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Overview of the Construction and Start-Up of the 10 MWe Solar Thermal Central Receiver Pilot Plant April 1983

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OVERVIEW OF THE CONSTRUCTION AND START-UP OF THE 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT

April 1983

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ABSTRACT

This report presents an overview of the construction and start-up of the 10 MWe Solar Thermal Central Receiver Pilot Plant in Barstow, California. The costs and schedule of the project are discussed, the planned test program is outlined, and significant experiences to date are presented.

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OVERVIEW OF THE CONSTRUCTION AND START-UP OF THE 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT

April 1983

Introduction

The Solar One Project is the world's largest solar electric generating station. This pilot-scale research and development experiment is a cooperative effort of government and private industry to demonstrate technical feasibility, economic potential and environmental acceptability of the solar thermal central receiver concept. The project, which is formally known as the 10 MW Solar Thermal Central Receiver Pilot Plant, has been constructed in the Mojave Desert on 130 acres of Southern California Edison Company's Cool Water Generating Station near Barstow, California, and will supply ten megawatts of electrical power to the Edison grid. Solar One is a joint project of the Department of Energy (DOE), Southern California Edison (SCE), the Los Angeles Department of Water and Power (LADWP), and the California Energy Commission. The solar portion of the facility was designed and constructed under the direction of the DOE, and the turbine-generator facilities, including the control building, were designed and constructed by SCE.

This paper presents an overview of the project, discusses the costs and schedule, highlights the planned test program including operation and maintenance, and briefly discusses the significant experiences to date.

Siting and General Design Data

The pilot plant is located east of Daggett, California, and is approximately 12 miles east of Barstow, California. The site is at a latitude of 34.87°N and longitude of 116.83°W. The site is contained in the western half of Section 13, Township 9N - Range 1E, San Bernardino County: San Bernardino Meridian. The reference location for the pilot plant is the receiver tower vertical centerline with coordinates N 501, 260 and E 2, 349, 950. The nominal elevation of the site is 1,946 feet above mean sea level. Figure 1 shows the plant with SCE's Coolwater Generating Plant and evaporation ponds in the background.

The plant is designed to produce at least 10 MWe of electrical power to the utility grid (after supplying the plant parasitic power requirement) for a period of 4 hours on the plant "Worst Design Day" (Winter solstice) and for a period of 7.8 hours on the plant "Best Design Day" (Summer solstice). The "Worst" and "Best Design Days" are based on assumed insolation (solar intensity) conditions which have been developed from actual site insolation measurements. During actual plant operation, the plant capability and electrical output will depend on the current sun and

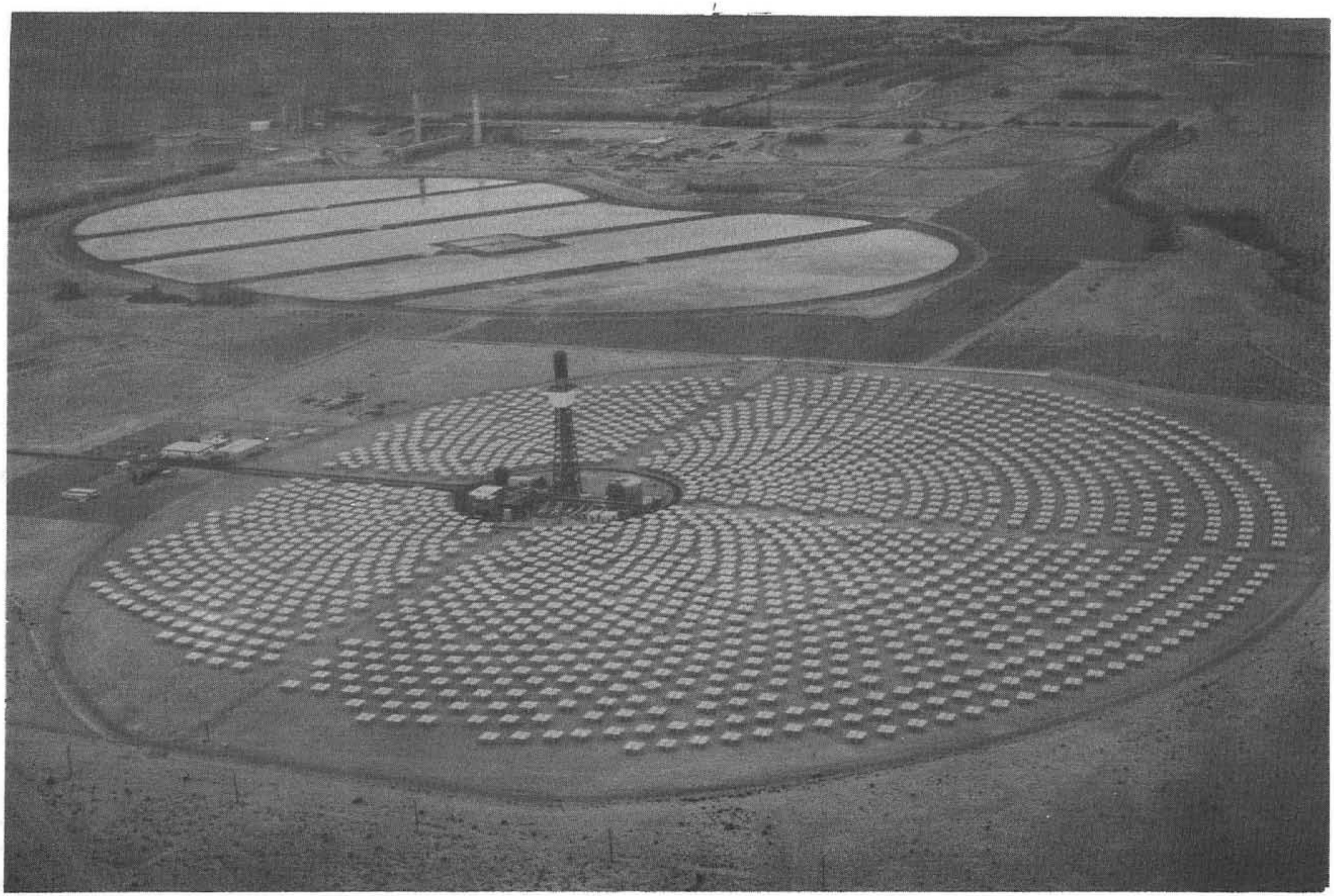


Figure 1. Overview of the Plant

atmospheric conditions. During certain periods of the year (near noon from March through September), the plant energy collection capability can exceed the 12.5 MWe turbine-generator rating.

Plant Systems

The central receiver concept being demonstrated at Barstow integrates the operation of six major systems. Figure 2 shows the plant in operation and the core area, where the major subsystems are located. The collector system, consisting of large suntracking mirrors (heliostats), concentrates the solar energy incident upon the earth and redirects it to a tower-mounted receiver (boiler). There the solar energy transforms water into superheated steam which can be used directly to drive a turbine-generator or diverted to the thermal storage system. The thermal storage system can store the energy as sensible heat to extend the turbine-generator operation after sunset. The electric power generation system (turbine-generator) can generate ten megawatts utilizing receiver steam and seven megawatts from thermal storage steam. The master control system is a series of computers that monitors and controls each of the major systems. The beam characterization system is used to align the heliostats and ensure their efficient operation. Other plant support systems include the raw water, fire protection, demineralized water, cooling water, nitrogen, compressed air, liquid waste, oil supply, and electrical distribution systems.

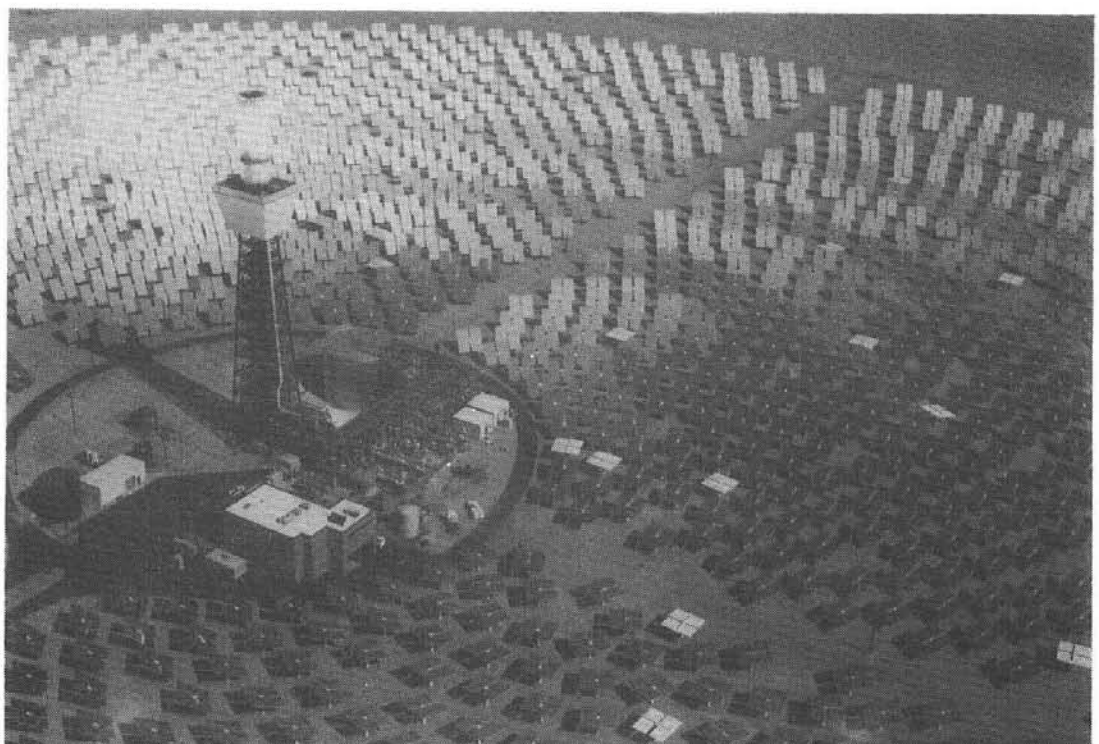


Figure 2. Plant in Operation

Collector System

The collector system is a 360-degree array of 1,818 Martin Marietta sun-tracking heliostats of the type shown in Figure 3.

