DOE/SF/10501--064

DE84 017038

10 MWe Solar Thermal Central Receiver Pilot Plant

Project Summary Report and Lessons Learned

June 1982

Department of Energy
Southern California Edison
Los Angeles Department of Water and Power
California Energy Commission

10 MWe SOLAR THERMAL

CENTRAL RECEIVER PILOT PLANT

PROJECT SUMMARY REPORT AND LESSONS LEARNED

CONTENTS

I. INTRODUCTION

This summary level report was prepared by the DOE Solar Ten Megawatt Project Office (STMPO) to (1) briefly describe the Pilot Plant, (2) provide lessons learned for future industrial developers, and (3) identify a bibliography of project reports and contacts for detailed reference. The time period covered is from the completion of conceptual design in 1977 through completion of construction and achievement of "Turbine Roll" on April 12, 1982, whereby solar generated electric power was first fed to the utility grid.

The key DOE objectives for the central receiver program are:

- Conduct research and develop technology to provide a basis for the private sector to invest in solar central receiver systems, thereby displacing and/or reducing the near term usage of fossil fuels by electric utilities and the process heat industry.

- Identify and perform long range, high risk, high payoff research and technology development for advanced solar central receiver systems.

The Pilot Plant contributes to the above program objectives by providing a major system level facility for:

- Concept technical feasibility/reliability validation
- Construction and operation/maintenance economic data collection
- Environmental impact assessment

The major project parameters are:

- 10 MW electric power to grid
- Water/steam working fluid
- External, single pass to superheat boiler

- Oil/rock thermal storage
- 1818 reflective assemblies (heliostats)
- Computer based control system

A listing of currently available contacts and reports from each participating organization is included in the Bibliography.

STMPO acknowledges and thanks those individuals from Aerospace, Energy Technology Engineering Center, Sandia, Martin Marietta, McDonnell Douglas/Rocketdyne/Stearns Roger, Southern California Edison, and Townsend and Bottum, who provided inputs which were used in the preparation of this report. The "Lessons Learned" represent the views and opinions of the Project Office only.

R. N. Schweinberg
SAN Project Manager

II. SOLAR 10 MWe PILOT PLANT DESCRIPTION

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A. GENERAL

The Pilot Plant system is composed of a number of major elements, as depicted in Figure II-1. The operational interaction of these elements is shown in the simplified schematic diagram in Figure II-2. The general plant arrangement, core arrangement, and collector field layout are shown in Figures II-3, II-4, and II-5 respectively.

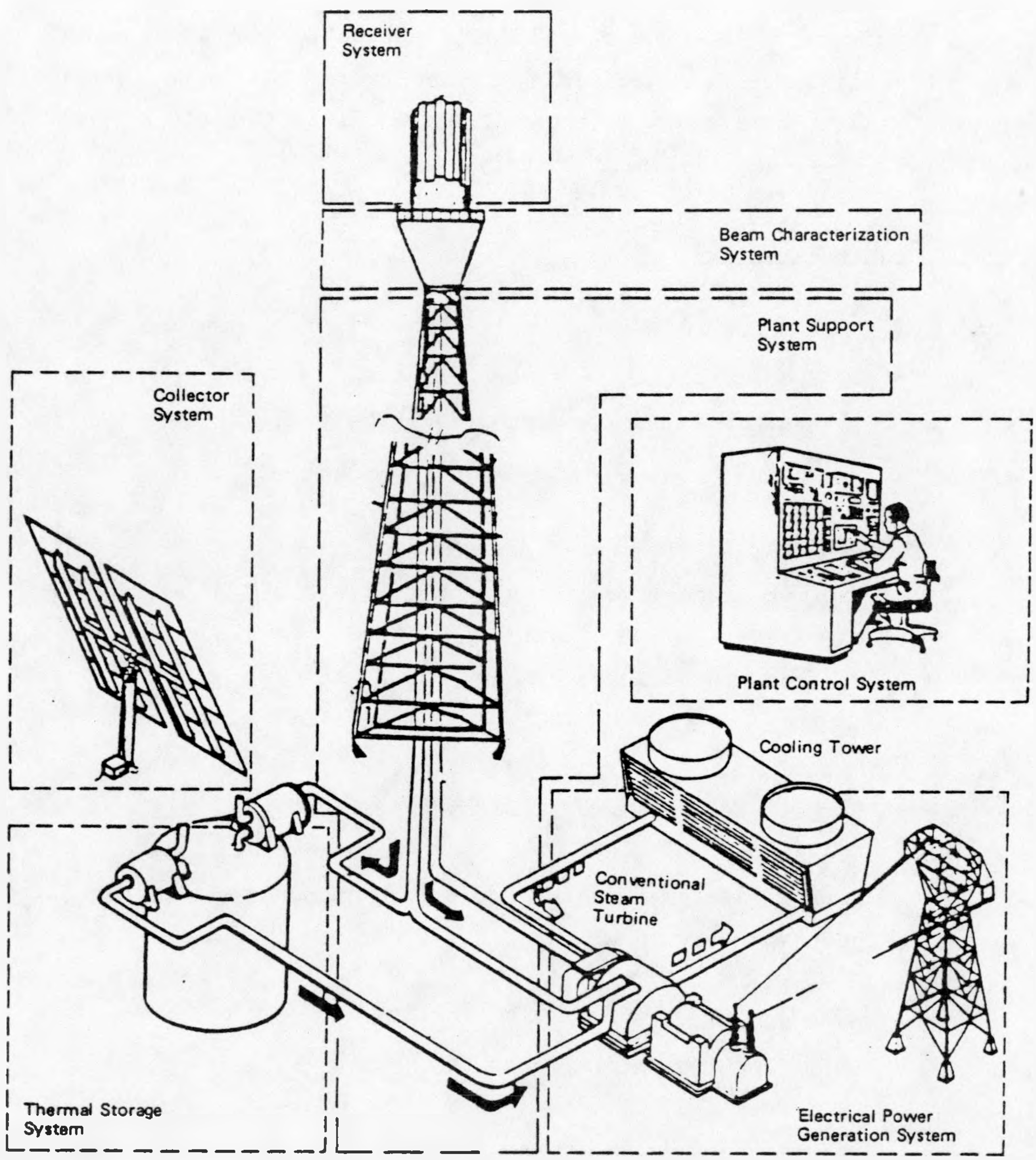
B. PILOT PLANT STATISTICS

1. PLANT RATING
   - o 10 MWe for 8 hours - summer solstice
   - o 10 MWe for 4 hours - winter solstice
   - o 7 MWe for 4 hours from Thermal Storage

2. GEOGRAPHIC FEATURES
   - o Minimum temperature: January, 10°F (-12.2°C)
July, 73°F(23°C)
   - o Maximum temperature: January, 60°F (16°C)
July, 115°F(46.1°C)
   - o Latitude: 34.86 degrees North
   - o Longitude: 116.83 degrees West
   - o Elevation: 1946 feet above mean sea level
   - o Approximately 3600-4000 hours of sunlight per year or 9.8-10.9 hours per day

3. SIZE OF PLANT
   - o 1900 feet from north to south
   - o 2500 feet from east to west
     - Total size 130 acres:

72 acres for the heliostat field; 58 acres for the power plant, control and administration buildings, construction laydown area and miscellaneous smaller areas.



Pilot Plant, Major Elements

Figure II-1.

SIMPLIFIED 10 MWe PILOT PLANT SYSTEM SCHEMATIC

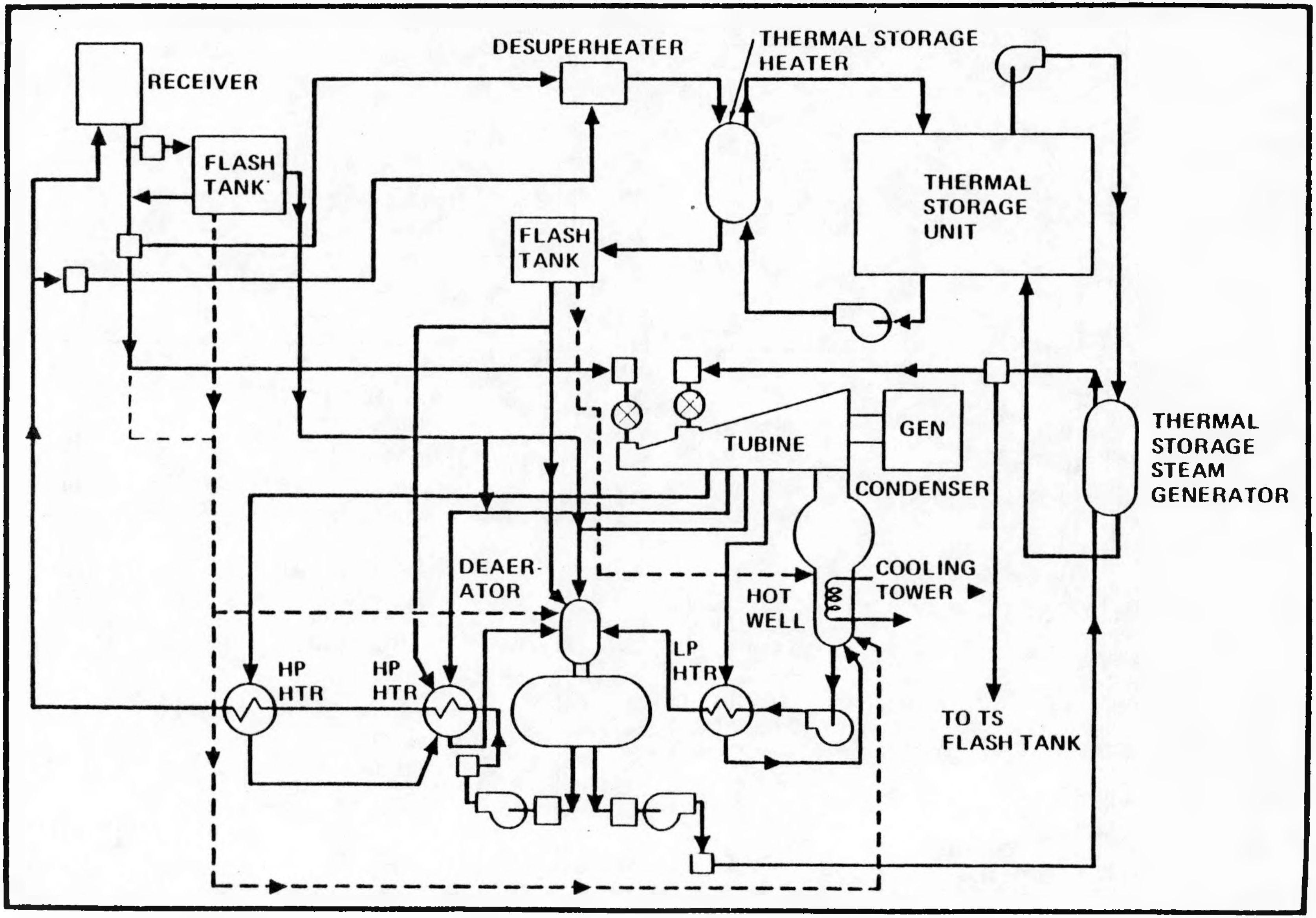


Figure II-2

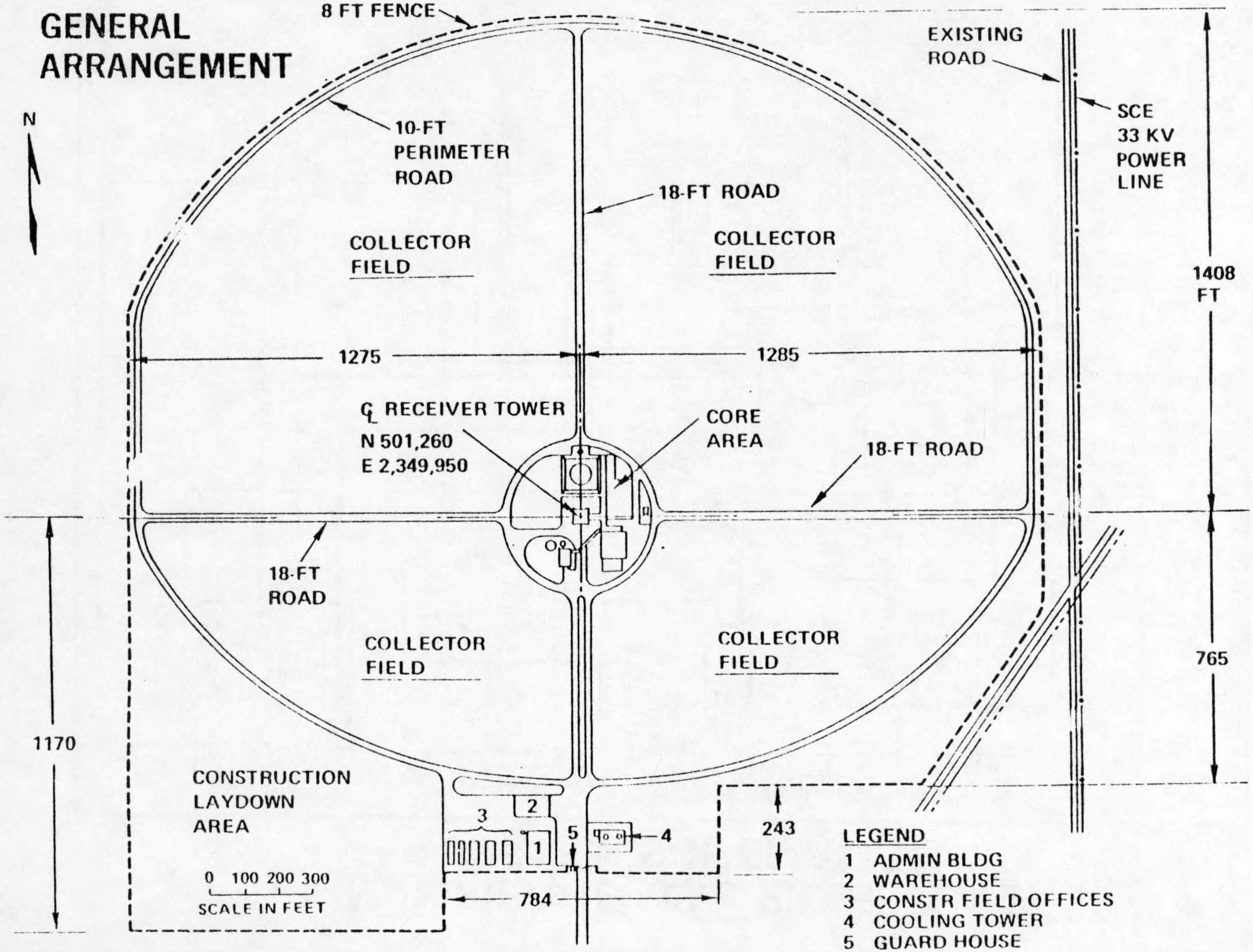
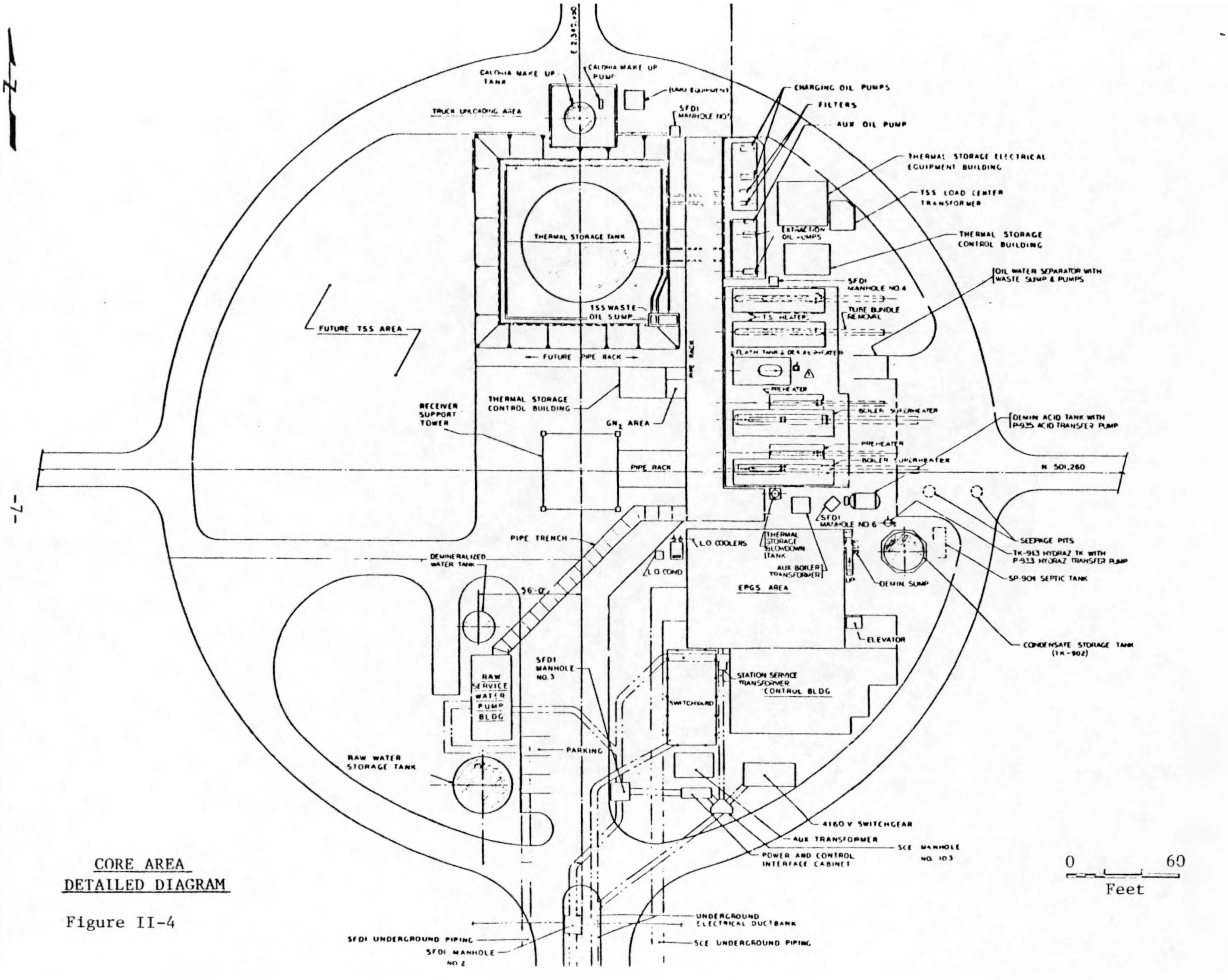
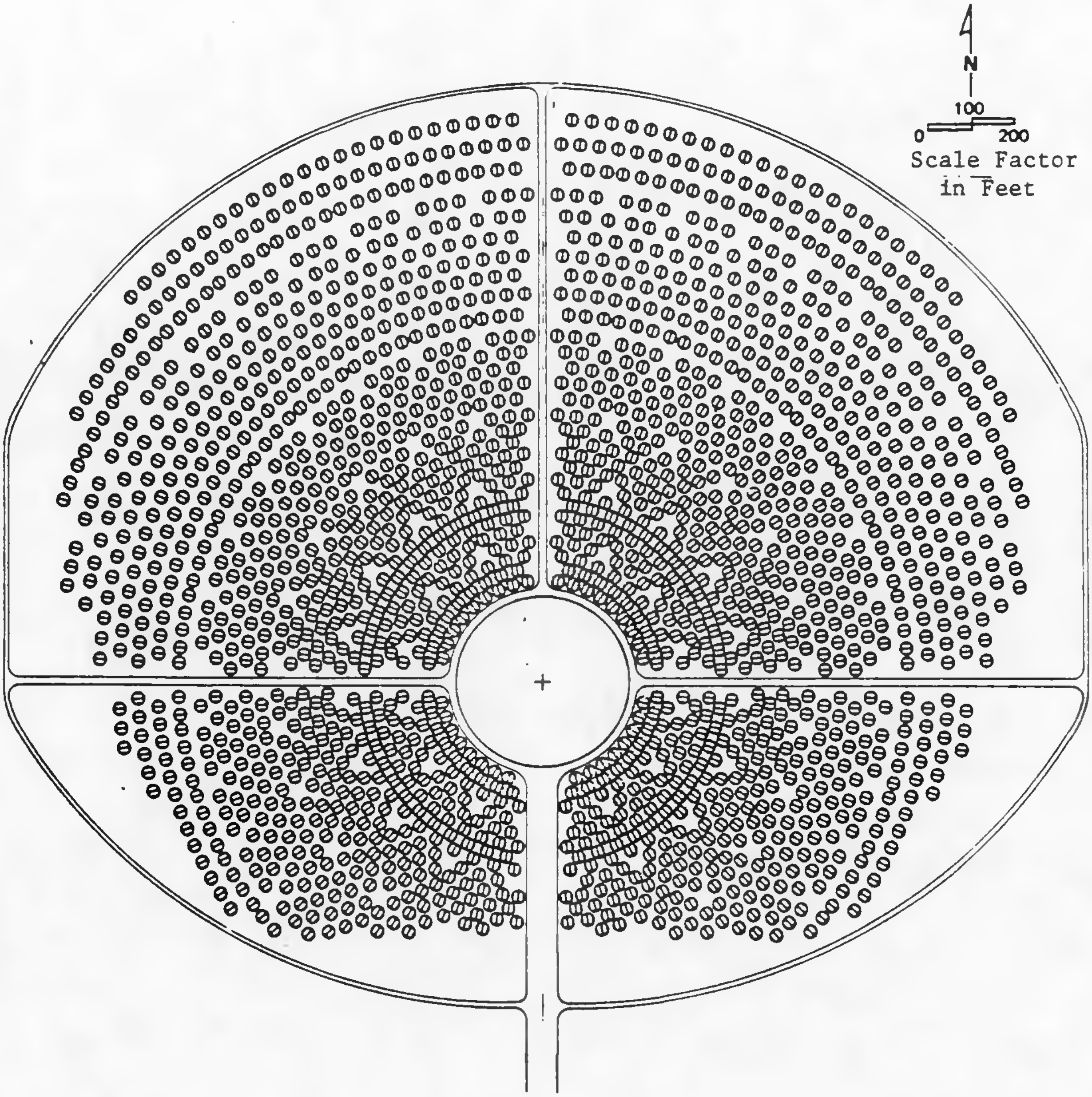

GENERAL ARRANGEMENT
8 FT FENCE
EXISTING ROAD
SCE 33 KV POWER LINE
N
10-FT PERIMETER ROAD
18-FT ROAD
COLLECTOR FIELD
COLLECTOR FIELD
1408 FT
1275
1285
℄ RECEIVER TOWER
N 501,260
E 2,349,950
CORE AREA
18-FT ROAD
18-FT ROAD
COLLECTOR FIELD
COLLECTOR FIELD
765
1170
CONSTRUCTION LAYDOWN AREA
3
2
5
4
1
243
0 100 200 300
SCALE IN FEET
784
LEGEND
1 ADMIN BLDG
2 WAREHOUSE
3 CONSTR FIELD OFFICES
4 COOLING TOWER
5 GUARD HOUSE

Figure II-3



CORE AREA DETAILED DIAGRAM

Figure II-4



Collector Field Layout

Figure II-5

4. POWER TO THE GRID

- o Maximum power to the grid:

  10.8 MWe (Operating Mode 1)

  12.5 MWe gross; 1.7 MWe parasitic

- o Maximum estimated daily energy:

  112 MWe-hrs on June 21

  48 MWe-hrs on December 21

- o Annual estimated energy generation:

  26,000 MWe-hrs for 365 day operation

5. GROSS PLANT EFFICIENCY

- o 17.4% - Noon on June 21
- o 15.4% - 2 PM on December 21.

6. WATER USAGE

Approximately 100 acre feet of water per year for pilot plant operation and heliostat washing.

7. USE OF ELECTRICITY

20% of electrical energy will go to the Los Angeles Department of Water and Power with 80% to Southern California Edison. Power transmission is by means of the 33 kV transmission lines to the local power grid.

C. OPERATING DESCRIPTION

Sunlight strikes the heliostats and is reflected onto a tower-mounted receiver/boiler which absorbs the heat and converts water to superheated steam. The steam is then directed to a conventional turbine-generator where electrical power is produced. During periods when excess steam is available, it is directed to the thermal storage system and extracted during periods when there is insufficient sunlight for operation. After its use, the steam is condensed back to water so that it can be pumped back up the tower to be reheated and put to work again.

