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Monograph Series, No. 1: 10 MWe Solar Thermal Central Receiver Pilot Plant Heliostat Experiences November 1981—February 1983

C. L. Mavis

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MONOGRAPH SERIES, No. 1: 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT HELIOSTAT EXPERIENCES NOVEMBER 1981 - FEBRUARY 1983

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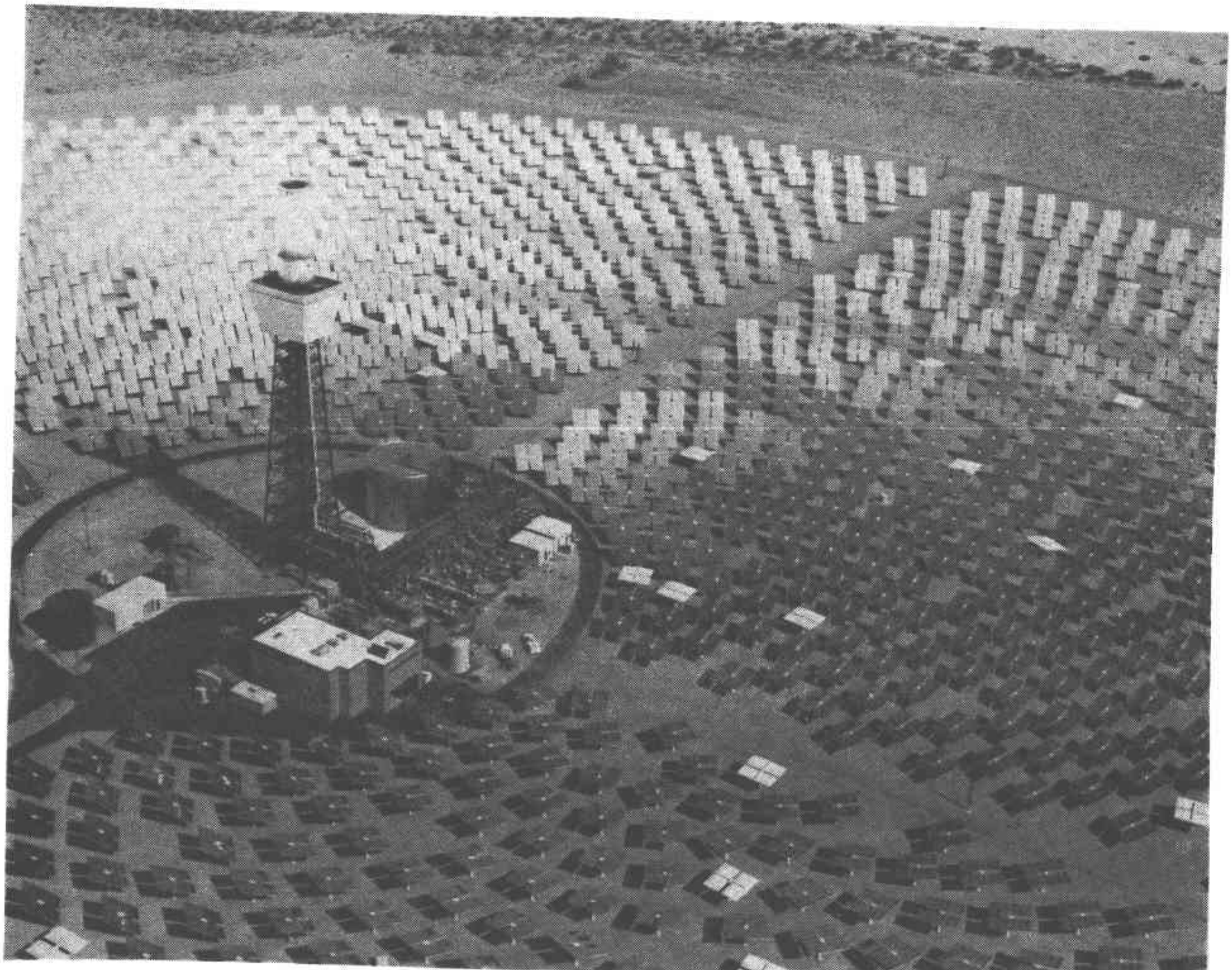
ABSTRACT

The heliostat design, installation, and operating experiences and the test and evaluation program are reported for the Sôlar Thermal Central Receiver Pilot Plant at Barstow, California. Operating and maintenance experiences and preliminary test results are reported from November 1981 through February 1983. Installation of the 1818 heliostats was made over a 10-month period with no major problems. Initial checkout of the heliostats was completed in nine days which included making minor software changes. Performance of the control system, including safe control of reflected light, and the heliostat structure and drives has been verified during the first year of operation. Heliostat maintenance requirements have been less than anticipated and can be accomplished with 160 manhours per month. Problems with evaluation instrumentation and mirror corrosion have occurred and they have been solved or are being evaluated.

PREFACE

This monograph is the first in a series of monographs designed to cover topics of interest on the 10 MW_e Solar Thermal Central Receiver Pilot Plant at Barstow, California. These short reports will provide up-to-date information on areas of current research and development at the plant. More detailed information can be found in the technical and evaluation reports prepared by Sandia National Laboratories. For a list of recent reports, contact the Solar Central Receiver Department, 8450, Sandia National Laboratories, Livermore, California 94550.



10 MWe Solar Central Receiver Pilot Plant showing the receiver, storage tank, control building and heliostats.

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Introduction

In August 1982, the Department of Energy (DOE) and the San Francisco Operations Office of the DOE initiated a two-year test and evaluation program for the Barstow 10-MWe pilot plant. Sandia National Laboratories, Livermore (SNLL) is responsible for defining and executing the test and evaluation program. This is an interim report for the pilot plant heliostat test and evaluation portion of the overall program, which is described in References 1 and 2. The heliostat Beam Characterization System and special heliostat instrumentation are also included.