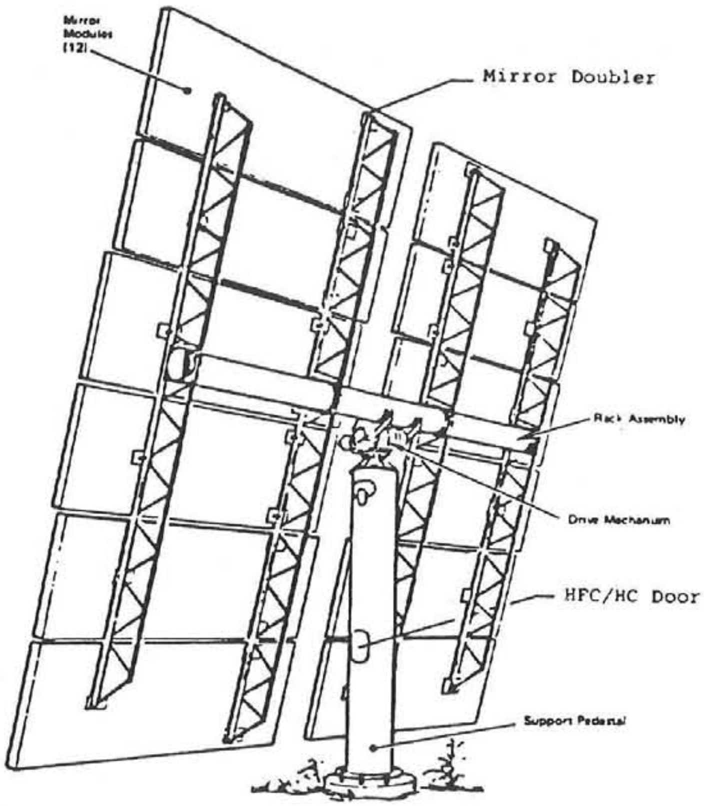


Figure 3. Heliostat Assembly

The heliostat field has a total reflective area of 782,000 square feet and is divided into four quadrants. There are a total of 1,240 heliostats in the two northern quadrants and 578 in the two southern quadrants. Each heliostat is made of 12 slightly concave mirror panels totaling 430 square feet of mirrored surface. The mirror assembly is mounted on a geared drive unit for azimuth and elevation control. The heliostat field is shown in operation in Figure 4 (note the standby point to the left of the receiver).

The collector control system consists of a micro-processor controller in each heliostat (HC), a heliostat field controller (HFC) for control of groups of up to 32 heliostats, and a central computer called the heliostat array controller (HAC). The annual and daily sun position information for aiming each heliostat is stored within this control system. The heliostats (Figure 5 shows a close-up) can be controlled individually or by groups in either manual or automatic modes through the HAC which is located in the plant control room. The heliostats are designed to operate in winds up to 50 mph and will withstand winds up to 90 mph when stowed in a mirror-down position.

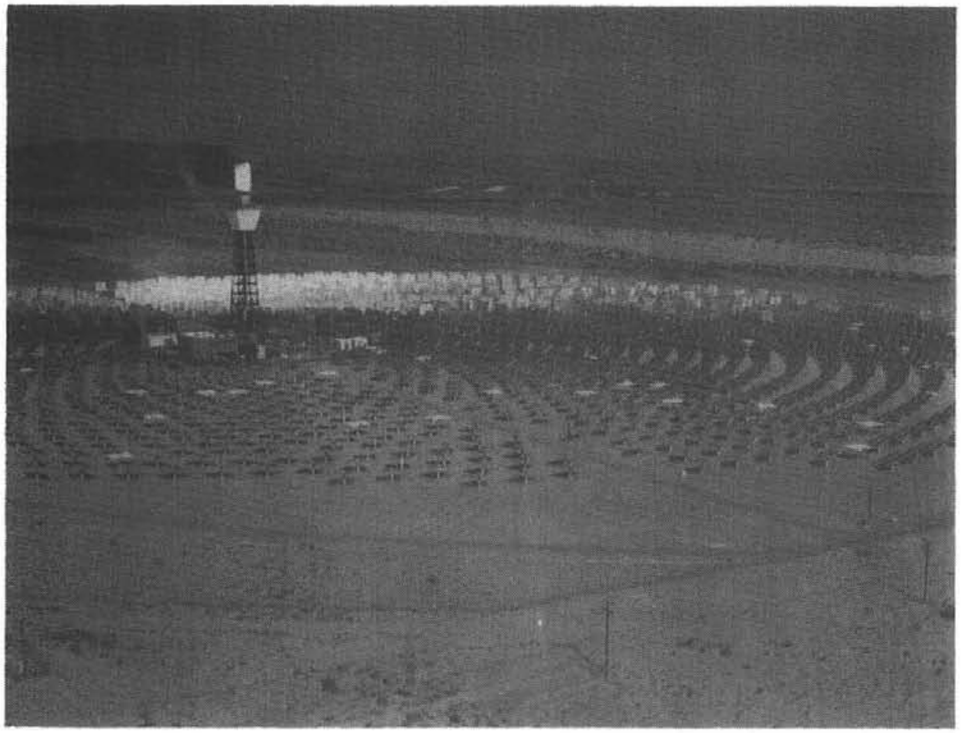


Figure 4. Heliostat Field in Operation

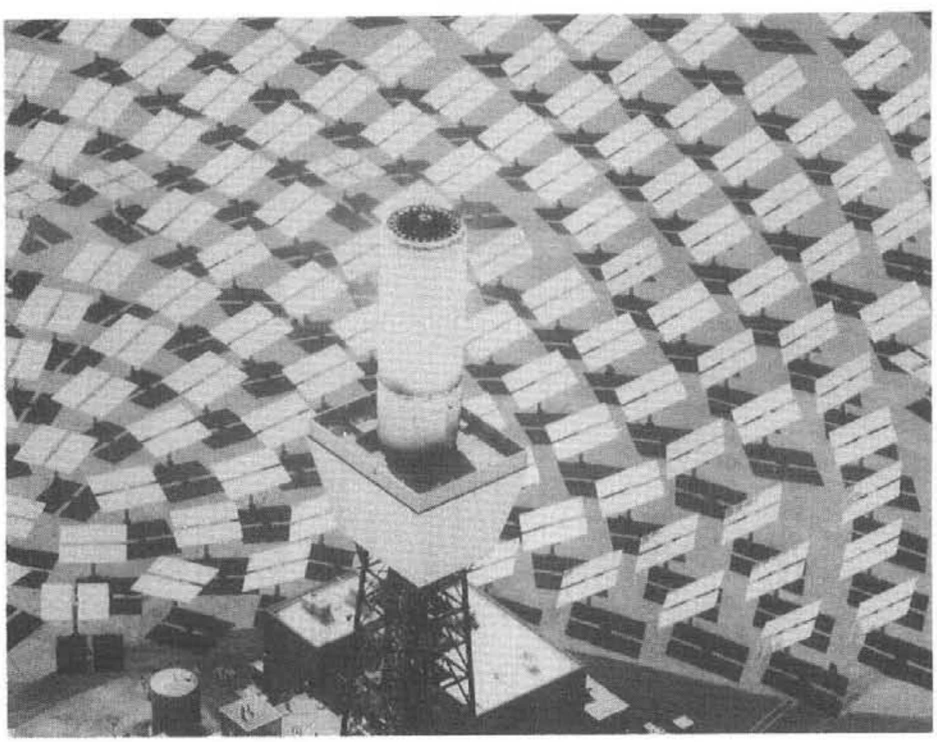


Figure 5. Close-up of Heliostats in Operation

Receiver System

The receiver system consists of a single-pass-to-superheat boiler with external tubing, a tower, pumps, piping, wiring, and controls necessary to provide the required amount of steam to the turbine. Steam demand can be varied from the control room by the operator, or the receiver system can react to a demand from the electric power generating system up to the receiver's rated output.

The receiver (Figure 6) is designed to produce 950°F steam at 1465 psia at a flow rate of 112,000 lb/hr. The receiver has 24 panels (6 preheat and 18 superheat), each approximately 3 feet wide and 45 feet long, as shown in Figure 7. Figure 8 presents a schematic of the receiver and tower.