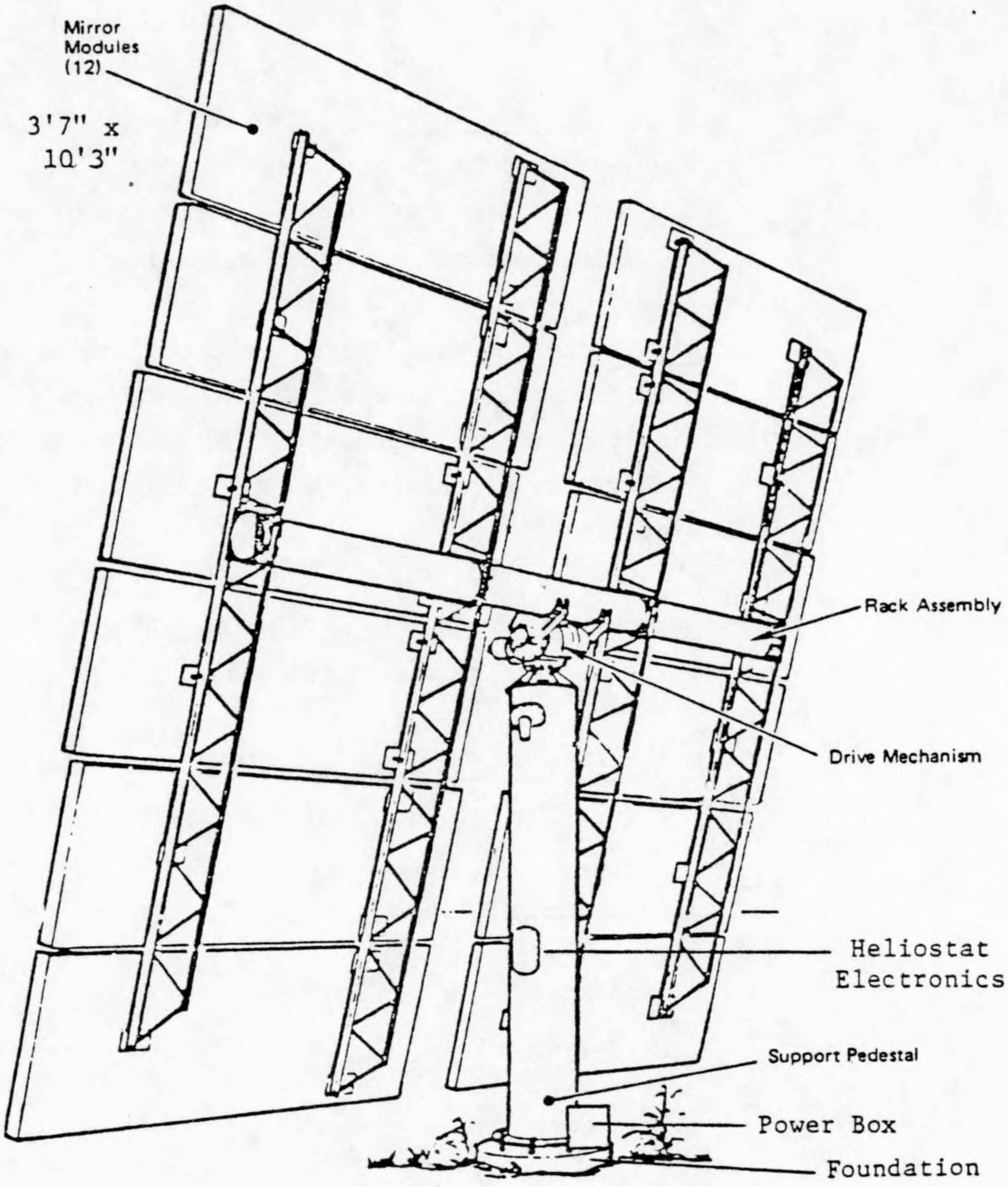
D. COLLECTOR SYSTEM

1. GENERAL STATISTICS

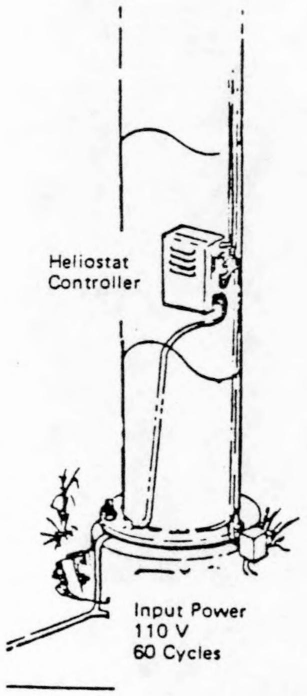
- Total heliostats in field: 1,818 (578 in south field and 1,240 in north field).
- Heliostat measurements: 22'6" x 22'7" consisting of 12 mirror panels each measuring 120.3" long by 43.3" wide or 10'3" x 3'7".
- Slightly concave: 1/2" by 10' length and width.
- Reflective area: 430 square feet or 39.9 square meters.
- Mirror Reflectivity: 90%
- Weight: 4,132 total lbs. or 2,546 lbs. for the rack assembly, 923 lbs. for the drive mechanism, 601 lbs. for the support pedestal and 62 lbs. for the cable and electronics.
- Rotational Capability: Azimuth $\pm 270^\circ$, Elevation $\pm 95^\circ$.
- Life expectancy: 30 years
- Cleaning procedure: Spray washed several times per year with demineralized water (deferred for first year).

2. CONSTRUCTION (See Figure II-6)

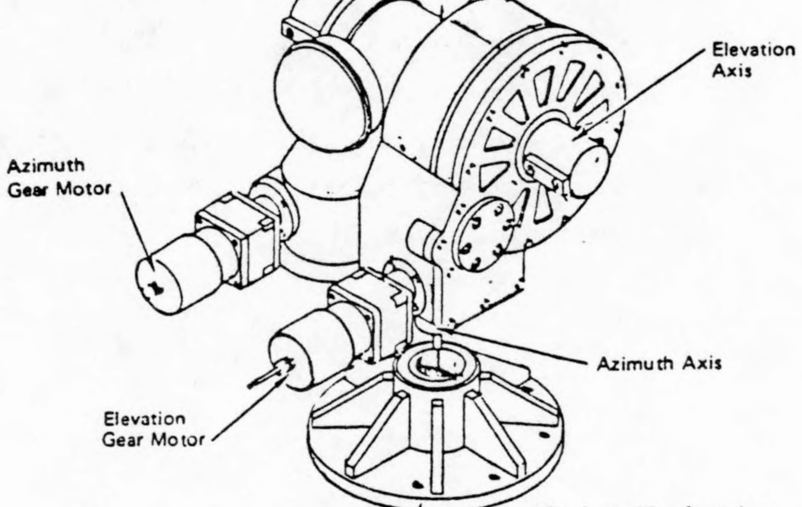
- Mirrors: Each panel consists of a second surface (silver backing) glass mirror bonded to a vented aluminum honeycomb core (2-1/2" thick). This core is bonded to a steel enclosure pan and sealed with an environmental edge seal. The heliostats are turned in a stow position (or mirror surface down) when the wind gusts exceed 45 mph and during adverse weather conditions. They are capable of withstanding 50 mph winds in any position and 90 mph winds in the stow position.



Heliostat Assembly



Pedestal Showing Heliostat Controller



Drive Mechanism

Figure II-6

- Heliostat Rack Assembly: The rack consists of four bar joists riveted to a 12 inch diameter torque tube, which constitutes the heliostat elevation axis. The mirror modules are mounted to the bar joists in three places with doubler pads.

- Drive Mechanism: Fully enclosed mechanism provides the driving force for positioning the heliostat azimuth and elevation axis. Each axis is driven by a DC motor (1/6 HP), and the axis position is identified by a 13-bit incremental encoder.

- Support Pedestal: 10' tall and 20" in diameter steel pipe which houses the electronic controls for the heliostat.

- Drilled Pier Foundation: 10' deep and 36" in diameter reinforced concrete with 8 top-exposed support bolts.

- Power Requirements: 115 VAC single phase, 60 cycles, approximately 15° kW for running the full field of heliostats.

3. OPERATING DESCRIPTION

Each heliostat is a computer-controlled sun-tracking mirror. The computer system updates the heliostat position once per second so that the sunlight which strikes the heliostat is reflected to the elevated receiver/boiler (at the top of the 300 foot tower). The heliostats are raised from their stow positions before sunrise and normally remain up and tracking throughout the day. In operation, the reflected sunlight from each heliostat either is made to track one of four imaginary standby points in the sky, or is made to fall upon the receiver.

E. RECEIVER SYSTEM

1. GENERAL STATISTICS

a. Tower

- Height: 300 feet including aircraft warning light, receiver and 16 ft. shielding structure
- Weight: 202 tons (not including receiver section)
- Material: Steel
- Foundation: 150 tons reinforced concrete, buried approximately 25 feet below surface.

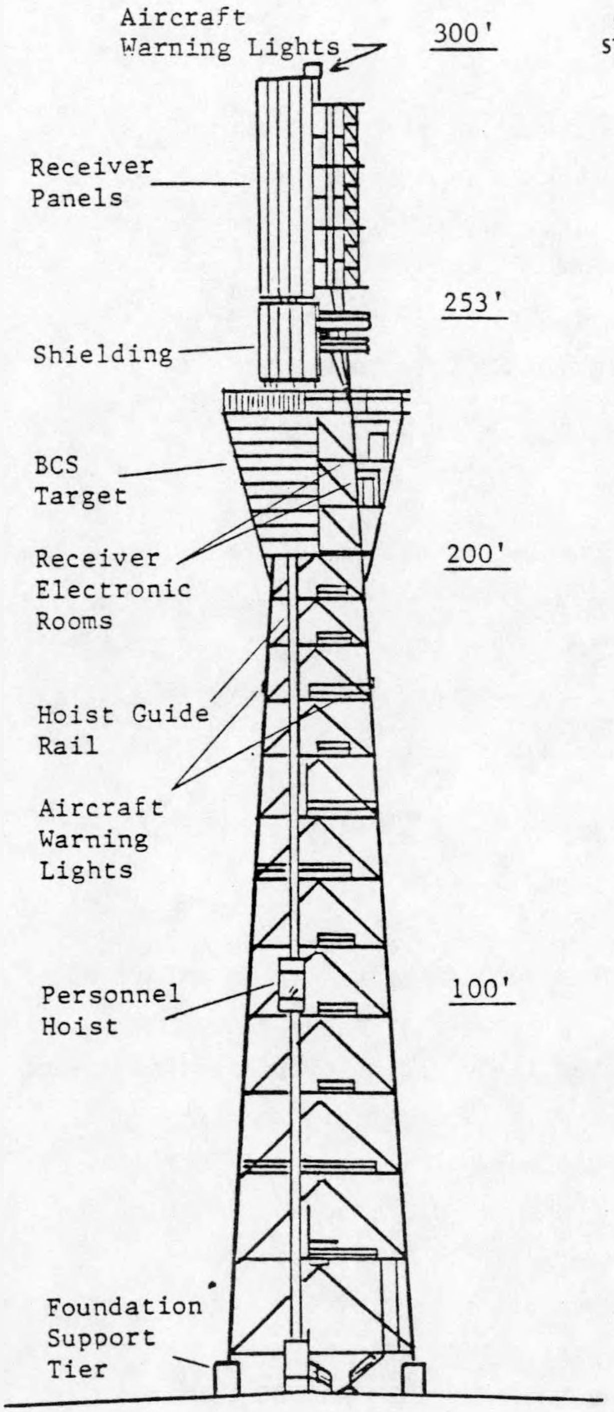
b. Receiver

- Dimension: 45 feet high, 23 feet in diameter
- Number of panels: 18 boiler panels and 6 preheater panels
- Weight: 330,000 lb. (150 tons) total weight of panels, backup structure, tower support structure, shielding, piping and misc. above 15th level of tower.

2. SPECIFIC DETAILS (See Figure II-7)

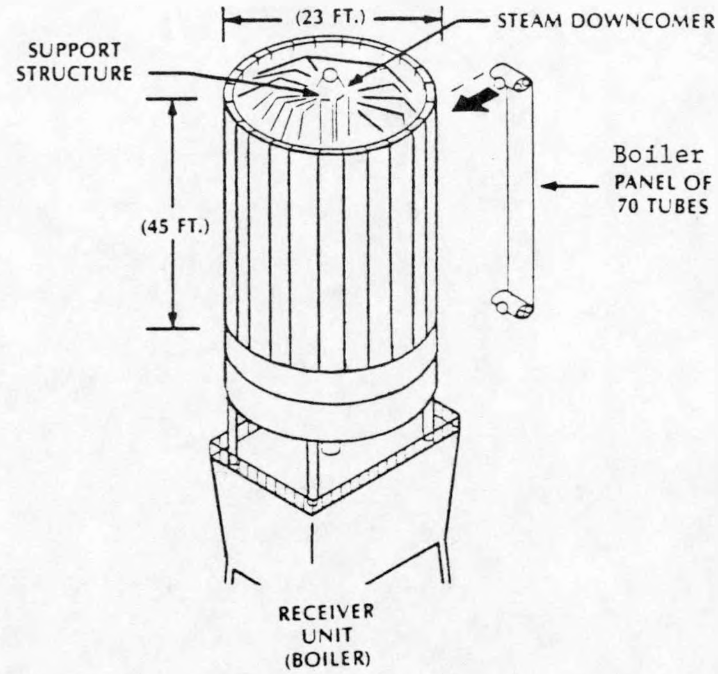
a. Receiver Panels

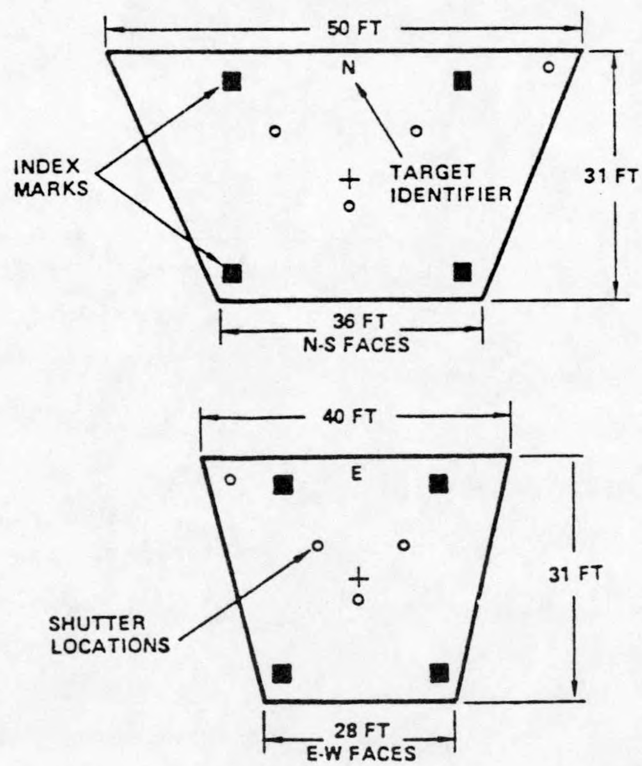
- Function: Provide a vessel through which water can be passed to absorb thermal energy from heliostat field and be evaporated to steam.
- Dimensions: Each panel is 45 feet high and 35 inches wide, composed of seventy 1/2 inch dia. tubes (internal diameter: 0.269 inch).
- Panel weight: panels - 7,000 lb. each, total
Boiler panels - 8,000 lb. each, total
(includes headers and valves)
Incoloy tubing weight -4,000 lb. ea. total
- Operating metal design temperature: 1150°F.



RECEIVER TOWER

(Looking East)





BCS Targets

Figure II-7

- Operational design thermal expansion: 4-5 in. vertically, 1 inch horizontally.
- Life expectancy: greater than 30 years.
- Material: Incoloy 800, externally coated with Pyromark paint.

b. Incoloy 800

- Composition: (Percentages by weight)

Iron	44.7%	Titanium	0.4%
Nickel	30.8%	Aluminum	0.3%
Chromium	22.8%	Silicon	0.2%
Magnesium	0.8%		

- Density: 0.29 lb/in^3
- Thermal conductivity: 85 $Btu/hr\text{-}ft^2\text{-}^{o}F/in.$
- Melting point: 2540-2600^{o}F

3. OPERATIONAL CONDITIONS

- Direction of flow: Vertically upward through panels
- Steam temperature: 960^{o}F
- Pressure: 1550 psi

(Note: Feedwater is extensively demineralized to less than 10 ppb iron)

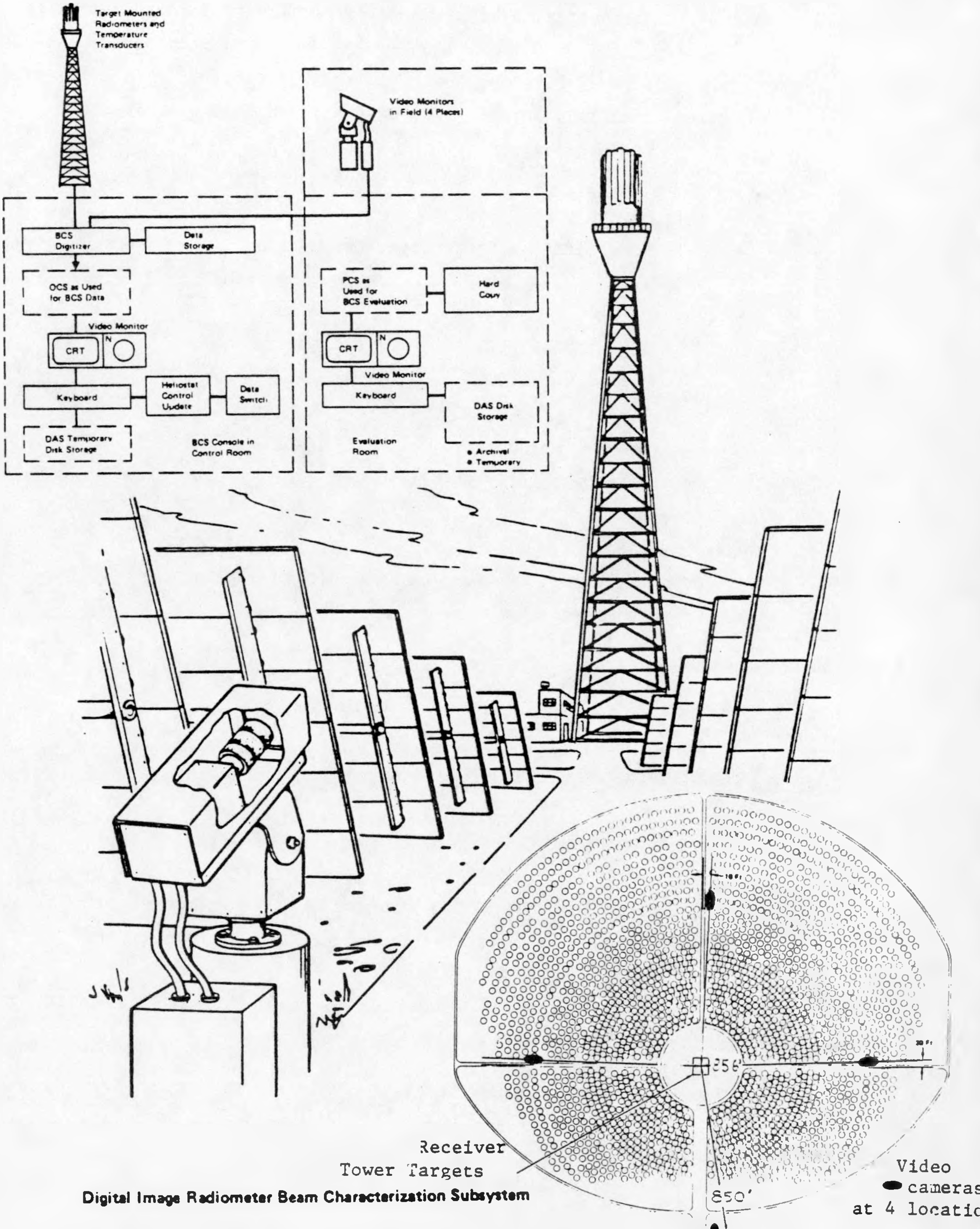
F. BEAM CHARACTERIZATION SYSTEM (BCS)

1. GENERAL STATISTICS (See Figure II-8)

The BCS is composed of the following equipment with interfaces to the plant operator and other computer and display equipment.

- Four (4) video cameras located along the roads in the collector field.

- Four (4) large target panels which are located on the tower directly below the receiver. (See Figure II-7)



Digital Image Radiometer Beam Characterization Subsystem

Figure II-8

- o Computer interface equipment which digitizes the signals from the cameras, displays and records the data automatically. The BCS hardware is integral with computer software resident in the plant master control computer and the instrumentation system data processor. In addition, the BCS automatically programs radiometer shutters which are located in the target panels. These shutters open and close the radiometer sensor openings to the reflected light.

2. SPECIFIC DETAILS

a. Beam Characterization System (BCS) Targets (See Figure II-7)

- o Function: Four large targets are used for periodic calibration and alignment of individual heliostats, in cooperation with the 4 BCS field cameras and the Master Control System.

- o Dimensions: North and South targets: 31 ft. high by 36-50 ft. wide - East and West targets: 31 ft. high by 28-40 ft. wide. Composed of 20 individual panels.

- o Panel composition: 6061-T6 Aluminum

- o External coating: Similar to Nextel paint (made by 3M Corporation), flat white, stable at 250-300°F with a lifetime greater than one year.

- o Radiometers: Four radiometers are located in each target panel. Three are shutter controlled and oriented in a triangle design about the target center. The fourth is located in an upper corner and senses background light.

b. BCS Cameras and Signal Processor

- o Function: Four COHU Model 2850C-207 video cameras are used to view the target panels on the four sides of the tower. An A to D converter digitizes the camera output signal and provides a measure of the beam intensity incident on each target from an individual heliostat aimed on that target. The digitized intensity is correlated with absolute intensity by a calibration procedure utilizing the radiometers mounted on the target.

- Hardware: Four COHU environmentally protected video cameras are mounted on concrete pads along the spoke roads in the heliostat field.

- Signal Processor: A Quantex Model DS-12 Digital Image Memory/Processor accepts the video signal from the cameras, converts it to a digital form, and transmits these data to the OCS computer for processing and storage.

- Monitor: A single nine-inch monitor is included in the Master Control Console. This monitor displays BCS data. The data are automatically stored for review by the operator at the end of the day.

- Output Data: The BCS provides the following data on each heliostat tested:

  Beam centroid coordinates
  Net power in the beam
  Theoretical power in the beam
  Percent of theoretical power achieved
  Peak power
  Plots a two-dimensional flux contour
  Alarms if acceptable envelopes are exceeded

3. OPERATING DESCRIPTION

Continuously each day, heliostats in each of the four field quadrants will automatically direct their beams to the targets. The BCS video cameras each scan their targets twice in less than one second and the signal is processed to provide data on the power of the reflected beam, its shape and its centroid. Following data acquisition, the beam is removed from the target and the next heliostat in the pre-arranged sequence is tested. This sequence continues throughout the day with no operator interface. At the end of each day the operator reviews the data and makes the necessary corrections to the heliostat aim points or identifies heliostats for further visual inspections/repairs. The BCS system can evaluate the entire heliostat field approximately once per month. The data are used to monitor for heliostat tracking errors, soiling of the mirrors, breakage and misalignment of mirror panels due to winds or other factors.

G. THERMAL STORAGE SYSTEM

1. GENERAL STATISTICS (See Figures II-9 and II-10)

a. Dimensions

- A steel tank 45 feet deep, 65 feet across with a volume of 149,288 cubic feet. Circumference is 204 feet. Expands 3" in diameter when thermally charged.
- Walls are graduated thickness steel and 15 inches of insulation.
- Roof is A 537 steel plus 2 feet of insulation.

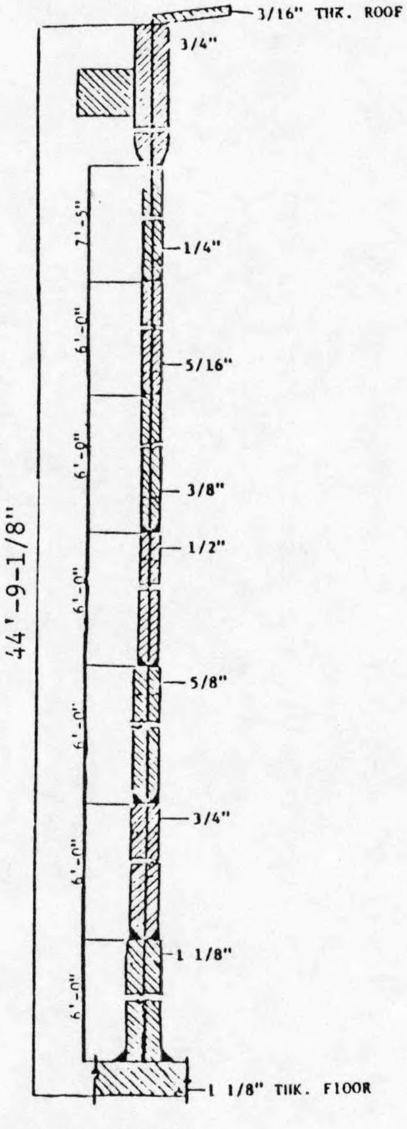
b. Contents

- 4,532 tons of crushed granite.
- 2,266 tons of pure silica Monterey sand.
- 239,600 gallons of Exxon Caloria HT-43 oil.

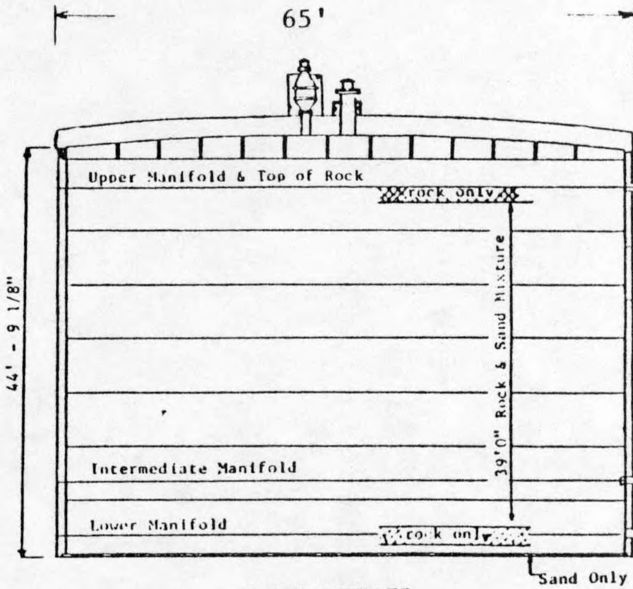
2. SPECIFIC DETAILS

a. Caloria HT-43 Oil

- A light petroleum base lube oil
- Decomposes at a design rate of 48 lb/hr at 580°F, producing methane, ethane, and hydrogen as waste byproducts.