The 1818 heliostat field is 9-20 times larger than any other field and the performance has been excellent. Performance of the controls, structure, and drives has been verified. Some problems have occurred and these are being either solved or evaluated.

The test program and some preliminary results are discussed below along with installation and operating experiences through February 1983. A final report on the test program results will be published in the last quarter of 1984.

Design Descriptions

Heliostats

The pilot plant heliostats were designed, produced, and installed by the Martin Marietta Corporation, Denver, Colorado. A heliostat photograph is shown in Figure 1. The more significant design features are shown in Table I. There are 1818 heliostats which surround the receiver with 1240 heliostats in the two northern quadrants and 578 in the southern quadrants.

The collector control system consists of a microprocessor 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 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 22 m/s (50 mph) and will withstand winds up to 40 m/s (90 mph) when stowed in a mirror-down position.

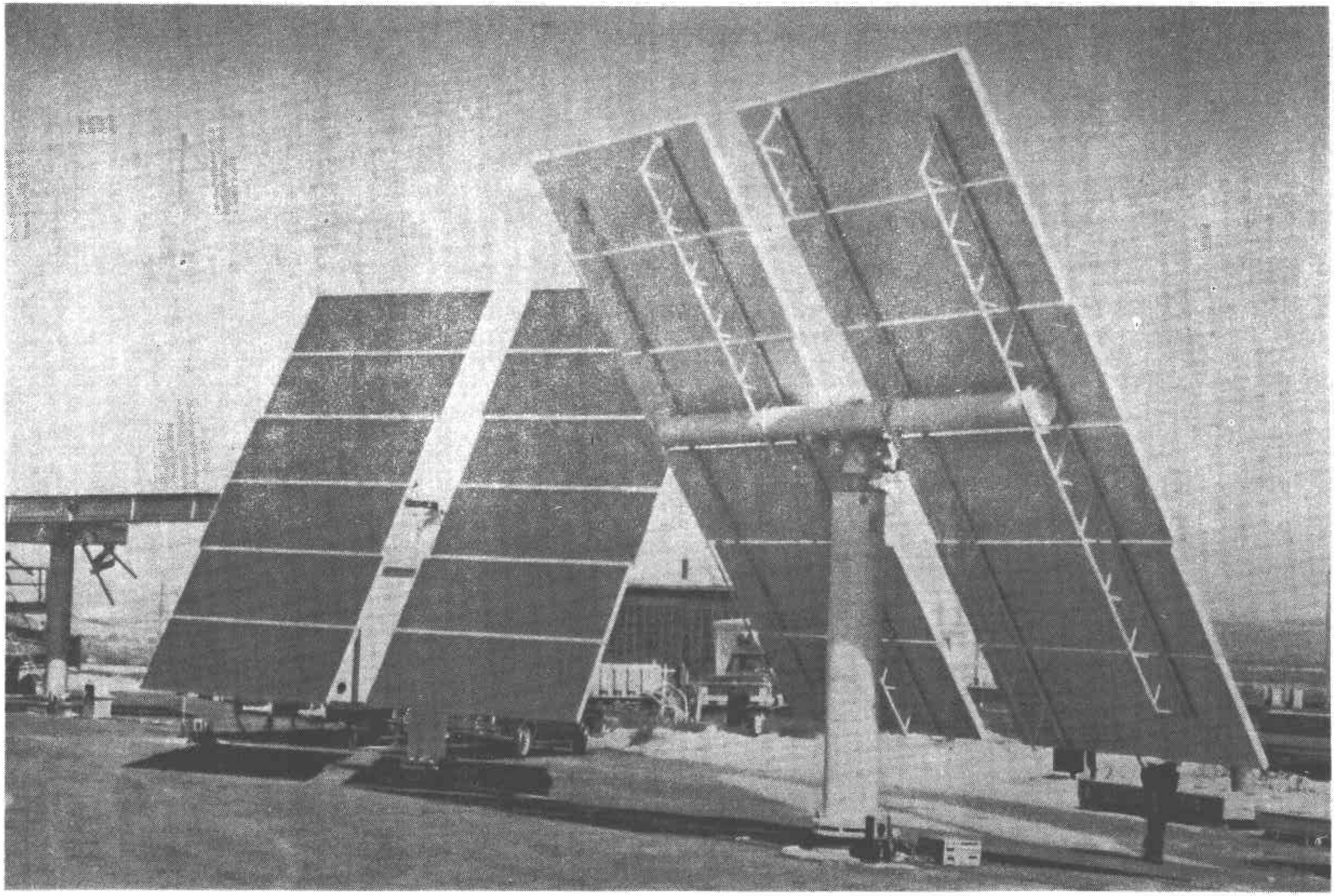

Figure 1. Pilot Plant Heliostat

TABLE I

HELIOSTAT DESIGN FEATURES

Mirror Module Assemblies:

- 39.9 m^2 total reflective area
- Glass--3.2 mm x 1.09 x 3.05 m
- Reflectivity: 91%
- Aluminum Honeycomb core 6.4 cm thick
- 3-point mount, flush plate mounts
- 1-piece formed pan backing
- High temperature epoxy adhesive
- "Spherical" (2-axis) curvature
- Edge seal
- Painted finish

AZ-EL Drive Mechanisms:

- Combined AZ-EL drives contained in single housing; totally sealed unit
- Azimuth drive: 1st stage reduction (input)--worm gear; 2nd stage reduction (output)--helical pinion gear
- Elevation drive: same internal drive as azimuth, with external connecting arms to torque tube
- Motors: two, each requiring 18Vdc for tracking and 120Vdc for slewing
- Separate azimuth drive-to-pedestal adapter

Mirror Support Structure:

- Cross beams: 35.6 cm deep welded steel truss members
- Torque tube: 30.5 cm dia., .48 cm wall steel cylinder
- Weight: 588 kg (torque tube and cross beams)
- Joints (cross beam/torque tube): bolted mech./friction joint, weld beads added for tested units
- Finish: painted

Pedestal Structures

- 3.1 m long, .51 m dia., .64 cm wall
- Base flange: 2.5 cm thick
  Finish: painted

Total Weight: 1878 kg

Special Instrumentation

Load Cells and Wind Measurements--There are 120 load cells (force transducers) located on six heliostats to provide mirror module wind load data. The locations of the specially instru- mented heliostats are shown in Figure 2. Six wind towers located near the instrumented heliostats provide wind direction at 10 m and wind speed at 10, 6.1 and 3 m. The wind tower and four meteorological station locations are shown in Figure 2. Each meteorological station also provides wind and other meteorological data, including hail cubes, rainfall, temperature, and insolation. The seven-spoke road pyranometers shown in Figure 2 provide field cloud-cover data.

Temperature Sensors--Three heliostats each have been instrumented with six temperature measurement sensors to provide temperature data for the structure, mirrors, motors, and controls. The locations of each sensor are:

Temperature Sensor	Location
1. Heliostat Control Box	Box Exterior
2. Heliostat Control Box	Air Temp, Box Interior
3. Elevation Motor	Exterior Frame
4. Mirror Module 7	Front
5. Mirror Module 7	Back
6. Pedestal	Exterior

Power Measurements--Electrical power consumption is measured for two field transformers and five heliostats.

Beam Characterization System

The Beam Characterization System (BCS) hardware consists of four video cameras, each of which views an elevated target mounted on the tower beneath the receiver. An artist's illustration of a beam characterization system is shown in Figure 3. The cameras are located in the collector field along the four access roads.

Each video camera senses the analog image of the light source reflecting from the tower target into the camera. The video image is transmitted over a hardline to the control room, where it is digitized and processed to provide the heliostat beam centroid location and characterizes the reflected beam with respect to beam size and shape, flux distribution, and beam power. An additional camera will be added in 1983 to measure sunshape. The system operates automatically and will measure the beam characteristics from 60 heliostats at three different times each day. The purpose of the BCS is to provide heliostat tracking error and performance evaluation data. Heliostat tracking errors are used to provide tracking correction (bias) values for the heliostats.

