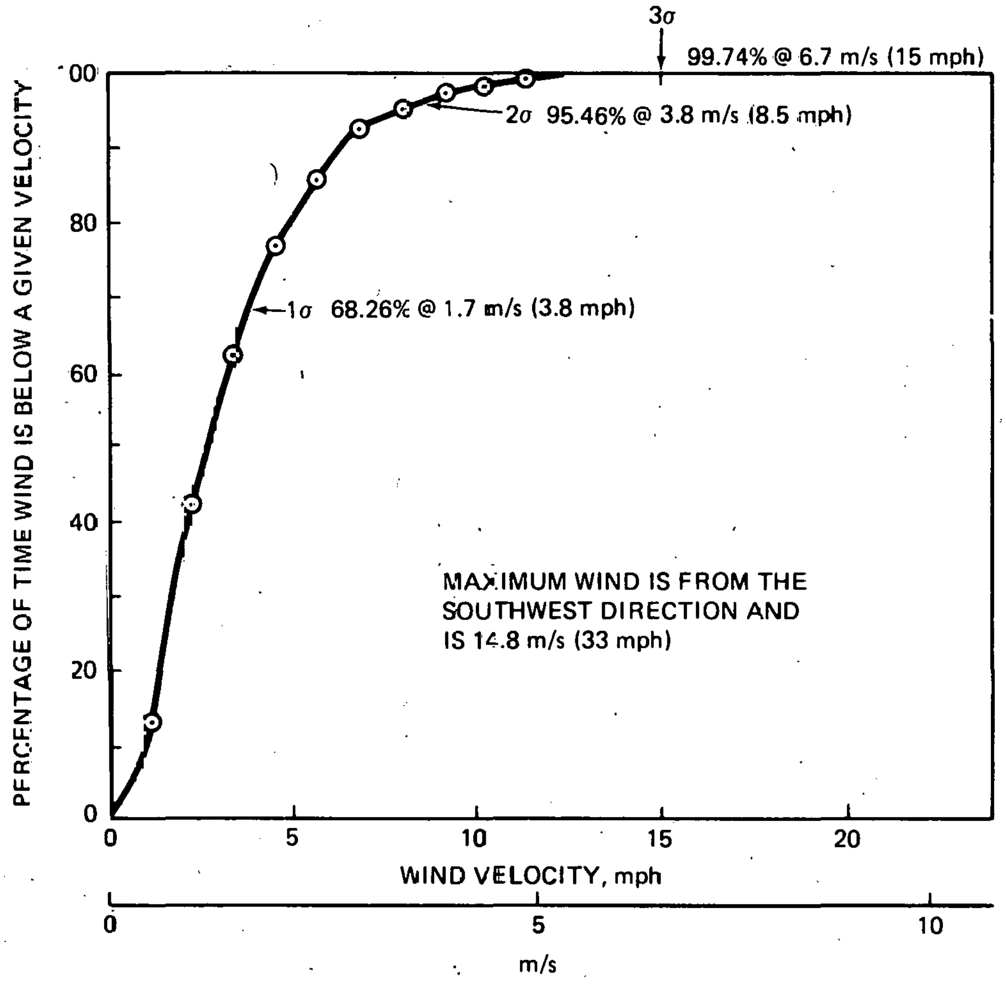


Figure A.4-1 PIONEER MILL WIND PROFILE AT 10-METER ELEVATION SEPTEMBER 1964 TO SEPTEMBER 1968

The system shall be capable of surviving appropriate combinations of the environments specified below:

- Wind. The facility shall survive winds with a maximum speed, including gusts of 40 m/s (90 mph), without damage. A local wind vector variation of +10° from the horizontal shall be assumed for the survival conditions

- Wind rise rate. A maximum wind rise rate of 0.01 m/s^2 (0.02 mph/min) at 10 m (30 ft) elevation) shall be used in calculating wind loads during stowage and for tower survival.

However, the facility should withstand, without catastrophic failure, a maximum wind of 22 m/s (50 mph) from any direction, for any heliostat orientation, such as might result from unusually rapid wind rise rates, e.g., severe thunderstorm gust fronts.

4.1.3 Rain

The facility shall survive the following rainfall conditions:

Average annual	345 mm (13.6 in.)
Maximum 24-hr rate	152 mm (6 in.)

4.1.4 Earthquake

Peak ground accelerations shall be as presented below per applicable UBC zone. This peak ground acceleration is combined with the response spectrum given by NRC Regulation Guide 1.60 and the damping values given for the operating bases earthquake in NRC Regulation Guide 1.61. Zone 2 values shall be used for the baseline design.

The maximum survival ground acceleration for UBC Zone 2 under average or firm conditions is 0.1 g.

4.1.5 Hail

The facility shall be able to survive hail impact up to the limits given below.

	Heliostats in Any Orientation	Heliostats Stowed
Diameter	10 mm (0.75 in.)	25 mm (1.0 in.)
Specific gravity	0.9	0.9
Terminal velocity	20 m/s (65 fps)	23 m/s (75 fps)

4.1.6 Lightning Considerations

The facility shall be provided with a lightning protection system. Such protection shall be cost-effective with respect to risk of lightning strike.

Total destruction of a single heliostat and its controller when subjected to a direct lightning strike is acceptable.

Damage to a heliostat adjacent to a direct lightning strike shall be minimized. The central controller and the local controllers of heliostats adjacent to a direct lightning strike shall be protected, or alternative control methods provided to minimize loss of collector subsystem control.

4.2 ENVIRONMENTAL STANDARDS

4.2.1 Air Quality Control Standards.

The facility pollution emission requirements are shown below. Other requirements TBD.

Particulates	1.0 lb/MBtu
Stack gas capacity	40 percent

4.2.2 Water Quality Standards

The retrofitted plant shall not discharge any effluent that adversely affects groundwater quality.

Appendix B

SITE INSOLATION MEASUREMENT PROGRAM

Appendix B

SITE INSOLATION MEASUREMENT PROGRAM

Prior insolation measurements in the vicinity of Pioneer Mill are an insufficient basis for the solar model needed to determine the annual performance of the solar cogeneration facility. Available measurements include 6 to 8 years of data from the "wig wag" instrument used at Pioneer Mill for determining irrigation requirements. Approximately 1 year of global radiation data from a pyranometer at the Lahaina Recreation Center are also available. To provide added data for the insolation model, an insolation measurement station was placed in operation in October 1980.

The station was installed by Professor Paul Ekern of the University of Hawaii Natural Energy Institute. In addition to taking "wig wag" instrument readings, the station records pyranometer measurements of total global radiation and direct normal insolation measurements from an Eppley normal incidence pyrheliometer (NIP).

These instruments, installed on the grounds of the Pioneer Mill offices, have provided insolation measurements since October 1980. (Calibration and mounting problems were experienced during the first 2 weeks.) This appendix presents tabulations of integrated hourly NIP measurements through February 1981 and pencharts of instantaneous NIP measurements for 3 weeks in November-December 1980. Every major division on the penchart time scale represents one half hour. Penchart time is not synchronized with local time. The penchart vertical scale measures 0 to 10 millivolts. Corresponding insolation values (in W/m^2) are obtained by dividing the penchart reading (in millivolts) by 0.00892. The tabulated NIP insolation values are converted from cal/cm^2 to W/m^2 by multiplying by 11.6222.

PIONEER MILL DIRECT STATION 50 HOURLY SOLAR RADIATION - CAL./SQ. CM

HOUR DAY	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	TOTAL
21080	*****	*****	*****	*****	*****	69.0	75.2	80.3	78.0	74.6	69.0	49.8	15.3	0.0	0.0	*****
31080	0.0	0.0	20.9	63.9	74.1	78.0	70.7	30.5	2.8	1.1	1.1	1.1	0.6	0.0	0.0	344.9
41080	0.0	0.0	23.7	66.2	74.1	71.2	53.1	12.4	1.1	1.1	1.1	1.1	0.6	0.0	0.0	305.9
51080	0.0	0.0	53.1	71.2	72.4	63.9	31.1	5.1	1.1	1.1	1.1	0.6	0.0	0.0	0.0	300.8
61080	0.0	0.0	49.2	68.4	68.4	57.7	17.5	1.1	0.6	0.6	0.6	1.1	0.6	0.0	0.0	265.7
71080	0.0	0.0	20.9	43.5	69.0	52.0	11.9	76.3	58.2	68.4	65.0	41.8	10.2	0.0	0.0	517.3
81080	0.0	0.0	18.1	54.3	74.1	49.8	11.3	1.1	1.1	20.9	37.3	43.5	19.2	0.0	0.0	330.8
91080	0.0	0.0	3.4	55.4	68.4	73.5	75.2	75.8	76.9	70.7	66.2	56.0	20.9	0.0	0.0	642.3
101080	0.0	0.0	0.0	17.0	25.4	18.7	40.7	44.7	37.9	52.6	29.4	48.1	17.5	0.0	0.0	331.9
111080	0.0	0.0	4.5	35.6	20.4	57.7	75.8	75.8	69.0	65.6	60.5	55.4	20.9	0.0	0.0	541.1
121080	0.0	0.0	8.5	2.3	22.1	42.4	31.1	56.5	76.9	75.2	70.1	54.3	18.7	0.0	0.0	458.0
131080	0.0	0.0	10.2	19.8	31.7	35.1	62.2	49.8	61.6	8.5	18.1	0.6	0.0	0.0	0.0	297.4
141080	0.0	0.0	40.1	59.9	67.8	77.5	78.6	73.5	75.2	74.1	67.3	50.9	18.7	0.0	0.0	683.6
151080	0.0	0.0	43.0	65.0	67.8	62.8	76.3	62.8	72.9	61.6	59.4	39.6	9.0	0.0	0.0	620.2
161080	0.0	0.0	5.7	18.7	69.5	53.7	25.4	71.2	68.4	61.1	70.7	57.1	20.9	0.0	0.0	522.4
171080	0.0	0.0	9.0	56.5	65.6	74.1	78.0	79.2	78.0	75.2	69.0	53.1	19.2	0.0	0.0	657.0
181080	0.0	0.0	43.0	67.8	75.2	78.6	80.3	80.3	78.0	75.8	70.1	52.0	20.9	0.0	0.0	722.0
191080	0.0	0.0	43.0	68.4	74.1	78.6	79.7	78.6	75.8	75.2	68.4	45.2	13.6	0.0	0.0	700.5
201080	0.0	0.0	43.0	36.2	73.5	78.0	74.1	27.1	33.9	9.6	67.8	56.0	18.1	0.0	0.0	517.3
211080	0.0	0.0	1.7	56.5	74.6	75.2	47.5	22.6	32.2	72.9	66.7	53.7	15.3	0.0	0.0	519.0
221080	0.0	0.0	35.1	65.0	68.4	77.5	79.7	72.4	62.8	49.2	37.9	33.4	13.6	0.0	0.0	594.8
231080	0.0	0.0	26.6	69.0	76.3	79.7	81.4	80.3	79.7	75.8	69.0	57.7	14.1	0.0	0.0	709.6
241080	0.0	0.0	0.0	17.0	45.8	40.7	14.1	1.1	45.8	74.1	69.0	53.7	11.3	0.0	0.0	372.6
251080	0.0	0.0	0.0	0.0	2.3	2.8	24.9	44.7	78.6	75.8	67.3	44.1	12.4	0.0	0.0	352.8
261080	0.0	0.0	18.7	37.9	63.9	36.2	48.6	41.8	75.2	73.5	64.5	33.9	7.9	0.0	0.0	502.1
271080	0.0	0.0	9.6	39.0	43.5	49.8	46.9	66.7	32.2	60.5	65.6	46.4	10.7	0.0	0.0	471.0
281080	0.0	0.0	41.8	69.5	75.8	80.3	80.9	80.9	65.0	63.9	68.4	54.8	13.0	0.0	0.0	694.3
291080	0.0	0.0	43.5	70.7	76.9	80.3	81.4	81.4	79.7	76.9	71.2	55.4	14.1	0.0	0.0	731.6
301080	0.0	0.0	1.1	41.8	71.2	50.9	53.1	47.5	67.8	54.3	60.5	53.7	11.9	0.0	0.0	513.9
311080	0.0	0.0	2.8	59.4	62.8	35.1	5.1	37.3	70.1	54.3	65.6	54.8	11.3	0.0	0.0	458.5
AVERAGE	0.0	0.0	21.4	48.1	60.5	59.3	53.7	52.0	54.6	53.5	53.3	41.6	12.7	0.0	0.0	506.2
MAXIMUM	0.0	0.0	53.1	71.2	76.9	80.3	81.4	81.4	79.7	76.9	71.2	57.7	20.9	0.0	0.0	731.6
MINIMUM	0.0	0.0	0.0	0.0	2.3	2.8	5.1	1.1	0.6	0.6	0.6	0.6	0.0	0.0	0.0	265.7