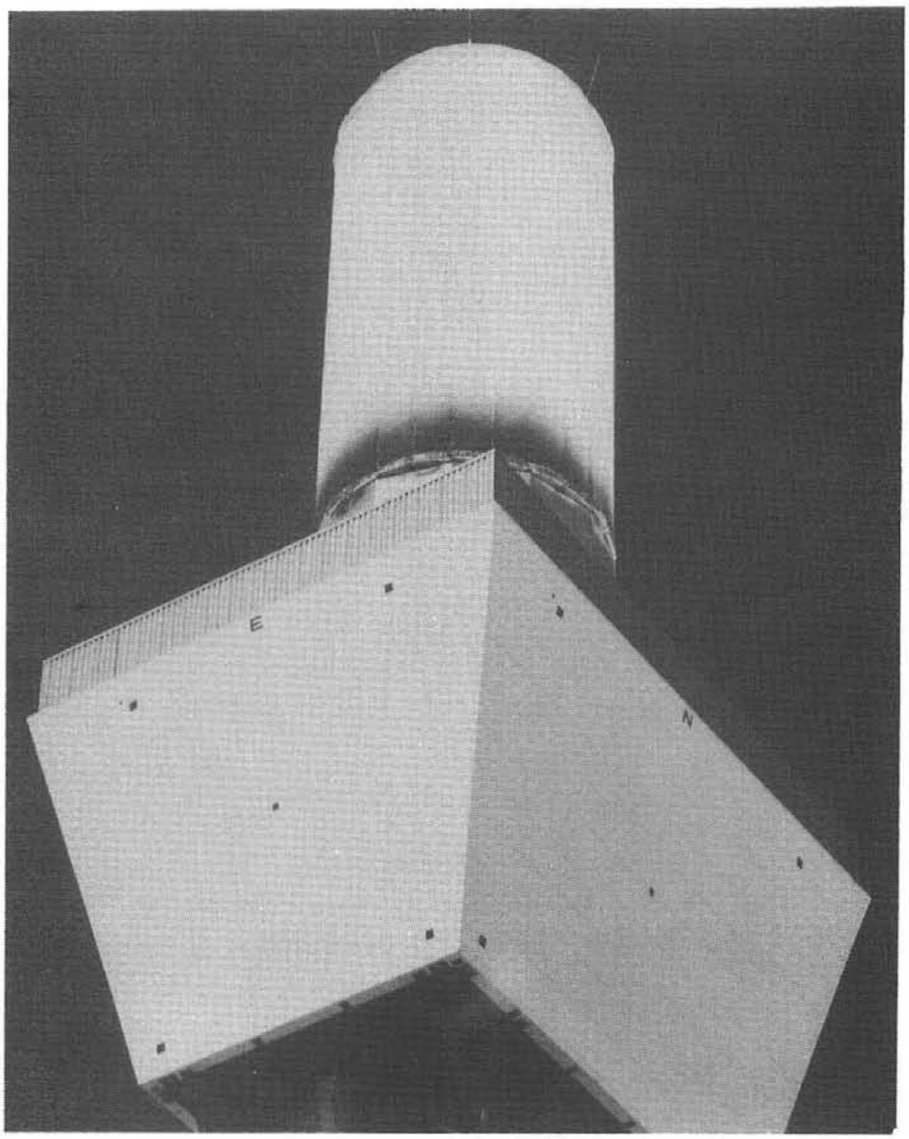


Figure 6. Receiver in Operation

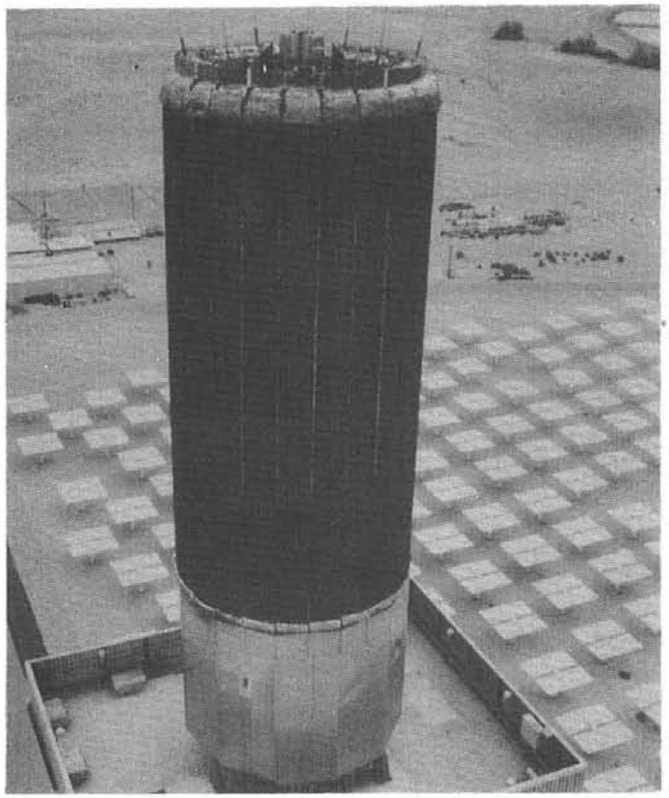


Figure 7. Receiver Panels with Boiler Tubes

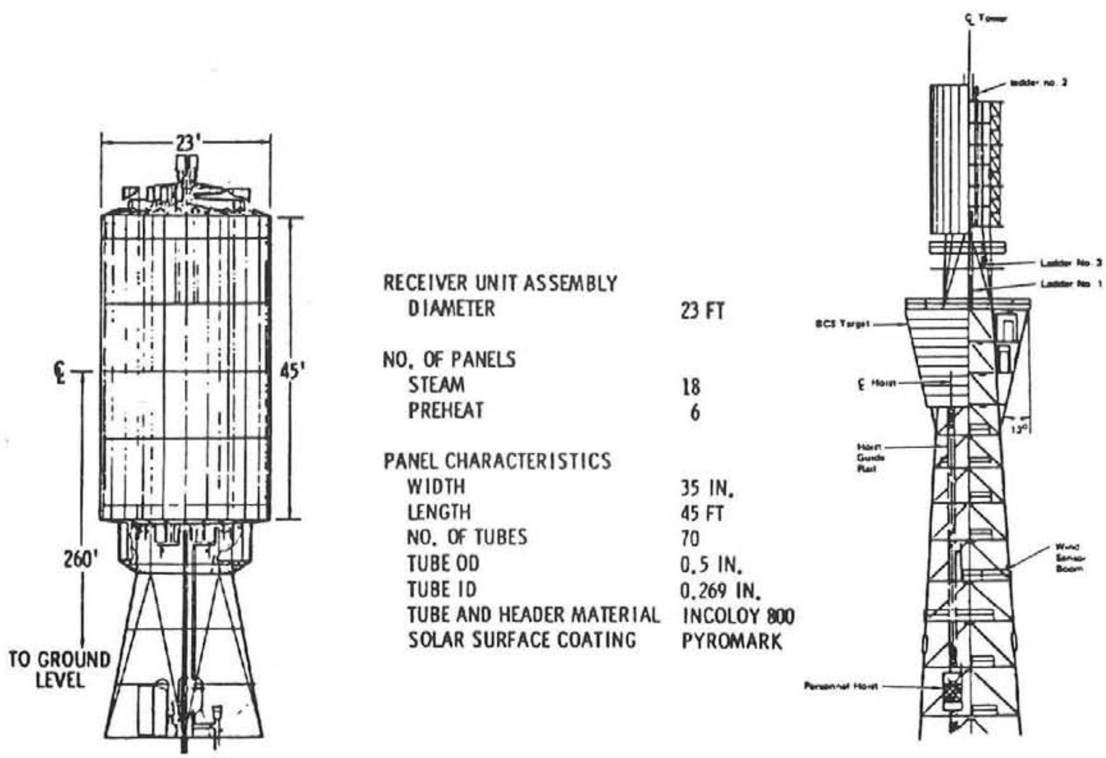


Figure 8. Schematic of Receiver and Tower

The panels are arranged in a 23-foot-diameter vertical cylindrical configuration with a total surface area of 3252 square feet. Each panel consists of 70 small tubes (0.5 in. OD, 0.27 in. ID) through which the high purity feedwater is pumped and converted to super-heated steam. The external surface of the receiver tubes under normal operating conditions is approximately 1150°F. These thick-walled tubes are made of Incoloy 800 in order to withstand the effects of daily heat cycling as well as cloud transients. Within each panel the tubes are welded to each other over their full length and the panel is coated with a special black paint (Pyromark) to increase thermal energy absorption. The back surface of each panel is heavily insulated and sealed against light leaks.

The lattice steel tower, shown in Figure 9, holds the receiver 300 feet above the desert floor. It stands on four 25-feet-deep footings attached to a 1500-ton concrete base. The flaired area of the tower immediately beneath the receiver is formed by four white aluminum sheet metal targets used for the beam characterization system. The tower space inside these targets houses air-conditioned rooms where the receiver computer and some of the beam characterization system controls are located.

Figure 9. Receiver Tower

Thermal Storage System

The thermal storage system, shown to the right of the tower in Figure 10, provides for storage of solar energy to extend the plant's electrical power generating capability into night-time or during periods of cloud cover. It also provides steam for maintaining selected portions of the plant in a warm status during non-operating hours and for starting up the plant the following day. For example, sealing steam is required in the turbine casing even when it is not running in order to maintain vacuum in the condenser and hold proper feedwater chemistry. Even though the primary source for this turbine sealing steam is thermal storage, a small auxiliary electric boiler is also available in case the thermal storage system is depleted or not operating. The thermal storage system is shown schematically in Figure 11.

The thermal storage tank (Figure 12) is 45 feet high and 65 feet in diameter. It sits upon a special lightweight, insulating concrete foundation for reducing heat loss to the ground. The walls are made of steel plate with one foot of insulation, and the roof is made of aluminum plus two feet of insulation. The 946,000-gallon-capacity tank, filled with 7,000 tons of rock and sand, and about 240,000 gallons of thermal oil (Caloria HT-43), acts as a heat storage vessel. Thermocouples are vertically spaced from the bottom to the top of the tank.

Desuperheated steam from the receiver is routed through a heat exchanger in which cold thermal storage oil from the bottom of the tank is heated. The heated oil is pumped back into the top of the tank and thermal energy is transferred to the rock and sand. When the tank is fully charged, the thermal storage mixture (oil, rock, and sand) will have a temperature of approximately 575°F. When the tank is discharging, the hot oil is pumped from the top of the tank through another heat exchanger to boil water, and the cold oil is returned to the bottom of the tank. Steam at 525°F and 385 psia can be produced from the thermal storage system and delivered to the turbine at a rate of 105,000 lbs/hr. The rated electrical capacity of the plant operating on thermal storage energy is 28 megawatt-hours net output, e.g., 7 MWe power for four hours. After the tank is discharged, sufficient thermal energy is still available in the tank for heating, sealing steam, and restarting the plant the next day.