WALL DETAIL



TANK DETAIL

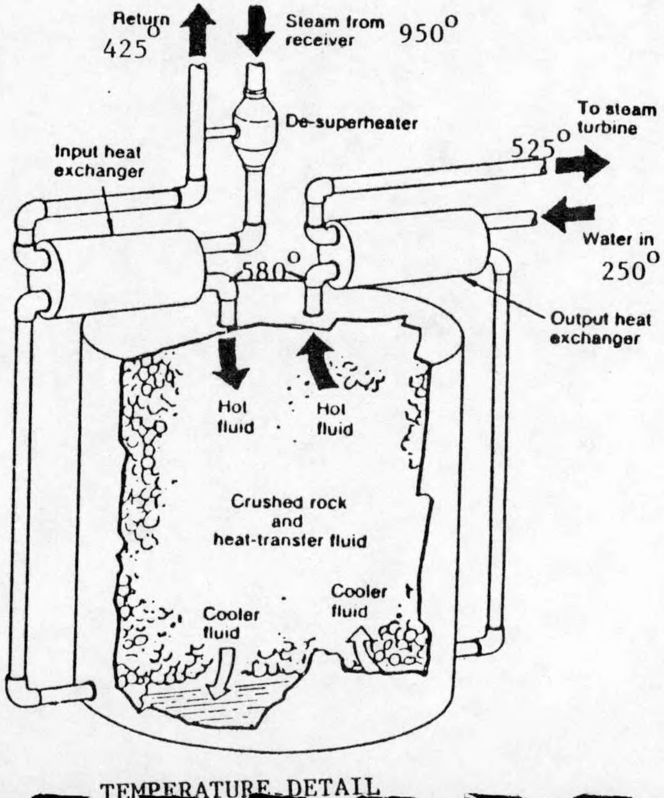


Figure II-9

TEMPERATURE DETAIL

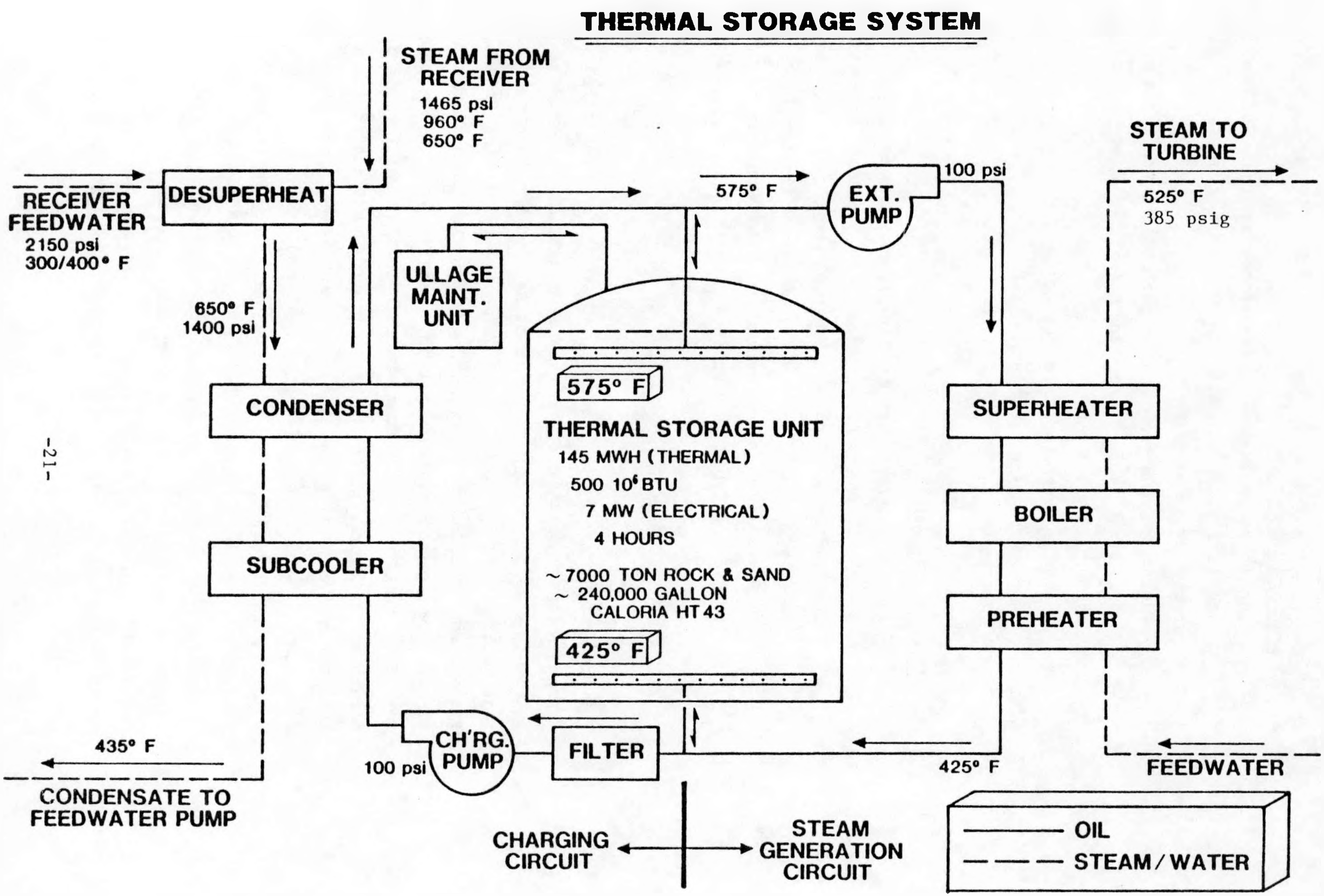

THERMAL STORAGE SYSTEM
STEAM FROM RECEIVER
1465 psi
960° F
650° F
RECEIVER FEEDWATER
2150 psi
300/400° F
DESUPERHEAT
575° F
EXT. PUMP
100 psi
STEAM TO TURBINE
525° F
385 psig
ULLAGE MAINT. UNIT
650° F
1400 psi
CONDENSER
575° F
THERMAL STORAGE UNIT
145 MWH (THERMAL)
500 10⁶ BTU
7 MW (ELECTRICAL)
4 HOURS
~7000 TON ROCK & SAND
~240,000 GALLON
CALORIA HT 43
425° F
SUPERHEATER
BOILER
SUBCOOLER
PREHEATER
435° F
CONDENSATE TO FEEDWATER PUMP
100 psi
CH'RG. PUMP
FILTER
425° F
FEEDWATER
CHARGING CIRCUIT
STEAM GENERATION CIRCUIT
OIL
STEAM/WATER

Figure II-10

b. Operating Temperatures

- The charging steam is desuperheated from 960 to 650°F and then goes into the charging heat transfer system to raise the temperature of the oil.
- During the charging and extraction processes the Caloria oil, at a temperature range from 425 to 580°F, flows through the rock and sand.
- Steam is generated from the hot oil from the extraction heat exchangers, and goes into the turbine at 525°F (385 psia).

c. Discharge Power

- Thermal storage system can discharge to the admission ports of the turbine-generator to produce 7 MWe power. The system can hold a charge for 7 days at maximum capacity. The discharge time is 4 hrs for the 7 MWe rate.
- Extractable energy capability 145 MWt-hr; Charging rate is 1.5 to 31.6 MWt; Discharge rate is 1.7 to 33.3 MWt.

3. OPERATING DESCRIPTION

The Thermal Storage System is designed to absorb and store thermal energy by condensing receiver generated steam and to serve as a source of thermal energy for a simultaneous or subsequent steam generation process. In addition, it provides the heat to maintain a small amount of steam which is used to continuously condition the plant. The thermal storage unit is a sealed vertical cylindrical tank filled with a sand/rock mixture through which the Caloria oil passes. Hot Caloria is introduced through a manifold at the top of the tank and passes downward. As the oil passes through the rock and sand mixture, it transfers its heat and is cooled to the exit temperature of 425°F. The process continues until the thermal storage unit is fully charged. An Ullage Maintenance Unit (UMU) disposes of gases which build up at the top of the tank. Gases such as methane, ethane, and hydrogen are disposed of by catalytic combustion. The UMU also introduces heptane as a pressurizing agent to prevent ingress of air into the Thermal Storage System.

H. ELECTRIC POWER GENERATION SYSTEM

1. TURBINE GENERATOR (See Figure II-11)

Manufacturer: General Electric

Equipment Cost: $2,120,372.28

Weight: 214,280 lbs. or 107.14 tons

Turbine generator length: 36'9.94"

Turbine Width: 14'

Generator Width: 7'8"

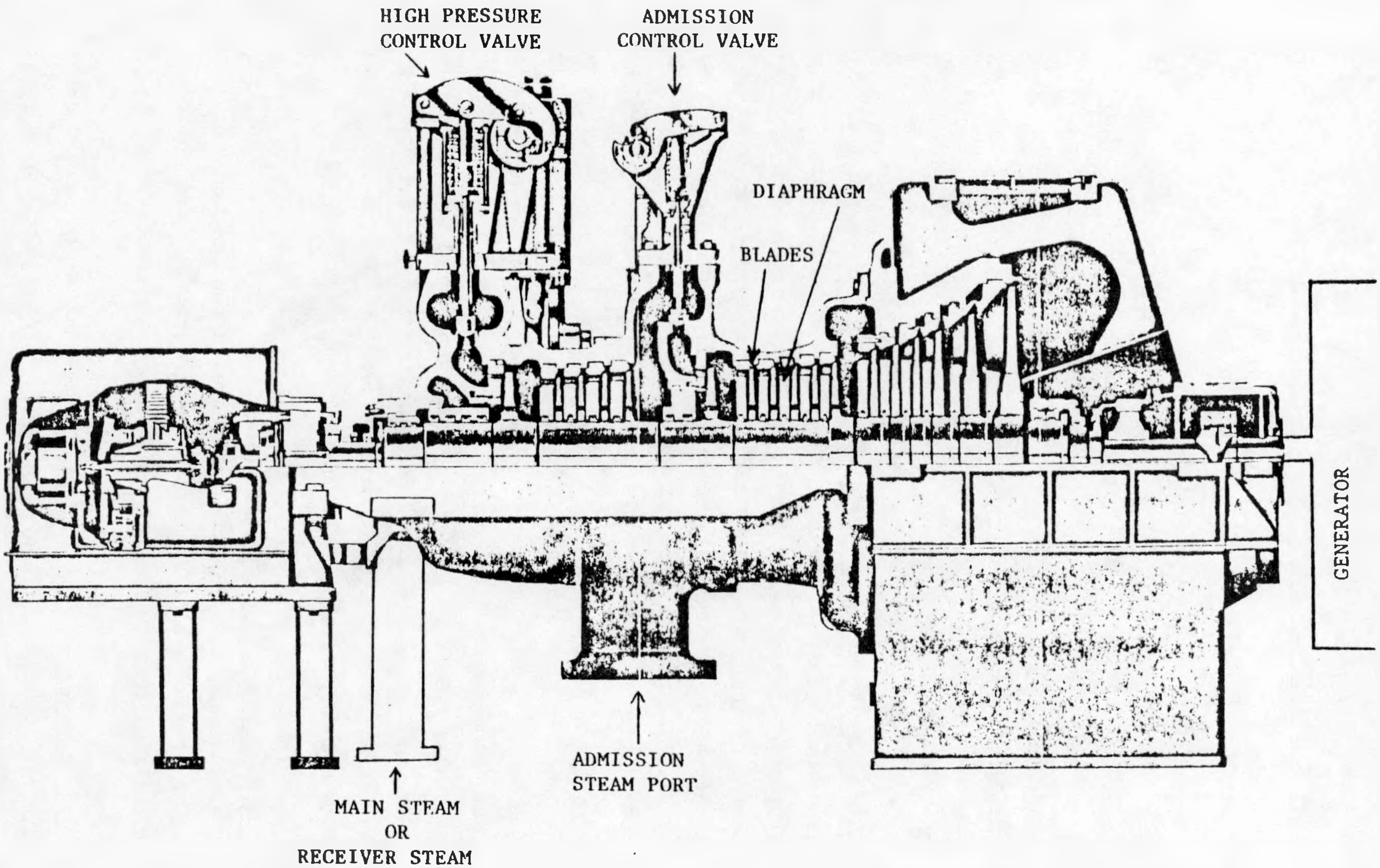
Rated turbine output: 12.8 MWe

a. Specific Statistics

- Rated generator capacity - 13.8 kV (14.23 MVA), grounded wye connected, 3 phase, 60 Hz. The short circuit ratio of the generator at maximum output is 0.58 or greater. Operates at power factors of 0.90 lagging to 0.95 leading without exceeding the guaranteed temperature rise. The unit is rated at 12.8 MWe gross electrical output at a 2.5 inch Hg condenser back pressure at a throttle steam inlet condition of 950°F, 1465 psia, and flow-rate of 112,140 lb/hr (Mode 1 operation). It operates at a synchronous speed of 3600 rpm and is directly coupled to a 13.8 kV generator. The unit is configured with four steam extraction ports which supply bleed steam for feedwater heating. The unit is also guaranteed to produce 8.0 MWe gross at a 2.5 inch Hg condenser back pressure at an admission steam inlet condition of 525°F, 385 psia and flow-rate of 105,000 lb/hr (Mode 6 operation).

- During normal operation, the plant generator, auxiliary transformer, and 33 kV line are interconnected thereby allowing the generator output to accommodate the auxiliary electrical load plus provide net power to the utility grid.

- Back-up power - Prior to turbine startup, power can be drawn directly from the utility 33 kV grid as required to supply the plant startup load. A 125 V DC emergency power backup system,



Turbine Generator

Figure II-11

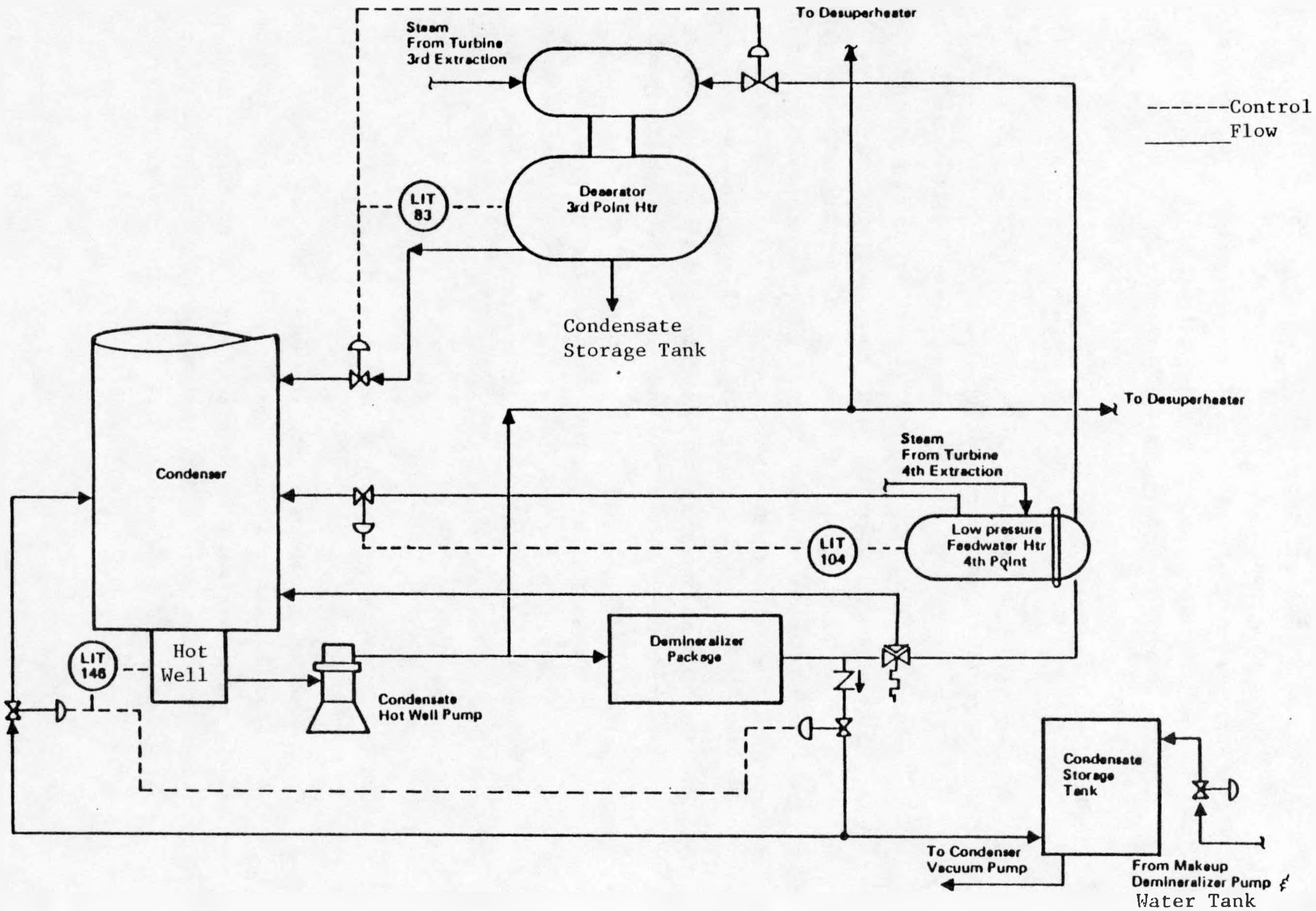
which is battery operated, is designed to provide power to critical components (turbine DC lube oil pump and solenoids on critical control and isolation valves and the Master Control room computers) which must be maintained in an operational status even when the primary AC power is lost.

b. Operating Description

The steam turbine is an automatic admission, single flow, extraction, condensing unit capable of accepting and admitting steam either through the main control valve, through the automatic admission control valves or through both valves simultaneously under the operating conditions (Modes) defined for the plant. The turbine is within a high pressure casing which contains disks. Turbine blades surround the turbine shaft forming blade disc assemblies. Incoming steam flows through these blade discs, and the shaft is forced to rotate. The turbine shaft is connected to the generator which is a rotating field type with a separate exciter. As the shaft is turned, the magnet turns inside the coil, inducing electricity. After passing through the turbine, the steam then passes to a condenser/hot well located under the turbine where it is condensed back into water. The water is pumped through preheaters back to the receiver to be made into steam once again.

2. CONDENSATE SYSTEM (See Figure II-12)

The Condensate System refers to the water handling portion of the EPGS and includes the condenser, deaerator and the condensate supply equipment. Major elements of the system also include the condenser vacuum pump, condensate pump, in line demineralizer, No. 4 heater and condensate storage tank. The condensate system is functioning anytime the plant is operating.



CONDENSATE SYSTEM

Figure 11-12

a. General Statistics on Major Components

- Condenser - An Ecolaire Industries surface unit. Inlet cooling water at 70°F flows at 7625 gpm through tubes which condense the steam from the turbine. The water exits at approximately 90°F. The maximum continuous heat rejection capability is 142 x 10^6 Btu/hr. The condenser shell pressure is maintained at 2.5" Hg by a vacuum pump in the condensate extraction line.

- Deaerator - A Chicago Heater Series TC unit. Condensate entering is heated to between 228-281°F by steam from the turbine 3rd extraction points to allow for adequate deaeration. The shell is vented to the atmosphere. The deaerator reservoir serves as a source of feedwater for the rest of the EPGS system. Excess water is pumped back either into the condenser or the condensate storage tank. The unit maintains the O_2 level at a maximum 0.005 cc/liter for flow rates up to 238,625 lb/hr.

- In Line Demineralizer - A parallel flow system with two vessels which are operated on an alternating basis while the off-line unit is being regenerated. The condensate is polished by a Crane-Cochrane, deep-mixed bed ion exchange unit. All equipment is skid mounted. The inlet water temperature is kept below 135°F. The system is designed to provide the following purity water at a design flow rate of 75 GPM:

	Parts per Billion (ppb)
Total Dissolved Solids (C_aCO_3)	50
Sodium (Na)	2
Chloride (Cl)	2
Total iron (Fe)	10
Copper (Cu)	2
Silica (SiO_2)	20
Cation conductivity @ 25°C	0.15 mho (max)
pH @ 25°C	6.5-7.5

- Condensate Storage Tank - A 24,000 gallon reservoir for excess condensate. Tank size is 15 ft. high by 18 ft. diameter. Located near the condenser hotwell, the tank provides condensate flow to the hotwell by natural pressure differences. The tank was sized to provide sufficient water for regeneration of the polishing demineralizer (three complete cycles) plus normal operating makeup water.

b. Operating Description

Condensate is drawn from the condenser hotwell, is circulated through the inline demineralizer and 4th point feedwater heater before entering the deaerator. The flowrate capability is 218,000 lb/hr with a discharge pressure of 140 psia. Additional condensate is drawn into the hotwell from the storage tank, as needed. Makeup water for the condensate tank is derived from wells and is initially purified by a makeup demineralizer and stored in a plastic lined makeup water tank. The condensate storage tank is the source of purified water for cleaning the heliostat mirrors.

3. MISCELLANEOUS SUPPORT SYSTEMS

The miscellaneous support systems described below are all conventional items with the exception of the TSS Admission Steam System.

a. Steam Turbine Support Systems

- Hydraulic System
- Lubricating Oil System
- Turning Gear System
- Gland Steam Seal System

b. Flash Tank Systems

- Receiver Flash Tank - for receiver startup/shutdown
- Thermal Storage Flash Tank - for TSS startup

c. Auxiliary (Blanketing) Steam System

- Auxiliary Electric Boiler - An HSI electric resistance element type rated at 5610 lb/hr and 1650 kw at about 300°F. Pressure is 55-65 psia. Provides blanketing steam flow to maintain the seals when the EPGS system is inactive.

- Admission Steam System - When the TSS tank is charged or the admission steam system to the turbine is active, heat is bled off and converted to steam which is used for blanketing purposes instead of the electric boiler.

  TSS generated blanketing steam is by means of a separate manifold located low in the TSS tank. The blanketing steam is generated at a temperature of approximately 300°F.

d. Plant Support Systems

- Pressurized Air System
- Nitrogen System
- TSS Oil Makeup System
- Cooling Tower System
- Water Chemistry System
- Water Chemistry Laboratory
- Uninterruptible Power Supply System

I. MASTER CONTROL BUILDING

1. GENERAL BUILDING DESCRIPTION (See Figure II-13)

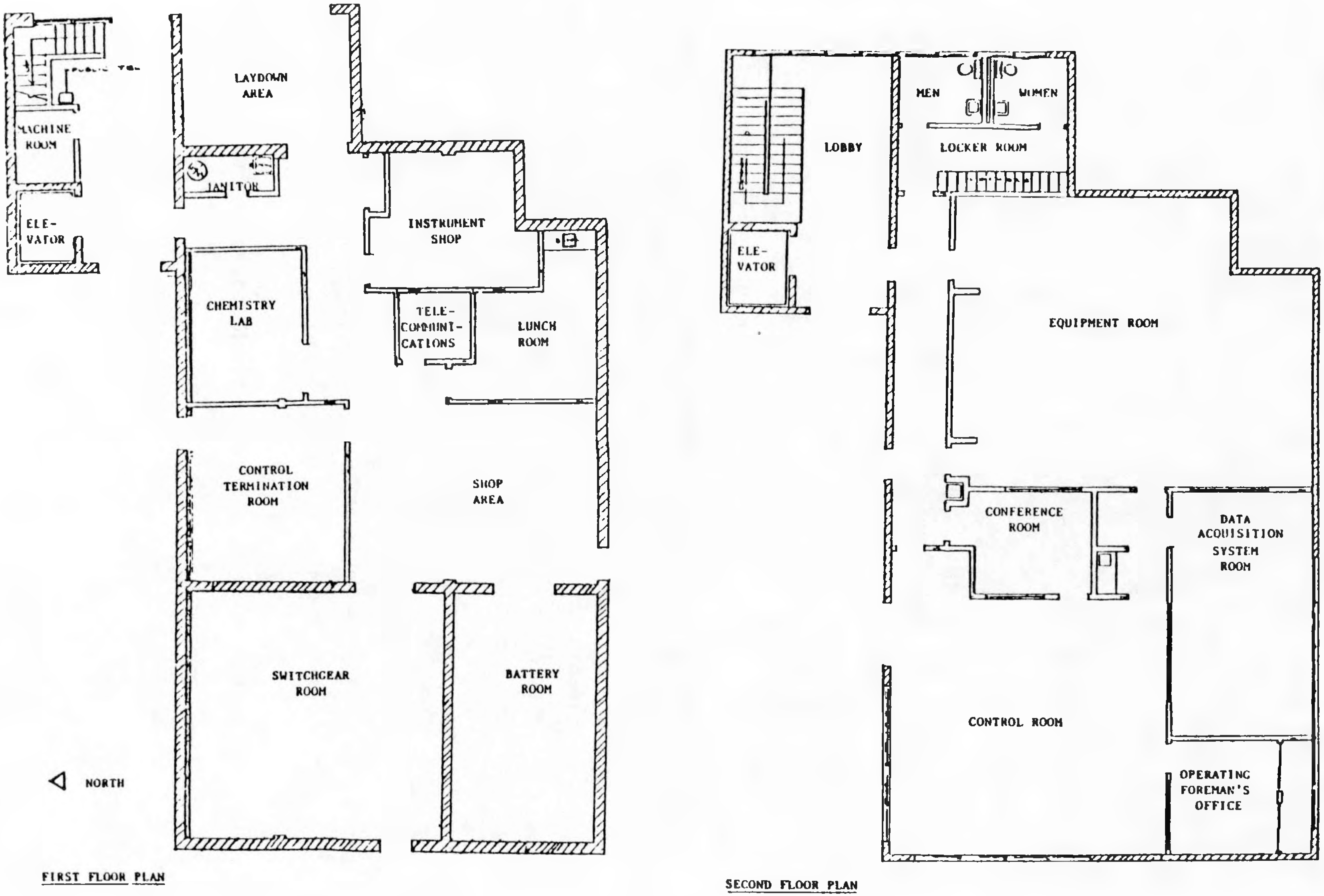
The control building is a two-story reinforced masonry block structure. The Plant Control room, Equipment Room and Personnel Office space are located on the second floor, with the electrical switchgear and battery rooms located on the first floor. Building plan dimensions are approximately 45'-0" by 72'-0".

a. First Floor

- Machine Room: Contains the elevator apparatus, hydraulic pumps.
- Laydown Area: Assembly and disassembly area.
- Chemistry Lab: For analyzing the quality of feedwater
- Control Termination Room: Containing the computer equipment for the plant controls, plant data processing and storage.
- 480 Volt Switchgear Room: Contains electrical equipment which runs the motors and/or the plant apparatus (air compressors, pumps, valves, etc.).
- Battery Room: Contains batteries and a DC to AC converter for the emergency control equipment and computers (the ultimate backup in case of power failure).
- Shop Area: For parts maintenance and repair of plant equipment.
- Telecommunications: Switchboards for telephone systems.
- Instrument Room: A repair room for the plant instruments.

b. Second Floor

- Equipment Room: The four computer systems and their hardware are installed in this room.
- Conference Room: For conferences and VIP visitors. Contains windows for viewing the Equipment Room and the Control Room.



General Building Arrangement

Figure II-13

- Control Room: The control operators are stationed in this room with computer terminals to operate the plant.
- Operating Foreman's Office: For the shift supervisor.
- Data Acquisition Room: The scientific participants, namely DOE and contractors, receive information pertaining to the operation of this plant from computer display terminals installed in this room.

J. MASTER CONTROL COMPUTER SYSTEM

1. EQUIPMENT TYPE

There are four MODCOMP (Modular Computer Company) computers installed at the plant. Two control the heliostats, one controls the plant and one collects the plant data.