PIONEER MILL DIRECT STATION 50 HOURLY SOLAR RADIATION - CAL./SQ. CM

HOUR DAY	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	TOTAL
11180	0.0	0.0	31.7	66.2	46.9	28.3	1.1	45.2	28.3	32.8	58.8	54.3	11.3	0.0	0.0	404.8
21180	0.0	0.0	38.4	66.7	76.3	79.2	78.6	81.4	77.5	58.2	66.2	54.3	9.6	0.0	0.0	686.4
31180	0.0	0.0	37.9	68.4	74.6	79.2	80.9	78.6	76.9	71.2	64.5	50.9	7.4	0.0	0.0	690.4
41180	0.0	0.0	7.9	20.9	65.6	59.4	70.7	67.8	69.0	64.5	55.4	39.6	4.5	0.0	0.0	525.3
51180	0.0	0.0	32.8	64.5	71.2	78.0	79.2	78.0	78.0	74.6	67.3	52.0	5.1	0.0	0.0	680.7
61180	0.0	0.0	0.6	6.8	56.5	77.5	24.9	75.8	76.3	75.2	69.0	55.4	7.4	0.0	0.0	525.3
71180	0.0	0.0	24.9	58.8	72.9	76.3	24.9	69.5	66.2	70.1	61.1	40.7	3.4	0.0	0.0	568.8
81180	0.0	0.0	1.1	23.2	7.4	25.4	56.5	44.7	39.6	44.1	59.9	49.2	4.0	0.0	0.0	355.1
91180	0.0	0.0	6.2	20.4	48.6	59.4	59.9	50.3	23.2	35.1	26.6	26.0	1.7	0.0	0.0	357.3
101180	0.0	0.0	10.7	26.0	45.8	57.7	63.9	58.2	35.1	62.2	36.8	6.8	0.0	0.0	0.0	403.1
111180	0.0	0.0	15.8	58.8	66.7	74.1	76.9	73.5	73.5	70.7	62.2	39.0	2.8	0.0	0.0	614.0
121180	0.0	0.0	21.5	57.1	59.4	75.2	77.5	76.9	76.3	72.4	60.5	38.4	2.8	0.0	0.0	618.0
131180	0.0	0.0	22.6	64.5	73.5	78.0	79.2	78.6	75.8	74.1	67.3	50.3	2.8	0.0	0.0	666.6
141180	0.0	0.0	24.3	60.5	71.8	79.7	82.0	80.9	77.5	75.2	68.4	49.2	1.7	0.0	0.0	671.1
151180	0.0	0.0	0.6	28.3	46.9	27.7	28.3	28.3	26.6	9.0	0.6	1.7	0.0	0.0	0.0	197.9
161180	0.0	0.0	6.2	44.1	69.0	79.2	81.4	80.9	79.2	75.2	67.8	49.8	1.7	0.0	0.0	634.4
171180	0.0	0.0	15.8	63.3	72.9	76.3	78.6	79.7	78.6	75.2	68.4	54.3	1.7	0.0	0.0	664.9
181180	0.0	0.0	17.5	65.6	74.1	78.6	79.2	79.7	78.0	71.8	66.7	16.4	0.0	0.0	0.0	627.6
191180	0.0	0.0	19.8	65.6	72.4	79.7	80.9	80.9	79.7	76.3	67.8	52.0	2.3	0.6	0.0	677.9
201180	0.0	0.6	21.5	63.3	67.3	69.5	69.0	75.2	73.5	70.7	58.8	43.0	2.3	0.0	0.0	614.6
211180	0.0	0.0	8.5	59.4	64.5	69.5	79.2	78.0	75.8	60.5	40.1	36.8	2.3	0.0	0.0	574.4
221180	0.0	0.0	11.3	30.0	53.1	68.4	56.0	67.3	73.5	66.2	55.4	32.2	2.3	0.0	0.0	515.6
231180	0.0	0.0	13.0	60.5	69.5	74.1	53.7	44.7	73.5	72.4	65.0	45.8	2.8	0.0	0.0	575.0
241180	0.0	0.0	20.9	61.1	31.1	71.2	76.9	71.2	48.6	58.2	63.9	48.6	3.4	0.0	0.0	555.2
251180	0.0	0.0	20.9	63.3	72.9	76.9	76.3	64.5	49.8	71.2	9.6	6.8	2.8	0.0	0.0	515.1
261180	0.0	0.0	1.1	18.7	57.7	75.2	78.0	78.0	76.3	60.5	45.2	4.0	2.3	0.0	0.0	497.0
271180	0.0	0.0	19.8	61.1	71.2	76.9	79.2	79.7	72.9	64.5	62.8	30.0	1.1	0.0	0.0	619.1
281180	0.0	0.0	19.8	64.5	74.1	78.0	80.3	79.7	78.6	74.6	67.3	49.2	4.0	0.0	0.0	670.0
291180	0.0	0.0	20.9	65.6	74.1	78.6	81.4	82.0	79.7	75.8	68.4	31.1	1.1	0.6	0.0	659.3
301180	0.0	0.0	20.4	63.3	74.1	79.2	82.0	80.9	79.7	76.3	69.5	53.7	4.5	0.0	0.0	683.6
AVERAGE	0.0	0.0	17.2	51.3	62.7	69.5	67.2	70.3	66.6	64.6	56.7	38.7	3.3	0.0	0.0	568.3
MAXIMUM	0.0	0.6	38.4	68.4	76.3	79.7	82.0	82.0	79.7	76.3	69.5	55.4	11.3	0.6	0.0	690.4
MINIMUN	0.0	0.0	0.6	6.8	7.4	25.4	1.1	28.3	23.2	9.0	0.6	1.7	0.0	0.0	0.0	197.9

PIONEER MILL DIRECT STATION 50 HOURLY SOLAR RADIATION - CAL./SQ. CM

HOUR DAY	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	TOTAL
11280	0.0	0.0	18.7	63.9	73.5	77.5	24.9	79.7	48.1	44.1	68.4	54.8	4.5	0.0	0.0	558.0
21280	0.0	0.6	19.8	69.0	77.5	82.0	84.8	84.8	83.7	79.7	73.5	59.4	5.1	0.0	0.0	719.8
31280	0.0	0.0	18.1	68.4	76.3	82.0	83.7	83.1	82.0	78.0	67.8	51.5	4.0	0.0	0.0	694.9
41280	0.0	0.0	15.8	63.3	74.1	79.2	80.3	65.0	74.1	17.0	0.0	0.6	0.6	0.0	0.0	469.8
51280	0.0	0.0	0.6	2.8	1.1	1.1	3.4	2.8	2.3	0.6	1.7	0.0	0.0	0.0	0.0	16.4
61280	0.0	0.0	0.6	0.6	1.1	16.4	53.7	50.9	45.2	30.0	1.7	0.6	0.0	0.0	0.0	200.7
71280	0.0	0.0	9.6	37.3	66.7	74.6	78.0	58.8	74.1	47.5	65.6	50.9	5.1	0.0	0.0	568.2
81280	0.0	0.6	13.0	58.2	70.1	74.6	76.3	72.9	72.4	67.3	64.5	47.5	4.5	0.0	0.0	621.9
91280	0.0	0.0	12.4	59.9	70.7	75.8	76.9	76.9	51.5	17.0	41.3	40.1	4.0	0.0	0.0	526.4
101280	0.0	0.0	13.0	63.3	72.9	77.5	78.6	79.2	78.6	75.2	68.4	51.5	5.1	0.0	0.0	663.2
111280	0.0	0.0	11.3	59.9	10.7	15.8	78.0	78.6	78.0	75.2	68.4	53.1	5.7	0.0	0.0	534.9
121280	0.0	0.0	11.3	62.8	65.0	62.8	79.7	78.0	79.2	57.1	34.5	32.2	5.7	0.0	0.0	568.2
131280	0.0	0.0	0.0	5.1	32.2	75.8	79.2	80.3	79.7	76.3	69.5	55.4	6.8	0.0	0.0	560.3
141280	0.0	0.0	0.0	0.0	0.6	8.5	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.4
151280	0.0	0.0	4.0	43.0	43.0	52.0	50.9	61.6	10.2	0.6	0.0	0.0	0.6	0.0	0.0	265.7
161280	0.0	0.0	9.0	62.8	72.9	76.9	79.7	46.9	52.6	74.1	68.4	54.3	7.9	0.0	0.0	605.5
171280	0.0	0.0	8.5	63.3	72.4	70.7	59.4	76.3	77.5	53.7	57.1	49.2	4.5	0.0	0.0	592.5
191280	0.0	0.0	0.0	20.9	8.5	0.6	0.6	1.7	0.6	1.7	13.0	15.8	2.3	0.0	0.0	65.6
201280	0.0	0.0	8.5	63.3	74.1	79.2	35.6	58.8	58.2	49.8	46.4	41.3	0.0	0.0	0.0	515.1
211280	0.0	0.0	1.7	18.1	15.3	0.6	2.3	9.0	8.5	4.5	1.1	0.0	0.0	0.0	0.0	61.1
221280	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	6.2	3.4	6.2	1.1	0.0	0.0	19.8
231280	0.0	0.0	0.0	11.3	22.6	23.7	46.4	43.5	74.6	59.4	52.6	24.9	6.8	0.0	0.0	365.8
241280	0.0	0.0	0.0	0.6	0.6	0.6	2.8	4.0	1.1	11.9	26.0	4.0	1.1	0.0	0.0	52.6
251280	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.6	0.0	0.0	0.6	0.0	0.0	0.0	0.0	1.7
261280	0.0	0.0	4.5	49.8	56.5	65.6	50.3	74.6	64.5	19.2	54.8	32.8	4.0	0.0	0.0	476.6
271280	0.0	0.0	0.0	0.0	1.7	1.1	0.6	0.6	0.6	0.6	1.7	26.6	9.6	0.0	0.0	43.0
281280	0.0	0.0	0.0	0.0	0.6	30.0	6.2	0.6	20.9	15.8	0.6	0.0	1.7	0.0	0.0	76.3
291280	0.0	0.6	2.3	53.7	67.3	74.6	79.2	79.7	62.8	23.7	15.3	26.0	2.3	0.0	0.0	487.4
301280	0.0	0.0	3.4	63.3	73.5	47.5	78.0	63.3	64.5	72.9	13.6	8.5	11.9	0.0	0.0	500.4
311280	0.0	0.0	4.0	58.2	69.0	62.2	79.7	80.3	79.2	76.9	71.2	59.4	14.1	0.0	0.0	654.2
AVERAGE	0.0	0.1	6.3	37.4	42.3	46.3	48.4	49.8	47.6	37.9	35.0	28.2	4.0	0.0	0.0	383.3
MAXIMUM	0.0	0.6	19.8	69.0	77.5	82.0	84.8	84.8	83.7	79.7	73.5	59.4	14.1	0.0	0.0	719.8
MINIMUM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7