As with other plant systems, the thermal storage system has its own computer controls and also can be controlled manually. By selecting plant operating modes, the operator can use receiver steam to charge the thermal storage system alone, or receiver steam can be divided to drive the turbine and charge the thermal storage system simultaneously.

Master Control System

The master control system is a series of computers which provides for control of the plant from the central control room. It supplies overall coordinated supervisory control to individual systems. A sketch of the master control console is shown in Figure 13. Ultimately, the plant will be operated fully automatically with only operator override, making it possible for one person to operate the entire plant. Initially, however, the plant systems must be operated separately with multiple operators.

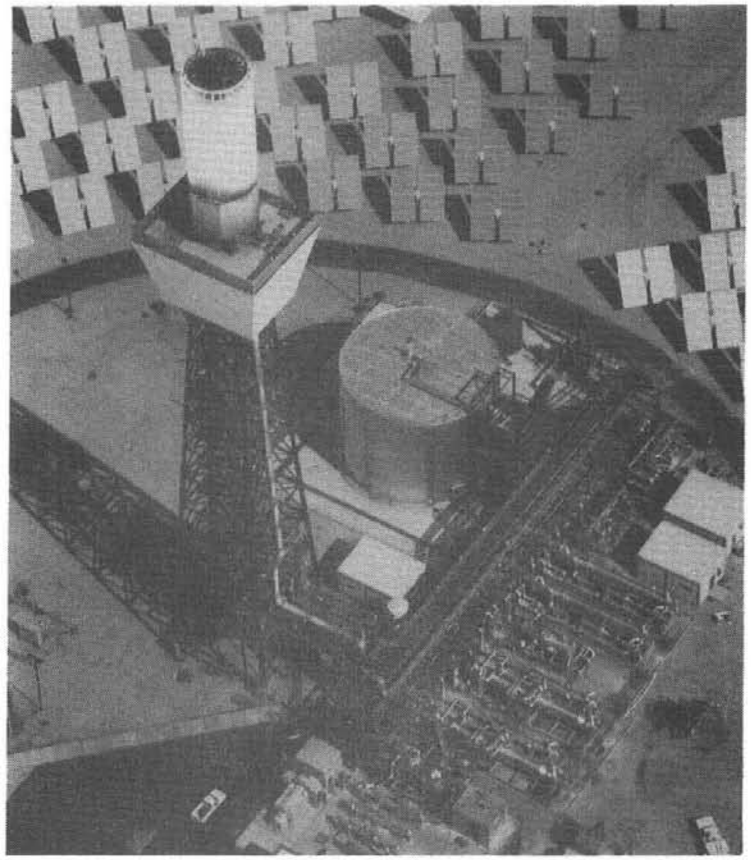
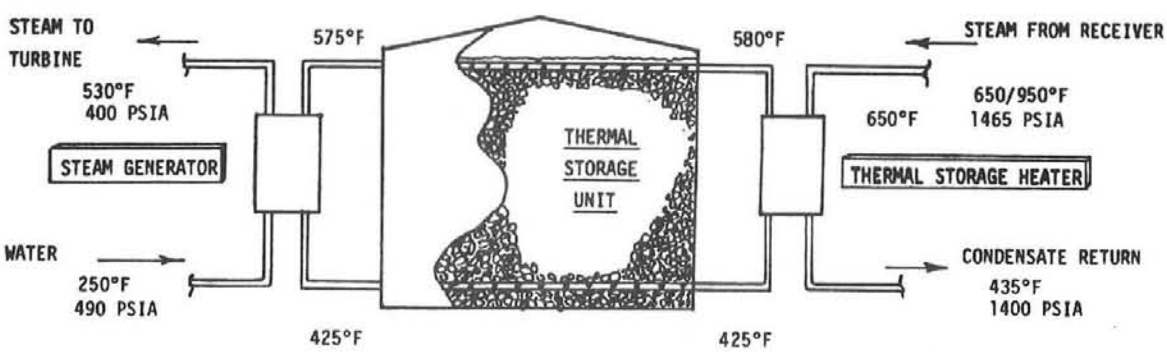


Figure 10. Thermal Storage Heat Exchangers and Thermal Storage Unit



DISCHARGE TIME	4 HR
EXTRACTABLE CAPACITY	145 MWHt
CHARGING RATE	1.6 TO 31.6 MWt
DISCHARGING RATE	1.7 TO 33.3 MWt

Figure 11. Storage System Schematic

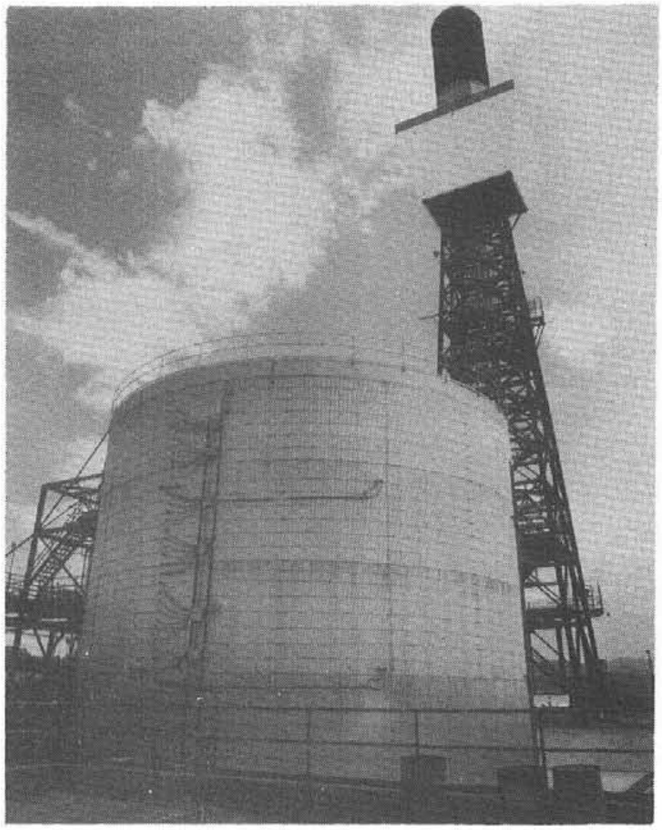


Figure 12. Thermal Storage Unit

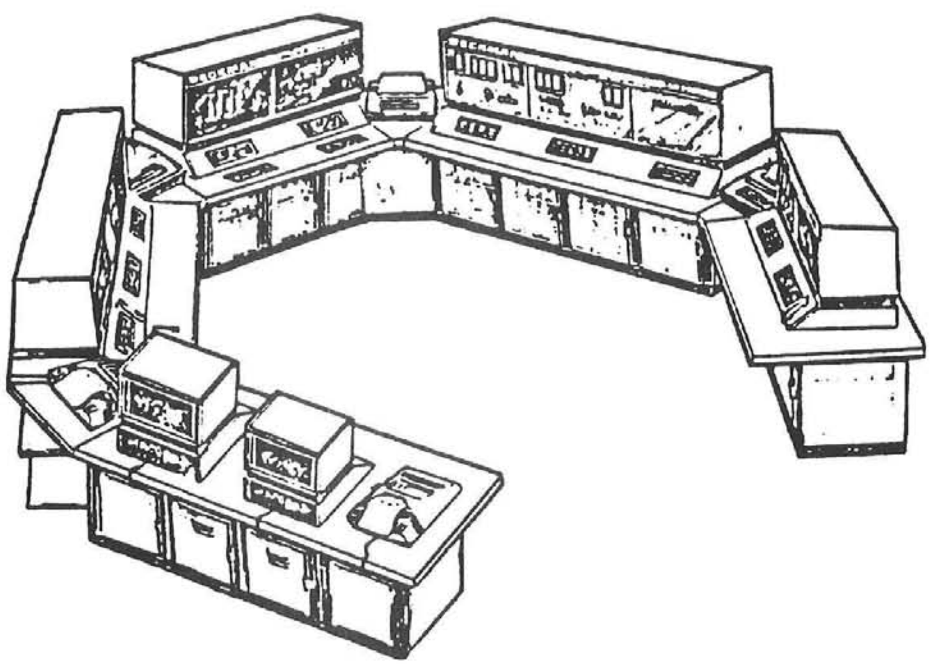


Figure 13. Control Room

Approximately 2,000 continuous, discrete measurements from throughout the plant are transmitted to the master control system and recorded. Operating data, alarms, and alerts are displayed on control consoles and on graphic displays (CRTs). Additionally, plant piping and instrumentation diagrams are displayed with live time process parameters and valve operating configurations indicated for system status.

To augment the master control system and also provide individual system control and trouble isolation, each system has its own distributed process controller. The process controllers are digital computers and are tied into the master system. These process controllers control the system valves, motors, pumps, relays, and other equipment, and are physically located near the respective system's hardware in remote stations. As an example, the receiver process controller is located in the tower within a remote station immediately beneath the receiver.

The control system hierarchy is shown in Figure 14. Four Modcomp classic 7863 computers are located in the control room and are designated as follows:

OCS - Operational Control System which provides a console for single operator control.

DAS - Data Acquisition System which records selected control and monitoring data.

HAC - Heliostat Array Controller which supervises the collector field. Two Modcomp units are utilized. One provides full redundancy for the other.