2. CONTROL AND DATA SYSTEM (See Figures II-14, II-15, and II-16)

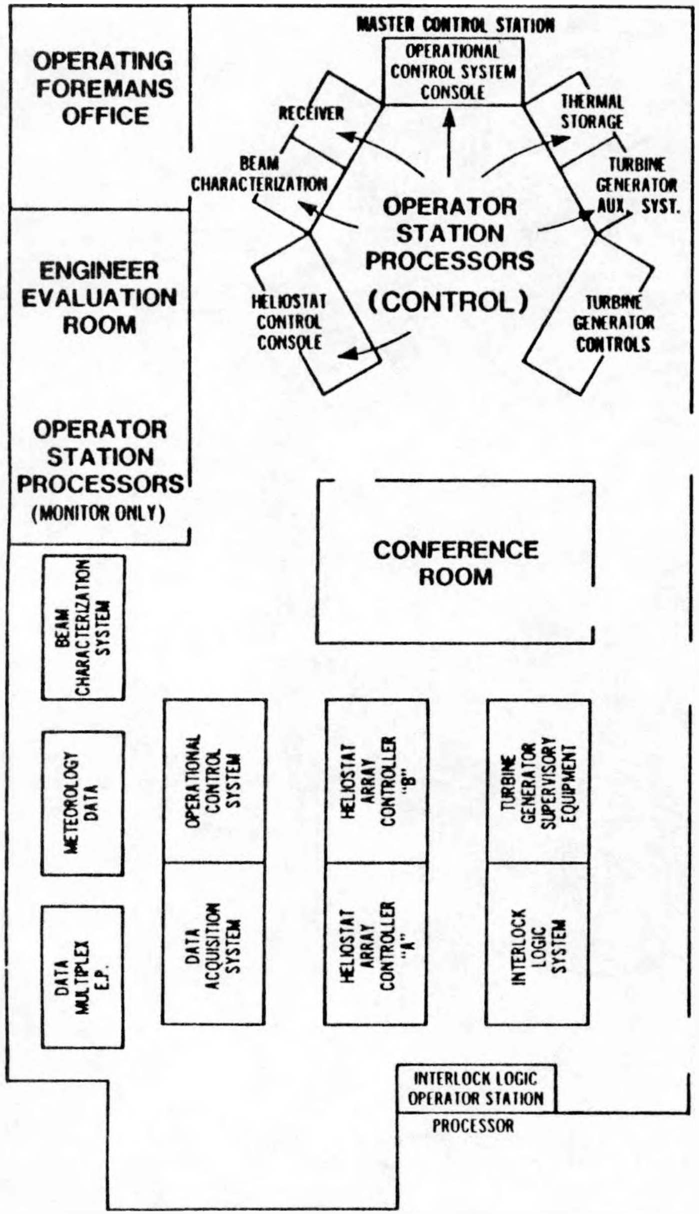
- Master computer control provides overall coordinated supervisory control with individual system controls.

- Beckman Instruments provided the Distributed Process subsystem control equipment stationed throughout the plant, and the control room consoles.

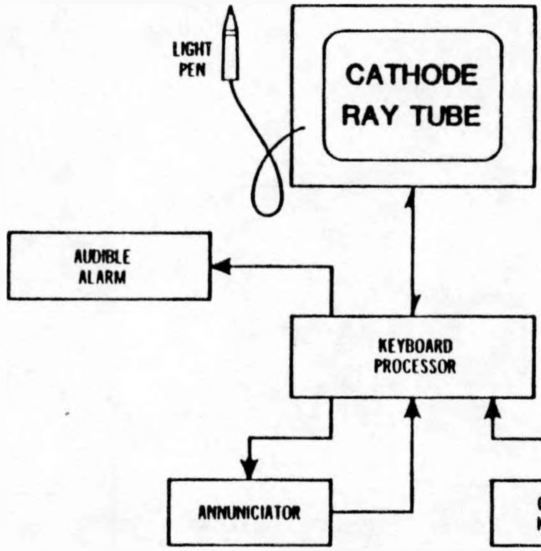
- McDonnell Douglas, the integrating contractor, together with Southern California Edison provided the control logic (software equations) which instruct the computer how to operate the pumps, valves, etc.

- Martin Marietta provided the control logic which operates the heliostats.

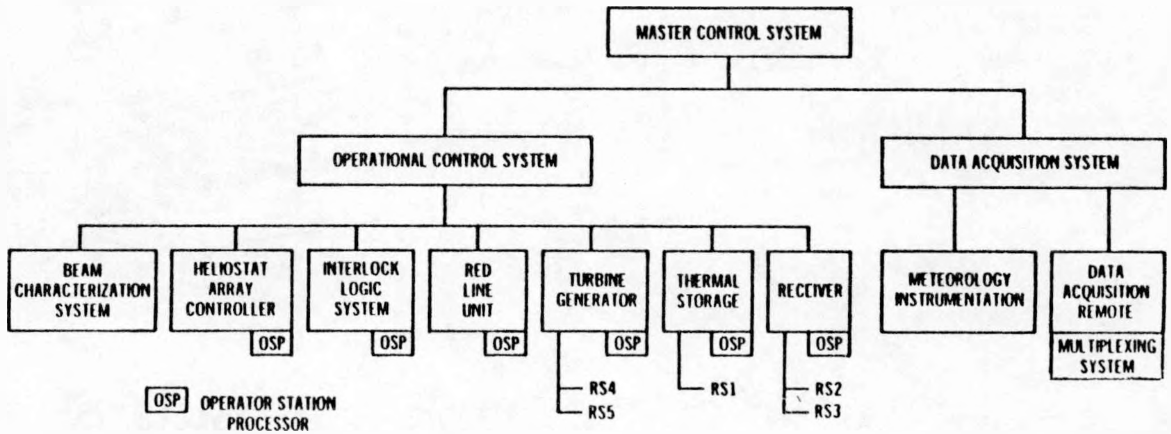
SOLAR ONE
GENERATING STATION



MASTER CONTROL SYSTEM PHYSICAL LAYOUT



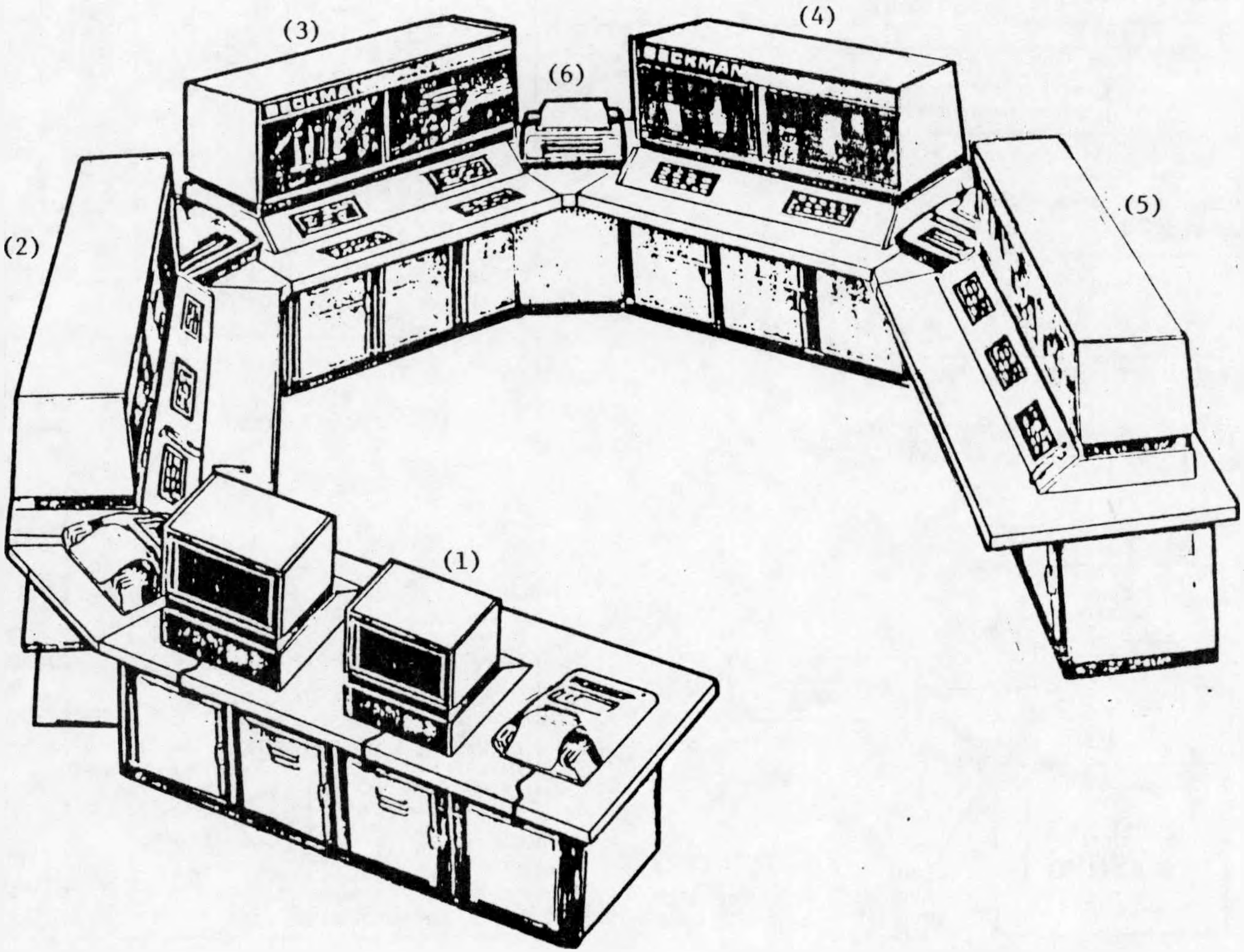
TYPICAL OPERATOR STATION PROCESSOR



MASTER CONTROL SYSTEM HIERARCHY

Figure II-14

SOLAR 1 PLANT CONTROL CONSOLE



(1) Heliostat/Field Control Console

(2) Receiver Control Console

(3) Overall Plant Operational Control Console

(4) Thermal Storage/EPGS Control Console

(5) Turbine-Generator Control Console

(6) Alarm Printers and Loggers (Typ.)

Figure II-15

CONTROL/MONITOR/EVALUATION ARCHITECTURE

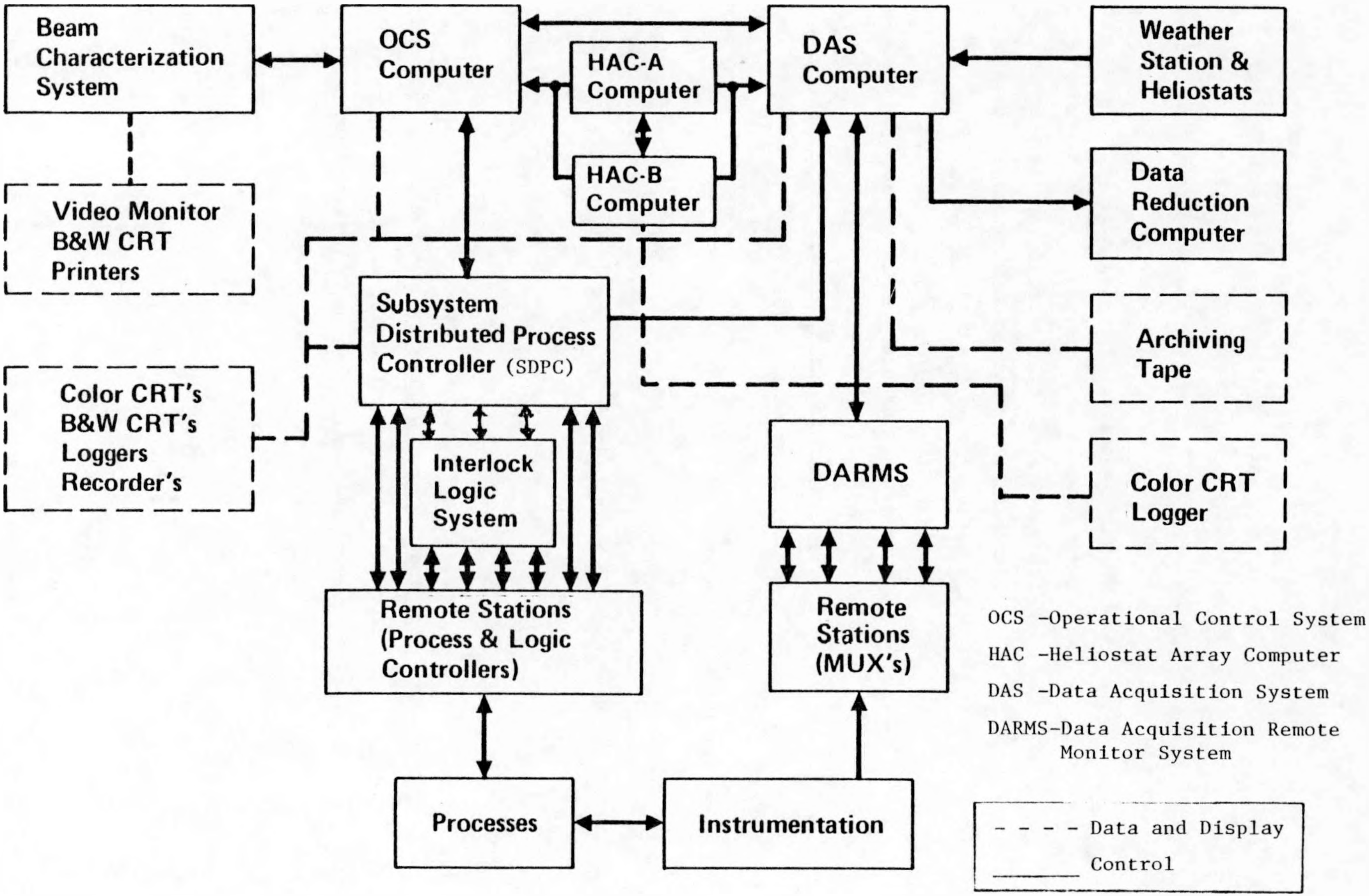


Figure II-16

3. CHARACTERISTICS

- o Control of each system is independent via a Subsystem Distributed Process Control (SDPC) system and Heliostat Array Controller (HAC). Specific characteristics of this system are:

  - Primary automatic operating mode with operator override
  - Single operator, operating from a single Operational Control System (OCS) console (software under development)
  - Alerts/alarms provided and recorded; automatic initiation of safety/protective actions.
  - Single control room.
  - Major control modules include Master Control System (MCS) computer system, including displays and control console; SDPC system including displays, peripherals, integrated control console, and HAC.

4. LEVEL OF AUTOMATION

Fully automatic for a clear/cloudy day operation (software under development); semi-automatic includes various levels of manual plant control.

5. DATA ACQUISITION SYSTEM (DAS)

a. Kind and Number of Channels - Approximately 2900 analog (12 bit) channels (maximum capability)

- o Approximately 1978 DAS measurements are currently recorded, broken down as follows:

Receiver system	556
Thermal storage system	441
Electrical power generating system	691
Collector system	172
Meteorological	68
General plant support	50

- In addition, approximately 200 selected data "points" will be recorded on the DAS from the OCS operating system.

6. DATA PROCESSING PHILOSOPHY

- Obtain and record plant performance, evaluation and control data.
- Process real time data and display to operator.
- Collect and store data which can be used for off-line plant performance evaluation.

K. PILOT PLANT DESIGN POINT, ENVIRONMENTAL ASSUMPTIONS

1. DESIGN POINT

Primary Design Point: December 21, 2:00 pm

Insolation assumed at that moment: 900 W/m^2

2. DIRECT INSOLATION VALUES AT NOON

March 21, September 21:	950 W/m^2
June 21,	900 W/m^2
December 21:	967 W/m^2

3. ENVIRONMENTAL CONDITIONS FOR OPERATION

Minimum insolation assumed is 690 W/m^2, maximum is 1150 W/m^2

Average, peak and lowest temperature: 66°F, 115°F, 10°F

Operational temperatures: 16° - 113°F (dry bulb)

14° - 77°F (wet bulb)

a. Wind Design Speeds

Average annual	- 11.7 mph	
Operational	- 27 mph	(Specification values)
Survival	- 90 mph (stowed)	"
	- 50 mph (any position)	"

b. Acceleration Due to Earthquakes

Horizontal response spectrum - up to 0.25 g

Vertical response spectrum - 2/3 of horizontal

Damping ratio - 7%

c. Aggressive Environmental Conditions on Heliostats

Snow load - 5 lb/ft^2 at 1 ft/24 hr

Ice buildup - 2 inches

Hail - 3/4 in. dia. at 65 ft/sec (any orientation),
1 in. dia. at 75 ft/sec (stowed position)

d. Rainfall - average annual rainfall is 9.4 cm. (3.7 in).

L. PILOT PLANT EFFICIENCY

1. DESIGN BEST DAY ENERGY EFFICIENCY (See Figure II-17)

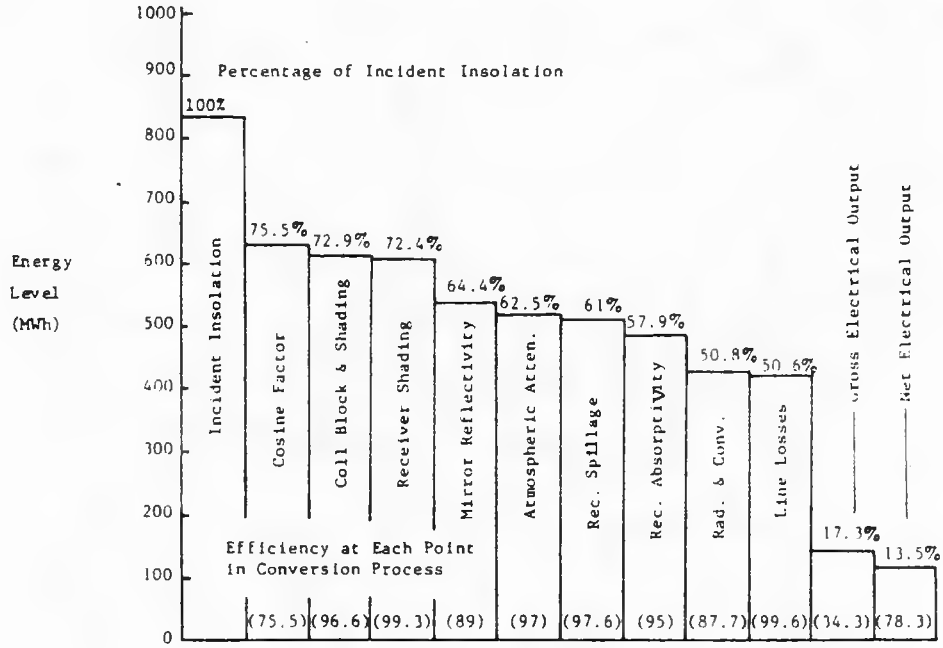
The design day energy efficiency is defined as the ratio of the total electrical energy delivered to the grid assuming maximum energy operation to the total thermal energy available to the collector field assuming a full insolation day (mirror area x integrated normal insolation). The best day efficiency is 13.5% as illustrated at the top of Figure II-17. Using full storage operation, this efficiency drops to 12%.

2. DESIGN WORST DAY ENERGY EFFICIENCY (See Figure II-17)

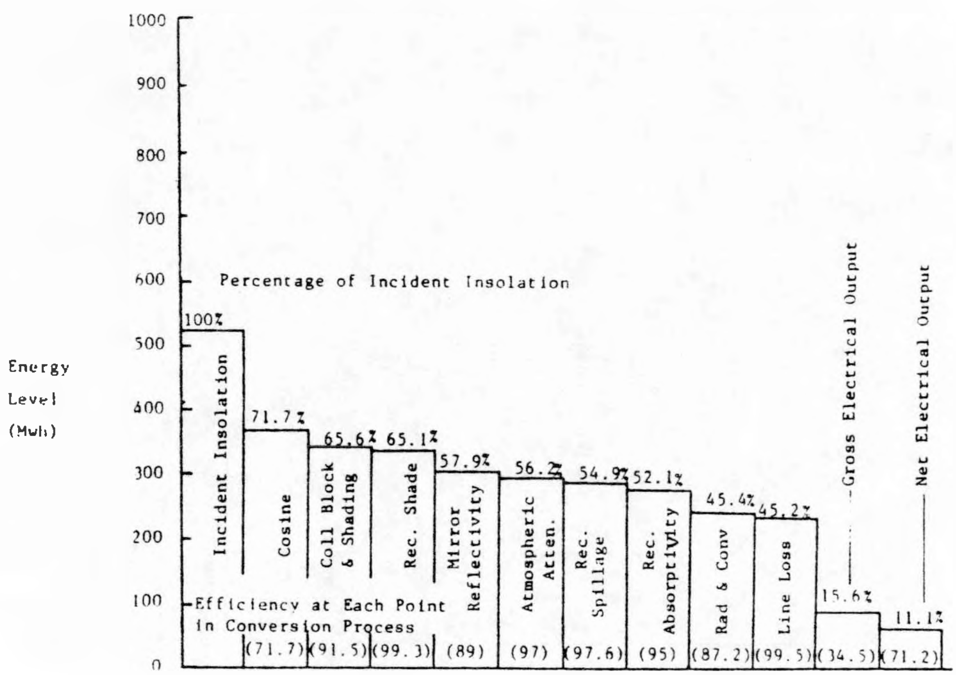
The worst day energy efficiency is 11.1% based on maximum power operation and 10.6% based on full energy storage operation. The energy loss staircase is shown at the bottom of Figure II-17.

3. ANNUAL ENERGY EFFICIENCY (See Figure II-18)

The Pilot Plant annual energy efficiency is 13.0% based on available incident insolation of 2.02 x 10^5 MWt-hr, maximum power

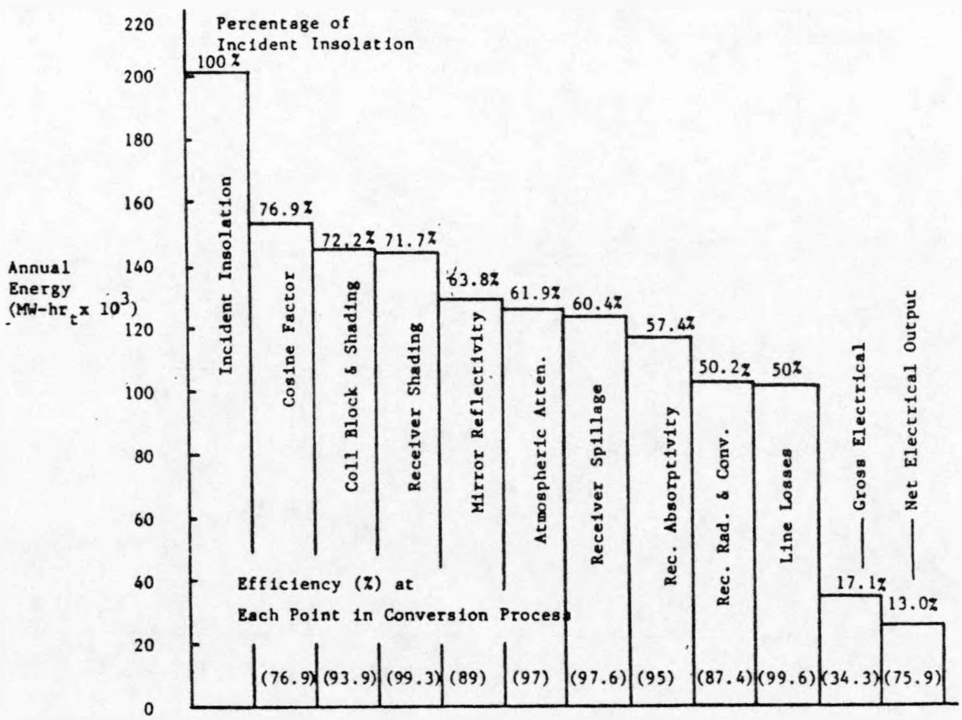


Summer Solstice Energy Efficiency (Daily Average)

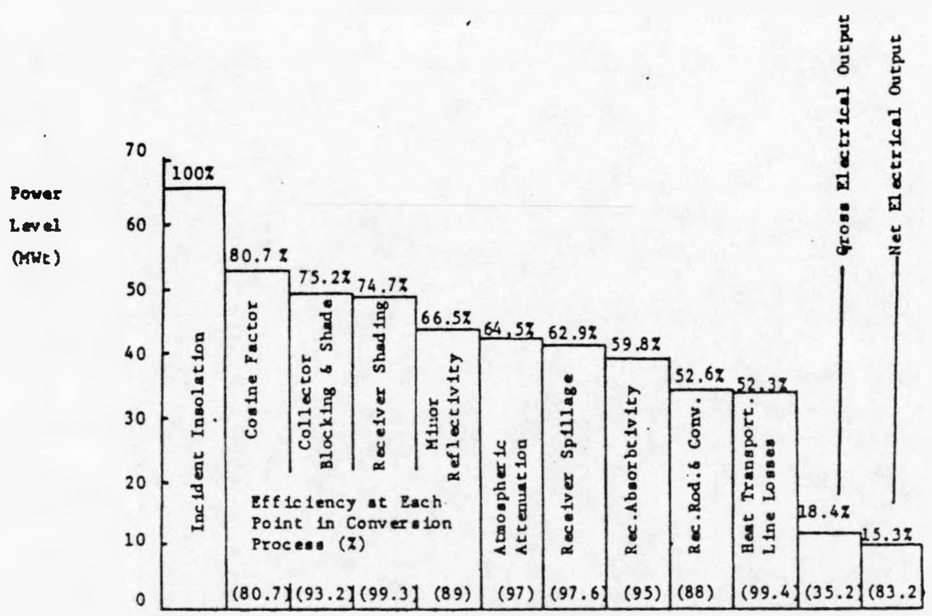


Winter Solstice Energy Efficiency (Daily Average)

Figure II-17



Annual Energy Efficiency (Typical Year)



Winter Solstice Design Point Efficiency (2 PM, December 21)

Figure II-18

operating strategy, and no allowance of shutdown for maintenance. The energy staircase is shown at the top of Figure II-18.