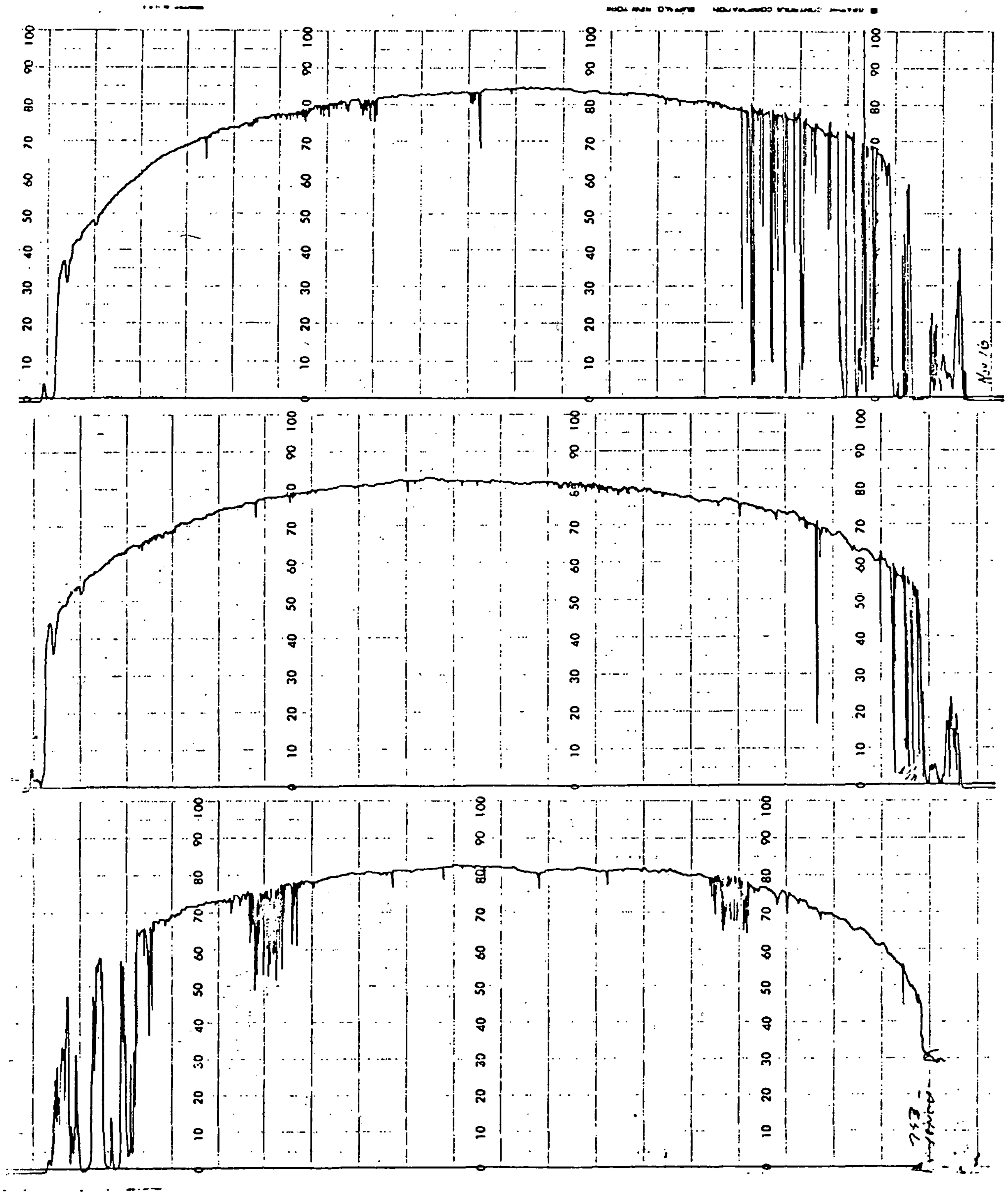
PIONEER MILL DIRECT STATION 50 HOURLY SOLAR RADIATION - CAL./SQ. CM

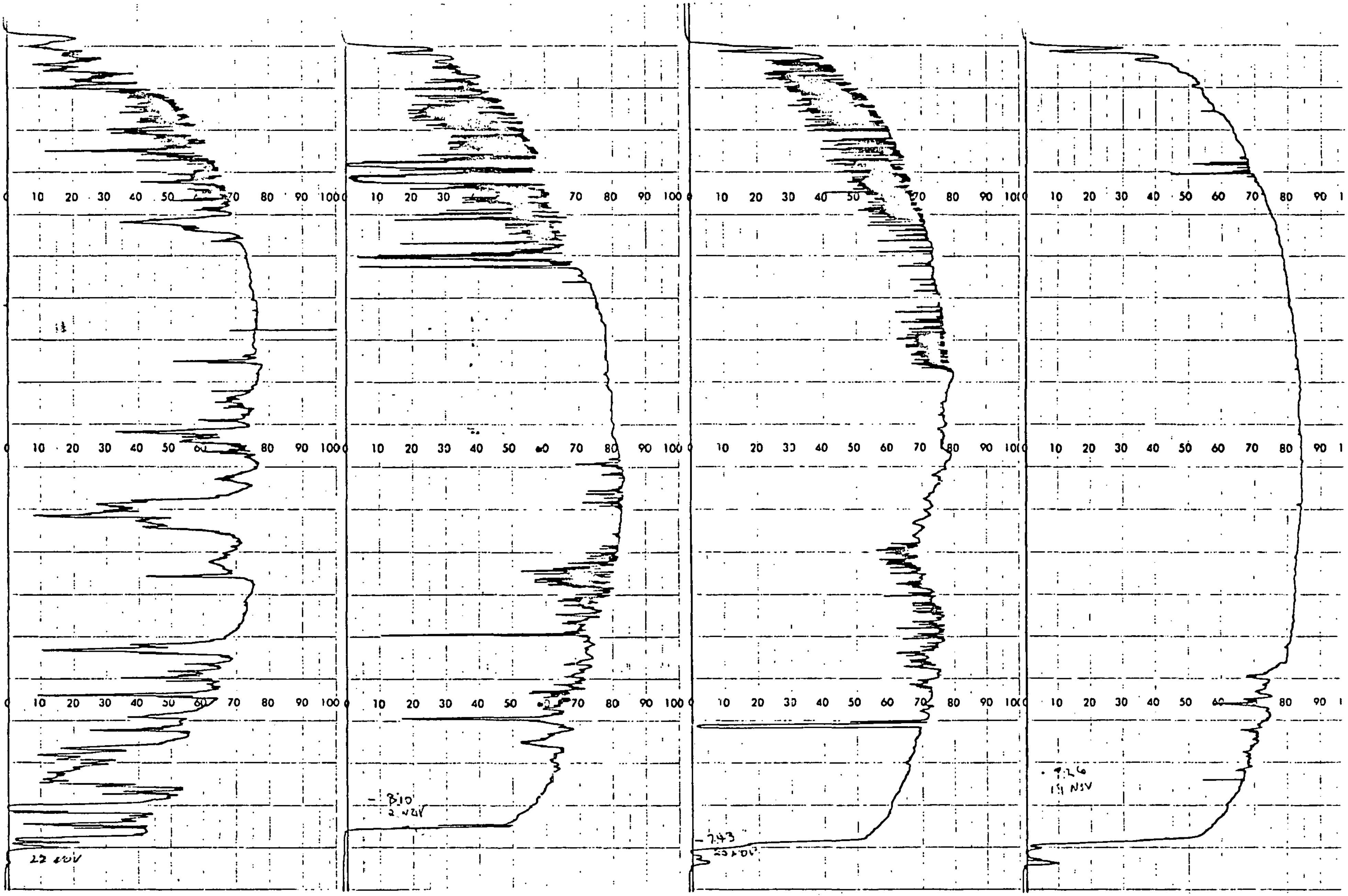
HOUR DAY	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	TOTAL
1 181	0.0	0.0	2.8	57.7	70.1	75.8	79.7	80.9	72.9	50.9	64.5	50.3	11.9	0.0	0.0	617.4
2 181	0.0	0.0	2.3	61.6	73.5	79.7	81.4	56.5	49.2	76.3	70.7	57.1	13.0	0.0	0.0	621.4
3 181	0.0	0.0	0.0	34.5	34.5	50.3	37.3	33.9	62.2	3.4	0.0	0.0	0.0	0.0	0.0	256.1
4 181	0.0	0.0	0.6	58.8	71.2	76.3	75.8	75.2	74.1	71.2	64.5	50.9	11.3	0.0	0.0	629.9
5 181	0.0	0.0	0.6	38.4	58.8	74.1	76.9	77.5	76.3	75.8	69.0	56.5	14.7	0.0	0.0	618.5
6 181	0.0	0.0	0.6	58.2	72.4	77.5	80.9	82.0	80.9	77.5	72.4	61.6	17.0	0.0	0.0	680.7
7 181	0.0	0.0	0.6	58.2	72.4	76.9	78.6	79.2	75.2	59.9	70.1	59.4	7.4	0.0	0.0	637.8
8 181	0.0	0.0	0.0	41.8	18.1	60.5	79.7	80.3	79.7	76.3	71.2	59.9	18.1	0.0	0.0	585.8
9 181	0.0	0.0	0.6	59.9	74.1	80.3	82.0	82.0	80.9	78.6	73.5	62.2	19.2	0.0	0.0	693.2
10 181	0.0	0.0	0.6	63.3	76.3	81.4	83.7	84.2	83.7	80.9	75.8	65.6	22.1	0.0	0.0	717.5
11 181	0.0	0.0	0.6	58.2	71.8	78.0	70.1	35.6	30.0	18.7	18.7	35.6	0.6	0.0	0.0	417.8
12 181	0.0	0.0	0.6	62.2	74.6	79.2	82.0	82.5	82.0	80.3	71.2	36.2	20.9	0.0	0.0	671.7
13 181	0.0	1.1	0.6	60.5	70.7	79.2	81.4	82.0	69.0	58.2	73.5	62.2	22.1	0.0	0.0	660.4
14 181	0.0	0.0	0.6	59.9	72.9	79.2	81.4	81.4	82.0	78.0	53.7	62.2	22.1	0.0	0.0	673.4
15 181	0.0	0.0	0.6	60.5	73.5	79.7	82.0	82.5	81.4	79.2	74.6	63.3	22.6	0.0	0.0	700.0
16 181	0.0	0.0	0.0	6.8	24.9	22.1	46.9	66.2	74.6	49.2	1.7	4.0	3.4	0.0	0.0	299.7
17 181	0.0	0.0	0.0	3.4	36.2	70.1	76.9	75.2	76.9	75.8	67.3	56.5	18.7	0.0	0.0	556.9
18 181	0.0	0.0	0.6	43.0	64.5	71.8	74.1	75.2	70.1	66.2	59.4	48.1	13.6	0.0	0.0	586.3
19 181	0.0	0.0	0.0	2.3	9.0	46.4	62.2	0.6	0.6	1.7	6.2	41.8	4.0	0.0	0.0	174.7
20 181	0.0	0.0	0.6	24.3	34.5	24.9	35.1	30.0	32.2	62.2	65.6	51.5	15.8	0.0	0.0	376.6
21 181	0.0	0.0	0.6	46.9	68.4	70.7	52.0	65.0	75.8	68.4	66.7	41.3	0.6	0.0	0.0	556.4
22 181	0.0	0.0	0.6	31.7	63.9	71.2	76.3	72.4	48.6	72.9	66.7	44.7	22.6	0.0	0.0	571.6
23 181	0.0	0.0	0.6	47.5	68.4	75.2	78.6	78.0	77.5	75.2	69.5	59.4	23.2	0.0	0.0	653.0
24 181	0.0	0.0	0.0	45.8	70.1	76.3	79.7	79.2	75.2	78.0	72.9	61.1	23.7	0.0	0.0	662.1
25 181	0.0	0.0	0.6	49.8	72.4	79.2	81.4	82.0	79.2	67.3	54.8	56.5	20.9	0.0	0.0	644.0
26 181	0.0	0.0	1.1	43.0	70.7	77.5	80.9	82.5	82.0	80.3	75.2	65.6	27.7	0.0	0.0	686.4
27 181	0.0	0.0	0.6	14.7	1.1	9.6	35.1	62.8	74.6	69.0	64.5	37.3	6.2	0.0	0.0	375.4
28 181	0.0	0.0	0.6	49.8	70.1	76.9	79.7	80.9	79.7	76.3	71.2	60.5	24.9	0.0	0.0	670.6
29 181	0.0	0.0	0.6	0.6	70.1	75.8	79.2	75.8	76.3	37.3	24.9	1.1	0.0	0.0	0.0	441.6
30 181	0.0	0.0	0.6	48.1	69.0	76.3	79.2	80.9	80.3	78.0	71.8	59.4	24.3	0.0	0.0	667.7
31 181	0.0	0.0	0.0	50.3	70.1	75.2	78.6	70.1	44.1	34.5	68.4	50.9	0.6	0.0	0.0	542.8
AVERAGE	0.0	0.0	0.6	43.3	59.6	68.6	72.5	70.1	68.6	63.1	59.0	49.1	14.6	0.0	0.0	569.3
MAXIMUM	0.0	1.1	2.8	63.3	76.3	81.4	83.7	84.2	83.7	80.9	75.8	65.6	27.7	0.0	0.0	717.5
MINIMUM	0.0	0.0	0.0	0.6	1.1	9.6	35.1	0.6	0.6	1.7	0.0	0.0	0.0	0.0	0.0	174.7