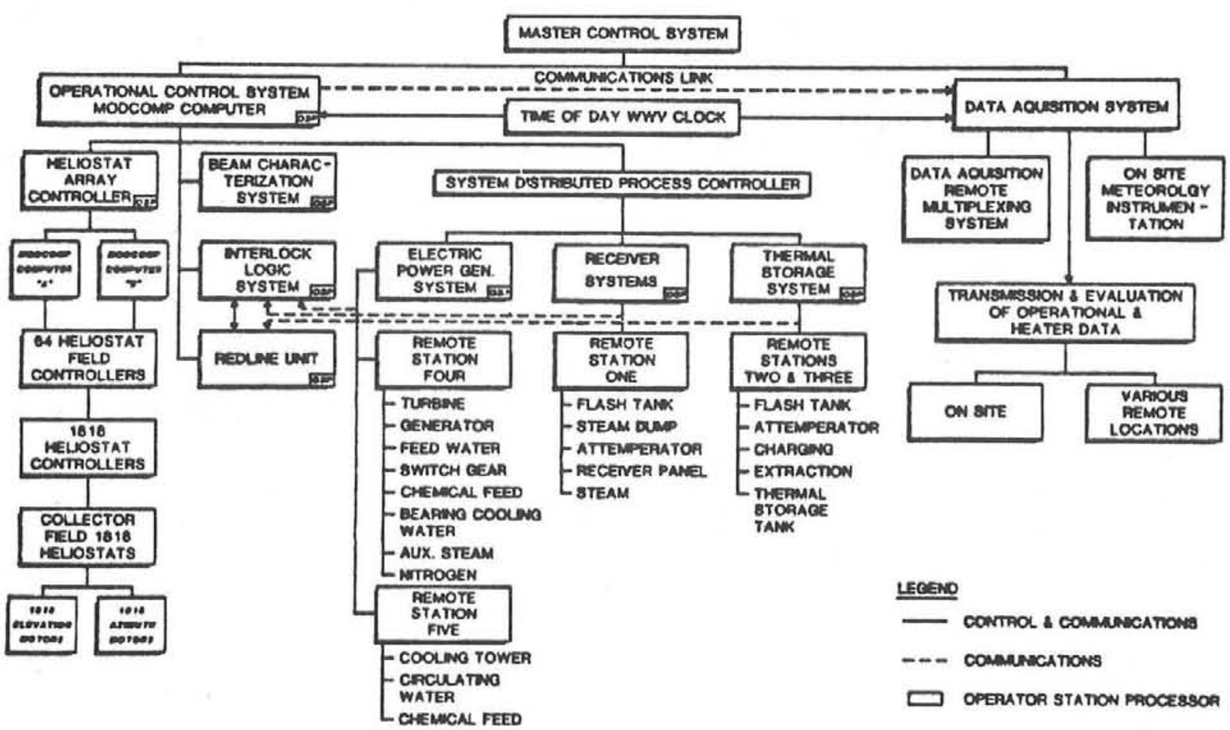


Figure 14. Master Control System Block Diagram

Control and monitoring data are collected and processed from field instruments by way of the distributed process controllers (SDPC). This control hardware is the Beckman MV 8000 system. Five remote processing stations are located outside the control room.

Turbine Generator

The General Electric turbine generator (Figure 15) is rated at 12.5 MWe and is a single case design for cyclic duty. It is the same general machine used for marine drives. The turbine has two steam admission ports, one high pressure for receiver steam and a lower pressure port for thermal storage steam. The rated turbine thermal-to-electric efficiency from receiver steam is 35%, and from thermal storage steam, 25%. Receiver steam conditions are 112,000 lb/hr, 950°F, 1465 psia throttle valve capacity for 10 MWe net. Thermal storage steam conditions are 105,000 lb/hr, 525°F, 385 psia admission valve capacity for 7 MWe net.

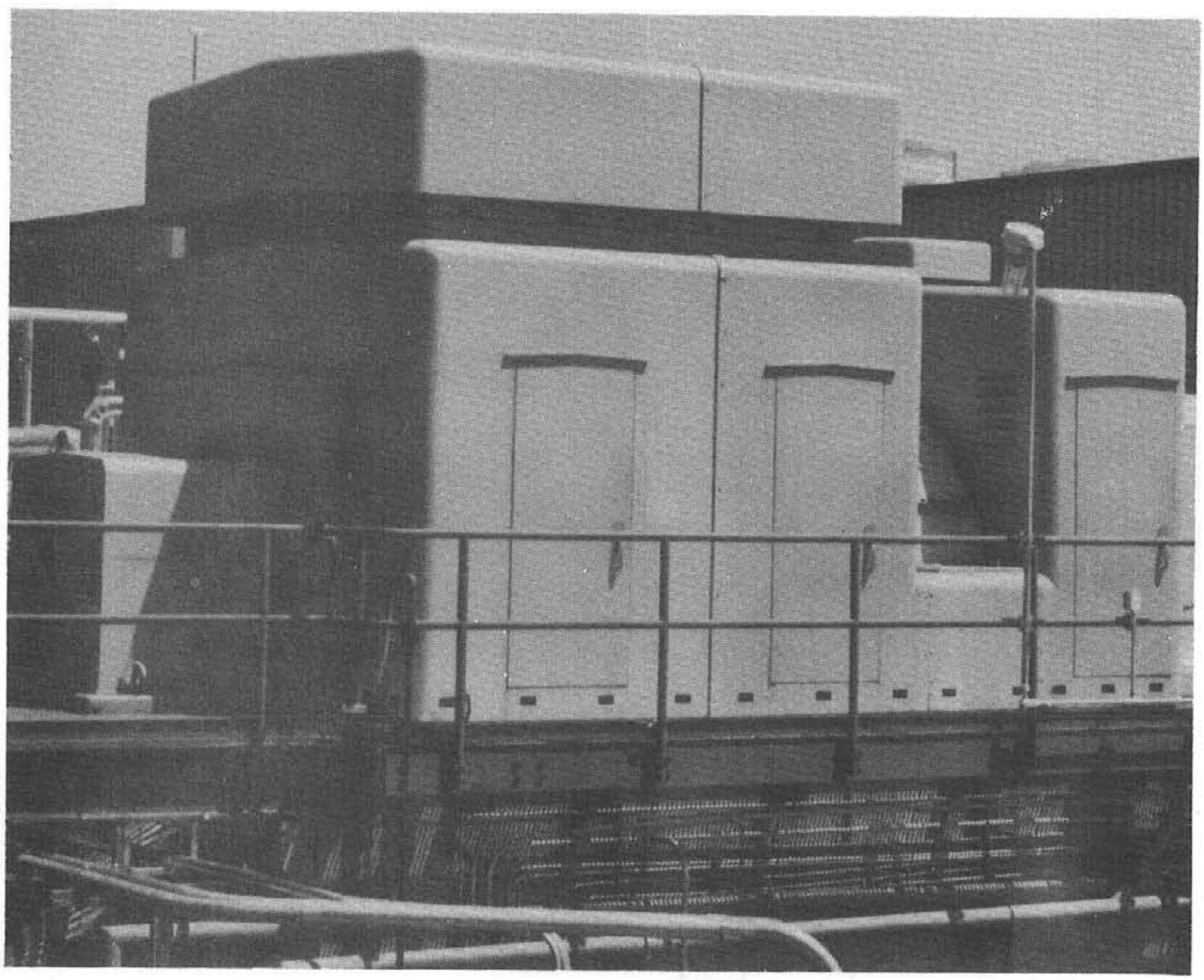


Figure 15. Turbine Generator

Figure 16 shows a schematic diagram of the plant. Spent steam is condensed by circulating water from the evaporative cooling tower. Condensed steam is then routed back to the receiver through a full-flow demineralizer and a series of feedwater heaters. The turbine has four steam extraction ports used for three feedwater heaters, and a deaerator. The second point and first point feedwater heaters only operate during receiver operation. The generator is air cooled with a static exciter and 13.8 kv rated output voltage.

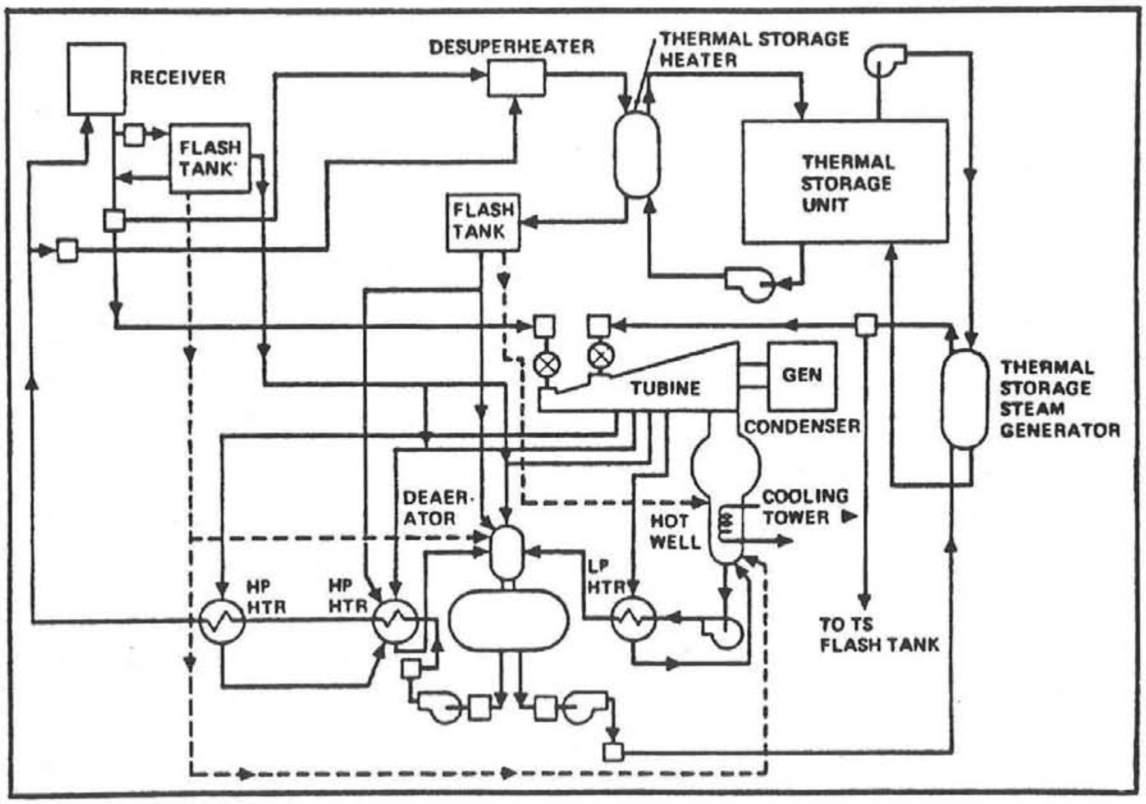


Figure 16. Schematic of Major Plant Systems

Additional support functions in the electric power generating system (EPGS) include the water chemistry control facilities and an uninterruptible power supply (UPS) battery system for providing power to the computer should the main and backup power sources fail.