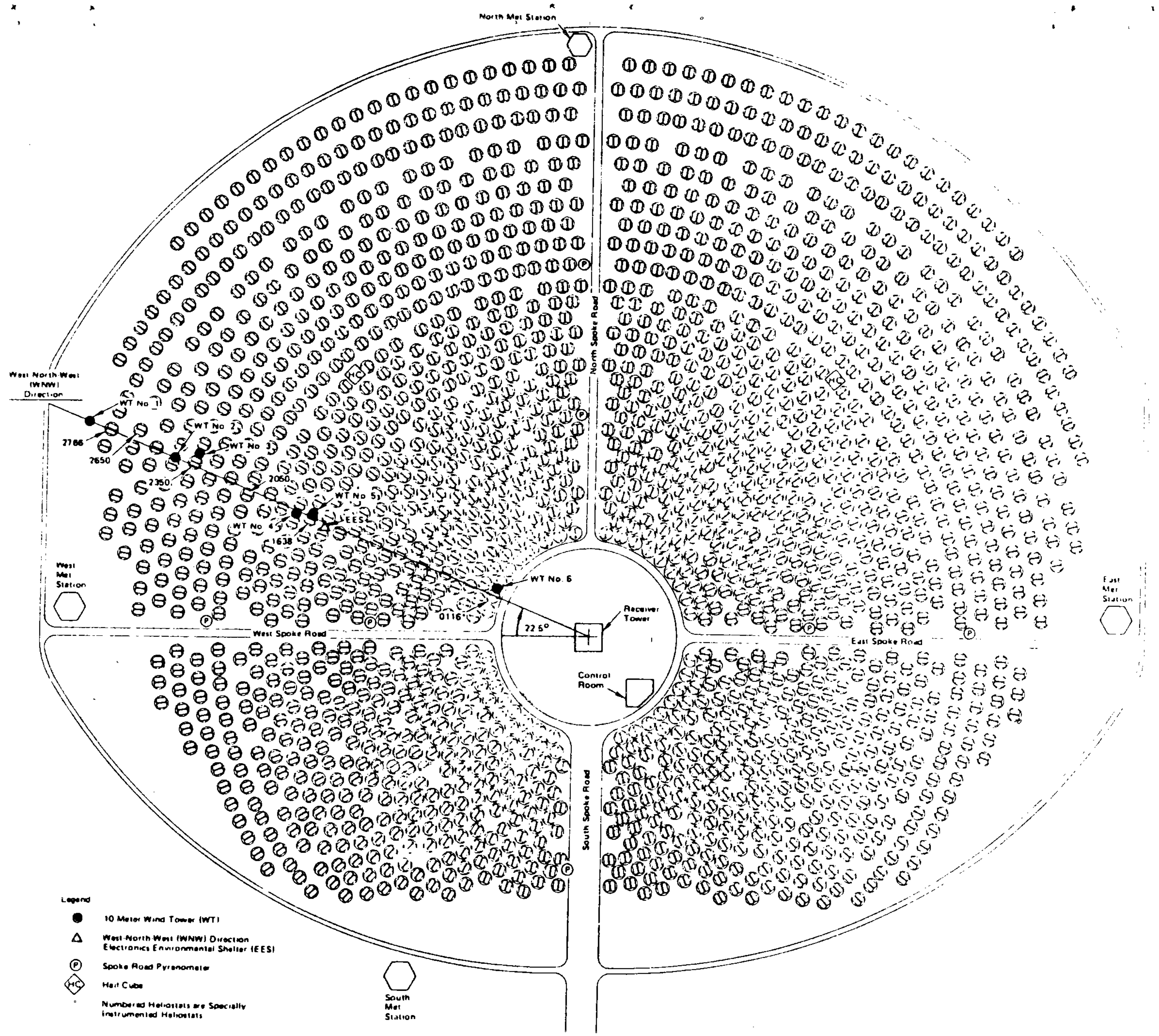

Figure 2. Collector Field Instrumentation and Meteorological Equipment

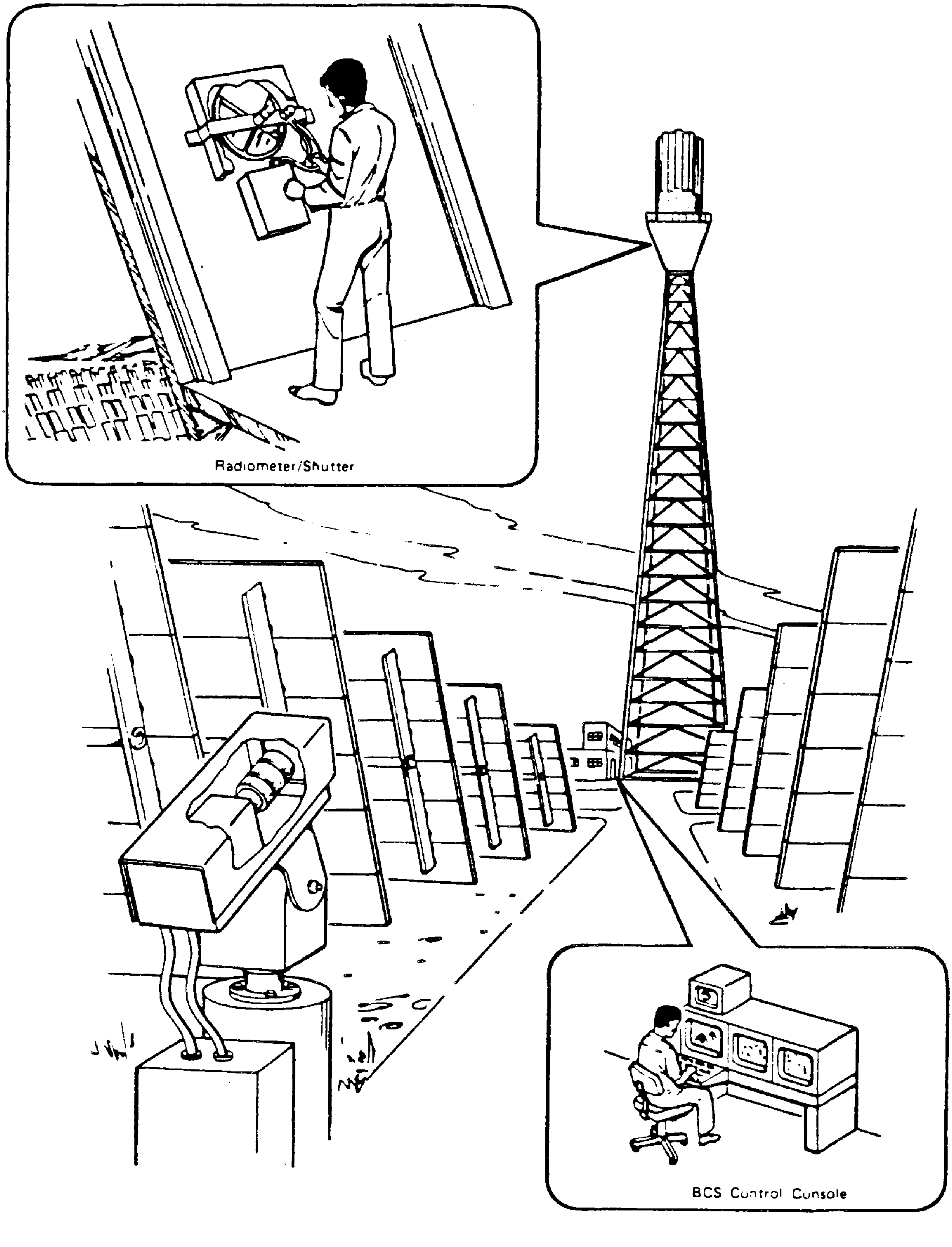

Figure 3. Beam Characterization Subsystem

Installation Experiences

Heliostat Installation

The installation of the collector field at the pilot plant was started in November 1980 and completed in September 1981. Fabrication and installation experience by major component is summarized below:

Component	Installation Start	Installation Complete	Units per Day Min	Units per Day Max
Pedestals	Nov 1980	June 1981	27	60
Drives	Nov 1980	Aug 1981	5	50
Mirror Assemblies (12 mirrors)	Feb 1981	Sept 1981	4	40
Heliostat Controls	Feb 1981	Sept 1981	10	40

Problems which have been experienced with the heliostats during the fabrication, production testing, assembly, installation, and initial operation are summarized in Table II. Problems after the initial operation are discussed in a later section.