PIONEER MILL DIRECT STATION 50 HOURLY SOLAR RADIATION - CAL./SQ. CM

HOUR DAY	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	TOTAL
1 281	0.0	0.0	0.0	0.6	38.4	26.0	58.2	61.1	33.4	16.4	37.3	35.6	23.2	0.0	0.0	330.2
2 281	0.0	0.0	0.6	23.2	73.5	77.5	80.3	80.9	80.3	78.6	74.6	65.0	32.8	0.0	0.0	667.2
3 281	0.0	0.0	0.6	2.8	43.0	27.1	41.3	66.2	79.7	69.5	54.3	63.3	33.4	0.0	0.0	481.2
4 281	0.0	0.0	1.1	53.7	48.1	31.1	53.7	70.7	51.5	77.5	74.1	65.6	33.9	0.0	0.0	560.9
5 281	0.0	0.0	0.0	0.0	0.0	2.3	0.6	1.1	0.6	11.3	55.4	27.1	2.3	0.0	0.0	100.6
6 281	0.0	0.0	1.1	62.2	75.2	80.9	83.1	83.1	82.5	80.3	75.2	65.6	36.8	0.0	0.0	726.0
7 281	0.0	0.0	1.7	59.4	69.0	78.6	80.3	61.1	69.5	71.2	46.4	50.9	21.5	0.0	0.0	609.5
8 281	0.0	0.0	0.0	0.0	0.0	20.4	24.9	2.8	6.2	56.5	31.7	7.9	17.0	0.0	0.0	167.4
9 281	0.0	0.0	1.1	53.7	15.8	26.0	71.8	63.3	28.8	4.5	0.6	2.3	0.0	0.0	0.0	268.0
10 281	0.0	0.0	0.0	9.6	11.3	71.2	81.4	82.0	75.2	80.3	63.9	16.4	7.4	0.0	0.0	498.7
11 281	0.0	0.0	0.0	0.0	13.6	24.9	0.0	0.0	4.0	9.6	6.8	1.1	0.6	0.0	0.0	60.5
12 281	0.0	0.0	0.6	11.9	10.2	74.1	72.4	72.9	70.7	56.0	71.8	1.1	0.6	0.6	0.0	442.7
13 281	0.0	0.0	0.0	13.0	66.2	78.0	67.8	79.7	82.0	80.9	76.3	68.4	46.9	0.6	0.0	659.8
14 281	0.0	0.0	1.1	57.1	66.2	76.3	75.2	42.4	0.6	0.6	0.6	45.8	12.4	0.0	0.0	378.3
15 281	0.0	0.0	0.6	48.1	66.2	58.2	19.2	2.3	2.8	60.5	73.5	62.2	28.3	0.0	0.0	421.8
16 281	0.0	0.0	0.6	57.7	70.1	74.6	57.7	80.3	78.6	75.2	71.8	62.8	36.2	0.0	0.0	665.5
17 281	0.0	0.0	0.6	56.0	72.4	78.0	80.9	80.3	78.6	76.3	72.4	55.4	18.1	0.6	0.0	669.4
18 281	0.0	0.0	0.6	49.2	69.5	74.1	76.3	72.4	80.9	80.3	76.9	69.0	48.1	1.7	0.0	698.8
19 281	0.0	0.0	0.6	48.1	28.3	62.2	41.8	19.8	72.4	65.6	8.5	30.0	33.4	2.3	0.0	412.7
20 281	0.0	0.0	5.7	58.2	72.4	30.5	20.9	25.4	1.1	40.1	48.1	36.8	26.6	0.6	0.0	366.4
21 281	0.0	0.0	1.1	4.5	57.3	78.6	76.3	82.5	82.0	80.3	72.9	68.4	37.3	1.7	0.0	653.0
22 281	0.0	0.0	0.0	54.8	48.1	67.3	76.9	81.4	82.0	79.7	76.3	69.5	49.8	4.5	0.0	690.4
23 281	0.0	0.0	9.6	56.7	70.1	78.0	83.1	84.2	82.5	80.9	76.9	69.0	50.3	6.8	0.0	758.2
24 281	0.0	0.0	1.1	17.5	33.9	46.9	64.5	67.3	70.1	72.9	67.8	57.7	41.8	4.0	0.0	545.6
25 281	0.0	0.0	2.8	24.3	27.1	11.9	1.7	67.8	80.3	77.5	72.9	63.3	43.0	3.4	0.0	476.1
26 281	0.0	0.0	0.0	18.1	28.3	4.0	4.0	2.8	52.6	70.7	52.6	45.8	25.4	0.0	0.6	304.7
27 281	0.0	0.0	0.0	32.2	26.0	52.6	63.9	69.5	69.0	70.1	63.3	51.5	17.5	1.1	0.0	516.8
28 281	0.0	0.0	0.0	0.6	19.2	62.8	70.1	74.1	76.3	74.5	70.7	64.5	47.5	6.2	0.0	566.5
AVERAGE	0.0	0.0	1.1	31.5	43.9	52.6	54.6	56.3	56.2	60.5	56.2	47.2	27.6	1.2	0.0	489.2
MAXIMUM	0.0	0.0	9.6	66.7	75.2	80.9	83.1	84.2	82.5	80.9	76.9	69.5	50.3	6.8	0.6	758.2
MINIMUM	0.0	0.0	0.0	0.0	0.0	2.3	0.0	0.0	0.6	0.6	0.6	1.1	0.0	0.0	0.0	60.5

TIME	SUNDAY NOV 16	MONDAY NOV 17	TUESDAY NOV 18	WEDNESDAY NOV 19	THURSDAY NOV 20	FRIDAY NOV 21	SATURDAY NOV 22
8:00	72.3	183.1	203.6	229.9	249.6	78.8	131.4
9:00	512.3	735.6	761.8	761.8	735.6	689.6	348.1
10:00	801.3	847.2	860.4	840.6	781.6	748.7	617.4
11:00	919.5	886.6	912.9	926.0	807.8	807.8	794.7
12:00	945.8	912.9	919.5	939.0	801.2	919.5	650.2
1:00	939.2	926.0	926.0	939.0	873.5	906.3	781.6
2.00	919.5	912.9	906.3	926.0	853.8	880.0	853.8
3:00	873.5	873.5	834.1	886.6	820.9	702.7	768.4
4:00	788.1	794.7	775.0	788.1,	683.0	466.3	643.6
5:00	578	630.5	190.5	604.0	499.0	426.9	374.4
6:00	19.7	19.7	0	26.3	263.0	26.3	26.3

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0 10 20 30 40 50 60 70 80 90 100
0 10 20 30 40 50 60 70 80 90 100
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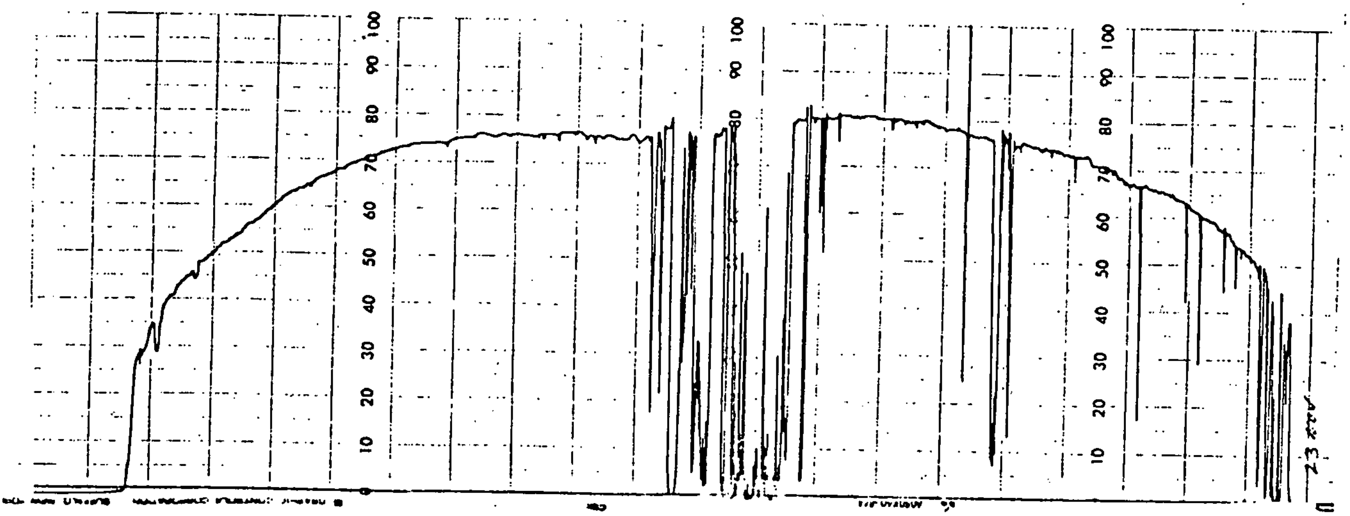
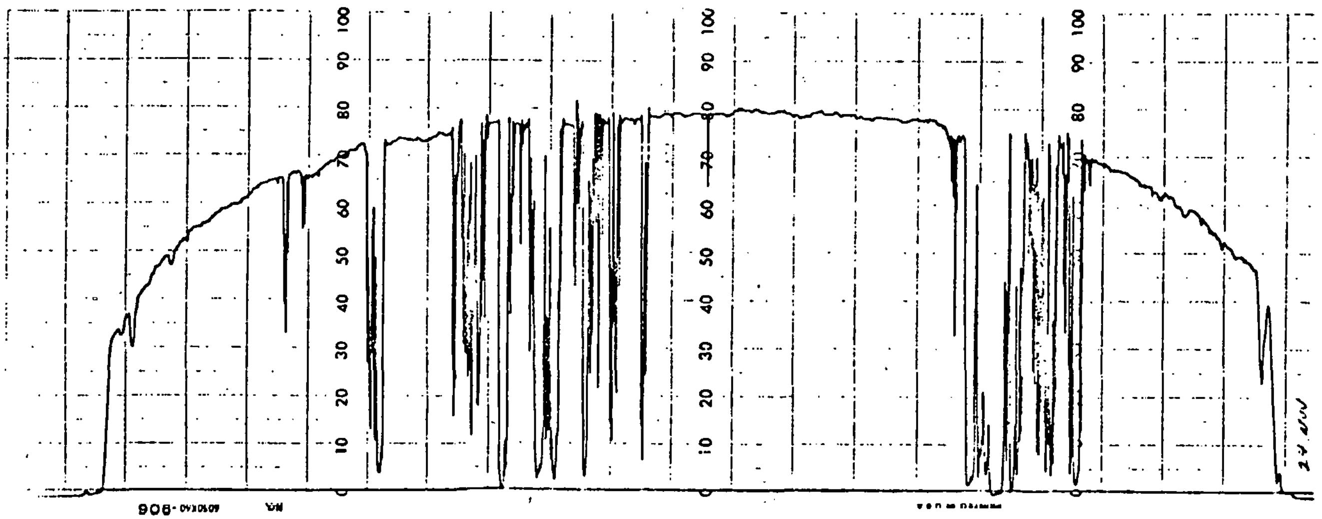
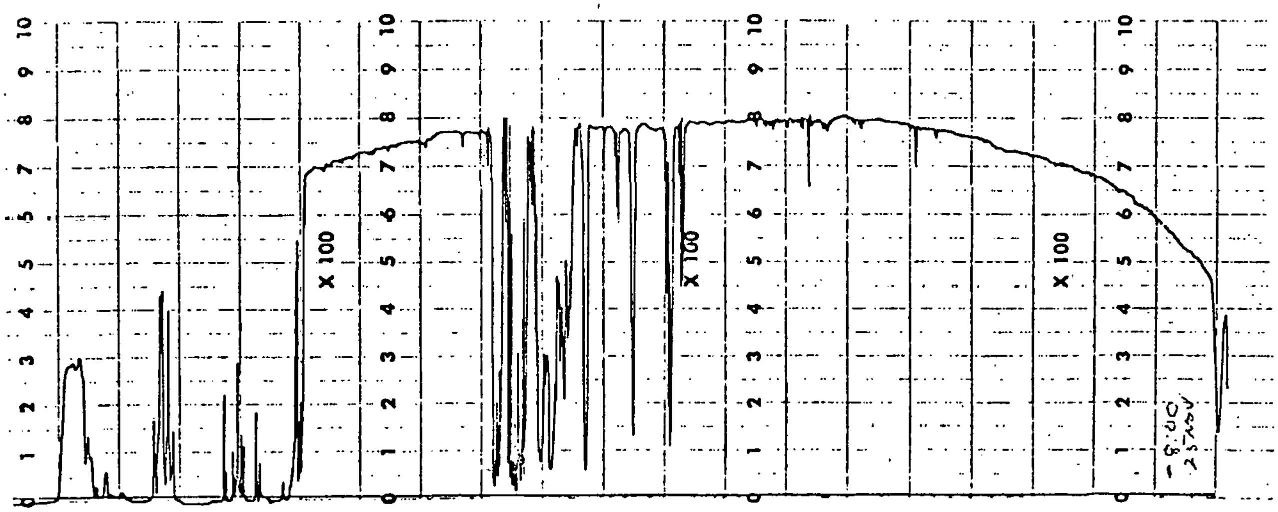
8:10'
2 NOV
7:43
25 NOV
9:26
19 NOV