Beam Characterization System

Since each mirror module (glass facet) can be canted in one axis, the overall beam from each heliostat can be focused. The beam characterization system is used to calibrate each individual heliostat beam with respect to its aim point on the receiver, its beam shape, and the beam power density. This system consists of a vidicom camera (Figure 17), a microcomputer, and associated controls and is coupled to the collector control system.

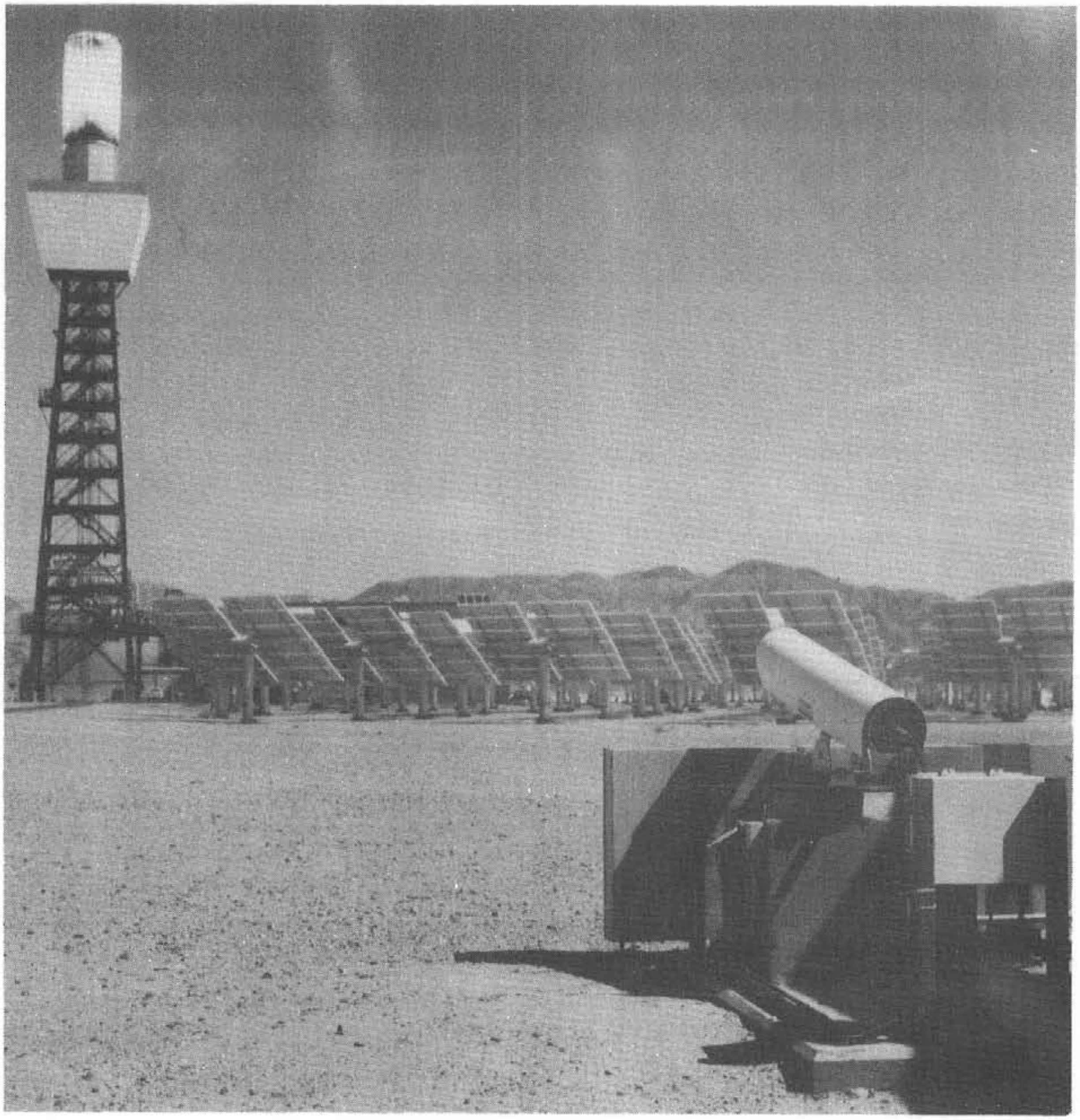


Figure 17. Beam Characterization System Camera

Environmental Monitoring

Environmental impacts during construction of the pilot plant have been monitored by the Laboratory of Biomedical and Environmental Sciences at the University of California at Los Angeles. Their studies have found that during plant construction the existing ecosystem within the plant site was completely removed, an estimated 160 metric tons of sand have been blown from the heliostat field to adjacent downwind areas, and some of the annual plant growth has decreased where the most sand has been deposited.

Their studies on restoring vegetation to the disturbed desert areas around the plant site conclude that the most limiting factor will be grazing damage from small animals.

Project Construction Cost

DOE was responsible for funding the design and construction of the solar facilities including the collector system (heliostats), receiver, thermal storage, and master control systems. The prime contractors were:

- Martin Marietta--Fabrication and installation of heliostats and associated controls;
- McDonnell Douglas Astronautics--Systems integration, master control, receiver (Rocketdyne), thermal storage (Rocketdyne), and A/E services (Stearns-Roger);
- Townsend & Bottum--Construction management.

The DOE budget of $120 million covered completion of construction (April 15, 1982). Start-up of all major systems beyond functional performance was deferred; the following have been or will be activated during the two-year start-up and experimental test phase:

- thermal storage;
- plant level operational status displays software development;
- coordinated and automatic control software development.

SCE was responsible for design, construction, and start-up of the turbine-generator facilities. The $21.5 million capital cost for these facilities is shared on an 80%-20% basis between SCE and LADWP, respectively.

A summary of the total capital costs for the project is shown in Table I.

TABLE I
SOLAR ONE CAPITAL COST
(MILLIONS)

SOLAR FACILITY	COST	PERCENT
Solar Facility Design Cost	$ 31.2	22%
Collector Field Fabrication & Construction	40.0	28%
Receiver Fabrication & Construction	23.4	17%
Thermal Storage Fabrication & Construction	12.0	8%
Plant Control System	3.0	2%
Beam Characterization System	1.0	1%
Miscellaneous Support Systems	9.4	7%
TOTAL SOLAR FACILITY DESIGN/FABRICATION/CONSTRUCTION COST	$120.0	85%
TURBINE-GENERATOR DESIGN & CONSTRUCTION COST	$ 21.5	15%
TOTAL PLANT COST	$141.5	100%

A key to future cost reductions for central receiver plants of this type is a reduction in the cost of heliostats. As shown in Table I, collector field fabrication and construction accounted for 28% of the total plant cost. Receiver fabrication and construction and turbine-generator design and construction costs were 17% and 15%, respectively, of the total cost. SCE's costs totaled $21.5 million, consisting of approximately 25% Edison labor, 25% SCE-furnished materials and equipment, 25% construction contract costs, and 25% construction overheads including an allowance for funds used during construction (AFDC). The largest single piece of equipment, the turbine-generator, accounted for $2.2 million of the equipment cost.

Project Schedule

Start-up testing was initiated in April 1981 and progressed through the piping system cleaning, flushing, subsystem operations and circulating high purity cold water through the receiver and other piping systems to verify system integrity. Controls testing of the major systems, receiver, thermal storage, EPGS, plant support and the data systems were completed in April 1982. Coupled systems tests, receiver and turbine-generator have been underway with an operational procedure developed for weekend power production using receiver-generated steam. The thermal storage tank has been fully charged and discharged and the system has been placed in service. The originally scheduled goal to have the operators trained for turbine-direct operation from receiver steam, storage charge and extraction by early CY-1983, without technical supervision, has been partially realized. SCE operators are now authorized to operate the plant for the test manager on weekends, holidays and non-test days in Mode 1 (Turbine Direct) and Mode 5 (Storage Charging) without direct supervision. The balance of the test program will be devoted to exploring the basic operating modes, evaluating performance data from these operations, and incorporating automatic control as detailed in the following planned test plan:

Mode 1 - Turbine Direct (TD)

All thermal power reflected from the Collector System (CS) and absorbed by the Receiver System (RS) flows as superheated steam to the Electric Power Generation System (EPGS) for direct turbine-generator operation. The Thermal Storage System (TSS) is bypassed in this mode.

Mode 2 - Turbine Direct and Charging (TD&C)

Thermal power collected by the receiver is divided between thermal storage (charging function) and the EPGS for direct turbine-generator operation.

Mode 3 - Storage Boosted (SB)

All thermal power collected by the receiver flows to the EPGS and is augmented by admission steam power extracted from thermal storage.

Mode 4 - In-Line Flow (ILF)

All power collected by the receiver flows to thermal storage. Thermal power is extracted from storage for turbine-generator admission steam operation. This mode is used on partially cloudy days to buffer thermal transients from the receiver.

Mode 5 - Storage Charging (SC)

All thermal power collected by the receiver is used for thermal storage charging.