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.

There was also a "shortage of memory" problem with the heliostat array control (HAC) computer which shut down the system whenever the BCS was operating. The major problem with the BCS and the HAC were corrected during March 1983 to allow beam centroid measurements. The entire system will be completed by October 1983.

Initial Heliostat Alignment

The Beam Characterization System was not available for the initial heliostat alignment. Therefore, the heliostat pointing errors were determined by visually estimating the beam centroid on the BCS target. Heliostat tracking correction (bias) values were then made. The field has been operating with these initial bias values since there have been numerous problems with the BCS as discussed below.

TABLE II
HELIOSTAT EXPERIENCES

Problem	Resolution
- Production drive failed during simulated 40 m/s (90 mph) wind load test	- Additional elevation pinion gears tested without failures; high wind stow position revised to reduce loading
- High glass breakage occured during start-up of mirror module fabrication on ceramic tools	- Standard float glass used for approximately 136 heliostats; field performance impacted less than 1%
- Sixty-nine doubler pad bond failures 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	- Additional grounding protection of control cable in core and field areas provided to protect against electromagnetic pulses

Beam Characterization System

The BCS was not completed as initially planned due to limited construction funds and higher priority work during the initial plant start-up. The circumsolar telescope for sunshape measurements was not installed and there were numerous system calibration and software refinements that were not completed.

Operating Experiences

The collector system has been operating since November 18, 1981, when the functional testing was completed. The collector field was stowed after sunset, with the mirrors face-down, during 1982 and was brought up to a standby position prior to sunrise. There have been no major problems with the heliostats and the plant operators had no trouble learning how to control the field. The heliostats were operated for approximately 3000 hours and the controllers were powered up 100% of the time during 1982. There were 50 to 100 heliostats out of service on any one day. When repair parts were available, service on any one day. When repair parts were available, the goal was to have less than 50 heliostats out-of-service at any one time. Heliostat availability was not a major concern and there were only limited funds for maintenance during 1982; therefore, heliostat maintenance was performed so as not to interfere with other plant start-up and test activities. A brief summary of the heliostat component failures, stow position considerations, washing, and special instrumentation experiences follows.

Heliostat Component Failures

Operation of the complete field was not required for plant checkout and in order to reduce 1982 costs heliostat maintenance was given low priority and a complete record of maintenance activities was not made during 1982. There were 540 heliostat maintenance orders, where a problem was found, between January 1 and October 19, 1982. The maintenance orders have been for heliostat controllers, encoders, limit switches, connectors, and drive motors as shown in Table III.

The reason for the large number of heliostat controller problems is being investigated by Martin Marietta. Drive motor problems have been primarily due to electrical noise from the motor and a loose fit between the output gear and shaft in some of the first stage gear boxes. Under high wind conditions, the gear slips on the output shaft. The electrical noise is usually due to a loose electrical lead connection at the motor brush holder. The connector and cable problems have been caused primarily by a poor connection at the plug for the encoder. Cleaning the plug generally fixes the problem. The limit switches generally require readjustment or the switch is found to be hung-up in one position. The majority of the mirror assembly problems have been loose mounting bolts. The mirror doubler pad bond failures which were an early problem were evidently fixed when pads were riveted on 5400 modules. Recent experience shows that the level of effort required to maintain (excluding washing) the collector field is 160 manhours per month.

TABLE III
HELIOSTAT MAINTENANCE ORDERS

Maintenance Item	Number of Maintenance Orders
Azimuth Motor	56
Elevation Motor	9
Gear Box Noise	1
Heliostat Controller	278
Heliostat Field Controller	22
Azimuth Encoder	17
Elevation Encoder	25
Mirror Assembly	22
Elevation Limit Switch	40
Azimuth Limit Switch	4
Connectors and Cables	66
	540

Heliostat Operating Strategy

Normally, the heliostat field is moved from the mirror face-down stow position to standby at some time before sunrise. There are four standby aim points for the reflected beam. The heliostats are brought to the standby points by following an aim point up an imaginary line from a starting aim point that is below ground level. Motion from standby to stow is normally made after sunset and it reverses the start-up path. The aim point moves from the focal point at ground level to the standby position adjacent to the receiver in about six minutes. When the reflected beams are directed onto the receiver from standby, the beam path is not controlled in any special manner.

The high wind stow position is "mirror face down" with the torque tube aligned east/west parallel to the prevailing wind direction. This alignment reduces the wind load on the gear train and reduces the chance for gear failure. During 1982 the normal stow position was with the mirrors facing down. However, in January 1983, normal stow was changed to "mirrors vertical" to minimize water standing on the mirror module seals and on the mirror backing paint. The water problem is discussed later in the mirror corrosion section.

Washing

Heliostat washing cost was not included in the 1982 budget; however, in late July the mirror reflectivity had degraded to a point where a wash program was required. A random sample of heliostat reflectivity indicated that the clean reflectivity (91%) had decreased to 72%. An experimental program was instituted using an existing Southern California Edison (SCE) substation insulator washing truck in an attempt to upgrade the power delivered from the field. SCE operators developed a technique, using pressurized demineralized water, to rinse off the heliostats and return the reflectivity to greater than 86%. Two men washed 700 heliostats during two shifts, which averages out to 23 heliostats per manhour or 2.6 manminutes per heliostat. The remaining heliostats were washed by rain.