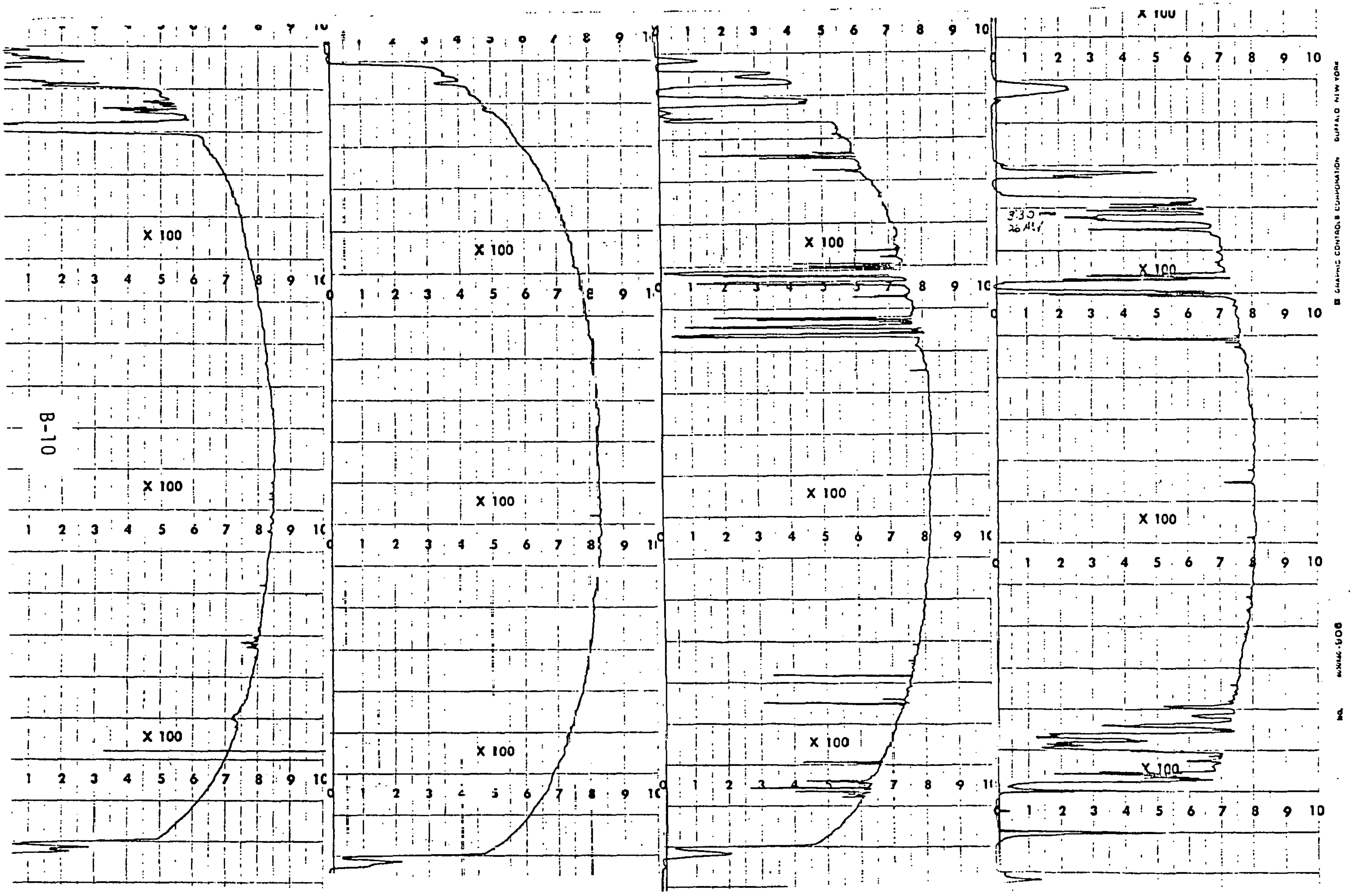
W/m^2 INSOLATION - LAHAINA PYRHELIOMETER - NOVEMBER 23-29, 1980

TIME	SUNDAY NOV 23	MONDAY NOV 24	TUESDAY NOV 25	WEDNESDAY NOV 26	THURSDAY NOV 27	FRIDAY NOV 28	SATURDAY NOV 29
8:00	151.1	.	243.0	13.1	229.9	229.9	243.0
9:00	702.7	709.3	735.6	216.7	709.3	748.7	761.8
10:00	807.9	361.2	847.2	669.9	827.5	860.4	860.4
11:00	860.4	827.5	893.2	873.5	893.2	906.3	913.0
12:00	623.9	893.2	886.6	906.3	919.5	932.6	945.7
1:00	518.8	827.5	748.7	906.3	926.0	926.0	952.3
2:00	853.8	564.8	577.9	886.6	847.2	912.9	926.0
3:00	840.6	676.5	827.5	702.7	748.7	866.9	880.0
4:00	755.3	742.2	111.6	525.4	729.0	781.5	794.7
5:00	532.0	564.8	78.8	45.9	348.0	571.4	361.2
6:00	32.8	39.4	32.8	26.3	13.1	45.9	13.1





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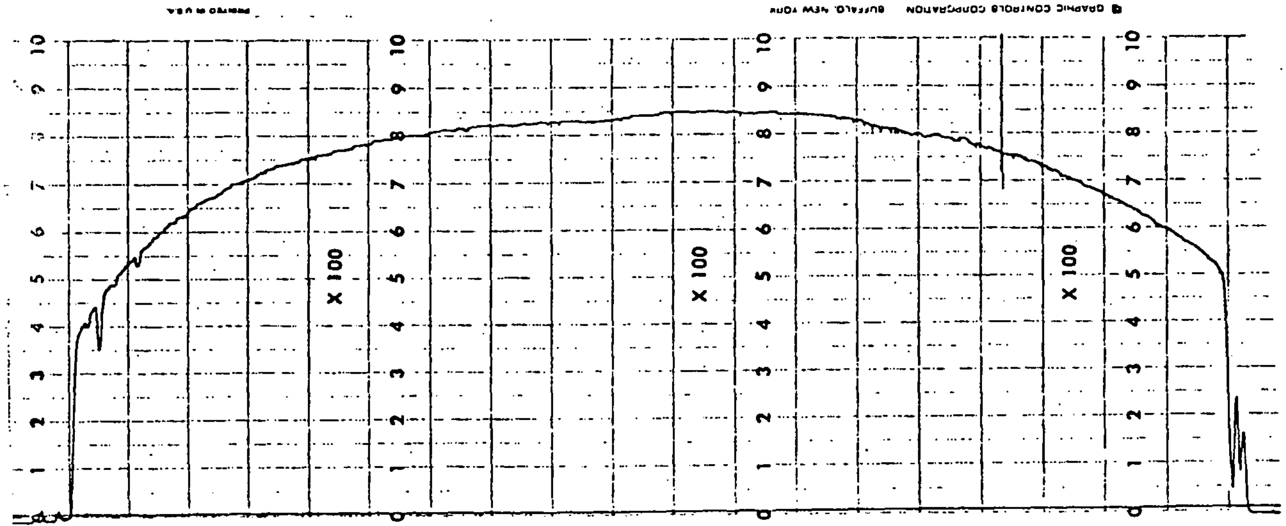
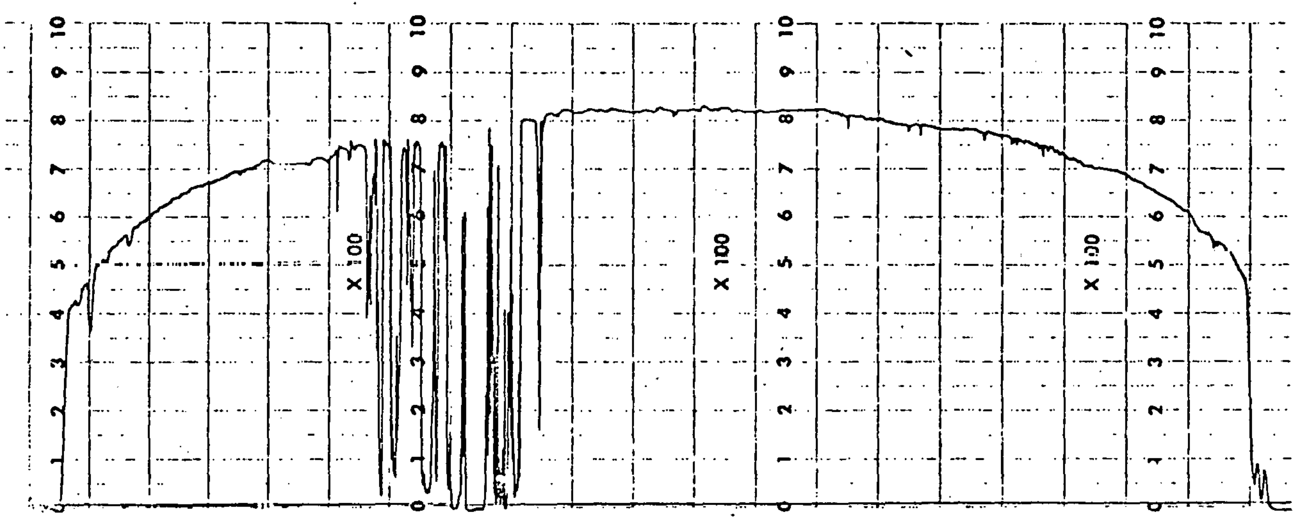
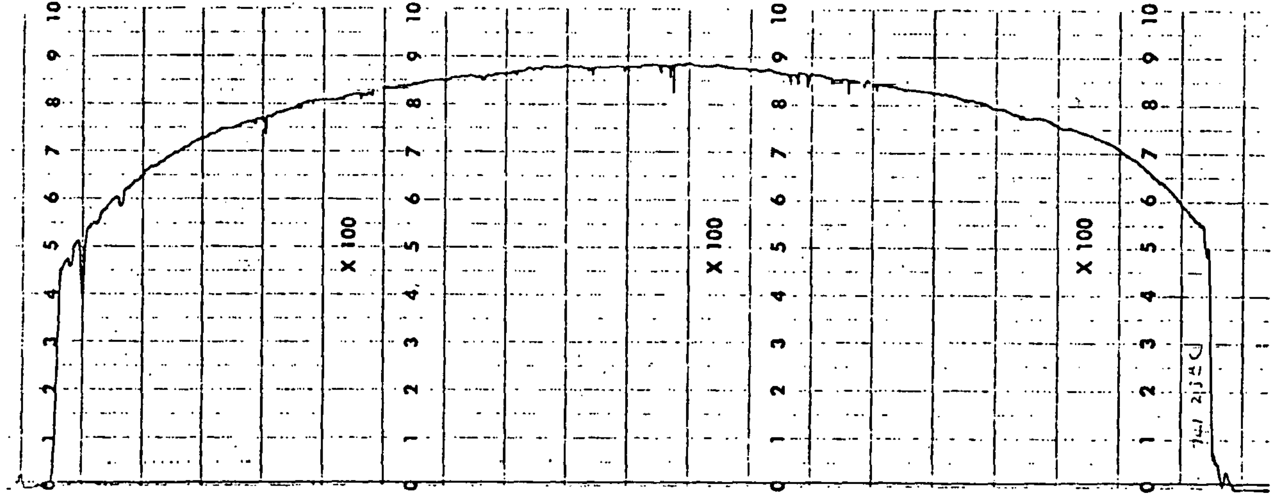
GRAPHIC CONTROLS CORPORATION BUFFALO NEW YORK