4. PRIMARY DESIGN POINT SYSTEM POWER EFFICIENCY (2 PM, DECEMBER 21)

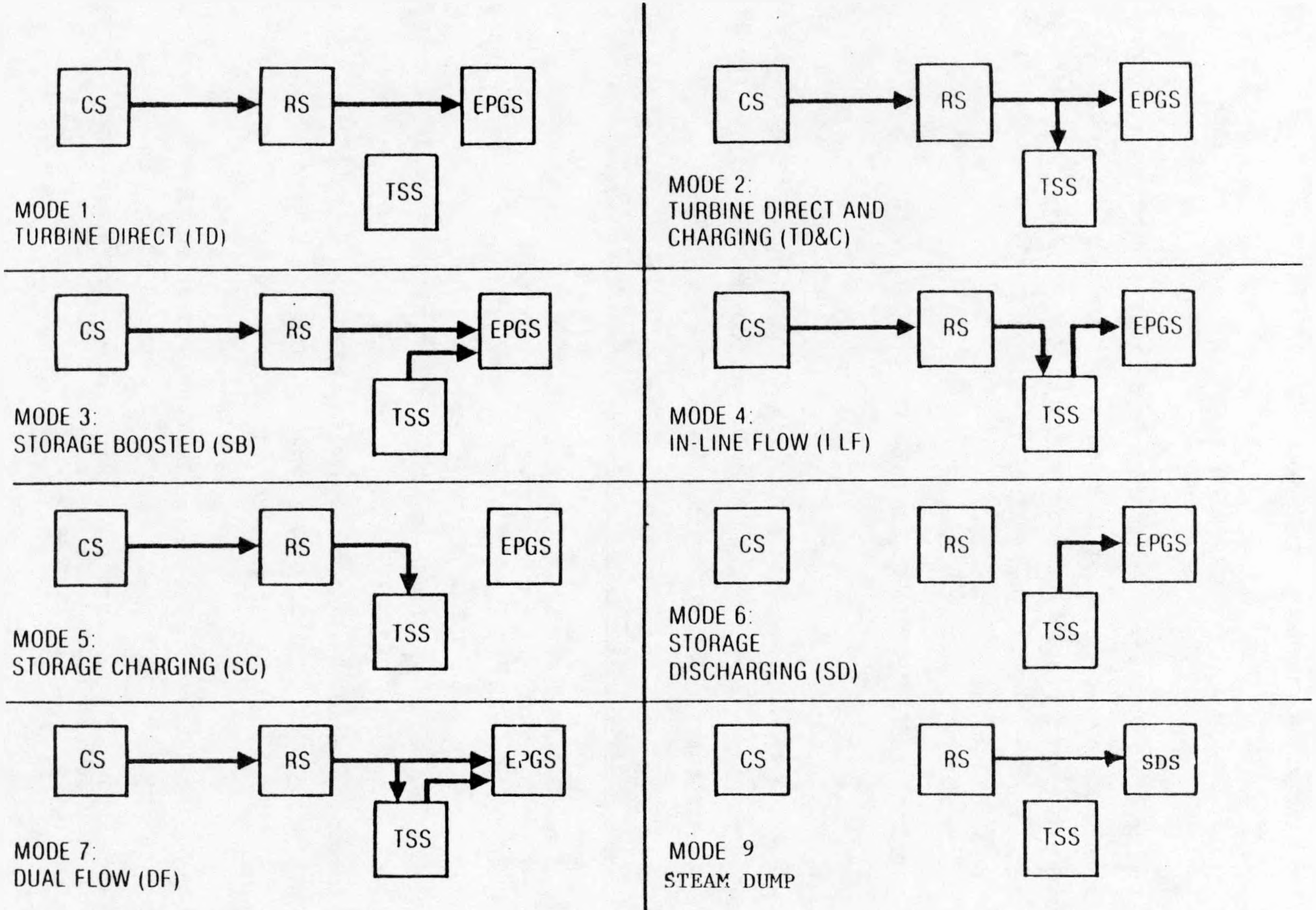
The design point power efficiency is defined as the ratio of rated power (10 MWe) to that portion of the thermal power available to the collector field, which is directed to support EPGS operation (exclusive of TSS). This efficiency, shown at the bottom of Figure II-18, is a minimum of 15.3%.

5. SECONDARY DESIGN POINT SYSTEM POWER EFFICIENCY

This efficiency is defined as the ratio of rated net power (7 MWe) while the plant is operating in Mode 6 (extended operation) to the thermal power extracted from the TSS storage media (oil) by the TSS heat exchanger. This efficiency is a minimum of 20%.

M. PILOT PLANT STEADY STATE OPERATING MODES (See Figure II-19)

	Mode	Description
1.	Turbine Direct	All thermal power absorbed by the receiver flows to the EPGS for direct turbine-generator operation.
2.	Turbine Direct	Thermal power collected by the receiver is divided and Charging between thermal storage(charging function) and the EPGS for direct turbine-generator operation.
3.	Storage Boosted	All thermal power collected by the receiver flows to the EPGS and is augmented by admission steam power extracted from thermal storage.



MODE 8
INACTIVE

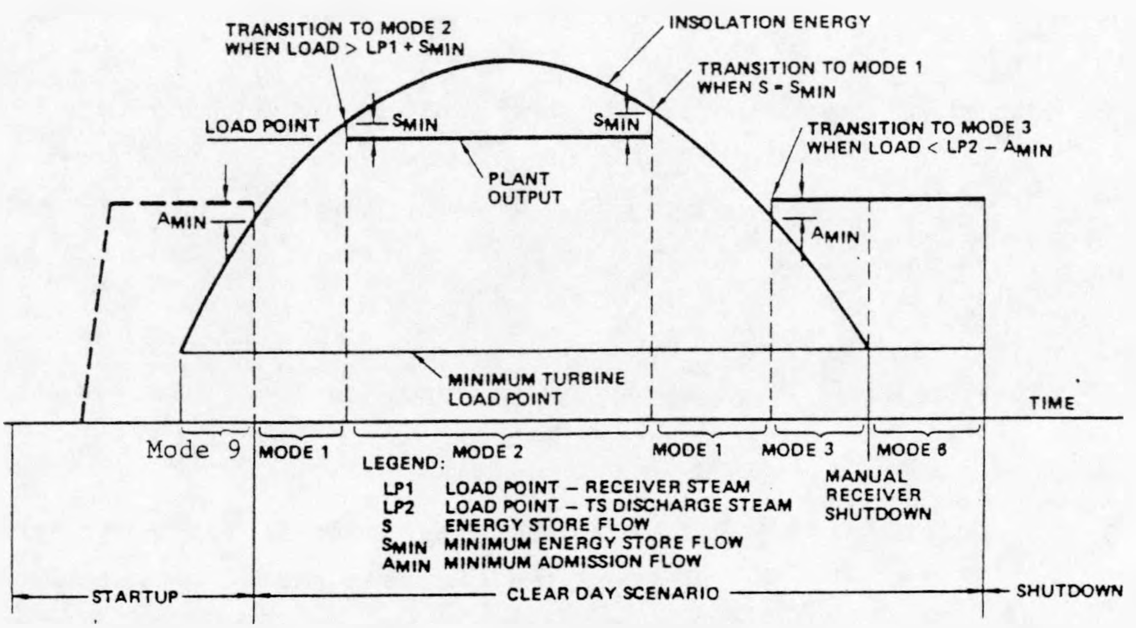
CS = COLLECTOR SYSTEM
RS = RECEIVER
TSS = THERMAL STORAGE SYSTEM
EPGS = ELECTRICAL POWER GENERATOR SYSTEM
SDS = STEAM DUMP SYSTEM

Pilot Plant Steady State Operating Modes

Figure II-19

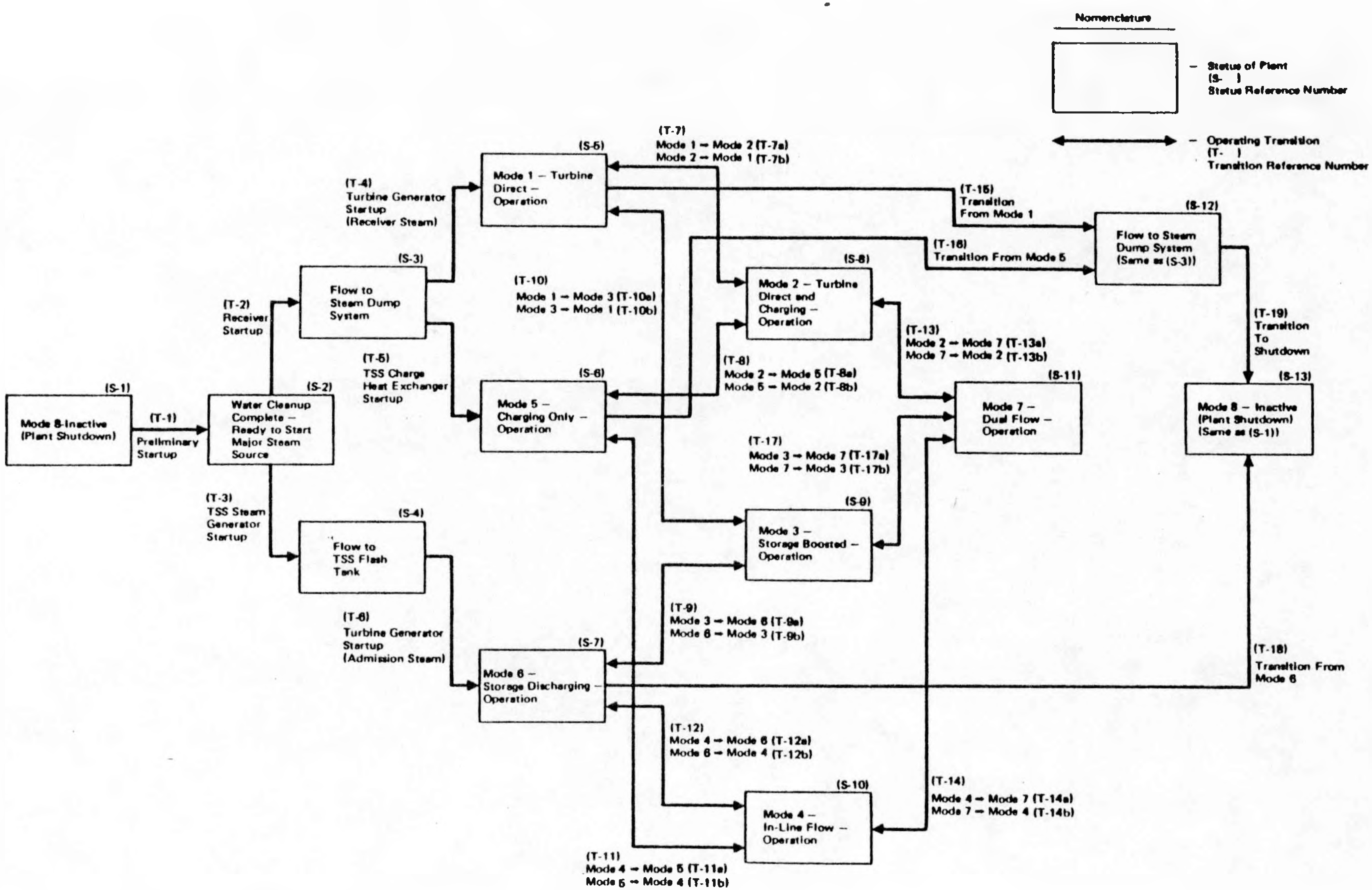
4.	In-Line	All power collected by the receiver flows to thermal storage. Thermal power is extracted from storage for turbine-generator admission steam operation.
5.	Charging Only	All thermal power collected by the receiver is used for thermal storage charging.
6.	Discharging Only	Thermal power is extracted from storage for admission steam turbine-generator operation.
7.	Storage Boosted	Thermal power collected by the receiver is divided and Charging between both storage and the EPGS. Thermal power is also extracted from storage and routed to the admission steam input of the EPGS.
8.	Inactive	All subsystems are inactive and held in a standby condition during overnight shutdown.
9.	Steam Dump	All thermal power absorbed by the receiver flows to the condenser where it is condensed back to water. This process is used during startup and shutdown.

How the plant is transitioned between operating modes during a clear day, based upon solar insolation, is depicted in Figures II-20 and II-21.



Clear Day Operating Scenario

Figure II-20



Operational Flow Diagram

Figure II-21

III. PROJECT ORGANIZATION AND PROCUREMENT METHODS

III. PROJECT ORGANIZATION AND PROCUREMENT METHODS

A. DESCRIPTION

1. DEPARTMENT OF ENERGY

The Solar Thermal Program Division in DOE Headquarters designated the San Francisco Operations Office (SAN) in 1977 to be responsible for day-to-day management of the project. SAN created a project office under the direction of Richard N. Schweinberg.

Figure III-1 shows the project office organization. DOE was responsible for the funding and management of the Solar Facilities while the Utility Partner (Associates) provided the funding and management for the Turbine Generation Facilities. The Solar Facilities include the solar collectors (heliostats or mirror assemblies), beam characterization, receiver and tower, thermal storage, and master control systems.

During the design phase, the project office was located in the Los Angeles area. At the start of construction, an office was established at the plant site in Daggett. This site office was staffed with the SAN construction engineer and representatives from SCE construction, Townsend and Bottum, (the DOE construction manager) and Stearns Roger (SFDI A/E subcontractor). During the plant startup phase, site representation was expanded to include MDAC, Rocketdyne and Stearns Roger checkout personnel and SCE startup/operations staff and DOE technical monitors.

In order to provide technical overview assistance to the government members of the project office, technical monitors were used from the following organizations:

a. The Aerospace Corporation - Focused on overall system design, systems integration, safety and master control.

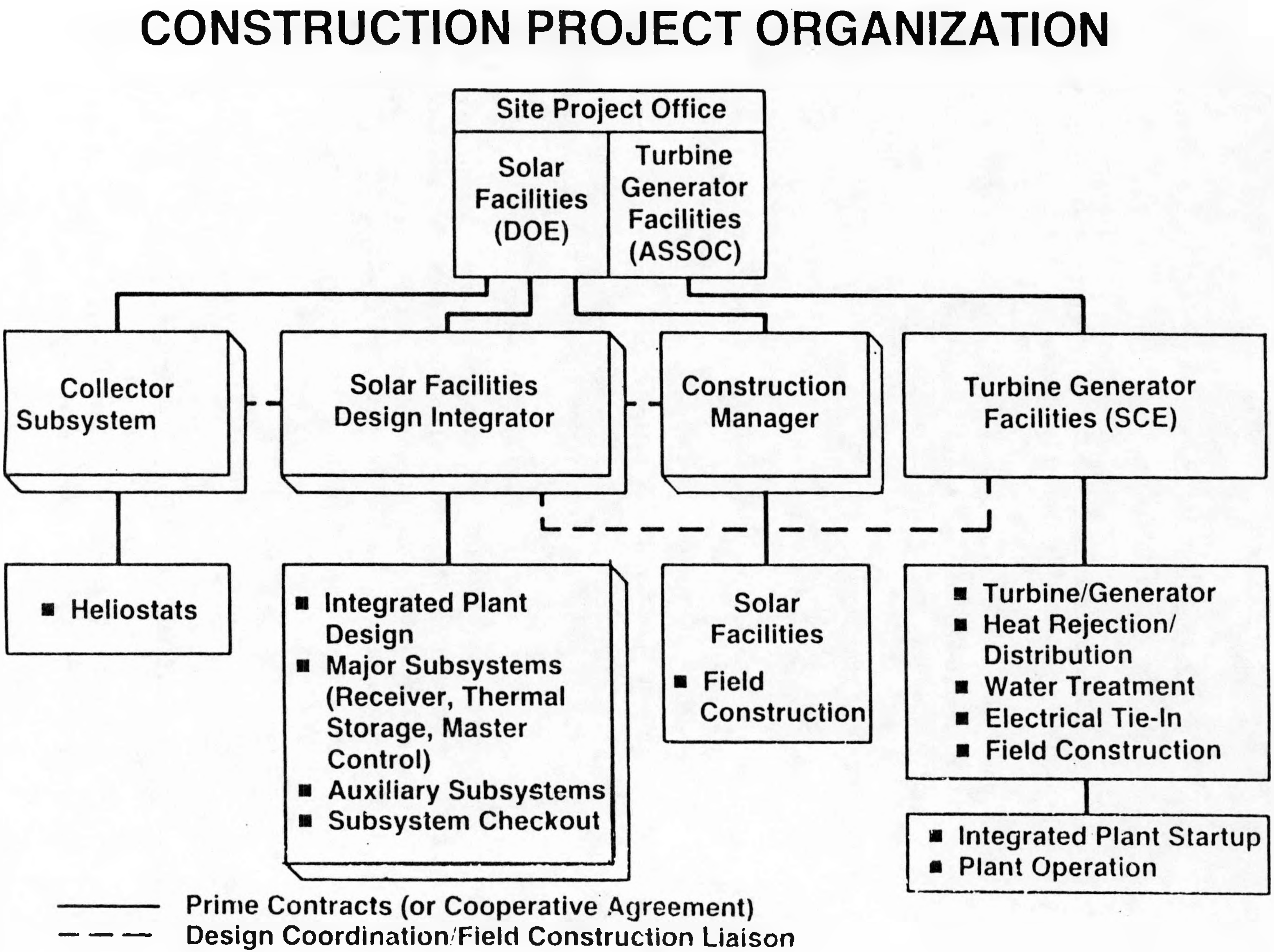

CONSTRUCTION PROJECT ORGANIZATION
Site Project Office
Solar Facilities (DOE)
Turbine Generator Facilities (ASSOC)
Collector Subsystem
Solar Facilities Design Integrator
Construction Manager
Turbine Generator Facilities (SCE)
■ Heliostats
■ Integrated Plant Design
■ Major Subsystems (Receiver, Thermal Storage, Master Control)
■ Auxiliary Subsystems
■ Subsystem Checkout
Solar Facilities
■ Field Construction
■ Turbine/Generator
■ Heat Rejection/ Distribution
■ Water Treatment
■ Electrical Tie-In
■ Field Construction
■ Integrated Plant Startup
■ Plant Operation
Prime Contracts (or Cooperative Agreement)
Design Coordination/Field Construction Liaison

Figure III-1

b. Energy Technology Engineering Center - Focused on the receiver and thermal storage.

c. Sandia National Laboratory - Focused on heliostats and the Beam Characterization System design.

These technical monitors assisted the SAN project office throughout the initial contracting, design, construction, and startup phases of the project.

2. DOE PRIME CONTRACTORS

a. Collector System - Boeing, Honeywell, Martin-Marietta (MMC), and McDonnell Douglas (MDAC) were not considered ready to proceed with production at the completion of the Concept Design Phase. Following DOE's designation of a single pedestal, glass mirror heliostat approach and a competitive contractor selection by DOE, MMC and MDAC performed final designs and built test heliostats under Cost Plus Fixed Fee (CPFF) contracts (Phase I).

From the results of hardware/software testing at the completion of Phase I as well as evaluations of proposals from MMC and MDAC, MMC was selected by DOE as the Phase II contractor to produce and install the collector field and associated controls. The contract form was Fixed Price Incentive Fee (FPIF) with the incentive tied to total cost.

Paul R. Brown was the MMC heliostat project manager.

b. Solar Facilities Design Integrator (SFDI) - Following completion of total plant concept designs, by Honeywell, MMC, and MDAC, DOE baselined the specific approach of a single pass to superheat external water/steam boiler and oil/rock storage

A competitive selection by DOE resulted in placing MDAC under a Cost Plus Award Fee (CPAF) contract as the Solar Faoilities Design Integrator (SFDI). The award fee was judged on cost, schedule, technical and management performance.

Major SFDI subcontractors were:

(1) Rocketdyne, who designed and fabricated the receiver panels and thermal storage hardware.

(2) Stearns-Roger, who provided conventional A/E design services; e.g., buildings, grading, tower, electrical design, and site engineering services during construction.

(3) University of Houston, who designed the collector field and determined the heliostat aiming strategy.

MDAC performed the overall plant level design analysis as well as design/procurement of the master control and beam characterization hardware and software. In addition to integrating the SFDI team's systems, MDAC was also responsible for integrating the collector system and the utility partner's Electric Power Generation System designs to meet overall plant objectives.

The SFDI Program Manager was Ray W. Hallet.

c. <u>Construction Manager</u> - Shortly after DOE specified the major system design concepts, Townsend and Bottum (T&B) was competitively selected and placed under a Cost Plus Fixed Fee (CPFF) contract. T&B's initial tasks included overall project scheduling and construction package cost estimating. DOE initially prime-contracted several construction packages, but ultimately decided to have T&B subcontract the construction. Exceptions were a few packages provided to the Small Business

Administration (SBA) for contractor selection. The SBA contractors were retained as DOE primes. All field construction work was performed under Fixed Price (FP) contracts.

The T&B Construction Manager was Roger J. Schwing.

3. UTILITY PARTNER

In response to a competitive solicitation by the government, the Associates were selected to be the Utility Partner. The Associates are comprised of Southern California Edison (SCE), Los Angeles Department of Water and Power (LADWP) and the California Energy Commission (CEC). SCE was designated the team leader.

SCE/LADWP were responsible for providing the land (Coolwater Ranch), turbine generator facilities, tie-in to the electric network and startup/operation/maintenance personnel. The turbine generator facilities were designed by SCE engineering, who also performed the construction management function for their portion of the plant. The SCE site construction was performed using fixed price contracts and companies selected from the SCE approved bidders list.

The CEC was responsible for transferring the Pilot Plant experience to future commercial development. In order to facilitate State approvals of these plants, CEC was to: (1) review siting procedures, (2) minimize institutional barriers, and (3) coordinate efforts of public agencies.

DOE and the Associates functioned under an arrangement described by a formal Cooperative Agreement. A key element of this agreement was that the Associates would totally fund and be responsible for the non-solar or standard portion of the plant. No DOE design or construction funds were used by the Associates. In the same sense, DOE was fully responsible for its portion of the plant. Physical interfaces were designated for design and construction purposes.

The SCE Program Manager was Joseph N. Reeves.

4. SMALL/DISADVANTAGED CONTRACTING

The government has a major commitment to encourage participation by small/disadvantaged firms. The targets for the Solar Facilities were 25% Small and 10% Small/Disadvantaged.

In order to increase the potential number of participants, the Project Office contacted and worked with the local Business Development Centers of the Department of Commerce.

Local business and community groups were also contacted and apprised of work opportunities on the project.

B. LESSONS LEARNED

1. TRANSITION FROM CONCEPT DESIGN TO PRELIMINARY/FINAL DESIGN

a. Process Used for Pilot Plant - Four contractors were competitively selected to develop water-steam system/subsystem concept designs and provide cost estimates and schedule projections for both a 100 MWe plant and 10 MWe pilot plant. At the end of this phase and with advice from government agencies, labs and the utility partner, DOE selected the basic component and subsystem characteristic which were to serve as the basis for proceeding. A second competitive procurement was held to select the Solar Facility Design Integrator.

Several disadvantages of this approach are:

- No enforceable commitment by second phase proposers to concept cost and schedule estimates, since second phase has no contractural connection to concept phase.

- Concept phase experience will be of varying value to second phase proposers depending on whose plant characteristics are chosen. Only limited competition was generated during the second phase procurement, as only two offers were received.

- A second procurement is expensive in time and money and risks losing concept phase continuity and team personnel. DOE's selection process takes 6-9 months to complete, and design progress is on "hold" until the procurement effort is completed. All project costs are automatically increased due to inflation during this period. Offerors who participated in the concept phase may not be able to hold their team together or regroup them, because of the long period between phases.

b. Alternate Approaches - Two approaches to diminish these disadvantages are:

- Require that a proposal be delivered for the follow-on work at the end of the concept phase. The owner could then select the plant design and offeror at the same time. Concept experience and data would be directly applicable. Follow-on work could proceed swiftly.

- Have the concept phase performed by an independent organization (e.g., national lab, A/E, R&D Institute, etc.) who will not propose on any follow-on work. All options can be considered without supplier bias. The key to this approach is to end up with complete technical specifications and a good Statement Of Work for the follow-on procurement. A competitive selection can then be held with all offerors starting at the same point with respect to what is wanted. No competitive edge is gained in the concept phase. Design teams can be formed during the procurement process without a delay period to live through.

2. DEDICATED PROJECT OFFICE

a. Timing - The office should be formed no later than transition between concept and preliminary design phases and when funding and management approvals have high probability of being obtained. Bring in project people early enough to add insights and experience to key elements of technical feasibility, cost estimates, schedule projections and procurement strategies. Be sure that project team "owns" these key elements and they are not forced to achieve what others said was possible.

b. Project Office Responsibility - Should include technical, cost, schedule and procurement aspects within a defined envelope. When actions are outside this envelope, corporate management should become involved. The Project Office should serve as the point contact for all contractors and cooperative partners. In order for this approach to be meaningful, the Project Office must have sufficient authority to deal with day-to-day situations, particularly contract administration authority and engineering change authority.

c. Organization - Needed Project Office capabilities include contracts management, technical design review, independent assessments, construction inspection, startup, and cost/schedule control. If support is used from Government Labs, then colocation of support personnel is imperative. As the number and value of contracts increases so should the size of the Project Office. The number of manhours expended by all personnel on the administration of contracts is extremely high. If the staff is too small, then technical/cost/schedule aspects will suffer because of the demand for administrative actions.

3. DESIGN INTEGRATION

a. Role - Multiple design participants make this management task difficult. Multiple designers, suppliers and constructors make a difficult management task even more so. Since the Pilot Plant fell under the latter case, there was a continual need for the Project Office to act as referee during the finger-pointing game among participants.

In order to focus responsibility/authority, it is desirable to have the fewest lead contractors possible. If obtainable, one lead contractor to design, fabricate, construct and start up a plant would be desirable. Owner management of a lead contractor would be more focused and less of a shotgun response.

The Pilot Plant was fortunate to have a design integrator to pull together the heliostats, turbine-generator and all other parts of the system design. Unfortunately all that responsibility did not have any accompanying authority, since heliostats and the turbine-generator designers were not coupled contractually. It is particularly important to have a design integrator, to whom the plant operator can turn for system descriptions, startup/operational/maintenance/safety procedures and personnel training.

b. Desirable Attributes - Whatever type of generic facility (in this case, an electric power plant) is to be built, look for a lead designer who has done it many times before. The unique parts of a first-of-a-kind plant will be difficult enough without on-the-job learning of the basics of power plant design. If unique design tools are necessary, then the lead designer should subcontract or otherwise procure the needed expertise.

c. Two Part Contract - The contract work statement was initially prepared for a single contract covering all project phases, i.e., design fabrication, field construction, and startup. In order to (1) maximize and encourage the largest possible number of proposers and (2) facilitate negotiations for the start of work, DOE divided the work into two phases. Phase I was to include design and long lead procurement while Phase II would include fabrication, construction and startup. This division proved to be extremely difficult to administer since a large amount of overlap was necessary and Phase I didn't stop at a clean point. In addition, total costs (Phase I plus Phase II) were difficult to ascertain until a large portion of Phase I had been completed.

If concept design is complete, then a single contract covering all subsequent phases should be pursued under a single negotiation.

d. Cost Plus Award Fee (CPAF) Contract - Because of the first-of-a-kind nature of the Pilot Plant, a fixed price contract did not seem appropriate. The award fee provisions have proven successful in focusing attention on areas where the owner's team felt the contractor had been deficient; e.g., cost control, documentation, etc. Evaluations were done periodically and afforded early feedback and corrective action.

It should be recognized that additional manhours are needed from technical and business personnel to administer this type of contract. This additional manpower allocation will be needed on both the owner and contractor staffs.