Special Instrumentation

The wind measuring instruments and heliostat load cells have been a problem. The wind speed and direction data were found to be faulty late in 1982 when a meteorological report was being prepared. Most of the electronics interface cards were found to be incorrectly installed and most of the instruments had worn-out bearings and/or potentiometers. At this time it was determined that maintenance is required every six months in a desert environment. The meteorological data are recorded and stored in one of the plant control computers which was off-line for repair or software changes during much of the time during 1982. Therefore, even when the instruments were working, the data were incomplete. The meteorological data system should have been periodically checked and independent from the plant control computers.

There are 120 heliostat load cells which contain strain gages. The strain gages started to fail in mid-1982 due to corrosion from water that entered through a hole that should have been sealed during production. There were 21 bad load cells in November 1982, 24 in January 1983, and 30 on March 3, 1983. The hole in the load cells was plugged early in January 1983 to prevent additional water from entering the load cell.

Test Program and Preliminary Results

Collector System Functional Tests

The initial collector system functional tests were performed from November 9, 1981, through November 18, 1981. This testing was performed to demonstrate the systems level operational performance of the collector system on a stand-alone basis. The testing involved issuing commands from the Heliostat Array Controllers (HACs) and verifying responses by visual observation of the heliostat movements in the field and by observation of the readouts on the HAC displays and printer.

The collector system functional tests consisted of the following:

1. HAC control verification of legal commands/modes
2. Wire walk verification
3. Heliostat response verification to singularity condition
4. Illegal commands verification for each operating mode
5. Graphics display console segment verification
6. Emergency commands verification
7. Special commands verification
8. Heliostat targeting verification

The heliostats passed all of the functional tests with only minor modifications to the software. Heliostat targeting verification was intended to be performed using the Beam Characterization System. Since the BCS was not available, the tests consisted of a visual estimate of the pointing error when the heliostat was tracking its aim point on the receiver.

Heliostat Tests

The objectives of the heliostat tests are to characterize heliostat performance identify areas where heliostat research and development may lead to performance improvement and establish the need for a Beam Characterization System in future plants. The test activity will evaluate optical performance and environmental survival over a two-year period ending in August 1984.

Heliostat optical performance will be derived from beam pointing, beam quality, and reflectivity data. Beam pointing and quality will be measured on every heliostat by the BCS. Individual heliostats will be aimed to reflect their beams onto large tower-mounted targets. Field-mounted cameras will send the target images to a computer, where the images will be analyzed to determine the flux distribution (quality) and the centroid (pointing). The BCS interfaces directly with the Heliostat Array Controller (HAC). Daily operation is automatic and only requires that the operator input the list of heliostats to be tested. This system is capable of characterizing the entire field every 60 days. If the heliostats do not change much with time, it is possible that future plants will not require a BCS of the type used at the Pilot Plant.

Beam pointing accuracy is output directly by the BCS. The effect of the wind loads on beam pointing will be evaluated with Special Heliostat Instrumentation and Meteorological Measurement System (SHIMMS). Six heliostats located near wind sensors have been instrumented with load cells. Tracking accuracy will be determined as a function of wind loads. This will be compared with the static load testing previously performed on prototype and production heliostats at the Central Receiver Test Facility (CRTF), in Albuquerque, New Mexico, and at SNLL.

Assessment of beam quality requires the analysis of the flux distribution using HELIOS or MIRVAL. Because of the time and expense of running these codes, detailed analysis of beam images will be performed for selected heliostats throughout the field. A simplified functional approximation, developed from these analyses, will provide a method for quantifying heliostat images and will allow rapid evaluation of beam quality by the operator. Since beam quality is strongly influenced by focal length (which is a function of temperature), SHIMMS data will be used in this analysis to determine module temperature and focal length.

Reflectivity measurements will be taken by trained SCE operators with a portable specular reflectometer. Biweekly measurements will be taken of several heliostats throughout the field. Some of these heliostats will be used in an experimental washing program to assess different washing techniques and frequencies.

Beam pointing and quality will be compared with specifications. Heliostats out of specification will be corrected and reported under the plant O&M. Probability distributions of pointing accuracy, beam quality and reflectivity, and their changes over time will be determined.

Heliostats are designed to have a service life in excess of 30 years. The major environmental conditions which affect this lifetime are the drive and structure loads imposed by high winds, corrosion of mirror module silvering as a result of attack by water, and survival of controllers and motors under operating thermal loads.

SHIMMS data will be analyzed to evaluate load distributions for individual heliostats throughout the field as a function of wind speed and angle of attack. Results will be used to derive aerodynamic design criteria for future heliostats.

Sensors, which will provide measurements of motor, controller, mirror module, and structure temperatures, have been installed on the six SHIMMS heliostats. These measurements will be compared with design specifications including ambient operating conditions, allowable temperature rise under load, and duty cycle. Mirror module temperature, which affects the focal length, will be input into HELIOS or MIRVAL as part of the optical performance evaluation.

Mirror module silver corrosion occurs when water attacks the silvering on the back surface of the mirror. Leak testing, controlled thermal cycling, in-situ temperature and humidity measurements, radiography to locate water, and computer simulation of mirror modules will be performed to determine the extent and source of water in modules and possible remedies.

There was very little heliostat data obtained in 1982 due to the lack of wind data and a BCS. Wind data have been recorded since the beginning of 1983; however, they will not be analyzed until the data tapes are available at SNLL. The BCS is being made operational for beam centroid measurements.

If the system operates satisfactorily, all of the heliostats will be characterized for tracking accuracy starting in March. Heliostat beam power and sunshape measurements will not be available until the BCS capabilities are completed in August 1983.