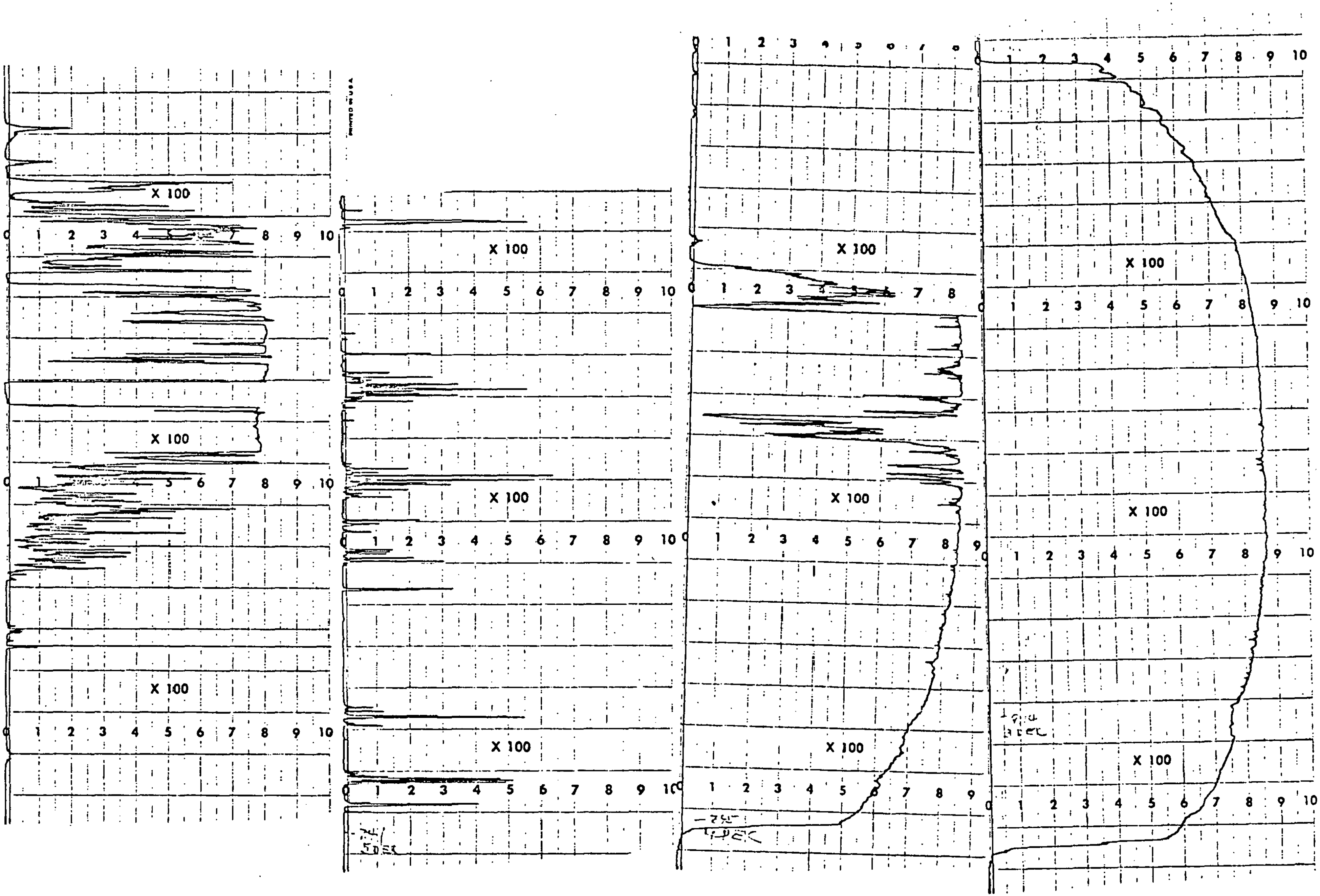
W/m^2 INSOLATION - LAHAINA PYRHELIOMETER - NOVEMBER 30-DEC 6, 1980

TIME	SUNDAY NOV 30	MONDAY DEC 1	TUESDAY DEC 2	WEDNESDAY DEC 3	THURSDAY DEC 4	FRIDAY DEC 5	SATURDAY DEC 6
8:00	236.4	217.6	229.9	210.2	183.9	6.6	6.6
9:00	735.6	742.1	801.2	794.7	735.6	32.8	6.6
10:00	860.4	853.8	899.8	886.6	860.4	13.1	13.1
11:00	919.5	899.8	952.3	952.3	919.5	13.1	190.5
12:00	952.3	919.5	985.1	972.0	932.6	39.4	623.9
1:00	939.2	926.0	985.1	965.4	755.3	32.8	591.1
2:00	926.0	558.2	972.0	952.3	860.4	26.3	525.4
3:00	886.6	512.2	926.0	906.3	197.0	6.6	348.1
4:00	807.8	794.7	853.8	788.1	0	19.7	19.7
5:00	623.9	637.1	689.6	597.6	6.6	0	6.6
6:00	52.5	52.5	59.1	46.0	6.6	0	0





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Appendix C

PRELIMINARY SITE SOLAR MODEL

Appendix C

PRELIMINARY SITE SOLAR MODEL

This appendix describes the solar model for direct normal insolation at Pioneer Mill that was used in the Task 2 comparison of annual performance for the two candidate heliostat field sites. The solar model is based on the ASHRAE clear sky model for direct normal insolation with modifications to make it applicable to Hawaii and Pioneer Mill. The ASHRAE model for direct insolation is given by the equation

$$I_{DN} = \frac{A\ (CN)}{\exp\ (B/\sin E)}$$

where

A = apparent solar irradiation at air mass = 0
B = atmospheric extinction coefficient
E = solar elevation (angle of sun vector above horizon)
CN = clearness number

The normal seasonal variation of the coefficients A and B due to changes in the dust and water content of the atmosphere were assumed to be representative of the continental United States but not representative of Hawaii. Professor Ekern and others at the University of Hawaii Natural Energy Institute agreed that, for Pioneer Mill, it would be more accurate to assume no seasonal variation in turbidity of the atmosphere. The model was therefore modified to give the following relationship.

$$I_{DN} = \frac{I_0\ (CN)}{\exp\ (0.142/\sin E)}$$

where

I = solar irradiation above the earth's atmosphere (varies only with distance from the sun)

The value of 0.8251 was then assigned to the clearness number in order to make the resulting direct normal incidence insolation value calculated for November agree with the peak mid-day measurements (953 W/m^2) at Pioneer Mill taken during November 1980.

The resulting model was used to calculate clear sky insolation for the fifteenth day of each month. These insolation values were used as input to the computer program STEAEC to calculate typical clear sky performance of the Task 2 candidate heliostat fields. The estimates of actual annual performance for each heliostat field was obtained by multiplying monthly clear sky performance by weather factors for each month of the year.

The weather factors were formulated by taking the ratio of existing global radiation measurements, recorded at Lahaina, to global radiation values calculated from the ASHRAE global model (also modified to remove seasonal variations in the atmosphere). These weather factors are tabulated in Table 3-6, in the main body of this report.

Appendix D

OUTLINE OF THE DRAFT FINAL REPORT

Appendix D

OUTLINE OF THE DRAFT FINAL REPORT

1. Executive Summary
    - 1.1 Project Summary
    - 1.2 Introduction
    - 1.3 Facility Description
    - 1.4 Conceptual Design Description
    - 1.5 System Performance
    - 1.6 Economic Findings
    - 1.7 Development Plan
    - 1.8 Site Owner's Assessment
2. Introduction
    - 2.1 Study Objective
    - 2.2 Technical Approach and Site Selection
    - 2.3 Site Location
    - 2.4 Site Geography
    - 2.5 Climate
    - 2.6 Existing Plant Description
    - 2.7 Existing Plant Performance
    - 2.8 Project Organization
    - 2.9 Final Report Organization
3. Selection of Preferred System
    - 3.1 Introduction
    - 3.2 System Configuration
    - 3.3 Technology
    - 3.4 System Size
    - 3.5 Heliostat Field Site Selection

4. Conceptual Design
    - 4.1 System Description
    - 4.2 Functional Requirements
    - 4.3 Design and Operating Characteristics
    - 4.4 Site Requirements
    - 4.5 System Performance
    - 4.6 Energy Load Profile
    - 4.7 Capital Cost Summary for Project
    - 4.8 Operating and Maintenance Costs and Considerations
    - 4.9 Supporting System Analyses

5. Subsystem Characteristics
    - 5.1 Collector System
    - 5.2 Receiver System
    - 5.3 Thermal Transport System
    - 5.4 Nonsolar Energy System
    - 5.5 Master Control System

6. Economic Analysis
    - 6.1 Method
    - 6.2 Assumptions and Rationale
    - 6.3 Plant and System Simulation Model
    - 6.4 Results and Conclusions
    - 6.5 Economic Scenario

7. Development Plan
    - 7.1 Design Phase
    - 7.2 Construction Phase
    - 7.3 System Checkout and Startup Phase
    - 7.4 System Performance Validation Phase
    - 7.5 Joint User and DOE Operations Phase
    - 7.6 Schedule and Milestone Chart
    - 7.7 Roles of Site Owner, Government, and Industry

Appendix A — System Specification
Appendix B — Site Insolation Measurement Program
Appendix C — Site Specific Solar Model
Appendix D — Maui Electric Company System Characteristics
Appendix E — One-Page Project Summary

Appendix E

ONE-PAGE PROJECT SUMMARY

PIONEER MILL COMPANY, LTD. — Lahaina, Maui, Hawaii

PRIME CONTRACTOR	SUBCONTRACTORS
Bechtel	Amfac Sugar Foster Wheeler Northrup

Site Description. Pioneer Mill Company, Ltd., subsidiary of Amfac Sugar Company, operates a sugarcane plantation and sugar factory near Lahaina on the island of Maui. The plantation occupies 8,766 acres on the west coast of the island on gently sloping ground between the coast and the foothills of the West Maui Mountains. The climate is tropical, but the site is dry (average rainfall of 14 inches) because it is sheltered from the tradewinds by the mountains. Average direct normal insolation at the site is estimated to be 7.4 kWh/m^2-day. The sugar factory processes sugarcane at an average rate of 102 tons/hr into raw sugar and molasses during a 9-month harvest season. The mill has an existing cogeneration facility, supplying intermediate- and low-pressure steam for mechanical drive turbines and process evaporators, and electric power for irrigation pumps and plant auxiliaries. Excess electric power is supplied to the Maui Electric Company grid. The mill consumes No.6 oil to supplement the use of bagasse, the cellulose residue of the processed sugarcane, in the existing dual-fuel boilers to produce steam at 850 psia and 750F.

Project Summary. The objective of the project is the conceptual design of a solar central receiver system to retrofit the existing cogeneration facility for the displacement of oil consumption. The use of bagasse in lieu of thermal storage will allow the maximum utilization of solar energy while accommodating the weekly and annual variation of the factory operating cycle. The retrofit is expected to save 40,000 barrels of No.6 oil per year. It is estimated that the project facilities can be designed and built in about 3 years.

Conceptual Design. The solar retrofit consists of the addition of a collector field, a tower-mounted receiver, and a pipeline connecting the receiver with the existing plant and controls. Approximately 785 heliostats, each with 52.8 m^2 reflective area, are arranged in a 150° north field which covers about 42 acres of land. The two-cavity, natural-circulation water-steam receiver is supported upon a 250-foot steel tower. The receiver output is approximately 26 MWt, supplying about 45 percent of the total steam demand for the factory at the design point. Steam and condensate pipelines about 3,500 feet long connect the receiver with the plant. An expanded control room and additional bagasse storage capacity are also needed to accommodate the retrofit.

Functional Description. A water-steam solar receiver will operate in parallel with the existing boilers. When solar-produced steam is available, bagasse will be diverted from the boiler to the storage house, from which it can be reclaimed when solar steam is not available. This use of bagasse eliminates the need for thermal energy storage and allows the displacement of about 73 percent of all the oil currently consumed during the harvest season. During the 3-month off season, when the factory does not produce bagasse, solar-produced steam will displace a portion of the oil currently burned to meet the year-round irrigation requirements.