4. HELIOSTATS

a. Fixed Price Incentive Fee (FPIF) Contract - When this type of contract was initially being considered, the cost control incentive advantages of a FPIF contract made it preferable to a cost type even though it was recognized that this was the first-of-a-kind buy of a large number of heliostats. This cost control expectation was validated as MMC was cost conscious during the production and field assembly efforts. On the other hand, the cost reduction incentive made it more difficult for the Government to receive assurance that MMC was maintaining what an owner would consider a high quality product and to make design corrections when deficiencies were discovered. In addition, the following two activities after contract signing tended to compromise the fixed price type of contract:

- Mirror Module Edge Seal Development: A design correction was necessary prior to initiating full scale production. This development was extensive in time and cost.

- Davis Bacon labor rates were imposed by the Government for both the Daggett final assembly work and site installation. A significant cost impact resulted.

b. Requirements Confusion - The Government required that the heliostats meet specified performance criteria as well as be made to owner approved specifications/drawings. This dual requirement caused confusion/disagreement throughout the contract as to the order of precedence and cost impact responsibility.

If production on future procurements is to be done according to owner approved drawings, the contract language should clearly call out that this approval is for configuration and material control only and does relieve the contractor from meeting performance criteria on the delivered system.

c. <u>Preferred Contract Method</u> - A preferred method of contracting for the next heliostat buy would be FP with FPIF as a second choice. The key to making any fixed price arrangement work is to (1) provide a performance specification with minimum material and configuration requirements or (2) provide a detailed prescriptive specification and (3) identify contractual warranties on components and delivered systems. In every case, any additional owner requirement, after contract signing, must be carefully screened as to necessity and corresponding cost/schedule impact.

Since the Pilot Plant heliostats were first-of-a-kind and in the development stage of R&D, no system warranties were offered by MMC or required by DOE after completion of the acceptance testing in December 1981. Component supplier warranties under MMC subcontracts are applicable until they expire. Warranties are expected to be a key element in future heliostat buys. As discussed in the next section, warranties can be associated with entire field performance subsystems, heliostats, or components.

d. <u>Specified Performance</u> - The production heliostats were required to meet the same individual heliostat requirements, including pointing accuracy, beam quality, and environmental conditions, as the Phase I units. No overall field energy performance; e.g., megawatts thermal delivered at the receiver was specified at the Pilot Plant. (The IEA contract with MMC did specify energy at the receiver.) (Note: The Pilot Plant field configuration and number of heliostats were specified by the plant designer, not MMC.) One early production unit was delivered for testing at Albuquerque. Testing at Albuquerque and the Pilot Plant site confirmed that the individual heliostats and the heliostat control system would meet beam performance requirements.

The amount of power actually delivered by the heliostats will be calculated from heat balances once the plant is operating. There is no apparatus incorporated in the diagnostic instrumentation to directly measure heat flux over the full length of the receiver panels.

If a future owner procures heliostats as a separate system, then individual heliostat beam characteristics are appropriate. However, if the owner requires the plant designer to specify and procure the heliostat system, then a requirement for thermal power at the receiver may be appropriate. Even more practical to measure would be a requirement for electric or process heat output from the plant as a whole.

If heliostats are purchased as a separate system then a decision of the contract scope must be made. Scope could include any or all of the following:

Heliostats
Control (Local vs. Control Room)
Field Wiring
Foundations
Installation
Startup

5. CONSTRUCTION CONTRACTING

a. Contract Provisions - T&B was eventually permitted to subcontract most of the construction packages directly. However, their DOE approved contract provisions were very similar to the Federal Procurement Regulations (FPRs). FPR requirements such as those shown below should be recognized:

- Prequalification of Bidders - Public bidding does not permit use of a prequalified bidders list. When the schedule is tight, a prequalified list is extremely desirable so that selections can be made rapidly after bid receipt and time can be used more effectively prior to bid opening to fully assure that firms have successfully completed work of a similar nature.

- Union vs. non-union - The procurement guidelines do not specify or in any way give preference to union or non-union contractors. Trade unions are still very strong in power generation type projects. In addition, the fact that the Project was constructed on SCE's property rather than a federally owned facility strengthened the union's position. The Project was very fortunate in losing only approximately two weeks of scheduled time due to labor relations work stoppages. Several contractors submitted damage claims for time and associated expense incurred due to the above delay. Had a large construction package, such as the mechanical contract, been low bid by a non-union contractor the Project could easily have been substantially delayed.

  The FPRs provide no protection against mixing union and non-union contractors. Prospective bidders should be clearly advised of this situation in procurement documents and at preproposal conferences. Early and continued contact with local trade halls by the Construction Manager can, and did, help to minimize labor problems.

6. UTILITY PARTNER

a. Cooperative Agreement - The Cooperative Agreement partner should be selected during the concept phase, particularly if site selection is involved. The partner should participate in concept reviews and participate/concur in selection of plant characteristics. Early site identification permits the environmental process to proceed and ideally be completed before preliminary design begins or at least concurrent with the end of preliminary design. Site identification is a key element in estimating construction costs and schedules during the concept phase. Site identification prior to the preliminary/final design procurement will eliminate this complicating factor from offeror's proposals.

The partnership interface has been facilitated because one utility (SCE) was designated to speak for the Associates. It is extremely helpful to have a point contact in both organizations who has the responsibility and authority to represent his organization.

b. Design Split - The Pilot Plant approach whereby the Government and Utility partner's scopes were split physically and monitarily has proven mutually satisfactory to both parties. However, because of the potential for different parts of the plant to be completed at different times, an agreement on how schedule slip impacts would be recognized should be part of the Cooperative Agreement negotiation. It is important to agree that cost increases not caused by the partner will be self-funded. Be sure that both partners have the resources and management commitment to proceed under escalating cost conditions. From an engineering standpoint, this splitting of the plant has the following disadvantages:

- o Additional design interfaces are artificially created which can increase design errors, drawings, and total plant costs. Unnecessary arguments arise as to what is best or cheapest for my side of the interface rather than what's best for the total plant.

- o Designers can suffer from "tunnel vision" whereby they are only concerned about their side of the interface. It is particularly unfortunate if either partner relegates review of the other's work to a low priority or doesn't even want his work reviewed. Each side needs maintenance and operational feedback during the design phase. The partners may become quite unhappy when they realize, too late, what type of plant design they are faced with.

- o Additional construction interfaces are artificially created, which make site contractor scheduling and control more difficult. The need for two Construction Management staffs increases total plant costs. Plant construction costs will also increase because of the need to mobilize duplicate contracts; e.g., two mechanical, two electrical, etc.

If the organizations will only work under a split scope, then it can be done. A single entity responsible for design and construction will facilitate the engineering and schedule aspects and lead to reduced plant costs. It is very important that, even under a split scope, both organizations review the total plant designs during the design phase

7. SMALL/DISADVANTAGED PARTICIPATION

a. <u>Design Phase</u> - Major design firms seem to have adequate capability in-house and, therefore, exhibit little desire to subcontract to small/disadvantaged firms. In addition they appear to want the experience gained from pilot efforts to remain in-house for its potential resale value. Getting firms involved in the design phase as subcontractors is a major challenge. Major facility design is often too large a task for small firms to tackle by themselves and they are, therefore, stuck with selling themselves as potential subcontractors. Beating on the door of big firms is the only way to break into the field and gain a track record, but this approach is tough going.

b. Construction Phase - Small/disadvantaged firms have their best opportunities here.

Fabrication opportunities can best be realized by prior acceptance on a large firm's "approved bidders list". If new business is being sought, small/disadvantaged firms should find out who the perspective bidders are and then make contact with them directly. Suppliers who provide information to a prime firm during the proposal phase usually have a head start in eventually getting a contract. It is difficult to come in and ask for business after prime contracts are let.

Many small/disadvantaged firms exist. They often cannot compete for large jobs ($2M) because of the lack of capital equipment, previous experience, or bonding capability. The Pilot Plant was successful in showing a high level of small/disadvantaged participation because the work was broken down into 14 packages rather than the four traditional ones; i.e., foundations, structural, mechanical, and electrical. This extensive breakdown does cost more and does complicate construction management. Some firms are excellent, others are marginal. You're sure to get a mix so plan on increased CM manhours to help the marginal ones.

Be cautious with set-asides. Find out if a large enough number of bids will be received to assure competition. If not, open bidding to all. Otherwise you'll end up with rebids and a schedule impact.

c. Department of Commerce Interface - Business Development Centers (BDCs) are a potential resource to aid in acquainting the community with project opportunities. Make sure you both have the same objective; i.e., to bring small/disadvantaged firms to procurement opportunities. Be aware that several different BDCs may be operative in your local area. They may not work well together, so you're better off treating them equally with information flow on upcoming procurements. BDCs can be a resource, but they are not the full answer. The owner must beat the bushes to find as many organizations and bidders as possible. This requires lots of manhours.

d. Utilization Statistics - Of the $120M Government funded Solar Facility activities, approximately $73M was subcontracted by MMC/MDAC/T&B or directly awarded by DOE to SBA contractors. Of this $73M, approximately 30.8% was awarded to small businesses including 11.6% to small/disadvantaged firms.

IV. DESIGN AND FABRICATION LESSONS LEARNED

IV. DESIGN AND FABRICATION LESSONS LEARNED

A. PLANT DESIGN

1. COMPLEXITY

The complexity of the Pilot Plant was much greater than its size of 10 MWe would indicate. The Pilot Plant was to be representative and scalable to a 100 MWe plant. The degree of complexity was generally underestimated by plant designers during the concept phase.

2. PLANT LEVEL REQUIREMENTS AND ANALYSIS

Complete plant level engineering analysis should be performed and documented before proceeding into system designs.

3. WORK SPLIT

Designs were generally done using a system approach; e.g., receiver, thermal storage, collectors, etc. Normally, large power generation projects are designed by discipline rather than system. In that manner one key individual is responsible for mechanical design development for the entire project, as compared to the assignment of managers by system. The discipline approach is more common and is generally accepted as more reliable than a system approach.

4. EARLY SITE ENGINEERING

The project benefited greatly from preliminary site engineering, and environmental definition work. A localized cloud measurements experiment was performed at Daggett and resulted in an early definition of receiver life cycles and some control system requirements, thereby saving engineering analysis and field test trial-and-error time after the plant was built.

Effluents from nearby plants can degrade heliostat reflectivity. Material samples should be placed in the local environment preferably prior to site selection or at least prior to irreversible site design. Future plans for nearby construction should also be considered, since the construction activities or new plant effluents could adversely affect site conditions.

5. CONFIGURATION CONTROL

Proper hardware/software configuration control is vital to timely and cost effective integration of plant requirements. In order to minimize this problem, initial meetings among participants should clearly identify roles and responsibilities in this area.

A single organization should have ultimate responsibility for configuration control. Configuration control should include design requirements, hardware/software designs, hardware and software design interfaces, purchased material/equipment/spares, vendor specifications, and construction site design changes.

6. UNIQUE STARTUP REQUIREMENTS

The plant design should be evaluated to encompass special provisions for startup as well as normal operations. In many instances, normal operating arrangements are inadequate for startup; e.g., faster water cleanup requirements, more vent locations are required for steam blows and flushes, additional isolation valves are needed, and there are different graphics displays and data acquisition requirements.

7. PERSONNEL

The Project was fortunate in most instances to have had continuity of personnel from design through startup within the SAN/SCE project offices as well as the contractors.

It is very important to have construction management people review the designs for improved constructibility early in the project. In the same sense, startup/operational/maintenance people must also review designs with their interests in mind.

8. GROUNDING TECHNIQUES

Plant grounding and induced voltage surge protection should be carefully analyzed to avoid problems such as experienced at the Pilot Plant. Because of the large amount of cabling and the wide area over which power and control cables are spread, special care must be taken. A lightening strike near the site caused failure of components in the heliostat field and control room.

9. CONTROL BUILDING DESIGN

a. Windows - The Pilot Plant control room has windows on two sides. These were installed to partially view the weather conditions over the heliostat field. More glass area and a full circumferential view would have improved plant visibility and weather observations. However, because it improves viewing of the CRTs, a darkened setting is used with window shades normally closed. A compromise between good CRT viewing and good plant/weather observation should be examined in future plants. Designers wishing to expand the window area should be conscious of overall building energy conservation and the effect of heliostat reflected beams inadvertently moving past the windows. A closed circuit TV should be considered for reviewing the field, receiver exterior, and possibly the internal portions of the receiver during operations.

b. Data Acquisition Room - Separating this area from the data room and the operational control room has proven wise. However, personnel communication links between the areas are important to maximize recognition of off-normal occurrences as they arise.

c. Remote Station 4 - Located on the first floor is the station where EPGS equipment control and instrumentation is terminated before multiplexing to the control room. The space allocated to this electrical equipment should have been increased for construction and maintenance access.

10. FOUNDATION DESIGNS AND SOIL INVESTIGATIONS

Soils investigations are required on all construction projects to provide site specific information for equipment and structural foundations. For central receiver plants two important categories are the heliostat foundations and the tower foundation. For both of these categories the effect on beam aiming accuracy is the principal consideration. Heliostat pedestal stiffness and movement in a high wind depends upon the foundation loading. In a like manner, the movement of the receiver in a high wind depends upon the structural stiffness of the tower and the foundation loading.

For the Pilot Plant a soil investigation was conducted at the site during the design phase. Test holes were bored on a grid over the entire area. For a heliostat foundations test, poured-in-place concrete piles were located in an area considered to have the poorest soil. Lateral test loads were then applied to determine the soil reaction and elasticity. The test results determined that a reduced heliostat foundation pile length would be adequate.

The above approach to heliostat foundation design is believed to be a good one. In future plants it might be prudent to accomplish the above procedure during Conceptual Design. The results impact the design and plant cost. It is important to know the foundation costs as early as possible as the heliostat field is the major cost item.

11. SITE PREPARATION

Prior to the start of construction activity at Barstow, considerable effort was expended in obtaining a smooth, graded surface with a slight crown for drainage. Shortly thereafter, much of this effort was disturbed by (1) boring for heliostat foundations, (2) trenching for piping and wiring, and (3) traversing of heavy construction equipment. Clearing and rough grading would be sufficient for future plants. Rough grading for drainage should be retained. Final heliostat alignment can be done with adjustments on the pedestal.

12. ROADS AND CENTRAL CORE AREA

Access to the central core area and to the heliostat field surrounding the tower at the Barstow Plant is provided by four spoke roads at the four main compass points. These roads are linked together by a curved road around the outer periphery of the heliostat field. None of the roads are hard surfaced.

The north, east and west spoke roads could be reduced in width or eliminated in future plants with a surrounding heliostat field, while retaining the relatively short spoke road through the south field for access to the central core area. This would permit an increase in the number of heliostats which, therefore, would reflect more energy than comparable heliostats in the south field. All main access roads should be hard surfaced.

The central core area should be expanded slightly by deleting the innermost rows of heliostats, which are inclined at a very steep angle.

Most of the western side of the core has been reserved for future thermal storage additions. Without this restriction, the core could be rearranged, particularly to allow more room for Electric Power Generation System equipment.

13. SAFETY ANALYSIS

The safety of a plant depends upon meeting the design requirements of recognized codes and standards. An organized plan to review the safety hazards and address the method for protection is usually accomplished with a Safety Analysis.

The pilot plant project only prepared an equipment safety analysis which utilized the preliminary piping and instrumentation diagrams. Each individual valve or component in the plant was evaluated for its life expectancy on its effect upon plant operation. This approach tended to be too simplistic.

It is suggested that prior to, or during contract negotiations, it is imperative to define "Safety Analysis". There should be complete agreement of the following terms: Fault Tree Analysis, Single Point Failure, Flow Down Analysis, etc. Once the P&I diagrams are <u>fixed</u> then the final System Safety Analysis should be accomplished. The Safety Analysis should include the control system, all hardware, plant equipment, and control logic, not just individual components.

14. ENVIRONMENTAL ACTIVITIES

a. <u>California Approval</u> - California State approval wasn't required because the Pilot Plant was less than 50 MWe. County approval was required. Fortunately San Bernardino County environmental people took a leadership roll and wrote an Environmental Impact Report (EIR) which was close to the Federal Environmental Impact Statement (EIS). County approvals proceeded expeditiously. Being a solar facility was a facilitating factor.

b. <u>Federal Approval</u> - DOE HQ took the EIR and reduced it to an Environmental Assessment. Approval was given without the need for an EIS.

c. Site Monitoring - UCLA was funded to do baseline work. UCLA has the experience to do an independent job and has credibility within the field.

B. HELIOSTATS

1. FINAL DESIGN AND PROTOTYPE TESTING (PHASE I)

Concept phase contractors were not ready to proceed with production so a final design and test phase was necessary.

MMC and MDAC were chosen for Phase I. Unfortunately, concept phase projections on cost and schedule for production were not enforceable because the phases were not contractually connected. Production cost estimates escalated significantly for both firms during this phase. Since the two heliostat designs required different cut glass size and field power requirements; i.e., electrical/control and spacing, the plant designers task was complicated and the Government was required to recut GFE glass at a cost twice as high as the original glass contract. The lesson learned is to either proceed with a single component supplier in the final design phase or to write the procurement technical specification so tightly that all interfaces and size parameters are the same for each multiple contractor.

Owner testing or closely overviewed contract testing of preproduction hardware is well worth the cost and effort. Nothing serves to surface problems as well as component testing. Test as long and extensively as time permits.

2. PERFORMANCE SPECIFICATIONS

Contractors should be given the opportunity and incentive to take advantage of cost saving reductions in prescriptive criteria as long as performance requirements are met. For example, tolerances of glass and mirror imperfections might be reduced as long as total reflectivity and strength are not substantially affected.

3. WIRE WALKS

Heliostats are brought from the stow position to the receiver standby position along four imaginary wire walks. All wire walks begin in the south quadrants during November - February. During the remainder of the year a wire walk begins in each quadrant. This wire walk philosophy, although effective for beam safety, requires considerable software and firmware to execute. A significant reduction in cost may be realized if an alternate method were developed such as that developed recently at CRTF.

4. MIRROR MODULE DESIGN

Both Phase I designers developed a sandwich design. MDAC used styrofoam, while MMC used aluminum honeycomb. Both contained the glass and sandwich material in a steel pan. This sandwich approach was a departure from the CRTF laminated glass approach, which was considered too expensive.

A key concern in module lifetime is prevention of mirror silver corrosion. Laboratory and field tests have demonstrated that entrapped water can attack the gray paint normally provided by mirror manufacturers and proceed to corrode the copper and silver mirror layers. The MMC Phase I edge seal material degraded during environmental tests and corrosion was found on the mirror surface. Extensive efforts were undertaken in the production phase to prevent corrosive attack. In addition to a double edge seal, a second coat of acrylic paint was added to each mirror.

To prevent internal gas pressure buildup as ambient temperatures go up in summer, a vent was added as insurance against debonding of the glass/honeycomb interface.

Even with the design improvements by MMC over the last two years, an inherent weakness may exist with the sandwich, which permits corrosive attack of the mirror. If manufacturing control is not perfect, if vents plug up, or if edge seals deteriorate with environmental exposure, moisture will enter the sandwich or pressures will build up which may lead to mirror damage. The designer should either consider a long lasting waterproof coating or use a glass laminate to protect the silver.

The Pilot Plant modules will be closely observed over the five year operational period. Inspection and recording of the condition of each module will be done to establish baseline data. As part of the planned periodic destructive inspection, one mirror module showing evidence of minor corrosion was recently taken apart. Standing water droplets were clearly evident and the paint and copper layers had been penetrated allowing silver corrosion to proceed. Whatever the source of water, it does show that moisture trapped in the module can lead to mirror corrosion.

5. COMPONENT FABRICATION

The difficulty in going from the fabrication of two heliostats in Phase I to 1818 production heliostats (21,816 mirror modules) was underestimated. New manufacturing processes required extensive development and tight process controls including the following:

a. Ceramic Tools - A cost effective change in the production tooling was proposed by MMC for the production phase. Ceramic tools with embedded heating elements were to be used. However, significant difficulty was experienced during tool fabrication due to tool cracking and lack of curvature control. Tool fabrication and curvature adjustments after fabrication became more of a costly art than a science.

b. High Glass Loss was experienced during startup of the mirror fabrication time. Standard float glass instead of low iron glass was used for approximately 136 heliostats. (Field performance is impacted less than 1%.)

c. Edge Seals - Most of the module seals were installed by hand. The first seal of PIB was eventually automated with a corresponding improvement in process control.

d. Doubler Pad Attachment - This pad is attached to the back of the painted mirror module with adhesive. It provides the connection for bolting the modules to the support structure. The pad to module bond had three problems during fabrication. First, adequate process control of the adhesive epoxy mixture was not maintained and adhesion strength was unacceptably low. Second, poor pad metal preparation before painting resulted in corrosion at the metal/paint interface with subsequent bond failure. Third, poor pan surface preparation before painting also resulted in bond failures. Although corrections were attempted for these problems, doubler pad failures did occur after modules were installed at the Pilot Plant. In December 1981, rivets were installed in 5400 highly suspect modules as a mechanical backup to the adhesive.

The heliostat drives also experienced quality control problems. When a production drive (chosen at random) was tested under simulated load conditions, the elevation pinion gear failed. Additional supplier quality inspection was initiated and an alternate high wind stow orientation (N-S vs. E-W) was incorporated to reduce elevation drive loads on the assembled drives which were subsequently accepted.

In summarizing fabrication quality control, it should be noted that commercial quality control was applied to the heliostat production rather than aerospace industry controls. Quality requirements and inspections were initially held to a minimum both in-house and at vendors. These quality standards were in some cases found to be inadequate and required much greater emphasis than originally expected.

6. PRODUCTION UNIT TESTING

Strong consideration should be given to testing the first production units. If the production involves many units, few sample production units should be periodically sent to the most representative site environment and testing should be done through an accelerated cycling scheme.

7. PRODUCTION RECORDS SHOULD BE KEPT

Production parts should be numbered, wherever possible, and records kept of their manufacture date, vendor lot, and upon which assembly these parts were finally installed, as was done for the mirror modules. These records should be put in some computer-accessible form (cards or magnetic tape) so that the data may be searched easily should this be necessary as field problems arise.

C. RECEIVER SYSTEM

1. MODULARIZATION/PHYSICAL MODEL

The mechanical/electrical design interfaces within the receiver core are very complex because of severely restricted space. Although the designer proposed modularizing this area in a factory and then erecting the modules at the site, DOE rejected this approach due to the risks associated with heavy, high lifts.

Future receivers may have the same congestion in the tower and core area and, therefore, a physical scale model should be considered as a design/installation aid. Such a model would have helped to minimize mechanical/electrical interferences, some of which were experienced in the receiver core area.

2. PANEL TESTING

Although a representative 70 tube receiver panel was tested with radiant heaters during the concept phase, it was considered desirable to test the panel in an actual solar environment at the Central Receiver Test Facility (CRTF) in Albuquerque. This CRTF testing proved extremely beneficial in identifying the need for improvements in the receiver control loops. The initial control arrangement had panel outlet steam temperature feedback to the water inlet value as the only control loop. This was found to be inadequate for stable control under changing insulation conditions. The final Pilot Plant design has back wall thermocouples and front wall heat flux measurements included in the control loop, (as well as steam outlet measurements) for improved anticipatory corrections.

3. FABRICATION TERMINATIONS AND TESTING

In order to expedite site construction the following are suggested:

a. Instrumentation and control wiring for a single panel or modular unit should be pulled to a single junction box during factory fabrication.

b. Factory fabrication should emphasize modularity whereby as much instrumentation, wiring, trace heating, lighting, piping/valving and insulation as possible is completed before shipment. These items should be factory checked, and where appropriate; precalibrated prior to shipment to the site; e.g., control valves and flowmeters.

4. RECEIVER TUBE JOINING AND THERMAL EXPANSION

Consideration should be given to a receiver design permitting greater compliance of the individual tubes in a receiver panel. Recent tests at CRTF involved a new receiver panel in which the individual tubes were not joined by welding or brazing along their length. This not only led to cost savings in fabrication but, more importantly, permitted each tube to expand individually, resulting in less panel distortion.

5. RECEIVER STRESS ANALYSIS

An approved analysis plan should have been part of the preliminary-design statement of work. Most of the analysis performed on the receiver and, especially, the receiver steam piping, was done after the design was frozen and fabrication was under way. Some of the analysis was not completed until after installation of receiver modules on the tower had begun. Thus, the stress analysis was of questionable benefit and was used to justify the design, rather than to guide it.

6. BLOCKED TUBE DETECTION

The boiler panels on the east and west sides of the receiver contain small orifices in some of the tubes. These are necessary for stability of the once-through to superheat boiler system. If one of these orifices becomes blocked due to contamination, the temperature of the tube increases from 1150 to over 1300°F. Several blocked tubes in parallel can result in dangerously high temperatures, substantially decreasing the useful life of the panel. An Infrared Monitor was developed to indicate a blocked boiler tube condition. This monitor observes the receiver from the heliostat field on the ground. However, program cost reductions necessitated using a single laboratory model monitor which is transportable instead of procuring permanent/automatic monitors. A permanent field infrared monitoring system should be considered to preclude the possibility of damaging the receiver due to blocked tubes. It would be extremely helpful if the monitor could also indicate absolute temperatures along the panel length and width.

7. 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 damaged panel during operation. After the crane was procured and installed, it was finally acknowledged that it could not easily be protected from the elevated temperatures expected immediately above the receiver during operation. As a result, the crane was removed after receiver erection was completed. If panel removal is required, a rental crane will be necessary. If a permanent maintenance crane is desired, then thermal analysis should be performed early enough to properly specify the appropriate crane operational requirements and thermal shielding.

D. THERMAL STORAGE SYSTEM

1. MODULARIZATION

Early in the design phase the decision was made to assemble the thermal heat exchange equipment on skids which would then be shipped to the site as modules. Eleven skids were assembled in Los Angeles and trucked, one per flatbed, to the site. Skids contained heat exchangers, pumps, valves, piping, instrumentation, etc. This was a cost-effective approach.

Increased use of factory assembly; e.g., insulation and wiring terminations, should be considered for future plants. In addition, equipment calibrations/checkouts should be performed when practical before shipping to the site.

2. STORAGE MEDIA

The Pilot Plant utilizes an oil-rock thermocline storage system based upon temperature stratification within a single vessel to provide containment for both the hot and cold storage media. Rock and gravel provide increased volumetric storage density, reduce the amount of oil required, and impede mixing of the hot and cold oils. It is suggested that future plants consider replacement of the thermocline storage system with hot tank/cold tank storage using two or more tanks in which all the fluid in a given tank is at one temperature. The oil-rock thermocline storage system has a number of disadvantages which offset the cost advantage of a single vessel. (1) Once in place, the rock-sand can be removed only at very great expense to permit examination or repairs to the interior of the vessel; (2) Differential expansion and contraction of the sand-rock aggregate and the containment vessel due to changes in the thermocline lead to thermal ratchetting of the containment vessel; and (3) The design temperature limit of about 600°F (to prevent excessive decomposition of the oil) limits the maximum temperature of steam which can be produced, and this decreases overall system efficiency.