Mirror Corrosion Tests

Silver corrosion is occurring in the pilot plant mirror modules. The corrosion is caused by water inside the modules which diffuses through the mirror backing paint and dissolves the copper, and then the silver corrodes. The corrosion will not affect plant performance for several years; however, the existence of corrosion has been one factor in the adoption of alternate mirror module designs by industry. These new designs do not require sealing of a box type structure to keep water away from the silver. There have been several activities underway to establish the cause of the corrosion and estimate the corrosion growth rate and area affected. A summary of these activities and the results follows.

Degradation Mechanisms--Samples of mirrors with corrosion were studied by the Solar Energy Research Institute (SERI). The interpretation of preliminary results of surface analysis is that the primary degradation mechanism is a dissolution of the copper layer at elevated pH. This causes a delamination of the protective paint layers from the reflective silver layer. The silver may then be attacked by atmospheric constituents or impurities from elsewhere in the mirror module. Circular areas in the silver layer, which show substantial reflective loss, all contain four major impurities throughout the bulk of the layer that are not found in the undisturbed silver layer. These elements are Zn, Cr, Mg, and Al.

Researchers suspect that the Zn and Cr are components of the paint primer applied to the copper layer and that the Al and Mg are components of the outer paint.

Mirror Module Leak Tests--In March 1982 a mirror module leak test was performed at the pilot plant on 13 modules that had been previously leak-tested as part of the production process. Twelve of the 13 had air leaks when the module was slightly pressurized.

Mirror Module X-Ray--In May 1982, 100 randomly selected mirror modules were x-rayed to determine the water content. The x-rays showed that 75 of the 100 contained water. In December 1982, x-rays were again made on 11 of the 100 modules; 10 contained water, and the amount of water had increased considerably. The amount of water cannot be determined from the x-rays.

Mirror Modules with Corrosion--The number of mirror modules with at least one spot of silver corrosion has increased with time as follows:

Mirrors with Corrosion

February 1982	100
May 1982	439
August 1982	665
February 1983	3900

Corrosion Growth Rate--The corrosion on the 100 randomly selected mirror modules that were x-rayed was photographed in May, August, and December 1982. A detailed inspection was made in February 1983 of all the mirror modules on the 98 heliostats that contain the 100 mirror modules. The photographs of corrosion on the 100 mirrors and the field inspection of the 1176 mirror modules (12 x 98 = 1176) indicate that the corroded area increased by a factor of 10 in one year. The area corroded is shown below.

	Date	Area Corroded
Photographed Corrosion Growth (100 mirror modules)	May 1982	.0003%
	Aug 1982	.0007%
	Dec 1982	.002%
Field Inspection Corrosion (1176 mirror modules)	Feb 1983	.006%

Location of Corrosion and Water--During the detailed field inspection of the 1176 mirror modules, the location of the corrosion was noted along with the estimate of the area affected. There were 208 mirror modules out of the 1176 that were corroded. The number of modules with corrosion versus the position on the heliostats is shown in Figure 4.

17	6
19	7
26	7
32	10
30	14
28	12

Figure 4. Number of Corroded Mirrors in Each Mirror Position (looking at mirror)

As shown in Figure 4, most of the corrosion is on the left side of the heliostats and on the lower mirror modules. (The reason is not known.) The occurrence of the corrosion on each mirror module is predominantly on the sides and the end away from the mirror module vent hole. This is shown in Figure 5 for the 1176 mirrors inspected in February. The number of times that corrosion was seen somewhere within each area of the mirror module is shown.

150	30	13	5	5	3	vents	9	3	4	7	12	35
91	2	1			1		1	2	2		2	14
169	35	24	15	4	2		12	8	12	11	13	26

Left Side — Right Side

Figure 5. Occurrences of Corrosion in 1176 Mirror Modules

The x-ray results show that the water is also predominantly on the ends away from the existing vent.

During 1982 the heliostat stow position at night and during bad weather was with the mirrors horizontal facing the ground. This was also true during rain storms until July 1982 when rain washing was started. During 1983 the stow position will be with the mirrors vertical except during high winds when face-down stow will be used. Rain washing will occur during rain storms when the heliostats will be at a 45-degree angle with the mirrors facing up. This new stow and the washing position will minimize water standing on the mirror module seals and tend to keep water in the modules from standing on the mirror backing paint. Additional vents were added in 14 mirror modules during February 1983 to determine if the water content and corrosion growth rate could be decreased with additional ventilation.

Mirror Reflectivity and Cleaning Tests

The clean reflectivity for the majority of the pilot plant mirrors is 91.1%; however, there are 1500 mirrors which use low transmissivity glass which are 79.8% reflective. In both cases the reflectivity is for an air mass 1.5 solar spectrum. The cleanliness of approximately 10 mirrors was measured 14 times between January 31 and December 1, 1982, using a portable single wavelength reflectometer. The data are corrected to estimate the solar weighted reflectivity with an accuracy of about 1%. Because of the two types of glass the percent clean value is reported as shown in Figure 6 along with the amount of rainfall. The slope of the percent clean lines (the rate of the decrease in cleanliness) is estimated from the measured data points which are shown. When there was little rainfall, the decrease in cleanliness is about 0.25% per day (8%/month), and 0.1% per day (3%/mo) during the months that have more frequent occurrences of rain. As discussed previously, 700 heliostats were washed with an insulator washing truck just prior to the rain in July when the reflectivity was down to about 75% of clean. The mirrors regain about 97% of their clean reflectivity when there is 12 mm (0.5 in.) or more of rain.

The rainfall at the Daggett, California, airport is shown in Table IV, along with the data for 1956-1970. During 1982, more rain than average fell and more occurrences of rain took place during most of the months. Based on the cleaning results in 1982 and the historical rainfall data, the field will require 3 to 6 artificial washings per year to maintain the reflectivity above 90% of clean.