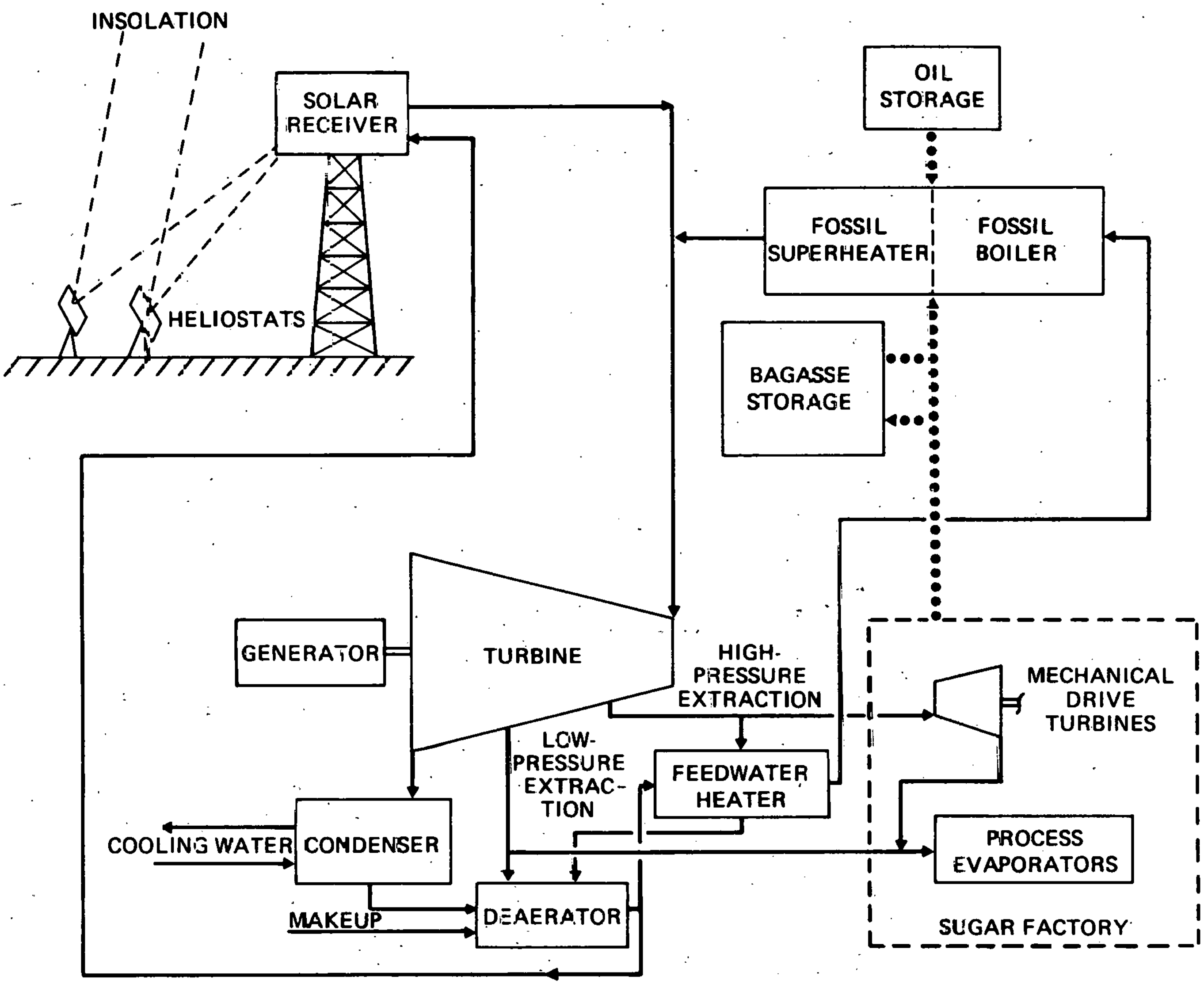

Figure E-1 SKETCH FOR ONE-PAGE PROJECT SUMMARY

Appendix F

MAUI ELECTRIC COMPANY INTERFACE DATA

Appendix F

MAUI ELECTRIC COMPANY INTERFACE DATA

Maui Electric Company operates the isolated grid on the island of Maui. Most of its generating capacity, tabulated in Table F-1, is located in the central area. Pioneer Mill has the only generating capacity in west Maui. It is linked to the Maui electric system by two parallel transmission lines that traverse the West Maui Mountains. When these lines are out of service, which occurs occasionally as a result of windstorms, Pioneer Mill must isolate from the grid because it cannot carry the west Maui load.

Table F-1

MAUI ELECTRIC CO. INSTALLED CAPACITY

Units	Rating, kW	Totals, kW
Diesel		
Units 1 to 3	2,750	8,250
Units 4 to 7	5,600	22,400
Units 8 and 9	6,160	12,320
Units 10 and 11	12,500	25,000
Subtotal		67,970
Steam		
Units 1 and 2	6,000	12,000
Unit 3	12,000	12,000
Unit 4	13,000	13,000
Subtotal		37,000
Total system installed capacity		104,970
System momentary peak expected for 1980 (approximate)		90,000

Maui Electric Company regularly requests power from Pioneer Mill and the other two sugar plantations on the island. During 1980, they paid between 39.3-61.3 mills/kWh for power on demand and a rate of 8 mills/kWh lower for unregulated power. This rate is expected to increase significantly because the Maui Electric units are totally oil-fired and new EPA regulations will soon force them to burn low-sulfur oil at a premium over the current oil costs.

The projected load growth for the west Maui area is given in Table F-2. Any excess power generated by Pioneer Mill can be easily absorbed by the Maui electric system.

Table F-2

PROJECTED ELECTRIC LOAD GROWTH ON MAUI

Year	West Maui Peak, MW	MECo System Peak, MW
1980	29.8	89.7
1981	31.1	93.6
1982	32.0	96.5
1983	33.1	99.6
1984	34.1	102.7
1985	35.2	105.9
1986	36.2	109.2
1987	37.4	112.6
1988	38.5	116.1
1989	39.7	119.7
1990	41.0	123.4
1991	42.2	127.2
1992	43.5	131.1
1993	44.9	135.2
1994	46.3	139.4
1995	47.7	143.7
1996	49.2	148.2
1997	50.7	152.8
1998	52.3	157.5
1999	53.9	162.4

Note: The line loss is 1.8% of the west Maui peak load for a 24-hour period.

Typical weekly load variations for the Maui electric system are presented in Table F-3. Figures F-1 through F-5 show examples of the daily load curve at different times of year.

Table F-3

MAUI ELECTRIC COMPANY
TYPICAL WEEKLY LOAD PROFILES

Date	Day	Daily Minimum, MWe (3-5 a.m.)	Morning Peak, MWe (10-11 a.m.)	Evening Peak, MWe (6-8 p.m.)
4/6/80	Sun	33	55	64.5
4/7/80	Mon	31.5	69	74
4/8/80	Tues	33	68	75.5
4/9/80	Wed	32.5	67	76
4/10/80	Thurs	31	68	75
4/11/80	Fri	33.5	68.5	73
4/12/80	Sat	34	60.5	65.5
8/3/80	Sun	37	61	70
8/4/80	Mon	36.5	73	75.5
8/5/80	Tues	37	73	80.5
8/6/80	Wed	37	74	78
8/7/80	Thurs	38	74	79.5
8/8/80	Fri	38.5	76	81.5
8/9/80	Sat	38.5	68	74
12/24/80	Wed	40	78	84
12/25/80	Thurs	39.5	67.5	71.5
12/26/80	Fri	36	71.5	87
12/27/80	Sat	38	69.5	82.5
12/28/80	Sun	37.5	68	80
12/29/80	Mon	37.5	76.5	89
12/30/80	Tues	38.5	78	87.5
12/31/80	Wed	38.5	76	87.5