Mode 6 - Storage Discharging (SD)

Thermal power is extracted from storage for admission steam turbine-generator operation.

Mode 7 - Dual Flow (DF)

Thermal power collected by the receiver is divided between both storage and the EPGS. Thermal power is also extracted from storage and routed to the admission steam input of the EPGS.

Mode 8 - Inactive (I)

All systems are inactive and held in a standby condition during overnight shutdown.

The eight operating modes are diagramed in Figure 18. Initially, the testing will concentrate on operation in Mode 1--receiver steam direct to turbine--along with activation of the thermal storage system and testing in Modes 5 and 6--storage charging and discharging. Concurrently, the plant operational displays software package will be completed and installed. This effort is expected to be completed in mid-1983.

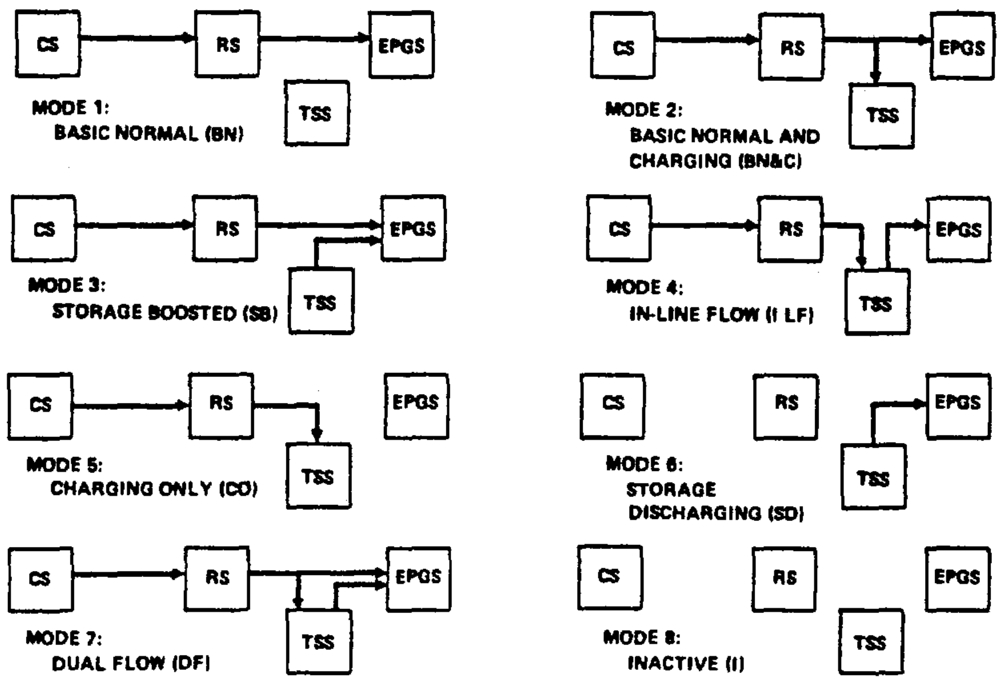


Figure 18. Plant Operating Modes

In 1983, the balance of the operating modes will be verified, and the coordinated and automatic control software will be developed and tested. Several engineering tests are planned and the clear/cloudy day automatic test requirements will be developed. At this point, the plant will be operational under fully automatic computer control and completely tested in all of its operating modes. Test schedules have been worked out so power production is "piggy backed" on receiver and thermal storage testing.

The last three years of the five-year test program will then be devoted primarily to optimizing power production and testing of the plant as a utility resource.

Operation and Maintenance

In accordance with the Utility Associates Cooperative Agreement with the DOE, SCE is responsible for the operation and maintenance of the pilot plant. A prudent minimum level of staffing by full-time experienced SCE operators and maintenance personnel has been developed, consisting of 6 administrative, 20 operating and 12 maintenance people. Of the 38 total, 26 are represented by the local union.

The basic operating crew consists of five people (operating foreman, control operator, two assistant control operators, and plant equipment operator). This crew will be required for two energy production shifts per day, seven days per week. A caretaker crew consisting of two people (control operator and plant equipment operator) will make up the back shift. The balance of the personnel will perform administrative, material control, and maintenance activities. Only light maintenance capability has been provided at the pilot plant site. Heavy maintenance will be accomplished at Cool Water Generating Station or other off-site facilities. For the initial year of operation, heliostat maintenance and washing was not performed on a regular basis but only as required to maintain an adequate power level.

The estimated annual operation and maintenance cost for the power plant is $3,369,700. This estimate is summarized in Table II.

TABLE II

SOLAR ONE FY83 OPERATING AND MAINTENANCE BUDGET

	Cost	Percent
Company Labor	$2,090,000	62%
Material	471,800	14%
Contract	288,800	9%
Other Miscellaneous Expenses	49,900	2%
Administration and General Overheads	469,200	13%
TOTAL ANNUAL COST	$3,369,700	100%

Construction and Start-Up Experience Highlights

During the design, construction, and start-up phase of the project, several valuable first-of-a-kind experiences have happened that are worth sharing. Some can be categorized as lessons learned and others demonstrate that the project is on the cutting edge of central receiver technology.

Tower Crane

Design of the tower-mounted receiver called for a service and maintenance crane to be mounted on top of the receiver. Its dual purpose was to facilitate installation of the receiver panels during construction and to remove and replace a panel during operation if one should become damaged beyond in-place repair. After the crane was procured and installed by the tower erector, it was concluded that the crane itself could not accommodate the elevated temperatures expected immediately above the receiver during plant operation. As a result, the crane was removed after construction rather than attempting to modify or protect it at an excessive cost. If panel removal is required, a rental crane will be used.

This exemplifies the complex job of integrating all of the construction and operational requirements into plant equipment specifications.

Heliostats

The installation of the collector field was accomplished on schedule and clearly demonstrated the benefit of the "learning curve" when performing repetitive tasks. Fabrication and installation experience by major components is summarized below:

Pedestals--

- Installation started November 1980 and was completed June 1981
- Units installed per day were 27-60 (minimum-maximum)

Drives--

- Final assembly at Daggett started November 1980 and was completed July 1981
- Units assembled per day were 1-18 (minimum-maximum)
- Installation started November 1980 and was completed August 1981
- Units installed per day were 5-50 (minimum-maximum)

Mirror Assemblies--

- Mirror module fabrication in Pueblo, New Mexico, started January 1981 and was completed August 1981
- Module production was 100-279 (minimum-maximum) per eight-hour day
- Final assembly at Daggett started February 1981 and was completed September 1981
- Final assembly production was 2-18 (minimum-maximum) per eight-hour day
- Site installation started February 1981 and was completed September 1981
- Units installed per day were 4-40 (minimum-maximum)

Heliostat Controls--

- Denver, Colorado, fabrication started November 1980 and was completed May 1981
- Installation at Daggett started February 1981 and was completed September 1981
- Units installed per day were 10-40 (minimum-maximum)

Problems (and resolutions) which have been experienced with the heliostats during the fabrication, production testing, assembly, installation and initial operation are summarized in Table III.

TABLE III
PROBLEMS AND RESOLUTIONS

Problem	Resolution
Production drive failed during simulated 90 mph wind load test	Additional elevation pinion gears tested without failures; high wind stow position revised to reduce loading
High glass loss during start-up of mirror module fabrication on ceramic tools	Standard float glass used for approximately 136 heliostats; field performance impacted less than 1%
Seventy-four doubler pad bond failures have occurred at site. Doubler pads hold mirror modules to structural rack assembly	Adhesive process control improved; pad pull test initiated; riveting retrofit performed on 5400 modules; approximately 150 spare modules available at site
Random communication failures occurred in heliostat control boxes	Boxes modified to increase capacitor size and jumper connections added
Lightning storm caused failure of I/O communication couplers in field and control room	Provide additional grounding protection of control cable in core and field areas to protect against electromagnetic pulses
Corrosion in mirror facets	Under study; however, a new vertical stow position was initiated in January 1983 to keep water off the back of the mirrored glass.

Based on pilot plant experience, Martin Marietta has recommended for future central receiver plant installations that the following site construction items be completed prior to the start of heliostat installations:

- Data cabling installed in entire field;
- Power cabling energized in entire field;
- Control room available for permanent control console;
- BCS targets installed.

Thermal Storage Tank Leak

About one month after oil was placed in the tank, evidence of a leak in the tank bottom was observed at the northern edge of the tank. The leak rate remained constant at less than 1 gallon per day (capacity of the system approximates 240,000 gallons). At operating temperatures, however, it was calculated that this rate would increase to approximately 60 gallons which was unacceptable. A tunneling effort was required to expose the leak and a flaw was discovered in one of the floor plates rather than in a weld as initially assumed. The leak has been repaired and the thermal storage system is now being conditioned. This experience points out the need to examine all tank plate material very thoroughly prior to erection.

Freeze Protection

In January 1982, temperatures below 18°F were experienced at the site which caused freezing of some small diameter tubing and components (e.g., flow meters, pressure and temperature indicators, etc.). This initiated a review of the freeze protection criteria and several measures have been taken to correct this situation (e.g., heat tracing of lines has been increased, temporary enclosures and space heating have been installed, special operating procedures have been instituted). Start-up testing was continued after a one-week delay.

Operator Training

Operator training was initiated early in the program utilizing a control room simulator which was developed by McDonnell Douglas at their headquarters in Huntington Beach, California. This approach allowed SCE operators to become familiar with each system early so they could meaningfully contribute during the start-up of the plant. In a matter of days after controls were installed, SCE operators were demonstrating operating capability with the systems.

Site Safety

Site safety measures have been carefully evaluated during start-up. Safety controls were instituted based upon a series of heliostat beam safety tests completed by SCE and Sandia National Laboratories. The tests confirmed the location of limited areas of high solar flux near ground level within the heliostat field as heliostats are moved from the stow position to the receiver standby points. These areas have been appropriately marked to warn site personnel. Several safety briefings were held with all personnel to inform them of the safety precautions necessary during testing.