Beam Safety Tests

The pilot plant heliostats are always operated in a controlled manner when the reflected beams are above ground. There are four reflected beam standby points around the receiver which are reached by a "wire-walk" from a point below ground. The heliostat beams for each wire are collected below ground and walk up the wire in unison. The reverse path is taken when the heliostats move from standby to stow. The stow position is with the mirrors vertical except during high winds when the mirrors face the ground.

Several helicopter fly-overs have been made to measure the reflected light above the field. Measurements at ground level were also made at the bottom of the wires and along the roads to the center of the field and around the perimeter road. Above the field there is no safety hazard for the human eye above 305 m (1000 ft). The area around the bottom of the wires is an eye hazard region for a short time during the wire-walk. A stay-out area is marked off around these hazardous areas. No one is authorized to enter the field without being informed of the potential hazard areas and how to avoid the hazard. A warning horn is sounded whenever the heliostat beams are moving along the wires.

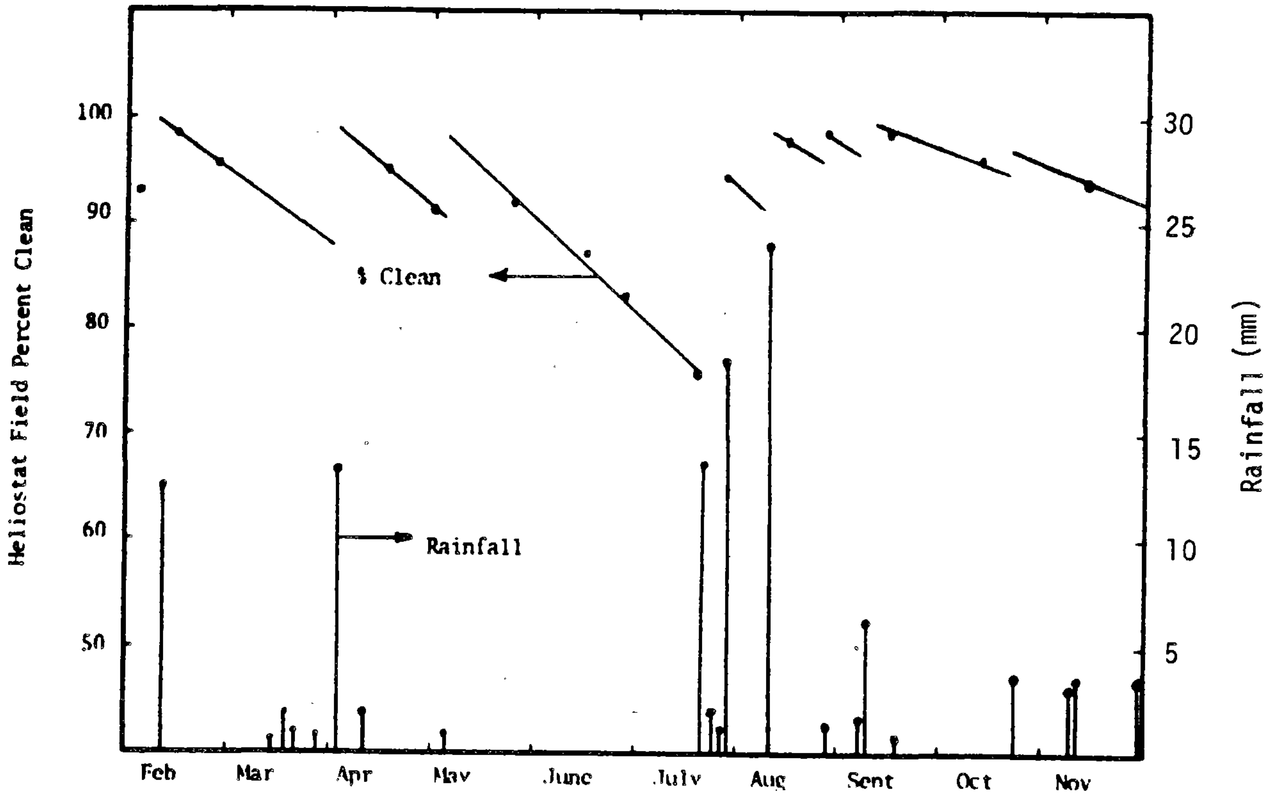

Figure 6. Barstow Rainfall and Mirror Cleanliness

TABLE IV

BARSTOW RAINFALL SUMMARY (mm)

1956-1970	J	F	M	A	M	J	J	A	S	O	N	D
AVG/MO	7.9	8.1	7.1	5.3	1.8	1.3	7.9	15.2	12.9	5.6	9.4	8.9
MAX/24 HR	18.5	17.8	22.4	16.5	9.4	8.1	24.4	52.3	28.2	16.8	27.4	25.7
AVG/OCCUR/ MO	3.2	3.3	2.4	2.1	.7	.5	1.8	2.4	1.6	1.9	3.3	2.7
MO/W/NO RAIN	0	2	2	3	10	10	2	4	6	5	1	4
1982												
RAINFALL	22.9	12.9	4.1	15.5	1.3	0	35.6	25.9	7.9	4.1	8.9	21.6
MAX/24 HR	8.6	13.0	2.3	14.0	1.3	0	18.8	24.4	6.4	3.8	3.3	13.2
OCCURRENCE	10	2	13	3	2	0	5	5	5	3	3	4

The reflected light from the receiver has also been measured from various places around the field. There is less than one sun of reflected light from the receiver at any place on the ground. Reference 3 is a report which will be published to describe the beam safety tests and results.

REFERENCES

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