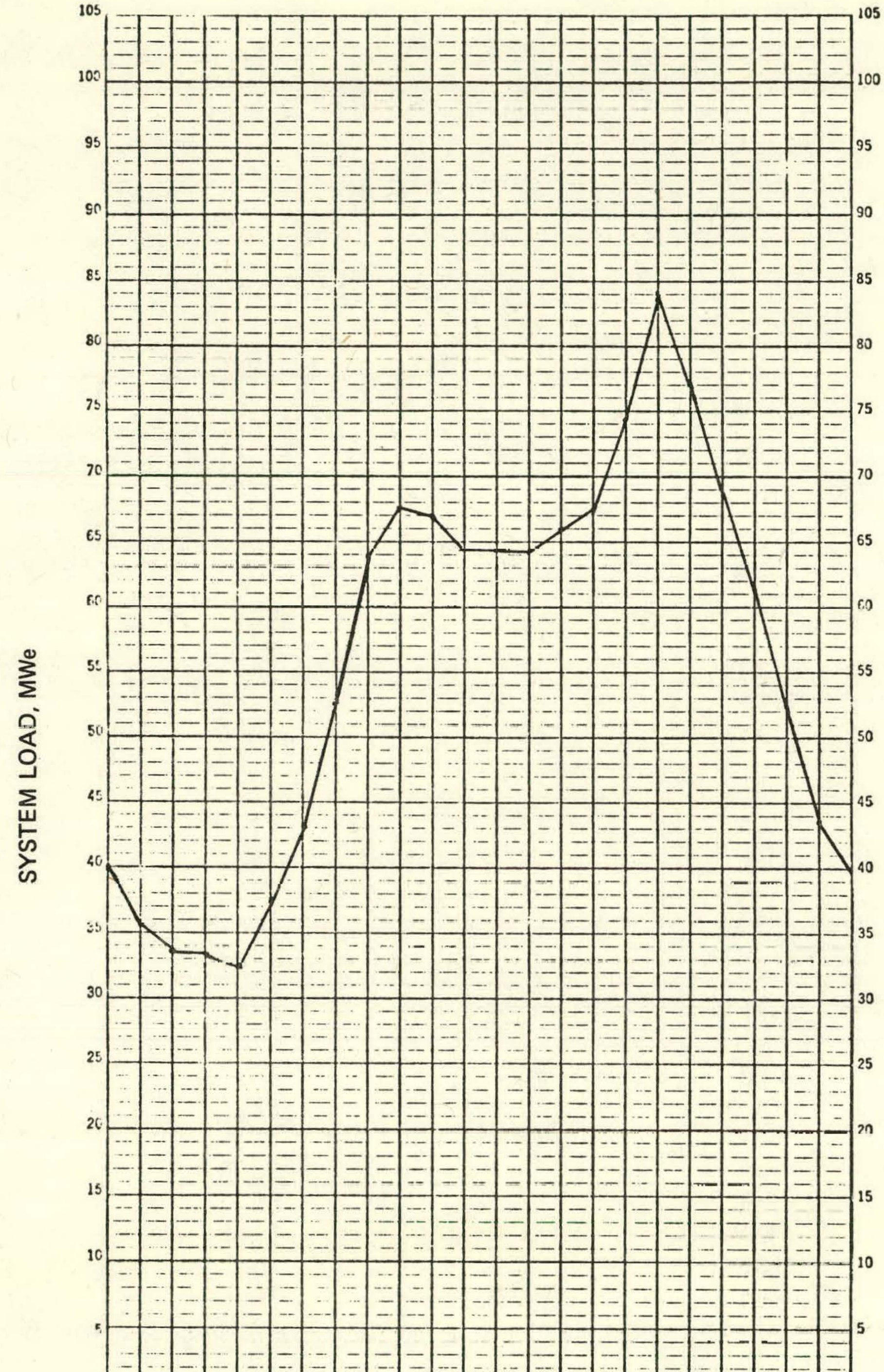

Figure F-1 TYPICAL MAUI ELECTRIC DAILY LOAD PATTERN, 27 DEC 79

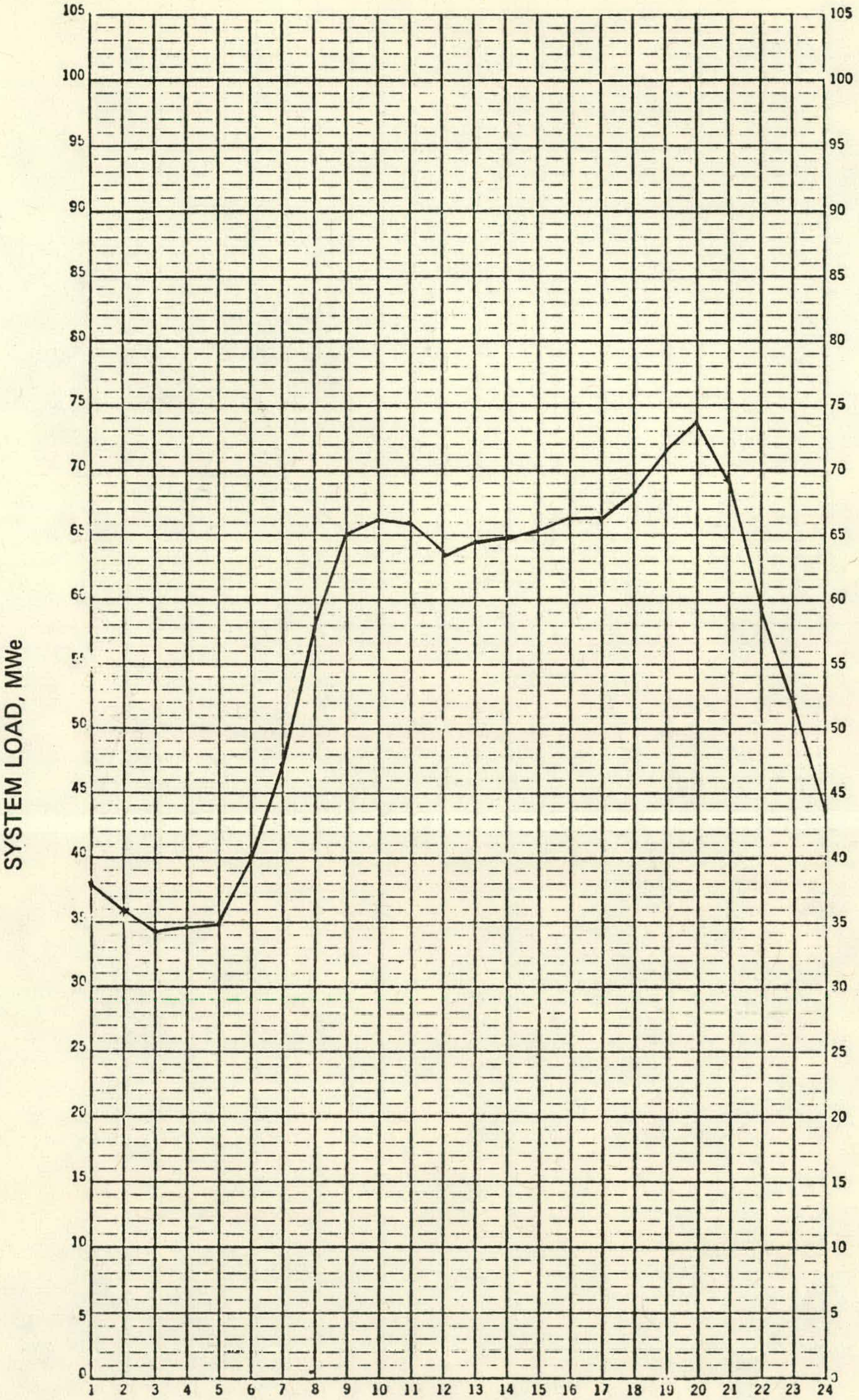

Figure F-2 TYPICAL MAUI ELECTRIC DAILY LOAD PATTERN, 17 APR 80

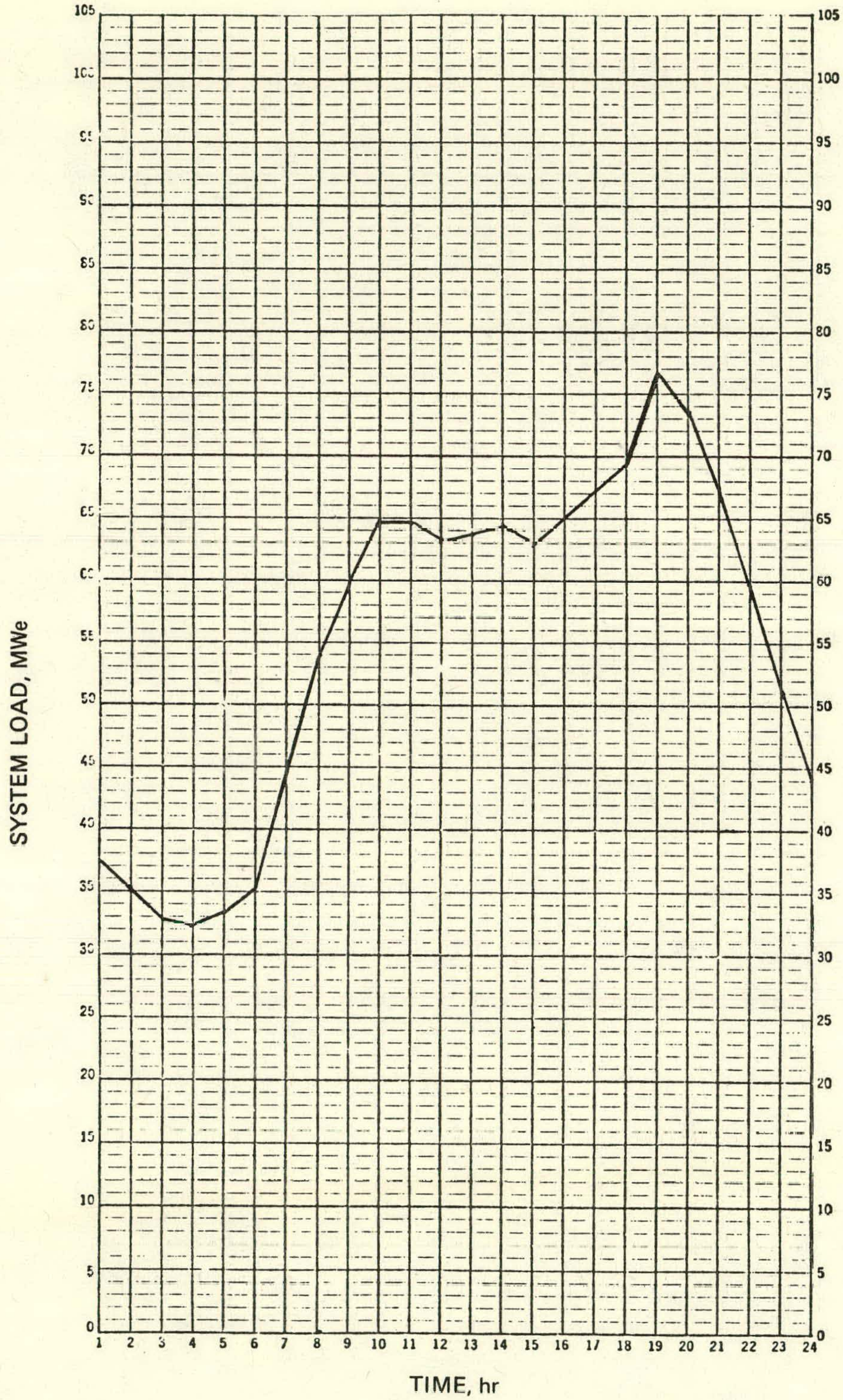

Figure F-3 TYPICAL MAUI ELECTRIC DAILY LOAD PATTERN, 19 DEC 79

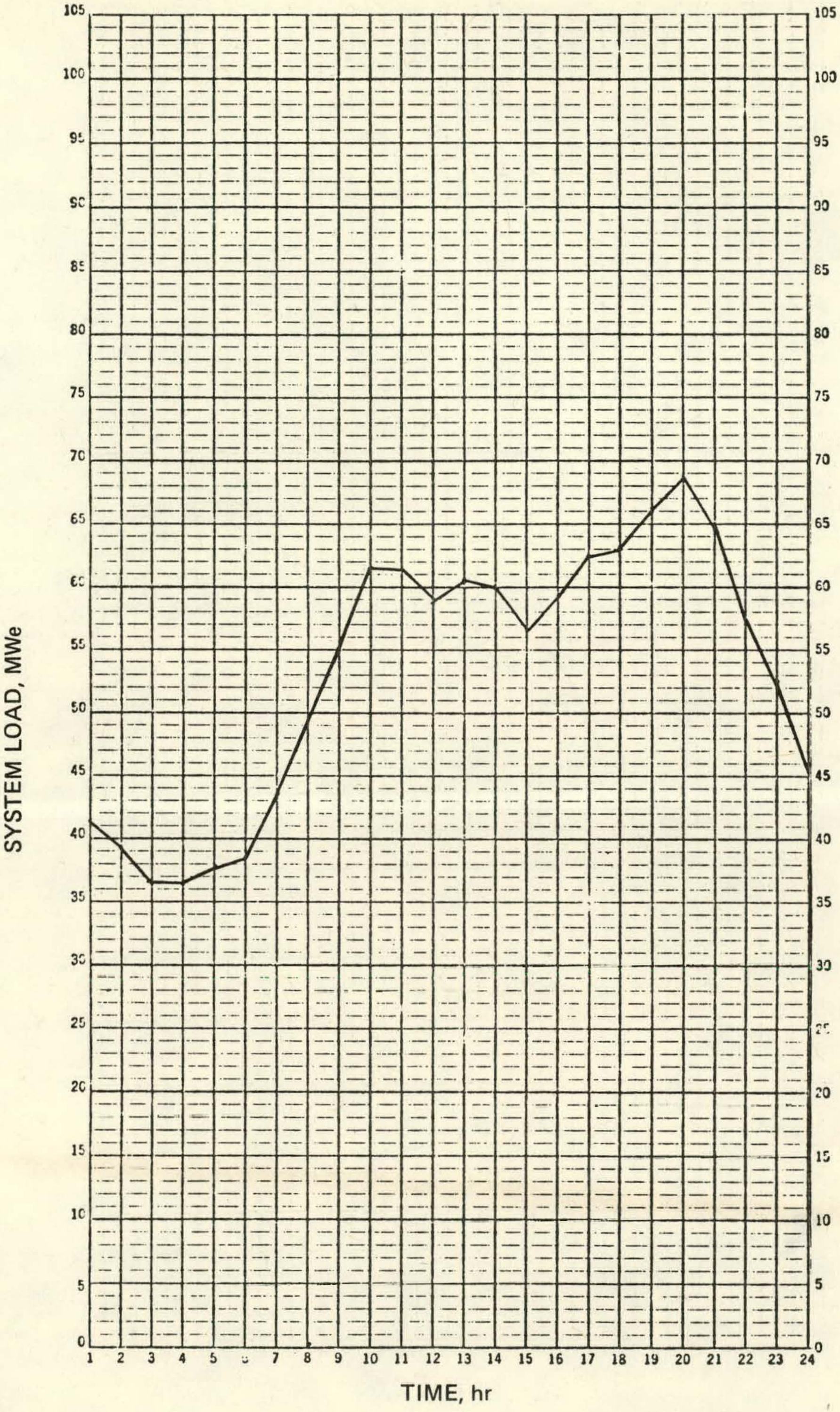

Figure F-4 TYPICAL MAUI ELECTRIC DAILY LOAD PATTERN, 14 JUNE 80

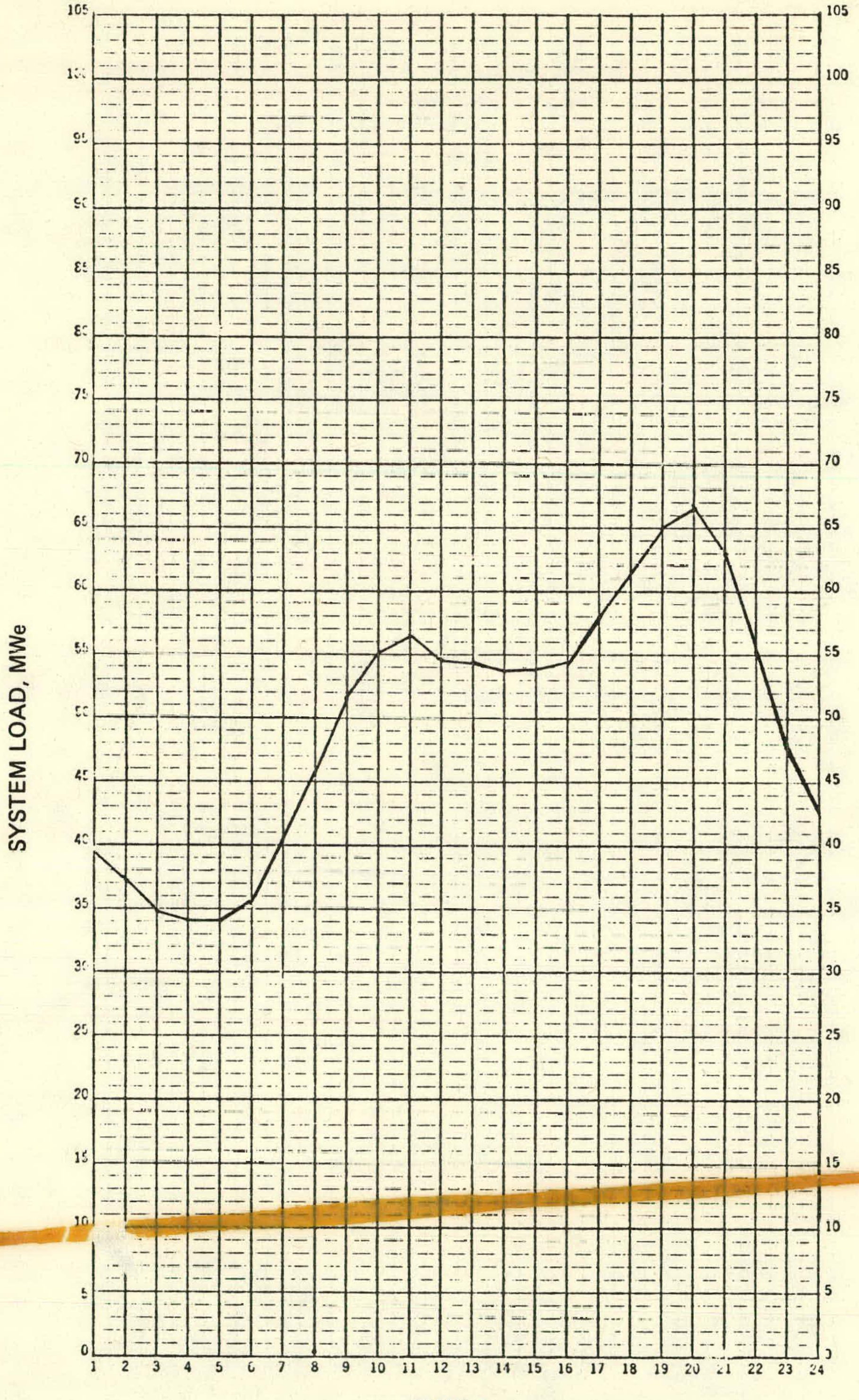

Figure F-5 TYPICAL MAUI ELECTRIC DAILY LOAD PATTERN, 4 MAY 80