3. THERMAL STORAGE TANK

The tank design did not come under any single recognized API, ASME, AWWA standard or design code. CAL-OSHA (California Administrative Code - Title 8) and the National Fire Protection Code Standard 30 requires tanks to be built to recognized standards. CAL-OSHA specifically calls out API-620, API-650, and ASME Section VIII Division 1. Since CAL-OSHA guidelines were deviated from on the pilot plant, their approval was required and was subsequently obtained. It should be noted that the oil in the tank is above its flash point, and NFPA considers the fluid flammable (Class I) rather than combustible.

Because of the unique nature of the thermal storage tank, an experienced tank contractor should be used to design, build, inspect, and bring into service this unit. This responsibility should also include filling with the oil/rock/sand mixture. Non-destructive examination options for the tank plates and welds should be critically reviewed and specified clearly. The tank bid package should be issued as a performance specification.

4. THERMAL STORAGE OXYGEN MONITORING

In order to detect and take corrective action prior to buildup of an explosive mixture at the top of the tank, an oxygen monitoring system has been included to sample ullage gas. A gas chromatograph was specified for the Pilot Plant.

E. CONTROL SYSTEM

1. OVERALL SYSTEM COMPUTER SELECTION

Since two major contractors (McDonnell Douglas and Martin) were involved in the Pilot Plant project, it became clear that there was a need on the government's part to identify a single source for the main frame computers so that each contractor would have identical hardware and software systems and use an identical computer language. MODCOMP computer company and their MAXNET language was chosen.

There have been significant problems and added costs associated with debugging the computers, writing new software, and obtaining adequate field service support from the computer company.

2. COMPUTER SIMULATIONS AND MODELS

System analysis work, computer simulation and modeling programs were started early in the Pilot Plant project, some even before the industrial design contract was let. These analyses enabled an early definition of the control system requirements. The models were verified using the very limited data available from single receiver panel testing at the CRTF. Use of these models has substantially reduced the guesswork associated with the design of a control system for this first-of-a-kind solar power plant boiler. Without these, the closed loop control settings would be strictly on a trial-and-error basis rather than a "fine tuning" of set points. Trial-and-error adjustments require substantial field test time after construction is complete whereas modeling and simulation work is performed during the project design phase. Also to verify new control settings and flow fixes on a computer simulation program is much safer and cost effective than doing these verifications using costly field test time. Simulations also provide the designers advanced information for selecting valve and actuator characteristics as well as a preview of what type of data readouts are needed by the operators to control the system.

3. DISTRIBUTED PROCESS CONTROL SYSTEM

To meet the complex control needs of the Pilot Plant, a decision was made early in the program to use a computerized System Distributed Process Control (SDPC) approach and a programmable Interlock Logic System. These decisions essentially freed the hardware designers from the need to guess (at the beginning of the project) just how this first-of-a-kind system should start up, shut down, protect itself and "safe" itself in the event of failures and trips. The decision enabled control limit settings, gain settings and safing logic to be changed without the need for wiring changes. New instrument settings (set points, alarm points) can be put in place from the control room. During pre-operational checkout, each subsystem, down to the component level, could be incrementally checked out without hard wiring changes or endangering other parts of the subsystems.

4. EARLY DEFINITION OF SYSTEM SOFTWARE REQUIREMENTS

The failure to translate system requirements into detailed software requirements early enough in the Pilot Plant Program has resulted in increases in software development costs. As an example, the

Data Acquisition System software development costs have been two to three times the estimated costs. This system has experienced startup problems and needs additional work before it will reach its full potential.

5. CONTROL ROOM MOCKUP

In the Pilot Plant project, the SFDI built a System Integration Laboratory (SIL) mockup for the purpose of integrating and checking out the control system. The control equipment was connected to the contractor's computer which simulated plant operation so that control and feedback operations could take place much the same as would happen in the field. The testing uncovered a number of problems which would have severely impacted field startup. These included: delivery of the wrong vendor equipment, equipment anomalies, incorrect drawings, incorrect displays, new equipment mortality problems, incorrect procedures, software problems, problems with interface to others' equipment, etc. Other benefits of a mockup include: hands-on equipment experience, training of operators, a chance to try out new displays and control schemes, an awareness of omissions, a re-evaluation of operator needs, etc. More schedule time should be allocated for fully using the mockup before hardware is shipped to the site on future projects.

6. CABLING

More extensive use of prefabricated cabling would have expedited SIL and site assembly.

7. PROBLEMS WITH CONTROL HARDWARE/SOFTWARE

a. Fabrication and Factory Test

Problem	Resolution
-SDPC data hiway throughput did not meet specification	-Redesign of hardware and firmware

-SDPC system schedules delivery to SIL slippages	-SFDI top management reviews with supplier top management
-SDPC system documentation and configuration management inadequate	-Participation of quality assurance departments of MDAC and supplier
-DAS computer system delivered late	-Use of MDAC computers for early software development
-Several SDPC algorithms found faulty	-Redesign of algorithms
-SDPC/computer functional interface malfunctions	-Modification of SDPC protocols and firmware
-SDPC data base security violations	-Modify firmware and change core memory type
-OCS/DAS network software did not support all selected interfaces	-Reconfigured computer systems with supported interfaces

F. BEAM CHARACTERIZATION SYSTEM

1. MOCKUP

The BCS system design should be started early and be incorporated into the SIL to minimize site startup activities. Software and camera problems were experienced at the site, and the system was not available when it was needed during plant startup to verify heliostat aim points.

2. DESIGN OPTIONS

The large targets and camera/computer system are expensive. While this system can provide centroid corrections as well as flux distribution information, Pilot Plant operational data should be monitored to determine if such a costly and sophisticated system is continuously required. The panel canting tool and laser alignment techniques used during heliostat assembly/installation appear to have done a good job of initial alignment.

G. ELECTRIC POWER GENERATION SYSTEM

1. FEEDWATER CHEMISTRY

Because of the low Fe requirement of 10 PPB, condensate filters and additional purification capability would be very appropriate. Significant time was lost during startup as acceptable Fe chemistry was reestablished after opening new lines to water or steam circulation. Filters could either be of the permanent in-line type or in bypass lines for use primarily during startup.

2. FEEDWATER PUMP

The feedwater pump(s) size was carefully reviewed from operational and reliability standpoints. Various options; e.g., two 50 percent rated units, 25 and 75 percent units, two 100 percent units, etc., were considered. The decision was made to use a single 100% rated unit but to also procure key replaceable parts as standby spares. Because of the experimental nature of the plant and the ability to utilize the non-operating night period to make repairs, this approach seemed adequate for the Pilot Plant.

H. INDEPENDENT ANALYSIS AND ASSESSMENTS

Both prior to and during the design period, DOE provided for independent analysis and assessments to be conducted by technical organizations such as Aerospace, ETEC, and Sandia. These services resulted in benefits to the owner such as detailed definitions of technical requirements prior to contract award, assurance of early detection and correction of design errors, and in some instances actually providing new analytical tools to assist in design tasks. These services also benefited the owner by enabling substantive technical re-evaluations during critical milestones and determining the effect of cost reductions to the plant.

Although future plants may not be government owned, industrial owners should consider maximizing technology transfer from the Pilot Plant by requesting DOE technical assistance. Requests can be directed to the Department of Energy Field Office in Oakland or DOE Headquarters in Washington.

V. FIELD CONSTRUCTION AND STARTUP LESSONS LEARNED

V. FIELD CONSTRUCTION AND STARTUP LESSONS LEARNED

A. CONSTRUCTION

1. GOVERNMENT CONTRACTING

DOE should not prime contract for construction and ask a construction manager to be responsible for managing those construction contractors. This violates the principle of giving authority commensurate with responsibility, since DOE as contracting agent would be looked upon as the source of authority by each of the construction contractors. Subcontracting is strongly recommended for construction.

2. MATERIAL PROCUREMENT

The major bid packages for the Solar Facilities included a minimum amount of contractor furnished equipment. This was due in most cases to the material procurement lead times required for the equipment specified. Therefore, the SFDI was requested to supply this material as Government Furnished Equipment (GFE) to the construction site.

Whenever possible, material should be detailed and specified as a portion of the construction work scope specification. This approach makes the work package much more desirable since the prospective bidders know that some amount of markup on material can be included in their bid. This, in turn, allows the contractor to "gamble" on labor productivity assumptions in formulating the balance of their bid. Several contractors stated that their decision not to bid was based on no procurement possibilities within the various specifications.

Using contractor furnished equipment/material also eliminates claims due to GFE delivery delays. The contractor is totally responsible for schedule performance when contractor procurement is specified. Contractors can be amazingly flexible in scheduling workaround solutions to solve delivery problems when their own procurement efforts are involved. Conversely, delays to GFE material/equipment deliveries are almost always an invitation to the contractor to submit a damage claim.

On the solar project the electrical construction package was issued with virtually no contractor cable procurement. In subsequent construction package revisions, a significant amount of contractor cable procurement was included in the work scope. This cable procurement should have been included in the bid specification to create a much more attractive bid package and thus increased competition. In addition, this approach would have provided a savings for the cable procurement cost since bid markup is always less than change order markup after contract award.

The utilization of conduit and a standard type of power and control cable in the collector field would have allowed for contractor procurement of the materials involved. The decision to utilize direct burial cable in the collector field required a GFE procurement approach due to the long lead time involved with this cable. Delays to this GFE cable created scheduling problems which were resolved by contractor workaround solutions. The cost associated with the schedule workarounds was recovered by the contractor.

In situations involving GFE procurement, the designer and Construction Manager are both involved where the equipment furnished is installed and fails to operate properly. In each such instance, the question arises as to whether the problem is due to the contractor's faulty installation or whether the vendor's equipment is deficient. In cases of contractor procurement, this dispute is the responsibility of the contractor to resolve. In this situation the designer and/or Construction Manager can simply demand corrective action by the contractor.

The GFE procurements were troublesome from a schedule standpoint since several suppliers did not meet their agreed-to delivery dates.

Recognition of this potential problem requires a greater degree of upfront surveillance and expediting of commercial suppliers.

3. FIXED PRICE CONTRACTING

Firm price lump sum bids are generally recognized as the best means of cost control in contracting for construction. However, it is imperative that the utilization of firm price lump sum bidding be accompanied by complete technical specifications. In several cases, major construction packages were issued with the knowledge that significant refinements would follow at a later date when additional design detail was completed. This was a conscious decision by all project participants and was formulated out of necessity to maintain the overall project schedule. This approach did, however, result in a significant number of change orders which naturally impacted costs. The costs associated with this approach were significant since change order pricing and markups are always greater than those utilized in competitive bidding.

Future owners should consider an alternate approach where schedules are tight and designs are incomplete. A firm unit price approach is best applied with mechanical or electrical work. This allows the ultimate number of terminations to be estimated and bid upon with detailed locations and exact numbers finalized by the design in a parallel approach. Work on well defined areas can begin immediately while other areas are finalized.

4. ON SITE QUALITY CONTROL

While a central QA function under the Construction Manager applicable to all solar facility construction was considered, DOE instead mandated through the bid document the "terms and conditions" for individual quality control programs for each construction package. The successful bidder was required to submit a quality control program for approval by the Construction Manager.

Each contractor, in an effort to remain competitive, made their construction superintendent responsible for quality control. These individuals are normally overloaded as it is without this additional responsibility. In effect, much of the quality control effort ended up as a meaningless statement that "the contractor will abide with the Technical Requirements and insure that current design drawings are utilized for construction". The contractor has these responsibilities without the use of any type of Quality Control Plan.

The addition of Construction Manager or owner quality control personnel would have allowed for a much greater degree of work performance monitoring.

The concept of a central quality control function would afford a greater degree of inspection as work progresses thereby reducing the chances of discovering significant construction errors which could impact others. In addition, it would allow for a much greater degree of inspection of Government Furnished Equipment.

5. HELIOSTAT INSTALLATION

a. Interfaces - MMC was not responsible for all its interfacing support systems, and the schedule for these support systems was critical for completion and checkout of the heliostat field. Several interface problems occurred: (1) power was not available to the field during initial heliostat installation thereby requiring the use and associated cost of portable generators, (2) the control room was not initially available for installation of computer hardware thereby requiring costly moves from a temporary trailer and disruption of normal checkout activities, (3) neither the BCS targets or electronics were available thereby requiring the use of a portable laser system for pointing verification and encoder bias measurements, and (4) the control room uninterruptible power system was not adequately checked out for proper equipment operation and grounding thereby creating the potential for substantial equipment damage.

b. On-Site Personnel - Proper on-site engineering support is a key element to successful system installation. Trained engineers in both hardware and software are essential for a smooth and timely installation.

c. Test Equipment - The electronic test equipment that was designed to aid the installation process, while adequate for trained engineers, was too sophisticated and fragile for use by tradesmen under field conditions. Simple and more rugged equipment should be designed for future projects.

B. STARTUP

1. ORGANIZATION

DOE and SCE formed an on-site Test Working Group (TWG) which included participation by MMC, SFDI, SCE, and DOE representatives. This group reviewed SFDI prepared startup procedures, worked problems, and performed the day-to-day startup scheduling.

Utilization of a utility partner to start up, operate and maintain a pilot power plant or larger facility has a number of advantages:

a. Ready source of experienced operators, maintenance personnel and startup engineers.

b. Plant will be operated and maintained more as it would be in industrial practice.

c. Only method for obtaining first hand utility assessment of the technology.

d. Adds credibility to DOE projects and test results.

e. Results in substantial design inputs from the industrial sector for future plants (helps prevent making the same mistakes twice).

The only disadvantage of a utility partner as the plant operator is the dilution of DOE direct control over the test program. This disadvantage is far outweighed by the above strong points.

2. TESTING PROCESS

The startup testing process was divided as follows:

a. Prerequisite/Preoperational Tests - Their purpose was to demonstrate the basic operability of equipment associated with each individual plant system. Typical prerequisite tests were mechanical (hydrostatic, leak, rotation, etc.), electrical (insulation resistance, continuity, etc.) and I&C (wiring checks, hardware functional checks, and software verifications). Following prerequisite tests there were preoperational tests such as equipment checks (startup, shutdown, operating functions, and emergency functions), failure status, I&C sensing and display functions, alarming functions, and tripping functions.

   These tests were initiated in the Spring of 1981 with main water/steam checkouts complete in December 1981.

b. Integrated Tests - Their purpose was to verify operation of the main steam to turbine flow loop to enable positive power to be placed on the utility grid. Development of control functions and/or field tuning of individual plant controllers was performed. The two key tests were receiver cold flow controls testing and receiver steam generation testing. The cold flow tests were accomplished by the end of January 1982, and heliostats were brought onto the receiver for the first time in early February. The first solar steam was fed to the turbine on March 31 followed by the first net generation of electricity on April 12, 1982. Steam conditions were approximately 720°F, 740 psi, and 60,000 lbs/hr. Output was 2.2 MWe gross and 1.2 MWe net.

3. THE TURNOVER PROCESS

After construction was completed by SCE and T&B construction forces, the plant hardware was turned over to SCE 'Startup' and ultimately to SCE 'Operations'. This process was complicated because of the many organizations involved in the project.

The flow path and checkpoints should be developed early on and simplified as much as possible.

4. PERSONNEL

After equipment release, SCE power plant operators were in charge of plant equipment and their associated controls. SFDI, MMC, and SCE engineering provided key technical inputs to the startup process for each of their designed systems. These engineering personnel were available on-site from the initiation of startup through the first power production.

5. STARTUP PROBLEMS

The startup of the Pilot Plant has been plagued by events many of which were not within the control of the startup team. These include: prolonged periods of bad weather, lightning storms, a leak in the thermal storage tank, water cleanup limitations, poor computer vendor support, and temperature gradients on the receiver.

All these factors have added to the shakedown and startup time and startup costs. Some details on specific hardware/software problems experienced during startup are reviewed below:

a. Heliostats

Problem	Solution
Random communiction failures occurred in heliostat control boxes	Boxes modified to increase filter 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 and boxes in core and field areas to protect against electro-magnetic pulses.
Noise on computer communication lines in control room causes failover to backup HAC	Signal line filters are being developed
Early evidence of mirror corrosion was detected on over 100 modules. Water found in modules during destructive examination	Non-destructive testing techniques being used to survey the field. Origin, correction and prevention of water leaks under investigation.

b. 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. The leak rate remained constant at less than 1 gallon per day at ambient temperature (capacity of the system approximates 240,000 gallons). At the operating temperatures, however, it was calculated that this leak rate would increase to approximately 60 gallons per day. A tunneling effort was required to expose the source of the leak, and a flaw was discovered in the middle of one of the floor plates. The leak has been repaired and the thermal storage system is being brought into service. This experience points out the need to examine the tank plate material very thoroughly prior to erection and all welds, and to thoroughly test the tank for leaks prior to filling. Because of the problem of the tank leak, thermal storage checkout was substantially delayed. Preoperational tests, including oil cold flow, were not completed until May, 1982..

c. Freeze Protection - In January 1982, temperatures below 18^{o}F were experienced at the site which caused freezing of some small diameter tubing and components (e.g., pressure, level and temperature indicators, etc.) primarily in the EPGS portion of the plant. This occurred prior to installation of freeze protection methods which corrected this situation (e.g., heat tracing of lines has been increased, temporary enclosures and space heating have been installed around EPGS equipment, special operating procedures have been instituted). Start-up testing suffered a one-week delay.

d. Water Chemistry - While steam cleaning of the piping systems had been completed in October 1981, the long period prior to initiation of steam tests in February 1982 caused water chemistry (particularly Fe) problems each time a new line was brought into service. The most effective cleaning method was to blow steam through the piping and release the contaminated water to atmosphere or sumps/drains. Special attention should be paid during design to the need for adequate piping/valving for cleaning as well as sufficient makeup water rates. Use of a rental boiler should be considered all during startup. Filters for removal of Fe should also be considered.

e. Receiver Panel Thermal Expansion - Panels are designed to expand freely downward on a roller/support tube system. At least one panel was overheated due to flow meter inaccuracies and instrument bias problems. This panel exceeded its design expansion limit and buckled slightly. Low-flow startup procedures were revised, improved flowmeters were installed, and the allowable travel for each panel was increased.

f. Earthquake Constraint - An earthquake constraint system was designed for the piping down through the center of the tower so that earthquake induced motion would not damage the piping. When the main steam downcomer was initially heated, spiders (attached to the pipes) and collars (attached to tower crossbeams) did not allow the pipes to move freely as designed. The gap between the spiders and collars was increased by machining along the spider lengths.

6. PERSONNEL COMMUNICATION SYSTEM

Permanent communication networks between the control building and plant equipment locations is very important for efficient installation/startup. Radio communication proved effective, but it could be improved by a multichannel system with both permanent locations and hand-held units.

Telephone communications in and out of the control building were also too limited. Outside telephone lines in the computer room within easy reach of all equipment would significantly decrease the time spent on the phones with vendors while resolving installation problems. This type of telephone service would therefore significantly reduce cost. All equipment cabinets should have integral telephone jacks installed.

7. MAINTENANCE TRAINING

A significant amount of on-the-job training is required to become effective in the electronic troubleshooting process. A period of training where skilled electronic engineers perform troubleshooting activities with the site maintenance personnel in the operational setting is needed. This period allowed an orderly transition from contractor-performed maintenance to owner-performed maintenance, with a corresponding decrease in the time required to perform post-startup troubleshooting.

8. COMPUTER MAINTENANCE

The on-site maintenance of vendor-supplied equipment, such as the computers and their peripherals, is important for successful installation, checkout and operation. This aspect should be given careful consideration early by the site startup team. It should be an important factor in the computer selection process.

9. SOFTWARE SUPPORT

Continued post-startup computer software support work has proved to be invaluable for enhancements and expedient problem resolution. This type of support should be provided on future projects for at least 6 months following system checkouts.

10. RECEIVER PAINT CURE

The black pyromark coating on the receiver panels must be time/temperature cured after spray application. Paint curing was done using the heliostats at the start of receiver steam tests. Accomplishing paint cure before delivery to the site would be more efficient and would have saved a several weeks of startup scheduling.

11. RECEIVER CORE ACCESSIBILITY

Because of the high degree of congestion in the receiver core, valves, filters, and other high maintenance items should be placed below the core for better accessibility.

12. SPARES

Spares and spare parts should be procured at the same time as installed parts. Spares need to be available during startup, as well as having an adequate supply to proceed into plant operation.

13. TEST PROCEDURES

The Test Working Group agreed on the format and content of Test Procedures to be written by the SFDI. These procedures were voluminous. Future plants should consider limiting the amount of information contained with each procedure. The integrated tests should be developed with the intent of easy translation to standard operating procedures.

14. WATER CONSUMPTION

Current water consumption is significantly underruning design predictions; e.g., 100 acre - ft/yr actual vs. 220 acre - ft/yr estimated. This is due to delayed mirror washing (natural rainfall cleaning will be used during the first year), and makeup water demineralization is a leased portable unit with offsite regeneration rather than a permanent plant unit.

15. CONTROL SYSTEM

All plant controls appear to be working very well for this first-of-a-kind plant. Particularly encouraging is the performance of the Subsystem Distributed Process Control and the method initially used for individual receiver panel control. Receiver steam testing up through Turbine Roll was done using backwall thermocouples and front wall heat flux sensors to control the water inlet valves (under simulated changes of up to 40% in heat flux, the outlet steam temperature varied by less than 15°F). Further testing using outlet steam temperature in the close-loop control mode will be accomplished during the test operations phase.

16. EQUIPMENT PERFORMANCE

All industrial grade plant equipment appears to be performing well.

17. PREOPERATIONAL READINESS REVIEW

Technical experts, who were not directly involved in the project, from users, designers, universities, laboratories, and the Government conducted a two day review in March 1982 to determine the adequacy of plant design/construction completion and the readiness to proceed with operations after turbine roll. This type of independent peer review is recommended for future projects and should be conducted prior to all major phase transitions; e.g., preliminary to final design, construction to startup, and/or startup to operations.

18. OPEN ITEMS FOR FOLLOW-ON DEVELOPMENT

Due to current DOE funding and schedule constraints, the following items will be developed and implemented during the Test Operations phase of the project:

a. Plant Level Operational Status Displays - These graphic displays will be based on overall plant and system P&IDs. They will be incorporated into the center two control room consoles where a single operator can be stationed for total plant control.

b. Collector Field Modulation - At present, heliostats may be called to the receiver in rings, segments, or wedges. Improved software will be developed to give the operator the ability to call up any power level resulting in automatic movement of the appropriate number of heliostats.

c. Clear/Cloudy Day Automatic - For both types of days, automatic software will be written to perform all mode operations and mode transitions automatically. Automatic operation is expected to maximize power output, minimize risks to plant equipment, and reduce operator involvement.

VI. SCHEDULE AND COST LESSONS LEARNED

VI. SCHEDULE AND COST LESSONS LEARNED

A. OVERVIEW

1. SCHEDULE

A simplified overall project schedule is shown as Figure VI-1. All project activities through Turbine Roll were completed on April 12, 1982, when solar produced electricity was first fed to the utility grid. A more detailed project schedule is provided as an attachment to this report.

Figure VI-2 is a representative startup schedule covering the period October 1981 through April 12, 1982. Two major items remained open at Turbine Roll, i.e., BCS checkout and TSS oil cold flow. The BCS activity involved replacement of hardware components while TSS oil cold flow involved cleanup and circulation of oil in all four heat exchanger loops. The OCS activity was completed in May and the TSS cold flow was completed at the end of April.

The initial project schedule developed in 1977 showed 36 months for design, construction, and startup. Authority to proceed with Preliminary Design was assumed as January 1978 with project completion, therefore, targeted for December 1980. Although the definition of startup has been slightly modified, it is a credit to those involved that Turbine Roll was accomplished in 35.5 months; i.e., full authority to proceed with preliminary design was given to MDAC in May 1979, and startup was completed with Turbine roll on April 12, 1982.

2. COST

The initial project estimates in 1977 were $106M for DOE and $14.2M for the Associates giving a total project capital cost of $120.2M. During the period from 1977 through 1981 both of these participant estimates increased. Final project funding estimates are $120M DOE and $21.35M Associates for a total of $141.35M.

10 MWe SOLAR PILOT PLANT START-UP WORKING SCHEDULE

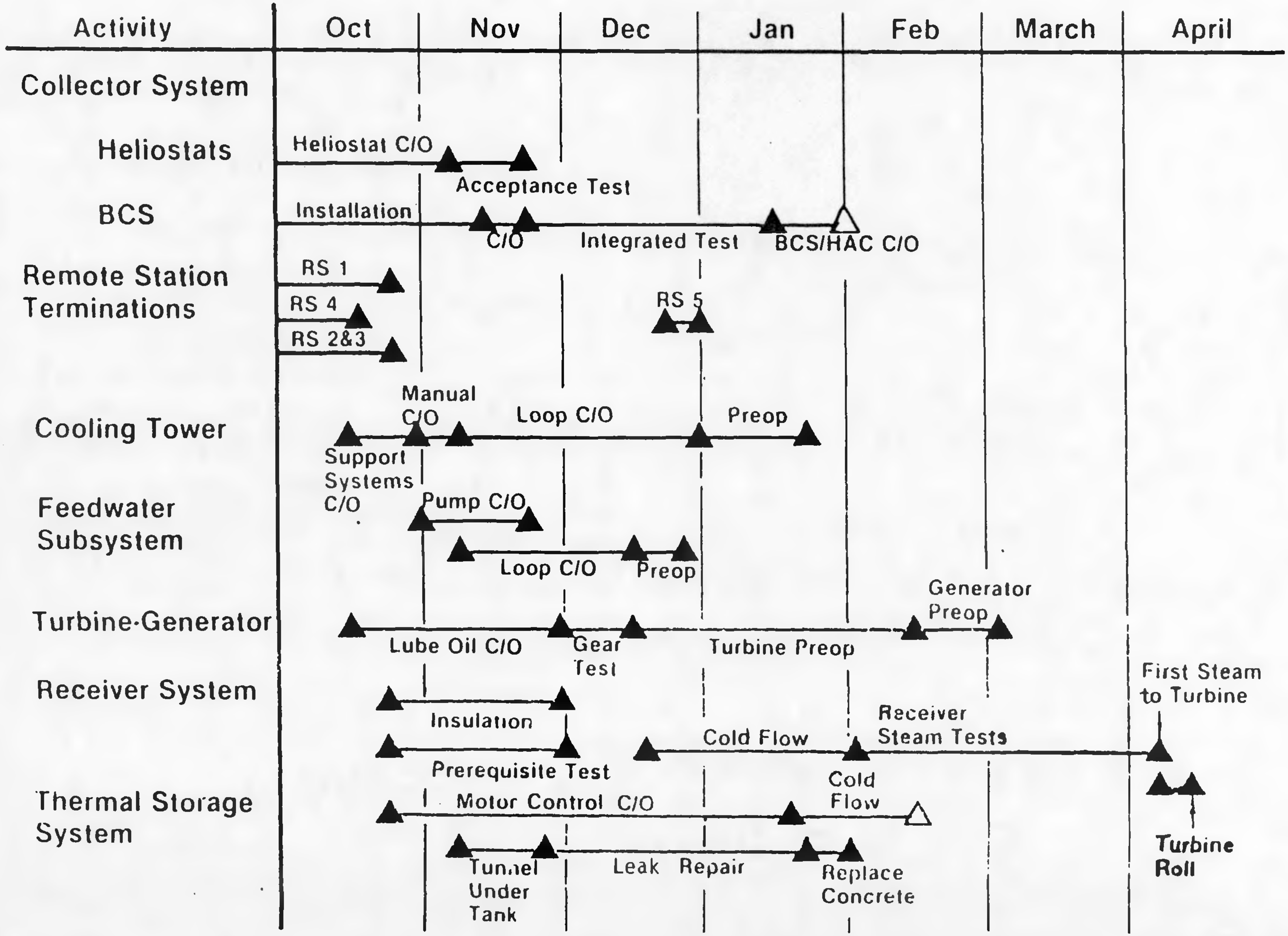


Figure [illegible]-2

Inflation had a major impact on project costs. Estimates developed in 1977 were based on an expected inflation rate of 8%. Actual inflation turned out to be 12% and for certain specific items substantially higher. The annual compounding effect of higher inflation was the major component of both DOE's and the Associates' cost growth.