Thermal Cycling

Without the immediate availability of thermal storage, the major plant systems have been subjected to diurnal temperature cycling from ambient to operating temperature. As a consequence, numerous minor leaks and malfunctions have been experienced. Systematic repair has accommodated most delays and long-lead measures have been identified to minimize the effect of transients. A specific example is that of the steam dump system isolation valve which failed in mid-July. Cooperative efforts between the manufacturer, site maintenance and technical personnel resulted in short-term resolution and a long-term repair. Short-term, the plant operation was impacted by the fact that daily receiver start-up was delayed. Ultimately, the valve was electrically trace-heated to reduce thermal transients while minimizing the delay of start-up. With thermal storage activation, the number of plant systems which undergo thermal cycling will be reduced.

Plant Test and Operating Data

Test and operating statistics are presented in Table IV and illustrated in Figure 19. As systems have been activated and operated, trends are favorable: test and power production hours increasing, with plant outage hours decreasing as time has progressed. Review of this data should be accompanied by the fact that the prime activity during the initial months has been start-up testing. Weekend power production by SCE has been in operation since July 15. An interim operational procedure was prepared and the operators trained during the testing periods. The effect of this is seen in the better than 150% improvement in monthly power production time and energy following June. April and May and, more recently, January and February were good power energy months because the major test activities allowed concurrent power production. The period from June to November has tested receiver and storage performance realms which precluded turbine operations during the week.

Weather has had a greater than expected effect upon the testing. Weather outage hours have increased since April. In addition, the insolation level has been low. For example, during August insolation, above 950 watts per square meter was not observed. The base design year, 1976, recorded insolation above 950 watts per meter, over four hours, on nineteen days during August.

TABLE IV
MONTHLY HOURLY ACTIVITY SUMMARY

					1982						1983
	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB
Test	62	46.5	41	93	94	124	33	19	15	69	60
Plant Outage	61	59	88	96.5	73	75	86	136	46	24	12
Weather Outage	7	34	31	50	102	120	90	144	98	89	116
Power Production	28	48	10	29	27	55	16	10	44	58	44
MWe-Hr Net	56	215	46	99	143	112	155	44	186	246	202

Activities

Rec'r Control Test	xxxxxxxxxxxxxxxxxxxxxxxxxx
Storage Activation	xxxxxxxxx
Storage Testing	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
Rec'r-Turbine Testing	xxxxxxxxxxxxxxxxxxxxxxxxx
Weekend Power Prod.	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

Figure 19 shows a summary of activities that are tabulated on a monthly basis. Those activities below the line (test hours plus energy production hours) are an indication of the productivity at the plant. In October start-up time and the time that the insolation level was above 450 watts per square meter were added to the statistical tabulations to make the chart more meaningful. The chart shows a steady improvement since November when the plant was shut down for two weeks because of maintenance. In February, all useful sunshine was utilized. Start-up time may be misleading because total hours are tabulated; therefore, a large number of starts would appear as a significant time period.

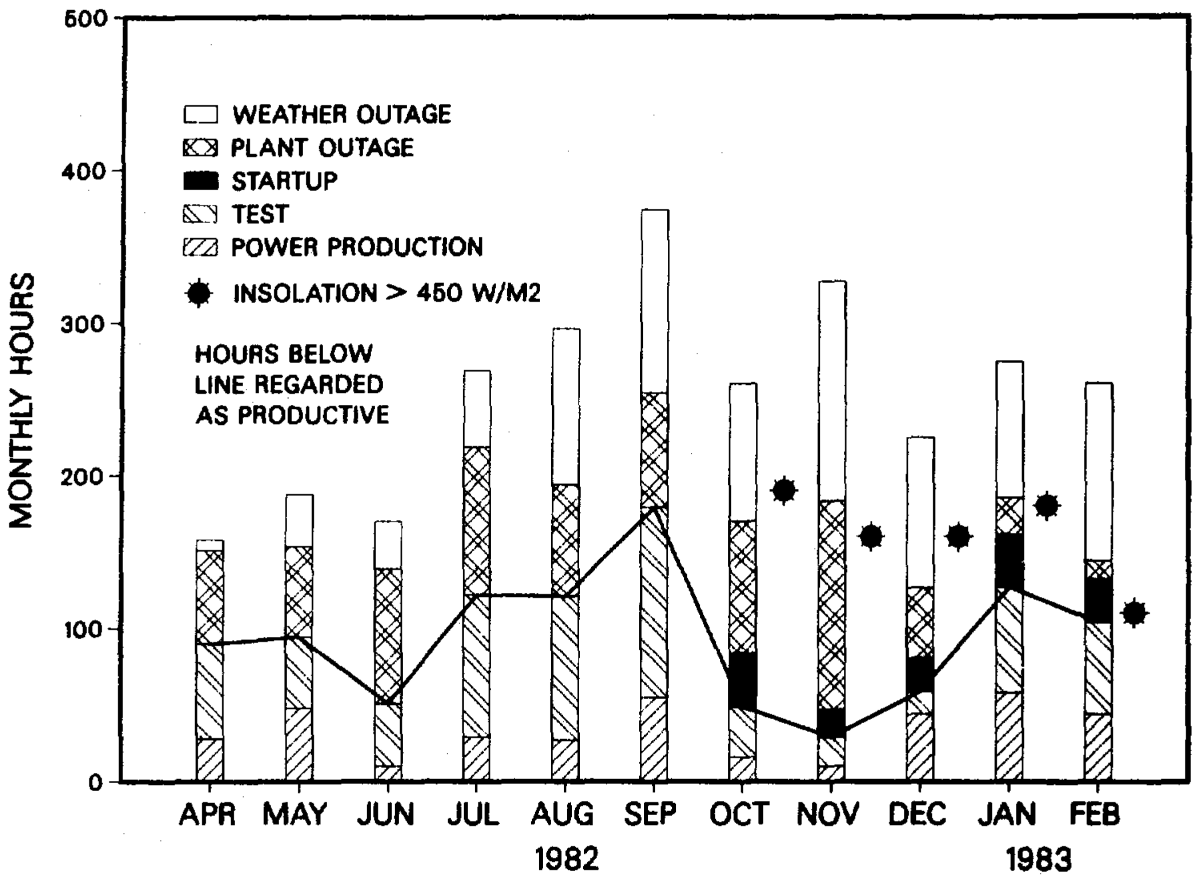


Figure 19. Distribution of Plant Activities

Public Interest

Public interest in the project has been high even prior to any visual attraction from plant operation. The visitors information center, which is open 9 am - 5 pm seven days per week, has recorded over 77,000 visitors since its opening in July 1980. Attendance increased as the plant became highly visible due to receiver reflectivity and heliostat beams focusing on standby points adjacent to the receiver. A photograph of the plant illustrating its visibility is shown in Figure 20.

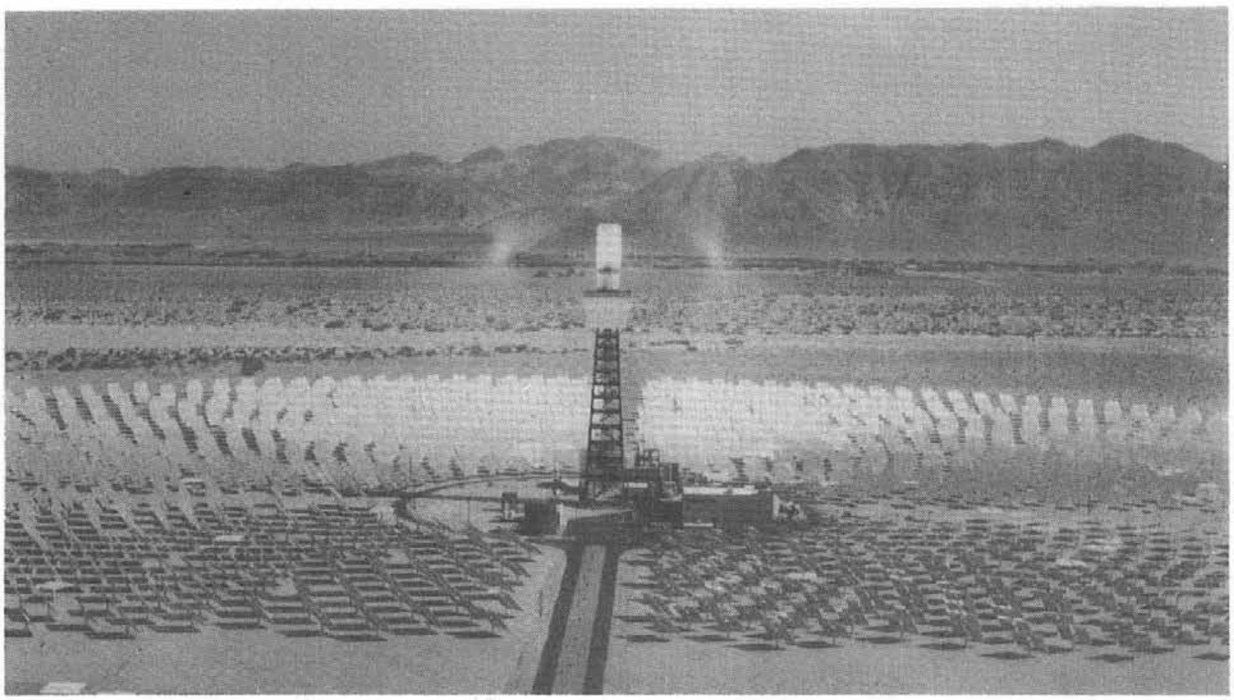


Figure 20. Beams at Standby Points and Upon the Receiver

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