A detailed project cost report is being prepared by T&B. It covers all phases of the project and is based on inputs from all participants. The target date for report completion is summer 1982. Sandia should be contacted regarding report availability.

B. SOLAR FACILITIES

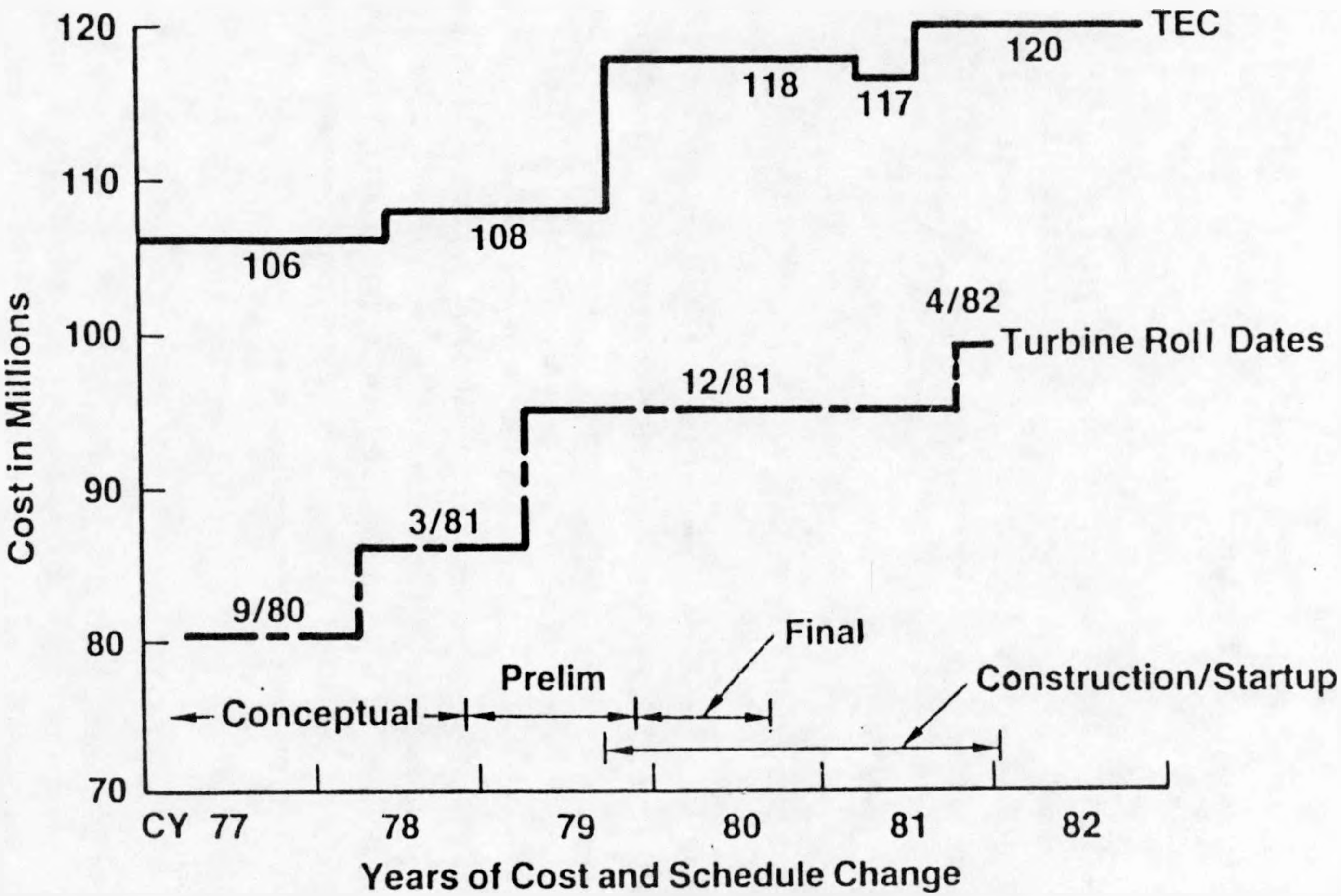
1. SCHEDULE AND COST TRENDS

Figure VI-3 shows the trends in Total Estimated Cost (TEC) and Turbine Roll dates. All schedule delays had a direct impact on costs. Throughout the project, estimates-at-completion were developed. When these estimates exceeded the available funding, scope reductions were implemented. However, it is to the credit of those involved that the original plant sizing objectives have remained unchanged, i.e., 10 MWe power to grid from receiver; approximately 8 hours and 4 hours of 10 MWe operation on the summer and winter solstice, respectively; 28 MWe hrs thermal storage; and 7 MWe rated output from thermal storage.

2. SCHEDULE

a. Schedule Compression - The normal progression of work in a construction project is to complete the design prior to fixed price contracting for construction and erection. In some projects the construction activity is initiated even prior to design completion to shorten the overall project schedule. However, while there are some general cost savings, there are also cost risks associated with changes.

SCHEDULE AND CAPITAL COST TRENDS



Schedule Changes

1. 9/80 to 3/81: Presidential Deferral on Funding and Procurement Delays
2. 3/81 to 12/81: Delay in SFDI Start of Design
3. 12/81 to 3/82: Start-Up Extensions

Cost Changes

1. \$106M to \$108M: Schedule Delay;(Scope Reductions)
2. \$108M to \$118M: Escalation Due to Schedule Delays;(Scope Reductions)
3. \$118M to \$117M: FY81 Deferral
4. \$117M to \$120M: Heliostat Fabrication Problems; Receiver Core Construction Problems; Start-Up Requirements; (Scope Reductions)

Figure VI-3

Due to delays in contract negotiation, funding authorizations, etc., the construction of the pilot plant was broken into phases to assist in meeting a fixed start date. The schedule for the pilot plant final design was very short. There were too many critical paths, and estimated values were used excessively in preparing the design. The schedule should have been relaxed to allow for better development of design information.

It is suggested that a stepwise design and construction method be followed, i.e., Conceptual Design, Preliminary Design, Final Design, and then Construction. The scheduling of each design phase should recognize that schedules of subsequent phases must be flexible to allow for the necessary changes. The importance of maintaining contingency money, the importance of cost escalation in estimates, and the importance of relating these items to schedules, cannot be emphasized enough. Schedules should include allowances for weather delays during construction and the intermittent availability of sunshine for plant startup.

Management is usually unwilling to recognize a separate period for schedule contingency. Therefore, contingency must be built into each activity duration. Estimate the most realistic durations and add time for unknowns. Nothing will be done in the shortest possible period.

Government procurement durations were not adequately recognized in the original concept phase project schedule. Design selections are extremely time consuming. Plan for it to take longer than planned. Recognize durations for procurement package preparation, package approval, offeror proposal preparation, reviews with offerors, board recommendations, selection official decision, negotiation, and work startup.

b. Vendor Incentives - Problems were experienced with equipment vendors not meeting agreed to deliveries. Future projects should consider (1) implementing a more cost effective vendor contracting structure, e.g., delivery incentives, and (2) greater use of expediters.

c. Heliostats - Fabrication and installation experience by major heliostat component is summarized below:

- o Pedestals

  - Installation started November 3, 1980 and was completed June 19, 1981
  - Units installed per day were 27-60 (minimum - maximum)

- o Drives

  - Final assembly at Daggett hangar started November 17, 1980 and was completed July 31, 1981
  - Units assembled per day were 1 - 18 (minimum - maximum)
  - Installation started November 20, 1980 and was completed August 7, 1981
  - Units installed per day were 5 - 50 (minimum - maximum)

- o Mirror Assemblies

  - Pueblo module fabrication started January 9, 1981 and was completed August 31, 1981
  - Module production was 100 - 279 (minimum - maximum) per 24 hour day
  - Final assembly at Daggett hangar started February 16, 1981 and was completed September 10, 1981
  - Final assembly production was 2 - 18 (minimum - maximum) per 8 hour day

- Site installation started February 20, 1981 and was completed September 10, 1981
- Units installed per day were 4 - 40 (minimum - maximum)

o Heliostat Controls

- Denver fabrication started November 3, 1980 and was completed May 15, 1981
- Installation started February 16, 1981 and was completed September 25, 1981
- Units installed per day were 10 - 40 (minimum - maximum)

d. Receiver - The panel fabrication history at Rocketdyne's facilities in Canoga Park, CA. and site installation data are shown below:

o Panel Fabrication (24 total plus 2 spares)

- Tube bending started February 13, 1980 and panel fabrication was completed June 1, 1981.
  Shortest production time was 16 weeks for a single panel

o Panel Installation

- Installation started April 15, 1981 and was completed June 17, 1981
- Units installed per day were 1 - 3 (minimum - maximum)

There were no significant fabrication problems encountered during panel assembly. Panel development work was done under an earlier DOE contract during the concept design phase in 1975-77.

3. COST

All cost information is preliminary in nature and will be better defined in the final project cost report available this summer from Sandia. This breakdown is for the government costs only and does not include the Associates costs.

a. Breakdown

Solar Facility Design Effort		$31,170,000
- Collector Field Fabrication & Construction	$41,365,000	
- Receiver Fabrication & Construction	21,924,000	
- Thermal Storage Fabrication & Construction	10,323,000	
- Plant Control System	3,048,000	
- Beam Characterization System	865,000	
- Miscellaneous Support Systems	11,305,000	
Total Solar Facility Fabrication/Construction Cost		$ 88,830,000
Total Solar Facility Cost		$120,000,000

b. Government Funding ($ in thousands)

Fiscal Yr.	Authorizations	Appropriations	Obligations	Costs
1976	$ 5,000	$ 0	$ 0	$ 0
Trans.Qtr.	1,250	0	0	0
1977	0	2,500	592	0
1978	41,000	41,000	3,474	574
1979	24,250	28,000	22,636	9,712
1980	36,500	36,500	68,933	31,660
1981	10,000	9,000	21,323	63,861
1982	2,000	3,000	3,042	14,193

c. Major Contract Values ($ in thousands)

Construction

-DOE Primes: (Earthwork, Visitor Center, Warehouse, Heliostat Foundations)	$ 2,925
-T&B Construction Management: (Office, Staff, all Fees)	4,428
-T&B Subcontracts: (Hardware Installation and Startup)	20,053
Total	$27,406

Solar Facility Design Integration

-McDonnell Douglas: (Plant Design Integration, Master Control Design and Hardware, Startup)	18,139
-Rocketdyne: (Detailed Design and Fabrication of Receiver and Thermal Storage Hardware)	24,300
-Stearns-Roger: (A/E Plant Support Systems, Long Lead Procurements)	7,460
-University of Houston	203
Total	$50,102

Collector System

-Martin Marietta Denver: (Fabrication, Assembly, Installation, Test of 1819 Heliostats and Controls)	$36,009
-Ford Motor Company: (Heliostat Glass)	803
Total	$36,812

d. <u>Solar Facility Construction Contract ($ in thousands)</u>

-Earthwork, Grading (DOE Prime)	$ 1,093
-Visitors Center (DOE Prime)	334
-Collector Foundations (DOE Prime)	1,249
-Warehouse (DOE Prime)	249
-Receiver Tower Foundation	201
-Receiver Tower	1,715
-PSS Tanks (Water Tanks)	110
-Collector Field Electrical (Incl. Grounding)	2,219
-PSS/TSS Foundations	1,294
-TSS Field Erected Tanks	1,893
-Piping and Mechanical	6,829
-Core Electrical	3,679
-PSS/TSS Structural Steel	574
-Insulation	685
-Start-up (Rental Boiler, Crafts, Materials)	854
Total Construction and Start-up	$22,978

e. Installed Unit Costs

-Earthwork: 175,000 cubic yards (C.Yds.)& fill	$ 6.25/C.Yd.
-Collector Foundations: 1818 Foundations (Fdns), Concrete Design Volume, 4760 C.Yds., (Actual 5989 C.Yds.) plus an additional:	$208.48/C.Yd.
42 Misc. Fdns. of 100 Yds.	$(686.00/Fdn)
242 Tons Steel	
-Warehouse: Open steel prefab type 6,000 ft^2	$41.50/Sq.Ft.
-Visitors Center: Prefab trailer 4,148 ft^2	$80.62/Sq.Ft.
-Receiver Tower Foundation: 631 C.Yds. Concrete, 24 Tons steel	$318.19/C.Yd.
-Receiver Tower: 200 Tons Steel	$7,425/Ton
Crane & Elevator Fab/Erect	$230,000
-Pipe Racks: 90 Tons Steels	$6,378.82/Ton
-TSS/PSS Foundations: 2,750 Cyds Concrete, 190 Tons Steel	$470.66/C.Yd.
-Electrical Cable: CS Field - 165 K.Ft.Power 195 K.Ft. Control	$6.16/L.Ft.
Core - 153 K.Ft. Power, I&C	$24.05/L.Ft.
-Caloria HT-43 oil: (Material Only) 240,000 Gal.	$1.75/Gal
-TSS Tank: 149,288 Cu.Ft. steel	$12.68/C.Ft.
4,532 Tons Rock	
2,266 Tons Sand	
-Heliostats: 1818 (430 Sq.Ft. each)	$20,237/Ea $(47/Sq.Ft)
-Pipe: 2" & under w/fittings (10,048 L.Ft.)	$37.61/Ft.
2" & over w/fittings (10,066 L.Ft)	$98.12/Ft.
Primary Water/Steam/Oil 2,371 L.Ft	$230/Ft.
Fire Protection System (Total)	$284,000

f. <u>Contingency Percentage</u> - Initial project contingency was 20%. Risk assessments during concept design are helpful in understanding where this contingency will be needed. Project funding should allow for uncertainties in design, fabrication, construction and startup. For a first-of-a-kind project like the Pilot Plant, 20% was inadequate. Contingency values up to 40% have been suggested as more reasonable by various participants. Setting contingency is ultimately a matter of judgment. Past experience with Government or owner facilities is helpful in bringing realism to the process.

C. TURBINE GENERATOR FACILITIES

1. SCHEDULE AND COST TRENDS

In 1979 the Associates recognized the need to increase their funding from $14.2M to $21.35M. This increase resulted primarily from higher actual escalation rates and schedule extensions.

The Electric Power Generation System schedule was readjusted to match extensions in the Solar Facilities schedule.

2. COSTS (through March 31, 1982)

a. <u>Breakdown</u> (in dollars)

o Corporate Support	$ 551,853
o Engineering & Construction Labor	4,197,027
o SCE-furnished materials and equipment	5,518,902
o Construction contracts	5,082,354
o Consultants, permits and licenses	51,089
o Indirect Construction Costs	586,224
Subtotal	$15,401,225
Construction Overhead	4,281,118
Total Costs	$19,682,343

b. Construction Contracts

Contract	Description	Cost ($)
Civil/Underground	Installation of underground piping, structural foundations and cooling tower foundation	332,340
Control Building	Construct control building	693,550
Turbine Pedestal Erection	Erect turbine pedestal and install equipment foundations	310,285
Mechanical/Structural	Erect auxiliary equipment structure, install mechanical equipment, piping, instrumentation, insulation	2,702,274
Switchyard/Electrical Apparatus	Install electrical apparatus including switchyard installation for 33 kV electric grid intertie. Pull & terminate power, control. & instrumentation wiring	620,996
Cooling Tower	Construct and install tower	153,290
Restroom	Construct restrooms	103,222
Paving/Misc.Concrete	Pave roads & misc. concrete	62,898
Fencing	Install perimeter chain link	43,729
Communications	Install communications	43,095
Office Trailer	Misc. installation costs	10,545
Turbine Delivery	Special equipment for installation	6,130
	Total Construction Contracts	$5,082,354

c. Major Equipment Procurements

Equipment Item	Supplier	Approx. Cost ($ thousands)
Steam Turbine/Generator	General Electric	$2,200.0
TSS Feedwater Pump	Bingham Williamette	34.0
Feedwater Heaters	Struthers-Wells	127.6
Deaerator	Marley Co.(Chicago Heater)	32.4
Polishing Demineralizer	Crane Cochrane	247.4
Condenser	Ecolaire & Allegeny Ludlum	123.5
Cooling Tower	BAC Pritchard	153.3
Elec.Aux. Boiler	Hydro-Steam Industries	44.1
Condensate Pump	Peerless Pump	11.7
Circulating Water Pumps	Peerless Pump	22.4
Cooling Water Heat Exch.	Southwest Engineering	41.6
Cooling Water Pump	Peerless Pump	2.5
Air Compressors	Gardner Denver	80.6
Main Transformer	Westinghouse	48.4
Uninterruptible Power Syst.	Exide Electronics	73.6
Station Service Trans.	General Electric	20.6
480 V Switchgear & Contr.	General Electric	129.0
	TOTAL	$3,392.7

VII. BIBLIOGRAPHY AND MAJOR PARTICIPANTS

VII. BIBLIOGRAPHY AND MAJOR PARTICIPANTS

The following reports may be obtained after July 1982 by writing to the DOE Technical Information Center (TIC) at the following address:

USDOE - TIC
P.O. Box 62
Oak Ridge, TN. 37830

For copies of the listed Professional Papers, write directly to the professional organization or to the authors.

A. McDONNELL DOUGLAS CORPORATION - KEY DOCUMENTATION

(Contract No. DE-AC03-79SF 10499)

RADL No.	Report Title
2-1	Station Manual
	Vol. I System Description
	Vol. II Equipment Data Book
	Vol. III Selected Assembly Drawings
2-12	Collector Field Layout Specification
2-15	Heat and Mass Balance Analysis
2-19	Master Equipment List
2-25	Collector Field Optimization Report
2-36	Plant Operating/Training Manual
	Vol. 1 Operating Instructions
	Vol. 2 Appendices
2-38	Integrated (Operational) Piping & Instrumentation Diagrams
2-46	Plant Startup and Acceptance Test Plan
3-1	BCS Technical Objectives/Design Reqmts.

3-2	BCS Hardware/Software Specification
4-1	Receiver Subsystem Analysis Report
5-1	Thermal Storage Subsystem Analysis Report
6-4	System Integration Laboratory Test Plan
7-17	Heliostat Washing Requirements
--	System Safety Analysis

B. MARTIN MARIETTA CORPORATION - KEY DOCUMENTATION

Contract No.	Report Title
DE/AC03-80 SF10539	Heliostat Design Drawings (Final)
" "	Control Hardware Drawings (Final)
" "	O&M Manual (Final)
" "	Safety Analysis (Final)

C. THE AEROSPACE CORPORATION - KEY DOCUMENTATION
(Contract No. DE-AC-03-78-ET20517)

Report No.	Report Title
ATR-81(7747)-1	"Solar Ten Megawatt Pilot Plant Performance Analysis," J. Coggi, H.D. Eden, Feb. 1981
ATR-81(7747)-3	"Functional and Performance Characteristics for the 10 MWe Solar Thermal Central Receiver Pilot Plant," H.D. Eden, J. Coggi, September 1981
ATR-80(7747)-1	"Measurements of Typical Insolation Variation at Daggett, California," C.R. Randall, B.R. Johnson, M.E. Whitson, March, 1981. Vol. I and Vol. II.

ATR-81(7747)-4 "An Infrared Sensor for Remote Temperature Monitoring of Solar Thermal Central Receivers." D.W. Warren, H.D. Eden, January 1982.

ATR-78(7695-05) Rev. 1 "Pilot Plant Environmental Conditions (OPDD Appendix C)", C.M. Randall, M.E. Whitson, J.V. Coggi, August, 1978.

ATR-78(7695-05)-4 "Requirements Study for the 10 MW Solar Thermal Pilot Plant Master Control Subsystem." R.H. Leatherman, N.A. Nelson, June 1978.

ATR-78(7695-02)-2 "Transient Simulation of the MDAC Receiver Test Panel in its STTF Test Configuration." K.L. Zondervan, E.N. Best, R.A. Jamieson, J.V. Coggi. June 1978.

ATR-78(7747)-1, Vol. I, II "10 MW Solar Thermal Pilot Plant Dynamic Simulation." E.N. Best, J.W. Duroux, C.L. Thacker, K.L. Zondervan. December 1978.

D. SANDIA LIVERMORE LABORATORIES - KEY DOCUMENTATION

Report No.	Report Title
SAND/81-8008 April, 1981	Testing of the Prototype Heliostats for the Solar Thermal Central Receiver Pilot Plant
SAND/79-8179 December, 1980	Pilot Plant Receiver Panel Testing at the Central Receiver Test Facility - Final Report

E. UNIVERSITY OF CALIFORNIA, LOS ANGELES - KEY DOCUMENTATION

UCLA 12-1223 November 1979	"Ecological Base Line Studies at the Site of the Barstow 10 MWe Pilot Solar Thermal Power System." F. Turner
UCLA 12-1311 October 1981	"Ecological Observations During Construction of the Barstow 10 MWe Pilot STPS." F. Turner 94 pp.

F. PROFESSIONAL PAPERS

1. "Comparison of Test Results with a Non-Linear Model of a Solar Powered Once-Through Boiler." K.L. Zondervan & E.E. Schiring, - Aerospace Corp., 1981 Annual Meeting - American Section of International Solar Energy Society, May 1981.

2. "Regulation of a Solar-Powered Steam Generator in the Presence of Clouds." D.D.Sworder, Aerospace Corp. - Asilomar Conference on Circuits, Systems and Computers, November 1980.

3. "A Simplified Linear Dynamic Model for First-Cut Controller Design of a Solar-Powered Once-Through Boiler." E.E. Schiring, R.O. Rogers, - Aerospace Corp.; E.J. Riel, - McDonnell Douglas; A.J. Welch, - Rocketdyne. ISA Power Division Symposium, Instrumentation in the Power Industry, Vol. 23, May 1980.

4. "Preventing Eye Hazards at the 10 MW Solar Thermal Power Plant." S. Konopken, - Aerospace Corp.; C. Boehmer, - McDonnell Douglas. Environmental Control Symposium, Washington, D.C., March 1980.

5. "Continued Concept Implementation of the Master Control System for the 10 MW Pilot Plant." C.P. Winarski, - So. Calif. Edison, R.C. Rountree, E.E. Schiring, R.O. Rogers, - Aerospace Corp. Energy Sources Technology Conference & Exhibition, New Orleans, February 1980.

6. "Environmental Considerations in Siting Solar Thermal Power Systems in Deserts of the Southwestern UPSA", by R.G. Lindberg and F.B. Turner, - University of California, Los Angeles. Solar World Forum. Proceedings of the ISES Congress. Brighton, England, August 1981.

G. CURRENT CONTACTS OF MAJOR PARTICIPANTS

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  Livermore, Ca. 94550
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- <u>The Aerospace Corporation</u>
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  Los Angeles, CA. 90009
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June 1982

SOLAR PILOT PLANT SUMMARY SCHEDULE

GLOSSARY

1. Schedule Organization (Top to bottom)

Department of Energy
Collector Contractor (Martin)
Southern California Edison
Solar Facility Design Integrator
Townsend and Bottum

Each activity has an Identification Code followed by a unique activity identification.

2. Work Activity

The status line through the schedule activity represents "Actual Dates" (not "Scheduled Dates") with the exception of "Plant Acceptance Testing".

The working days numerical summary at the end of an activity bar represents a 5-day work week (a 20-day activity spans approximately one month).

Logic relationships are by broken lines. Interrelationships are defined as follows:

FS - Finish to Start
SS - Start to Start
FF - Finish to Finish
F - Finish

FS - The schedule activity must be completed prior to the succeeding activity being started

SS - The schedule activity cannot be started until its predecessor activity is started (can be completed independently, however)

FF - The schedule activity cannot be completed until its predecessor activity is complete (can be started independently, however).

The logic relationships are followed by a numerical value representing the number of work days required.

Examples: FF10 = 10 work days required to complete after preceeding activity is completed.

SS10 = 10 work days required to start activity after preceeding activity is started.

Numerical values on the broken lines represent schedule float in "work days".

Activity XXX-02 = work continues or is deferred until 11 April 1984, which is this schedule end date.

REV.	DATE	DESCRIPTION	BY	APPROVED

PREPARED UNDER RESPONSIBLE SUPERVISION OF
TOWNSEND AND BOTTUM, INC.
CONSTRUCTORS - FOR THE ENERGY INDUSTRY

PROFESSIONAL REGISTRATION NO.

OWNER AND LOCATION

TITLE
10MW SOLAR PILOT PLANT
SUMMARY SCHEDULE
(NETWORK CHART)
CURRENT EARLY

BASE DATE	01 JAN 77	DATA DATE	01 JUN 82	ACTIVITY SIZE	1/10 INCHES
FNSH DATE	11 APR 84	CUTF DATE		SHEET 1	GROUPS 1 - 5
LOWR SPAN	04 JAN 77	RUN DATE	01 JUN 82	REVISION	
UPPR SPAN	11 APR 84				

SPAN NETWORK GRAPHICS--PROPRIETARY PRODUCT OF T&B COMPUTING